PDHonline Course E371 (3 PDH)

Pre-Design Energy Analysis

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Pre-Design Energy Analysis

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This course is based on information from the National Renewable Energy Laboratory (NREL), a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

Introduction

When contemplating the design of a new facility, the future energy consumption of the facility should be considered in the early stages of the design. One way to do this is with a pre-design energy analysis.

A pre-design energy analysis uses general information about a building and site to estimate energy performance, characterize energy uses, and identify potential energy savings opportunities for a new building. The objective is to use results to develop design concepts that minimize energy loads and costs from the outset. Results also provide important guidance for setting energy performance goals. At this early stage in the design process, the building siting, orientation, zoning, internal organization, massing, and appearance of the facade can be manipulated to maximize performance without adding significant cost.

The energy performance of a building depends on complex interactions between the outdoor environment, indoor conditions, building envelope, and mechanical systems, so computer simulation programs are the best tool to perform building energy analyses. A whole-building computer simulation tool that calculates hourly or sub-hourly loads for the building is critical for all high-performance projects.

In most cases, a professional energy consultant should be hired to perform a pre-design energy analysis based on information provided by the owners, architects, and engineers. The consultant will perform most of the simulation work in advance. The energy consultant must be given sufficient time to prepare and execute the required simulations. The lead time for the analysis depends greatly on the magnitude of the project and the desired level of analysis.

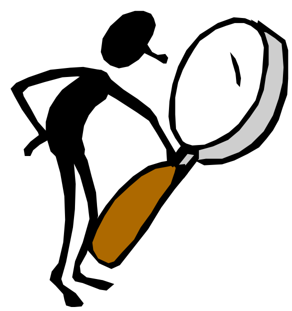
Energy cost is also closely related to energy performance. Energy cost savings form the basis for earning LEED points under the Energy and Atmosphere credit. A comprehensive pre-design energy analysis provides a head start for the simulation work required to calculate LEED points throughout the design process.

This course is intended to help you know what type of information to give the energy consultant and what results to expect. The types of pre-design energy analyses are described and tips for presenting results are also discussed. Chapter One begins with a look at the different types of pre-design energy analysis procedures.

Chapter 1
Pre-design Energy Analysis

This chapter discusses the various types of pre-design energy analyses that may be used in a building design. This chapter includes the types of information to supply to an energy consultant, questions for the energy consultant, and how to set performance goals for a new facility.

Pre-design energy analyses can be divided into one of these five basic types:



1. Baseline analysis
2. Load elimination parametric analysis
3. Sensitivity analysis
4. Energy conservation measure analysis
5. Utility bill analysis (if applicable)

The first four types of analyses can be performed for any building project. The fifth type, utility bill analysis is mainly applicable to renovation projects or projects that will build a new version of an existing building. The following sections introduce the intent and application of each type of analysis. Examples of analysis results and ways to present them are shown later. Remember in all cases that a pre-design energy model is a simplified sketch of a potential building. Results are best used to compare and explore alternatives and will not necessarily be representative of the actual performance of the final design.

Determine with the energy consultant which specific analyses are most appropriate for the budget, and available time. At the very least a baseline analysis is recommended. Chapter Two describes the methods and procedures for each type of analysis in detail.

1. Baseline Analysis

Baseline analysis (also known as base case analysis or base building analysis) characterizes the energy uses and costs that would be expected if the building were built to code with no high-performance features. In the pre-design stage, the architecture and geometry have not yet been decided. The baseline building is therefore merely a box that meets all the owner’s program requirements. The performance of building materials and mechanical equipment is dictated by the applicable minimum energy code requirements for the site. The most common energy code for commercial buildings is Standard 90.1 of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The applicable year of the Standard can vary by state and municipality. California has its own energy code called Title 24.

The baseline analysis yields several results that are relevant for the design team. Estimated total annual energy use, total annual energy cost, and peak demand provide guidance on the magnitude and profile of the anticipated energy consumption. These numbers comprise the benchmarks against which all energy conservation measures can be compared. The breakdown of end-use energy consumption such as heating, cooling, lighting, and plug-in equipment (plug loads), reveals the largest energy consumers and helps to target areas for improving energy efficiency. Energy use profiles show the variation in energy use on daily, monthly, or seasonal time scales. Such profiles can be useful when considering time-of-day demand charges or energy storage.

Understanding the energy performance of the baseline building is the first step toward setting goals and selecting high-performance features. The building simulation model developed for the baseline analysis is also a prerequisite for the remaining three types of pre-design energy analyses.

2. Load Elimination Parametric Analysis

Load elimination parametric analysis shows the impact of individual loads on overall energy use. Individual loads include the heat loss or gain through the building envelope, solar gain through windows, infiltration heat loss or gain, and internal heat gain from people, electric lights, plug loads, and process loads. The analysis is performed by sequentially "eliminating" each load in a separate simulation (e.g., the windows, lights, or infiltration) to measure its energy impact.

The results of the completed series of simulations provide a crude means of ranking the relative importance of individual loads or components. Loads that significantly affect the whole-building energy use can be targeted first for improvement. The results also show the load contribution of key programmatic details, such as occupancy schedules or lighting power densities. Careful examination of load elimination parametric analysis results can also reveal coupling between different types of loads. For example, reducing the electric lighting load decreases the cooling load, but also increases the heating load.

Load elimination parametric analysis starts with the baseline simulation model and requires minimal additional model development.

3. Sensitivity Analysis

Sensitivity analysis measures the sensitivity of whole-building energy use to changes in key design parameters. Typical parameters that are analyzed include wall and roof insulation levels, window area, overhang depth, lighting power density, and equipment and system efficiency. Parameters that show significant impact on overall performance should be considered carefully. Further analysis can be used to optimize the parameter and reduce energy use.

Like the load elimination parametric analysis, crude sensitivity analysis starts with the baseline simulation model and usually does not require significant model development.

4. Energy Conservation Measure Analysis

Energy conservation measures (ECMs) are specific technologies or design strategies that are intended to save energy. Common ECMs include extra insulation, high-performance windows, daylighting controls, passive solar heating, natural ventilation, and high-efficiency mechanical equipment.

Energy conservation measure analysis estimates the potential savings in energy consumption, energy cost, and peak energy demand for an individual ECM or combination of ECMs. The analysis allows different ECMs to be compared and the best performing configuration to be determined. The analysis is also the first step for determining whether an ECM may be cost effective.

Specific ECMs to be explored should be discussed with the energy consultant. Some will require additional model development and some may be beyond the capabilities of the simulation program. For these reasons, ECM analysis is the most challenging task for the consultant. The consultant's ability to identify other promising ECMs can vary greatly, depending on his experience and judgment.

5. Utility Bill Analysis

Utility bill analysis uses the utility billing history from an existing building to characterize energy use and help set performance goals. It can be used to illustrate monthly trends or to calibrate a baseline model. This analysis is useful for renovation or remodel projects. It is also useful for new construction if the new building is similar to another building in size, use, orientation, and climate type, or if the project is a new version of an existing building. For example, big box retail stores are often built from the same set of construction plans, so this type of analysis could be used for a new building in this situation.

Chapter 2
Data Requirements

This chapter discusses base data requirements, questions to ask, and what type of data to provide for the pre-design energy analysis.

Information for the Energy Consultant

The consultant requires general information about the site and building before starting an analysis. This information is usually the same for all types of analyses and includes:

- Site location
- Total floor area
- Number of floors
- Applicable building energy code
- Principal building activity
- Space use descriptions (including occupancy and operation schedules)
- Special process loads (e.g., refrigeration or data center)
- Utility availability and utility companies

Most of this information should be included in the building or project program. A building program questionnaire is helpful in stating the design objectives. Questions for the questionnaire are included later in this chapter. This questionnaire (or something similar) should be provided to the energy consultant.

The consultant is responsible for obtaining additional information required for the analysis. This may include weather data, utility tariffs, and building energy code requirements.

Questions for the Energy Consultant

Once the types of analyses have been selected and the required site and building information has been collected for the consultant, you are ready to decide the scope of each analysis. The scope defines how many and what types of simulations the consultant will run and the results that will be provided for the charrette. Because the options for simulations and results differ for each type of analysis, the scope should be discussed in detail and agreed upon in advance. The scope of the sensitivity analysis, for instance, should define the building parameters and the range and granularity of values that are to be examined. The scope of the ECM analysis should list the specific ECMs to be simulated. The baseline and load elimination parametric analyses have fewer simulation options but do have a variety of results options.

The consultant should summarize the raw output generated by the computer simulation into meaningful charts and tables. He should depict results so that the design team can quickly and easily understand them when presented. We recommend using charts for most results, but tables are useful for absolute numbers. Work with the consultant to agree on how results will be rendered.

The following sections offer options for simulations and results for each type of analysis to help formulate the scope of analysis you will ask for. Example results in the form of charts and tables are also shown below.

Baseline Analysis

A baseline analysis typically comprises one annual simulation of the baseline building model and can provide results for:

- Annual site energy use
- Annual source energy use
- Annual energy cost
- Annual energy use intensity
- Annual emissions (carbon and others) by fuel
- Annual water consumption
- Breakdown of energy end uses
- Monthly energy use
- Monthly peak electric demand
- Daily electricity demand profiles

The annual results for site energy use, source energy use, and energy cost are typical metrics to be communicated to the design team. Carbon emissions or water use can be of equal or greater importance for some projects. Whichever metrics are selected, these numbers form the benchmarks against which all ECMs are compared. The results are best displayed in a table such as Table 1.

Table 1

	Site	**Source**	**Cost**
Annual Energy Use	2,807 MMBtu	7,717 MMBtu	$52,871
Annual Energy Use – Intensity	52.3kBtu/ft^2	133.7 kBtu/ft^2	$0.99/ft^2

The annual results should also be presented in terms of energy use intensity. *Energy use intensity* normalizes the energy use on a per area basis so the results can be compared to buildings of different sizes, national averages, or high-performance benchmarks. Annual energy use intensity is a useful metric for setting performance goals.

The distinction between "site" and "source" energy is relevant in some projects. *Site* energy is the measure of energy consumed by end uses at the project site—essentially the same as the utility bill. *Source energy*, on the other hand, is the measure of energy consumed to produce and deliver the site energy. Usually site energy, source energy, or energy cost is selected as the reference metric for all of the analyses.

The annual energy results should be broken down by end use: heating, cooling, fans, pumps, plug loads, and lighting. Some buildings may have special end uses that should also be included. A supermarket, for instance, will have refrigeration as a significant end use. As far as possible, all end uses should be identified—none left as "miscellaneous."

A bar chart is a convenient way to show the relative magnitudes of the different end uses (see Figures 1 and 2). This quickly identifies the largest end uses that should be targeted for improvement.

