ENERGY INFORMATION HANDBOOK

Applications for Energy-Efficient Building Operations

BERKELEY LAB

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

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Applications for Energy-Efficient Building Operations

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Glossary

Balance Point: The outside air temperature at which building heat gains are equivalent to heat losses, so that no mechanical heating or cooling is required. A building's balance point is dependent on its particular design and construction.

Baseline: A representation of "standard" or typical energy performance, used for comparative purposes. Baselines may be expressed according to a variety of metrics, and may account for weather or other independent variables that influence energy consumption.

Base Load: The constant temperature-independent energy demand of a building.

Benchmarking: Comparing building energy performance to that of similar buildings (cross-sectional benchmarking), or its own historic performance (longitudinal benchmarking). Benchmarking may also be performed at the system or component level.

Building Automation System (BAS): A system that is designed to control building operations and indoor climate, and can sometimes monitor and report system failures. While subtle differences may exist, in the context of this work, the terms *building automation system, building management system (BMS), energy management system (EMS), and energy management control system (EMCS)* refer to similar systems.

Changepoint: The outside air temperature (OAT) at which the slope of the load vs. OAT plot changes, marking a different relationship between load and temperature.

Cooling Load: The amount of heat energy that must be removed from a building in order to maintain comfortable indoor conditions.

Commissioning: The process of verifying and documenting the performance of building equipment to ensure that operational needs and design intent are satisfied.

Data Acquisition System (DAS) and Gateway: A DAS is used to gather data from meters and sensors in a building or at a site; a gateway allows the data to be transferred to a database via industry-standard communications protocols.

Degree Day: A measure of the heating or cooling load on a building relative to a "base" outdoor air temperature. Commonly calculated as the difference between the mean daily temperature and the base temperature.

Demand: The rate of energy use by a particular building or system, i.e., power. Common units of energy demand are kilowatts (kW) for electricity, tons for chilled and hot water, and therms/hr or cubic feet per minute for gas.

Demand Response (DR): Changes in electric usage by customers in response to changes in the price of electricity over time or when system reliability is jeopardized.

End Uses: The particular services that are delivered with building energy use, e.g., lighting, heating, cooling, or miscellaneous electric loads.

Energy Information System (EIS): Software, data acquisition hardware, and communication systems used to store, analyze, and display building energy data.

Energy Manager: The person who tracks and manages energy performance of a building or a portfolio of buildings.

Energy Use Intensity (EUI): A unit of measurement that describes a building's energy use, relative to its size, on an annual basis. The common metric is kBTU/sf/yr.

Equipment-Level Meter: A submeter that measures a subset of energy used for a specific piece of equipment, such as a chiller, boiler, or air-handling unit. Equipment-level meters are often combined with sensors measuring fluid flow, temperatures, or other equipment attributes.

Facility Manager: The person who manages day-to-day operation of the systems at a site or campus to maintain indoor environmental comfort and equipment operations.

Heating Load: The amount of heat energy that must be added to a building in order to maintain comfortable indoor conditions.

Interval Meter (Advanced Meter, "Smart Meter"): A meter that provides usage and rate of usage information frequently enough to be used for operational improvement, such as in hourly or 15-minute increments. For electrical meters, more detailed power quality analysis may be provided.

Load Shape: The variation in building or system-level demand over a period of time. Load shape is most commonly viewed as a plot of demand vs. time, over one or multiple 24-hour periods.

Measurement and Verification (M&V): The process of using measured data and other operational information to confirm the energy savings from energy-efficiency projects. The International Protocol for Measurement and Verification defines four standard M&V approaches.

Normalization: The process of dividing a set of data by a common variable, so that the variable's effect on the data is removed, a common scale is introduced, and comparisons can be made.

Power Density: Power per square foot of space served.

Regression Analysis: A statistical technique to describe the relationship between a dependent variable and one or more independent variables. Regression is used for forecasting and prediction across a broad range of applications, including building energy performance monitoring.

Site Energy Use: The total amount of fuel used to operate a building, not accounting for generation, transmission, and distribution losses.

Site Meter: A meter that measures the total amount of a certain energy type used at a site or campus of multiple buildings or structures.

Source Energy Use: The total amount of raw fuel that is required to operate the building including generation, transmission, and distribution losses.

Submeter: A meter that is downstream of another and measures a subset of energy usage for more granular billing or energy consumption analysis.

System-Level or End-Use Meter: A submeter that measures the energy used for a particular purpose in a building, such as heating, cooling, plug loads, or lighting.

Time Series Data: A set of measurements taken at successive points in time, usually at equally spaced time intervals.

Utility Meter: A revenue-grade meter provided by a utility or retail seller of energy.

Utility Submetering: The submetering of energy for the purpose of allocating a portion of an energy bill within a larger portfolio. The utility submeter is often used in multi-tenant commercial buildings or on campuses.

Utility Cost Accounting: Tracking billed costs for use in budgets and financial projections. May include energy and demand charges, and time-of-use analysis.

Whole-Building Meter: A meter that measures the total amount of energy used at a single structure and its associated grounds. Often it is a utility meter.

Introduction

There is a wealth of methods and tools to monitor and measure building energy use (both over the long haul and in real time) and to identify where best to focus your energy-efficiency efforts. But with so many options, where do you start? This handbook will give you the information you need to plan an energy-management strategy that works for your building, making it more energy efficient.

Target Audience

The primary audience for this handbook is commercial building owners, energy and facility managers, financial managers, and operators with little to no experience in data analysis and performance monitoring. The secondary audience is software developers and energy service providers in the commercial building industry, as well as more experienced owners and managers who wish to improve how they visualize, analyze, and manage their building's energy use.

The handbook's analysis methods are based on a review of publications related to continuous energy management and performance tracking. They focus on groups of owners, technology vendors, and service providers, and they represent the most critical set of analyses that can be integrated into a site or portfolio energy management program.

This handbook targets two primary areas for creating energy-efficient buildings:

(1) How to interpret energy data to improve efficiency and performance.

(2) How to use computation and programming to combine the use of spreadsheet or programmable analysis tools with data from on-site meter and sensor acquisition systems.

How to Use the Handbook

The handbook groups the analysis methods into three chapters: Reporting and Tracking Methods, Fundamental Methods, and Advanced Methods. Each chapter begins with a brief discussion section, and then reviews each individual method according to a common format. For each method, a one-page, high-level overview is followed by a description of how it relates to the other methods in the handbook. A computation page then reviews that method's data requirements, discusses how it can be implemented in programmable software tools, and includes numeric examples. Several pages of application examples are presented to illustrate how the methods are interpreted and used to save energy. Wherever possible, examples from real-world buildings are included.

The Appendix contains supplementary material, including technical details and resources for users who wish to explore further.

The final chapter is an introduction to fault detection and diagnostics, which are advanced techniques that may interest you once you have gained familiarity, confidence, and routine benefit from the primary set of analysis methods.

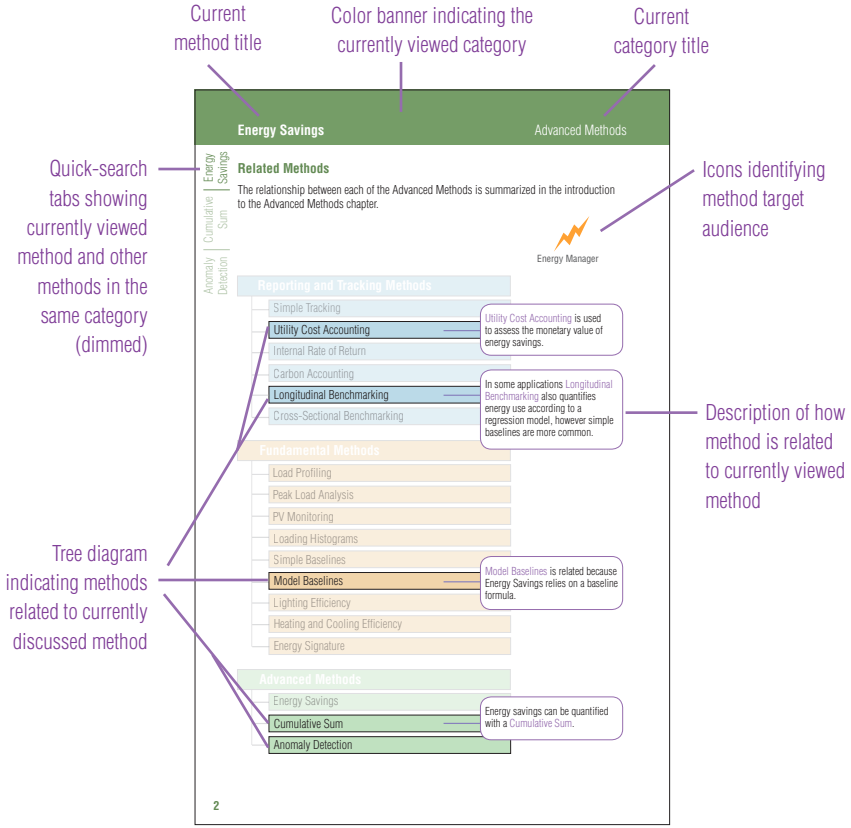
The handbook uses a number of design elements to help you navigate, and step-by-step instruction across the collection of analysis methods. For example:

A tree diagram illustrates how each method relates to the others.

Icons indicate the target audience, such as energy and facility managers, financial managers, or operators.

Quick-search tabs identify the current method, and other methods in the same category.

Key design elements are illustrated below.



Categories

The analysis methods run from those that are simpler and easier to use to those that are more technically complex. We have grouped them based on related characteristics into three categories: Reporting and Tracking Methods, Fundamental Methods, and Advanced Methods.

Reporting and Tracking Methods

- Simple Tracking
- Utility Cost Accounting
- Internal Rate of Return
- Carbon Accounting
- Longitudinal Benchmarking
- Cross-Sectional Benchmarking

Fundamental Methods

- Load Profiling
- Peak Load Analysis
- PV Monitoring
- Loading Histograms
- Simple Baselines
- Model Baselines
- Lighting Efficiency
- Heating and Cooling Efficiency
- Energy Signature

Advanced Methods

- Energy Savings
- Cumulative Sum
- Anomaly Detection

Reporting and Tracking Methods

These methods include approaches used to gauge financial, energy, and carbon performance. They can be applied to specific building systems; however, they are most commonly used at the site or portfolio level, perhaps with the exception of the method for finding an internal rate of return, which is often applied to specific energy conservation measures.

These methods can use utility billing information, and may not require interval-meter data or sensor time series data. Although they may include relatively sophisticated underlying computations, these methods do not require extensive subject matter expertise to interpret.

Reporting and tracking methods include the following:

Simple Tracking: By tracking monthly or annual energy use, you can quantify changes in energy use over time, to identify increases and decreases in consumption and/or expenditures. Simple tracking relies on energy use totals, and does not include normalization.

Utility Cost Accounting: This method converts energy consumption into billed costs, so you can use that information in budgets and financial projections. Accounting may include demand charges and tariff specifics such time-of-use rates.

Internal Rate of Return: By applying a capital budgeting metric that accounts for the time value of money, you can quantify the benefit of energy-efficiency measures.

Carbon Accounting: You can convert building energy consumption into carbon emissions, for footprinting and sustainability reporting.

Longitudinal Benchmarking: By comparing current energy performance to past performance, you can identify energy trends and opportunities for improvement.

Cross-Sectional Benchmarking: By comparing your building's energy performance to that of a comparable group of buildings, you can determine whether you are ahead of the pack, in the middle, or running behind.

Fundamental Methods

These methods include system-specific and whole-building analyses, and they require more expertise than the Reporting and Tracking or Advanced methods. They tend to require interval meter data or other time series, such as temperature. This core set of analyses are used to reveal energy waste and opportunities for operational efficiency improvements.

Fundamental methods include the following:

Load Profiling: Inspection of 24-hour periods of interval meter data enable you to identify efficiency opportunities or energy waste. Such profiling may include multi-day overlays.

Peak Load Analysis: Analysis of the size, timing, and duration of the peak load allows you to identify efficiency and cost-saving opportunities.

PV Monitoring: Investigation of time series of photovoltaic array generation enables you to quantify output or net energy consumption, as well as to prevent performance degradation.

Loading Histograms: Plots of HVAC system loading and operational hours at each load allows you to identify efficiency opportunities related to system sizing.

Simple Baselines: Use of simple normalization factors, such as degree days or square feet, enables you to characterize and quantify standard energy performance for comparative or benchmarking analyses.

Model Baselines: With this method, you can use regression models to characterize and quantify energy performance according to weather and other variables that drive energy consumption. Model-based baselines are significantly more robust than simple baselines, so you can use them for anomaly detection, and measurement and verification of energy savings.

Lighting Efficiency: By tracking and inspecting an as-operated efficiency metric that is calculated from interval data, you can reveal excessive use or commissioning and controls problems.

Heating and Cooling Efficiency: Using this method , you can track the operational efficiency of heating or cooling systems.

Energy Signature: Inspection of x-y plots of load versus outside air temperature to identify weather dependencies, and general potential for improved operations.

Advanced Methods

These methods all require a baseline to quantify expected, or projected energy use. Although they are the most sophisticated and computationally intensive methods in the handbook, they involve less manual inspection than the Fundamental Methods, so they require minimal expertise to interpret.

Advanced methods include the following:

Energy Savings: With this method, you can quantify total energy savings associated with an efficiency improvement, using a baseline model to characterize use before and after the improvement.

Cumulative Sum: This method provides you with running totals of energy savings or increases relative to a baseline period, accumulated over time.

Anomaly Detection: This method automatically identifies abnormal energy use based on the difference between the expected use indicated by a baseline model and actual metered energy use.

Summary Tables

Different types and levels of data are needed to support each of the analysis methods. The following tables will help you determine which methods will work with your existing data-gathering equipment and which would require new equipment. They summarize the minimum data requirements for each method, the systems to which they can be applied, and the level of expertise needed to interpret the output.

Minimum Data Requirements

Analysis Methods	Utility		Interval Meter		Submeter			Other*
	Gas	Electric	WB Gas	WB Electric	Heating Load	Cooling Load	Lighting Load	
Simple Tracking	●	●						
Utility Cost Accounting	●	●						
Internal Rate of Return	●	●						●
Carbon Accounting	●	●						●
Longitudinal Benchmarking	●	●						●
Cross-Sectional Benchmarking	●	●						●
Loading Profiling			●	●				
Peak Load Analysis				●				
PV Monitoring								●
Loading Histograms					●	●		
Simple Baselines	●	●						●
Model Baselines			●	●				●
Lighting Efficiency							●	●
Heating and Cooling Efficiency					●	●		●
Energy Signature	●	●						●
Energy Savings	●	●						●
Cumulative Sum	●	●						●
Anomaly Detection			●	●				●

WB = whole-building.

*Other includes for example, weather data, square footage, or equipmment costs.

Note that entries in the prior table reflect the *minimum* data requirements. Some methods may be applied continuously or at the system level, which would increase your data needs. Applicable systems for each method are summarized below.

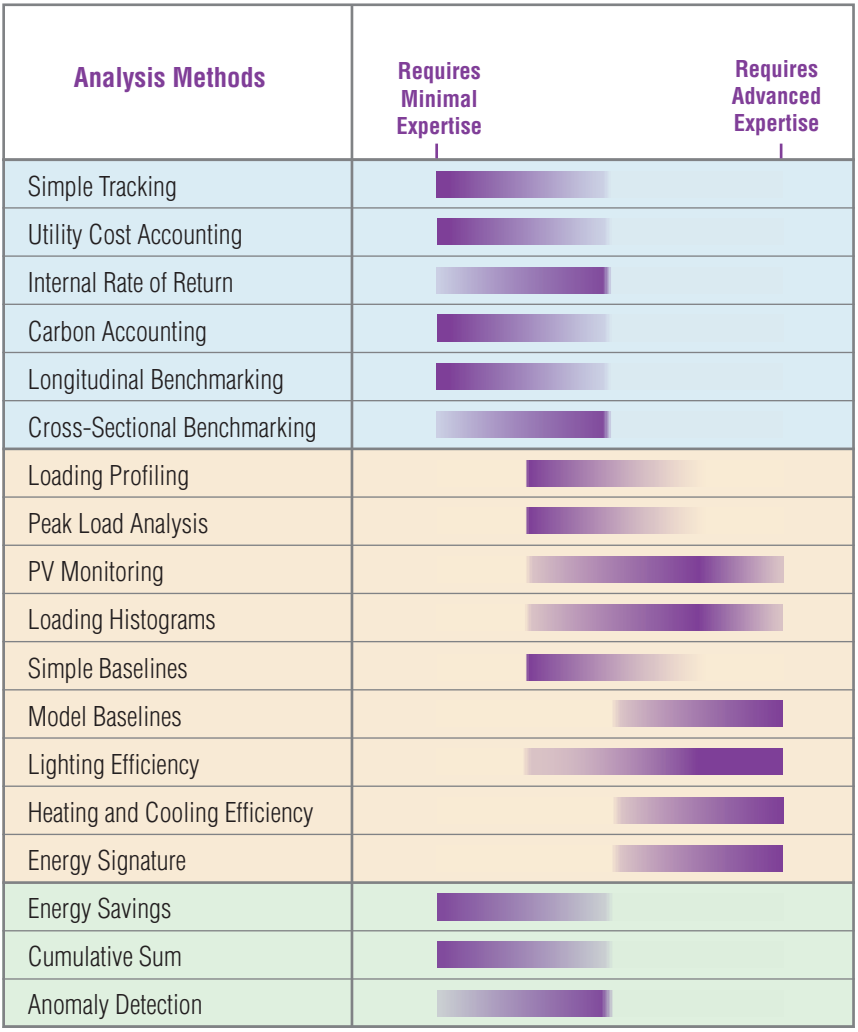
Applicable Building Systems

Analysis Methods	Whole Building	Heating	Cooling	Lighting	Plug Loads
Simple Tracking	●	●	●	●	●
Utility Cost Accounting	●	●	●	●	●
Internal Rate of Return	●	●	●	●	●
Carbon Accounting	●	●	●	●	●
Longitudinal Benchmarking	●	●	●	●	●
Cross-Sectional Benchmarking	●	●	●	●	●
Loading Profiling	●	●	●	●	●
Peak Load Analysis	●				
PV Monitoring*	●				
Loading Histograms		●	●		
Simple Baselines	●	●	●	●	●
Model Baselines	●	●	●	●	●
Lighting Efficiency				●	
Heating and Cooling Efficiency		●	●		
Energy Signature	●	●	●		
Energy Savings	●	●	●	●	●
Cumulative Sum	●	●	●	●	●
Anomaly Detection	●	●	●	●	●

*Energy production from PV arrays is typically accounted for at the whole-building level.

The Advanced Methods rely on sophisticated underlying analyses, but interpreting their output does not tend to require deep expertise, because much of the analysis is automated. In contrast, the Fundamental Methods may require more user expertise, to be able to translate graphs and data trends into an understanding of performance.

Interpretation of Method Output



Best Practice Uses

This handbook's collection of analysis methods spans multiple levels of analysis, from portfolio to whole-building and system investigations, and there is considerable overlap between many of the individual analysis methods. For example, Lighting Efficiency is effectively a system-level application of normalized load profiling. Similarly, Lighting Efficiency can be used to detect periods of excessive energy use that might also be identified in load profiling, or Anomaly Detection. Used in combination with one another, the collection of methods can be used to generate multiple insights into a common set of "root" aspects of energy performance.

Although each method summary addresses "related methods," it is useful to highlight best practice applications for readers who are new to continuous energy performance monitoring and data analysis. In general, it is best to first focus on monthly or annual energy tracking, then move into whole-building interval data analysis and system-specific investigations. This approach recognizes that insight and skill will increase with experience, and that data acquisition and analysis resources may need to be expanded gradually, as budgets and time permit.

Your first investigations should take advantage of the universally available utility billing data, to develop a habit of routine energy tracking and to understand how your building's energy performance ranks relative to its peers. Simple Tracking, Utility Cost Accounting, Carbon Accounting, and Cross-Sectional Benchmarking all support these first-stage investigations.

Next, target analyses that focus on whole-building interval data, to understand how much energy is used at different times of day and to identify efficiency opportunities relating to the scheduling and control of major building systems. This is also a good time to begin Longitudinal Benchmarking to quantify the resulting energy reductions. Longitudinal Benchmarking, Load Profiling, Peak Analysis, and Anomaly Detection are especially useful for gaining insight into whole-building aspects of operation.

Once you've gained a solid understanding of whole-building behaviors and energy performance, incorporate system-specific analysis methods into your continuous energy management approach. These powerful methods directly reveal energy waste related to building system operational performance. Lighting Efficiency, Sizing Histograms, PV Monitoring, Longitudinal Benchmarking, and Load Profiling are the simplest methods to apply and interpret. HVAC Efficiency and Energy Signatures can be applied to continuously monitor heating and cooling system operations once sizing has been verified and simple load profiles have been thoroughly reviewed.

Methods such as Internal Rate of Return, Utility Cost Accounting, Energy Savings, and Cumulative Sum should be used to explicitly quantify the financial and energy benefits of performance improvements. These can be applied to capital projects and to monitor continuous energy management initiatives. These analyses can also be used support the business case for further improvements, and to verify that expected benefits have been captured.

Data Sources

This section provides an overview of common data sources, energy quantities, and conversions for commercial building operations analysis. Many of this handbook's computation and programming examples begin with an initial step to "acquire data." The associated illustrations provide you with a given type of data with specific units, such as 15-minute interval electric demand data, in units of power, such as kilowatts (kW). You may find that your data are in a slightly different format; for example, hourly energy totals in units of kilowatt-hours (kWh). It is important that you are easily able to make full use of whatever data you have access to.

Common Data Sources:

Utility bills include maximum or peak electric demand and total electric and gas use for the billing period, as well as itemized charges for each. Some software tools offer automated acquisition of billing data from the utility, while others require manual entry of bill data. If commercial tools are not available, utility billing data may be input into spreadsheet tools for monthly tracking.

The image below shows the utility bill information that can be used for many of the analysis methods that are reviewed in this handbook.

- (A) Total electric energy consumption and cost
- (B) Peak demand and associated demand costs
- (C) Total gas consumption and cost

Electric Service for 12/12/2007 - 01/10/2008
Detailed Billing Information

Meter #	Season	Service Category	Peak		KWh Usage	Unit Charge	Amount
213313	WINTER	**Power Factor Rate**					
		KVARH	General		312688	0.0014	$437.76
		Large General Service - Network					
		KW	ON PK		1034	1.68	$1,737.12
			OFF PK		0	0.21	$0.00
		Maximum Demand for Billing Period			1034		$1,737.12
		KWH	ON PK		334970	0.0594	$19,897.22
			OFF PK		250103	0.0396	$9,904.08
		Total KWH Consumption			585073		$29,801.30
				Total Electric Charges			$31,976.18

Gas Service for 12/12/2007 - 01/10/2008
Detailed Billing Information

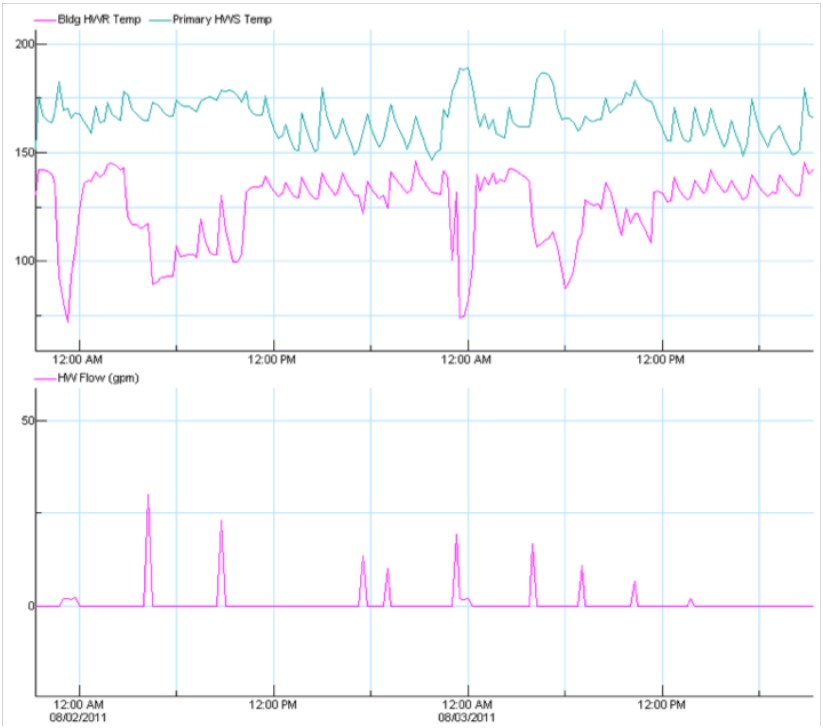
Meter #	Season				Therms Used	Unit Charge	Amount
12345	WINTER	Customer Charge					$150.72
		Current Gas Charges			40,000	0.92838	$37,135.20
				Total Gas Charges			$37,285.92

A more detailed discussion of demand charges and time of use tariffs is provided in Utility Cost Accounting.

Source: Better Bricks, Northwest Energy Efficiency Alliance

In addition, modern **building automation systems (BAS)** are able to store, trend, and plot system-level operational or control data such as setpoints, temperatures, and equipment status. It is also possible to integrate energy meters into BAS; however, it is not common practice in today's commercial buildings. Provided that sufficient metering is in place, data can be exported from BAS for energy analyses that may not be easily performed within the BAS itself.

The image below illustrates typical graphics and data points that might be stored in a BAS, with a multipoint overlay of hot water supply and return temperature (top), and flow (bottom), from which energy can be calculated.



Source: Lawrence Berkeley National Laboratory

Data exported from a BAS is often formatted as a comma-separated value (CSV) text file that can easily be opened in spreadsheet or other data analysis and plotting tools.

Point names can be misleading; take care that the points you have chosen correctly map to the calculation you wish to perform.

A The first data column is usually a time stamp, the format of which depends on the particular BAS.

B The titles of the data columns will reflect the point-naming convention that is used within the BAS, and may or may not include units.

C In this case, hot water heating energy can be calculated from the building hot water return temperature, supply temperature, and flow, from the second to fourth columns, respectively.

B-C

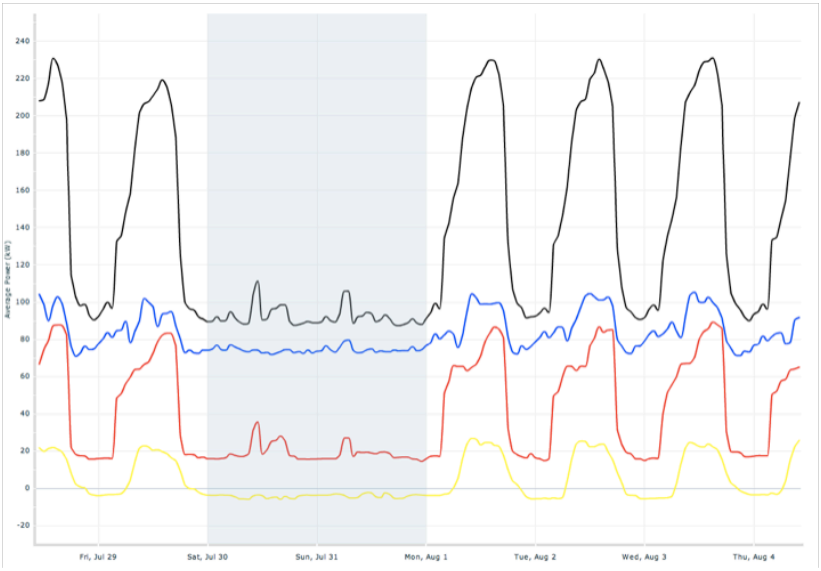
A

date	hw_bridge_0202_prim_hws_trend_log_694	hw_bridge_0202_bldg_hwr_trend_log_696	hw_bridge_0202_hw_flow_trend_log_693
2011-08-02 00:00:00	167.9	124.0	0.0
2011-08-02 00:15:00	164.2	135.5	0.0
2011-08-02 00:30:00	161.2	137.2	0.0
2011-08-02 00:45:00	159.0	136.8	0.0
2011-08-02 01:00:00	171.4	141.2	0.0
2011-08-02 01:15:00	164.0	138.7	0.0
2011-08-02 01:30:00	164.2	140.6	0.0
2011-08-02 01:45:00	173.1	144.4	0.0
2011-08-02 02:00:00	167.8	145.2	0.0

Source: Lawrence Berkeley National Laboratory

Meter visualization tools and energy information systems (EIS) commonly include interval data on electricity and gas consumption either at the whole-building or submeter level, and in the case of EIS may also contain system-level data. These data can be exported for further analysis that may not be provided in the visualization or EIS tool itself.

The image below illustrates the type of graphics and data that might be offered in an EIS. Here, whole-building electric interval meter data (black) is overlaid with end-use submeter data, showing the contribution of HVAC loads (blue), lighting loads (red), and miscellaneous end uses (yellow).



Source: Lawrence Berkeley National Laboratory

Similar to data from a BAS, data exported from an EIS is often formatted as a comma-separated value text file that can easily be opened in spreadsheet or other data analysis and plotting tools. The first column is usually the date; however, in contrast to BAS data, EIS point names may be more meaningfully labeled. Shown in the next image, an export of the whole-building and end-use data results in a data file with descriptive point names as well as units.

Date	Building 90 Total (Trailers Subtracted) (kW)	HVAC Total (kW)	Lighting Total (kW)	Other (losses, MELs, defunct meters) (kW)
7/28/11 10:15	213.1931208	61.3972462	24.77074725	94.49179402
7/28/11 10:30	219.5737338	65.34909993	24.72777086	107.096863
7/28/11 10:45	216.3758675	69.4954581	23.4345803	113.8094655
7/28/11 11:00	209.1552169	65.16251905	23.07364283	113.2047693
7/28/11 11:15	208.7567509	65.21445515	22.51692455	102.1022942
7/28/11 11:30	207.2567953	65.1969709	20.69270733	107.4337837
7/28/11 11:45	206.7671895	70.88027721	20.43204	93.72153899
7/28/11 12:00	204.3327667	67.84563235	20.46004273	103.2270916
7/28/11 12:15	209.0423021	75.82905467	19.48809056	104.1251569
7/28/11 12:30	213.487887	79.09398608	19.49409048	101.4331438
7/28/11 12:45	207.9251307	74.79038181	19.91788469	86.1501975
7/28/11 13:00	215.1960981	80.12719564	21.46602535	87.06954381
7/28/11 13:15	210.9145105	78.8489164	20.65843688	99.07382385

Source: Lawrence Berkeley National Laboratory

Common Data Values:
The units, interval frequency, and specific quantities reported in your data will depend on the specific measurement device and how it is configured, as well as the energy source being measured.

Three commonly encountered values are instantaneous demand sampled at a fixed frequency, such as every minute or 15 minutes; average demand over a time period or interval, commonly sampled every 15 minutes or hourly; and total energy over an interval, often 1 hour.

If energy or demand measurements are not directly available, they can often be calculated from mass flow and temperature measurements.

For natural gas: Multiply the volumetric flow rate by the volumetric energy content of natural gas and conversion factors associated with the particular energy and time units that you want.

> For example, given gas flow in standard cubic feet per minute, calculate energy demand in Btu/hr as:
>
> (flow ft^3/min)*(1,000 Btu/ft^3)*(60min/1hr)

For hot or chilled water: Multiply the difference between the supply and return water temperature by the volumetric flow rate, specific heat of water, and desired units conversions to get the energy and time units that you want.

> For example, given supply and return temperatures in degrees Fahrenheit, and flow in gallons per minute, you can calculate hot water demand in Btu/hr as:
>
> (Tr-Ts °F)*(flow gal/min)*(8.3 lb/gal)*(60min/1hr)*(1 Btu/1 lb-°F)

For steam: Multiply the mass flow rate by the heat content, which can be determined from steam tables, based on either pressure or temperature (assuming that the steam is saturated). As in the above cases, conversion factors depend on the desired energy and time units.

> For example, given steam flow in lb/hr, and either a temperature or pressure reading, calculate steam demand in Btu/hr as:
>
> (flow lb/hr)*(heat content Btu/lb)

Frequently Used Conversions:
Your data may be expressed differently than the required input for some of the analysis methods included in the handbook, or differently from the application and programming examples. If that is the case, four simple conversions may be useful.

To convert from instantaneous demand to average demand, "roll up" the data into the time interval that you desire. For example to go from 15-minute samples of instantaneous demand to average hourly demand, compute the mean over four readings.

Time	kW	Average kW
12:00	25	= average {25,26,24,25} = 25
12:15	27	
12:30	24	
12:45	26	

For each hour of the day, the average hourly kW will be the mean of four 15-minute readings.

To convert from average demand to energy, multiply the demand by the time period over which it occurred, and convert to desired units of time.

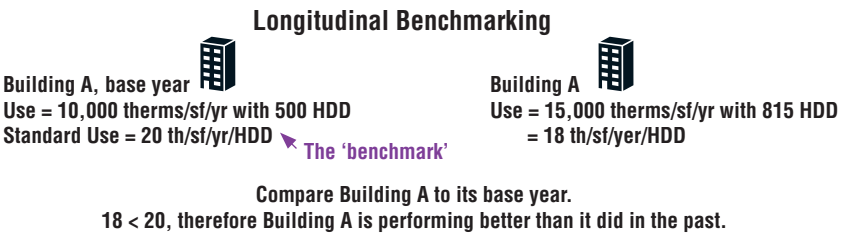
Time	Average kW	Total kWh
12:00	25	= 25 kW*(15 min)*(1hr/60min) = 6.25
12:15	27	=27 kW*(15 min)*(1hr/60min) =6.75

Time	Average kW	Total kWh
12:00	2	= 2 kWh*(15 min)*(1hr/60min) = 8
12:15	2.5	= 2.5 kWh*(15 min)*(1hr/60min) = 10

Discussion

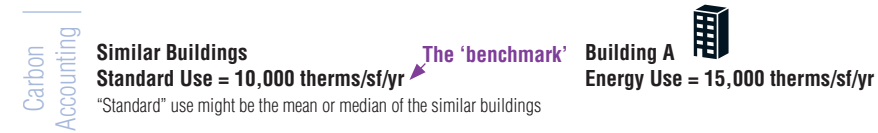
This chapter contains a variety of methods to report and track building performance. Energy and environmental aspects of performance are the focus of **Simple Tracking**, **Carbon Accounting**, and **Longitudinal** and **Cross-Sectional Benchmarking**, while financial considerations are the focus of **Utility Cost Accounting** and **Internal Rate of Return (IRR)**. The terminology associated with the Reporting and Tracking methods, particularly with the benchmarking methods, may not be familiar, or the definitions may be unclear. Therefore the terms *baselines*, *metrics*, and *benchmarks* are defined in the following, according to their use in this handbook.

In **Longitudinal Benchmarking** a building's performance is compared to itself over time. Simple Baselines (see Fundamental Methods) may be used to characterize this performance. In the illustration below, the simple *baseline* normalizes annual heating energy use by square feet and heating degree days, therefore the *metric* used to express performance is energy per floor area per weather unit. The particular units that are used are therms per square foot per base 65 heating degree days . Performance in later years is compared to performance in the "base year," which is the *benchmark*. In this example, Building A uses less energy than it did in the base year, and is therefore performing better than it did in the past.



The same general concepts apply in **Cross-Sectional Benchmarking**, with subtle differences. Here, a building's performance is compared to that of a group of similar buildings. In this example, Building A's energy use is compared to the "standard" use of a peer group of similar buildings. "Standard" is defined a number of ways, the simplest being the mean or average of the similar buildings. The standard use of the peer group then serves as the *benchmark* against which Building A's performance is compared. In this case, Building A performs less efficiently than an average, similar building.

Cross-Sectional Benchmarking



In this example, longitudinal benchmarking showed that the building's performance was improving; however, cross-sectional benchmarking provided the additional knowledge that performance was still relatively poor compared to similar buildings, indicating that further savings opportunities may exist.

Purpose

Simple tracking is the most basic form of energy consumption accounting. Energy use from one time period to another is inspected for increases or decreases, or for long-term upward or downward trends. Simple tracking is the starting point for the other analysis methods in this handbook, and is the first step in measurement-based approaches to energy management.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
▬			●	●

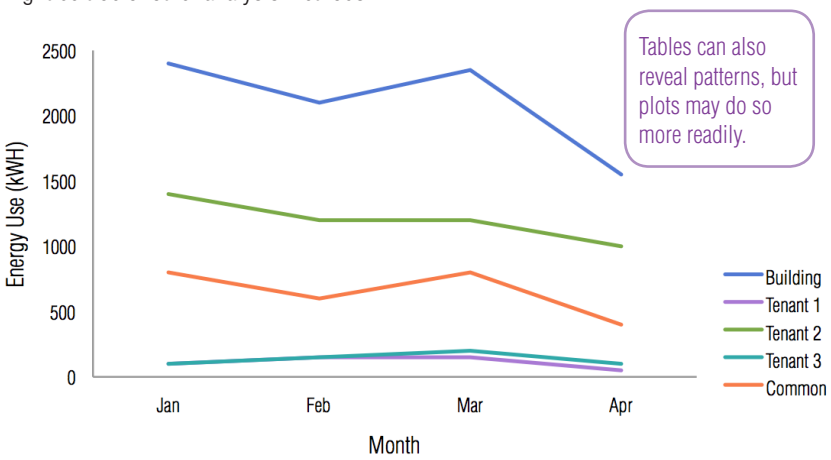
Energy Manager

Facilities Manager

Operator

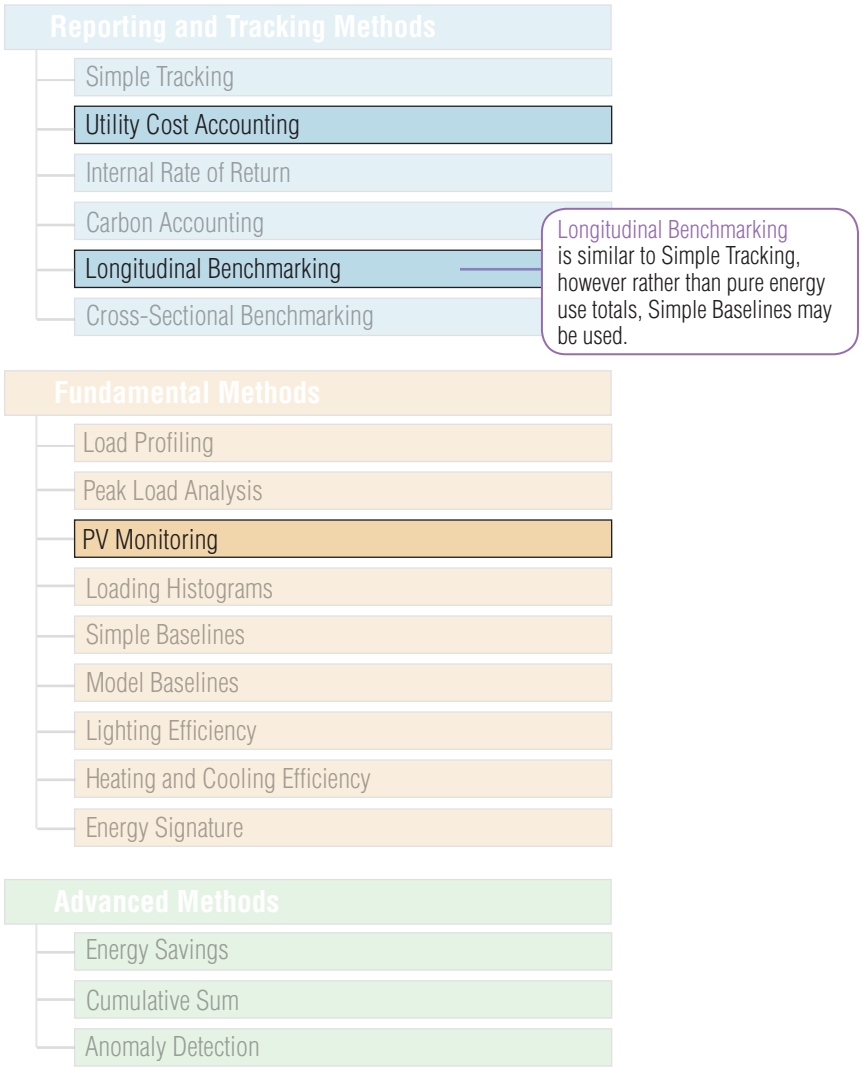
Technical Approach

Monthly or annual energy use totals are recorded either at the whole-building, system, or end-use level. You can use either utility billing data or interval meter data to quantify energy use totals. You can present these totals either in tables or plots, and examine them over time for irregularities or large increases or decreases in use that might indicate operational or efficiency problems. Simple tracking does not involve normalization of energy use data, as might be true of other analysis methods.



Related Methods

Simple Tracking begins the energy accounting; Utility Cost Accounting goes one step further, by associating a cost with energy usage and demand. One of the most basic investigations in PV Monitoring involves Simple Tracking of changes in array production.



Calculation and Programming

State of Commercialization: Simple tracking is provided in utility tracking tools and in energy information systems (EIS), and is possible in modern building automation systems (BAS), provided that the necessary energy meters are integrated.

Computation: You can also use stand-alone data analysis or spreadsheet tools to perform Simple tracking. Here's how:

Step 1: Gather input data.

Data Resolution

You can conduct Simple tracking with data of any resolution.