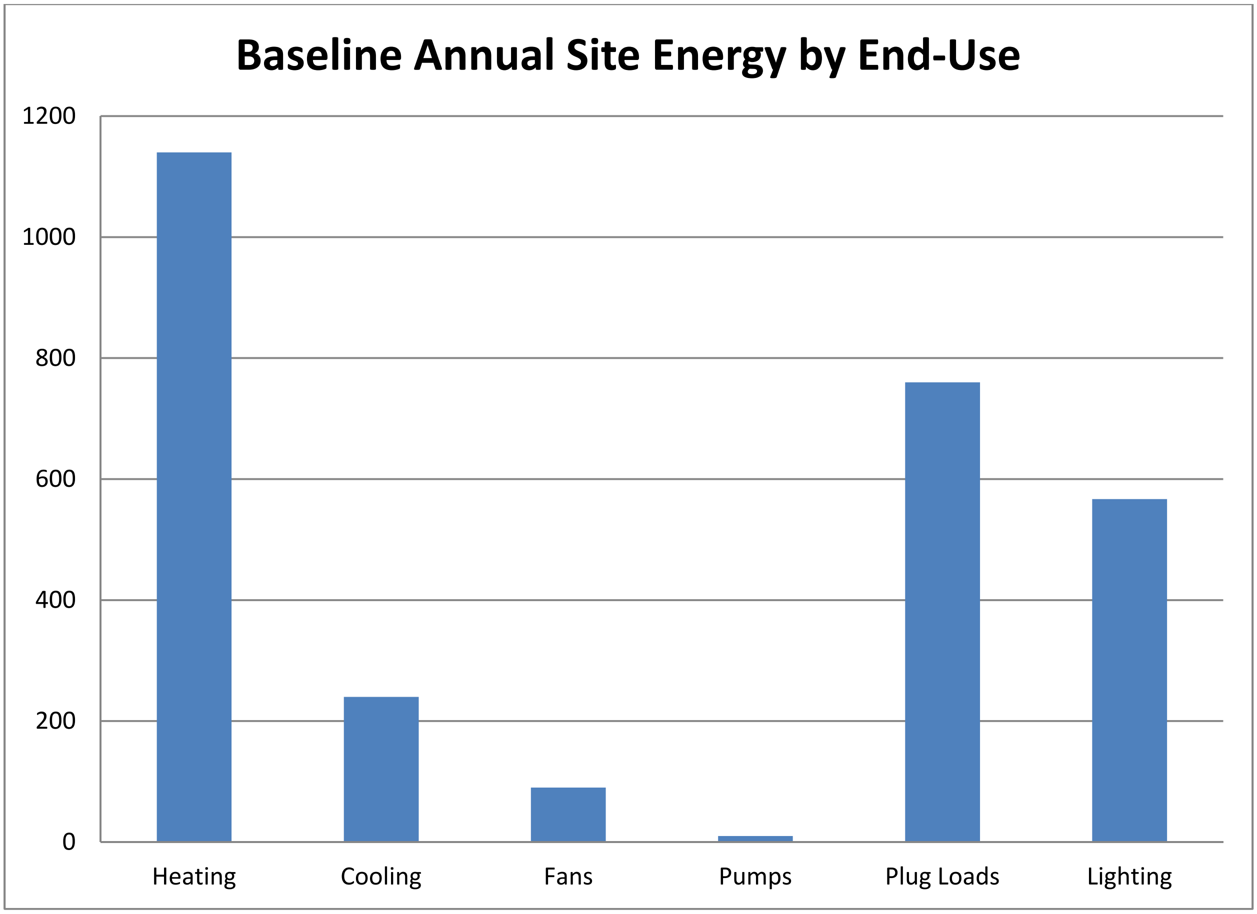

Baseline Annual Site Energy by End-Use
1200
1000
800
600
400
200
0
Heating
Cooling
Fans
Pumps
Plug Loads
Lighting

Figure 1

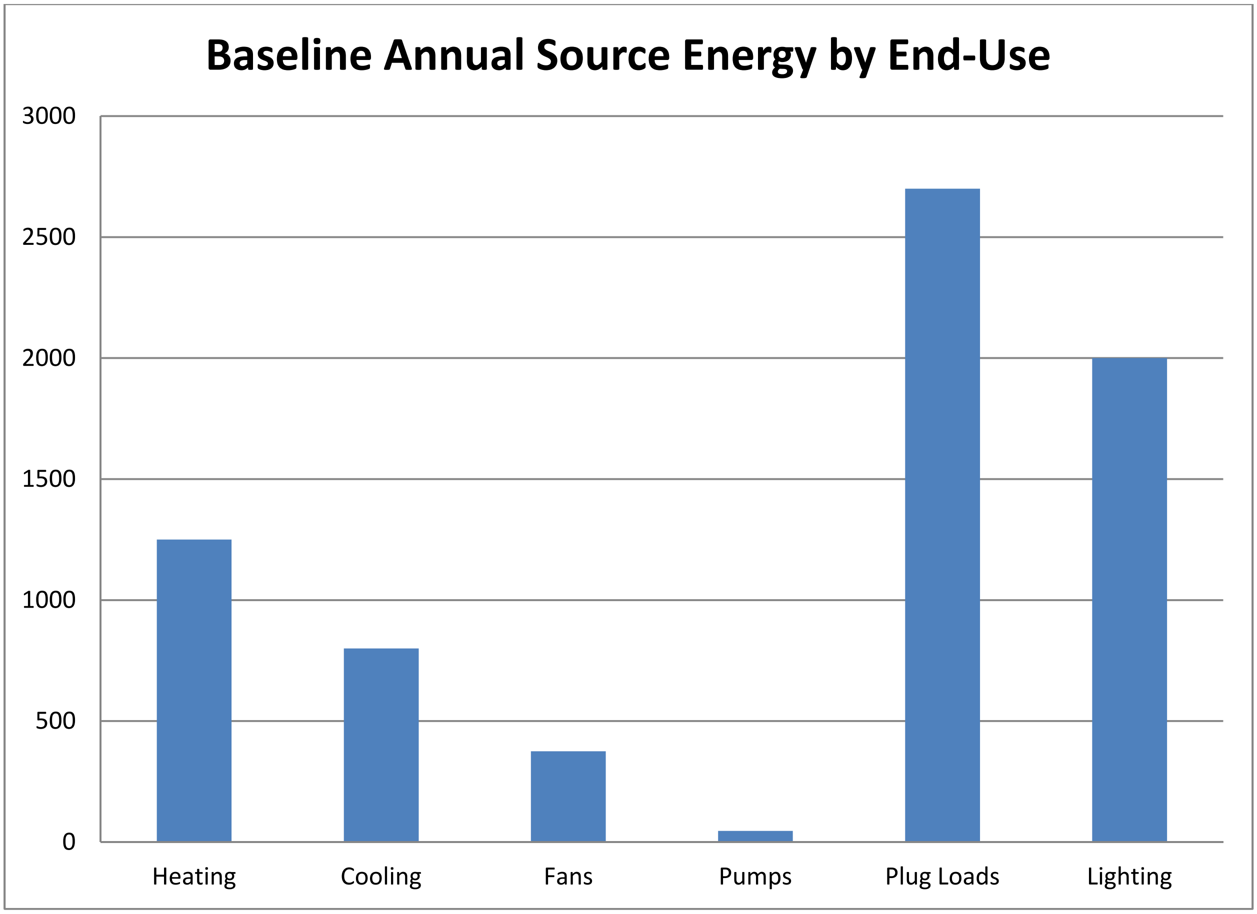


Figure 2

Pie charts are commonly used to display results. However, they should be used with caution because it is difficult to visually compare different slices to one another in a given pie chart, or to compare slices between pie charts. Pie charts can be safely used if the purpose is to compare each slice relative to the whole pie—for example, to compare percent energy end uses relative to the total (see Figure 3). For good measure, the data values should also be labeled for each slice of the pie.

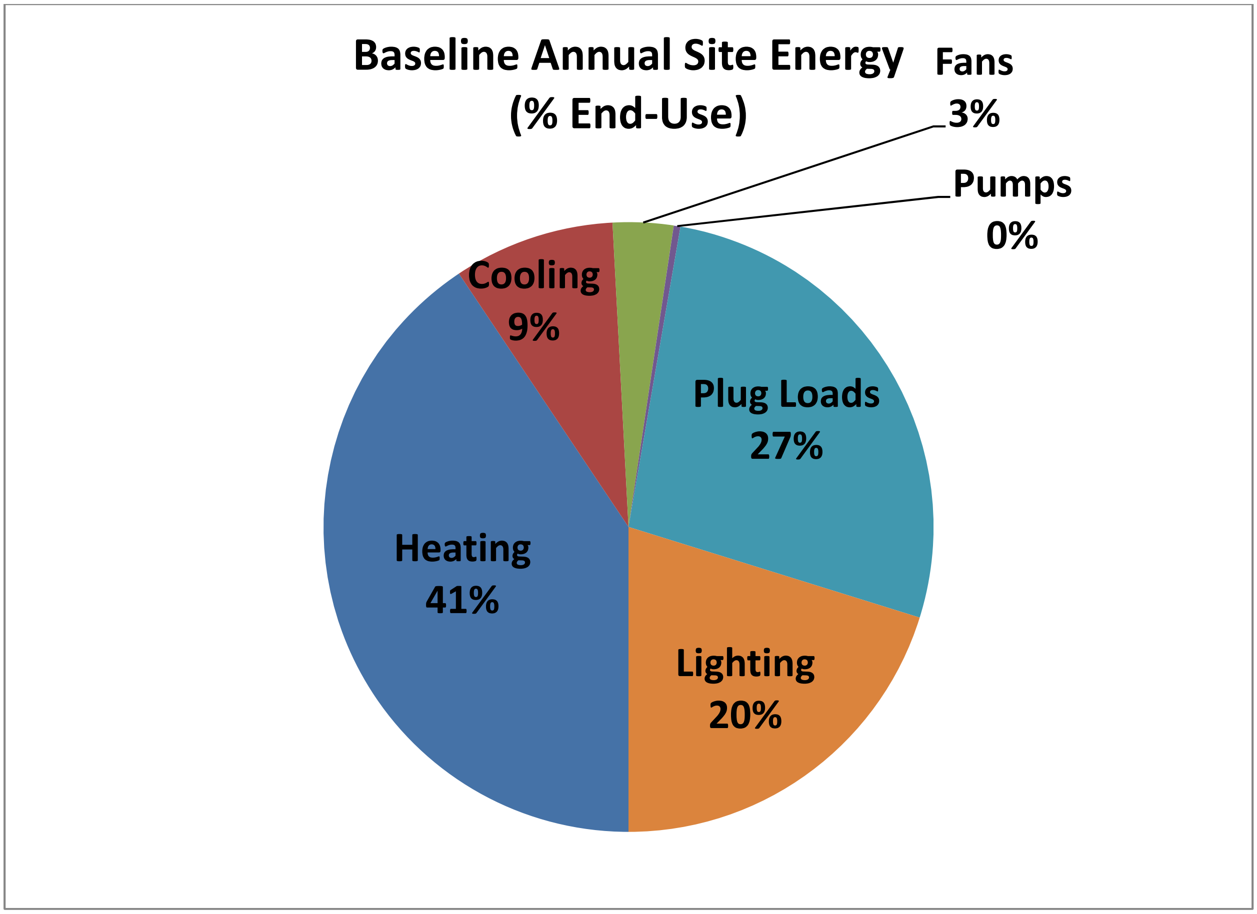


Figure 3

Energy end uses can be further broken down by month or billing cycle to show seasonal variations. A stacked bar chart is ideal for displaying these results (see Figure 4). This chart is especially useful for revealing the seasonal impact of heating and cooling loads.

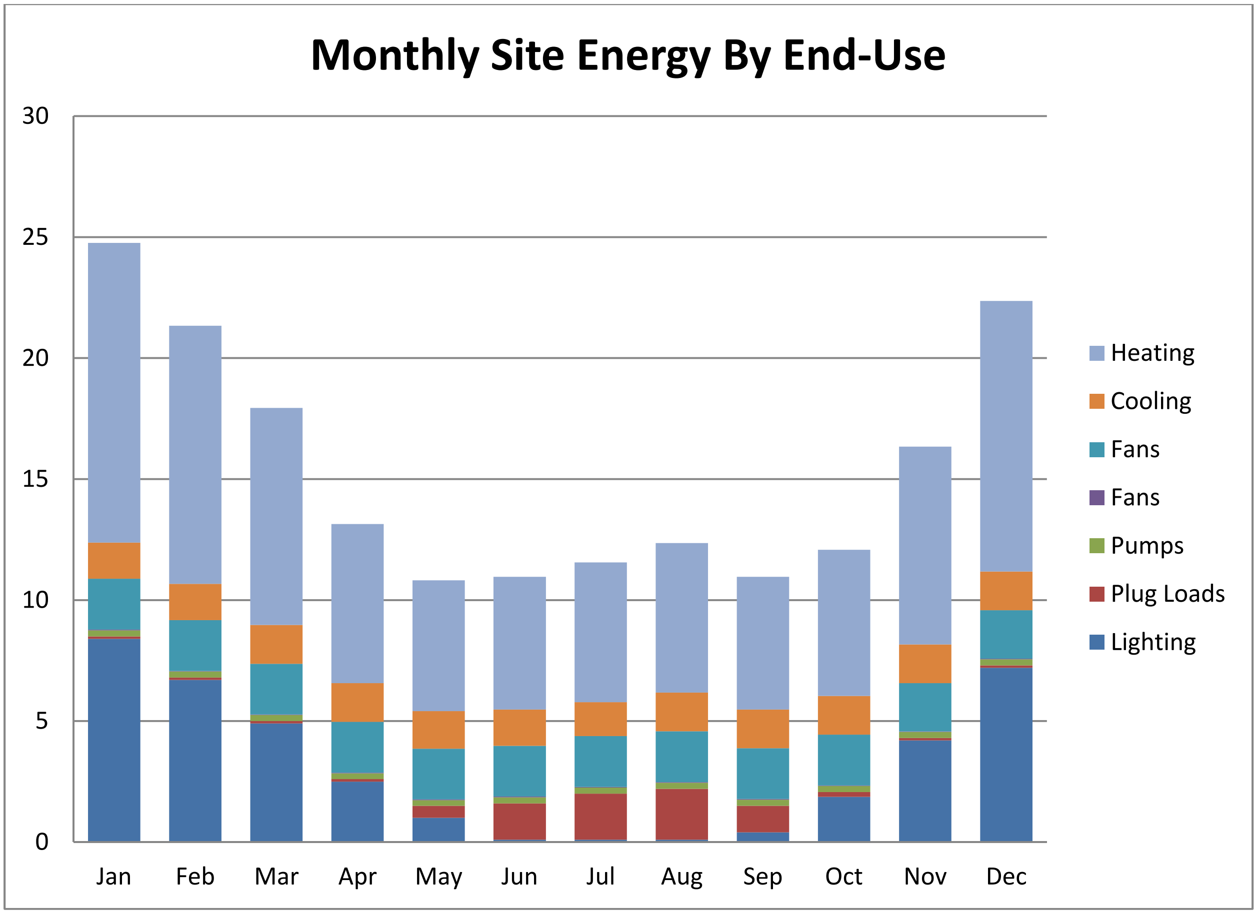


Figure 4

Daily electricity demand profiles show electricity use patterns over a 24-hour period. Utility companies usually base their electricity tariffs on a combination of electricity use and peak demand incurred during a given period (such as a month). Peak demand is measured as the average power over a specified time window, typically 15, 30, or 60 minutes. Daily demand profiles can identify which end uses contribute most to the peak demand and can illustrate the opportunity for cost savings from demand management strategies.

A variety of representative daily profiles can be selected to illustrate electricity demand on different days and at different times of year. In all cases, the demand results should be broken down by end use and averaged over the same demand window used by the utility company. Figure 5 shows the profile for December 16.

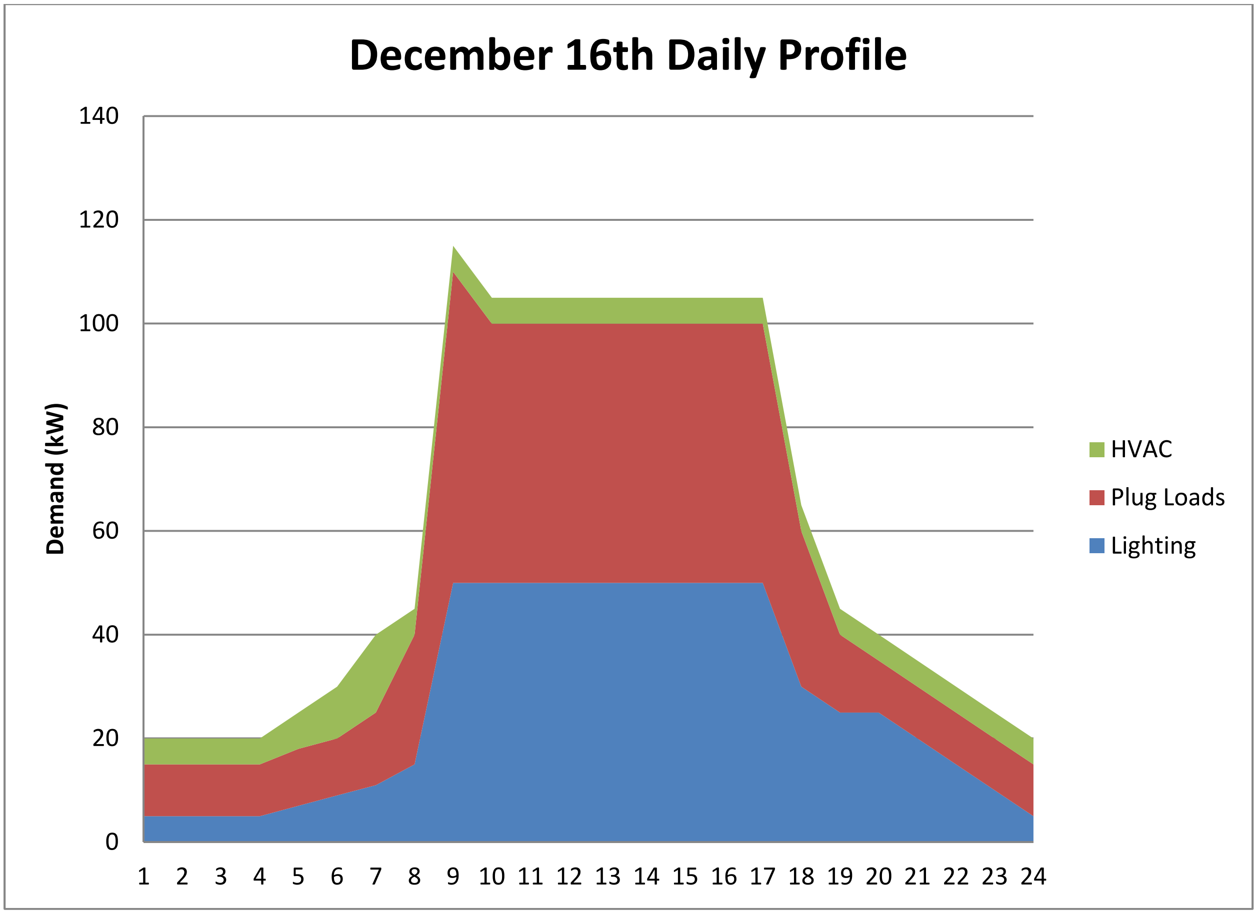


Figure 5

One or more peak demand days should be presented. A peak demand day is one that would likely set the demand charge for the month (see Figure 6). A peak heating day, a peak cooling day, plus one for each season is desirable.

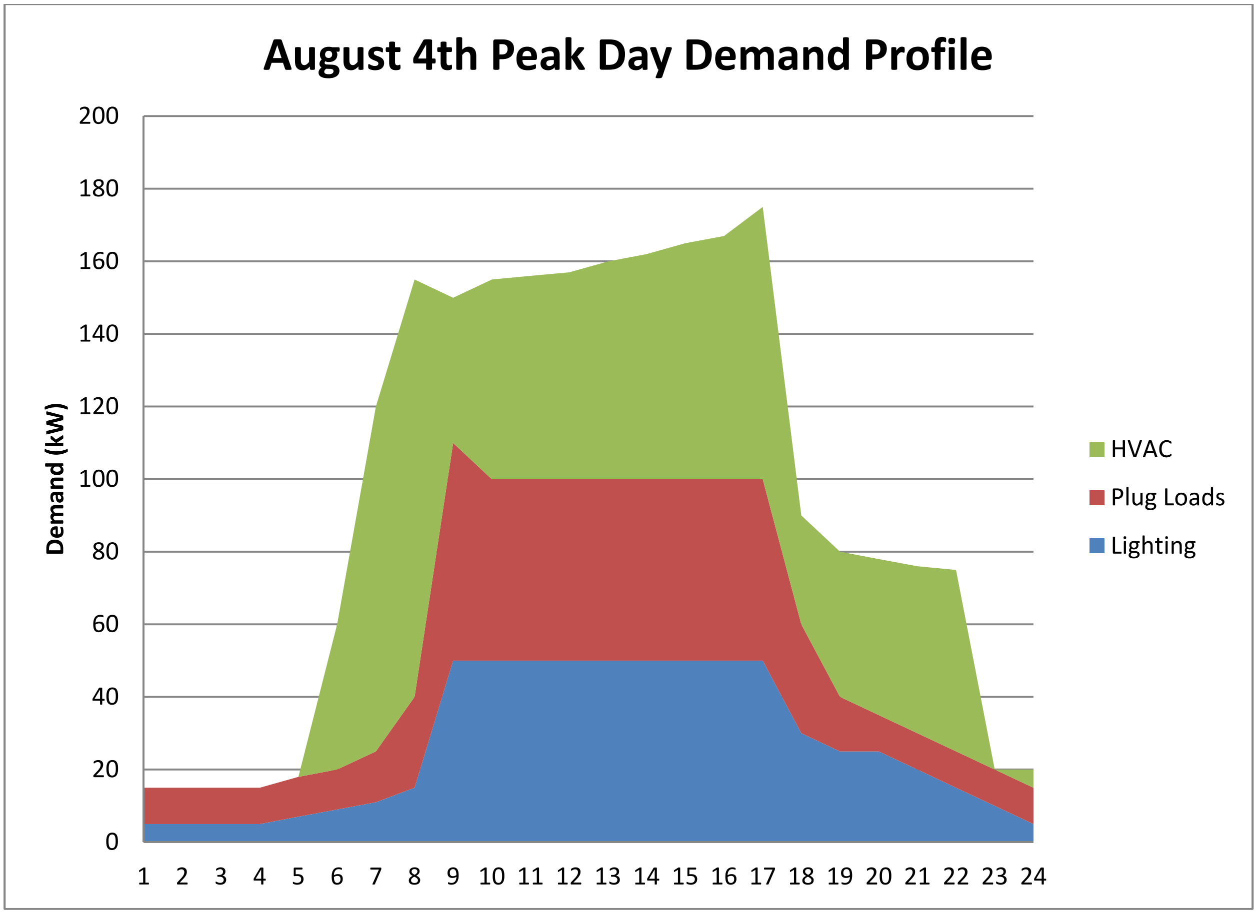


Figure 6

The daily profile can also be averaged over a month (see Figure 7) or an entire season to create an average daily profile. These profiles can be used to illustrate general trends over longer periods and can indicate opportunities for reducing peak demand under time-of-use billing arrangements.