1 Hr, 15 Min ◉ Monthly ◉ Annual ◉

Data Inputs

Export metered data from the acquisition system or BAS, or collect it from utility bills.

Metered Data

High accuracy is not required, but fill data gaps before computing.

Step 2: Calculate energy totals based on demand data.

For energy, if using interval demand data, multiply demand by the metering interval, and convert minutes to hours. This conversion is not necessary if you are using utility bills or interval energy data.

Demand x Metering Interval = Energy

Step 1			Step 2
Time	Demand (kW)	Interval	**Energy (kWh)**
12:00	117	15 min	**= 117 kW x (15 min) x (1hr/60 min) = 29**
12:15	125	15 min	**= 125 x (15 min) x (1hr/60 min) = 31**
12:30	95	15 min	**= 95 x (15 min) x (1hr/60 min) = 24**
.....	.....	.....	**.....**
Month Total			**= 29 + 31 + 24 +… = 75,400 kWh**

Step 3: Plot total energy on the y-axis and the time period on the x-axis for further inspection and analysis (see application examples).

Notes

Sketches

Application Examples

Interpretation: Simple tracking is easy to interpret. Increases indicate growth in energy use while decreases indicate reductions. However, since critical energy drivers such as weather and occupancy are not explicitly represented in the consumption totals, increases in use may not necessarily reflect less-efficient operations, and should be investigated.

Example 1: Monthly Whole-Building Energy Tracking

Energy consumption is plotted for a calendar year, for two retrofit buildings.

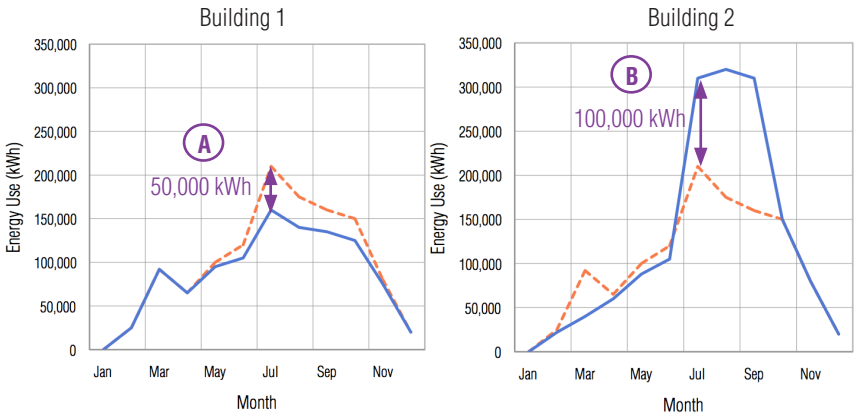
Energy use in the year before a retrofit is plotted with a dashed line.

Energy use in the year after a retrofit is shown with a solid line.

(A) Building 1 use after the retrofit is lower, with 50,000 kWh saved in July.

(B) In Building 2, July use is 100,000 kWh higher than before the retrofit.

Building 2 should be investigated for scheduling or other errors.

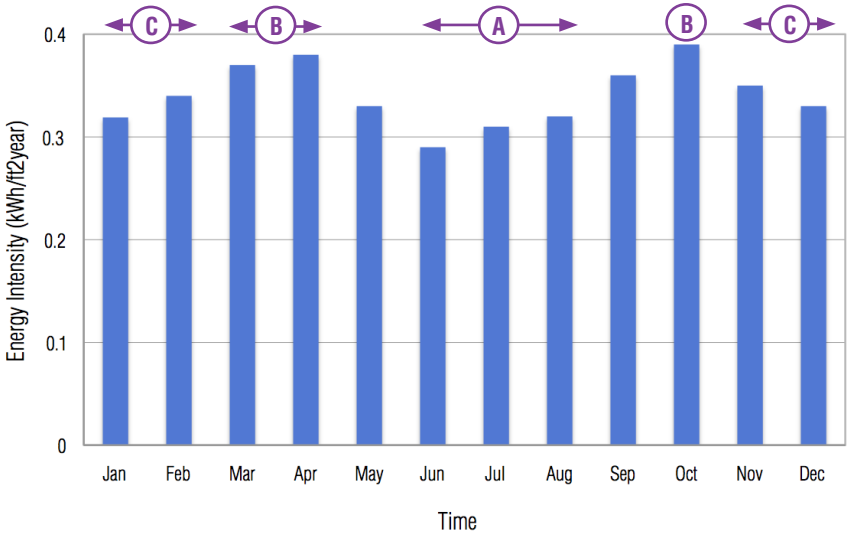


Source: Abraxas Energy Consulting

Example 2: Monthly End Use Tracking, Lighting Energy

Lighting energy is tracked over 12 months at a building with classrooms and offices. Lighting controls include scheduling and some photocontrols.

- (A) Summer usage is lowest, reflecting maximum daylight and minimum occupancy.
- (B) Spring/fall usage is highest, reflecting average daylight and maximum occupancy.
- (C) Winter use is lower than fall/spring, reflecting reduced occupancy.



Source: Lawrence Berkeley National Laboratory, UC Merced

Example 3: Monthly and Annual Electric End Use Tracking

A Submetered electric end use is plotted for a calendar year in a stacked bar chart.

The height of each bar shows the total electric use for the month.

B Each end use is represented with a different color.

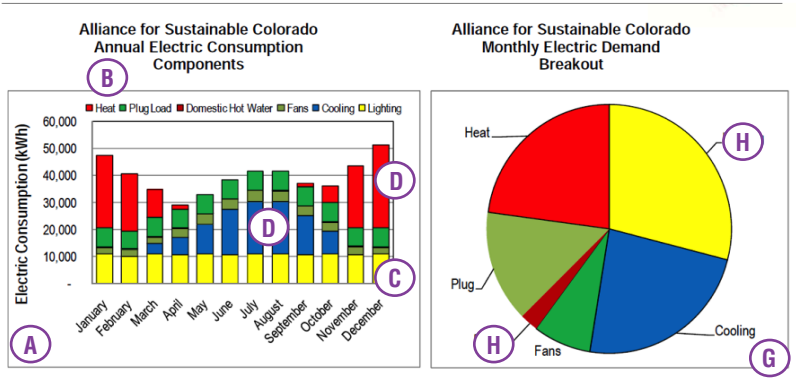
The size of the colored portion of each bar represents end use energy total.

C Lighting energy use (yellow) is nearly constant across the year.

D As expected, cooling (blue) is limited to summer months and heating (red) to winter months.

G Annual totals for each end use are also shown in a pie chart.

H The largest and smallest uses are lighting (yellow) and domestic hot water (red).

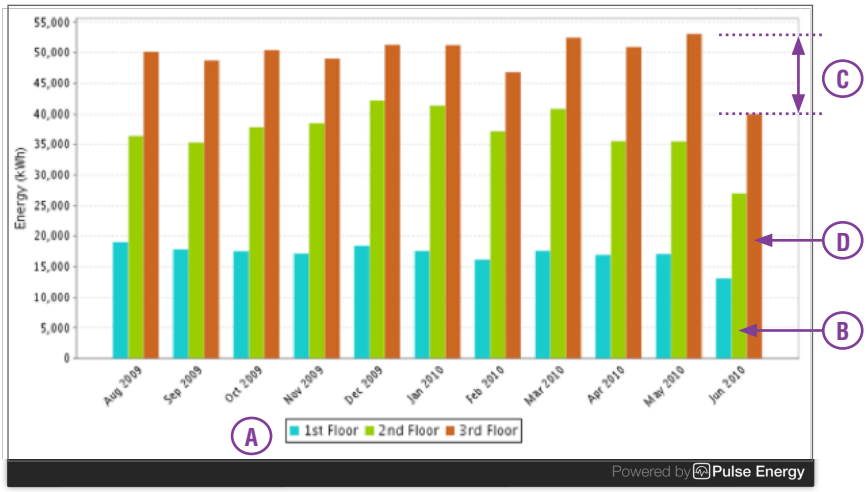


Source: Alliance for Sustainable Colorado

Example 4: Monthly Energy Tracking, Area-Based Submetering

- (A) Submetered electric energy use for each of 3 floors is plotted monthly.
- (B) 1st floor energy use is lowest, and remains relatively constant each month.
- (C) 3rd floor energy use is highest, with ~12,000 kWh difference from high to low months.
- (D) The 2nd floor use is lower than the 3rd floor, but the ups and downs track one another.

Not all months have the same number of days, introducing monthly variations in use totals. See Appendix for further discussion.



Source: Pulse Energy

Purpose

Utility cost accounting is one of the most basic energy analysis methods, and is used for high-level tracking. Cost accounting based on utility bills attributes energy costs to the account holder; whereas, cost accounting based on submeters downstream of the utility meter can be used to pass utility charges on to tenants. Likewise, submeter cost accounting provides a means of valuing operational and efficiency changes to systems or components.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
▬			●	●

Technical Approach

Gather utility bill data for electric, natural gas, and other fuels and identify the cost structure. Electricity usage is frequently divided into an energy charge, a peak demand charge, and various supplemental charges. Natural gas, other hydrocarbon fuels, chilled water, hot water, and steam carry energy and service charges, and may be delivered and billed by either a utility or a private distributor. Determine energy costs attributable to systems and components by multiplying submetered energy use by the energy charges reflected in the bill for the upstream utility meter.

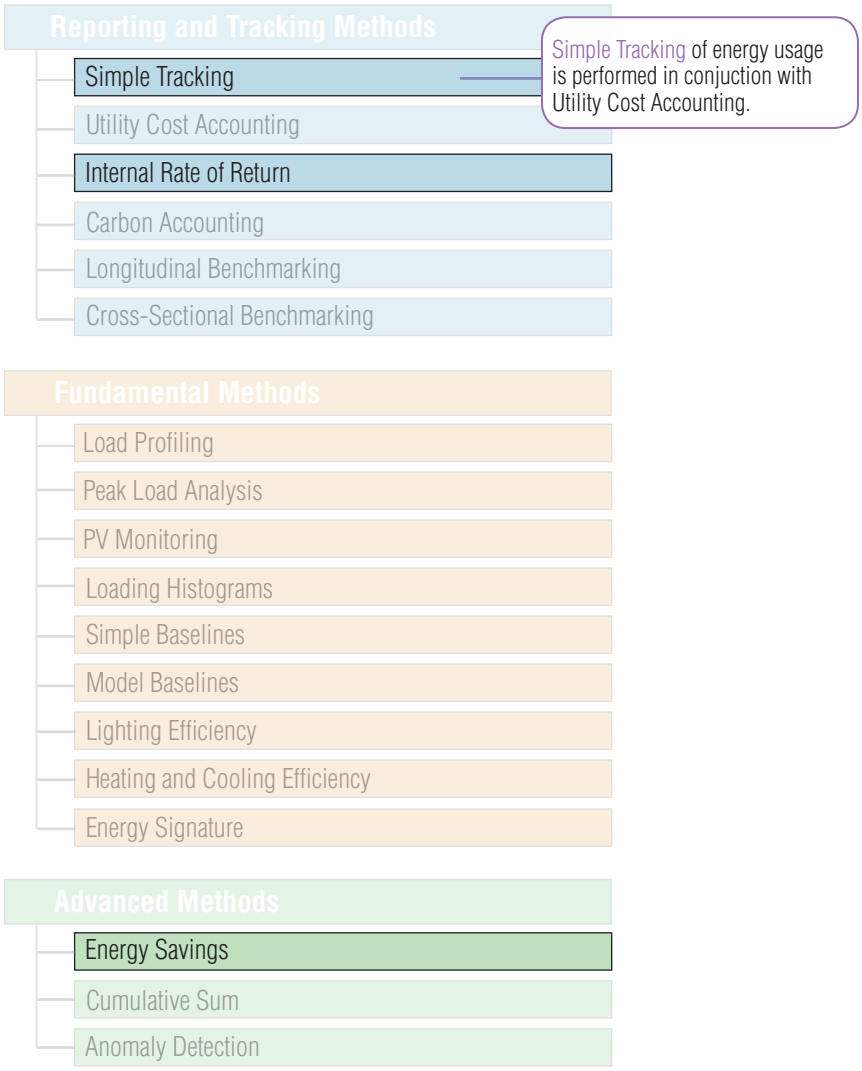
Utility costs are allocated to submetered loads using the "Charge per Unit".

	Energy		UtilityCosts				
Utility Charges	Usage	demand	Demand	Energy	Service	Total	Charge per Unit
Electric	23000	200	$ 5,000.00	$ 2,760.00	$ 20.00	$7,780.00	$ 0.34
Gas	1200	-		$ 2,880.00	$ 24.00	$2,904.00	$ 2.42

		Utility Costs			Energy	Utility Costs	
Electric Sub-Meter	Usage	Charge per unit	Total	**Gas Sub-Meter**	Usage	Charge per unit	Total
Tenant 1	3670	$ 0.34	$ 1,241.42	Café	210	$ 2.42	$ 508.20
Data Center	1200	$ 0.34	$ 405.91				

Related Methods

Utility Cost Accounting provides fundamental input data used in Internal Rate of Return (IRR) analyses. It is also used in combination with Energy Savings, to determine the economic benefit of efficiency improvements.



Calculation and Programming

State of Commercialization: Utility cost accounting is offered in commercial software packages such as utility tracking tools, energy information systems, and demand response systems. Sophistication varies, particularly in the handling of demand charges, complex tariffs, and submetered energy use.

Step 1: Gather input data.

Data Resolution

You can use monthly utility bills for whole-building accounting; system or component cost accounting requires interval data.

1 Hr, 15 Min ◉ Monthly ◉ Annual ○

Data Inputs

In general, high accuracy for metered data is not required; however, tenant submeters typically require accuracies of +/- 0.5%. Fill data gaps before computing.

Metered Data

Export building or system-level submetered gas or electric data from a BAS or meter acquisition system.

Cost per Unit

Use utility bills or a utility information portal to determine costs per unit of energy and demand.

Step 2: Apply rates to submeter data.

Multiply metered demand or energy usage by the associated cost per unit.

Cost = Metered Usage x Charge per Unit

Step 1			Step 2
Month	Submeter Charge per Unit	Submeter Usage	**Submeter Cost**
Jan	.35	550	**= .35 x 550 = $192.50**
Feb	.4	400	**= .4 x 400 = $160.00**

Step 3: Tabulate or plot monthly totals.

The whole-building annual energy cost or a monthly summary of energy cost per day are useful plots. System energy costs percentages can be shown as a pie chart.

Notes

Sketches

Application Examples

Interpretation: Utility cost accounting is easily interpreted, because it applies a dollar value to consumed energy. Decreases are desirable. You can also interpret utility costs relative to expected savings from efficiency projects or from continuous energy management efforts. As in the Simple Tracking method, increases in utility costs are the highest-level indication that energy waste may be occurring.

Example 1. Typical Utility Bill Demonstrating Time-of-Use Rates

(A) Electricity carries energy and demand charges, for peak and non-peak times of use.

(B) Total electric costs sum to $31,976.18 for the billing period shown.

(C) Gas usage carries an energy charge, and a service charge, totaling $37,285.92.

(D) Energy charges are determined by multiplying use by the unit charge.

Monthly totals are tabulated or plotted to form an accounting record.

Electric Service for 12/12/2007 - 01/10/2008
Detailed Billing Information

Meter #	Season	Service Category	Peak		KWh Usage	Unit Charge	Amount
213313	WINTER	**Power Factor Rate**					
		KVARH	General		312688	0.0014	$437.76
		Large General Service - Network					
		KW	ON PK		1034	1.68	$1,737.12
			OFF PK		0	0.21	$0.00
		Maximum Demand for Billing Period			1034 (A)		$1,737.12
		KWH	ON PK		334970	0.0594	$19,897.22
			OFF PK		250103	0.0396	$9,904.08
		Total KWH Consumption			585073		$29,801.30
			Total Electric Charges				$31,976.18 (B)

Gas Service for 12/12/2007 - 01/10/2008
Detailed Billing Information

Meter #	Season				Therms Used	Unit Charge	Amount
12345	WINTER	Customer Charge					$150.72
		Current Gas Charges			40,000	0.92838	$37,135.20
			Total Gas Charges				$37,285.92 (C-D)

Source: Better Bricks, Northwest Energy Efficiency Alliance

Example 2. Portfolio Accounting, Whole-Building Annual Cost per Day

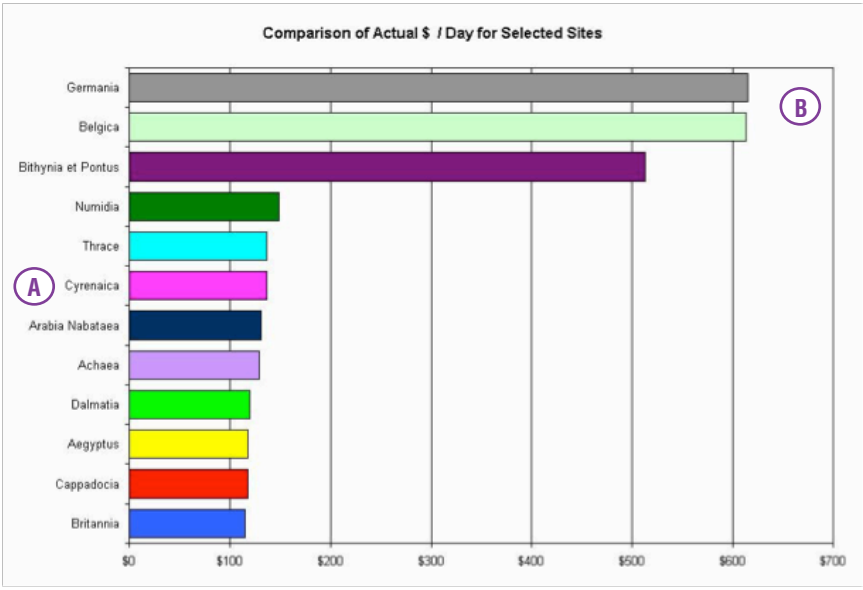
A Daily energy costs are tracked for each building in a portfolio.

The buildings have similar use-types and HVAC systems, making comparisons valid.

Billed utility costs for gas and electric are totaled for each site.

B The three buildings with high costs should be further investigated.

A simple model that normalized by sq ft would support more refined investigations.



Source: Abraxas Energy Consulting

Example 3. Whole-Building and System Cost Accounting

(A) The software apportions energy costs to whole-building and system-level meters.

(B) System costs are compared by percentage, helping to prioritize conservation actions.

(C) Total costs, and costs per day are each provided.

Costs per day results allow comparison to prior years and eliminate read date concerns from unmatched billing dates.

Source: Facility Dude

Example 4. Portfolio Cost Accounting, Energy Waste

(A) Energy waste (use above expected levels) is tracked for the submeters in a portfolio.

(B) These overages are converted to utility costs per week, reported to energy staff.

(C) Response time and responders are based on waste costs and meter type/location.

See Anomaly Detection and Longitudinal Benchmarking method summaries.

(A) Location	(B) Cost/Week ($)	(C) Response Time	Action
470-Bangor ME			
LD + LND	-378.21	Immediate	Energy Dept
481-Waterville			
MOTOR CONTROL CTR	-231.89	Immediate	Maintenance
391-Royal Ridge NH			
RACK B	-193.21	Next day	Maintenance
HVAC 2	-133.42	Within 2 days	Energy Dept
111-Pawtucket RI			
RACK S	-156.16	Next day	Maintenance
RACK A	-118.96	Within 2 days	Maintenance
PANEL LN	-91.36	Within 5 days	Energy Dept
126-Woonsocket RI			
LD	-126.88	Within 2 days	Energy Dept
124-Raynham MA			
PANEL DP2	-115.73	Within 2 days	Maintenance
341-Peabody MA			
MAIN HVAC	-98.45	Within 5 days	Energy Dept
463-North Windham			
HVAC-1	-90.09	Within 5 days	Energy Dept
356-Laconia NH			
XFMR, PNL, MOPL	-89.50	Within 5 days	Energy Dept
412-Berlin Corners VT			
T1 DP-1	-87.38	Within 5 days	Maintenance

Source: Parasense, Shaws

Purpose

Internal rate of return (IRR) is an investment decision-making method based on cash flow, which quantifies the expected or achieved financial benefit of energy improvements. Using IRR, you can evaluate potential efficiency measures or confirm that expected benefits have been achieved. It can be applied to the energy cost savings associated with any efficiency project, and therefore to any building system, building, or collection of buildings.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
				●

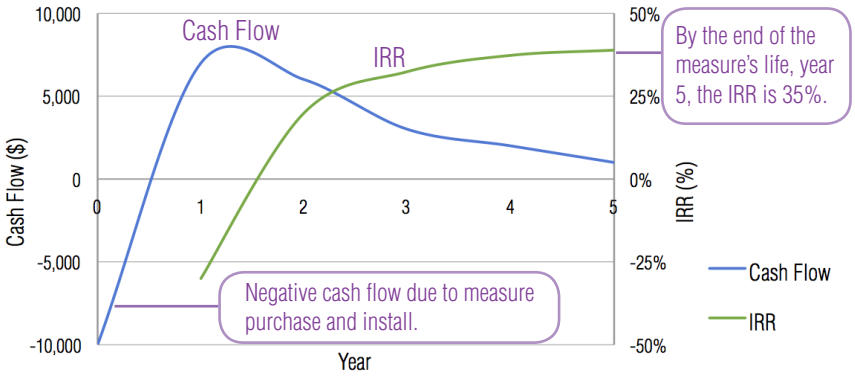
Monthly cash flows may be summed into annual totals; annual intervals are most common, although others are easily calculated.

Financial Manager

Energy Manager

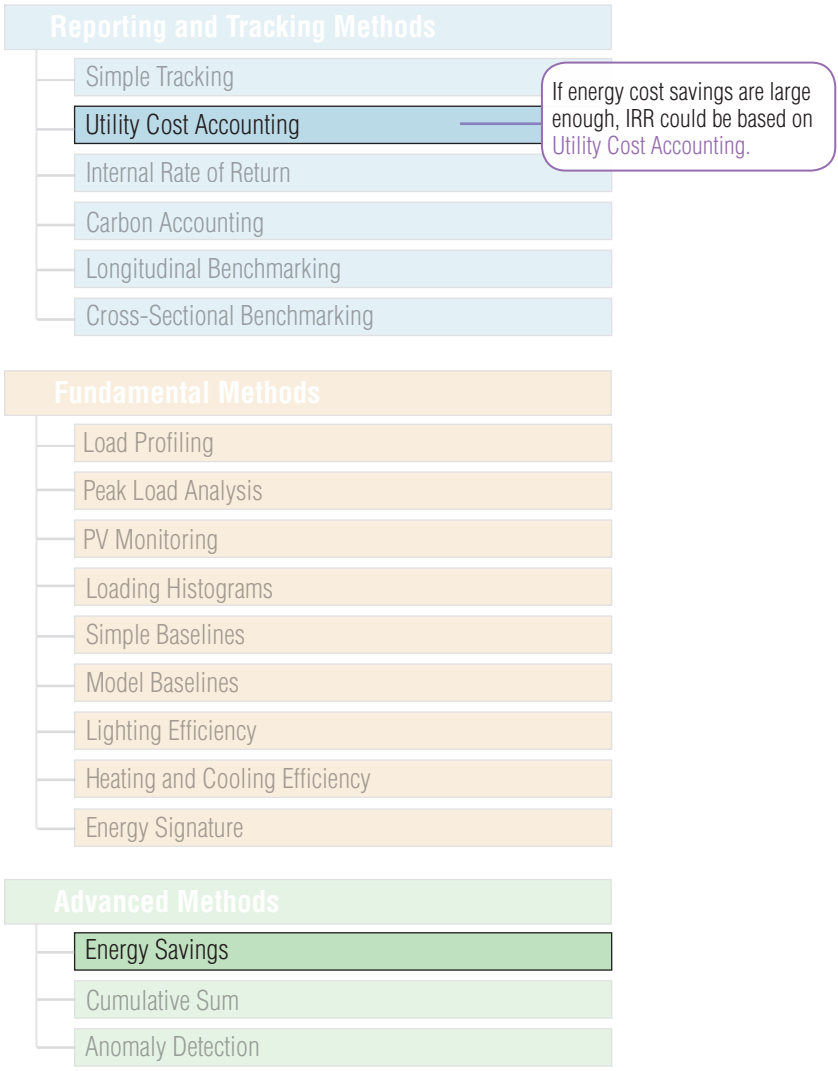
Technical Approach

IRR represents the expected profit or rate of growth for a given efficiency measure, i.e., the yield of the financial benefit of the measure. For those familiar with capital budgeting, IRR is the rate at which the net present value is equal to zero. The cost of the efficiency measure and associated energy cost savings are expressed as a cash flow, and IRR can be calculated for the full measure life or more frequently. In contrast to simple payback, IRR accounts for the time value of money, and for savings that accrue beyond the payback period.



Related Methods

Energy or cost savings could be normalized to account for changes in weather and building operations as in the analysis method Energy Savings.



Calculation and Programming

State of Commercialization: Proprietary tools used by energy service and data analysis and reporting providers may include IRR, as do financial online calculators. Spreadsheet and programmable data analysis tools may also support IRR calculations, as detailed below. IRR is not typically included in utility tracking tools or energy information systems, and would be difficult to program directly into the trends tracked in building automation systems.

Computation: In the absence of packaged software tools, you can use stand-alone data analysis or spreadsheet tools to support longitudinal benchmarking.

Step 1: Gather input data.

Data Resolution

Resolution depends on the chosen metric.

1 Hr, 15 Min ◉ Monthly ◉ Annual ◉

Data Inputs

Accuracy of the IRR calculation depends on the savings estimates that underlie the cash flow.

Metered Data

You can determine energy cost savings associated with an improvement with utility cost accounting and energy savings, or based on estimates.

Cash Flow

Energy cost savings - Improvement costs = Cash Flow

See: **Reporting & Tracking Methods: Utility Cost Accounting**

Advanced Methods: Energy Savings

Step 2: Calculate IRR.

IRR is the r-value in the equation, while C_n is the cash flow in any period. Solve the equation for r, using the mathematical functions provided in the tool.

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}$$

Step 1		Step 2
Year	Cash Flow ($)	**IRR (%)**
0	-10,000	
1	7,000	**-30**
2	5,000	**14**

The cost of the energy-saving measure is included as a negative value in the year 0 cash flow; savings are positive.

Step 3: Plot IRR vs. time and overlay with cash flow or with similar metrics for other measures that are also being tracked.

Notes

Sketches

Application Examples

Interpretation: Deep knowledge of capital budgeting is not required to interpret IRR. Generally, accept all opportunities for which IRR is greater than some minimum acceptable value, typically the cost of capital. The higher the IRR, the more desirable the improvement is.

Example 1: 10-Year Capital Budgeting Analysis

(A) A new controls strategy carries a Year 0 cost or initial investment of $269.5K.

(B) Annual energy cost savings are estimated at $133K.

(C) General inflation is set at 4.0%, and energy services increases at 3.5%.

(D) $8.4K in associated support costs begin accruing in Year 2.

(E) IRR is 49%, higher than the 7.5% cost of capital, indicating a sound investment.

(F) Net present value, return on investment, and simple payback are $710K, 49%, and 2.32 years.

Initial Investment (A)	$ 269,500	Yr 0
Annual Energy Cost Savings (B)	$ 133,087	Yr 1
Ongoing Support Costs	$ 8,400	Yr 2
Utility Incentive (D)	$ -	Yr 0
E = Expected Rate of Annual Increase for energy / services	3.0%	
General Inflation Rate (C)	4.0%	
Cost of capital	7.50%	
Estimated Cap Rate	6.5%	

Discounted benefit flow	**Year 0**	...	**Year 10**
Discounted costs	*$269,500*		*$4,076*
Discounted benefits	*0*		*84,253*
Total discounted benefit flow	*(269,500)*		*80,178*
Total cumulative discounted benefit flow	*(269,500)*		*709,687*

ROI measures	
IRR (Hurdle Rate)	**49.3%**
Net present value	***$709,687***
Return on investment (E-F)	**49%**
Payback (in years)	***2.32***
Increase in Building Value per assumed Cap Rate	***$ 2,542,290***

Source: Optimum Energy

Example 2: Measure Selection with IRR and NPV

(A) Either occupancy sensors or time clock scheduling could be implemented.

(B) Estimated annual savings and initial costs differ in each case.

(C) IRR is above the typical cost of capital in both cases, so either is a good investment.

(D) To determine which of the two options should be selected, NPV is considered.

(E) Since occupancy sensing carries a higher NPV, it is the better investment.

For each year, the cash flow is energy savings minus investment costs. See Appendix for further discussion of NPV and IRR.

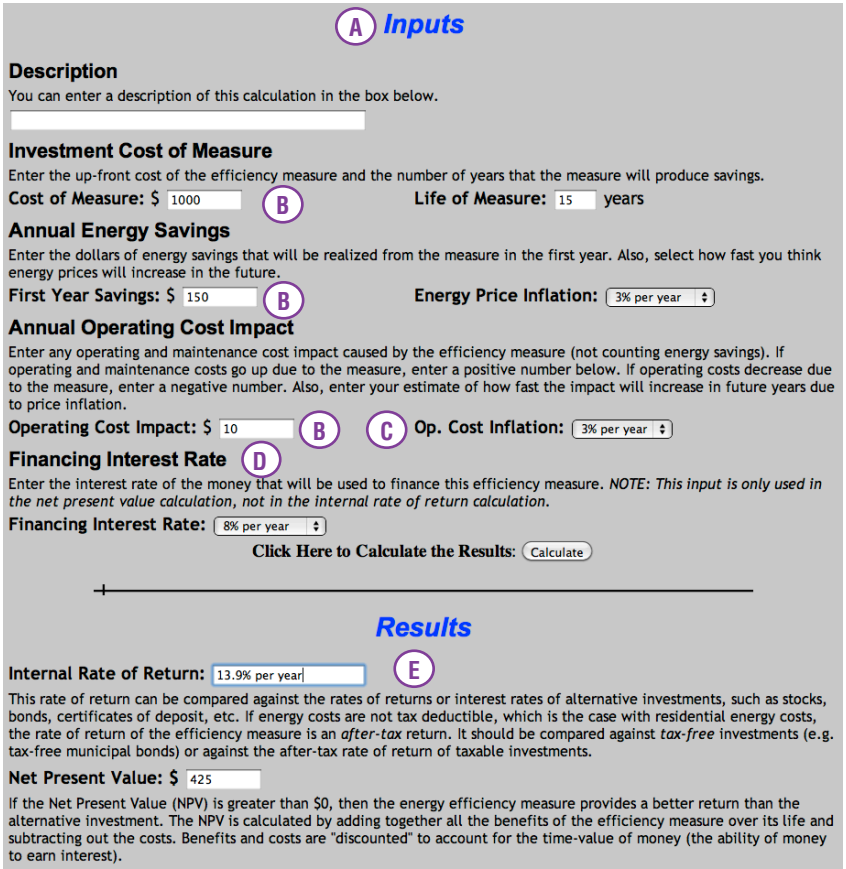
	Option A: occupancy sensors		Option B: central time clock	
Year	Initial investment ($)	Energy savings ($)	Initial investment ($)	Energy savings ($)
0	–42,000	—	–9,000	—
1	—	12,200	—	3,550
2	—	12,200	—	3,550
3	—	12,200	—	3,550
4	—	12,200	—	3,550
5	—	12,200	—	3,550
6	—	12,200	—	3,550
7	—	12,200	—	3,550
8	—	12,200	—	3,550
9	—	12,200	—	3,550
10	—	12,200	—	3,550
IRR		**26.2%**		**37.9%**
NPV (10% discount rate)		**80,000**		**26,500**

Source: Used with permission, © 2011 E Source Companies LLC, Boulder, CO.

Example 3: IRR and NPV Calculator

- (A) The calculator determines IRR and NPV based on user inputs.
- (B) Measure cost, lifetime, energy savings, and operating costs are specified.
- (C) Inflation in energy prices and operational costs are accounted for.

  Rates, costs and savings are fixed; the calculator does not permit annual variability.
- (D) Loans are presumed to finance the measure, at a user-defined interest rate.
- (E) This particular example measure results in 14% IRR and $425 NPV.



(A) **Inputs**

Description

You can enter a description of this calculation in the box below.

Investment Cost of Measure

Enter the up-front cost of the efficiency measure and the number of years that the measure will produce savings.

Cost of Measure: $ 1000 (B) **Life of Measure:** 15 years

Annual Energy Savings

Enter the dollars of energy savings that will be realized from the measure in the first year. Also, select how fast you think energy prices will increase in the future.

First Year Savings: $ 150 (B) **Energy Price Inflation:** 3% per year

Annual Operating Cost Impact

Enter any operating and maintenance cost impact caused by the efficiency measure (not counting energy savings). If operating and maintenance costs go up due to the measure, enter a positive number below. If operating costs decrease due to the measure, enter a negative number. Also, enter your estimate of how fast the impact will increase in future years due to price inflation.

Operating Cost Impact: $ 10 (B) (C) **Op. Cost Inflation:** 3% per year

Financing Interest Rate (D)

Enter the interest rate of the money that will be used to finance this efficiency measure. *NOTE: This input is only used in the net present value calculation, not in the internal rate of return calculation.*

Financing Interest Rate: 8% per year

Click Here to Calculate the Results: Calculate

Results

Internal Rate of Return: 13.9% per year (E)

This rate of return can be compared against the rates of returns or interest rates of alternative investments, such as stocks, bonds, certificates of deposit, etc. If energy costs are not tax deductible, which is the case with residential energy costs, the rate of return of the efficiency measure is an *after-tax* return. It should be compared against *tax-free* investments (e.g. tax-free municipal bonds) or against the after-tax rate of return of taxable investments.

Net Present Value: $ 425

If the Net Present Value (NPV) is greater than $0, then the energy efficiency measure provides a better return than the alternative investment. The NPV is calculated by adding together all the benefits of the efficiency measure over its life and subtracting out the costs. Benefits and costs are "discounted" to account for the time-value of money (the ability of money to earn interest).

Source: energytools.com, http://www.energytools.com/calc/EnerEcon.html, Visited May 24, 2011

Purpose

Carbon accounting, or "footprinting" is used to quantify the greenhouse gas (GHG) emissions associated with building energy consumption. Many organizations have adopted sustainability initiatives and carbon-reduction goals, so they track and report their emissions in annual sustainability reports or public registries. Emissions associated with building energy use include direct emissions from the fuel used to operate the building and indirect emissions to generate purchased utilities.

Carbon is typically reported at the building or portfolio level, but may also be tracked at the system or component level.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

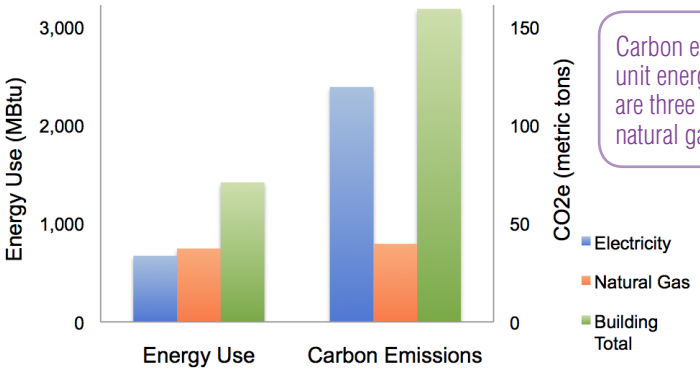
Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
				●

Financial Manager

Energy Manager

Technical Approach

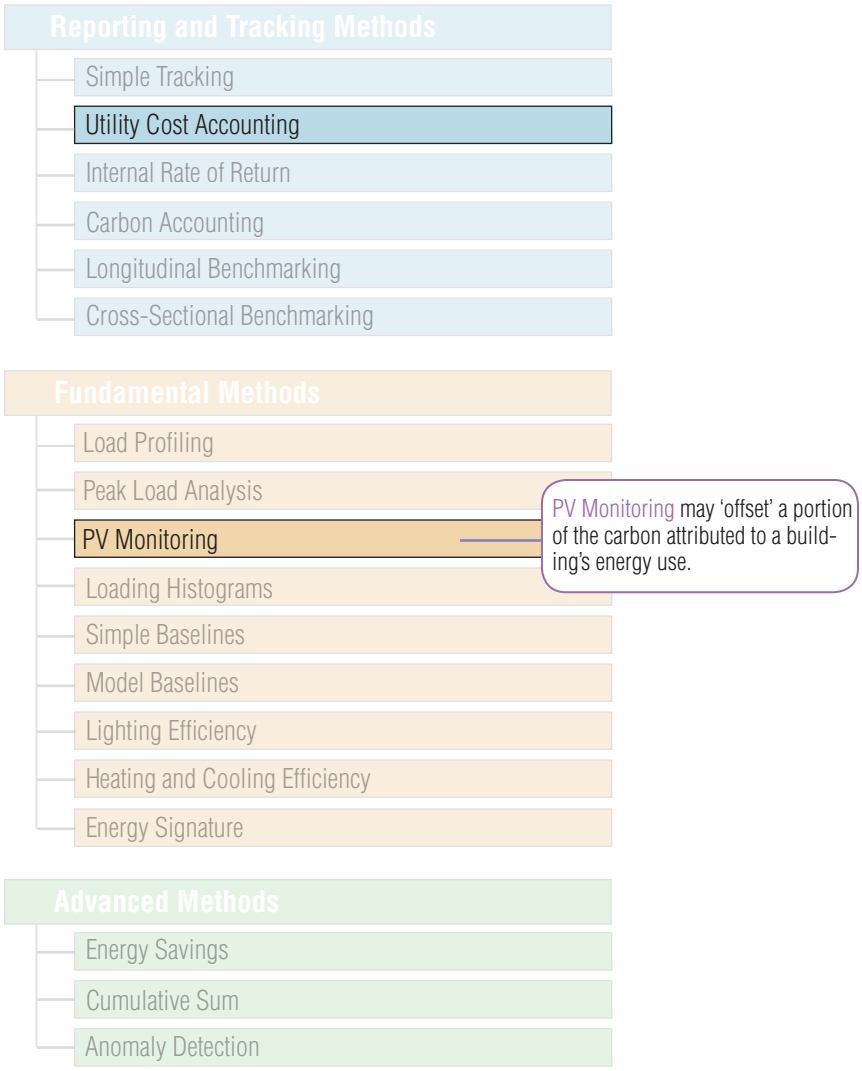
Total metered or billed energy consumption for each fuel type (usually over an annual period). Convert purchased electricity, heat, or steam to GHG emissions by applying a conversion factor that accounts for indirect emissions associated with generation. For direct emissions from on-site combustion, conversion factors depend on the fuel's heating value, carbon content, carbon oxidation factor, and carbon to CO_2 ratio. Convert emissions of each gas to CO_2 equivalents with factors specific to each gas's global warming potential (GWP), and total them into a single emissions or footprint quantity.



Carbon emissions per unit energy of electricity are three times that of natural gas.

Related Methods

Carbon Accounting is related to Utility Cost Accounting; however, rather than converting energy to cost, it is converted to carbon dioxide equivalents.



Calculation and Programming

State of Commercialization: Carbon accounting may be offered preprogrammed in commercial EIS, or in some in utility bill tracking or benchmarking tools. Environmental calculators may also provide support for carbon accounting.

Computation: BAS, and spreadsheet or programmable analysis tools may also support carbon tracking.

Step 1: Gather input data.

Data Resolution

Carbon accounting is applicable to all energy data; however, reporting is typically done annually.

1 Hr, 15 Min ◉ Monthly ◉ Annual ◉

Data Inputs

Metered values should reasonably reflect total energy use. Be sure to verify the accuracy of non-utility gas metering.

Metered Data

Export metered energy use from BAS or on-site data acquisition system, or use utility billing data.

Conversion Factors

You can find electricity emissions factors in the U.S. Environmental Protection Agency's eGrid. Factors for non-electric sources are published by the Energy Information Administration. See Appendix details for GWP values.

Greenhouse gases other than CO_2, N_2O and CH_4 are not typically associated with building energy use.

Step 2: Convert energy use to GHG emissions.

Multiply energy use by the emissions factors.

Step 3: Convert emissions to CO_2 equivalents.

Multiply emissions by the GWP values.

Step 1		Step 2			Step 3
Energy Source	Energy Use	CO_2 Emissions (kg)	N_2O Emissions (kg)	Methane - CH_4 Emissions (kg)	**CO_2e Emissions**
Electricity	187,600 kWh	= 0.589 *187,600 = 110,500 kg	=8.9x10^{-6} *187,600 =1.7 kg	= 1.1x10^{-5} *187,600 =2.1kg	**= 1 * 110,500 kg CO_2 + 310 * 1.7 kg N_2O + 21 * 2.1 kg CH_4 = 111,000 kg CO_2e**
Natural Gas	6,920 therms	= 5.4 *6,920 = 37,400 kg	= 1.1x10^{-5} *6,920 = 0.08 kg	= 5.4x10^{-4} *6,920 = 3.7 kg	**= 1 * 37,400 kg CO_2 + 310 * 0.08 kg N_2O + 21 * 3.7 kg CH_4 = 37,500 kg CO_2e**
Total CO_2e (kg)					**= 111,000 + 37,500 = 149,000 kg CO_2e**

Step 4: Plot emissions over time. Aggregate multiple sites

Notes

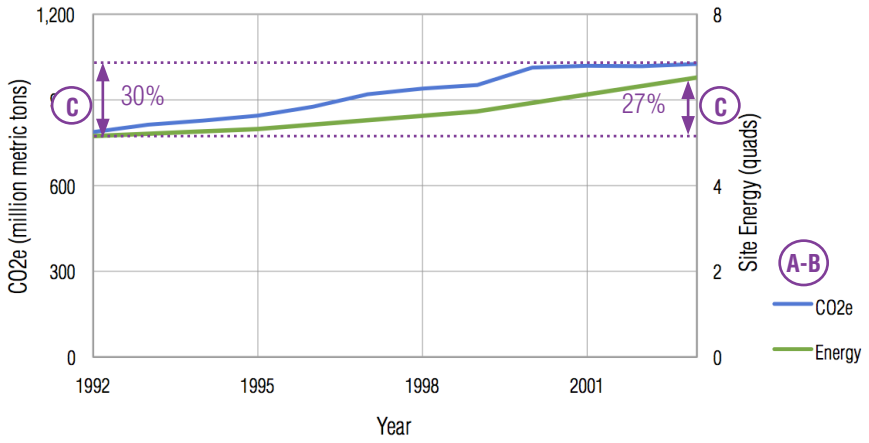
Sketches

Application Examples

Interpretation: In general, smaller emissions are better than larger emissions, regardless of the unit that is chosen or the specific gas. However, since the GHGs each have different environmental impacts, direct mass-based comparisons of emitted gases can be misleading. In this way, the use of CO_2 equivalents (CO_2e) can simplify interpretation. You can use EPA's Portfolio Manger to determine whether a building's total emissions are typical, high or low relative to its peers.

Example 1: Stock Carbon Emissions and Energy Tracking

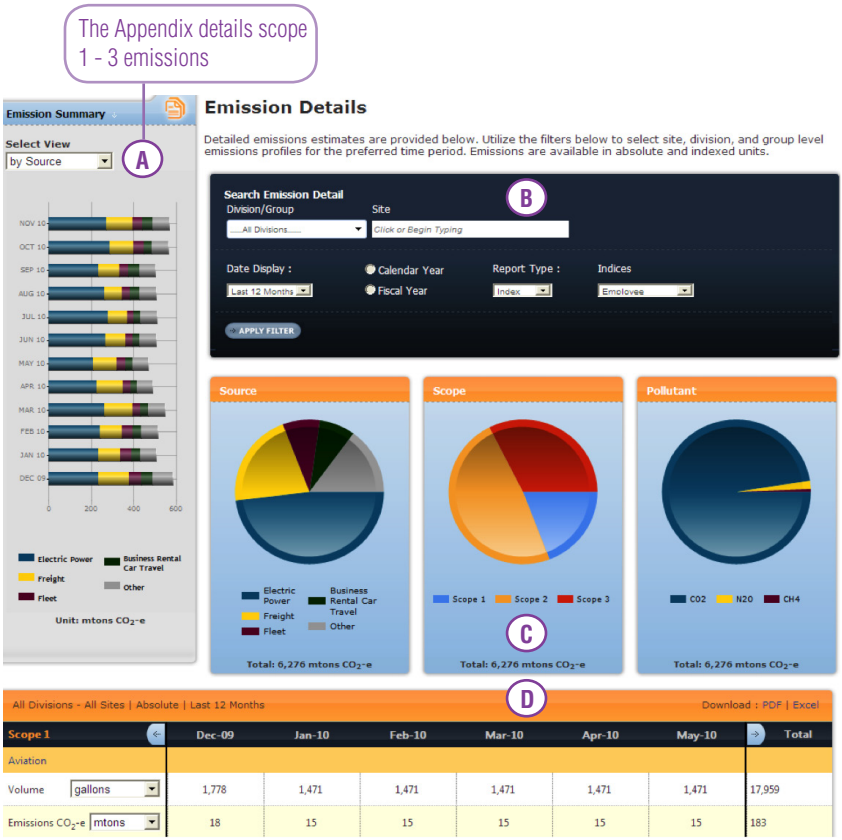
- (A) The annual energy use of the U.S. commercial building stock is plotted.
- (B) Energy use is converted to CO_2 emissions, and overlaid onto the plot.
- (C) Between 1992 and 2003, energy use increased 27% and emissions increased 30%.



Data Sources: U.S. Department of Energy *Buildings Energy Data Book* and Energy Information Administration *Energy Outlook*

Example 2: Detailed Carbon Accounting

- **A** Monthly CO_2e is shown in a stacked bar, by source, scope, and pollutant (gas).
- **B** The user selects the desired site, reporting time period, and emissions units.
- **C** Pie charts show relative contributions by source, scope, and gas.
- **D** A tabular summary is provided, from which data may be exported.



Source: Summit Energy/Schneider Electric

Example 3: Plant Carbon Tracking

- **A** Weekend and weekday CO_2 emissions from four plants are tracked.
- **B** Weekend emissions are lower than on weekdays, and Plant 2 emissions are lowest.
- **C** Emissions from a single plant are normalized by sq ft, and daily totals are plotted.
- **D** Lower emissions over the weekends are again visible.
- **E** The group plot in A is shown for the single plant in C.

Source: Schneider Electric

Purpose

Longitudinal benchmarking compares the energy usage in a fixed period for a building, system, or component to a baseline period of the same length, to determine if performance has deteriorated or improved, to set goals for a building or system, or to monitor for unexpectedly high usage.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
▬				●

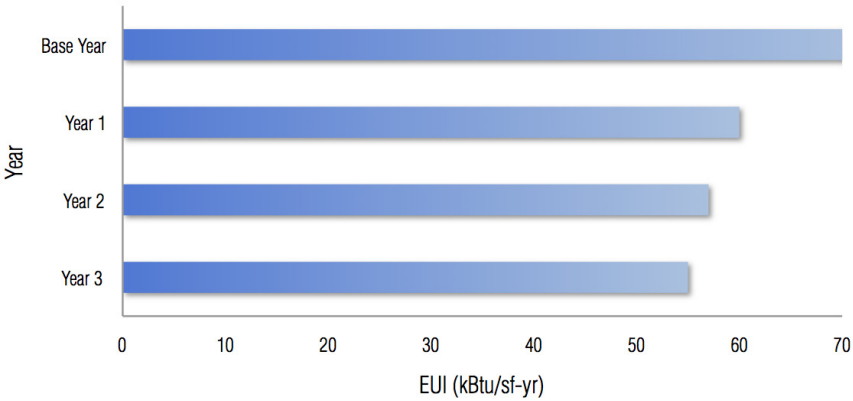
Energy Manager

Facilities Manager

Operator

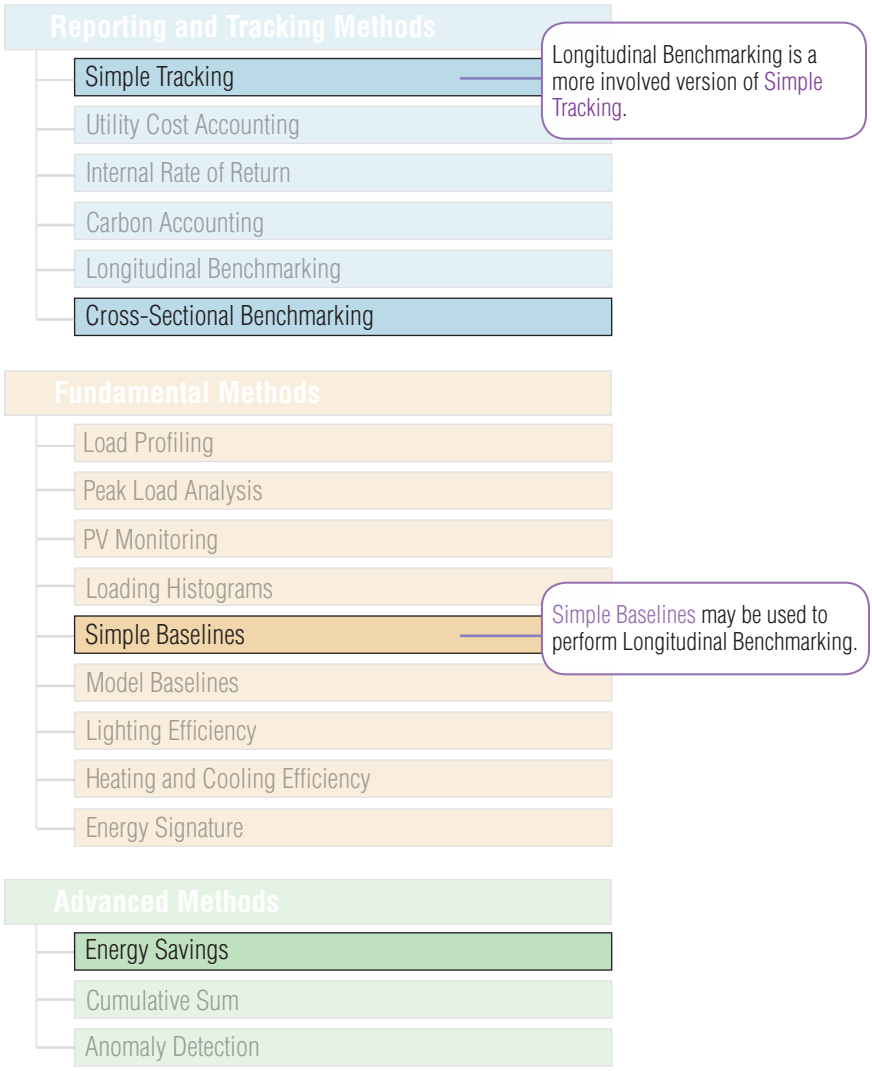
Technical Approach

Characterize energy use in the base, or reference, period with a simple or model-based baseline and express it according to your metric of choice, forming a "benchmark." Then track energy performance relative to the base-period benchmark. Annual whole-building benchmarking is most common, with kilowatt-hours per square foot per year (kWh/sf-yr) taken as the associated usage metric; however, longitudinal benchmarking may also be conducted seasonally and for systems and equipment.



Related Methods

Energy Savings is a more sophisticated analysis that extends the basic concepts of Longitudinal Benchmarking. Cross-Sectional Benchmarking is similar to Longitudinal Benchmarking, except that the building's energy performance is compared to that of a peer group.



Calculation and Programming

State of Commercialization: Longitudinal benchmarking is commonly offered in energy information systems, and in utility bill tracking and benchmarking tools. The associated benchmarking metrics and the form and robustness of the underlying baseline vary.

Computation: In the absence of packaged software tools, you can use stand-alone data analysis or spreadsheet tools to support longitudinal benchmarking.

Step 1: Gather input data.

Data Resolution

The required resolution depends on the baseline and the chosen performance metric.

1 Hr, 15 Min ● Monthly ● Annual ●

Data Inputs

High accuracy for metered data is not required. Fill data gaps before computing.

Metered Data

Export building or system-level gas or electric data from a meter acquisition system.

Baseline

Step 2: Formulate base period usage.

Formulate base period usage according to a baseline and chosen metric. This is the "benchmark" against which future performance is compared.

More complex model-based baselines may be required for systems or unusual usage or operations.

See: **Fundamental Methods: Simple Baselines**

Step 3: Express subsequent years' usage in terms of baseline model and chosen metric.

Step 1			Step 2
Year	Heating Energy (Therms)	Baseline Variables (HDD)	**Performance (Therms/HDD)**
Base	12, 050	5,050	**2.4**
1	11, 175	6,459	**1.7**
2	10, 548	6,701	**1.6**

Step 4: Examine the difference between the base year/period and subsequent years/periods, and express the results in a table, chart, or plot.

Notes

Sketches

Application Examples

Interpretation: Once normalized, the annual or seasonal data is compared against the benchmark year using simple plotted representations to look for unusual deviations that indicate good or bad changes in operations or equipment.

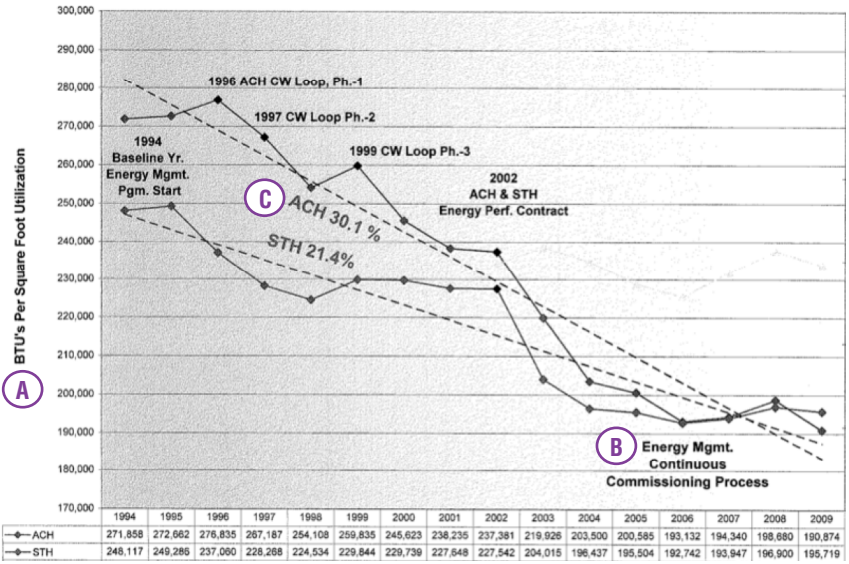
Example 1: Multi-Year Multi-Campus Benchmarking, Btu/sf-yr

Total site energy is tracked for two hospital sites over a 15-yr period, from 1994-2009.

(A) The benchmarking metric is Btu/sf, combining gas, steam, fuel oil and electric sources.

(B) Capital and operational improvements are annotated on the tracking plot.

(C) From 1994-2009 one hospital/site/campus improved 30%, and the other, 21%.



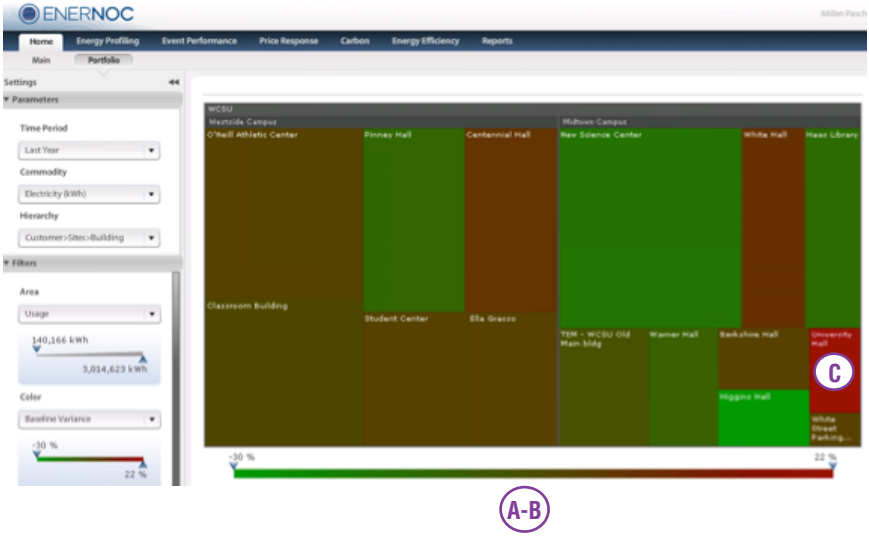
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
ACH	271,858	272,662	276,835	267,187	254,108	259,835	245,623	238,235	237,381	219,926	203,500	200,585	193,132	194,340	198,680	190,874
STH	248,117	249,286	237,060	228,268	224,534	229,844	229,739	227,648	227,542	204,015	196,437	195,504	192,742	193,947	196,900	195,719

Source: Summa Health

Example 2. Multi-Site Campus Benchmarking

Each building is represented as a rectangle.

- (A) Energy use is benchmarked vs. the previous year and color coded.
- (B) The color scale is indicated at the bottom of the screen.
- (C) The worst-performing building (22% above benchmark) is easily identified.



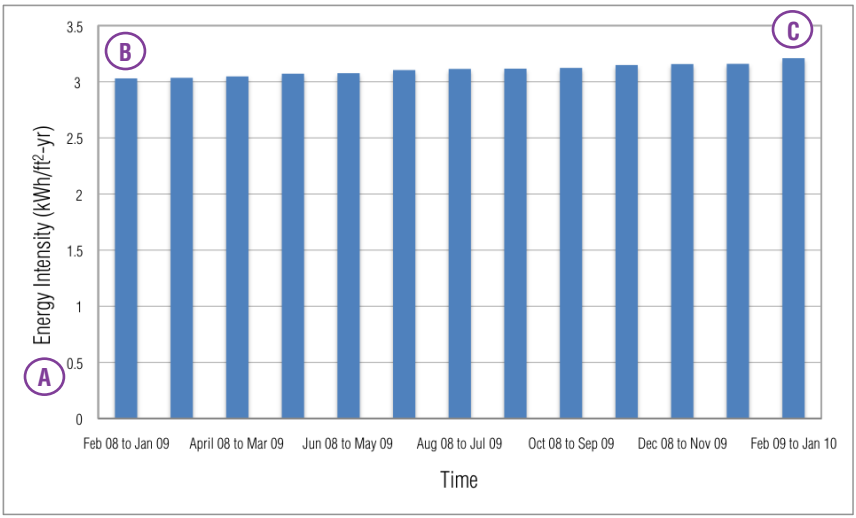
Source: EnerNOC

Example 3: Plug Load Benchmarking in an Academic Building

(A) Plug load energy use for an academic building is plotted on the y-axis in kWh/sf-yr. Each bar represents the total energy used in the prior 12-month period.

(B) From February 2008 to January 2009, the use was 3.03 kWh/sf-yr.

(C) By the February 2009 to January 2010 period, use grew 6%, to 3.21 kWh/sf-yr.



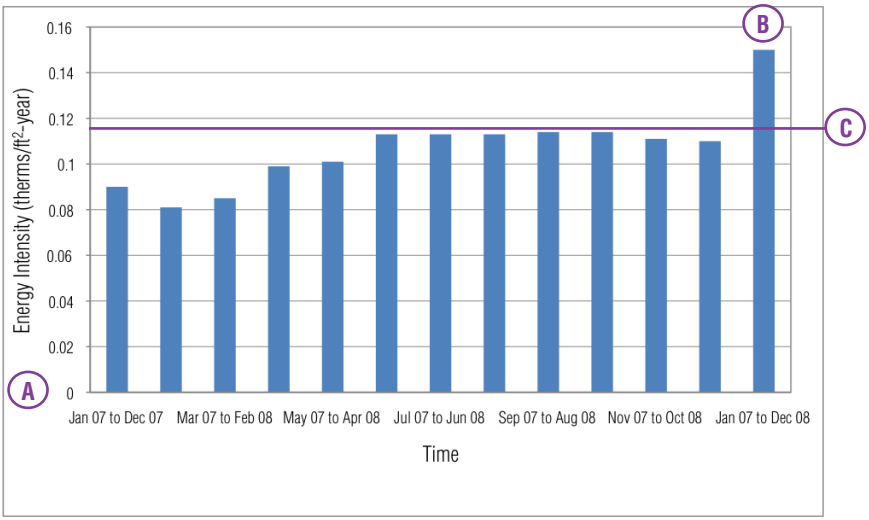
Source: Lawrence Berkeley National Laboratory, UC Merced

Example 4: Heating Energy Use Benchmarking

(A) Heating energy for an academic building is plotted on the y-axis in therms/sf-yr. Each bar represents total heating energy for the prior 12-month period.

(B) In January, the heating energy use abruptly increases from .11 to .15 th/sf-yr. Errors in the pump's control logic were found to cause excessive hot water flow. The energy and cost impact for this fault was estimated at 36% and $1,650.

(C) The horizontal line indicates the benchmark performance for similar buildings.



Source: Lawrence Berkeley National Laboratory, UC Merced

Purpose

Cross-sectional benchmarking is the process of comparing a building's energy efficiency relative to a peer group. It is the first step to determine if a building has the potential to improve its efficiency. It is usually done at the whole-building level, to assess a building's overall energy efficiency, using an EUI metric such as kBtu/sf or kBtu/student (for a school).

Cross-sectional benchmarking can also be performed using EUI metrics like watts per cubic foot per minute (W/cfm) for HVAC and kWh/sf for lighting.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
				●

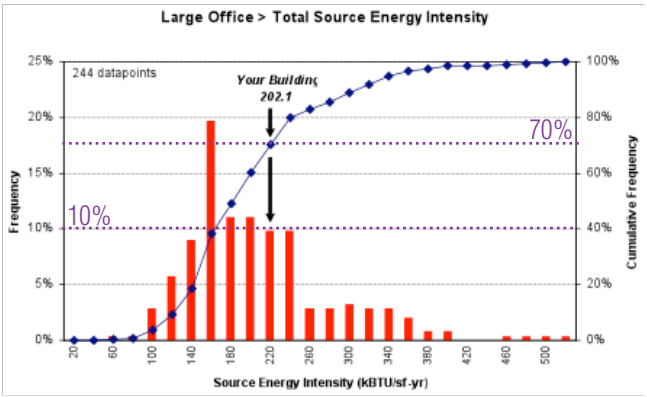
Energy Manager

Facilities Manager

Financial Manager

Technical Approach

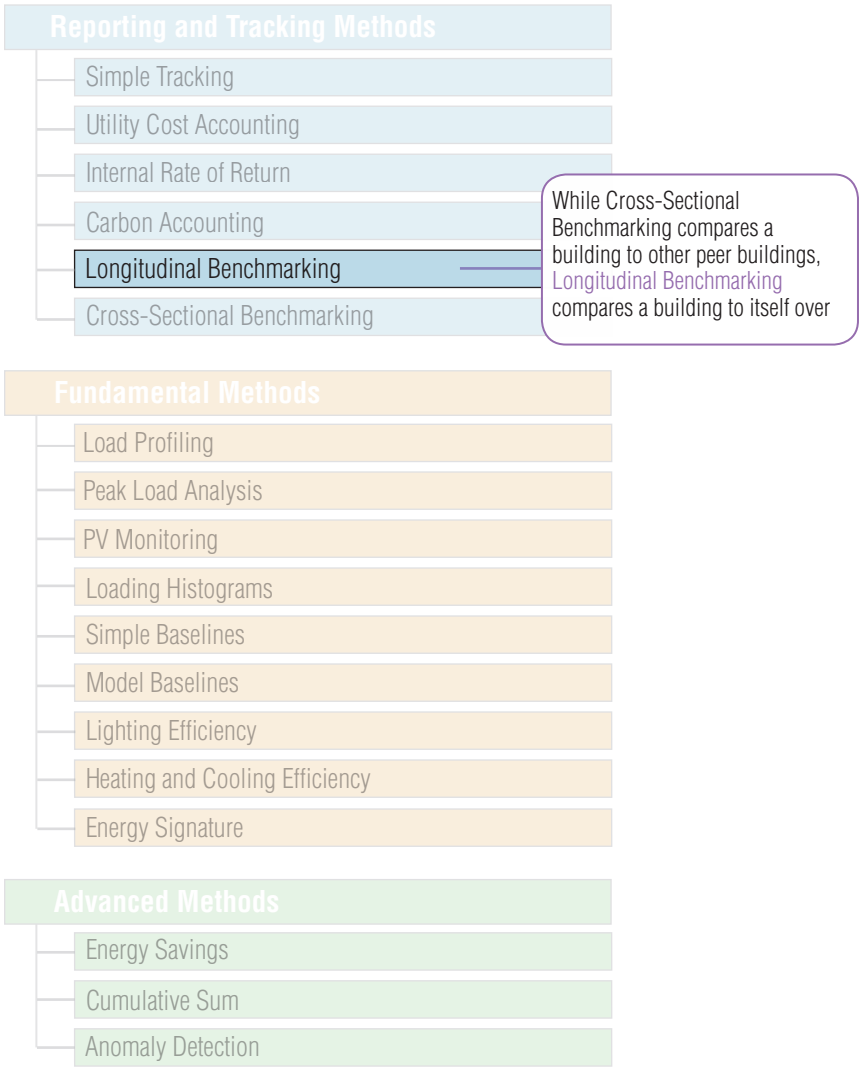
Total building energy use (typically annually) and express it according to a metric of interest, such as kWh/sf/yr. Normalize the energy use for parameters such as weather, operation hours, and other factors, and compare it to that of other buildings. A simple normalization approach is to directly filter the peer group for buildings with similar characteristics to the building being benchmarked. A more rigorous approach is to conduct a regression analysis on the peer data set, which yields an equation that relates the performance metric to normalizing parameters.



10% of peer buildings had EUIs in the same range as "your building." 70% of peer buildings had lower source EUI, and are more efficient than "your building."

Related Methods

Cross-Sectional Benchmarking is closely related to Longitudinal Benchmarking.



Calculation and Programming

State of Commercialization: There are several commercially available tools for cross-sectional benchmarking. ENERGY STAR Portfolio Manager is arguably the most widely used tool. Many EIS also offer cross-sectional benchmarking as a feature.

Computation: If you would like to use your own data set, you can do so with simple calculations using a spreadsheet, as described in the steps below.

Step 1: Gather input data.

Data Resolution

The required resolution depends on the chosen performance metric.

1 Hr, 15 Min ◉ Monthly ◉ Annual ◉

Data Inputs

For annual site energy intensity, the data required are:

- Annual electricity use
- Annual natural gas and other fuels use
- Annual district energy use (e.g., chilled water, steam)
- Total gross floor area of the building

Typically, you can obtain these data from utility bills or an EIS.

Metered Data

Select a peer group of buildings that has similar characteristics (operation hours, climate, etc.). Ensure that the data required to calculate the performance metric for the peer buildings are available.

The steps illustrate cross-sectional benchmarking with annual site EUI in kBtu/sf. Other performance metrics can be calculated in a similar manner. In this example, kWh is converted to kBtu by multiplying by 3.412.

Step 2: Calculate performance metric for buildings.

Step 1						Step 2
Bldg.	Elec. (kWh)	Gas (kBtu)	Steam (kBtu)	...	Floor Area (SF)	**Site Energy Use intensity (kBtu/sf)**
1	1,255,000	3,200,000		...	85,000	**(1,255,000 *3.412 + 3,200,000) / 85000 = 88.02**
2	653,000	1,030,000		...	33,000	**(653,000 * 3.412 + 1,030,000) / 33,000 = 98.73**
3	1,223,000	1,230,000	3,300,000	...	110,000	**(1,223,000 *3.412 + 1,230,000 + 3,300,000)/110,000 = 79.12**

Step 3: Plot the Results. You can plot the rank-ordered list of EUI values for the buildings using a simple bar graph.

Notes

Sketches

Application Examples

Interpretation: Cross-sectional benchmarking results are usually expressed in terms of the percentile rank relative to the peer group. When using EUI, lower values are better. Fiftieth percentile means that half the buildings in the peer group are more efficient and twenty-fifth percentile means that only 25% of the buildings are more efficient. Sometimes, the EUI scale is inverted into an efficiency "score," in which case higher values are better (e.g., twenty-fifth percentile in EUI translates into a score of 75 on a 1 to 100 scale).

Note that improving your score from 70 to 75 does not necessarily imply a 5% reduction in energy use intensity, but rather an improvement over 5% of the peer group.

You can also use cross-sectional benchmarking data to enhance the analysis from Simple tracking or baselining. For example, if simple tracking shows that a building's energy use intensity has reduced by 20%, cross-sectional benchmarking will reveal how that changes its ranking relative to a group of peers.

Example 1: ENERGY STAR Portfolio Manager Report, Single Building

A user enters his or her building data into Portfolio Manager.

(A) Portfolio Manager generates a Statement of Energy Performance (SEP).

(B) The SEP indicates the ENERGY STAR score from one to one hundred.

(C) In this case the score is 90, and the site performs better than 90% of the peer group.

OMB No. 2060-0347

STATEMENT OF ENERGY PERFORMANCE (A)
Office Sample Facility

Building ID: 2005550
For 12-month Period Ending: April 30, 2010[1]
Date SEP becomes ineligible: August 28, 2010
Date SEP Generated: July 02, 2010

Facility
Office Sample Facility
1234 Main Street
Arlington, VA 22201

Facility Owner
Sample Owner
1500 Test Avenue
Charlotte, NC 28227
555-555-5555

Primary Contact for this Facility
Jane Smith
1500 Test Avenue
Charlotte, NC 28227
555-555-5555
jsmith@jsmith.com

Year Built: 2000
Gross Floor Area (ft²): 53,232

Energy Performance Rating[2] (1-100) 90 (B-C)

Site Energy Use Summary[3]

Electricity - Grid Purchase(kBtu)	2,288,770
Natural Gas (kBtu)[4]	1,228,009
Total Energy (kBtu)	3,516,779

Energy Intensity[5]

Site (kBtu/ft²/yr)	66
Source (kBtu/ft²/yr)	168

Emissions (based on site energy use)

Greenhouse Gas Emissions ($MtCO_2e$/year)	413

Electric Distribution Utility
Dominion - Virginia Electric & Power Co

National Average Comparison

National Average Site EUI	114
National Average Source EUI	289
% Difference from National Average Source EUI	-42%
Building Type	Office

REGISTERED PROFESSIONAL ENGINEER — JOHN DOE — #0000001 — STATE OF VIRGINIA

Professional Engineer Stamp

Signature: _____

Based on the conditions observed at the time of my visit to this building, I certify that the information contained within this statement is accurate and in accordance with the Licensed Professional Guide.

Meets Industry Standards[6] **for Indoor Environmental Conditions:**

Ventilation for Acceptable Indoor Air Quality	Yes
Acceptable Thermal Environmental Conditions	Yes
Adequate Illumination	Yes

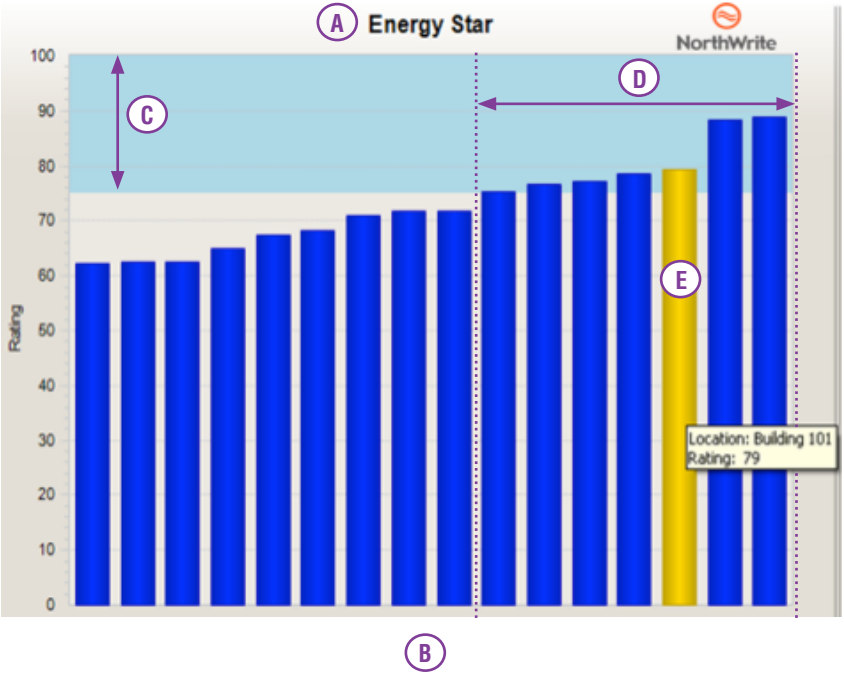
Professional Engineer
License Number: 0000001
State: VA
John Doe
333 Old Sample Lane
Arlington, VA 22201
555-555-1234

Notes:
1. Application for the ENERGY STAR must be submitted to EPA within 4 months of the Period Ending date. Award of the ENERGY STAR is not final until approval is received from EPA.
2. The EPA Energy Performance Rating is based on total source energy. A rating of 75 is the minimum to be eligible for the ENERGY STAR.
3. Values represent energy consumption, annualized to a 12-month period.
4. Natural Gas values in units of volume (e.g. cubic feet) are converted to kBtu with adjustments made for elevation based on Facility zip code.
5. Values represent energy intensity, annualized to a 12-month period.
6. Based on Meeting ASHRAE Standard 62 for ventilation for acceptable indoor air quality, ASHRAE Standard 55 for thermal comfort, and IESNA Lighting Handbook for lighting quality.

Source: U.S. EPA, ENERGY STAR Portfolio Manager

Example 2: Automated ENERGY STAR Benchmarking for a Portfolio

- **A** The tracking software shown is able to compute ENERGY STAR scores.
- **B** Scores from 16 buildings are shown on a bar chart, sorted from low to high.
- **C** The shaded band marks scores greater than 75, which qualify for the ENERGY STAR label.
- **D** Seven of the 16 buildings in the portfolio qualify.
- **E** Yellow indicates a user-selected building at the time of the screen capture.



Source: NorthWrite

Example 3: Ventilation System Benchmarking, W/cfm

(A) A benchmarking chart for the ventilation metric W/cfm is generated from user input.

(B) EUIs for 18 peer buildings are shown in purple; hash patterns indicate estimates.

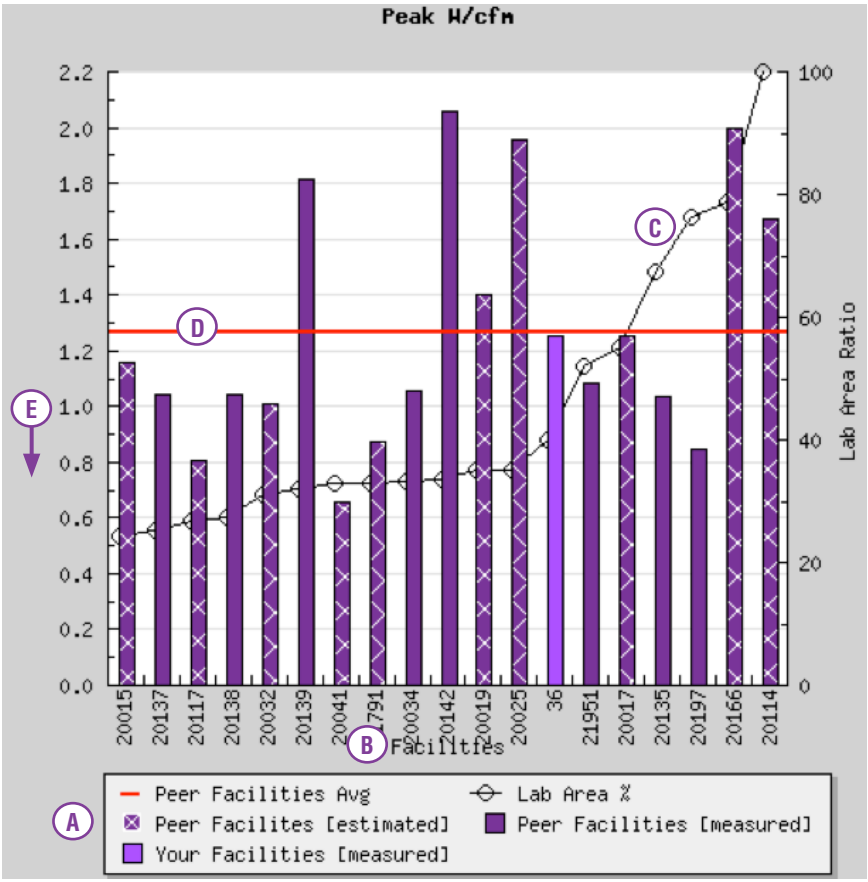
(C) Each building's lab-area ratio is plotted and ranked from low to high.

(D) The red line indicates average ventilation in W/cfm for the peer group.

The W/cfm can be compared to the peer group's average, minimum, and maximum.

(E) Lower W/cfm are preferred.

Efficiency can be improved with higher fan efficiency or lower pressure drop.



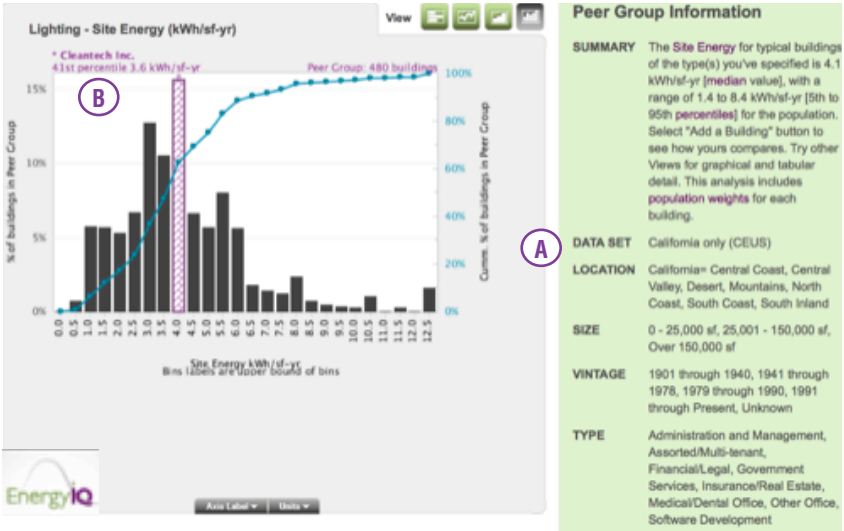
Source: Labs21 Benchmarking Tool

Example 4: Lighting System Benchmarking, kWh/sf-yr

The user enters data for lighting energy use in a building.

(A) The user selects a peer group data set for the comparison.

(B) The cumulative frequency plot gives a ranking in the 41st percentile.



Source: EnergyIQ

Discussion

The Fundamental Methods chapter marks a transition from the simpler Reporting and Tracking Methods into those that require a higher level of user expertise. This chapter also provides the foundation for the Advanced Methods that are presented in the following chapter. Fundamental Methods begins with **Load Profiling**, **Peak Analysis** and **PV Monitoring**, which largely rely on inspections of time series data. **Simple Baselines** are then introduced to provide an uncomplicated way to characterize energy performance, building upon the Simple Tracking approach that was presented in Reporting and Tracking. Moving into the operational efficiency of a building's major end uses, **Loading Histograms**, **Lighting Efficiency**, and **Heating and Cooling Efficiency** target the operational efficiency of a building's major end uses.

Model Baselines and **Energy Signatures** comprise the remainder of the chapter, and are the most complex methods in the handbook. They require an understanding of how building loads vary with outside air temperature (OAT), time and day of week, occupancy, and other independent variables such as humidity or season. Energy signatures are diagnostic plots of load vs. OAT that can be inspected directly, tracked over time or compared to other buildings for efficiency insights. The most straightforward Model Baselines may be constructed by defining the relationship between load and OAT, according to simple "change point models." More sophisticated baseline models account for cross dependencies between time of day and OAT and additional variables such as relative humidity, or business-specific production quantities such as number of guests at a hotel.

A key concept in the formulation and application of baseline models is to understand *when* they are updated, or recalculated, and the data from which they are "built." The addition of energy-intensive equipment such as server rooms or fountains, and major changes such as organizational expansion or remodeling may merit a baseline update. Moreover, when baselines are used in the context of efficiency improvements and in combination with the Advanced Methods, the following points are important to keep in mind:

> Baselines formulated from historic data *before* major improvements have been made can be used to determine the absolute or cumulative sum of energy savings attributed to the improvement.
>
> Baselines formulated from data *after* major improvements have been made can be used to detect anomalies and to ensure persistence in savings. The "original" baseline used to calculate energy savings must be recomputed to characterize the newly efficient building operations.
>
> These points are illustrated in the example that follows.

(A) Data from months 1 to 6 is used to build $Baseline_0$, an initial baseline.

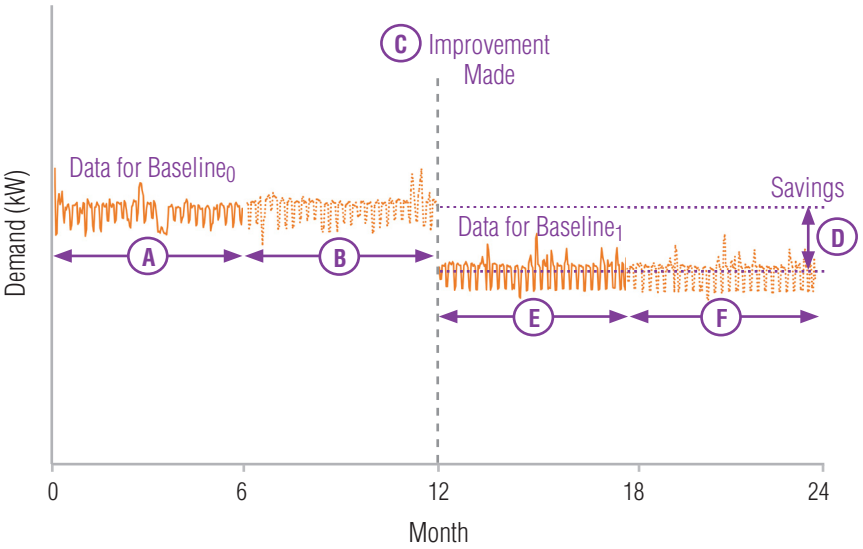
(B) $Baseline_0$ is used for anomaly detection in months 6 to 12.

(C) An efficiency improvement is made in month 12.

(D) $Baseline_0$ is used for cumulative and absolute energy savings due to the improvement.

(E) Data from months 12 to 18 is used to build $Baseline_1$, a new baseline.

(F) $Baseline_1$ is used after month 18 for anomaly detection to ensure persistence of savings.