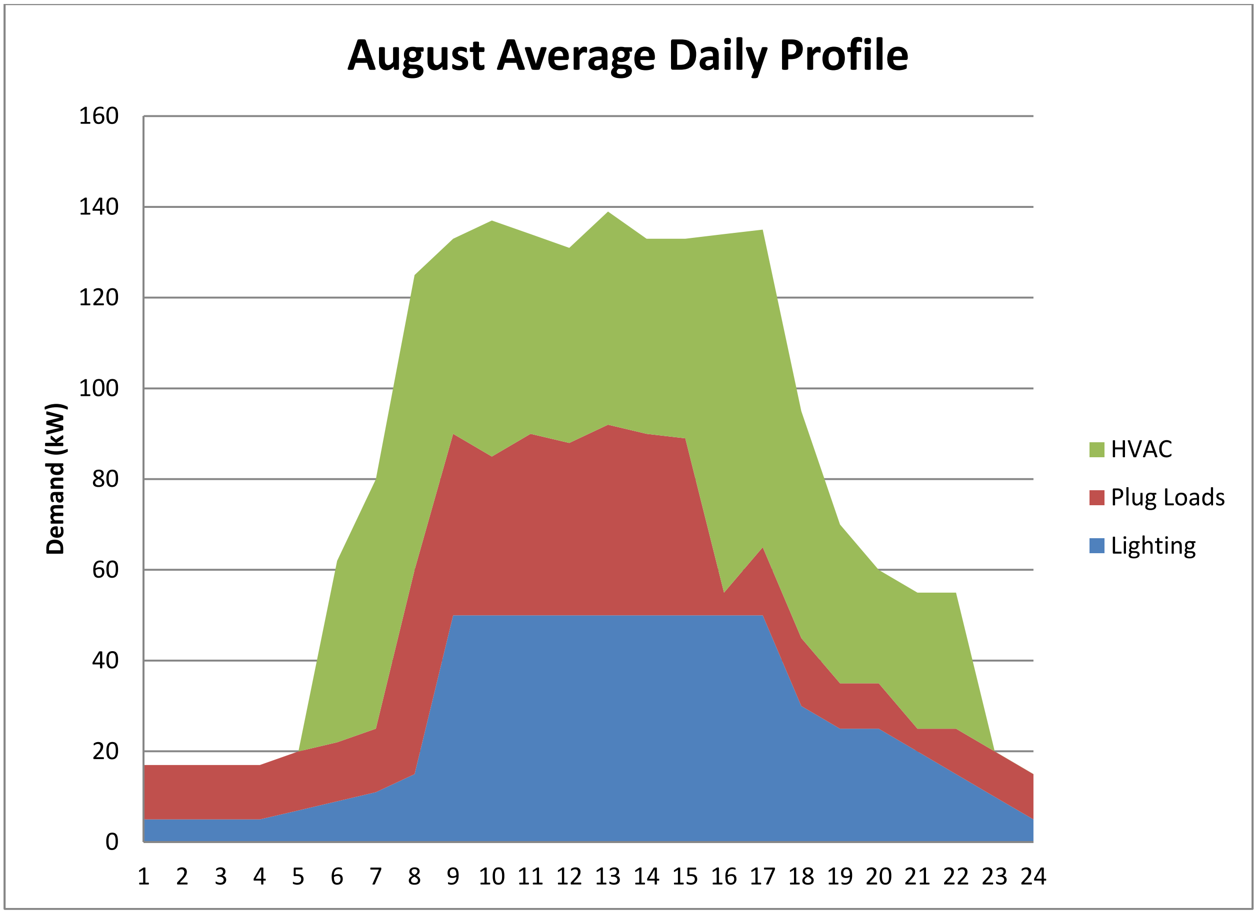


Figure 7

Load Elimination Parametric Analysis

Load elimination parametric analysis consists of a set of simulations that provide a comparison of the individual energy impacts of different loads to the baseline results. To compare the simulations, select a metric such as annual site energy use or annual source energy use. Figure 8 shows an example chart for a load elimination parametric analysis. Breaking the end uses down in each column helps to show relative changes for each load if eliminated completely.

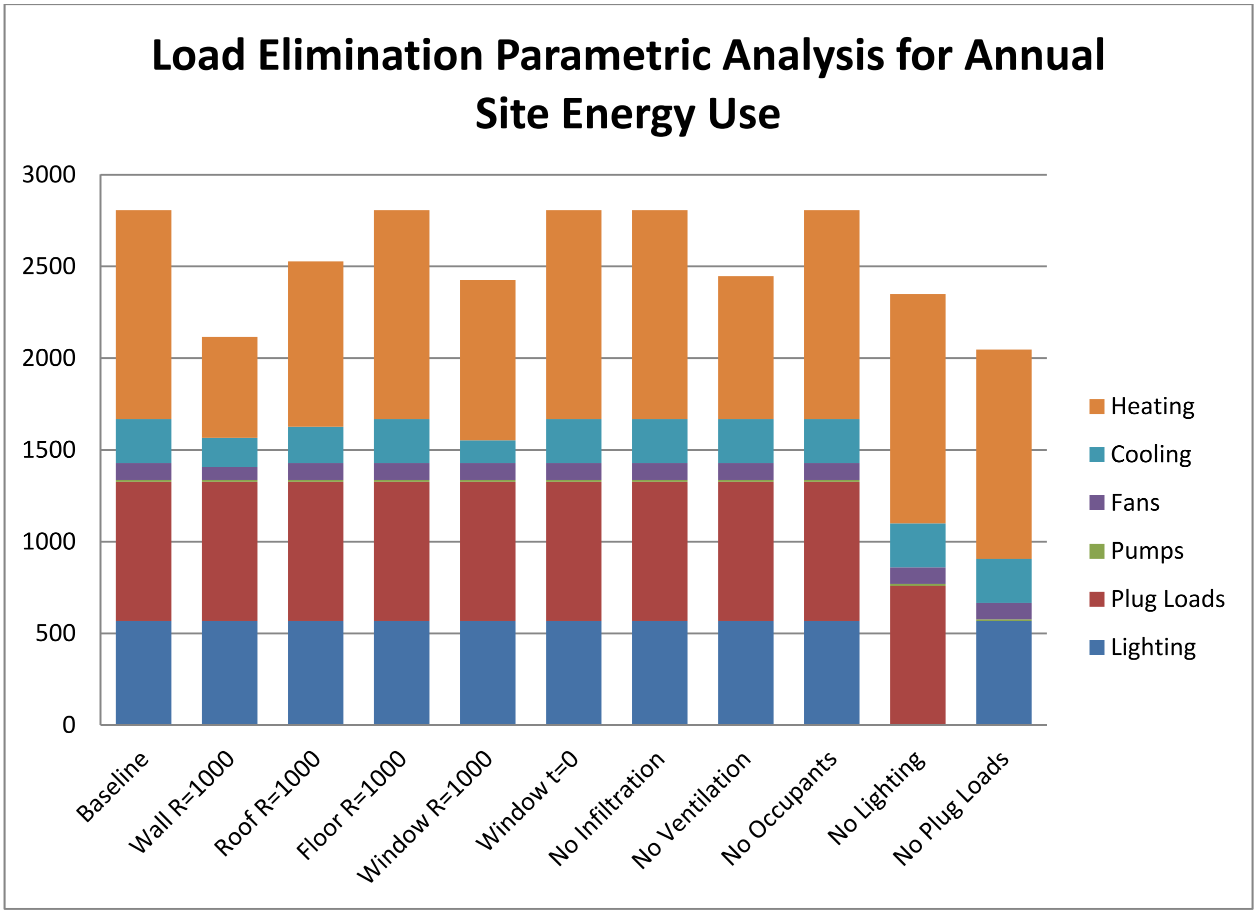


Figure 8

The analysis is performed by sequentially eliminating each load in a separate simulation. A load is eliminated by setting one of the simulation parameters to an extreme value—a theoretical limit that can never be reached in practice. Because the values are extreme, the results indicate trends and relative behavior rather than actual savings. A standard list of loads to be eliminated includes:

- **Wall R = 1000**. The wall insulation level (R-value) is set to a very high number to eliminate heat transfer through the walls. This gives an idea of the theoretical limit for energy savings that could be achieved by increasing the insulation in the walls.

- **Roof R = 1000**. The roof insulation level (R-value) is set to a very high number to eliminate heat transfer through the roof. This gives an idea of the theoretical limit for energy savings that could be achieved by increasing the insulation in the roof.

- **Floor R = 1000**. The floor insulation level (R-value) is set to a very high number to eliminate heat transfer through the floor. This gives an idea of the theoretical limit for energy savings that could be achieved by increasing the insulation under the floor.

- **Window R = 1000**. The window insulation level (R-value) is set to a very high number (or U-value is set to a very low number) to eliminate heat transfer through the windows. This gives an idea of the theoretical limit for energy savings that could be achieved with better insulated windows.

- **Window t = 0**. The window transmittance (t) is set to zero to eliminate solar gains through the windows. This gives an idea of the theoretical limit for energy savings that could be achieved by upgrading the solar performance of the windows.

- **No Infiltration**. The rate of outside air infiltration is set to zero. This gives an idea of the theoretical limit for energy savings that could be achieved by tightening up the building envelope.

- **No Ventilation**. The rate of outside air ventilation is set to zero. This gives an idea of the theoretical limit for energy savings that could be achieved by using air-to-air heat recovery.

- **No Occupants**. The internal heat gains caused by people are set to zero. This load cannot usually be reduced, but it is still helpful to know its impact on energy.

- **No Lighting**. Electric lighting is set to zero. This gives an idea of the theoretical limit for energy savings that could be achieved with daylighting.

- **No Plug Loads**. Plug-in equipment loads are set to zero. This gives an idea of the theoretical limit for energy savings that could be achieved by using high-efficiency equipment.

In special cases, additional process or other loads such as refrigerated cases in a supermarket should be eliminated separately.