Purpose

Load profiling is used on a daily or weekly basis to understand the relationship between energy use and time of day. Abnormalities or changes in load profiles can indicate inefficiencies due to scheduling errors, unexpected or irregular equipment operation, high use during unoccupied hours, or untimely peaks.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
		●		

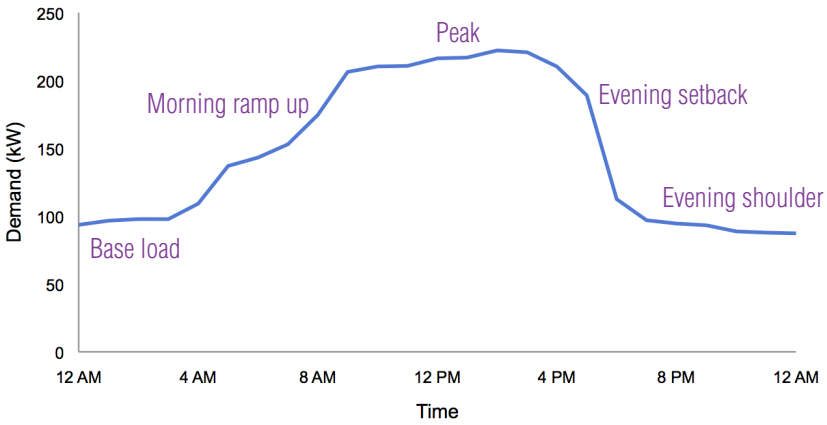
Energy Manager

Facilities Manager

Technical Approach

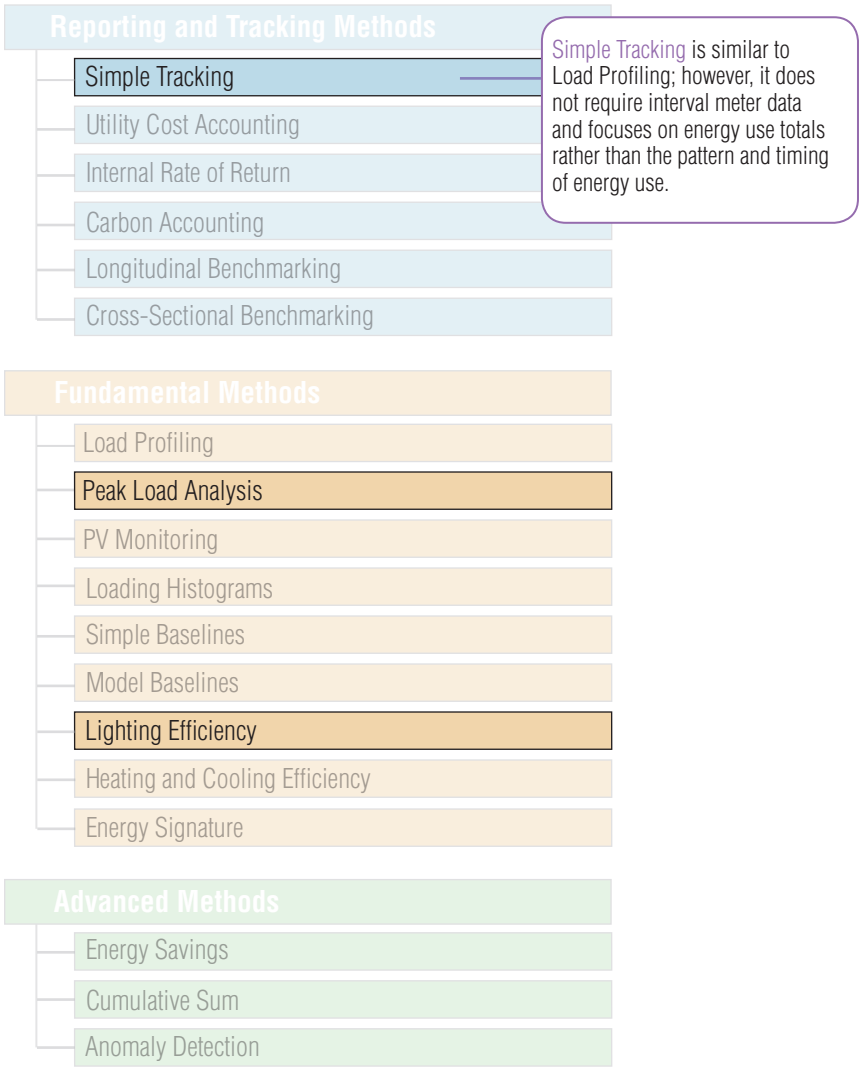
Inspect plots of at least 24-hour periods of interval meter data, or "profiles," and evaluate that information in the context of your building's operational hours and building schedules, or intended system control schedules. Consider changes in load size and shape against time of day, day of week, or season. Unexplainable differences may indicate operating errors or equipment faults, and therefore energy waste, and should be investigated.

Load profiling is largely qualitative; however, quantitative approaches are also reviewed in the Appendix.



Related Methods

Peak Load Analysis is similar to Load Profiling; however, it focuses on maximum demand, rather than the entire range of measured loads. Lighting Efficiency is effectively a system-level normalized version of Load Profiling.



Calculation and Programming

State of Commercialization: Load profiling is offered in a wide variety of commercial software tools, including meter or panel monitoring systems, energy information systems, BAS, and demand-response systems.

Computation: In the absence of packaged software tools, you can use stand-alone data analysis or spreadsheet tools to support load profiling.

Step 1: Gather input data.

Data Resolution

Load profiling requires interval meter data. 1 Hr, 15 Min (●) Monthly (○) Annual (○)

Data Inputs

High accuracy for metered data is not required. Fill gaps before computing.

Metered Data

Export building or system-level gas or electric data from a meter acquisition system.

Step 1	
Time	Metered Load (kW)
12:00	224
12:15	218
12:30	210
12:45	239
.....	.....

Step 2: Plot time on the x-axis and metered load on the y-axis for at least 24 hours of data.

Notes

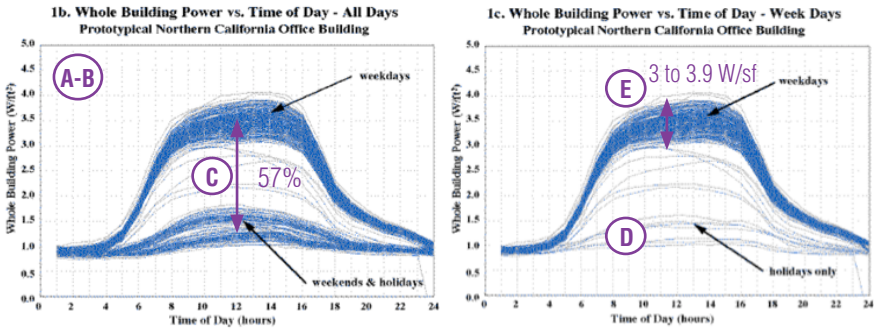
Sketches

Application Examples

Interpretation: Changes in load profiles that are visible to the eye are readily identified as indications of energy waste or reduction. When load profiling reveals increases in energy use, interpreting the cause of the increase may be possible purely based on time of day or other patterns. If this is not the case, submeter data can be used to resolve the source.

Example 1: Multi-Day Whole-Building Overlays

- (A) A year of 24-hr load profiles are overlaid on a single plot.
- (B) In this case, the load has been normalized by building size (sf).
- (C) Holiday/weekend loads are ~57% lower than weekdays, reflecting efficient operations.
- (D) The smallest weekday loads are on holidays, also reflecting efficient operations.
- (E) The overlay thickness shows the range in load across the year, for any time of day. For example, at noon the load varied between about 3 and 3.9 W/sf.



Source: Piette et al, Early results and fields tests of an information monitoring and diagnostic system for commercial buildings. LBNL#42338, 1998.

Example 2: Night Setback and Morning Peaks

(A) The load profile shows that overnight setbacks were relaxed.

(B) AM peaks are far in excess of the midday peak, leading to excessive demand charges.

Load and cost impacts for the week of January 9 were estimated at $3,130 and 870 kW.

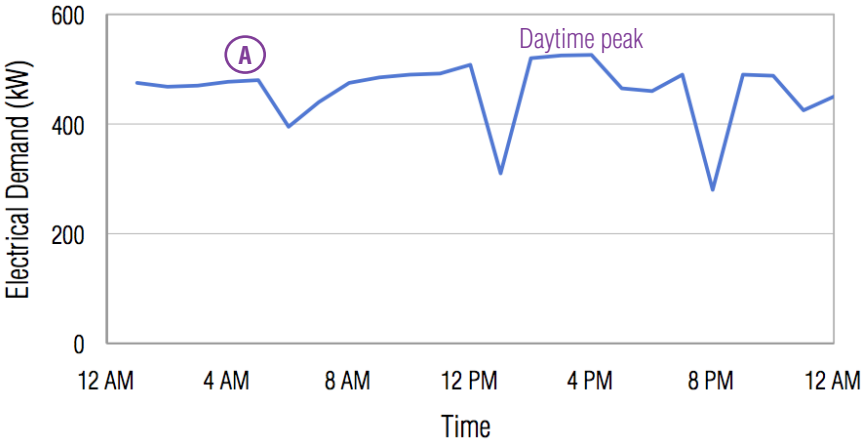
Source: EnerNOC

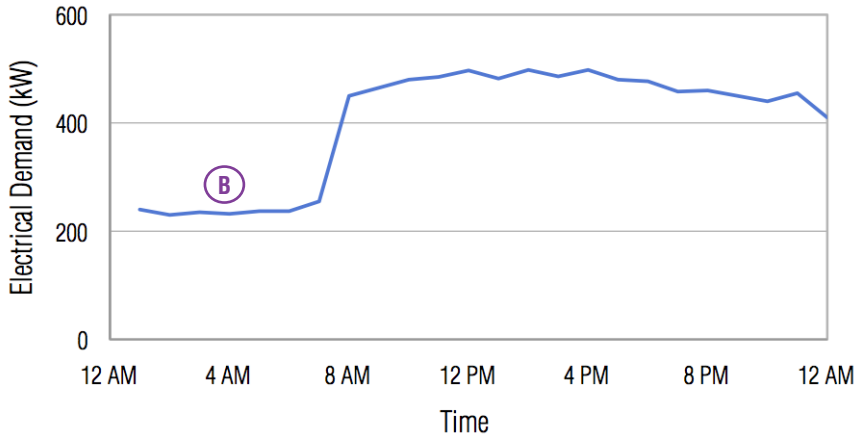
Example 3: Whole-Building Electric Load Profiling, Nighttime Loads

(A) Nighttime load was ~465 kW, nearly equal to the daytime peak of ~520 kW.

(B) Fan speed was reduced 50% from 12-7 AM, lowering the overnight load to 250kW.

Resulting energy savings were 1,840 kWh/day, with associated cost savings of $92/day.





Source: Motegi et al, Case studies of energy information systems and related technology: operational practices, costs, and benefits. International Conference for Enhanced Building Operations, 2003.

Example 4: Load Variability

(A) Load variability is calculated for each hour in a month-long period of analysis.

(B) Each row in the table corresponds to 30 days of data, for the given time interval.

(C) Load variability characterizes how different the loads are from one day to another.
Variability is a number > zero, with higher values indicating higher variability.
For commercial buildings, values >15% are classified as "high" variability.

(D) In this example, total site load variability is 6%, which is considered low.
Therefore, the loads can be predicted well using historic data.

Time	Loads	Average Load	Deviation in Load	Load Variability (A)
12-1 AM (B)	{115,…113}	=avg{115,...113} =113	=avg{(115-113),...(113-113)} =6	=dev/avg (C) =6/113 =5%
1-2 AM	{116,…113}	=avg{116,...113} =116	=avg{(116-116),...(113-116)} =8	=dev/avg =8/113 =7%
...	...	...	...	...
11-12 PM	{117,…118}	=avg{117,...118} =116	=avg{(117-116),...(118-116)} =7	=dev/avg =7/116 =6%
			Site Load Variability	=avg{5, 7,...6} = 6% (D)

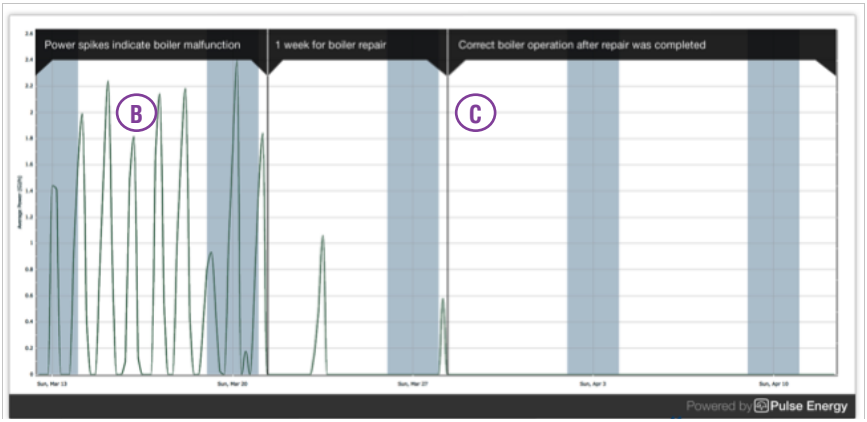
Source: Lawrence Berkeley National Laboratory

Example 5: System-Level Load Profiling, Seasonal Inspection

(A) A heating system boiler load profile is shown for a four-week period in the spring.

(B) Although not required given the season, the boiler cycles on each night.

(C) The boiler was serviced, saving 200 MWh per month in unnecessary gas use.



(A)

Source: Pulse Energy

Purpose

Peak load analysis is used for three key purposes: (1) to identify potential reductions in utility demand charges; (2) to identify potential improvements that are revealed in the relationship between minimum and maximum loads; and (3) to assess the sufficiency of system sizes during extreme weather.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●				

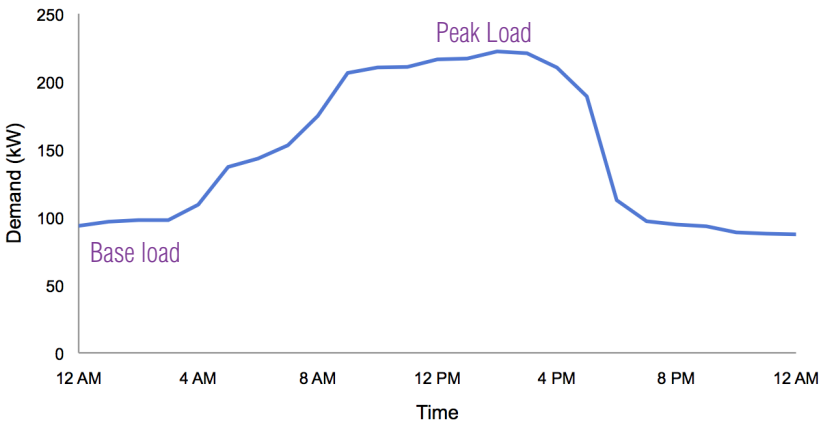
Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
		●		

Energy Manager

Facilities Manager

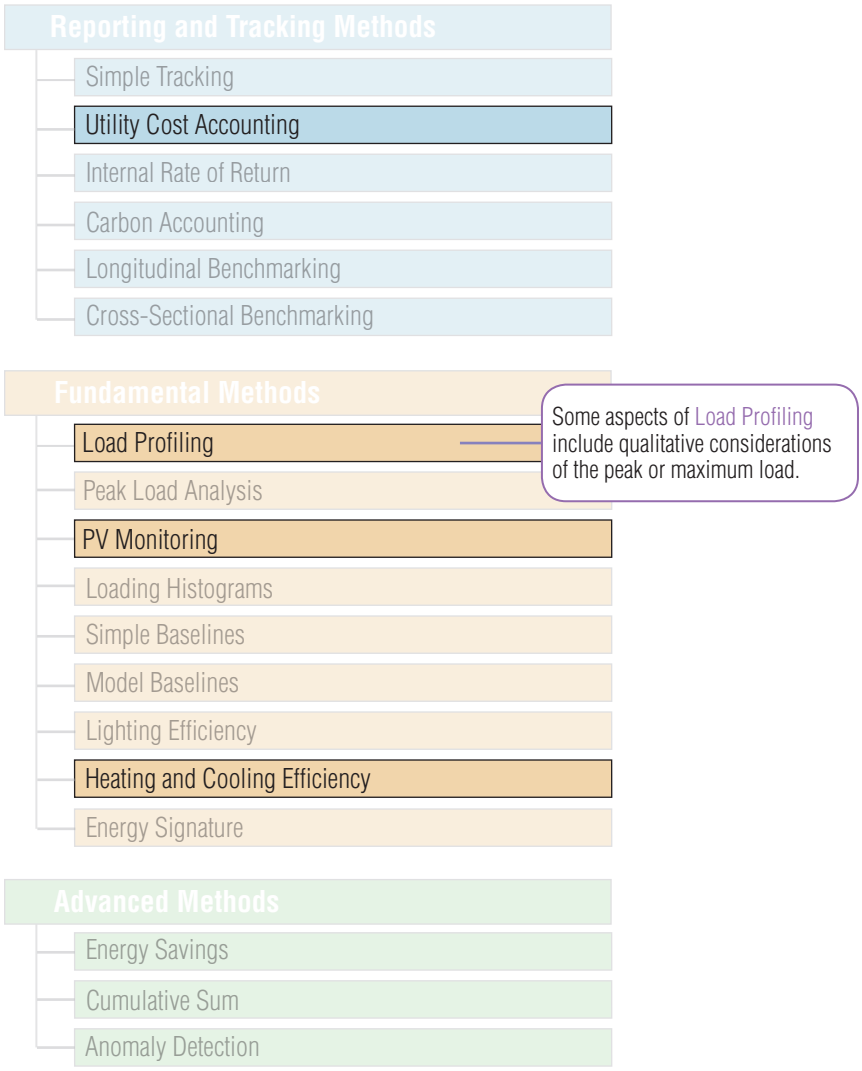
Technical Approach

For most applications, you can plot time series of whole-building interval data with demand on the y-axis and time on the x-axis. Identify the peak load either according to explicit utility definitions or simply as the maximum observed load, depending on the specific investigation. Since peak load is strongly dependent on building size, you can normalize the data by square feet. Then apply quantitative or qualitative analyses.



Related Methods

Utility Cost Accounting includes measures of peak demand charges that are typically based on utility billing data. Peak loads are often addressed in system-specific analysis methods such as PV Monitoring and Heating and Cooling Efficiency.



Calculation and Programming

State of Commercialization: Peak load analysis is accommodated at varying levels of sophistication in a variety of commercial software tools, including meter or panel monitoring systems, energy information systems, BAS, and demand response systems.

Computation: In the absence of packaged software tools, you can use stand-alone data analysis or spreadsheet tools to support load profiling.

Step 1: Gather input data.

Data Resolution

Peak load analysis requires interval electric data at the whole-building or system level.

1 Hr, 15 Min ● Monthly ○ Annual ○

Data Inputs

Peak load analysis may require higher accuracy metering, at higher frequencies than methods that are focused on energy.

Whole-building meters or panel monitoring systems are likely to be more accurate than system-level meters.

Export building or system-level electric interval data from a BAS or meter acquisition system.

Metered Data

Step 2: Compute the peak or maximum load, the base or minimum load, and the base-to-peak load ratio.

Step 1		Step 2		
Time	Load (kW)	Peak Load	Base Load	Base to Peak Ratio
12:00	224	= MAX {224, 218, 210,239,…118} = 239	=MIN {224, 218, 210,239,…118} = 118	= 118/239 =.49
12:15	218			
12:30	210			
12:45	239			
....	....			
11:45	118			

*Here the peak and base are defined as the max and the min. More sophisticated formulations and utility definitions are presented in the Appendix.

Notes

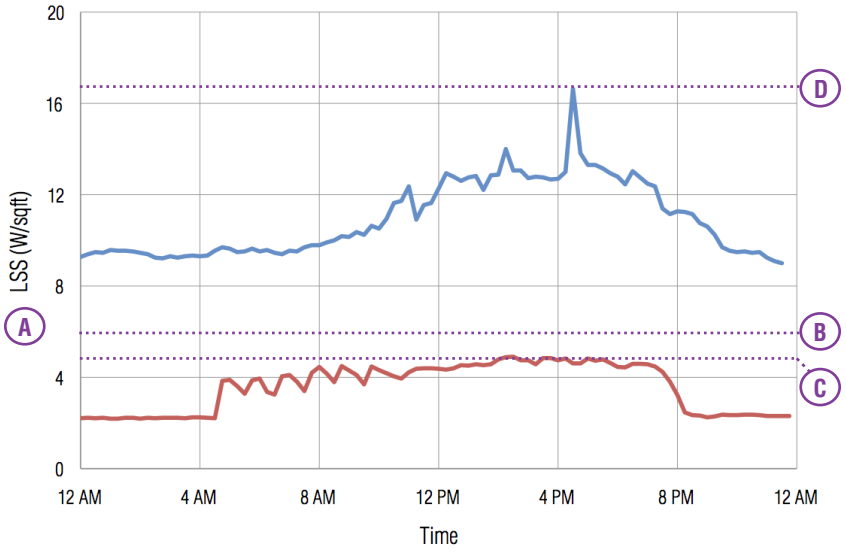
Sketches

Application Examples

Interpretation: National averages for peak loads are 5.4 W/sf for all commercial buildings, 6 W/sf for offices, and 4.3 W/sf for educational buildings. Peak loads should be significantly lower on weekends and holidays, or during unoccupied hours than they are during standard operations. Near static non-fluctuating loads are indicated by a base to peak load ratio close to one.

Example 1: Magnitude of the Peak

- (A) W/sf is plotted for two commercial office buildings over a 24-hr period.
- (B) The national average for commercial buildings is 6 W/sf.
- (C) One building peaks at 5 W/sf; lower than average.
- (D) The other building peaks at over 16 W/sf, indicating opportunity for improvement.



Source: Lawrence Berkeley National Laboratory

Example 2: Multi-Site Base-to-Peak Load Analysis

Base-to-peak load ratio is shown for two retail stores, based on a month of load data.

(A) The ratio for store A was initially .57, but abruptly increased to .76.

(B) The ratio for store B was initially .6, but abruptly increased to .7.

In both cases, the change in ratio was due to an increase in the base load.

The higher base loads were traced to failed implementation of nighttime setbacks.

Source: EnerNOC

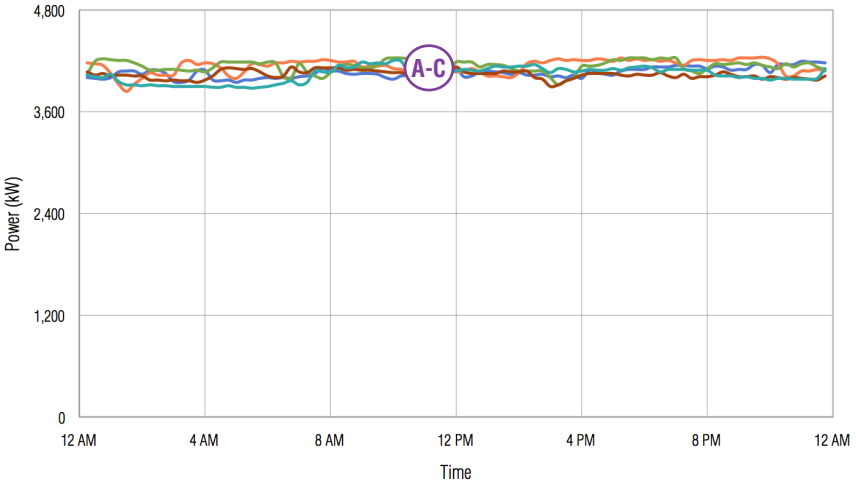
Example 3: Base-to-Peak Load Analysis, Data Center

(A) Five days of site electric use at a data center are plotted.

(B) In contrast to other commercial building types, data center loads are nearly constant.

(C) For this five-day period the average base-to-peak load ratio is .93.

This is in contrast to Example 2, with more common buildings, in the .55-.60 range.



Source: Lawrence Berkeley National Laboratory

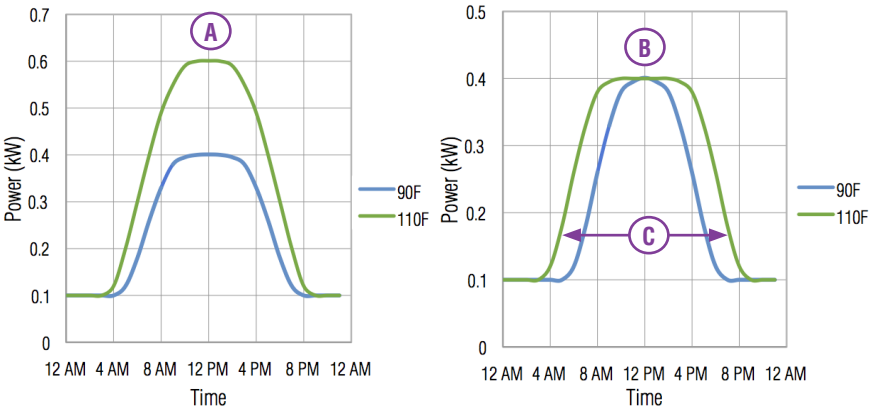
Example 4: Peak Load Duration and Building Sizing

(A) In a well-sized building the 110°F profile is similar to the 90°F profile, with a higher peak.

(B) In an undersized building the peak at 110°F equals that at 90°F and is reached early.

(C) In addition, the peak has a high duration, lasting most of the day.

Indoor temperatures will be above setpoint, reflecting inability to meet cooling loads.



Source: Lawrence Berkeley National Laboratory

Example 5: Load Duration and Peak Demand Charges

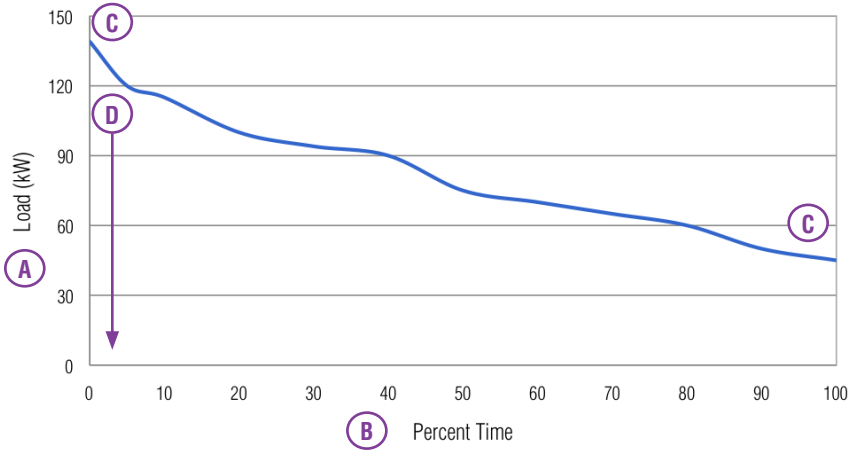
(A) A one year load duration curve is plotted, with load on the y-axis.

(B) The x-axis indicates the percent of time that the load was at or greater than the y-value.

(C) The base load is never less that ~40kW, and the maximum is about 135 kW.

(D) The peak demand is above 120kW only 2-3% of the time throughout the year.

The small portion of time that the demand is near the maximum indicates a potential opportunity to reduce peak demand charges.



Source: Modified from Foster, D, Hough, B, Barbose, G, Golove, W, Goldman, C. Using energy information systems (EIS): a guidebook for the US postal service. October 2004. Lawrence Berkeley National Laboratory, LBNL#54862.

Purpose

Photovoltaic (PV) monitoring is used for three key purposes: (1) determining renewable electrical energy production; (2) accounting for displaced conventional electricity, and "net" electrical energy use; and (3) evaluating the overall condition, or "health" of the PV array.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●				

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
		●	●	●

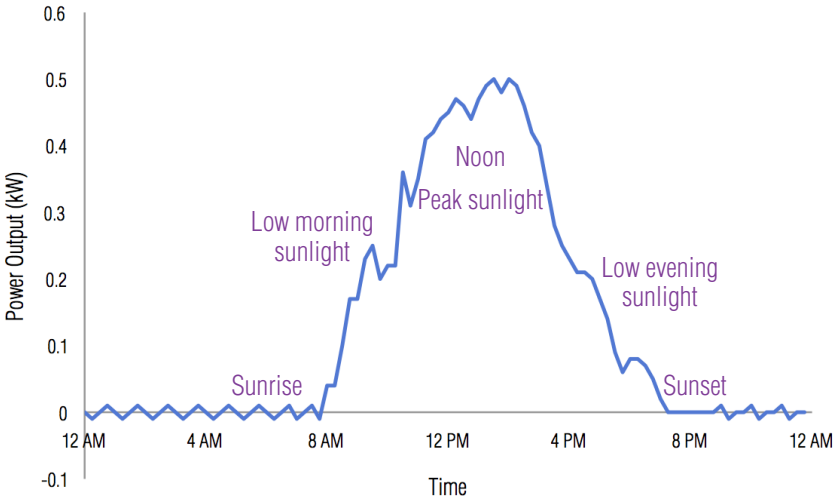
Energy Manager

Facilities Manager

Financial Manager

Technical Approach

Aggregate time series of array power production (AC kW) into monthly or annual energy production totals. Use these totals for renewable accounting, and in cases where there is no utility-provided net meter, you can subtract them from billing totals to determine net site energy use. You can then subtract power production time series from utility interval meter data, to generate a time series of net electricity use, or "virtual" net meter data. To evaluate the overall health of the array, overlay trends of power production with solar irradiance data, and compare array output to solar availability.



Related Methods

Utility Cost Accounting and Internal Rate of Return are related to PV Monitoring in cases when a PV array has been financed.

Reporting and Tracking Methods

- Simple Tracking
- Utility Cost Accounting
- Internal Rate of Return
- Carbon Accounting
- Longitudinal Benchmarking
- Cross-Sectional Benchmarking

Fundamental Methods

- Load Profiling
- Peak Load Analysis
- PV Monitoring
- Loading Histograms
- Simple Baselines
- Model Baselines
- Lighting Efficiency
- Heating and Cooling Efficiency
- Energy Signature

PV Monitoring is related to Load Profiling, but entails tracking energy production, rather than consumption.

Advanced Methods

- Energy Savings
- Cumulative Sum
- Anomaly Detection

Calculation and Programming

State of Commercialization: PV monitoring is offered in dedicated system-specific tools, much in the same way that HVAC systems can be monitored with BAS. PV energy and power data may also be integrated into BAS, and dedicated energy information systems can also offer PV monitoring, analysis, and reporting.

Computation: You can use stand-alone data analysis or spreadsheet tools to perform PV monitoring.

Step 1: Gather input data.

Data Resolution

An averaging interval of 5 to 15 minutes is recommended.

1 Hr, 15 Min	Monthly	Annual
●	●	○

Data Inputs

Export solar irrandiance and metered AC array output from acquisition system, or DC/AC inverter or inverter control unit.

Metered Data

High accuracy is not required, although inverter measurements should be verified. Fill data gaps before computing.

Weather Data

Inverter measurements may be up to 8% inaccurate, and should be verified. Calibrate irradiance data (W/m^2) to ± 5%.

Step 2: Aggregate AC total solar energy output produced vs. site energy use.

Step 1					Step 2
Day	Irradiance (W/m2)	DC Max (Peak) Output (kW)	AC PV Energy Produced (kWh/day)	AC Site Use from Utility Meter (kWh/day)	**Net Site Energy Production (kWh/day)**
1	1,000	16	50	15	**= (50-15) = +35**
2	1,050	15	47	18	**= (47-18) = +29**
3	300	6	15	20	**= (15-20) = -5**
....	.....	.....	.....	.....	**....**
Month Total			= 50 + 47 + 15 +.... = 1050	= 15 + 18 + 20 +.... = 825	**= 1050-825=+225 kWh Month surplus (or deficit, if -)**

Step 3: Plot kWh on the y-axis vs. time on the x-axis for further inspection and analysis (see application examples).

Notes

Sketches

Application Examples

Interpretation: Basic PV array monitoring provides kW power production (y-axis) compared to time (x-axis). Normally, the plot will have the shape of an inverted "V" with a peak power production at solar-noon when the sun is at its zenith, with possible, occasional drops in kW production caused by passing clouds.

Example 1: Daily PV Energy Production

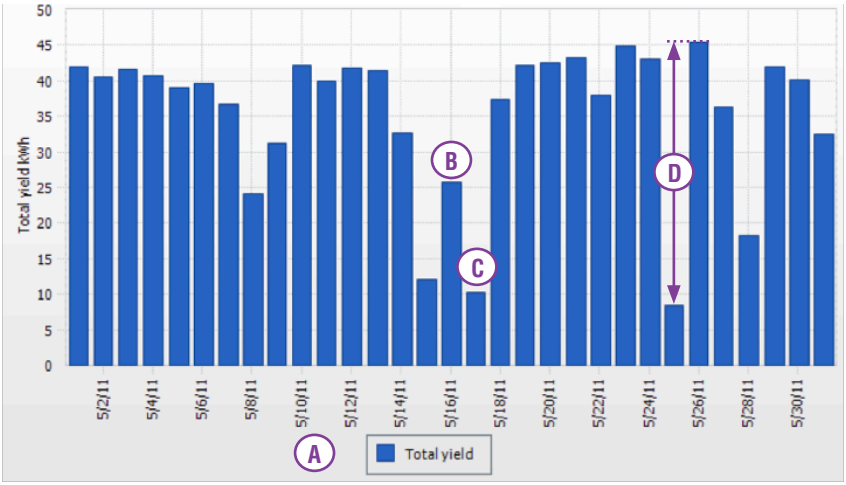
(A) Daily energy yield from a PV system is tracked for a month.

Weather conditions such as cloud cover cause variability in daily production totals.

(B) Partly cloudy conditions result in lower output.

(C) Overcast conditions result in even lower output.

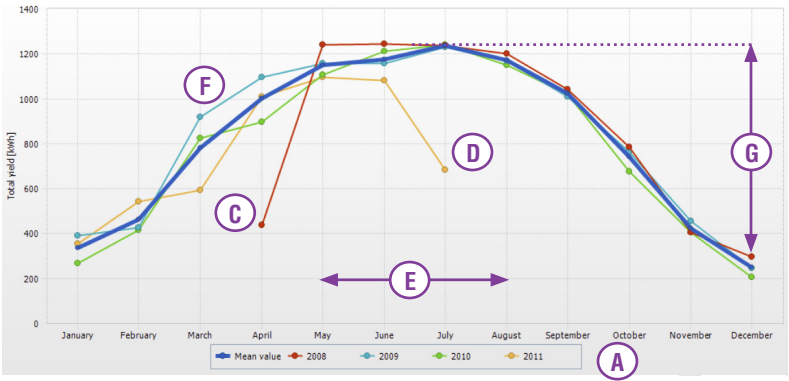
(D) In this month, the lowest daily output is 20% of the highest.



Source: Anonymous user, SMA Solar Technology AG.

Example 2: Multi-Year Monthly Energy Tracking

- (A) PV energy production is plotted and tabulated monthly for four years.
- (B) The calculated four-year average is plotted in dark blue and included in the table.
- (C) The array was commissioned and offline in April 2008 resulting in lower production.
- (D) Month-to-date reporting is reflected in the total for July 2011.
- (E) Half of annual production occurs from May to August, when solar availability peaks.
- (F) Production is consistent over the years with the greatest variability in spring.
- (G) December is one-fourth of the July peak.



Total yield [kWh]

	January	February	March	(C) April	May	June	July	August	...	Total
2008				438.19	1240.95	1246.01	1237.14	1200.22		7893.34
(A) 2009	390.05	426.04	920.35	1095.21	1156.17	1158.19	1231.17	1167.23		10017.81
2010	267.47	417.48	825.05	895.77	1105.72	1210.50	1242.08	1151.05		9423.48
2011	354.18	542.36	593.47	1010.92	1095.65	1082.71	682.31	(D)		5361.60
										32696.23
(B) Mean value	337.23	461.96	779.62	1000.63	1149.62	1174.35	1236.80	1172.83		9750.59
Year portion	3.46%	4.74%	8.00%	10.26%	11.79%	12.04%	12.68%	12.03%	...	100.00%

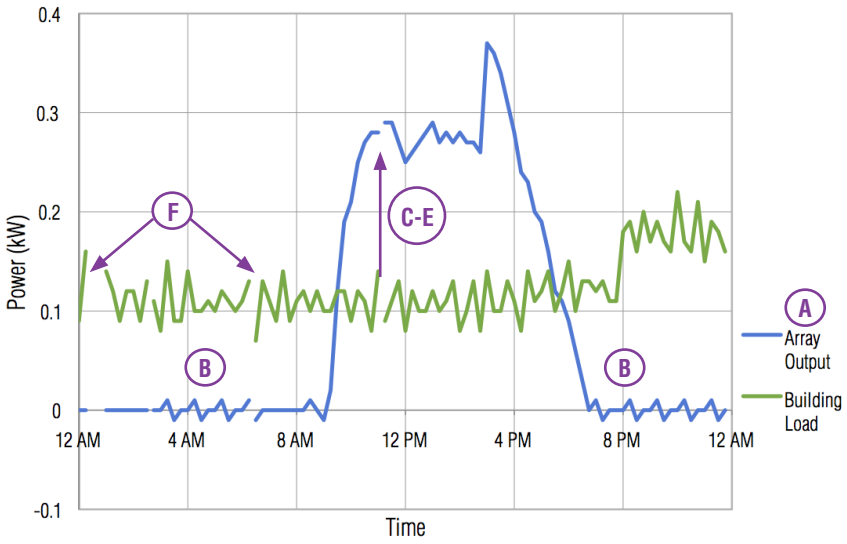
Commissioning: 4/20/2008

(E)

Source: Anonymous user, SMA Solar Technology AG.

Example 3: Net Electric Monitoring

- (A) Building load and PV array output are plotted for a 24-hour period.
- (B) At night, PV production is zero, and all building power is purchased from the utility.
- (C) Daytime load is entirely met by PV output, and utility costs are avoided.
- (D) "Net" power is PV output less the building load.
- (E) The utility credits the owner for generation that exceeds site use (i.e., "net" power).
- (F) Short gaps in data may be common depending on the data acquisition system.

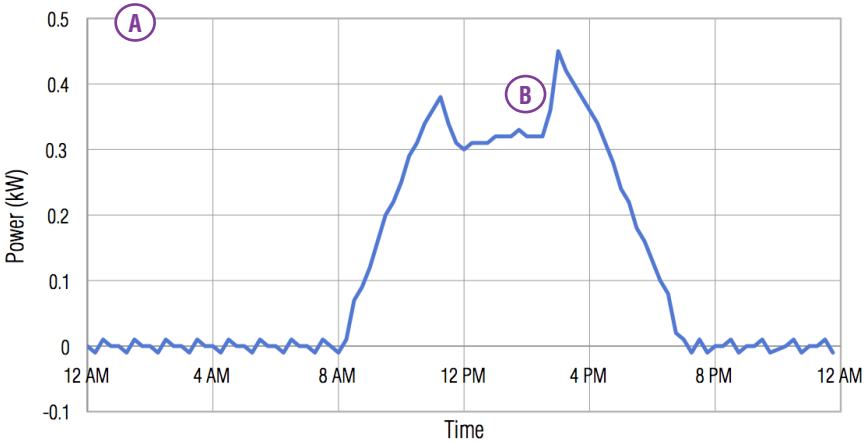


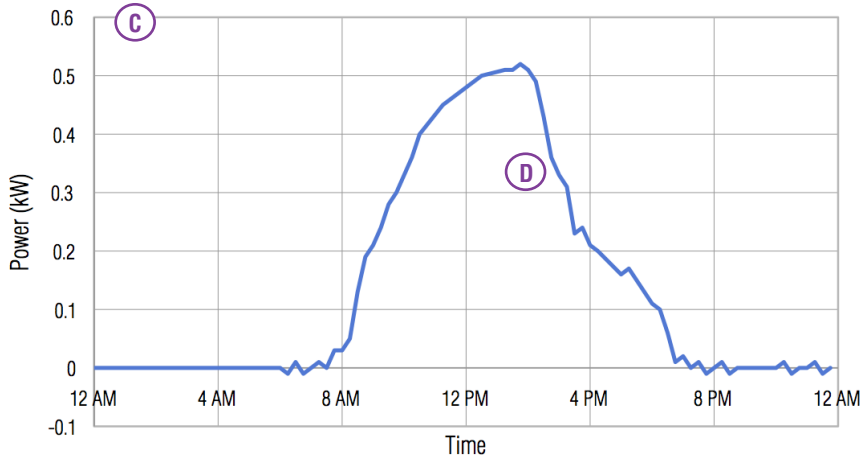
Source: Lawrence Berkeley National Laboratory

Example 4: Seasonal and Site Influence on Array Production

- (A) A 24-hour production profile is shown for a summer day.
- (B) Production peaks after noon, as expected.
- (C) A 24-hour production profile from the same array is shown for a winter day.
- (D) Array production drops after noon.

  This winter profile with afternoon drop off reflects a low sun angle and obstruction from trees.





Source: Lawrence Berkeley National Laboratory

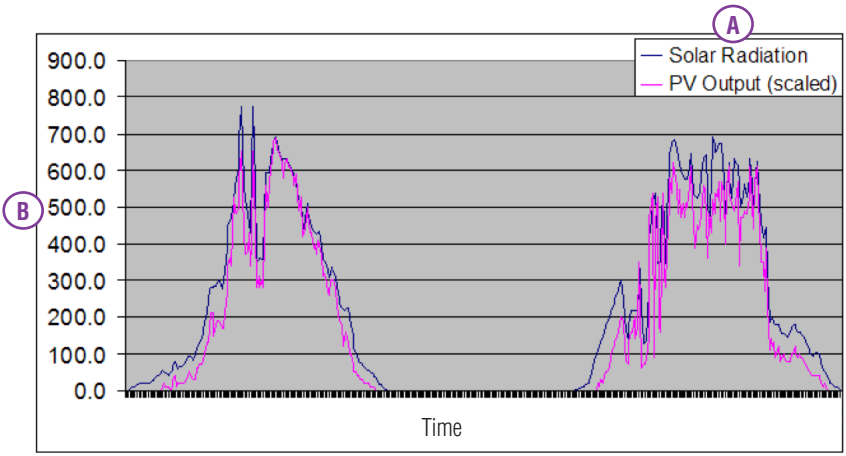
Example 5: PV Condition Monitoring

(A) Solar radiation and PV output power are plotted against time for two days.

(B) PV output is scaled to match the magnitude of the solar radiation.

As expected, the PV output tracks the solar availability.

A strong divergence between the two would reveal degradation (e.g., due to fouling).



Source: Glass, Analysis of building-integrated renewable energy systems in modern UK homes. University of Manchester, 2010.

Purpose

Loading histograms are used to evaluate whether HVAC equipment is properly sized and staged, given the operated condition of the building. They are useful in identifying potential retrofit solutions and optimizing control of multi-unit staging.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
	●	●		

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
				●

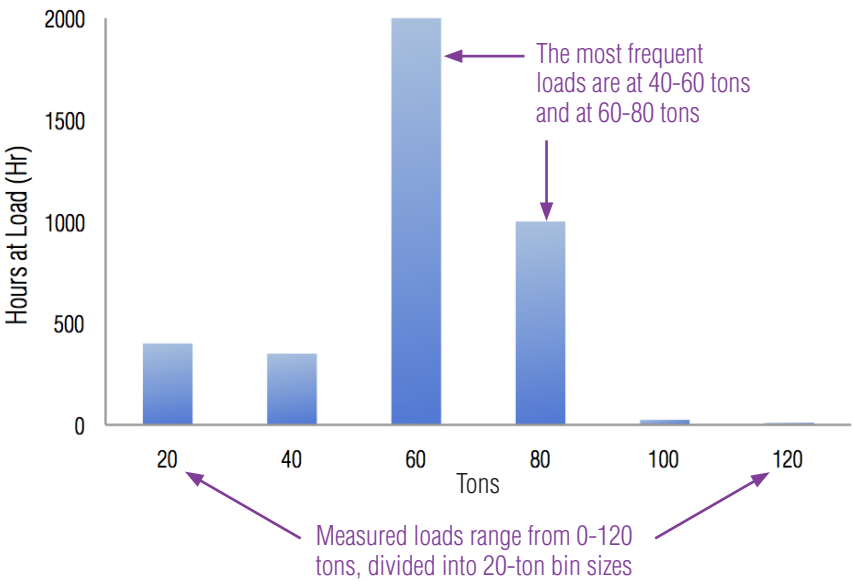
Energy Manager

Facilities Manager

Financial Manager

Technical Approach

Group system load measurements into "bins," or ranges, and count the number of hours at which the system operated within each range. Construct a bar chart with load plotted on the x-axis and the number of hours at each load plotted on the y-axis. Then compare the distribution of operational hours at each load to the manufacturer load ratings and equipment staging sequences.



Related Methods

Loading Histograms are analogous to Cross-Sectional Benchmarking, where "standard" performance is represented by the load distribution rather than an energy metric, and where the comparison is to the equipment rating rather than to a cohort of similar buildings.

Reporting and Tracking Methods

- Simple Tracking
- Utility Cost Accounting
- Internal Rate of Return
- Carbon Accounting
- Longitudinal Benchmarking
- Cross-Sectional Benchmarking

Fundamental Methods

- Load Profiling
- Peak Load Analysis
- PV Monitoring
- Loading Histograms
- Simple Baselines
- Model Baselines
- Lighting Efficiency
- Heating and Cooling Efficiency
- Energy Signature

Similar to HVAC Loading Histograms, PV Monitoring considers system sizing and measured output relative to manufacturer ratings.

Heating and Cooling Efficiency analysis moves beyond equipment sizing into operational performance that is a function of load, energy consumption, and heating or cooling output.

Advanced Methods

- Energy Savings
- Cumulative Sum
- Anomaly Detection

Calculation and Programming

State of Commercialization: Loading histograms are not within the scope of a utility bill tracking tool, yet may be offered preprogrammed in EIS. Building automation systems may track the required load data, but are not easily configured to compute and plot histograms.

Computation: You can use stand-alone data or spreadsheet analysis tools to generate loading histograms.

Step 1: Gather input data.

Data Resolution

Loading histograms require interval system-level load data, e.g., steam; hot and chilled water.

1 Hr, 15 Min (●) Monthly (○) Annual (○)

Data Inputs

BTU meters typically offer better accuracy than individual measures of flow and temperature, or pressure. Provided that sensors are calibrated, either approach is likely viable; however, make sure that metered loads are within capacity.

Metered Data

Export loading trend data from a BAS or on-site data acquisition system.

Step 2: Calculate values for the loading histogram.

The minimum and maximum metered loads form the "range." Subdivide the range into bins. Count the number of metered loads that fall into each bin. Convert the load count into Hours at Load based on the interval of measurement.

To determine hours at load, multiply the count by the measurement interval, and convert to hours. Here the conversion factor is 15/60, because the data is at 15-minute intervals.

Step 1		Step 2			
Time	Metered Load (Tons)	**Range**	**Bins**	**Load Count**	**Hours at Load**
12:00	24	**{17,42}**	**15-20 tons**	**1**	**= 1*(15 min)*(1hr/60 min) = .25 hour**
12:15	39		**20-25 tons**	**2**	**= 2*(15 min)*(1hr/60 min) = .5 hour**
12:30	20		**25-30 tons**	**0**	**= 0*(15 min)*(1hr/60 min) = 0 hour**
12:45	37		**30-35 tons**	**0**	**= 0*(15 min)*(1hr/60 min) = 0 hour**
1:00	17		**35-40 tons**	**2**	**= 2*(15 min)*(1hr/60 min) = .5 hour**

Step 3: Plot bins on the x-axis and load-hours on the y-axis.

Notes

Sketches

Application Examples

Interpretation: Equipment is sized according to *expected* building loads at the time of design, and a margin of safety. If the histogram shows frequent operation at loads much smaller than the rating, downsizing may be appropriate. For example, a chiller's efficiency sweet spot is typically at 70%- 80% of full load. Boilers, on the other hand, often cycle at loads below 20%, introducing energy waste and part wear. If multiple parallel units are present, the histogram can be also used to confirm staging sequences.

Example 1: Chiller Retrofit Analysis

A loading histogram is shown for one year for a 220-ton chiller installation.

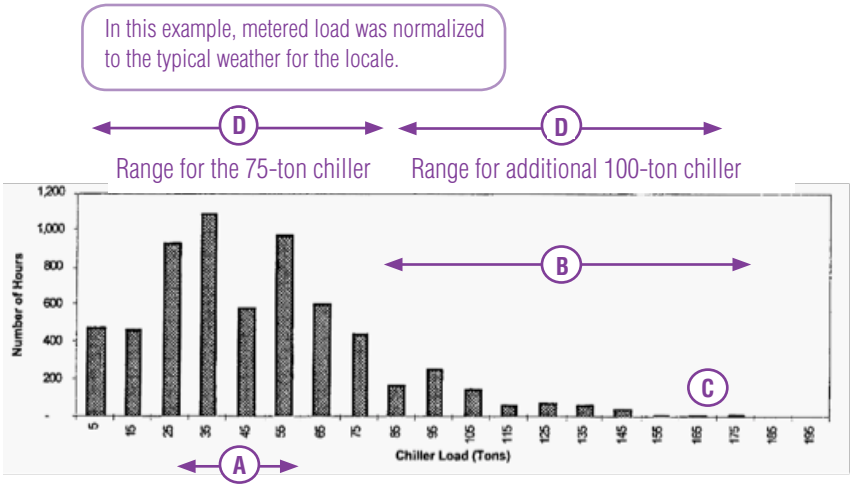
(A) Although 220 tons were available, only 35- 55 tons are required most of the year.

(B) Only 13% of load hours are at 75 tons or greater.

(C) The highest observed loads (hourly steady state averages) were around 165 tons.

(D) The ideal design would have been a 75/100-ton combination.

A 100-ton unit could save $3,411/yr, but was cost prohibitive at $25K.



Source: Piette et al, Model-based chiller energy tracking for performance assurance at a university building. LBNL#40781, 1997.

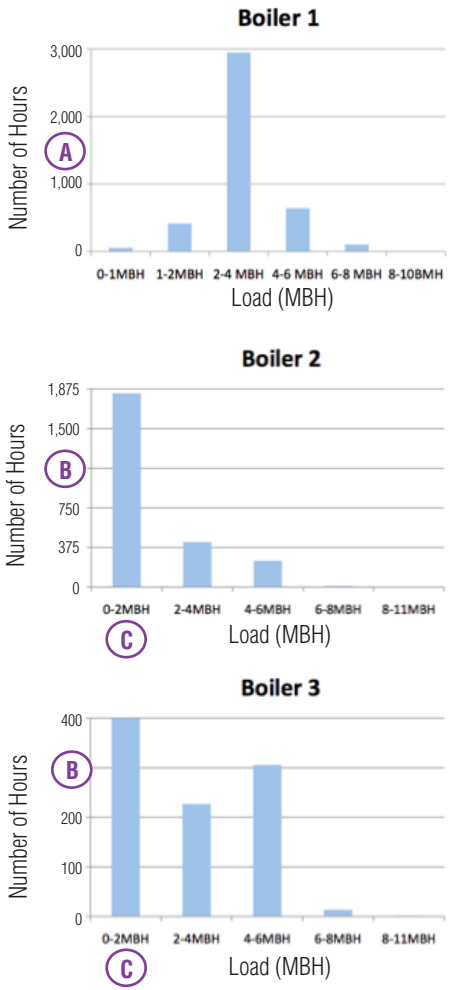
Example 2: Analysis of Sequenced Boilers

Loading histograms are shown for the three staged boilers at a central heating plant. The histograms can be used to verify the intended operational sequences.

(A) The plot confirms that Boiler 1 operates as the primary, with 4,100 hrs of run time. Boilers 2 and 3 are used in winter, when the capacity of Boiler 1 is insufficient.

(B) As expected, the plots indicate that Boilers 2 and 3 run less, for a combined 3,200 hrs.

(C) Boilers 2 and 3 operate at low load frequently, which may reveal potential savings.



Source: Lawrence Berkeley National Laboratory

Example 3: Loading Histogram and Efficiency Before and After

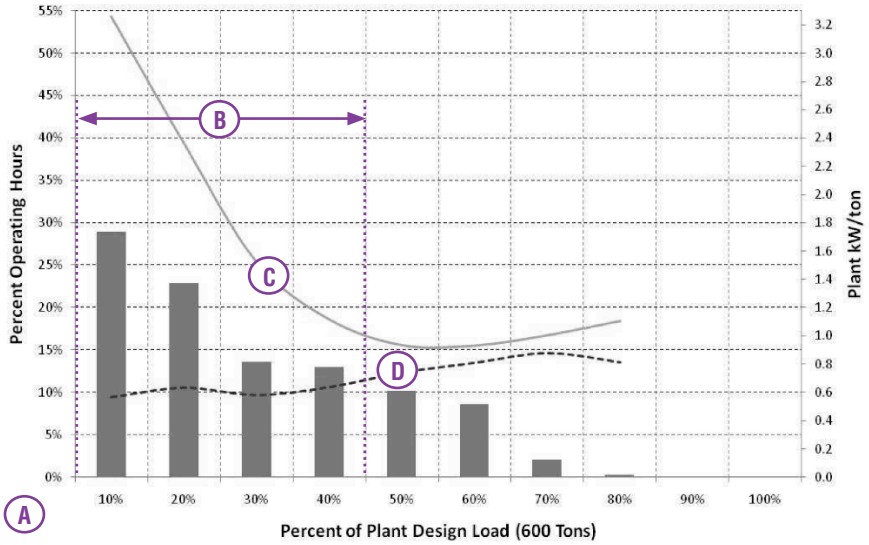
(A) A loading histogram is shown for two constant speed 300-ton chillers.

(B) 50% of the operating hours are at 20% load or less, and 75% are at 40% load or less.

(C) At these low loads, the average plant efficiency was poor, at 1.43 kW/ton (solid curve). The chillers were retrofit with two 150-ton compressors, with high part-load efficiency. Variable frequency drives and controls optimization software were also installed.

(D) The retrofit increased the average plant efficiency to .69 kW/ton (dashed curve). Annual energy, demand, and cost savings were 637 MWh, 37 kW, and $136,000. With utility incentives, the project paid back in less than three years.

Refer to Heating and Cooling Efficiency for further details on loading and efficiency metrics.



Source: Santamaria, C. Next generation energy efficient technologies: a case study demonstrating top operational performance. Journal of Green Building, 2009.

Purpose

Simple baselines are used to generate performance metrics for benchmarking and energy-savings estimates. They are used to characterize energy performance according to key variables, therefore providing the marker from which better or worse performance can be assessed.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
▬			●	●

It is difficult to characterize cooling systems with simple baselines.

Energy Manager

Facilities Manager

Technical Approach

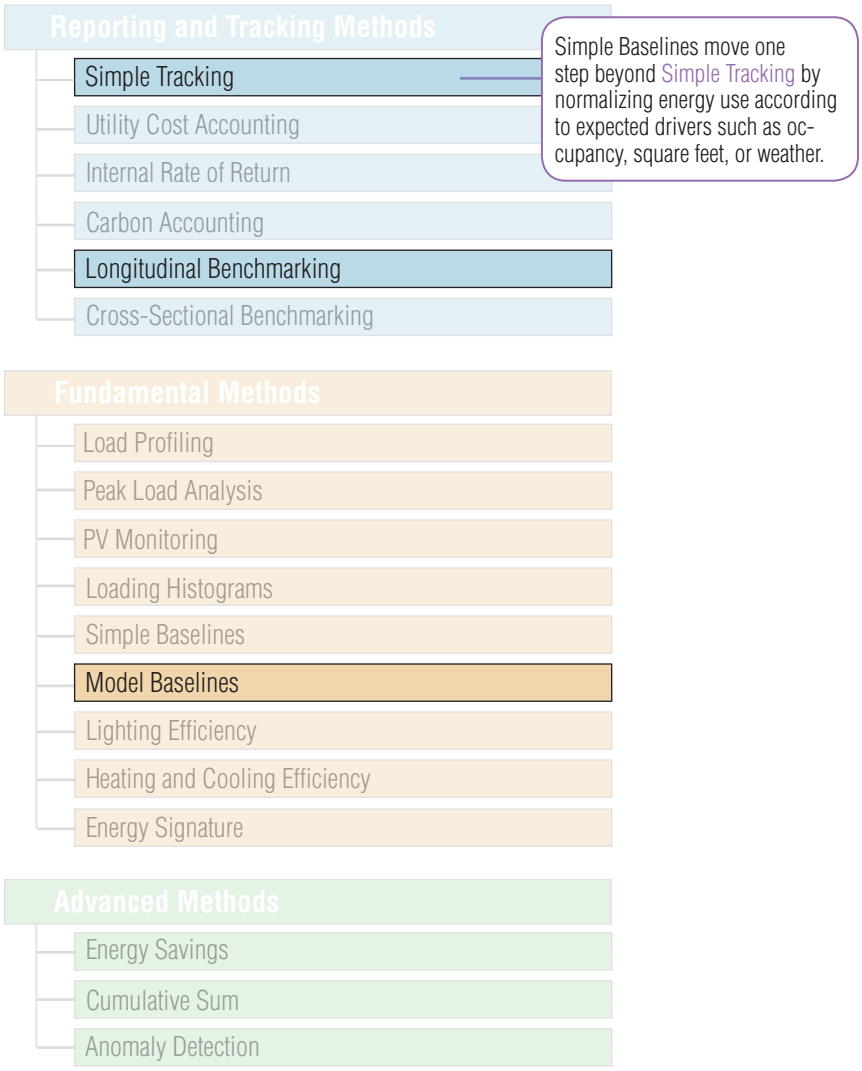
Total energy use for a base period (often a year), and normalize the data according to factors that are known to affect energy consumption. Floor area is frequently used in simple models of whole-building energy, plug loads, and lighting systems; whereas, heating degree days are commonly used for heating systems. Hours of operation or number of occupants are also useful modeling or normalization factors. Simple baselines are much less robust than model-based baselines.

Energy Load	Common Normalization Factors	Resulting Baseline Form
Whole-building electrical energy	Floor area served	kWh/sf-yr
Whole-building gas, or heating system energy	Heating degree days	kBtu/HDD-yr
Plug load electric use	Number of occupants	kWh/occ-yr
Lighting electric use	Floor area served, operating hours, number of occupants	kWh/sf, hrs-yr

Common formulations and metrics for simple baselines –the most appropriate model depends on the particular investigation and data availability.

Related Methods

Simple Baselines are often used in Longitudinal Benchmarking. Model Baselines are a more sophisticated approach than Simple Baselines.



Calculation and Programming

State of Commercialization: The ability to create and track simple baselines may be offered in commercial software packages such as EIS, and utility tracking tools. Building automation systems may also be used, provided that they support the creation of virtual trend points and common arithmetic functions.

Computation: In the absence of packaged software tools, you can use stand-alone data analysis or spreadsheet tools to develop simple baselines.

Step 1: Gather input data.

Data Resolution

Resolution depends on application.

1 Hr, 15 Min ◉ Monthly ◉ Annual ◉

Data Inputs

Simple baselines can be constructed from a variety of data, depending on the application or desired analysis.

Metered Data

High accuracy in meter and sensor data is not required for simple baselines.

Weather Data

Export available weather and energy data and site characteristics from a meter acquisition system, BAS, or weather service.

Site Data

Step 2: Calculate simple baseline.

Aggregate data into totals required for calculation of the simple baseline.

Step 1			Step 2
Week	Metered Energy Use (kWh)	Hours of Operation	**Baseline Energy (kWh/hrs-op)**
1	3,000	60	**= (3,000 + 2,580 + 3,225…+2,780)/ (60 + 48 + 60+…+50) = 51 kWh/hrs-op**
2	2,580	48	
3	3,225	60	
....	.....		
8	2,780	50	

Notes

Sketches

Application Examples

Interpretation: Simple baselines are typically not analyzed directly, but rather are used to quantify performance for comparative benchmarking and continuous tracking. In such applications, meaningful interpretations require sensible baselines, associated normalization factors, and metrics. For example, it is not possible to model and quantify lighting energy use according to weather variables.

Example 1: Whole-Building Site Energy, Base Year

(A) In the base year, Year 1, total site energy use was 8,900 kWh.

(B) Modest improvements were made in Year 2, and energy was tracked through Year 4.

(C) Energy use was normalized to the base year use by dividing by 8,900.

(D) Numbers greater than one indicate energy use greater than the base year.

(E) Numbers less than one indicate energy use lower than the base year.

Year	Total Site Energy Use	Normalized Energy Use (C)
1	8,900 (A)	= 8,900/8,900 = 1
2	8,750	= 8,500/8,900 = .96 (E)
3	9,100	= 9,250/8,900 = 1.04 (D)
4 (B)	8,600	= 8,500/8,900 = .91 (E)

Source: Lawrence Berkeley National Laboratory

Example 2: Total Portfolio Energy, Square Footage

(A) The total site energy use of a portfolio is shown over a four-year period.

(B) The size of the portfolio increases over the same four-year period.

(C) Energy use was normalized by the size of the portfolio in square feet.

The simple baseline accounts for changes in size, better revealing energy use changes.

In this example, performance is quite stable ranging from 88-90 kBtu/sf.

Multiplying by 1,000 converts MBtu to KBtu.

Year	Portfolio Size (sf) (B)	Portfolio Energy Use (MBtu) (A)	Normalized Energy Use (kBtu/sf) (C)
1	800,000	71,200	=1,000* 71,200/800,000 = 89
2	950,000	83,600	= 1,000* 83,600/950,000 = 88
3	1,250,000	111,250	= 1,000*111,250/1,250,000 = 89
4	2,000,000	180,000	= 1,000*180,000/2,000,000 = 90

Source: Lawrence Berkeley National Laboratory

Example 3: Site Heating Energy, Heating Degree Days (HDD)

(A) Site heating energy and degree days are collected for a four-month period.

(B) The average ratio of heating energy to degree days is selected for the simple baseline. This simple baseline begins to capture the influence of weather on heating energy use.

(C) In this example, .77MBtu is expected for each degree day in the month.

Heating degree days are defined in the glossary and further detailed in the Appendix.

(A)

Month	Site Heating Energy (MBtu)	HDD, Base 65	Normalized Energy Use (B) (MBtu/HDD)
November	315	396	= (sum energy) / (sum HDD) = (315+370+440+380)/ (396+475+613+466) = .77 (C)
December	370	475	
January	440	613	
February	380	466	

Source: Lawrence Berkeley National Laboratory

Example 4: Site Plug Load Energy Use, Number of Occupants

(A) Total site plug load energy use is shown over a four-year period.

(B) The number of occupants increases over the four-year tracking period.

(C) Energy use was normalized by the number of occupants in the building.

The simple baseline accounts for differences in occupancy, better revealing energy use changes.

Year	No. Occupants (B)	Site Plug Load Energy (MWh) (A)	Normalized Energy Use (kWh/person) (C)
2007	250	.85	= 1,000*.85/250 = 3.4
2008	280	.9	= 1,000*.85/280 = 3.2
2009	325	1.1	= 1,000*1.1/325 = 3.4
2010	380	1.2	= 1,000*1.2/380 = 3.2

Source: Lawrence Berkeley National Laboratory

Example 5: Lighting Loads per Square Foot or Hours of Operation

(A) Total site lighting energy use is shown over a five-month period.

(B) The number of business days fluctuates through the holiday season.

(C) Energy use was normalized by the number of business days in each month.

The simple baseline accounts for scheduling differences, better revealing energy use changes.

Month	Business Days (B)	Site Lighting Energy (kWh) (A)	Normalized Energy (kWh/bus.day) (C)
October	23	230	= 230/23 = 10
November	20	215	= 215/20 = 10.8
December	16	140	= 140/16 = 8.8
January	18	160	= 160/18 = 8.9
February	22	225	= 225/22 = 10.2

Source: Lawrence Berkeley National Laboratory

Purpose

Model baselines, as defined in this handbook, provide a mathematical characterization of energy use based on measured historic data, such as weather conditions and metered energy use. They are typically not used independently, but as the fundamental underlying component of advanced analyses such as Anomaly Detection, Cumulative Sums, and quantification of Energy Savings.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●
Interpretation		**Frequency of Use**		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
		●	●	

Technical Approach

Most commonly, model-based baselines use linear regression. Formulate an equation to define a "dependent variable," i.e., a load at a given time, based on the value of "independent" variables. Independent variables are those that drive energy use, for example day of week, time of day, outside air temperature (OAT), relative humidity, or solar availability. The number and type of independent variables that are required to accurately represent the load depends on the particular system and load being modeled and the baseline time interval, e.g., daily vs. 15-minute loads.

Other techniques such as neural networks, bin models, and weighted averaging are discussed in the Appendix.

Load	Common Independent Variables
Whole-building electric	OAT, time of week, operating hours, principle building activity (PBA)
Whole-building gas/heating system	OAT, time of week, operating hours, PBA
Heating/cooling system	OAT, time of week, operating hours, PBA, relative humidity, wet bulb
Plug loads	Time of week, number of occupants, area served, equipment type
Lighting system	Time of week, building schedule, area served, operating hours, solar availability
PV system	Time of day, OAT, wind speed, solar availability, relative humidity

Time of week can be expressed as the number of minutes or hours since midnight on Monday, for example.

Related Methods

Each of the Advanced Methods use Model Baselines, as described in the introduction to that chapter. Simple Baselines are a less rigorous form of baselining that is used in conjunction with simpler analyses.

Reporting and Tracking Methods

- Simple Tracking
- Utility Cost Accounting
- Internal Rate of Return
- Carbon Accounting
- Longitudinal Benchmarking
- Cross-Sectional Benchmarking

Fundamental Methods

- Load Profiling
- Peak Load Analysis
- PV Monitoring
- Loading Histograms
- Simple Baselines
- Model Baselines
- Lighting Efficiency
- Heating and Cooling Efficiency
- Energy Signature

Advanced Methods

- Energy Savings
- Cumulative Sum
- Anomaly Detection

Energy Signatures are often used to develop modeled baselines, but do not fully distinguish temperature-dependent load from time-dependent load. Temperature and load both tend to be highest in the afternoon for most buildings, so temperature and load are correlated, but not all of this correlation is due to a causal relationship between temperature and load.

Calculation and Programming

State of Commercialization: Automatic calculation of modeled baselines may be offered in EIS or specialized energy analysis software tools such as those used by energy service providers. Rigor varies widely. "Fitness" (how well the model characterizes actual performance) is a key consideration.

Computation: You can use programmable spreadsheets of data analysis tools to perform this analysis, but a higher level of technical expertise is necessary to generate and leverage them in further analyses. Regression baseline modeling is detailed below using the simplest case: modeling daily peak load during the cooling season, based on maximum daily temperature and day of week.

Step 1: Gather input data.

Data Resolution

At least 6 weeks of Interval data is required. 1 Hr, 15 Min (●) Monthly (○) Annual (○)

Data Inputs

High accuracy is not required, although metered use should reflect actual consumption. Fill in data gaps. **Metered Data**

Export weather and energy data from a meter acquisition system, BAS, or weather service. **Weather Data**

Step 2: Organize measured data.

Tabulate the daily peak load and maximum temperature.

Step 1		Step 2	
Date	Day	Peak Load (kW)	Maximum Temperature (°F)
06/13/2011	Mon	537	71
06/14/2011	Tues	529	73
06/15/2011	Wed	492	70
06/16/2011	Thu	509	68
.....	.....	.....	.....
06/20/2011	Mon	456	59

Step 3: Generate a regression matrix.

The variable being modeled (peak load) goes into one column. "Indicator variables" that influence the value of the modeled variable go into the remaining columns. The final column contains either 0, or the temperature minus 60 °F, whichever is greater.

From Step 2, the peak of 537 kW fell on a Monday, so the Monday column receives a value of 1, and all other day columns receive a zero. The max OAT that day was 71°, so the final column receives a value of (71°-60°) = 11°. The default 60 degree offset can be changed depending on building behavior.

Step 3								
Peak Load	Mon	Tue	Wed	Thurs	Fri	Sat	Sun	Max of (0, T-60 °F)
537	1	0	0	0	0	0	0	11
529	0	1	0	0	0	0	0	13
492	0	0	1	0	0	0	0	10
509	0	0	1	0	0	0	0	8
.....	.....	.....	.....	.....	.....	.....	.....	.....
456	1	0	0	0	0	0	0	0

Step 4: Fit the model.

The baseline model will have the following form:
Peak Load = (Day of Week Effect) + Constant * (T-60 °F)

Use a linear regression solver to find 8 numbers that represent 7 Day of Week Effects and 1 temperature constant. These 8 numbers are called "regression coefficients," and determine the baseline model.

For example, in Microsoft Excel, select Peak Load as the "y variable" (or "dependent variable") and the other columns as "x variables'"or "independent variables." Do the regression without an intercept term; select the "constant is zero" option in the same menu where you define the x and y variables.

For instance, if the "Monday peak load" coefficient is 448 and the "Temperature" coefficient is 9, then the baseline modeled-peak load on a Monday when the temperature reaches 80 degrees is: Peak Load = 448 + 9*(80 °F – 60 °F) = 628 kW.

Notes

Sketches

Application Examples

Interpretation: Baseline-modeled loads will not perfectly characterize the actual load; the difference between modeled and actual loads represent the "fitness" of the model and how similar future operations and building activities match those from which the model was developed. There is no simple rule for determining whether the model fit is "good enough." Plot the model predictions and the actual data versus time (as in the examples below) and judge whether the model is good enough to meet your needs.

Example 1: Baseline Accuracy, Model "Fitness"

(A) The daily peak electric load was modeled at two correctional facilities.

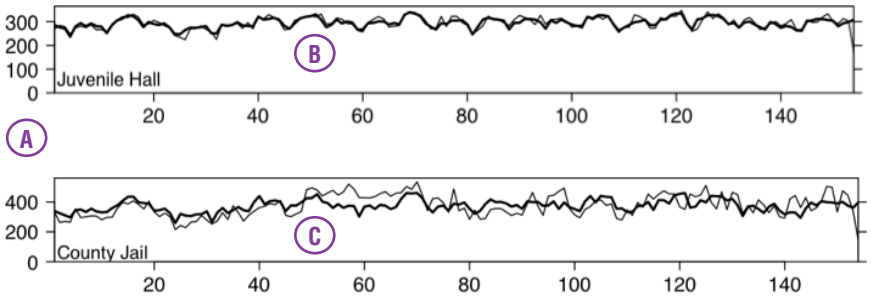
Variables used in the baseline model include day of week and peak temperature.

The metered daily peak (kW) is plotted for 150 days and marked with a thin line.

The peak projected with the baseline model is marked with a thick line.

(B) At one site the model fits well and closely matches the actual metered peak.

(C) At the other site the fit is poorer, and the model may be too inaccurate for some uses.



Source: Price, P. Methods for analyzing electric load shape and its variability. LBNL#3713E, 2010.

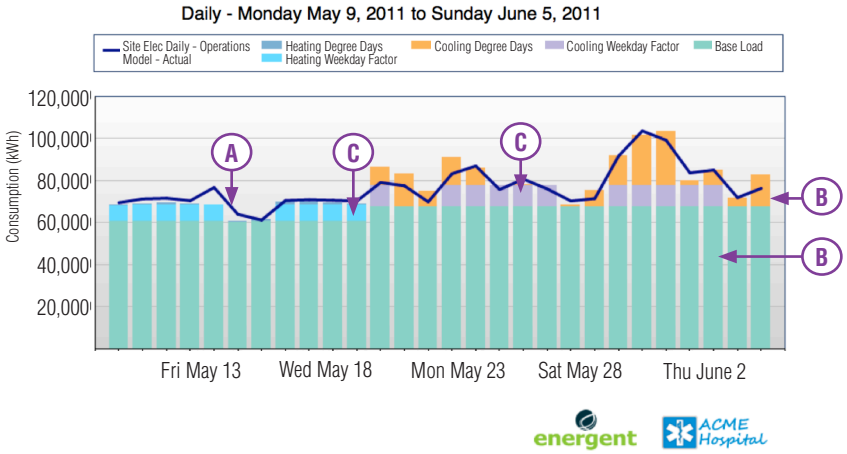
Example 2: Whole-Building Electric Baseline

(A) Actual daily electric use (dark blue) is overlaid with stack bars showing baseline use.

(B) Baseline components are: base load and weather (heating and cooling degree days).

(C) The baseline also accounts for occupancy in heating and cooling "weekday factors."

For the period shown, actual use is at or below baseline reflecting efficient operations.



Source: Energent

Example 3: System-Level Baseline

(A) Actual electric use (yellow) is overlaid with modeled baseline use (blue).

(B) This particular view shows monthly totals, summed from a daily baseline model.

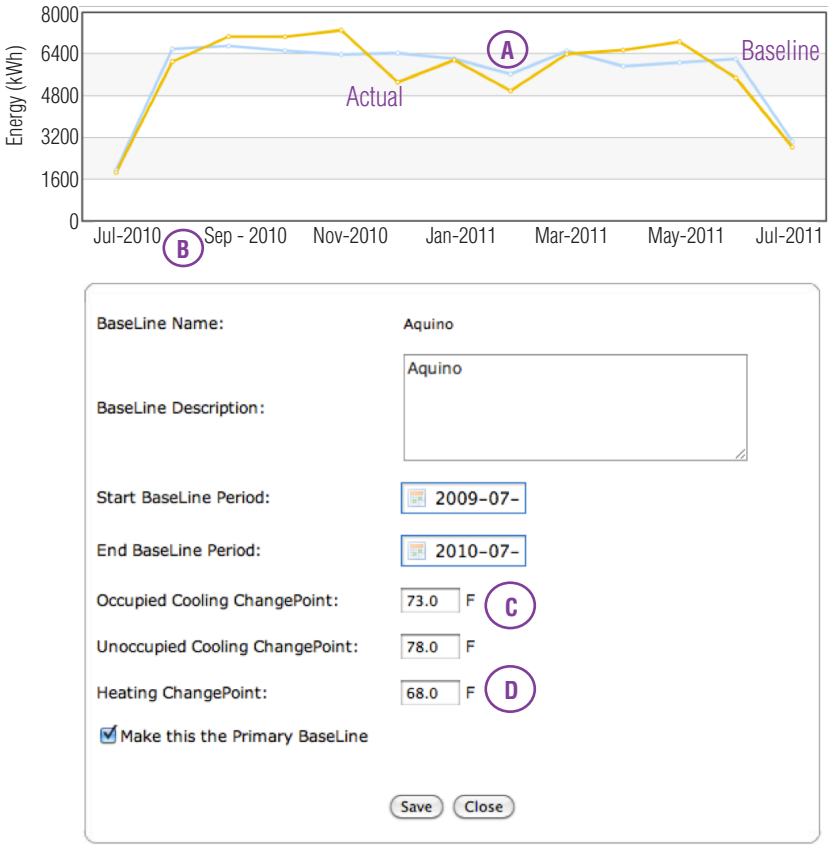
The default view in the tool includes the difference between baseline and measured use.

The default also shows CUSUMs of energy and cost savings, omitted here for clarity.

Here the model accounts for OAT, occupied status, and three user-supplied constants.

(C) One constant is the heating changepoint temperature.

(D) The occupied and unoccupied cooling changepoints are also user-defined.



Source: Serious Energy

Example 4: Evaluating Demand Response (DR) Effectiveness

A baseline model was fit to two months of 15-minute load data.

(A) One week of modeled (thick line) and metered data (thin line) is plotted for Mon-Fri.

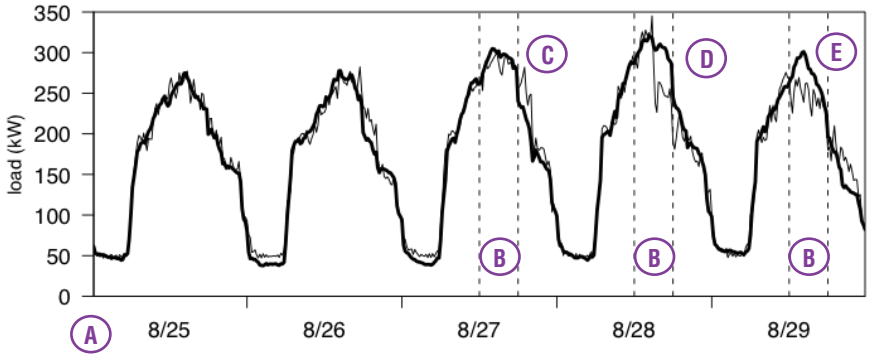
(B) Three demand-response events are indicated in vertical dashed lines.

The difference between the baseline and actual use reflects the DR load shed.

(C) The load shed on the first day was small, indicated by the closeness of the two lines.

(D) On the second DR day, ~50 kW was shed through the second half of the DR period.

(E) On the third DR day, ~25 kW was shed through the entire DR period.



Source: Price, P., Methods for analyzing electric load shape and its variability. LBNL#3713E, 2010.

Purpose

Lighting efficiency is tracked to identify potential improvements in system commissioning, control, or scheduling. The operational efficiency metric represents the percent of installed power that is actually being used at any point in time, and can be used to track the effectiveness of a diverse set of lighting control strategies.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
			●	

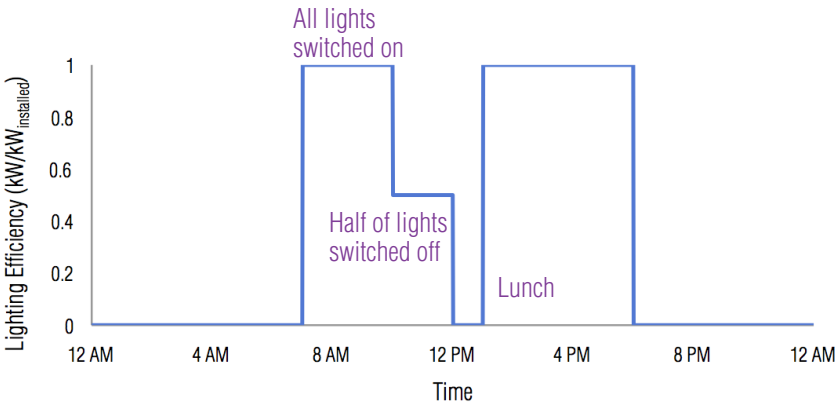
Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
		●	●	

Energy Manager

Operator

Technical Approach

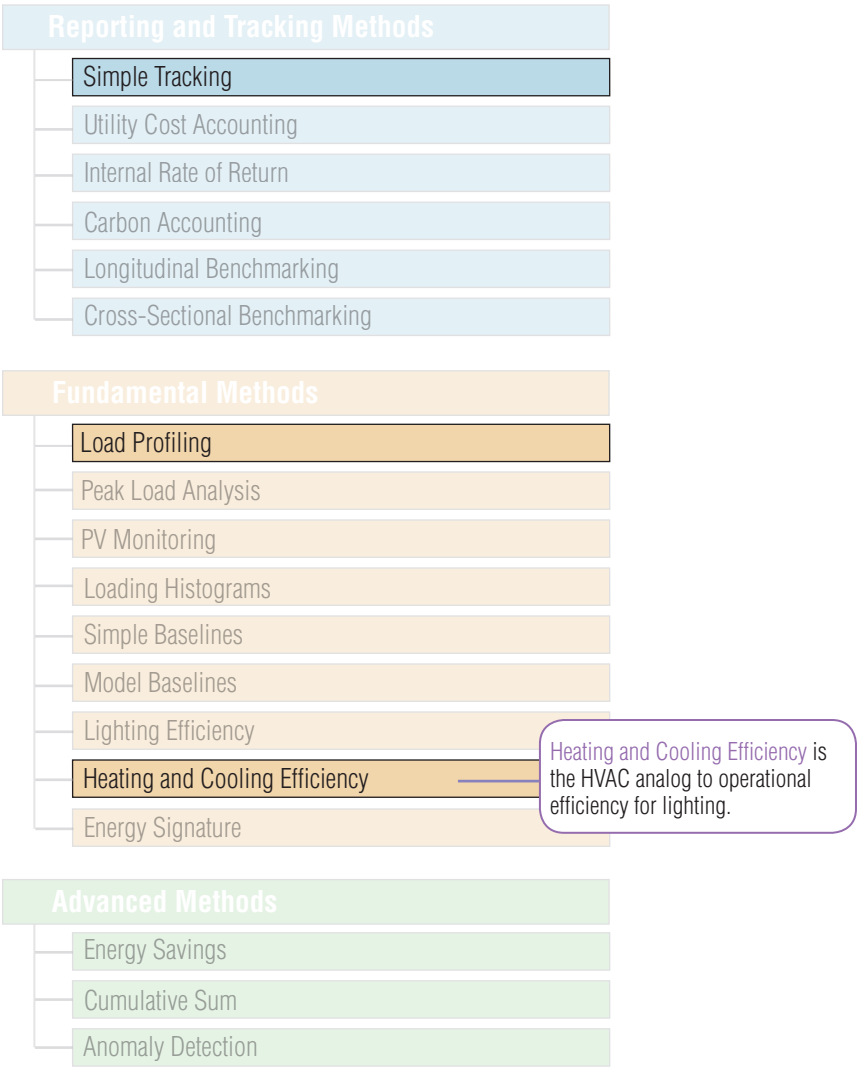
Divide metered lighting demand by the total installed lighting power and trend it over time. You can measure lighting power at the total whole-building end-use level, for specific lighting control zones, or for portions of the building area that may include multiple zones. Interpretation of the operational efficiency time series therefore depends on the level of metering, and the associated lighting strategy in use.



Single control zone with two step switching

Related Methods

Simple Tracking of lighting energy performance is a related method; although it captures total energy use, it does not capture as-operated efficiency. Load Profiling is similar, but is normalized to get operational efficiency.



Calculation and Programming

State of Commercialization: Lighting efficiency is not commonly applied in system tracking and analysis, but is an easily configured option in basic or advanced energy information systems and building automation systems.

Computation: Lighting efficiency is a straightforward analysis to program.

Step 1: Gather input data.

Data Resolution

Interval electric data at the system submeter level is required. Data can be for all lighting or for just an area of the building.

1 Hr, 15 Min ◉ Monthly ○ Annual ○

Data Inputs

High accuracy for metered data is not required. Fill data gaps before computing.

Metered Data

Export submetered lighting trend from a BAS, energy information system, or meter acquisition system.

Installed Lighting

Determine the total installed lighting power (kW_{inst}) for the submetered area of the building, using fixture schedules or building walkthroughs.

Step 2: Calculate the operational efficiency.

Metered lighting power divided by the total installed lighting power equals operational efficiency, or the percent of the installed load that is used.

Metered / Installed = Operational Effic.