A significant reduction in annual energy use for any one eliminated load indicates an area where the design team should investigate opportunities for energy savings. Conversely, a minimal reduction in annual energy use suggests that the particular load provides little opportunity for energy savings. Large loads related to occupants, plug loads, or process loads are often consequences of the building's programmatic requirements and leave little room for improvement.

Sensitivity Analysis

Sensitivity analysis consists of one or more sets of simulations that provide information about the sensitivity of annual building energy use to specific design parameters. Design parameters are basic properties of the building construction and geometry that can vary continuously or discretely over a range of values. Possible parameters are aspect ratio of the building footprint, window-to-wall area ratio, wall insulation R-value, window U-value, and infiltration rate. Sensitivity is indicated by the change in whole-building energy use per change in the given parameter.

One approach to sensitivity analysis is to perform several simulation runs over a range of parameter values. The whole-building energy use can then be extrapolated and interpolated to be plotted as a function of the given parameter. Figure 9 shows an example using wall insulation R-value as the parameter.

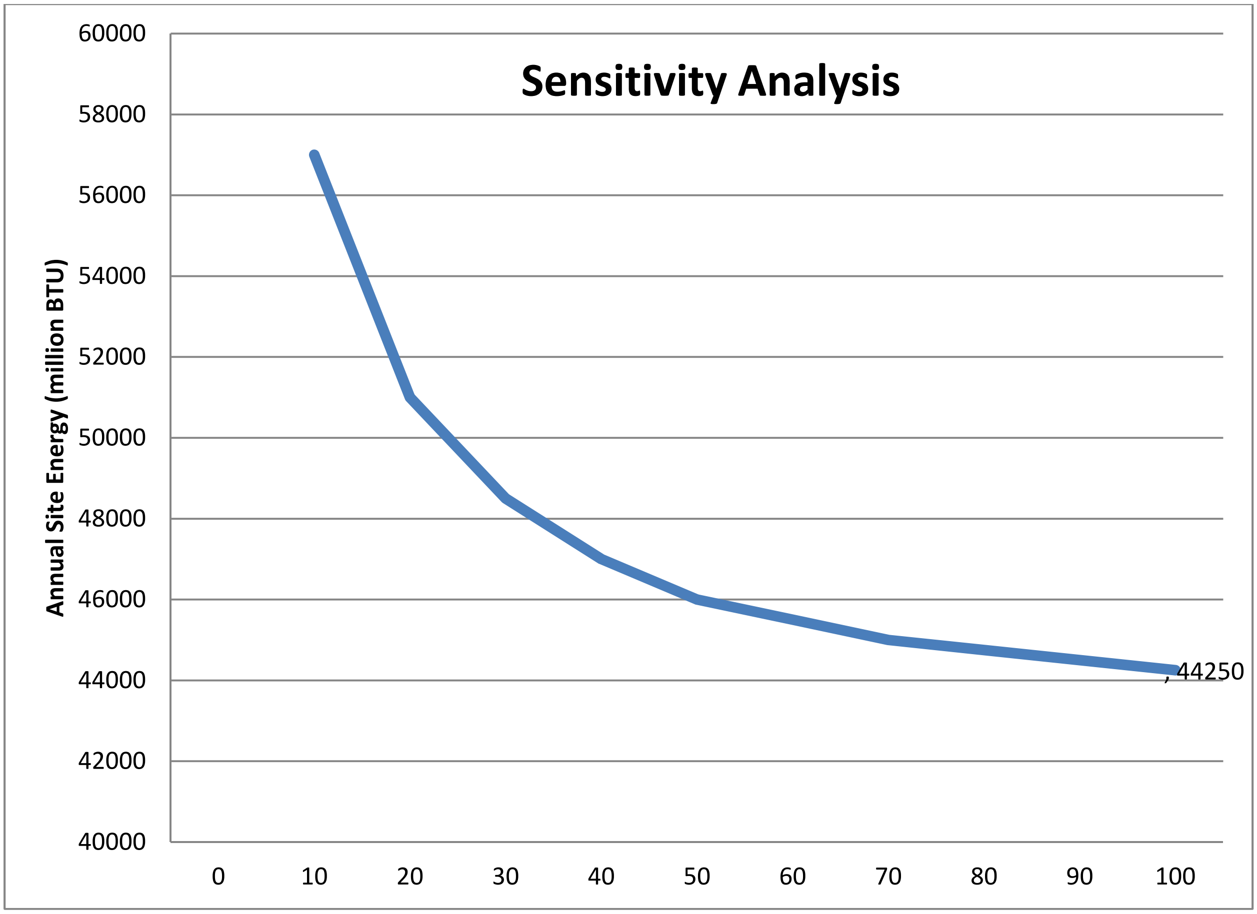


Figure 9

The curve gives an idea of the qualitative relationship between the parameter and energy use—in this case, the diminishing returns of increased insulation levels. Charrette participants can use this curve to estimate the optimal parameter value when taking into account the costs of increased insulation levels.

A related approach to sensitivity analysis that requires fewer simulation runs is to compare the baseline energy use to only two additional data points. The two simulations bracket the baseline parameter value by increasing it by a fixed value, e.g., 50%, in one run and decreasing it by the same value in the other run. The slope between the two extremes is a quantitative measure of the sensitivity. In Figure 10, the slope indicates an energy saving of 540 million Btu/year per added R-value of wall insulation. This slope can be used to interpolate the energy savings for intermediate parameter values. Caution should be exercised when extrapolating beyond the two extreme values. As Figure 9 demonstrates, the actual relationship between a parameter and energy use is not necessarily linear over a broad range.

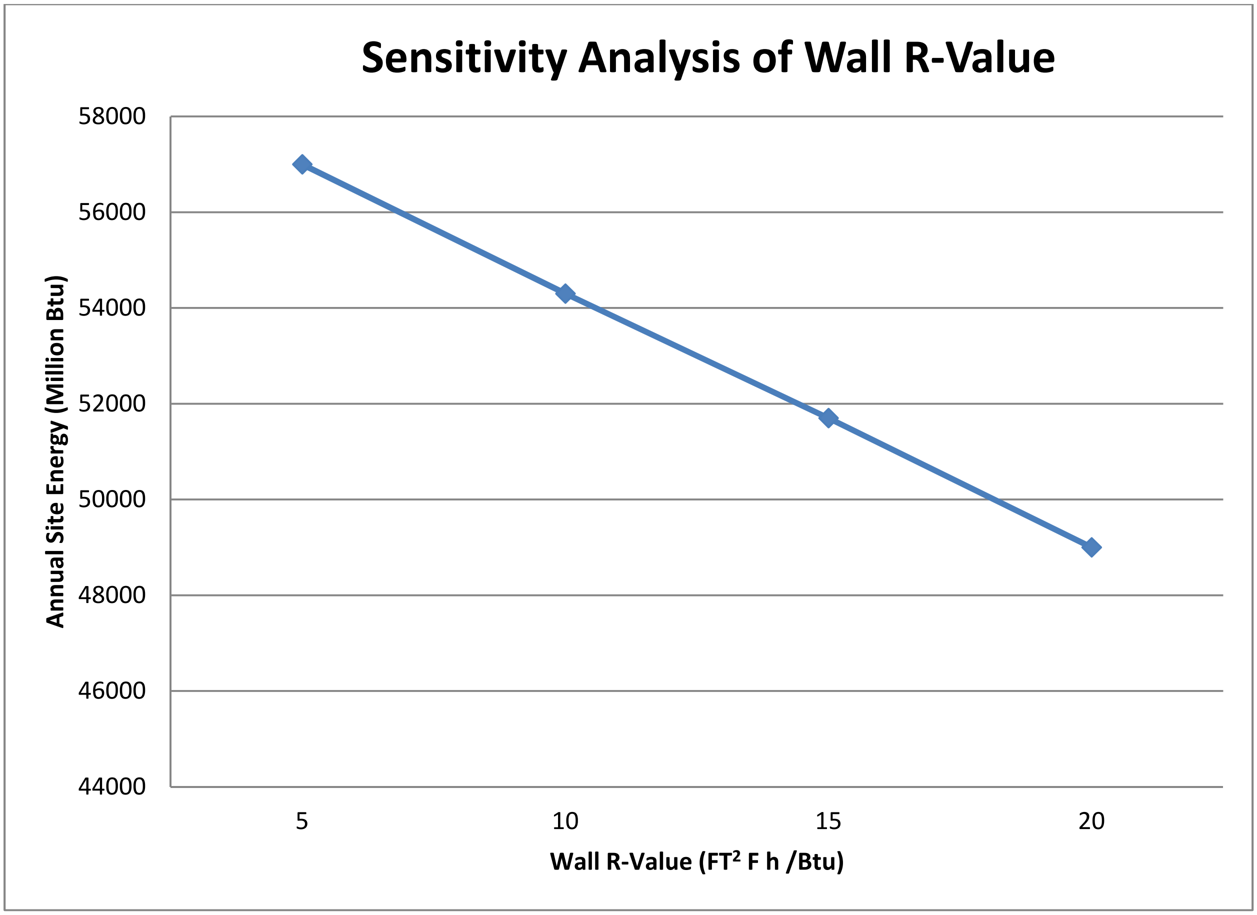


Figure 10

Energy Conservation Measure Analysis

An ECM analysis consists of a set of simulations that provide the following results:

- Potential energy savings for common ECMs
- Potential for onsite renewable energy generation
- Best-performing configuration of ECMs

Like the load elimination parametric analysis, a metric such as annual site energy use or annual source energy use should be selected to compare the simulations. Figure 11 shows an example chart for an ECM analysis.