Step 1			Step 2
Time	Metered Power (kW)	Total Installed (kW_{inst})	**Operational Efficiency (kW/kW_{inst})**
12:00	.5	2.5	**= .5/2.5 = .2**
1:00	2.0	2.5	**= 2.0/2.5 = .8**
2:00	1.0	2.5	**= 1.0/2.5 = .4**

Step 3: Plot operational efficiency vs. time.

Notes

Sketches

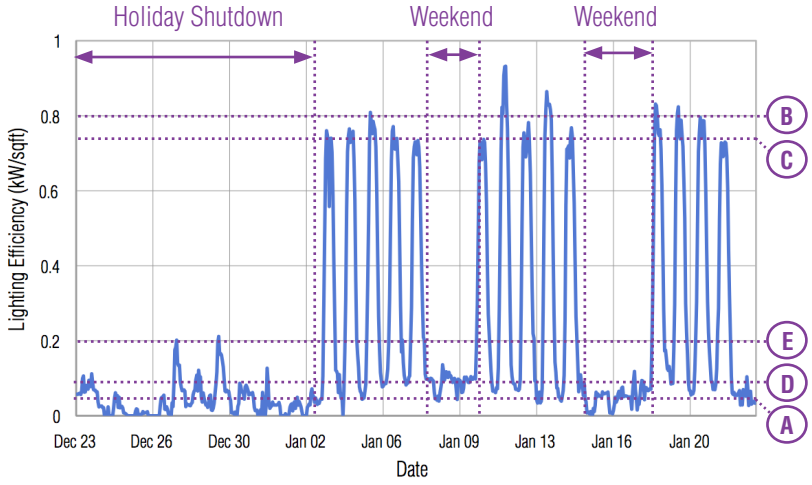
Application Examples

Interpretation: Depends on the level of metering, and the associated lighting strategy in use. For example if zone level metering is available and scheduling is employed, a near-one value after hours indicates a time-setting error. Similarly, if occupancy detection is used and the value of the metric does not fall between 4PM and 6PM as occupants leave for the day, there may be a commissioning problem with the occupancy sensors.

Example 1: Whole-Building Lighting Efficiency, Manual Control, and Occupancy Sensing

Lighting operational efficiency is plotted for one month of data.

- (A) Low occupancy during the holiday results in a low value of 5% of installed load.
- (B) Standard occupancy resumes. Average daily peak is 80% of the installed load.
- (C) Lower occupancy rates on Fridays results in a peak of 75% of the installed load.
- (D) Weekend use is twice that of holidays, with a value of 10% of the installed load.
- (E) The average over this whole month period was 20% of the installed load.

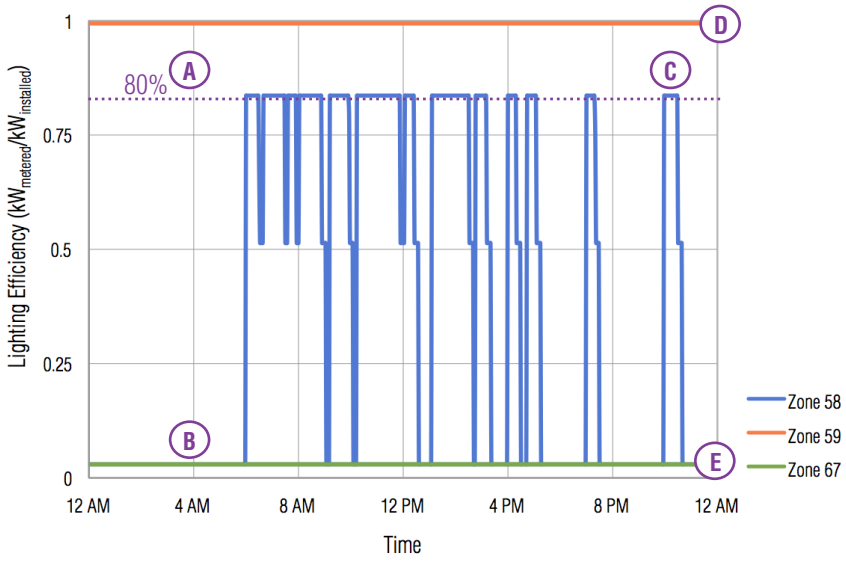


Source: Lawrence Berkeley National Laboratory

Example 2: Zone-Level Tracking: Occupancy Control and Setpoint Tuning

Lighting operational efficiency is plotted for three control zones in a building.

- (A) Zone 58 (blue line) shows good operation, tuning to ~80% of total output.
- (B) Zone 58 shows zero power at long periods of vacancy.
- (C) Zone 58 shows a late night spike from cleaning crew.
- (D) Zone 59 (orange line) has a failed occupancy sensor and shows 100% total output.
- (E) Zone 67 (green line) has a controls error and shows 0% total output.



Source: Lawrence Berkeley National Laboratory

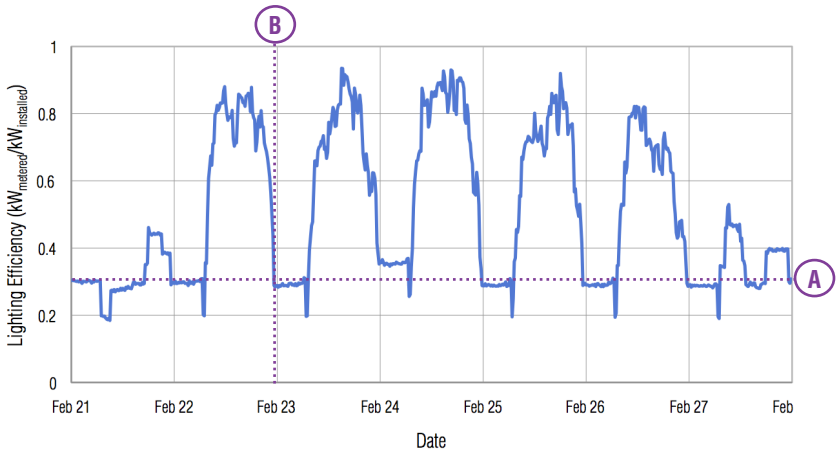
Example 3: Area-Based Submetering

Lighting operational efficiency is plotted for an area-based submeter.

(A) Nighttime use is higher than it should be at 30% of the installed load.

(B) Evening loads don't drop until very late, 10-11PM or later.

Improved scheduling and occupant controls should be considered to reduce after-hours and overnight loads.



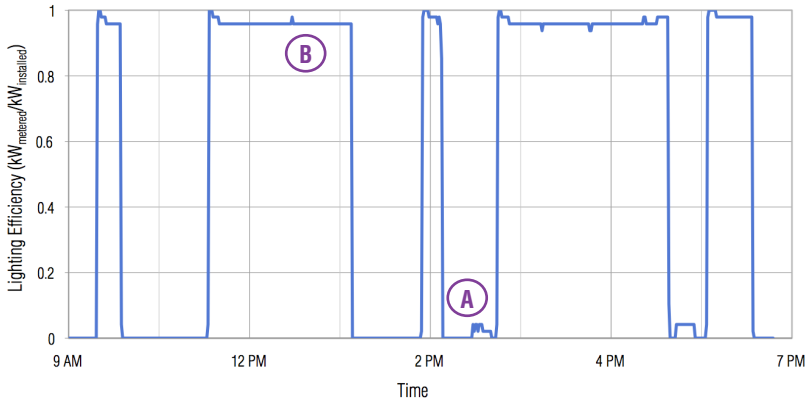
Source: Lawrence Berkeley National Laboratory

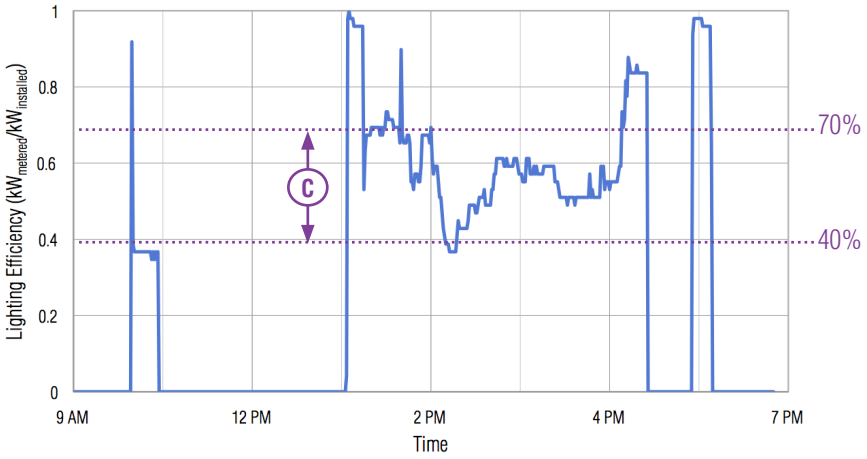
Example 4: Zone-Level Non-Dimming and Commissioning

A Occupancy controls are functioning properly.

B The daylighting controls are not functioning properly, since there is no dimming during daytime hours.

C The daylighting controls' illuminance setpoint is adjusted. Lighting dims to between 40% and 70% of installed load during daytime hours.





Source: Lawrence Berkeley National Laboratory

Purpose

The **Heating and Cooling Efficiency** method is used to identify and reduce inefficiencies in heating and/or cooling systems, which comprise a significant portion of commercial building load. The performance of these systems commonly degrades due to lack of proper maintenance and complex controls that may satisfy occupant comfort while obscuring efficiency problems. Operational efficiencies can be verified according to the manufacturer's performance specifications.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
	●	●		

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
		●		

Energy Manager

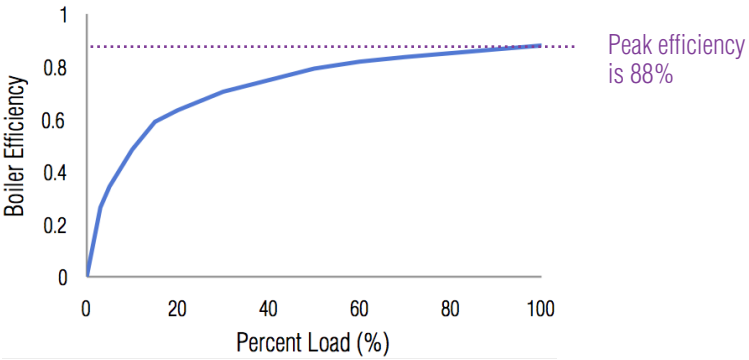
Operator

Facilities Manager

The techniques presented are most readily applicable to heating and cooling plant systems where the boundary for performance metrics is most accurately measured. Zonal system performance is harder to measure because of distribution losses.

Technical Approach

Calculate efficiency metrics from interval data on the amount of heating or cooling that is produced and the energy required to produce it. Generate and continuously inspect x-y plots of the efficiency metric and corresponding system load. Compare performance to specifications, and use the plots to verify that systems are optimally loaded and that efficiency changes with loading as expected. Some systems operate more efficiently at lower part-loads, and others do not. Changes or excessive scatter in the profiles reflected in the x-y plots may reveal control or sequencing problems.



Related Methods

Loading Histograms are a simpler assessment of efficiency that do not include explicit calculation of efficiency metrics. Load Profiling is the simplest means of assessing version HVAC system performance, but only captures load, not specific efficiency metrics.

Reporting and Tracking Methods

- Simple Tracking
- Utility Cost Accounting
- Internal Rate of Return
- Carbon Accounting
- Longitudinal Benchmarking
- Cross-Sectional Benchmarking

Fundamental Methods

- Load Profiling
- Peak Load Analysis
- PV Monitoring
- Loading Histograms
- Simple Baselines
- Model Baselines
- Lighting Efficiency
- Heating and Cooling Efficiency
- Energy Signature

Lighting Efficiency is the analogous analysis method for lighting systems.

Advanced Methods

- Energy Savings
- Cumulative Sum
- Anomaly Detection

Calculation and Programming

State of Commercialization: Heating and cooling efficiency analysis can be accommodated in energy information systems, provided that x-y scatter plotting is supported. Modern BAS may also be used, if they support the creation of virtual trend points and offer common arithmetic functions.

Computation: In the absence of packaged software tools, you can use stand-alone data analysis or spreadsheet tools to analyze heating and cooling system efficiency.

Step 1: Gather input data.

Data Resolution

Data should reflect steady-state operations. Remove start-up data from the analysis.

1 Hr, 15 Min ◉ Monthly ○ Annual ○

Data Inputs

For best accuracy, flow meters require a substantial run of straight pipe that is not near bends and turns. This is problematic in many central plants.

Export the following data from the BAS or an on-site meter acquisition system: power needed to produce heating or cooling; produced heating or cooling load.

Metered Data

For a cooling plant, the power should include pumps and tower fans, as well as chillers.

Step 2: Calculate common efficiency metrics such as kW/ton and COP.

COP = (1/kW/ton)*(1 kWh/3413 Btu)*(12,000 ton-hr/Btu)

Conversion factors: 3413 Btu = 1 kWh
12,000 Btu/hr = 1 ton

Step 1			Step 2		
Time	Chiller Power (kW)	Cooling Produced (Btu)	Cooling Produced (Tons)	**kW/ton**	**Coefficient of Performance (COP)**
12:00	120	2,425,000	= (2,425,000 Btu/1hr)* (1/12,000) = 202	**= 120/202 = .59**	**= (12,000/.59*3413) = 5.96**
1:00	127	2,500,000	= (2,500,000 Btu/1hr)* (1/12,000) = 208	**= 127/208 = .61**	**= (12,000/.61*3413) = 5.76**
2:00	112	2,375,000	= (2,375,000 Btu/1hr)* (1/12,000) = 198	**= 112/198 = .57**	**= (12,000/.57*3413) = 6.17**

Step 3: Plot the data on an x-y scatter plot

Plot kW/ton on the y-axis and tons on the x-axis. In some cases, the user may wish to convert tons to a percentage of full load.

Notes

Sketches

Application Examples

Interpretation: Coefficient of performance (COP) is a unit-less metric, and bigger numbers indicate higher efficiency; kW/ton is an inverse metric, where smaller numbers indicate higher efficiency. For chiller plants (pumps and tower fans included) above 1.0 kW/ton or below 3.5 COP marks relatively poor performance. Boiler efficiencies tend to range from 80%-83% for conventional units, 84%-88% for efficient units, and 89% and above for high-efficiency condensing units. These are basic rules of thumb that are influenced by equipment type and age, climate, operating conditions, and system/equipment analysis boundaries.

Example 1: Chiller kW/Ton vs. Tons, Efficient Operations

(A) Chiller efficiency vs. production is plotted for a typical office building in a mild climate. This profile shows good behavior from a well-controlled system.

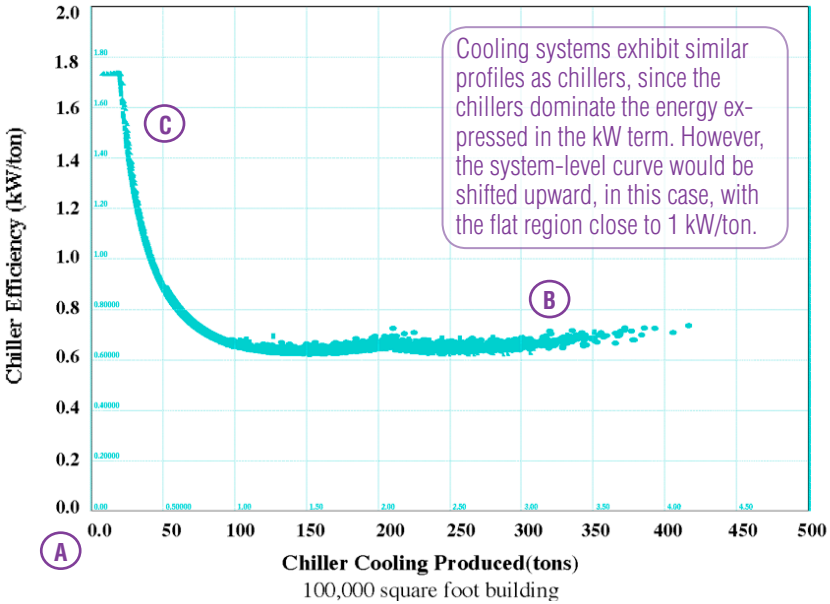
(B) The curve flattens at chiller loads >100 tons, marking the desired operational region.

(C) Below 100 tons efficiency decreases steeply, marking an undesired operational region.

A higher degree of scatter in the points would reveal poor performance.

Departures from this shape profile would also reveal poor performance.

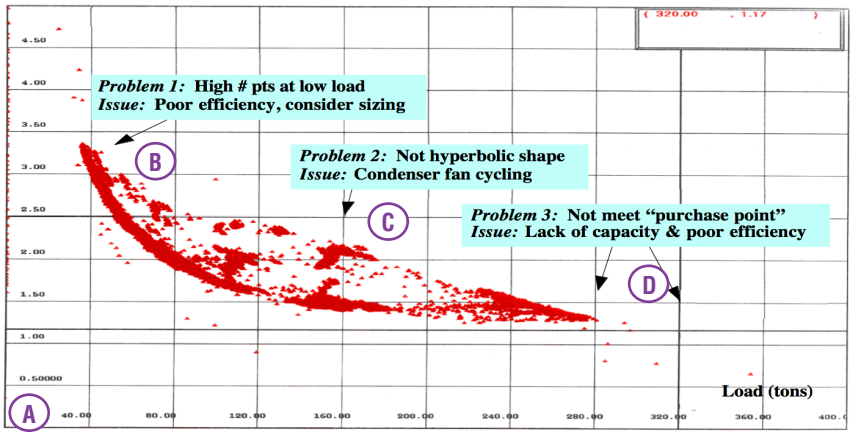
In general, downward shifts along the y-axis are preferred, marking higher efficiency.



Source: Piette et al, Early results and fields tests of an information monitoring and diagnostic system for commercial buildings. LBNL#42338, 1998.

Example 2: Chiller kW/Ton vs. Tons, Inefficient Operations

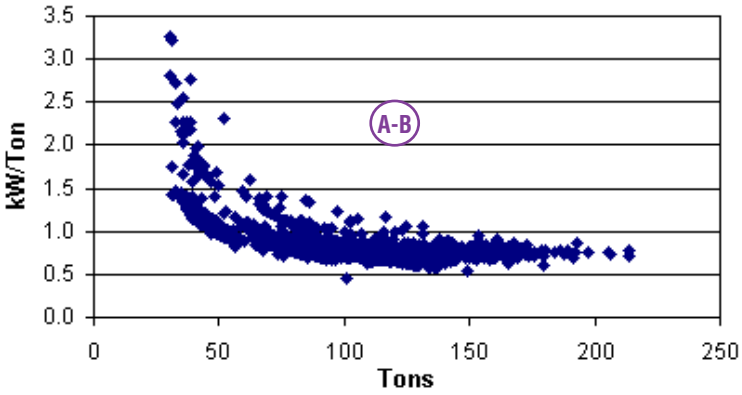
- (A) Chiller efficiency is plotted vs. production.
- (B) Many points at low load and low efficiency may indicate poor sizing or sequencing.
- (C) Divergence from the standard hyperbola shape may indicate condenser fan cycling.
- (D) The rated efficiency, or "purchase point" is not met.

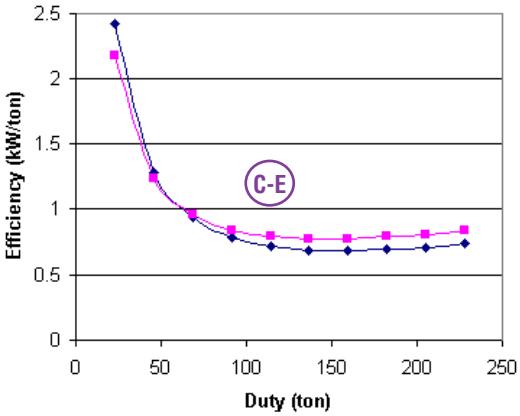


Source: Piette et al, Development and testing of an information monitoring and diagnostic system for large commercial buildings. ACEEE Summer Study on Energy Efficiency in Buildings, 1998.

Example 3: Measured Efficiency vs. Manufacturer Specification

- (A) Chiller kW/ton vs. ton was plotted for 14,000 points of data.
- (B) Points that did not correspond to steady-state operations were discarded.
- (C) The remaining 7,700 data points were fit to a curve.
- (D) Measured performance was plotted against the manufacturer specification.
- (E) The data show slightly lower efficiency than specification, but a remarkably good fit.





Manufacturer data typically maximizes the measurement tolerances in the standard rating procedures; this is very close agreement.

Source: Piette et al, Performance assessment and adoption processes of an information monitoring and diagnostic system prototype. LBNL# 44453, 1999.

Example 4: Chiller Retrofit Savings

(A) Prior to retrofit, a performance curve was generated by monitoring the existing chiller.

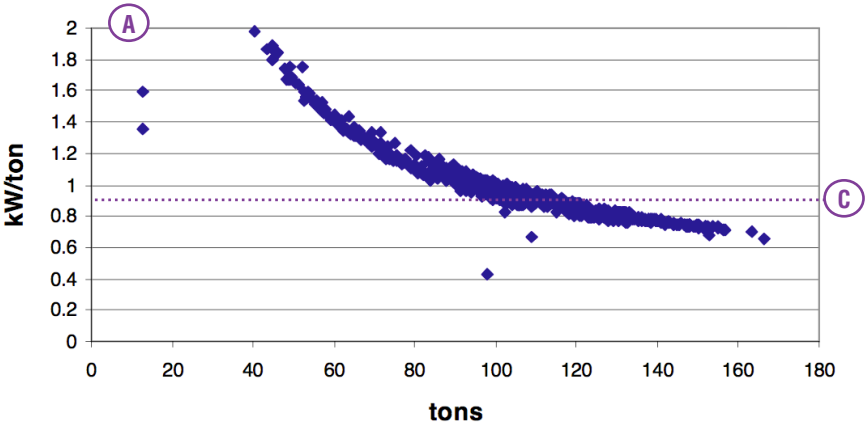
(B) Following retrofit, a performance curve was generated for the new chiller.

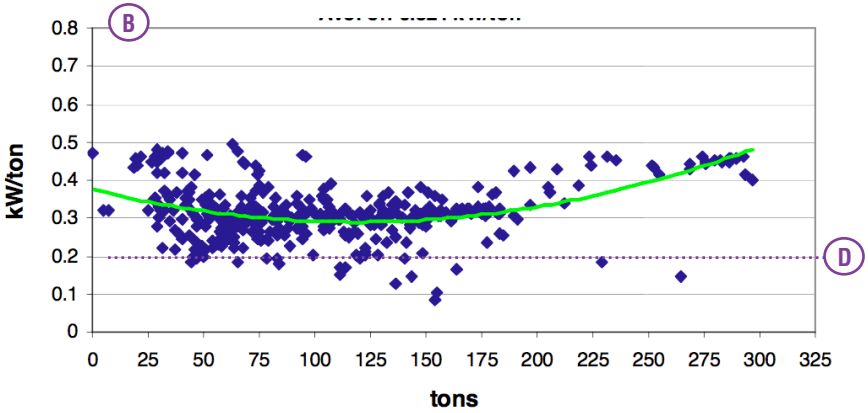
(C) In the pre-retrofit period, efficiency averaged .94 kW/ton and ranged from 2 to .7.

(D) Following the retrofit, efficiency improved averaging .32 kW/ton.

Calculated annual savings totaled 863 MWh; 98kW peak demand; $109k.

Calculated payback, including incentives, was 3.9 years.





Source: Turbocor Case Study, San Diego Regional Energy Office. Retrofitting a Water-Cooled Chiller with Turbocor's Newest Oil-Less Compressor. Turbocor, 2006.

Example 5: Boiler Efficiency vs. Part-Load Capacity

(A) Boiler efficiency is plotted and tabulated for a range of loads from 20%-80% capacity.

(B) Both combustion efficiency and overall boiler efficiency are included.

(C) The boiler efficiency is affected by the combustion efficiency, so it is always smaller.

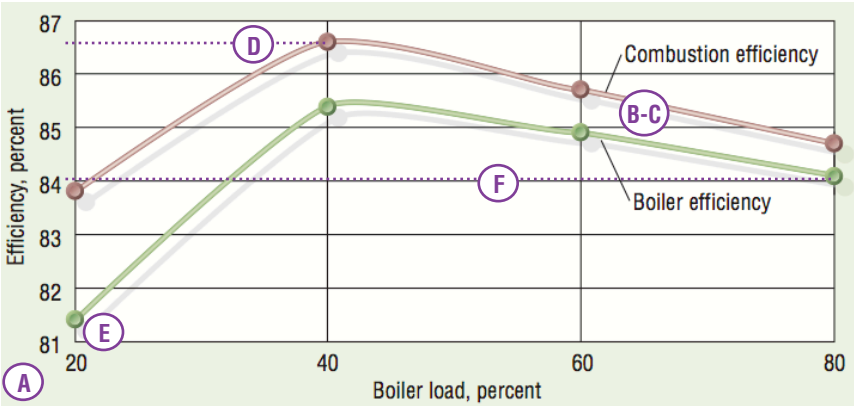
(D) For this particular boiler, peak efficiency, ~85% is reached at 40% load capacity.

(E) Below 40% loading, the efficiency falls to ~81%.

(F) Above 40% loading, efficiency falls to 84%.

A divergence between the two would reveal degradation, e.g., due to fouling.

The impact of loading on efficiency is also discussed in loading histograms.



Boiler Loading	Boiler Efficiency	Combustion Efficiency
20 percent	81.4 percent	83.8 percent
40 percent	85.4 percent	86.6 percent
60 percent	84.9 percent	85.7 percent
80 percent	84.1 percent	84.7 percent

Source: Showers, G. Boiler operation efficiency insights and tips. HPAC Engineering Magazine, 2002.

Purpose

An **Energy Signature** is a plot of energy use versus the outdoor air temperature for a certain period of time. It is used to monitor and maintain the performance of temperature-dependent loads such as whole-building gas and electric use or heating and cooling systems or components. The simple energy signature can be slightly modified to facilitate baselining, or over-time efficiency comparisons, or serve as a starting point for Model Baselines and more advanced analysis.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●		

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
			●	●

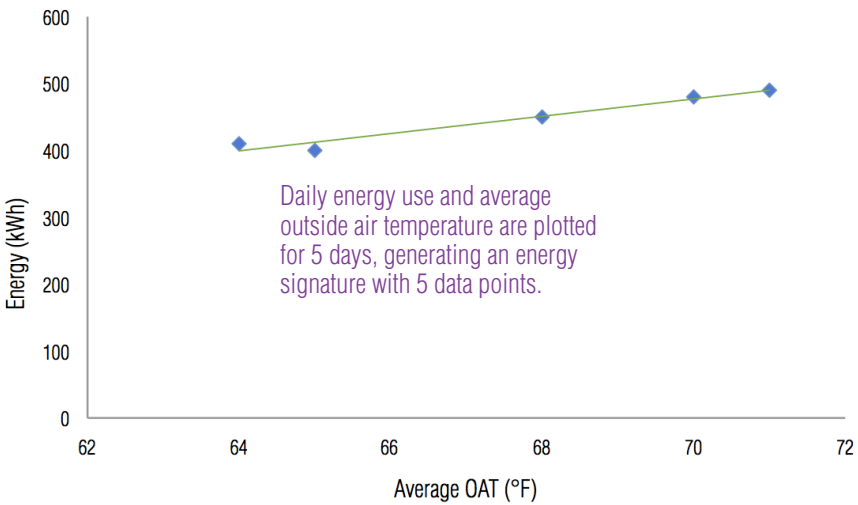
Energy Manager

Facilities Manager

Operator

Technical Approach

Plot energy use over for a given time interval versus the corresponding average outdoor temperature in that period. Normalize the energy data for time or building square footage. Sometimes temperature metrics such as degree days are used instead of outside air temperature. Compare the relationship between energy and temperature year to year, month to month, or against published numbers for expected performance.



Related Methods

The information included in an Energy Signature may be used to create Simple or Model Baselines. When applied at the heating/cooling system level, Energy Signatures allow simplified investigations of HVAC performance, and are therefore related to Heating and Cooling Efficiency.

Reporting and Tracking Methods

- Simple Tracking
- Utility Cost Accounting
- Internal Rate of Return
- Carbon Accounting
- Longitudinal Benchmarking
- Cross-Sectional Benchmarking

Fundamental Methods

- Load Profiling
- Peak Load Analysis
- PV Monitoring
- Loading Histograms
- Simple Baselines
- Model Baselines
- Lighting Efficiency
- Heating and Cooling Efficiency
- Energy Signature

An Energy Signature may be viewed as a more sophisticated version of Load Profiling.

Advanced Methods

- Energy Savings
- Cumulative Sum
- Anomaly Detection

Calculation and Programming

State of Commercialization: Energy signatures are offered in commercial software products, including energy information systems, dedicated load analysis programs, or as x-y plots of load versus air temperature in some BAS.

Computation: In the absence of packaged software tools, you can use stand-alone data analysis or spreadsheet tools to create energy signatures.

Step 1: Gather input data.

Data Resolution

Energy signatures are best created from interval meter data, and require temperature data of at least the same resolution.

1 Hr, 15 Min ◉ Monthly ◉ Annual ○

Data Inputs

Standard or better meter accuracy, i.e., less than 1.0% error, is recommended.

Metered Data

Export building or system-level energy and temperature data from a BAS, meter acquisition system, or weather service.

Air Temperature

Step 2: Prepare data for plotting.

Here the period of analysis is hourly. Daily or other periods are computed similarly.

Step 1			Step 2	
Time	Load (kW)	Outside Air Temperature (°F)	**Average Hourly Load (kW)**	**Average Hourly Outside Air Temperature (°F)**
12:00	118	74	**= avg {118, 124, 122, 109} = 118**	**= avg {74, 73, 74, 75} = 74**
12:15	124	73		
12:30	122	74		
12:45	109	75		
.....	.....	.....	.....	.....

Step 3: Plot data.

Plot average load on the y-axis and outside air temperature on the x-axis. As data accumulates over time, you can add it to the overall energy signature plot. After a significant amount of time has passed, or as building operations or efficiency change, create a new energy signature plot.

Notes

Sketches

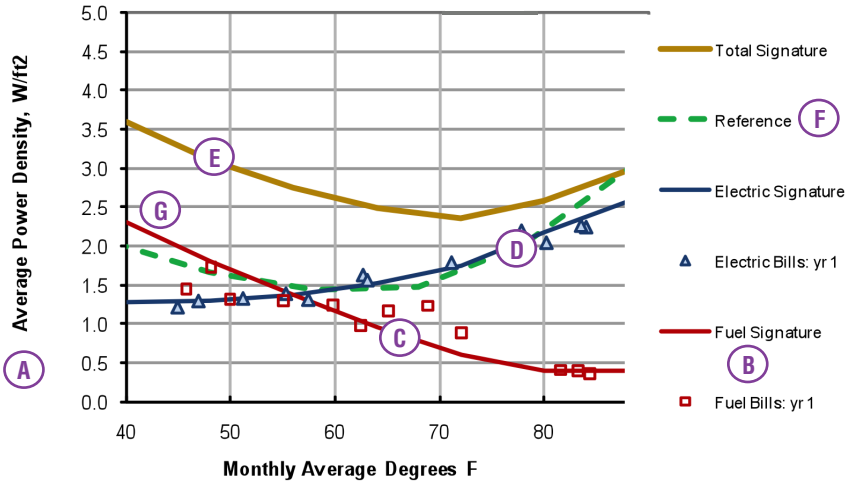
Application Examples

Interpretation: Energy signatures are inspected to identify errant behavior, or can be compared to reference signatures, signatures from similar buildings, or a theoretical model. The data points should follow an orderly line(s) reflecting consistent behavior. Very scattered data points should be investigated as potential indicators of inefficiency. Other useful areas to examine are (1) base loads where the energy use does not change with OAT, and (2) how quickly the load changes with OAT, known as the "heating and cooling slope."

Example 1: Whole-Building Electric, Gas, and Total Energy Signatures

- (A) Average monthly energy use in W/sf is plotted against electric and gas use.
- (B) Gas is also expressed in W/sf for ease of comparison to other buildings.
- (C) Gas heating is reflected in the negative heating slope where load decreases with OAT.
- (D) Electric cooling is reflected in the positive cooling slope where load increases with OAT.
- (E) The total energy signature combines electricity and gas use.
- (F) A reference total energy signature is also plotted, with a green dashed line.
- (G) The signature of the reference building is lower reflecting higher efficiency.

Heating and cooling slopes are further detailed in the Appendix.



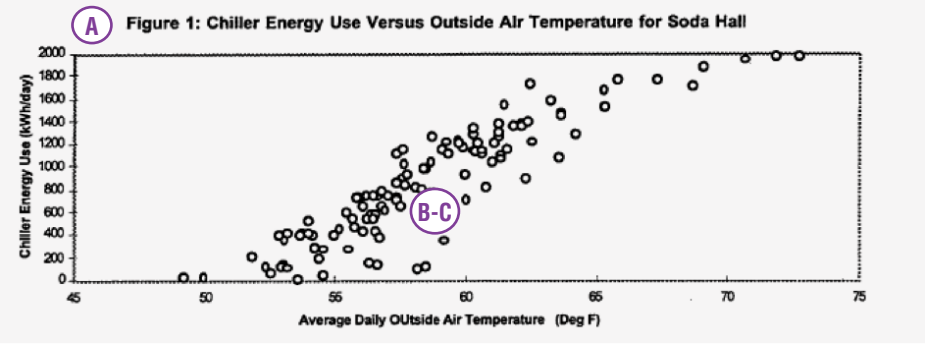
Source: New Buildings Institute

Example 2: Chiller Daily Electric Energy Signature

(A) Daily energy use is plotted vs. average outside air temperature.

(B) The points show a high degree of scatter.

(C) This lack of clustering makes it difficult to track performance.



Source: Piette et al, Model-based chiller energy tracking for performance assurance at a university building. LBNL#40781, 1998.

Example 3: Identification of Improper Controls

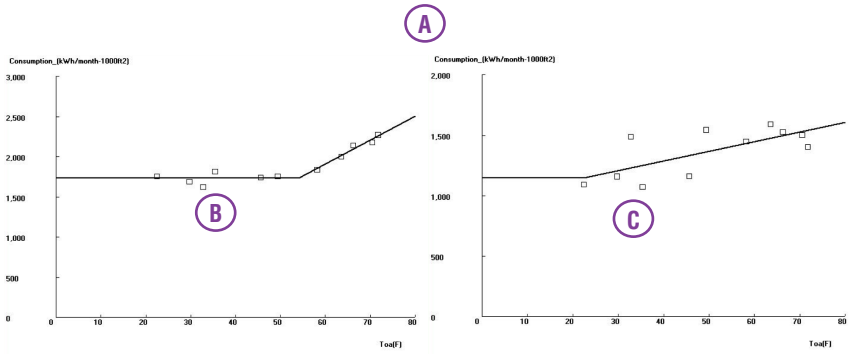
(A) Monthly energy signatures for two similar buildings were examined.

(B) The building on the left shows an orderly relationship with OAT and data clustering.

(C) The building on the right shows less order and more scatter.

In this case, improper control settings were the source of inconsistent performance.

(D) The R-squared value is a common metric to assess how well the data fit a line.



$R^2 = 0.94$ (D) $R^2 = 0.49$

R^2 values indicate how tightly the data are clustered, and are further detailed in the Appendix.

Source: Kissock, K, Improving model calibration using inverse modeling. Presentation to the International Building Performance Association, 2010.

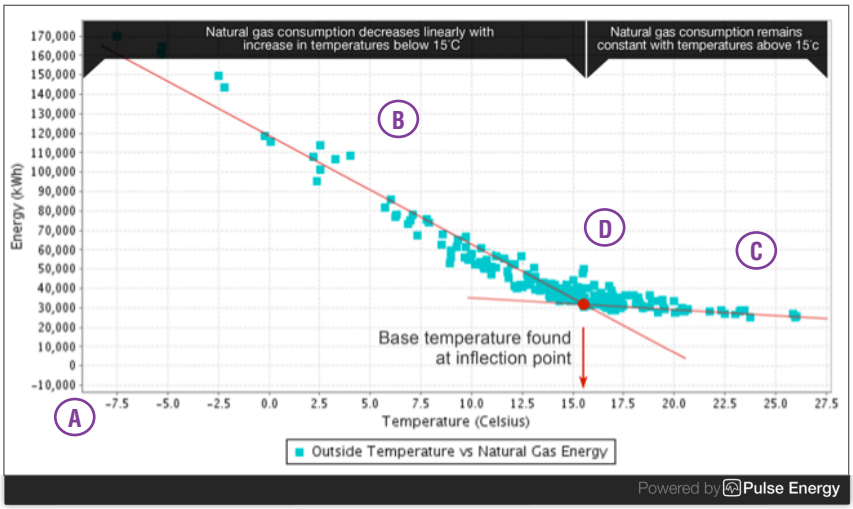
Example 4: Determination of Base Heating Temperature

A Natural gas consumption is plotted against outside air temperature.

B Below 15°C, consumption increases as temperature decreases.

C Above 15°C, natural gas consumption remains constant.

D The base temperature or balance point is at 15°C.



Source: Pulse Energy

Example 5: Heating and Electric Energy Signatures, Weekdays vs. Weekends

(A) Daily energy signatures were created for building electricity and hot water usage.

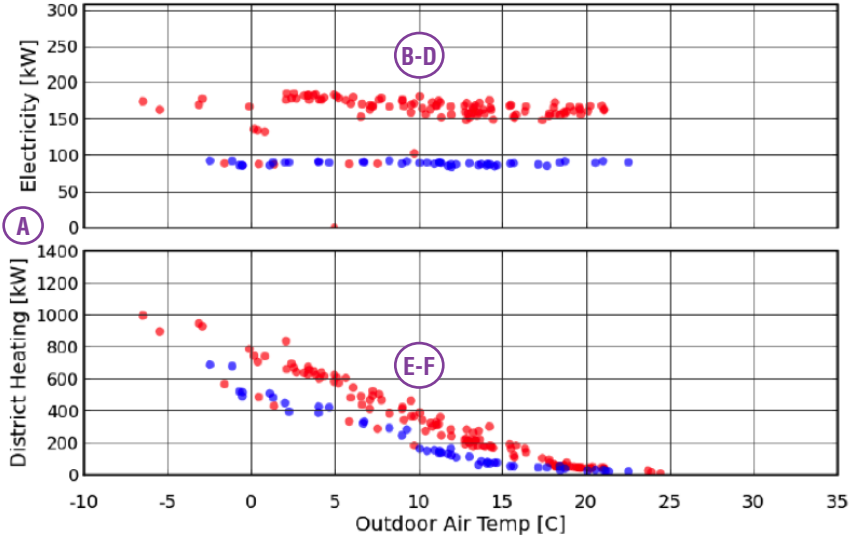
(B) Weekday use (red) is separated from weekend use (blue).

(C) Weekend use is lower than on the weekdays, as expected.

(D) The flat line, or absence of a cooling slope shows that the building has no air conditioning.

(E) The heating slope shows increasing heat energy used as the OAT drops.

(F) Weekend use is lower, but the offset is smaller than above, showing potential further savings.



Source: Mazzarella, L, et al, eds. Description of european prototype tool for evaluation of building performance and the national tools. Fraunhofer Institute for Solar Energy Systems, Intelligent Energy Europe, 2009.

Discussion

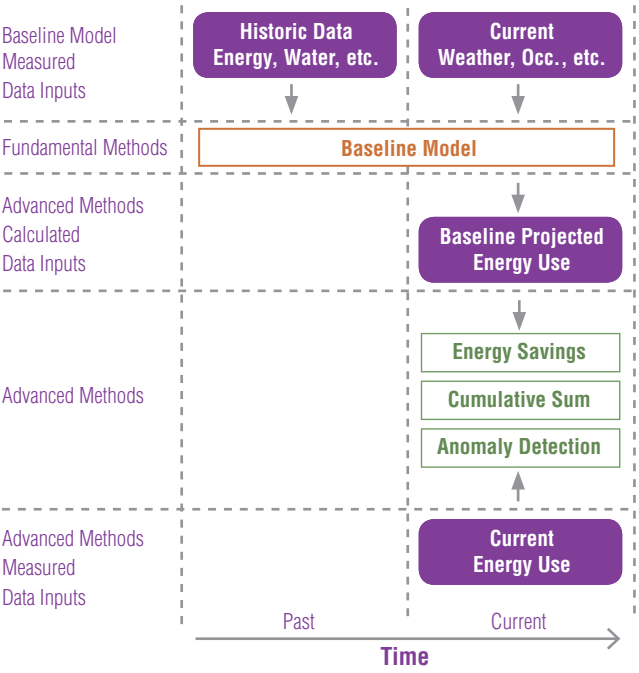
As classified and defined in this handbook, each of the Advanced Methods rely upon underlying baselines. Simple Baselines and Model Baselines are discussed and presented in Fundamental Methods. In the best-practice case, the baselines used in the advanced methods will be model-based, as reflected in the associated method summaries for each.

As illustrated in the image below, projected load is determined by inputting measured conditions into a baseline model.

Energy Savings defines energy savings as the difference between the projected and metered load, after efficiency improvements have been made.

Cumulative Sum represents the accumulation of the difference between metered and projected load over time, effectively expressing a running total.

Anomaly Detection compares the difference between metered and projected load to a threshold value.



Purpose

The **Energy Savings** method allows building owners, energy service companies, and financiers of energy-efficiency projects to quantify and verify the energy-savings performance of energy conservation measures (ECMs) or efficiency programs. In contrast to previously presented methods that can be used to estimate energy savings, this approach makes use of baseline models, with regression being the most common approach.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

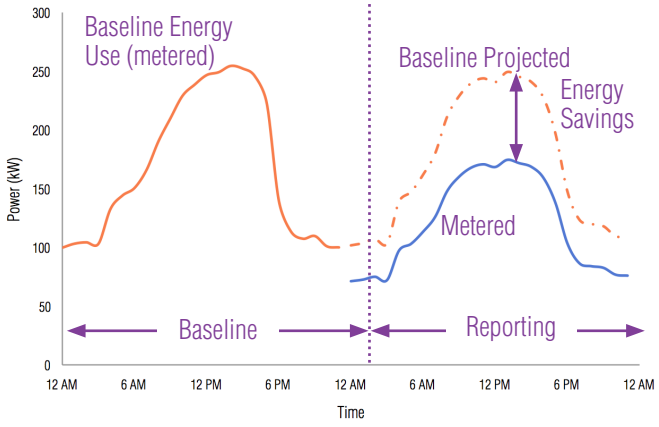
Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
▬			●	●

Energy Manager

Technical Approach

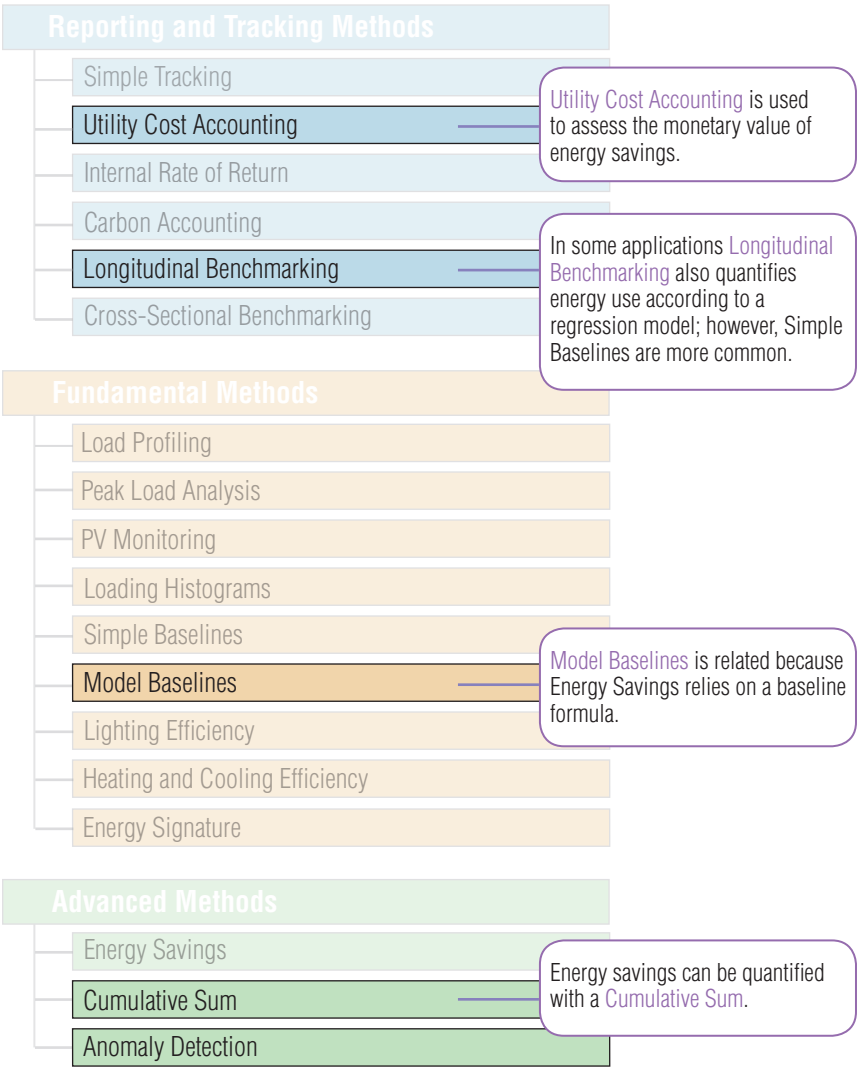
Collect metered energy use before and after an improvement has been made, or a tracking period is initiated. Then develop a baseline model that accounts for key energy drivers, i.e., "independent variables" such as outside air temperature, using metered data before the improvement period. Project the baseline model into the tracking/reporting period, to quantify the energy use that would have resulted had no improvements been made. Finally, subtract the energy use from the improvement period from the baseline projected energy use to quantify energy savings.

As detailed in the Appendix, this approach is largely commensurate with the overall principles in the international protocol for measurement and verification (IPMVP).



Related Methods

The relationship between each of the Advanced Methods is summarized in the introduction to the Advanced Methods chapter.



Calculation and Programming

State of Commercialization: Energy savings calculations are commonly automated in measurement and verification and continuous commissioning software tools used internally by providers. They may also be supported in commercial EIS, provided that baselining capability is sufficiently robust. However, there may be adjustments beyond baseline projections that are necessary to quantify savings, yet not automated in commercial software tools.

Step 1: Gather input data.

Data Resolution

Short interval data is frequently rolled up to daily or monthly increments for use.

1 Hr, 15 Min ◉ Monthly ◉ Annual ○

Data Inputs

High meter accuracy (0.5% error or less) is recommended in cases of performance contracting.

Metered Data

Export energy data from a meter acquisition system, and collect independent variables, such as OAT, required for the baseline model projection.

Baseline Projected

See: **Fundamental Methods: Model Baselines**

Step 2: Define the baseline period and reporting period and calculate energy savings.

Baseline Projected - Metered = Energy Savings

Step 1			Step 2		
Metered Energy Use Baseline Period (kWh)		Reporting Period Baseline Parameters (avg OAT)	**Baseline Projected (kWh)**	**Metered Energy Use Reporting Period (kWh)**	**Energy Savings (kWh)**
Month 1	60,000	58	**61,000**	**58,100**	**= 61,000 - 58,100 = 2,900**
Month 2	58,885	57	**59,075**	**56,250**	**= 59,075 - 56,250 = 2,825**
.....	.....	.....	**.....**	**.....**	**.....**
Month 12	62,590	52		**61,025**	.....
Total	= 700,000	.....	**= 715,000**	**= 625,000**	**= 715,000 - 625,000 = 90,000 or 13% relative to baseline period**

Step 3: Plot metered use for the baseline and reporting periods.

Plot energy on the y-axis and the reporting interval (day, month, year) on the x-axis. You can also overlay the baseline projected use on this plot to visualize the size of energy savings.

Notes

Sketches

Application Examples

Interpretation: Interpretation of the output of the energy savings analyses is straightforward. However, constructing the underlying baseline model used to quantify those savings may require significant expertise and interpretation of site-specific system and control parameters. Similarly, significant expertise may be required to resolve cases in which actual savings are significantly less than expected, based on the particular efficiency measure.

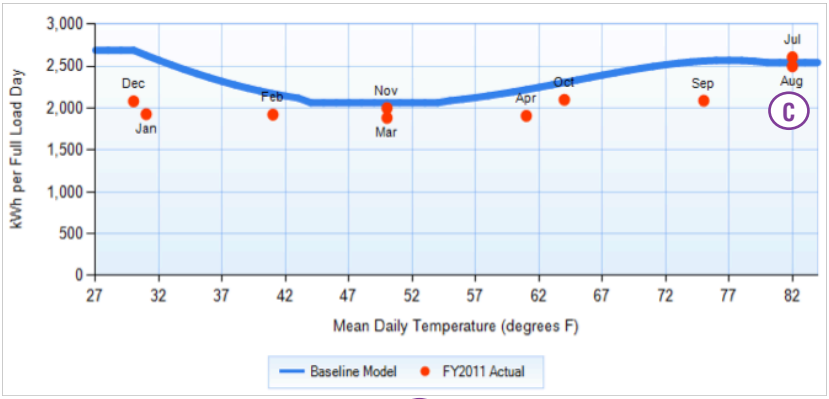
Example 1: HVAC System Energy Savings

(A) Monthly energy use and mean daily temperature are plotted for FY2011 (red).

(B) The baseline model (blue) included a base load and weather-sensitive components.

(C) Energy use is lower than baseline for each month except July and August.

FY11 savings were 10.8%, relative to the baseline period.



A-B

Source: Interval Data Systems

Example 2: Whole-Building Gas Savings

(A) Monthly billed use and HDD are tabulated for one year following a retrofit.

(B) The baseline model included a base load and a weather-sensitive component.

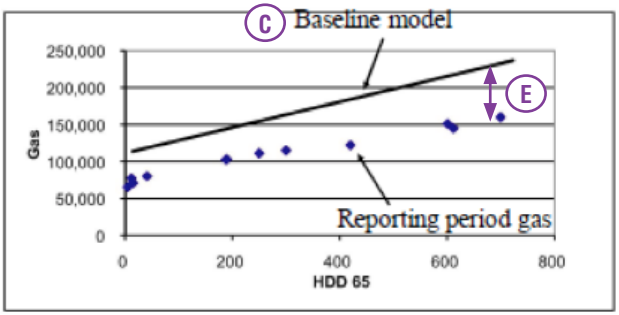
(C) The baseline was used to determine what use would have been without the retrofit.

(D) This baseline projection is also tabulated.

(E) Energy savings are equal to the difference between measured and baseline use.

Savings for 10 months totaled 511k units of gas and $3.2M.

Meter Reading Date	Actual Post-Retrofit Data		Projected Baseline (C-D)			Savings (E-F)	
			Baseload	Weather Sensitive (B)	Total	Gas	Value
	Consumption	HDD 65	Factors			(units)	Price =
	Units		111,358	173.27			$ 6.232
March 6, 2009	151,008	601	111,358	104,135	215,493	64,485	$ 401,871
April 4, 2009	122,111	420	?	?	?	?	?
May 6, 2009	102,694	188	111,358	32,575	143,933	41,239	$ 257,001
June 5, 2009	111,211	250	111,358	43,318	154,676	43,465	$ 270,874
July 5, 2009	80,222	41	111,358	7,104	118,462	38,240	$ 238,312
August 6, 2009	71,023	15	111,358	2,599	113,957	42,934	$ 267,565
September 8, 2009	65,534	5	111,358	866	112,224	46,690	$ 290,972
October 9, 2009	77,354	12	?	?	?	?	?
November 4, 2009	103,000	190	111,358	32,921	144,279	41,279	$ 257,251
December 10, 2009	115,112	300	111,358	51,981	163,339	48,227	$ 300,551
January 7, 2010	160,002	700	111,358	121,289	232,647	72,645	$ 452,724
February 4, 2010	145,111	612	111,358	106,041	217,399	72,288	$ 450,499

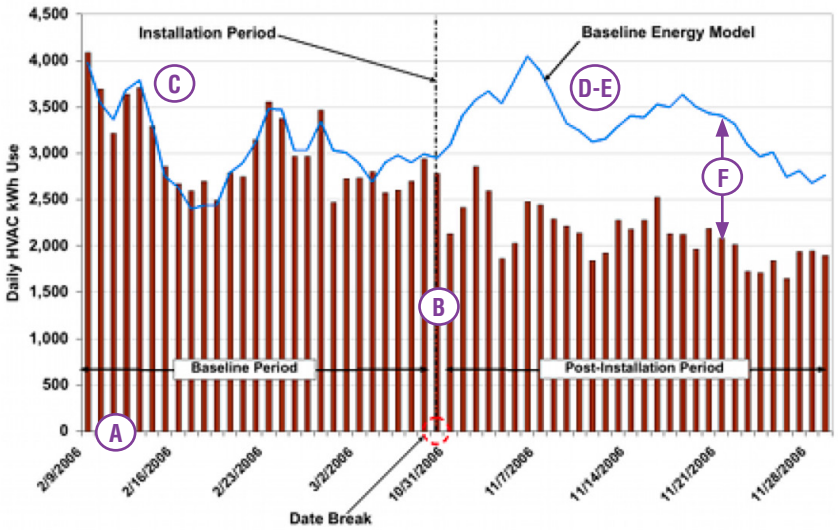


Source: Energy Valuation Organization (EVO)

Example 3: HVAC System Energy Savings

- (A) Metered daily HVAC energy use in a 109ksf building is plotted in bars.
- (B) A retrofit was conducted to improve the control system, and consumption decreased.
- (C) A regression baseline characterized energy use based on outside air temperature.
- (D) The baseline was used to determine what use would have been without the retrofit .
- (E) This baseline projection is shown in blue .
- (F) Energy savings are equal to the difference between measured and baseline use.

  A rough estimate indicates approximately 1300-1500 kWh/day energy savings.



Source: QuEST Engineering

Purpose

The **Cumulative Sum** (CUSUM) is used to quantify total accrued energy savings or losses over time and to detect energy waste or performance relative to operational changes. CUSUM analysis requires a baseline model, and is applicable to all building types and all building systems.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
▬		●	●	

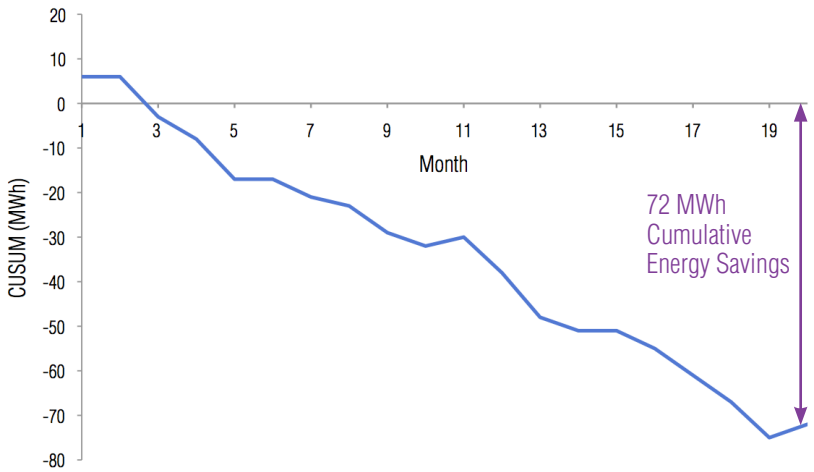
The need for interval data depends on the form of the baseline and the system of focus.

Energy Manager

Financial Manager

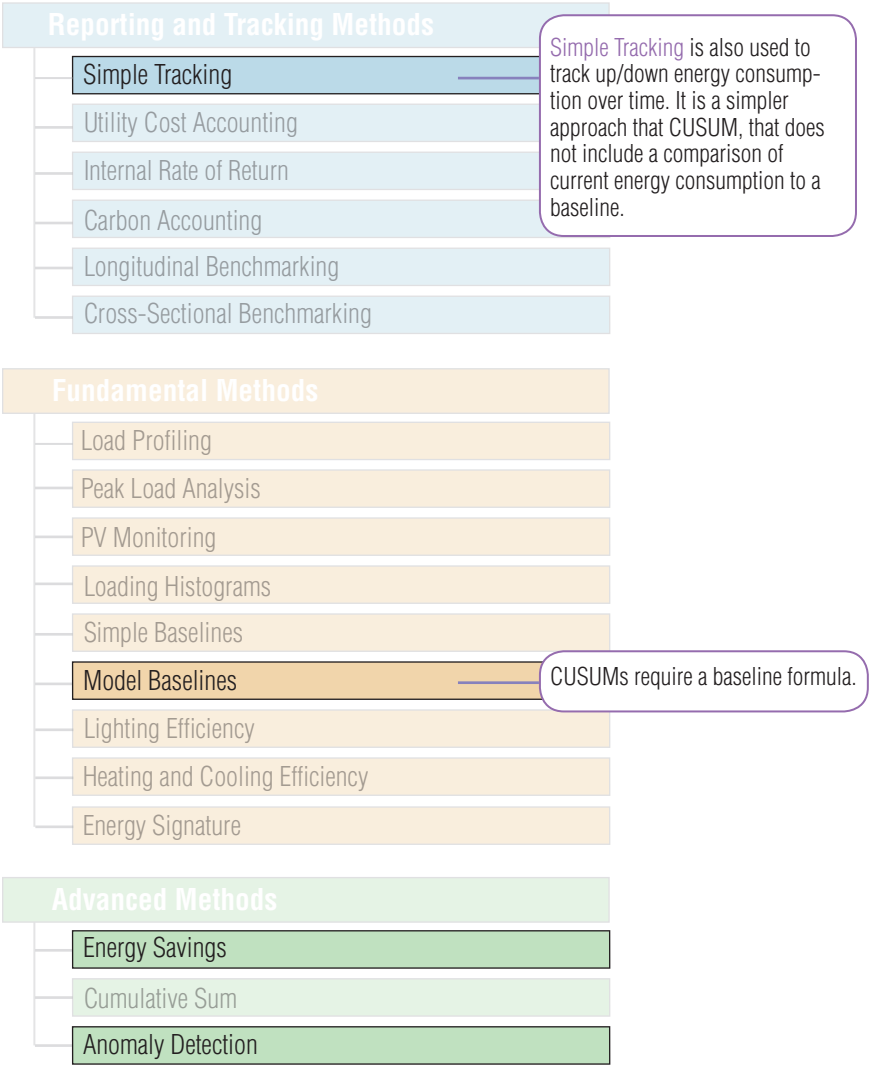
Technical Approach

Subtract actual metered energy use from the energy use projected by a baseline model to quantify a difference. Aggregate those differences over-time to determine the cumulative sum of difference relative to the baseline, or standard operations. Plot time on the x-axis, and plot CUSUM on the y-axis.



Related Methods

The relationship between each of the Advanced Methods, as well as to baselining, is summarized in the introduction to the Advanced Methods chapter.



Calculation and Programming

State of Commercialization: CUSUM is offered preprogrammed in advanced energy information systems, and may be used in fault detection and diagnostic (FDD) routines. The vendor automates the calculation of the cumulative sum, as well as the underlying baseline.

*Computation: You can also use s*tand-alone data analysis or spreadsheet tools to compute and plot cumulative sums.

Step 1: Gather input data.

Data Resolution

The interval depends on how often CUSUM is calculated. Smaller intervals allow for more granular calculations.

1 Hr, 15 Min ◉ Monthly ◉ Annual ○

Data Inputs

High accuracy for metered data is not required, but fill in data gaps before computing. Most critical is the accuracy of data inputs to the baseline model used to predict energy use, such as weather variables.

Metered Data

Baseline Projected

Export building or system-level electric or gas consumption interval data from a BAS or meter acquisition system.

Compute the associated baseline projected energy use

See: **Fundamental Methods: Model Baselines**

Step 2: Calculate the difference between metered data and baseline.

Subtract the baseline projected energy use from the metered energy use.

Step 3: Calculate the CUSUM.

Step 1				Step 2	Step 3
Interval	Time	Metered Use	Baseline Projected Use	Difference	**CUSUM**
1	1:00pm	34	36	= 34-36 = -2	**= -2**
2	2:00pm	28	29	= 2-29 = -1	**= -2 + -1 = -3**
3	3:00pm	30	28	= 30-28 = 2	**= -2 + -1 + 2 = -1**

Step 4: Plot the CUSUM. The x-axis is Time and the y-axis is CUSUM.

Notes

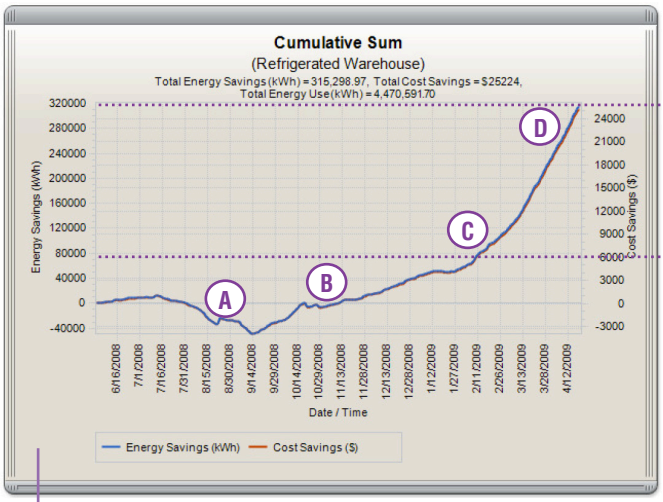
Sketches

Application Examples

Interpretation: A y-value of zero indicates no energy savings, a negative y-value indicates savings, and a positive y-value indicates usage in excess of the baseline. A flat slope marks a period of no change relative to the baseline, a negative slope marks a period of decreased energy use, and a positive slope marks a period of increased energy use.

Example 1: Verification of Energy Efficiency Measures

- **A** The CUSUM dips, marking a period of energy waste.
- **B** Efficiency measures are implemented. CUSUM rises to 70,000 kWh savings.
- **C** More measurements are carried out. The slope steepens, showing additional savings.
- **D** Five-month total cumulative savings reach 320,000 kWh.



Total savings after 5 months

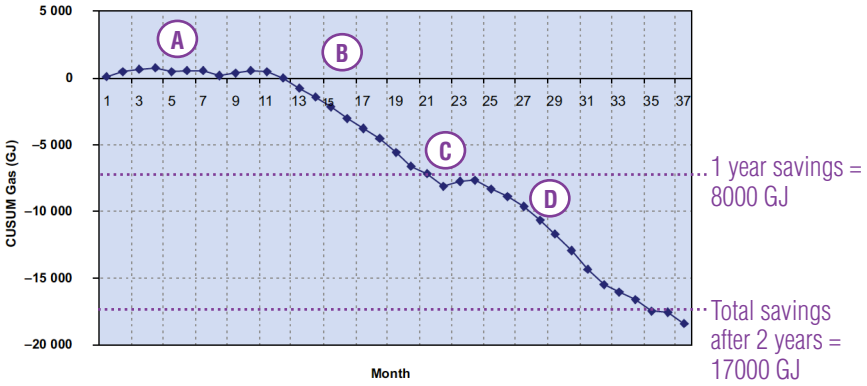
Savings after 3 months

Since energy savings (rather than cumulative sum of differences) are plotted, the sign convention is that positive values represent efficiency improvements, i.e., energy savings.

Source: NorthWrite

Example 2: Ensuring Persistence in Savings

- **A** Months 1-12 form the base year of measurement, and the CUSUM is zero.
- **B** The slope goes negative, reflecting 8,000 gigajoule (GJ) of efficiency savings.
- **C** The CUSUM slope goes positive, indicating lost savings.
- **D** Losses are traced to a missing part, which was replaced, and savings resume.



Source: Office of Energy Efficiency, Natural Resources Canada, Monitoring and targeting techniques in buildings. Cat. No. M144-144/2007E ISBN 978-0-662-45265-2, 2007.

Example 3: Quantifying the Effect of Lost Savings

(A) A new baseline was computed, following efficiency improvements at Month 13 in Example 2.

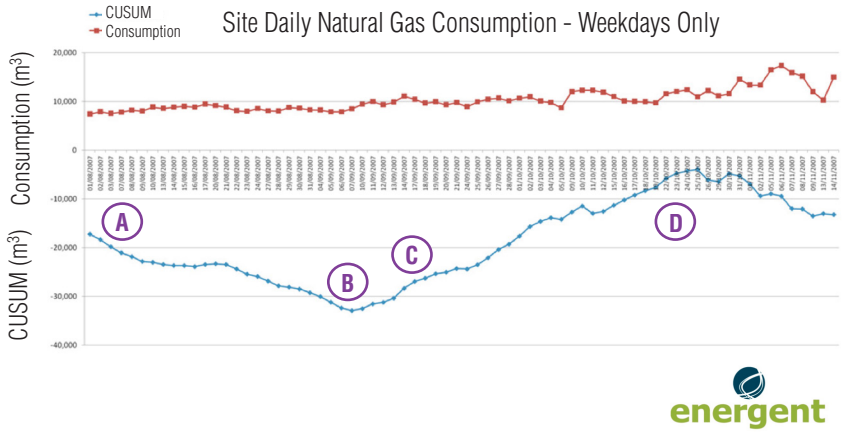
(B) The CUSUM increased due to the lost savings associated with the missing part.

(C) The cumulative lost savings were ~2,000 GJ, with an associated cost of $20K.

Source: Office of Energy Efficiency, Natural Resources Canada, Monitoring and targeting techniques in buildings. Cat. No. M144-144/2007E ISBN 978-0-662-45265-2, 2007.

Example 4: Detecting Waste, and Measurement and Verification

- (A) The CUSUM indicates 15,000 cubic meters (m^3) in total savings.
- (B) After one month the CUSUM indicates 30,000 m^3 in savings.
- (C) The slope changed, indicating waste, and an automated alert was generated.
- (D) A leaking valve was identified and repaired, leading to a new period of savings.



Source: Energent

Purpose

Energy **anomaly detection** is used to automatically identify abnormal energy consumption; it may be paired with alarming and used as part of monitoring-based commissioning routines. It is applicable to all building types and systems. Abnormal energy use can be isolated to a specific system or zone based on a combination of the user's knowledge of the building and supplementary data such as submetered loads, equipment schedules and setpoints, and outside air temperature.

Applicable Systems				
Whole Building	Heating	Cooling	Lighting	Plug Loads
●	●	●	●	●

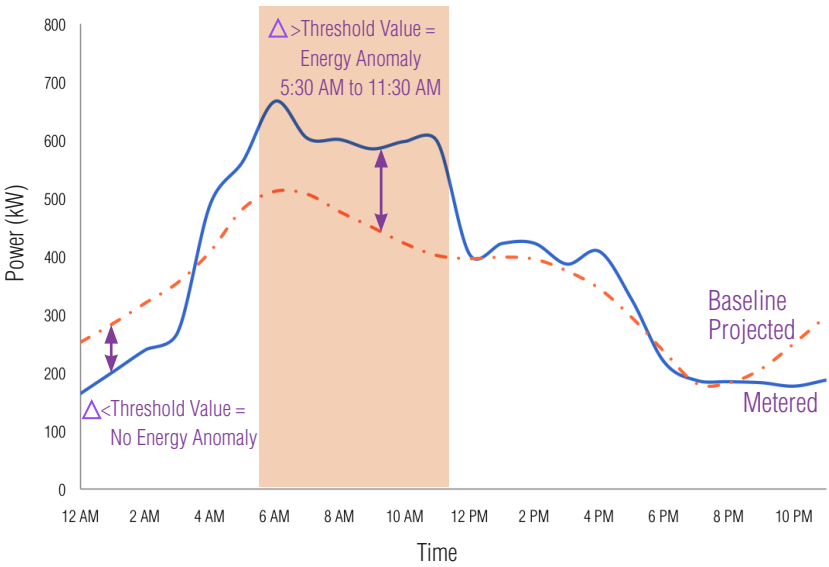
Interpretation		Frequency of Use		
Requires Minimum Expertise	Requires Domain Expertise	Continuous	Monthly	Annual
▬		●		

Facilities Manager

Operator

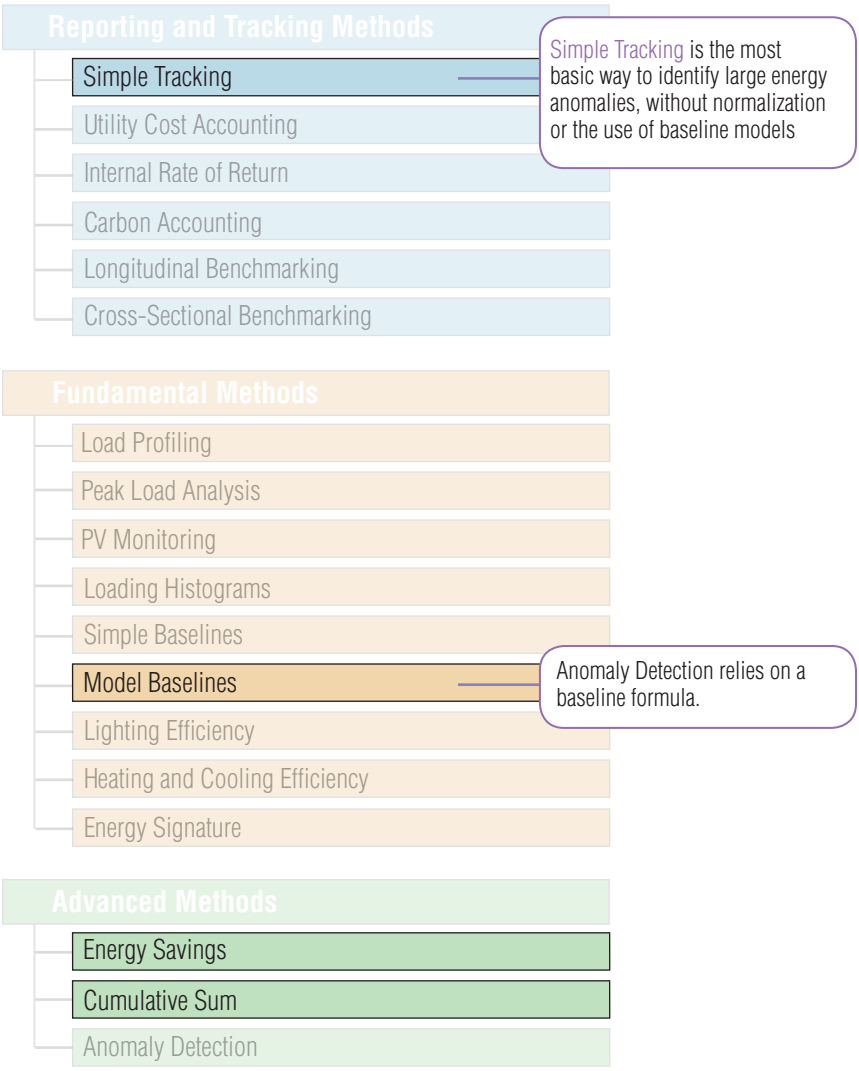
Technical Approach

Compare metered use to the use predicted with a baseline model. If metered use surpasses the prediction by a certain threshold value, you have identified an energy anomaly.



Related Methods

The relationship between each of the Advanced Methods, as well as to Baselining, is summarized in the introduction to the Advanced Methods chapter.



Calculation and Programming

State of Commercialization: Anomaly detection may be offered preprogrammed in advanced energy information systems, and is part of some FDD routines.

Computation: You can also use stand-alone data analysis or spreadsheet tools to perform anomaly detection, as described in the steps below.

Step 1: Gather input data.

Data Resolution

Anomaly detection requires interval electric or gas data at the whole-building or system level.

1 Hr, 15 Min ◉ Monthly ○ Annual ○

Data Inputs

High accuracy for metered data is not required. Fill in data gaps before computing. Ensure an accurate baseline.

Metered Data

Export building or system-level electric or gas consumption interval data from a BAS or meter acquisition system.

Baseline Projected

Compute the associated baseline projected energy use.

See: **Fundamental Methods: Model Baselines**

Step 2: Calculate the difference between metered data and baseline.

Subtract the baseline projected energy use from the metered energy use.

Step 3: Compute the threshold value for each baseline-projected value.

If the difference is greater than the threshold, an anomaly is detected.

Step 1			Step 2	Step 3	
Time	Metered Use	Baseline Projected Use	Difference	**Threshold***	**Anomaly?**
12:00pm	34	36	= 34-36 = -2	**.10(36)=3.6**	**-2>3.6= NO**
12:15pm	28	29	= 2-29 = -1	**.10(29)=2.9**	**-1>2.9= NO**
12:30pm	32	28	= 32-28 = 4	**.10(28)=2.8**	**4>2.8= YES**

*In this example the threshold is 10%.

Step 4: Plot time on the x-axis and metered use on the y-axis. Flag periods for which an anomaly is detected.

Notes

Sketches

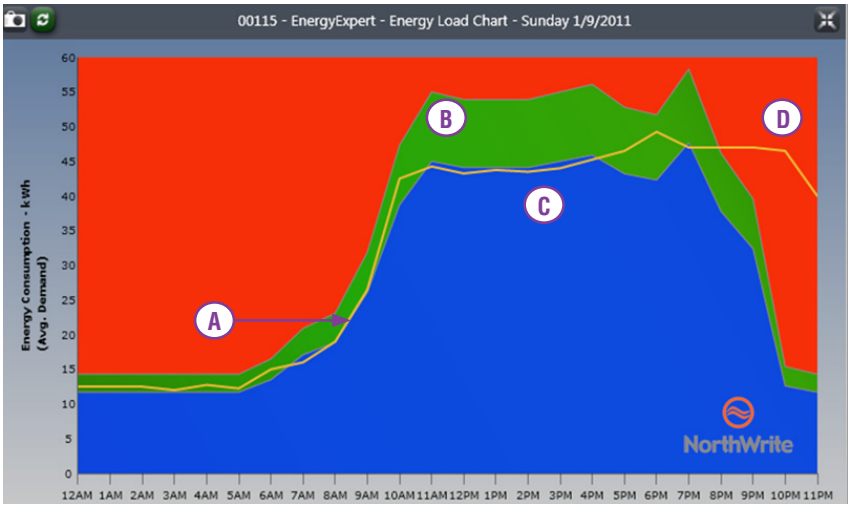
Application Examples

Interpretation: The threshold is not typically determined analytically; rather it is set according to a default value, such as percent different from predicted, which might be adjusted based on the user's experience. Anomaly detection is distinguished from simple alarming, in that baseline models are used to determine projected consumption.

Example 1: Identifying Abnormal Operations

- (A) A 24-hr Sunday load profile is shown for a retail store, with the actual load in yellow.
- (B) The green band shows the projected load +/- the anomaly detection threshold.
- (C) Energy use below that projected lies within the blue area.
- (D) Most of the day the load remains within the green band, but at 7PM it does not fall. Energy use is in the red area, above the projected load, and waste is detected.

  The problem was traced to a controls programming error that prevented initiation of nighttime setbacks.



Source: NorthWrite

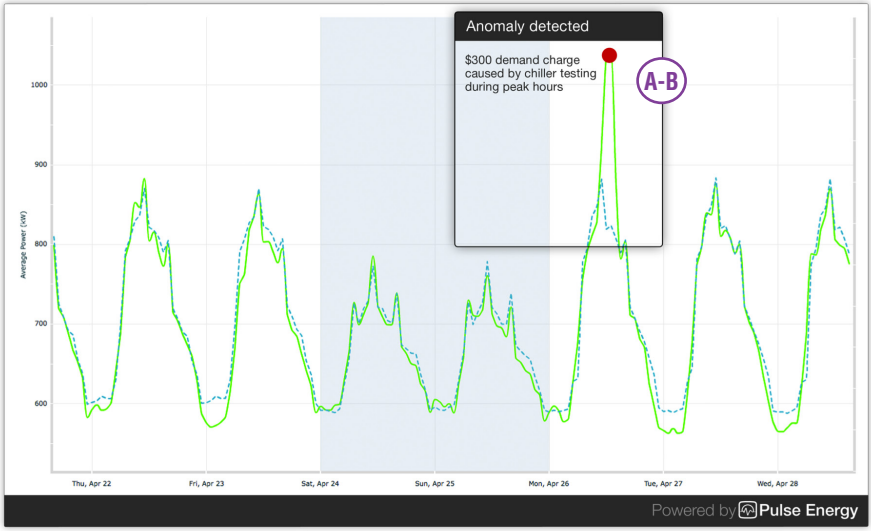
Example 2: Avoiding Excessive Peak Demand Charges

A A hospital experienced high energy consumption on a Monday in late April during the daily peak demand period.

B The spike in energy use led to a $300 peak demand charge.

Hospital staff discovered that the demand charge resulted from chiller performance testing in preparation for the summer cooling period.

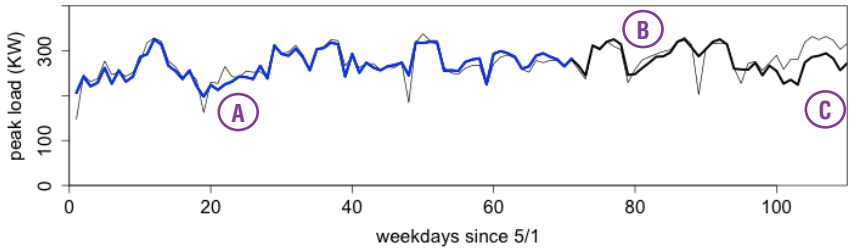
Future chiller testing was rescheduled for non-peak periods to avoid future demand charges.



Source: Pulse Energy

Example 3: Anomaly Detection of Daily Peak Loads

- (A) A baseline (blue line) was constructed from three months of load data (thin line).
- (B) The baseline was used to determine projected loads subsequent to the first three months.
- (C) The actual load consistently exceeds the baseline after weekday 100. Energy anomalies are detected, and it is concluded that the building is faulting.

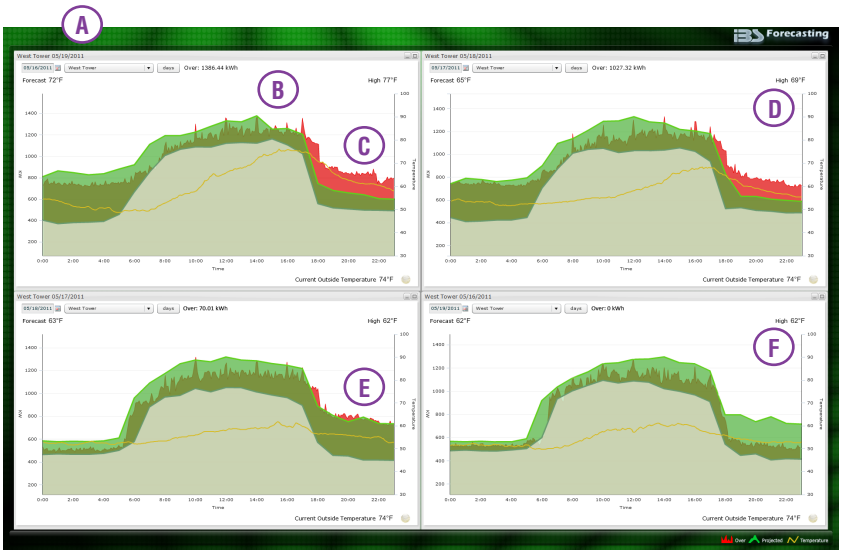


Source: Price, P., Methods for analyzing electric load shape and its variability. LBNL#3713E, 2010.

Example 4: Identifying After-Hours System Overrides

- **A** 24-hr profiles of OAT (yellow line), and projected load (green band), and actual load are shown.
- **B** Actual load is color coded red when above, and olive when within the expected range.
- **C** Excessive after-hours use on Day 1 was traced to a cleaning crew HVAC override.
- **D** On Day 2 the crew was notified, and reduced the load some, but not enough.
- **E** On Days 3 and 4 the expected after-hours load increased due to a repeating monthly event.
- **F** By Day 4, the BAS was programmed to limit HVAC override times, and no waste occurred.

In many software offerings, the range of the projected load is defined by the baseline-projected load, +/- the anomaly detection threshold.



Source: Integrated Building Solutions

Introduction

Poorly maintained, degraded, and improperly controlled equipment wastes an estimated 10% to 30% of the energy used in commercial buildings. Much of this waste could be prevented with widespread adoption fault detection and diagnostics (FDD), an area of investigation concerned with automating the processes of detecting faults in physical systems and diagnosing their causes.

For many years, FDD has been used in the aerospace, process controls, automotive, manufacturing, nuclear, and national defense fields. Over the last two decades, efforts have been undertaken to bring automated fault detection, diagnosis, and prognosis to the heating, ventilating, air conditioning, and refrigeration (HVAC&R) field. Although FDD is well established in other industries, it is still in its infancy in HVAC&R. Commercial tools using these techniques are only beginning to emerge in this field. Nonetheless, considerable research and development has targeted the development of FDD methods for HVAC&R equipment.

This chapter provides an overview of FDD, including descriptions of fundamental processes, important definitions, and examples that building operators and managers can implement using data collected from the building automation systems or dedicated logging devices.

The Generic FDD Process

The primary objectives of an FDD system are to detect faults early and to diagnose their causes, enabling building managers to correct the faults, to prevent energy waste, additional damage to the system, or loss of service. In most cases, fault detection is easier than diagnosing the cause of the fault or evaluating the impacts arising from it. FDD itself is frequently described as consisting of three key processes:

1. Fault detection: Determination that a fault has occurred in the system
2. Fault isolation: Determination of the specific fault that occurred including it's type, location, and time of detection
3. Fault identification: Determination of the size and time-variant behavior of a fault

Together, fault isolation and fault identification are commonly termed fault *diagnosis.*

Applications for FDD in Buildings

Automated FDD shows promise in three basic areas of building engineering: (1) commissioning/retro-commissioning, (2) operation, and (3) maintenance. However this handbook primarily focuses on operation. During building operation, FDD tools can detect and diagnose performance degradation and faults, many of which go undetected for weeks or months in most commercial buildings. Many building performance problems are compensated automatically by controllers so occupants experience no discomfort, but the penalty is often increased energy consumption and operating costs. Automated FDD tools could detect these, as well as more obvious problems.

Automated FDD tools not only detect faults and alert building operation staff to them, but also identify causes of those problems so that maintenance efforts can be targeted, ultimately lowering maintenance costs and ensuring good operation. When coupled with knowledge bases on maintenance procedures, other tools can provide guidance on actions to correct the problems identified by FDD tools. By detecting performance degradation rather than just complete failure of a physical component, FDD tools could also help prevent catastrophic system failure by alerting building operation and maintenance staff to impending failures before actual failure occurs. This would enable convenient maintenance scheduling, reduced down time from unexpected faults, and more efficient use of maintenance staff time leading to condition-based maintenance practices.