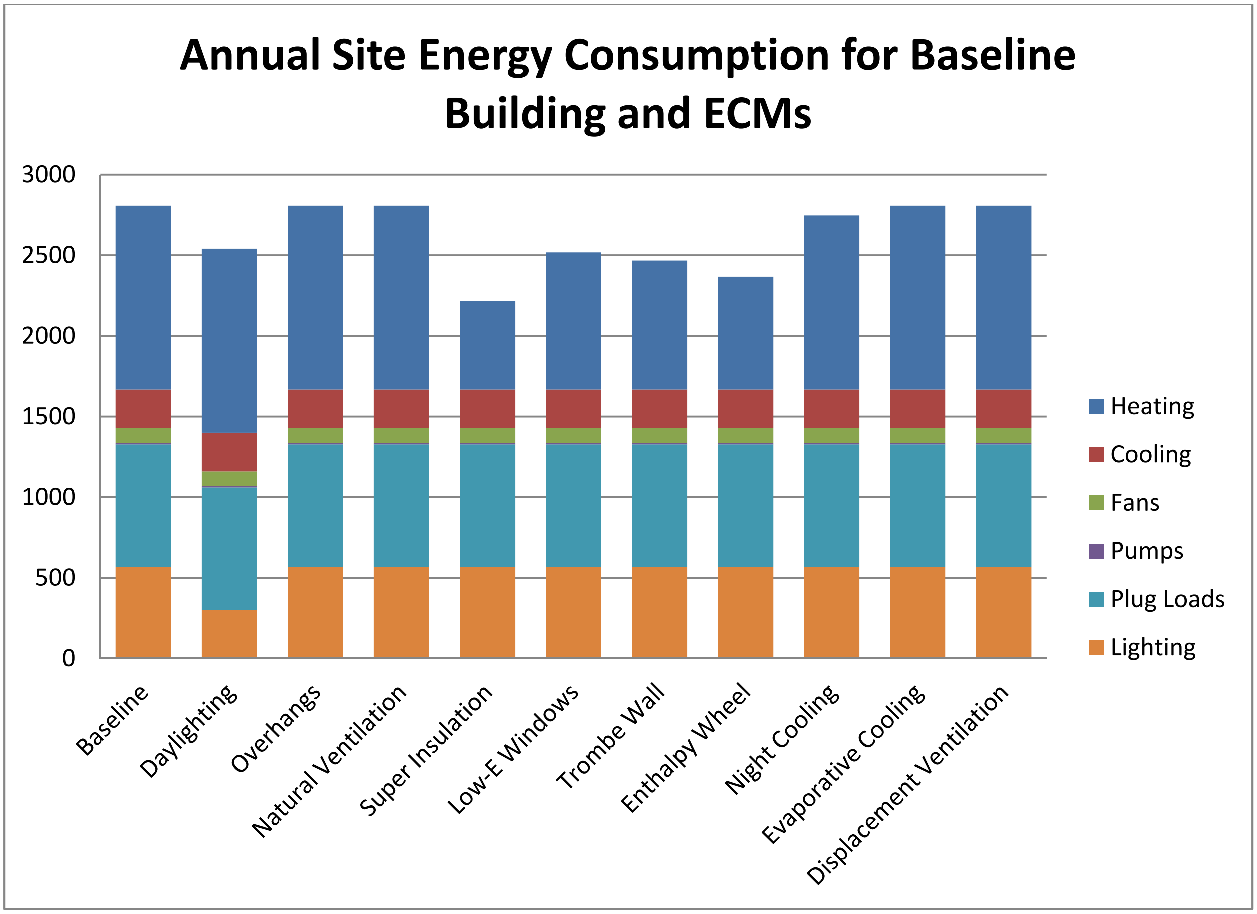


Figure 11

The list of ECMs will vary greatly by project. The results of the baseline analysis, load elimination parametric analysis, and sensitivity analysis may suggest favorable ECMs. Several common ECMs are listed below:

- **Extra Insulation**. Added insulation can reduce heating and cooling loads.
- **High-Performance Windows**. Several types should be explored.
- **Solar Control**. Use overhangs and fins to reduce solar gains in the summer when the sun is higher in the sky.
- **Tight Envelope**. Reducing infiltration of outside air can reduce heating and cooling loads.
- **Improved Lighting Design**. Better electric lighting design can reduce lighting power densities. Occupancy sensors can further reduce lighting energy use.

- **Daylight Integration**. Integrate daylighting with automatic dimming controls to reduce electric lighting loads and cooling loads.

- **Passive Solar Heating**. Integrated architectural devices such as sun spaces or Trombe walls can reduce heating loads and provide thermal comfort.

- **Reflective or Vegetated Roof**. White, light-colored, or vegetated roof systems can reduce heat gain in the summer to achieve annual energy savings in some climates.

- **Aspect Ratio and Orientation**. The basic shape of the building affects heating and cooling loads and can facilitate daylighting and passive solar heating.

- **Air-Side Economizer**. If not already required by code, an economizer can use outside air for cooling when conditions are favorable.

- **Natural Ventilation**. Uses air flow through windows and other openings to cool the building when conditions are favorable.

- **Night Cooling**. Precools the thermal mass of the building at night to reduce coolingloads during the day.

- **High-Efficiency Mechanical Equipment**. Once the building loads are reduced, high-efficiency equipment such as chillers, air conditioners, furnaces, boilers, water heaters, pumps, and fans can save energy. Explore nontraditional alternatives such as evaporative cooling, radiant heating or cooling, displacement ventilation, and low-pressure systems.

- **On-Site Renewable Energy Generation**. Photovoltaic panels generate electricity on site to offset building consumption.

The best-performing individual ECMs should be integrated into an optimal configuration. The energy saving of the optimal configuration is a good starting point for goal setting. During the charrette, some ECMs may be discarded and others added as the design concept evolves.

Presenting Results

The final results of the various analyses, in the form of a report with tables and charts, represent considerable effort on the part of the consultant.

All results must be available in advance and presented early in the first day of the charrette so participants can use this information as they develop designs. Make sure that sufficient time is reserved in the agenda for presenting results. Generally, if available, results should be presented in the following order:

- Historical analysis
- Baseline analysis
- Load elimination parametric analysis
- Sensitivity analysis
- ECM analysis.

When possible, the consultant should present the results so that he or she can answer any questions that might arise. The consultant should also prepare a written summary that includes all tables and charts and a brief interpretation of the results. The summary should be distributed with the other advance materials so the design team has time to digest all the results. The consultant should not overwhelm the design team with the technical details of the simulation. Providing a clear graphical presentation of the results is critical. Technical details should be put in appendices.

Setting Performance Goals

Setting achievable and understandable performance goals early in the design process is crucial to achieving high-performance buildings. Goals distill the project vision and secure commitment from the design team. To ensure goals are successfully attained, keep these points in mind:

- Goals must be set early in the design process, when changes can be made without adding to the cost of the project.
- Goals must be well-defined. Each goal should include a measurable value that can be tested and verified throughout the project.
- Goals must be embraced by the design team. Everyone must buy in to the project vision and commit to the goals. Each goal must also have a champion on the design team.
- Goals must be maintained after the design stages into construction and commissioning

A pre-design energy analysis is essential for setting attainable energy performance goals. Without analysis, energy performance goals are typically suggested by charrette participants based on previous experience with other projects. But because every project is a unique combination of program requirements, climate, and site, goals can quickly become arbitrary guesses. If, however, a pre-design energy analysis has been performed, goals can be set with greater confidence because they are based on simulation results that are tailored to the specifics of the project.

The baseline and ECM analyses are probably the most useful for setting energy performance goals. The results of the ECM analysis forecast potential energy savings compared against the benchmark results of the baseline analysis.

Some examples of well-defined energy performance goals are:

- Annual site energy use intensity lower than 40 $kBtu/ft^2$,
- Energy cost savings of at least 60% compared to a code minimum building,
- Peak electrical demand lower than 5 kW, and
- At least 20% of the annual site energy needs are met with on-site renewable energy sources.

Ideally, energy analysis will continue to play an important role in the succeeding stages of the design process. The simulation models developed during the pre-design stage form the foundation for more detailed building models. As the design evolves, detailed models help the design team to refine and optimize the broad decisions that were made during the charrette. During the construction stage, additional simulations may be needed to address unanticipated design problems. In the post construction stage, detailed models can aid with commissioning to verify that the building is performing as designed.

Building Program Questionnaire

A questionnaire should be completed by the building owners or architects according to the building program. The building program contains the functional requirements that form the basis for developing the building design. The instructions for completing the questionnaire should also be provided to the owner or architect. Projects with multiple buildings should complete a separate questionnaire for each building.

The questionnaire should cover three broad categories of details including,

1. Building Description
2. Space Descriptions

3. Utility Availability

The following is a description of what should be covered in each section of the questionnaire.

1. Building Description

The location of the building site, generally the city and state, is sufficient. The consultant will obtain the latitude and longitude and weather data for the location.

The main activity of the building corresponding to the *Principal Building Activity* categories used in the 1999 Commercial Buildings Energy Consumption Survey (CBECS 1999). The categories for Principal Building Activity are:

- Education
- Food Sales
- Food Service
- Health Care (Inpatient)
- Health Care (Outpatient)
- Lodging
- Mercantile (Retail, other than mall)
- Mercantile (Enclosed and Strip Malls)
- Office
- Public Assembly
- Public Order and Safety
- Religious Worship
- Service
- Warehouse and Storage
- Other
- Vacant

Give the total floor area of the building, including all floors and the number of floors above grade and below grade, listed separately.

Provide the governing energy code for the building that defines the minimum requirements for energy, such as insulation levels and HVAC efficiency. The consultant is responsible to determine the code requirements and apply them to the simulation models. For most commercial buildings, the energy code is ASHRAE Standard 90.1, but the year of the standard must be specified: 1989, 1999, 2001, 2004, or 2007. In California, the energy code is Title 24 (CEC 2004; 2005), which is stricter than ASHRAE 90.1. The International Building Code (IBC) (ICC 2006) is another energy code.

2. Space Descriptions

The space descriptions allow the space uses to be more finely delineated beyond the Principal Building Activity. The descriptions are especially important for mixed-use buildings.

Using the Principal Building Activity categories, select the main use of the space and provide the total floor area dedicated to this space use. The area can be specified as square footage or percentage of the total building floor area.

Provide the expected hours of operation and occupancy for the space. If left blank, the energy consultant will assume default values based on the Principal Building Activity. If the operation is unusual, some notes should be made here. For example, the space may be operated significantly more or less than might be expected. Notes can also be made here for unusual space conditioning requirements. An art gallery space, for instance, might have strict requirements for temperature and humidity control.

Provide notes for special equipment or loads in the space. For example, refrigeration cases in a supermarket, or a large number of server racks in an office space, qualify as special equipment.

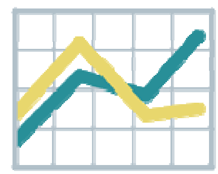
3. Utility Availability

Determine the availability and contact information for the local utility companies, including electricity, natural gas, water, communications, and other providers. The energy consultant is responsible to obtain the relevant utility tariffs for calculating energy and water costs.

Chapter 2
Energy Analysis Procedures

This chapter provides information on the procedures used for performing a pre-design energy analysis for a high-performance building project. Five types of pre-design energy analysis were introduced in Chapter One: baseline analysis, load elimination parametric analysis, sensitivity analysis, ECM analysis, and utility bill analysis. The consultant should become acquainted with the expectations for results laid out in Chapter One. It is assumed that the energy consultant has experience with building simulation, but not necessarily with high-performance projects or pre-design energy analysis. Chapter One may also be useful to the owner, architect, or design team for gaining further insight into pre-design energy analysis and the work of the energy consultant.

The analysis procedures described here focus on analyzing individual buildings. If the project is for multiple buildings, it is recommended that a separate analysis be performed for each building. Some of the same inputs, such as weather data and utility tariffs, will be shared by all the buildings.



Analysis Tools

The primary tool for pre-design energy analysis is a building energy simulation program. The program must be able to perform an annual simulation with time steps of one hour or less. It is recommended that a whole-building energy simulation program be used for all analyses. This type of analysis is essential for high-performance projects because it is the only way to capture the complex interactions between building loads and systems. Some popular whole-building energy simulation programs are EnergyPlus, DOE-2, TRNSYS, and ESP-r.

Other specialized software tools may be appropriate for analyzing a particular subsystem of a building, such as windows, airflow, daylighting, HVAC component performance, or on-site renewable energy generation. Results from a subsystem analysis can often become inputs into the whole-building simulation.

Baseline Simulation Model

Developing a baseline simulation model is a prerequisite step to performing energy analyses. This model represents the building with no high-performance features. Because the architecture and geometry have not yet been decided, the baseline model is a simple box that meets the owners' program requirements and satisfies the minimum energy code requirements.

ASHRAE Standard 90.1 is the most commonly used commercial building energy code. This document is the foundation for the minimum code requirements for the majority of buildings in the United States, although each locality might have a different year of the code in place (ASHRAE 1989; 1999; 2001; 2004; 2007). The Federal building code and the International Building Code, as well as most state and city codes, are based on ASHRAE 90.1 with some modifications. California's Title 24 (CEC 2004; 2005) is an energy code that is distinct from ASHRAE 90.1, and is generally considered more stringent.

ASHRAE 90.1 contains an Appendix G, which provides a performance rating method for comparing a proposed design against a proposed design baseline. Appendix G spells out the simulation requirements for creating the proposed design baseline model. As the name suggests, the proposed design baseline assumes there is already a "proposed design." For pre-design energy analysis, there is no design yet. Unfortunately, ASHRAE 90.1, Appendix G does not provide any guidance in this case. Nonetheless, ASHRAE 90.1 is still an essential document for developing a baseline simulation model.

The baseline simulation model requires the synthesis of a variety of information about the building including weather, building form, building fabric, internal loads, infiltration, HVAC system, and utility tariffs. Some of the required information is found in the Building Program Questionnaire, discussed in Chapter One, as completed by the owner, architect, or engineer. One of the key responses in the Questionnaire is the Principal Building Activity, which determines many of the default simulation parameters. The remaining information is contained in the applicable building energy code or ASHRAE 90.1. Instructions for developing the various parts of the baseline model are described below.

Weather

A full year of weather data is required for all pre-design energy analyses. Weather is one of the primary driving forces for the simulation, and should closely reflect the actual climatic conditions the building will experience. The data must be in hourly time steps, or shorter, if the simulation program can handle it.

Hourly weather data for many locations throughout the United States and the world are published as ready-made weather files intended for use with building simulation programs. The largest sets of weather files include the Typical Meteorological Year, Revision 3—TMY3 for locations in the United States, the Canadian Weather for Energy Calculations—CWEC for locations in Canada, and the International Weather for Energy Calculations—IWEC for other international locations. TMY3, CWEC, and IWEC weather files are available in several formats to suit different simulation programs.

If you cannot readily find a weather file for the building location in the required format for your simulation program, there are several possible solutions. If a weather file is available in a format for another program, the data can often be converted from one format to another with a utility program. Another approach is to choose a weather file that is located as near as possible to the proposed site or at least shares similar climatic conditions. There are also tools to generate a custom weather file based on a rough interpolation between nearby available sites.

Some projects might have weather data that have been measured on site. Measured weather data have the benefit of more accurately predicting some weather variables, such as patterns of wind speed and wind direction, which can depend greatly on the peculiarities of the site and surrounding terrain. Measured data can also be useful for calibrating a simulation model of a building that is to be renovated.

Historical and near-real time weather data for many sites can also be downloaded from several sources. The NREL Real-Time Weather Server connects to the National Weather Service network to access more than 4,000 weather stations around the world. Data requests are automatically sent to the user by e-mail. The National Climatic Data Center and WeatherBank also offer Web access to near real-time weather data. Once the raw weather data are obtained, the consultant must manually convert the data into the appropriate format for the simulation program, or find a utility program to do the job.

Measured weather data sets, from on-site measurements or other sources, all share the same disadvantage. The data do not represent a typical meteorological year and should not be relied on for design purposes. The ideal solution is to produce a hybrid weather file that uses general observations from the on-site measurements to modify the typical year weather file. This will produce a better result.

Form

The building form is the architectural geometry of the building design. Form includes orientation and shape of the envelope, location and size of the windows, and zoning of the interior spaces. In the pre-design stage, the form has not yet been determined. The Building Program Questionnaire provides the gross floor area of the building and the number of floors, but nothing else about form. ASHRAE 90.1, assumes that the building form has already been designed and does not offer recommendations for pre-design baseline models.

To fill the gap, you may assume the shape is a square footprint that meets the required gross floor area and the number of floors. The sides of the square face the cardinal directions. The total window area is distributed equally on all exterior walls. Overhangs and horizontal glazing (e.g., skylights) are not included in the baseline model.

Table 2 further determines the details of the geometry according to the Principal Building Activity specified on the Questionnaire. This table sets the thermal zoning of the interior space.

Table 2
Baseline Building Form Parameters

Principal Building Activity	Floor-to-Floor Height (ft)	Plenum Height (ft)	Zones	Perimeter Zone (ft)	Window-to-Wall Ratio
Office	13’	4’	5	15’	0.40
Warehouse (<30,000 ft2)	15’	n/a	1	n/a	0.03
Warehouse (>30,000 ft2)	20’	n/a	5	20’	0.03
Education (Primary)	13’	4’	5	n/a	0.18
Education (Secondary)	13’	4’	5	20’	0.18
Retail	15’	n/a	1	n/a	0.15
Food Sales	20’	n/a	5	15’	0.15
Service	18’	n/a	5	15’	0.15
Food Service	13’	4’	5	15’	0.175
Health Care (inpatient)	13’	4’	5	15’	0.25
Health Care (outpatient)	13’	4’	5	15’	0.25
Lodging	10’	3’	5	20’	0.21
Assembly	18’	3’	5	20’	0.15

For retail buildings and small warehouses the building is modeled as one zone per floor. For all other building types the interior spaces are modeled using a scheme of five thermal zones per floor: four perimeter zones and one core zone (see Figure 12). Table 2 also sets the floor-to-floor height, window-to-wall ratio, depth of the perimeter zone, and height of the plenum zone, if applicable.

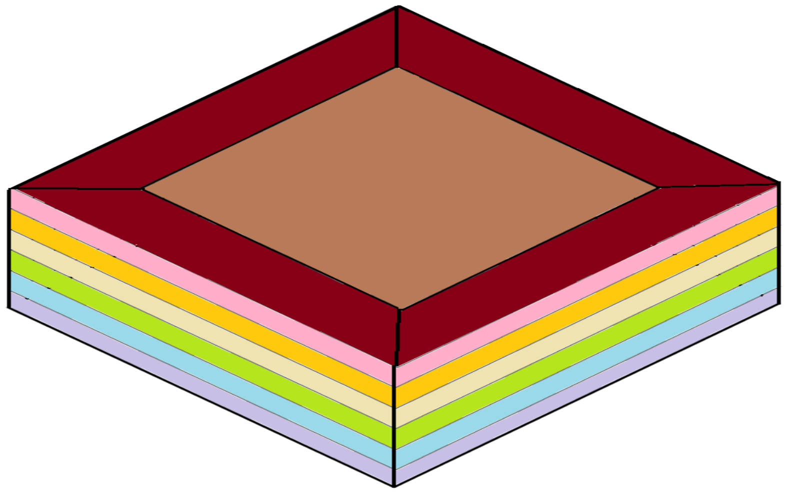


Figure 12

In ASHRAE 90.1, the proposed design baseline model is simulated at four different orientations to achieve a solar-neutral result. The final energy result is the average of the results from the four orientations. For the pre-design baseline, the square model is inherently solar neutral, so there is no need to simulate the building at multiple orientations; only one simulation is necessary.

Fabric

The building fabric is the construction composition of walls, windows, roofs, floors, and internal mass. As with form, the fabric has not yet been determined in the pre-design stage. The baseline model assumptions for exterior walls, roofs, and floors come from the tables in ASHRAE 90.1. The U-value or R-value for exterior walls, windows, roofs, and floors also come the ASHRAE tables for the minimum code standards specified according to the climate zone of the site location. Interior partitions, internal mass, and window shading devices (shades and blinds) are not included in the baseline model.

Infiltration

Infiltration is a heat gain or loss caused by outside air entering the building unintentionally, e.g., through seams in the building envelope. Infiltration rates are notoriously difficult to estimate. Nonetheless, here are two recommended options for establishing infiltration rates for the baseline model: one option is simple; the other is more detailed.

The simple option is to schedule the infiltration rate at 0.3 *air changes per hour* (ACH) for each exterior zone at all times when the HVAC system fans are not drawing outside air. When the fans are drawing outside air, schedule the infiltration rate at 0.075 ACH (25% of 0.3).

The detailed option is to first determine a highly pressurized reference value at 0.3 inches of water. The reference value, ACH_{ref}, is calculated separately for each exterior zone using the equation below:

$$ACH_{ref} = 0.4\ CFM/ft^2 * (\text{exterior envelope area}) * 60 / (\text{zone volume})$$

The reference value is then converted to an infiltration rate for normal leakage with low pressurization at 0.0161 inches of water for when the HVAC system fans are not drawing outside air.

$$ACH_{low\ press} = ACH_{ref} * (4 / 75) * 0.65 = ACH_{ref} * (0.149)$$

When the fans are drawing outside air, schedule the infiltration rate at 25% of $ACH_{low\ press}$.

Internal Loads

Internal loads consist of heat gains from occupants, electric lights, and plug-in equipment (plug loads). The Building Program Questionnaire should contain estimates for both occupancy and operation. If this information is not available, default values for peak loads in occupancy, ventilation, and plug loads should be taken from Table 3 according to the Principal Building Activity.

Table 3
Benchmark Building Loads

Principal Building Activity	Occupancy Ft^2/person	Ventilation CFM/person	Plug Loads W/ft^2
Office	275	17	1.3
Warehouse (<30,000 ft2)	5,000	.06 cfm/ft^2	0.1
Warehouse (>30,000 ft2)	15,000	.06 cfm/ft^2	0.1
Education (Primary)	75	15	0.8
Education (Secondary)	75	15	0.8
Retail	300	16	0.5
Food Sales	300	15	1.5
Service	300	19	1.0
Food Service	100	10	2.25
Health Care (inpatient)	200	25	2.2

Health Care (outpatient)	200	25	2.2
Lodging	250	11	0.7
Assembly	50	6	0.4

The electric lighting power density is set by ASHRAE 90.1 according to the different space types in the building. Schedules for all internal loads should be taken from the tables referred to in ASHRAE 90.1 according to the Principal Building Activity.

In all cases, if the Building Program Questionnaire has better information, or the owner, architect, or engineer has better knowledge about the peak loads or the intended schedules of operation, these values should be used instead of the default values. This more accurately reflects how the building will be used. However, if there is some doubt, the schedules in the tables make a good default.

Usually the space uses listed in the Building Program Questionnaire cannot easily be mapped to a simple five-zone model of the interior space. Instead, the occupancy and plug load schedules must be averaged by area into a single blended-use schedule that is applied to all occupied zones.

HVAC System

The HVAC system provides all space conditioning and service hot water needs for the building. Refer to ASHRAE 90.1, for all characteristics of the baseline model HVAC system, including system type, system sizing, component efficiency, temperature set points, and ventilation and economizer requirements.

Utility Tariffs

A utility tariff is a set of rules for calculating utility bills and is essential for calculating annual energy costs and cost savings. Energy cost savings may be used for goal setting and constitute the principal metric for earning LEED points under the "Optimize Energy Performance" and "On-Site Renewable Energy" credits.

If the names of the utility companies are provided on the Building Program Questionnaire, the utility tariffs can usually be obtained from the company Web site or by contacting a company representative.

Pre-design Energy Analyses

Once the baseline simulation model is completed, the model can be used to perform all the simulation-based pre-design energy analyses. The content below focuses on the simulation procedures for each type of analysis. (See Chapter One for full descriptions of the different types of analyses, their purposes, and how to use meaningful charts and tables to organize and present results.)

Baseline Analysis

Baseline analysis characterizes the energy uses and costs that would be expected if the building were built with no high-performance features. The baseline analysis is performed by using the baseline model to run one annual simulation. All the required results should be readily available from the outputs of the simulation program. Some results may require a minimal amount of post-processing before they can be presented as a chart or table. The baseline analysis has the most options for results. At minimum, the results for the annual energy use, the annual energy cost, and the breakdown of energy end use should be prepared for presentation.

Load Elimination Parametric Analysis

Load elimination parametric analysis shows the impact of individual loads on annual energy use. The analysis consists of a set of annual simulation runs. Each simulation run is a modification of the baseline model that sequentially eliminates a specific load. The standard list of loads to be eliminated includes:

- Wall R = 1000. The wall insulation level (R-value) is set to a very high number.
- Roof R = 1000. The roof insulation level (R-value) is set to a very high number.
- Floor R = 1000. The floor insulation level (R-value) is set to a very high number.
- Window R = 1000. The window insulation level (R-value) is set to a very high number.
- Window t = 0. The window transmittance (t) is set to zero to eliminate solar gains.
- No Infiltration. The rate of outside air infiltration is set to zero.
- No Ventilation. The rate of outside air ventilation is set to zero.
- No Occupants. The internal heat gains caused by people are set to zero.
- No Lighting. Electric lighting is set to zero.
- No Plug Loads. Plug-in equipment loads are set to zero.

The results of the load elimination parametric analysis should be presented in a single chart that compares all the elimination runs against the baseline run. The loads that significantly affect the annual energy use can be targeted for improvement with an appropriate ECM during the ECM analysis. For instance, significant energy savings for the “Window R = 1000” case indicates that it is a good idea to try triple- or quadruple-pane windows as an ECM.

Sensitivity Analysis

Sensitivity analysis consists of one or more sets of simulation runs that provide information about the sensitivity of annual energy use or cost to specific design parameters. Design parameters are basic properties of the building construction and geometry that can vary continuously over a range of values. Possible parameters include aspect ratio, window-to-wall area ratio, wall insulation R-value, window U-value, and infiltration rate. Sensitivity is indicated by the change in whole-building energy use per change in the given parameter.

Use the results of the load elimination parametric analysis to inform the selection of parameters for the sensitivity analysis. Load elimination parametric analysis achieves a crude estimation of sensitivity by using an all or nothing approach. By eliminating a load, the analysis reveals if there is any sensitivity to the related parameter. If a parametric elimination case does not show a significant reduction in energy consumption, we already know that the building is not very sensitive to that parameter, and there is no need to perform a sensitivity analysis on that parameter.

Load elimination parametric analysis, however, does not help to quantify the sensitivity. The procedure for sensitivity analysis is to perform several simulation runs over a range of parameter values. The slope of the curve defines the sensitivity to the parameter.

Energy Conservation Measure Analysis

ECMs are specific technologies or design strategies that are intended to save energy. ECM analysis quantifies the potential energy savings for an individual ECM or combination of ECMs.

The first step for the ECM analysis is to make a list of ECMs that should be evaluated. The owner and architect will likely have some ideas for ECMs that they would like to try out. There is also a short list of ECMs that are almost always winners. This includes tight building construction, overhangs, and daylighting controls. An extensive list of ECMs used in high-performance projects is shown in Table 4 to generate ideas. This list is by no means exhaustive; creative ECMs are always possible.

Once the list of ECMs has been prepared, the next step is to evaluate them with simulations. As with the other types of analyses, the starting point is the baseline model. For some simple ECMs, such as extra insulation, modifying the baseline model and rerunning the simulation might require only minor changes. Other ECMs, such as building form changes to facilitate daylighting and passive solar heating, can require additional model development that results in a new simulation model that is quite different from the baseline model.

Table 4
Some Suggested ECMs

ECM	Purpose	Simulation Notes
Form		
Window size and placement	Reduce solar gains; reduce heat losses.	Reduce glazing on east and west walls.
Overhangs	Reduce solar gains in the summer.	Mount horizontally above windows.
Fins	Reduce solar gains at certain times, usually in morning or afternoon.	Mount vertically on the sides of windows.
Daylighting design	Replace electric lighting with natural daylighting to reduce energy use and waste heat from lights.	Plenty of southern exposure (for the northern hemisphere) with sufficient windows. Most zones are within 15 ft of perimeter. Stairstep design. No energy savings unless used with daylighting controls to automatically dim the electric lights.
Passive solar heating design	Provide passive solar heating during the day.	Plenty of south-facing windows (for the northern hemisphere) with sufficient transmittance and internal mass inside to absorb heat. Zone temperatures must be allowed to float.
East–west orientation and increased aspect ratio	Minimize solar gains. Optimize for daylighting and passive solar heating.	Must be combined with daylighting design and/or passive solar to achieve energy savings.
Sunspace	Provide passive solar heating during the day.	Passive solar heating zone. More glazing and internal mass than a typical zone. Heat can circulate to other zones. Also can be sealed off from rest of building because the temperature falls at night. Sunspace

		temperature must be allowed to float.
Natural ventilation design	Design to take advantage of prevailing winds to ventilate and cool when outside temperatures are appropriate.	Requires manual or automatic operable windows. May require a separate air flow analysis.
Fabric		
Extra insulation, exterior walls	Reduce heat gains and losses to the outside.	Increase the R-value of the construction.
Extra insulation, roof	Reduce heat gains and losses to the outside.	Increase the R-value of the construction.
Extra insulation, under slab	Reduce heat gains and losses to the ground.	Increase the R-value of the construction.
Extra insulation, foundation	Reduce heat gains and losses to the ground.	Increase the R-value of the construction. May be difficult to model.
Better windows	Reduce heat gains and losses to the outside.	Use triple- or quadruple-pane insulated windows and/or low-e.
Tight envelope construction	Reduce heat gains and losses caused by infiltration.	Reduce the infiltration ACH.
Trombe wall	Provide passive solar heating with a lag so that heat is delivered at night.	Should be used with overhangs or a removable cover to prevent heating in the summer. Use a selective surface or double-pane glazing for better performance.
Double facade	Reduce heat gains and losses to the outside.	Model as a facade zone with a large window area and interzone windows to the building zones.
Reflective roof	Reduce solar heat gains.	Increase the roof solar reflectance.
Green roof	Reduce heat gains and losses to the outside.	Roof planted with grasses or plants. Difficult to simulate. Increase insulation and thermal mass.
Internal Loads		
Optically efficient electric lighting fixtures	Reduce energy use and waste heat from lights.	Reduce the required lighting power density to achieve the same light levels.

Electric lighting located in return air stream	Reduce waste heat from lights.	Heat from lights never enters the zone.
ENERGY STAR electric equipment	Reduce energy use from plug loads.	Reduce the plug load power density.
Occupancy sensors for lights and equipment	Reduce energy use from lights and plug loads	Match lighting and plug load schedules to occupancy schedules.
Daylighting		
Daylighting controls	Replace electric lighting with natural daylighting to reduce energy use and waste heat from lights.	Use automatic dimming controls to reduce electric lighting when natural daylight is sufficient. Use light-colored surfaces to allow light to penetrate deeper into the zone. Use for any zone with a source for daylight.
Light shelves	Allow daylight to penetrate deeper into the interior.	Must be paired with a window. No energy savings unless used with daylighting controls to automatically dim the electric lights.
Skylights	Allow daylight into core spaces.	No energy savings unless used with daylighting controls to automatically dim the electric lights.
Tubular daylighting devices	Allow daylight into core spaces.	No energy savings unless used with daylighting controls to automatically dim the electric lights.
Clerestory windows	Allow daylight into core spaces. Also avoid glare.	No energy savings unless used with daylighting controls to automatically dim the electric lights.
HVAC System		
HVAC system type	Air system or water system.	-
More efficient fans	Reduce fan energy use.	Decrease the fan power.
More efficient pumps	Reduce pump energy use.	Decrease the pump power.
Variable-speed fans	Reduce fan energy use.	Fan power varies with system demand

Variable-speed pumps	Reduce pump energy use.	Pump power varies with system demand.
Larger ducts	Reduce fan energy use by reducing system pressure drop.	Decrease the pressure drop for the fan.
Larger pipes	Reduce pump energy use by reducing system pressure drop.	Decrease the pressure drop for the pump.
High-efficiency chiller	Reduce chiller energy use.	-
High-efficiency boiler	Reduce boiler energy use.	-
High-efficiency furnace	Reduce furnace energy use.	-
High-efficiency water heater	Reduce water heater energy use.	-
Instantaneous water heater	Reduce water heater standby losses.	-
Heat pump water heater	-	-
Evaporative cooler	Cool air by adding humidity.	Effective in dry climates.
Ground-source heat pump	-	-
Nighttime cooling	-	-
Radiant heating	Provide space heating radiantly.	Lower thermostat heating set points because radiant heat is more comfortable.
Precooling	Reduce on-peak cooling energy use. Energy recovery ventilation	Recover sensible and latent energy from exhaust air.
Displacement ventilation	-	-
Under-floor air distribution	-	-
Ice storage system	Produce and store ice during off-peak hours for cooling use during peak	May not be an energy saving measure, but can be a cost saving measure.

	hours.	
Solar hot water system	Use solar collectors to heat water to offset hot water consumption.	Must be combined with a storage tank. Different types of solar collectors are available.
On-Site Energy Generation		
Photovoltaic system	Generate electricity to offset consumption.	-
Wind turbine	Generate electricity to offset consumption.	-
Microturbine	Generate electricity and waste heat to offset consumption.	Combine with a water tank to store recovered waste heat.
Fuel cell	Generate electricity and waste heat to offset consumption.	Combine with a water tank to store recovered waste heat.

Utility Bill Analysis

Utility bill analysis uses the utility billing history from an existing building to characterize energy use and help set performance goals. It can be used to illustrate monthly trends or calibrate a baseline model. Utility bills from recent years are usually available from the owner or can be downloaded from the utility company Web site. Utility bills provide numbers for monthly consumption and cost. Demand charges are also included if part of the tariff, and can be treated like simulation results from the baseline model and displayed in a simple chart.

Summary

When designing a new facility, it is important to quantify the energy performance, characterize energy uses, and identify potential energy savings opportunities for a new building. The objective is to use results to develop design concepts that minimize energy loads and costs.

Results also provide important guidance for setting energy performance goals. At this early stage in the design process, the building siting, orientation, zoning, internal organization, massing, and appearance of the facade can be manipulated to maximize performance without adding significant cost.

This course has reviewed the types of information needed to make pre-design energy analysis and the various tools to use to estimate building performance. Hopefully this information will aid you in improving the efficiency and comfort of new facilities.

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