FDD Implementation

Fault detection and diagnostics can be performed "manually" through visual inspection of charts and trends or can be fully automated. For example, the temperature of the supply air provided by an air-handling unit might be observed to be too high chronically during hot weather. This conclusion can be drawn by visually inspecting a time series plot of the supply-air temperature, for example, within a building automation system. Alternatively, an FDD system could be automated. A computer algorithm could process these data continuously to reach this same conclusion, reporting the condition via an alarm to the operator. Automated diagnostics generally goes a step further, and might conclude for example, that the outside-air damper is stuck fully open. As a result, during hot weather, too much hot and humid outdoor air would be brought in, increasing the mechanical cooling required and exceeding the capacity of the mechanical system for cooling; which would explain the chronically high supply-air temperature. This is a process that can be integrated into a commissioning process.

Visual FDD, Application Examples

Air-side economizers can obtain free cooling by using cool outdoor air in place of (or to supplement) mechanical cooling when outdoor conditions are suitable for doing so. Unfortunately, economizers often do not work properly, causing energy-use penalties rather than savings.

Interpretation: Several common incorrect behaviors of economizers result from: incorrect control strategies, stuck dampers, disconnected or damaged damper linkages, failed damper actuators, disconnected wires, obstructions preventing damper movement, and failed and out-of-calibration sensors.

A number of these incorrect operations can be detected visually by plotting the relevant data. Although there are a number of different ways that economizers can be controlled, in general, when the zone conditions are calling for cooling, and if the return-air temperature (RAT) (or energy content) is greater than outdoor-air temperature (or energy content), the conditions are favorable for economizing. Sometimes all the cooling needs can be met by outside air. When the outdoor-air temperature (OAT) is less than or equal to the discharge-air temperature (DAT) setpoint, no mechanical cooling is necessary. When the outdoor-air temperature is higher than the discharge-air setpoint, some mechanical cooling is need to supplement free cooling. By analyzing the data visually you can detect a number of problems with economizer operations. The following three examples illustrate visual FDD for economizers, using plots of outdoor-air, return-air, mixed-air (MAT), and discharge-air temperatures versus time.

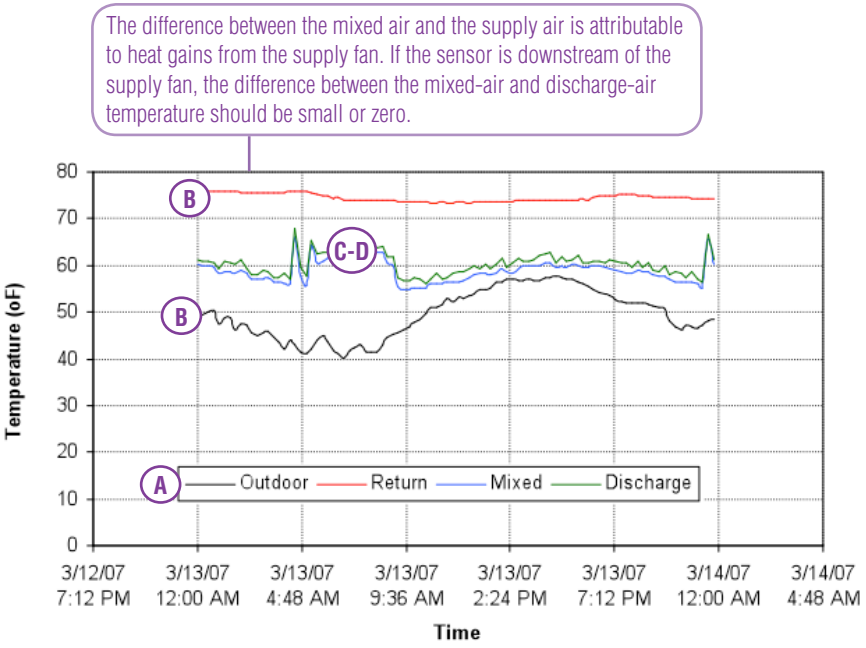
Example 1: Properly Operated Outside Air Economizer

(A) One day of temperature data is plotted: OAT, return air, mixed air, and discharge air. The return-air temperature varies between 72°F and 75°F.

(B) OAT is lower than the RAT, and is therefore acceptable for economizing.

(C) DAT closely tracks MAT, indicating no use of mechanical cooling.

(D) Discharge and mixed air trends also indicate proper modulation of outside airflow. In this example the MAT sensor is located upstream of the supply fan.



Source: Pacific Northwest National Laboratory

Example 2: Economizer Fault, Damper Stuck Fully Closed

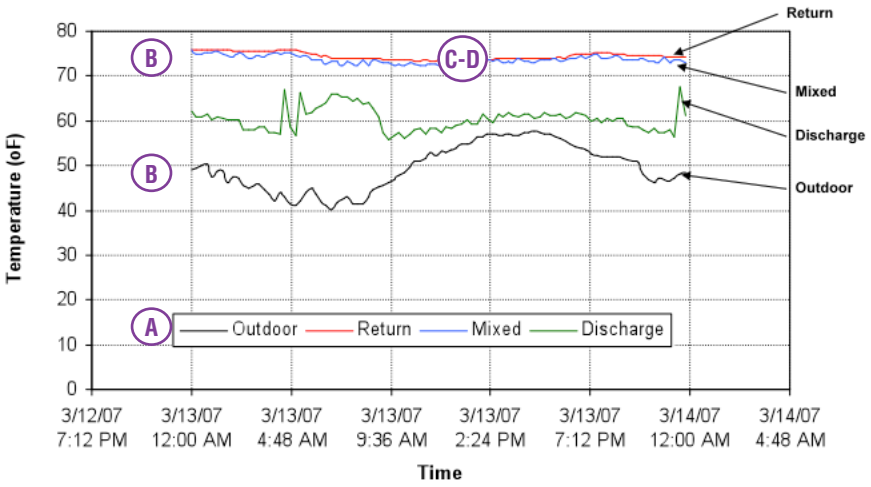
(A) One day of temperature data is plotted: OAT, return air, mixed air, and discharge air.

(B) OAT is lower than the RAT, and is therefore acceptable for economizing.

(C) MAT tracks RAT, indicating that outdoor air is not entering the mixing box.

(D) The outdoor air damper is not opening, as it should be.

Potential causes are a stuck damper or failed or disconnected actuators or linkages.



Source: Pacific Northwest National Laboratory

Example 3: Economizer Fault, Damper Stuck Fully Open

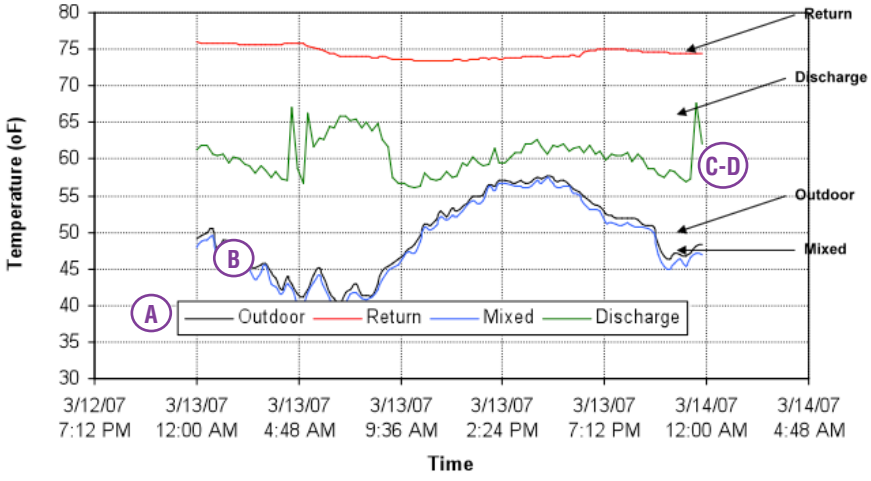
(A) One day of temperature data is plotted: OAT, return air, mixed air, and discharge air.

(B) MAT tracks OAT, indicating that the outdoor air damper is fully open.

(C) Since the discharge air setpoint is higher than OAT, the damper should not be fully open.

(D) The outdoor air damper is not closing, although it should be.

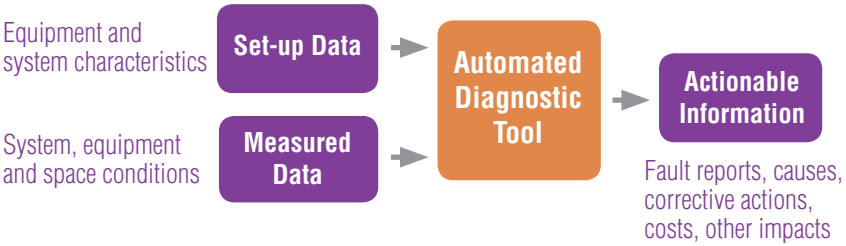
Potential causes are a stuck damper or failed or disconnected actuators or linkages.



Source: Pacific Northwest National Laboratory

Automated FDD

An automated FDD (AFDD) process uses measured time-series data and set-up data that describes the equipment and system characteristics (such as setpoints and type of control) to create actionable information to help building operations staff make informed decisions, as shown below.



In addition to the data, the basic building blocks of automated FDD systems are the methods for detecting faults and diagnosing their causes. Approaches to FDD range from methods based on physical and analytical models based entirely on first principles, to those driven by performance data and using artificial intelligence or statistical techniques. Both approaches use models and both use data, but the approach to formulating the diagnostics differs fundamentally.

First-principle model-based approaches use a priori knowledge to specify a model that serves as the basis to identify and evaluate differences (residuals) between the actual operating states determined from measurements and the expected operating state and values of characteristics obtained from the model.

Purely process data-driven approaches use no a priori physical knowledge of the process. Instead, they are dervied solely from measurement data and therefore may not have any direct physical significance.

Rule-based methods, broadly classified as first-principle qualitative models, are most commonly employed in commercial FDD solutions. (Qualitative relationships or rules derived from knowledge of the underlying system operation.) Strengths of these models are:

1. They are well-suited for data-rich environments and non-critical processes.
2. They are simple to develop and apply.
3. They employ transparent reasoning, and provide the ability to reason even under uncertainty.
4. They possess the ability to provide explanations for the suggested diagnoses because they rely on cause-effect relationships.
5. Some provide the ability to perform FDD without precise knowledge of the system and exact numerical values for inputs and parameters.

Weaknesses of these models include:

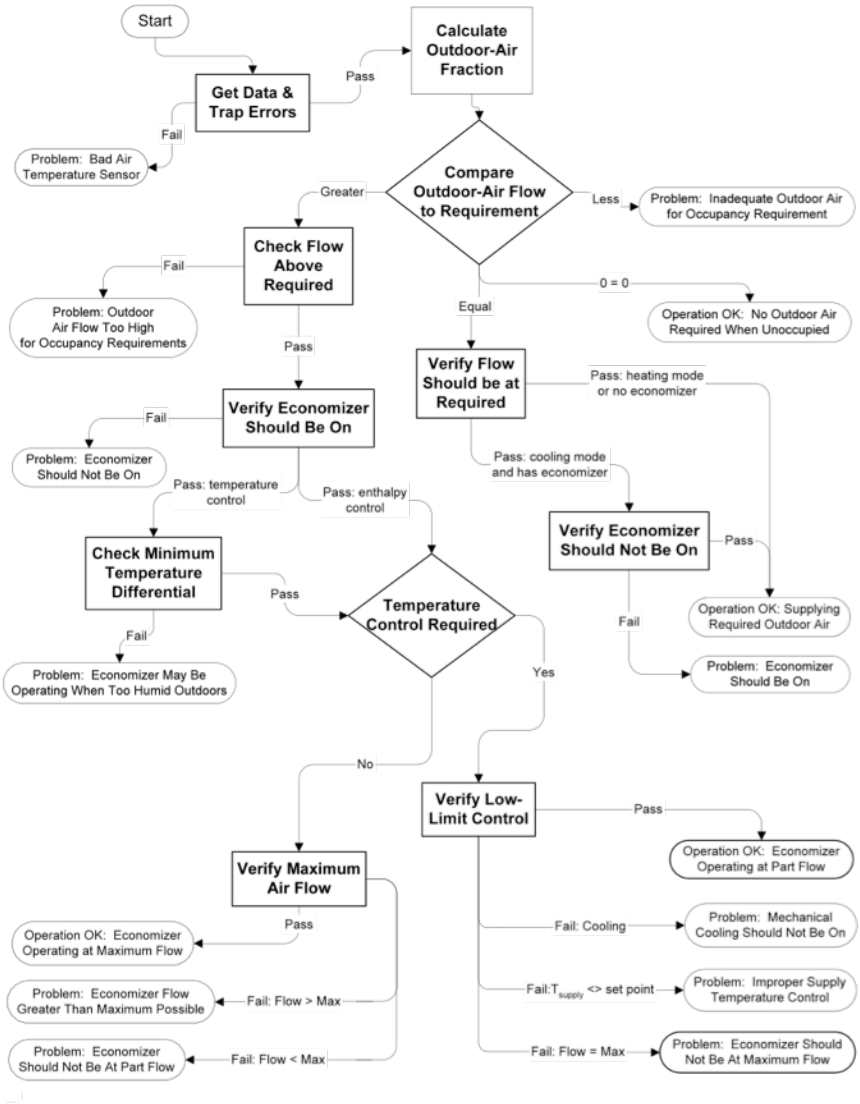
1. The methods are specific to a system or a process.
2. Although they are easy to develop, it is difficult to ensure that all rules are always applicable, and to find a complete set of rules, especially when the system is complex.
3. As new rules are added to extend the existing rules or accommodate special circumstances, the simplicity is lost.
4. To a large extent, they depend on the expertise and knowledge of the developer.

For information on the various methods used for AFDD please refer to the References and Technical Resources.

AFDD of Air Handler Unit Operations

As part of its mission in commercial buildings research and development, the U.S. Department of Energy (DOE) collaborated with industry to develop a tool that automates detection and diagnosis of problems associated with outdoor-air ventilation and economizer operation. The tool, known as the outdoor-air economizer (OAE) diagnostician, monitors the performance of air handler units (AHUs) and detects problems with outside-air control and economizer operation, using sensors that are commonly installed for control purposes.

The tool diagnoses the operating conditions of AHUs using rules derived from engineering models of proper and improper air-handler performance. These rules are implemented in a decision tree structure in software. You can use data collected periodically (such as that from a building automation system) to navigate the decision tree and reach conclusions regarding the AHU's operating state. At each point in the tree, a rule is evaluated based on the data, and the result determines which branch the diagnosis follows. The AHU's current condition is revealed when you reach the end of a branch. The following figure illustrates the logic tree used to identify operational states and to build the lists of possible failures.

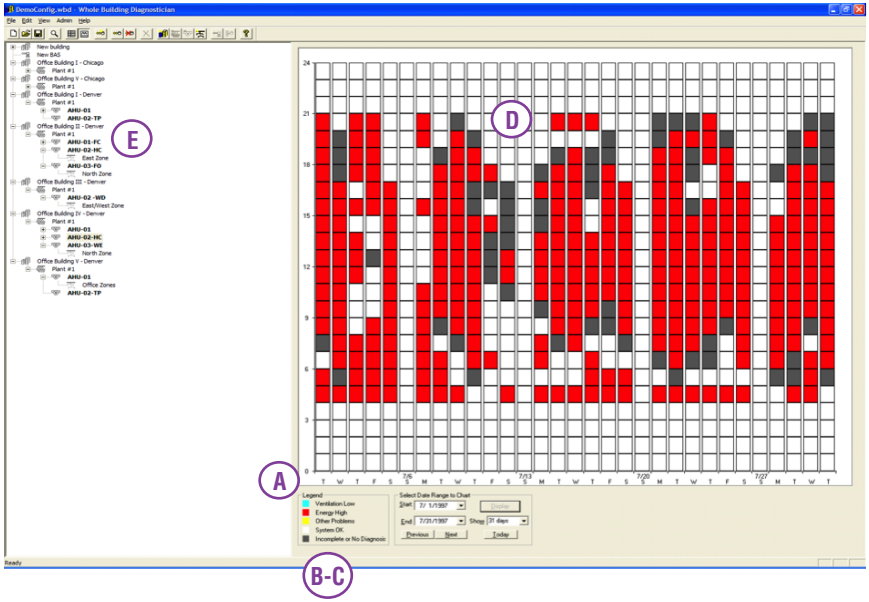


The boxes represent major sub-processes necessary to determine the operating state of the air-handler, the diamonds represent tests, i.e., decisions, and ovals represent end states that contain brief descriptions of “OK” and “not OK” states. Only selected end states are shown in this overview. The detection and diagnostic implementation details are provided in the literature by PECI and Battelle, and Katipamula et al. in the References and Technical Resources.

The outdoor air economizer diagnostician offers a variety of graphical displays; two examples are presented.

Example 4: OAE Diagnostician, Visual Display

- (A) Days of the week are plotted on the x-axis, with hours of the day on the y-axis.
- (B) Each hour of the day is color coded according to one of five diagnostic findings.
- (C) Though not present in the example, blue denotes low ventilation, and yellow is a catchall for "other" problems.
- (D) White indicates fault-free operations; red, a high-energy fault; and gray, no diagnosis.
- (E) An object tree allows the user to navigate between sites and air handlers.



Source: Outside Air Economizer Diagnostician

Example 5. OAE Diagnostician, Fault Descriptions

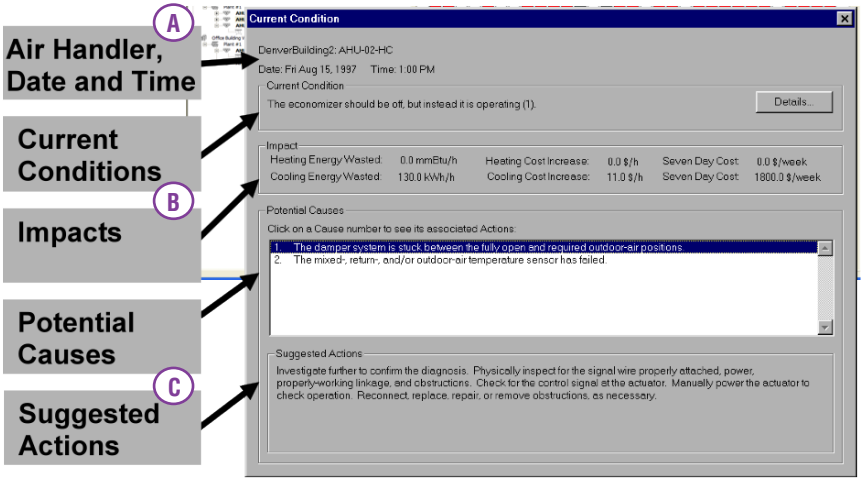
The OAE Diagnostician has the capability to generate problem summaries

Each summary describes:

A. The associated equipment, date, and time

B. Current conditions and cost impacts

C. Potential causes and suggested corrective actions



Source: Outside Air Economizer Diagnostician

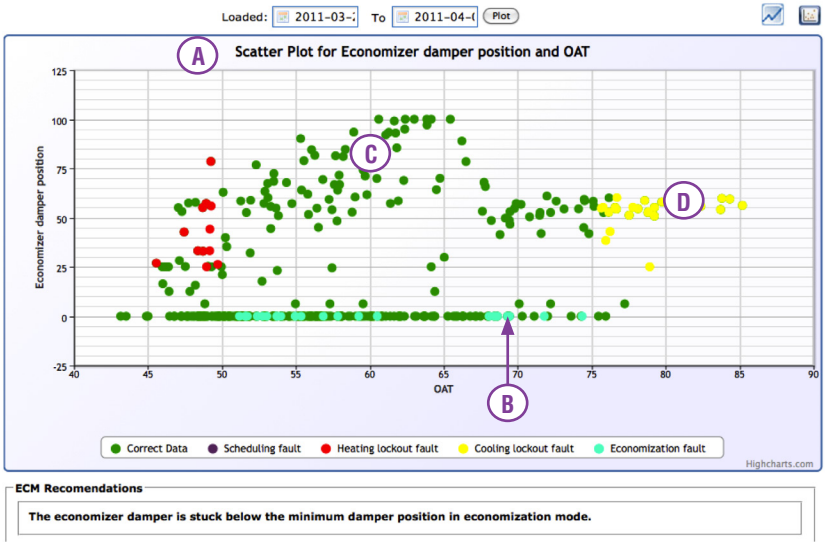
This display from a commercial energy information system illustrates another example of rule-based automated fault detection and tools.

Example 6: AFDD in a Large Commercial Office

The AFDD engine identifies operational inefficiencies in air handler units (AHUs).

- (A) A plot of damper position vs. OAT is color coded to show faulty and correct operations.
- (B) The light blue points show when the dampers are closed, even though "free cooling" is available.
- (C) Green points correspond to fault-free operations.
- (D) Yellow points indicate cooling lockouts, and red indicate heating lockouts.

Though not present in this example, purple is designated for scheduling faults.



Source: Serious Energy

References and Technical Resources

*All URLs provided for documents available on the Internet were accessed in the summer and fall of 2011.

Brambley, MR, Pratt, RG, Chassin, DP, and Katipamula, S. Automated diagnostics for outdoor air ventilation and economizers. ASHRAE Journal, Vol. 40, No. 10, pp. 49-55, October 1998.

This article discusses deployment of new automated diagnostic tools for building operation.

Friedman, H, Crowe, E, Sibley, E, Effinger, M. The Building performance tracking handbook: Continuous improvement for every building. Prepared by Portland Energy Conservation for the California Energy Commission. California Commissioning Collaborative, 2011. Available from: http://www.cacx.org/PIER/documents/bpt-handbook.pdf.

Handbook presenting basic concepts in tracking the energy performance of commercial buildings, including overall strategies, and FDD and other tool types.

Katipamula, S and Brambley, MR. Methods for fault detection, diagnostics and prognostics for building systems- A review part I." HVAC & R Research 11(1):3-25. 2005.

This paper provides an overview of FDD and prognostics (FDD&P), including definitions and descriptions of the fundamental processes, a review of research in HVAC and refrigeration, and a discussion of the current state of applications in buildings.

Katipamula, S and Brambley, MR. Methods for fault detection, diagnostics and prognostics for building systems - A review part II." HVAC & R Research 11(2):169-187. 2005.

This paper provides the second portion of an overview of FDD and prognostics (FDD&P), including definitions and descriptions of the fundamental processes, a review of research in HVAC and refrigeration, and a discussion of the current state of applications in buildings.

Katipamula, S, Pratt, RG, Chassin, DP, Taylor, ZT, Gowri, K, and Brambley, MR. Automated Fault Detection and Diagnostics for Outdoor-Air Ventilation Systems and Economizers: Methodology and Results from Field Testing. ASHRAE Transactions, Vol. 105 Pt. 1. 1999.

Article presenting field testing results of the OAE diagnostician.

Ulickey, J, Fackler, T, Koeppel, E, Soper, J. Characterization of fault detection and diagnostic (FDD) and advanced energy information systems (EIS) tools. Report for Project 4, Building Performance Tracking in Large Commercial Buildings: Tools and Strategies. September, 2010. California Commissioning Collaborative; California Energy Commission. Available from http://www.cacx.org/PIER/documents/Subtask_4-3_Report.pdf.

Report covering the evaluation and characterization of energy performance tracking tools, with a focus on FDD tools in particular.

Discussion

This Appendix provides additional details and references for each of the analysis methods summarized in the main chapters of the handbook. The Appendix material is divided into the following headings:

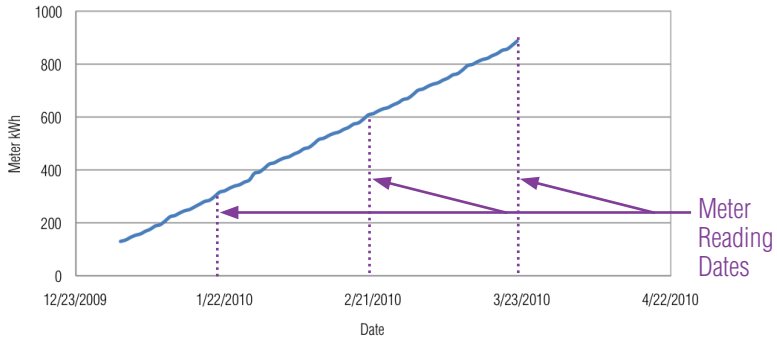
Technical and Analytical Details expands on the material presented in the first page summary of each method.

Use and Presentation describes the type of information the method entails, new knowledge that the method generates, and any recommended actions.

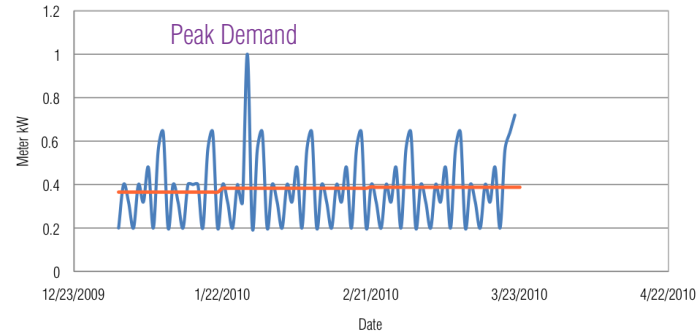
References and Technical Resources lists resources with brief descriptions for additional information. All URLs provided for documents available on the Internet were accessed in the summer and fall of 2011.

Technical and Analytical Details

Usage refers to the amount of energy measured by the meter in a particular interval of time. *Meter readings* are the value shown on the display at the time it is read. Often meters have a display that continuously increases. The usage for each interval is the difference between the meter readings, as indicated by the arrows in the image below. You can calculate the average power of electric usage in a period by dividing the energy use by the number of hours in the period. The bottom image below shows electric power, with a peak demand of 1 kW, for the same time period as the meter reading in the top image. The highest electric power in the period is recorded and set as the peak demand for that period, as shown in the bottom image. These concepts are also illustrated in the table that follows the images.



Source: New Buildings Institute



Source: New Buildings Institute

Start Date	End Date	Meter Reading Start	Meter Reading End	Usage	Average kWh per Day	Average Power	Peak Power
1/22/2010	2/21/2010	321	613	292	9.7	0.36	1.0
2/21/2010	3/22/2010	613	905	274	9.44	0.39	0.72

Energy usage is expressed in units that are convertible. Whole-building energy use is commonly expressed as an Energy Use Intensity (EUI) in kBTU/sf/yr (that is, in thousands of BTU per square feet per 365-day year). All electrical usage is converted to kBTU and added to the total usage of the other fuels and the heat/chilled water consumption. The table below summarizes common units of energy for building fuel use. Note that each fuel type has a specific rate of conversion from volume or mass to energy content.

Fuel	Energy Unit	Rate of Energy Use Unit
Electric	kilowatt-hour (kWh)	kilowatt (kW)
Gas	Btu or therm (100,000 Btu)	Btu per Hour (BtuH)
Hot or chilled water	Btu	BtuH
Steam	Btu	BtuH
Oil	Gallons or Btu*	Gallons per minute or BtuH
Photovoltaic	kWh	kW

* The energy content of oil and liquid fuel depends on the type. Each fuel type will have a Btu/gallon conversion that can be found in standard references.

It is important to use a consistent method for labeling the data in simple tracking. Billing periods and meter readings occur approximately monthly; however, submeter data may be available at hourly intervals or less. Synchronize meter readings of fuel meters and submeters to ensure that the periods of energy measurement align as closely as possible. Often the end meter reading is used as the date/time association for the usage, but you can also use the initial date/time reading. If the readings are not exactly aligned with month start and end dates, then you can use an approximate monthly label (June, July, etc.) or annual period (2004, 2005).

Start Date	End Date	Average kWh per Day	Average Power	Peak Power	Possible Labels
1/22/2010	2/21/2010	9.7	0.36	1.0	1/22/2010; February; 2/2010; Month 2
2/21/2010	3/22/2010	9.44	0.39	0.72	2/21/2010; March; 3/2010 ; Month 3

Dividing energy use by the number of days in the metering period is useful in aligning data from energy bills that may have different read dates. This strategy is recommended particularly for utility bill data, which can have widely varying bill period durations. Energy usage per square foot is discussed in simple baselines, and provides a simple means for comparing one site's energy use to another. Most often used is Gross Square Footage, which includes conditioned and unconditioned spaces, though usually excludes parking lots and underground parking garages.

Use and Presentation

Simple tracking is primarily focused on quantifying energy use and identifying up/down consumption changes. Use normalization when comparing energy use from one time period to another, or from one building to another. The Simple Baseline method details this concept; however, the table below provides a brief list of tracking points and normalized units. *Primary heating and cooling equipment* refers to equipment that generates the cooling fluid (air, water, or refrigerant) for the building. This could be a roof-top unit or a chiller but would not include the associated pumps, or fan powered boxes that distribute the cooling.

Level	Type	Period	Unit
Whole Building	Total Energy	Annual	EUI
	Electric	Monthly	Average energy per day
			Peak demand
			Load factor
	Gas	Monthly	Average energy per day
	Other Fuels	Monthly	Average energy per day
Systems	Heating	Monthly	Average energy per day
	Cooling	Monthly	Average energy per day
	Tenant Sub-Meters	Monthly	Average energy per day
	Lighting	Monthly	Average energy per day
	Plug Loads	Monthly	Average energy per day
Components or Equipment	Primary Cooling Eq.	Monthly	Average energy per day
	Primary Heating Eq.	Monthly	Average energy per day
Photovoltaic	Energy Output	Weekly or Monthly	Average energy per day

References and Technical Resources

Farnsworth, G. Performance benchmarking with energy bill data: Making the most of your energy accounting software. E SOURCE, Corporate Energy Managers' Consortium, CEMC-7, January 2006. Available from http://www.esource.com/esource/preview_list/20708.

Report reviewing energy accounting software tools in the context of benchmarking. Baseline considerations such as weather, production, and normalization are presented, with conclusions as to useful reporting, tool selection, and technical challenges.

Friedman, H, Crowe, E, Sibley, E, Effinger, M. The Building performance tracking handbook: Continuous improvement for every building. Prepared by Portland Energy Conservation for the California Energy Commission. California Commissioning Collaborative, 2011. Available from http://www.cacx.org/PIER/documents/bpt-handbook.pdf.

Handbook presenting basic concepts in tracking the energy performance of commercial buildings, including overall strategies, benchmarking, metrics, and a variety of tool types.

Granderson, J, Piette, MA, Ghatikar, G, Price, P. Building energy information systems: State of the technology and user case studies. Lawrence Berkeley National Laboratory, November 2009, LBNL-2899E. Available from http://eis.lbl.gov/pubs/lbnl-2899e.pdf.

Report containing a market characterization of energy information systems and related performance tracking tools, including common and advanced features and capabilities.

Hooke, JH, Byron, JL, Hart, D. Energy management information systems: achieving improved energy efficiency: a handbook for managers, engineers and operational staff. 2004. Office of Energy Efficiency of Natural Resources Canada, Cat. no. M144-54/2004E, ISBN 0-662-38024-X. Available from http://oee.nrcan.gc.ca/publications/industrial/EMIS.

Implementation handbook on energy information system technology, including metering, data collection, data analysis, reporting and cost/benefit analyses.

Northwest Energy Efficiency Alliance. Performance indicators: Better Bricks. Available from http://www.betterbricks.com/building-operations/tools/performance-indicators-0.

Website with instructional information on building performance indicators, including best practices and concepts relevant to metrics, data and tools.

Sullivan, GP, Hunt, WD, Pugh, R, Sandusky, WF, Koehler, TM, Boyd, BK. Metering best practices: A guide to achieving utility resource efficiency, Release 2.0. Federal Energy Management Program, US Department of Energy, August 2011. Available from http://www1.eere.energy.gov/femp/pdfs/mbpg.pdf.

Resource for federal facility energy management and technical staff covering energy metering, data acquisition and applications, and federal energy management mandates; concepts are also applicable to achieving energy and cost savings in non-federal facilities and portfolios.

Technical and Analytical Details

According to the Energy Information Administration's Commercial Buildings Energy Consumption Survey, electricity and natural gas are the most common fuels in commercial businesses, present in 95% and 51%, respectively, of U.S. commercial buildings. Chargers for electricity and natural gas were summarized in the primary handbook content. Other hydrocarbon fuels, and heated and chilled water or steam, are each present in 10% or less of buildings, and are usually charged in terms of an energy use charge per BTU delivered to the building in the billing period. Oil is sometimes delivered by a private company and can be difficult to associate with an energy charge unless the specific deliver amount and price is collected or a separate oil meter is used.

The billing periods for gas and electricity may not match, making it difficult to apply utility accounting to sub-meters, so it is useful to normalize usage by the number of days in the billing period. Demand charges associated with gas or electric use are difficult to distribute to submeters because their contribution to the total peak demand is difficult to determine. Frequently a bundled "charge per unit" of energy can be used to allocate utility cost to submeters because it is much simpler to calculate. There also may be one simple energy charge for different time-of-use rate categories. Electric and gas charges vary by month, but it can be difficult to keep up with this variation and so one simple energy charge is carried through the year. As long as the simple charge doesn't vary by more than a small percentage it will not significantly affect calculations.

Though simple energy and demand charges are still common for many utility commercial customers, especially those in smaller commercial buildings, more complex rate structures are become increasingly available, and energy managers should be aware of how these apply to their portfolio. This Appendix's references and technical resources cover these concepts in detail. In general, utilities structure rates to cover the costs that they themselves face, including customer costs, energy and commodity costs, and demand costs. These translate into billed charges, e.g., a flat fee to cover customer billing costs, a cost per unit of energy or commodity, and a charge to deliver the energy that you need, when you need it. These are referred to as: *customer charges, energy charges,* and *demand charges*.

Demand charges may not occur monthly. A *ratcheted demand charge* is an annual or season quantity that reflects the highest peak demand in the year or season and measures what the utility must be able to provide that to your facility. Demand charges may also be priced in reactive power (kVAR) measurements. *Reactive power* is a measurement of how well the customer's electric system characteristics match the utility power supply. Energy charges may be tiered, so that the first "block" of energy use in the billing period carries a given charge, with additional use above this block carrying a different, usually lower charge. With more innovative time-of-use (TOU) rates, energy costs may vary by the day of the week and time of day, by the existence of infrequent "critical" situations, or even hourly, in what's called *real-time pricing*. Natural gas rates are usually priced in dollars per MBtu, therm, or hundred cubic feet (CCF). Some gas utilities have demand charges based on the highest usage in a shorter period of time; for example, the highest daily usage. Natural gas deregulation has allowed some parts of the country to disaggregate charges and to offer

the customer the ability to selectively choose suppliers. These "unbundled" services include: balancing, procurement, storage, and transportation. Fixed or monthly varying rates can be negotiated with the utility and energy suppliers. In some parts of the country with particularly cold winters, the gas utility offers an '"interruptible rate," which is usually a reduced rate offered to facilities that can change fuels, usually to oil, in periods when demand for gas is highest.

Use and Presentation

Utility cost accounting gives the financial manager a clear view of the cost impacts and benefits of facility-related actions. In contrast, savings expressed in energy units or percentages do not convey financial impacts, which are often the deciding factor in building energy decision making.

In portfolio management, the cost per square foot of annual energy use is a valuable way to set goals and maintain oversight on energy use and costs within a portfolio of buildings. This is enhanced by the addition of submetered data and associated costs for systems and even components, though this level of detail becomes overwhelming unless it is well managed in the context of a continuous approach to energy management. For example, in addition to the annual cost per square foot of the whole building, the heating or cooling cost per square foot could track key drivers of overall building costs.

A number of presentations are commonly used to display the results of utility cost accounting. Spreadsheets are also commonly used for all manner of accounting, including utility costs and the examples provided in the main summary: illustrated tables, bar and pie charts, and typical utility bills. The specific form of the graphic presentation depends on the particular question the analyst wishes to answer, or on the specific software tool. For example, the upper portion of the image below shows a case in which energy costs are totaled for each hour of the day and plotted to compare one month to the next; the lower image shows energy costs totaled for each day of the week, which are plotted to compare for consecutive months.

Source: Schneider Electric

References and Technical Resources

Farnsworth, G. Performance benchmarking with energy bill data: Making the most of your energy accounting software. E SOURCE, Corporate Energy Managers' Consortium, CEMC-7, January 2006. Available from http://www.esource.com/esource/preview_list/20708.

Report reviewing energy accounting software tools in the context of benchmarking. Baseline considerations such as weather, production, and normalization are presented, with conclusions as to useful reporting, tool selection, and technical challenges.

Hooke, JH, Byron, JL, Hart, D. Energy management information systems: achieving improved energy efficiency: a handbook for managers, engineers and operational staff. 2004. Office of Energy Efficiency of Natural Resources Canada, Cat. no. M144-54/2004E, ISBN 0-662-38024-X. Available from http://oee.nrcan.gc.ca/publications/industrial/EMIS.

Implementation handbook on energy information system technology, written for all levels of management and operational staff, including metering, data collection, data analysis, reporting and cost/benefit analyses.

Northwest Energy Efficiency Alliance. Performance indicators: Better Bricks. Available from http://www.betterbricks.com/building-operations/tools/performance-indicators-0.

Website with instructional information on building performance indicators, including concepts relevant to utility data, metrics, data and tools.

Sullivan, GP, Hunt, WD, Pugh, R, Sandusky, WF, Koehler, TM, Boyd, BK. Metering best practices: A guide to achieving utility resource efficiency, Release 2.0. Federal Energy Management Program, US Department of Energy, August 2011. Available from http://www1.eere.energy.gov/femp/pdfs/mbpg.pdf?q...best-practices-guide.

Resource for federal facility energy management and technical staff covering energy metering, data acquisition and applications, and federal energy management mandates; concepts are also applicable to achieving energy and cost savings in non-federal facilities and portfolios.

US Energy Information Administration, US Department of Energy. Energy Information Administration: Commercial Building Energy Consumption Survey. 2003. Available from http://www.eia.gov/emeu/cbecs/contents.html.

The Commercial Buildings Energy Consumption Survey (CBECS) is a national data set for the stock of U.S. commercial buildings, their energy-related building characteristics, and energy consumption and expenditures. CBECS data is often used for benchmarking.

Technical and Analytical Details

Implicit in the cash flows that are explicitly represented in the internal rate of return (IRR) equation, you must determine an appropriate measure life over which energy cost savings will accrue, and therefore the time over which you will compute IRR. Beyond equipment and energy costs, other measure-specific factors may be represented in the cash flow, which can be influenced by inflation in energy and operational costs and changes in maintenance and operating costs.

Determination of energy cost savings can range from simple estimates to measurement-based approaches with varying levels of complexity and data requirements. In the most simple cases, and if efficiency gains large enough, you can use whole-building utility bills to determine changes in energy costs from one year to another. If submeter data is available, you could convert metered system or equipment-level energy use to energy costs, and use those to calculate energy savings and cash flows. In the most complex cases, whole-building or system/equipment level energy and cost savings may be normalized to account for weather, size, or other factors.

There are several advantages that IRR offers over more commonly used financial metrics such as simple payback. Simple payback is straightforward to compute and easy to comprehend, but it does not account for the time value of money, and it does not value energy savings that are gained after the payback point has been reached. IRR does have some drawbacks, however. For example, if the minimum acceptable rate of return changes from year to year, the simple decision making rules of thumb cannot be applied.

Use and Presentation

Regarding decision making, the general rule is to accept projects with an IRR greater than the opportunity cost of capital, which is typically equal to the weighted average cost of capital. The weighted average cost of capital is a company-specific value that depends on the different sources of capital and classes of securities that an organization may have. In theory, all opportunities with an IRR greater than the cost of capital should be pursued. If the cost of capital is not known, compare the project under consideration to the IRR from other recently adopted successful projects. The interest rate on measure-specific financing is also a useful point of comparison.

IRR is best used to determine whether a project is worth pursuing. To decide between a set of mutually exclusive options such as continuous dimming versus bi-level ballasts, net present value (NPV) may be more appropriate, since it quantifies the investment's total value. A measure with higher IRR might actually provide less total worth, because while IRR reflects the yield of the financial benefit, NPV reflects its magnitude. In cases where capital constraints are a concern, IRR remains useful.

Capital budgeting metrics can be tracked simultaneously for multiple efficiency measures. The report below shows a monthly summary of NPV, costs, simple payback, and estimated fuel and CO2 savings for several measures. IRR is not explicitly calculated in this example, yet is readily calculated from the cash flows used to compute NPV. In this example the efficiency measures are ranked by NPV to focus on the highest value opportunities.

Energy Efficiency Measures - In Progress

	Recommendation	Equipment	Net Present Value	Estimated Cost	Payback	Cost Category	Annual Savings Value	Annual Savings Electricity	Annual Savings Natural Gas	Annual Savings CO_2
EEM 10	Re-enable AHU Night and Weekend Setbacks	AHU - 6	$29,193	$0	0.0	No cost	$4,390	772	4,112	22
EEM 11	Waterside Economizer: Utilize Plate and Frame Heat Exchanger	Chiller 3	$23,501	$7,500	1.6	Capex	$4,662	94,557	-	79
EEM 15	Optimize Chiller #3 Chilled Water Temperature Delta	Chiller 3	$9,528	$100	0.1	Low cost	$1,448	29,366	-	24
EEM 16	Install Destratification Fan in Loading Dock and Remove Heater	RS-00378	$8,367	$2,000	1.3	Capex	$1,559	-	1,473	8
EEM 8	Re-enable AHU Night and Weekend Setbacks	AHU - 1	$8,203	$0	0.0	No cost	$1,234	292	1,152	6
EEM 9	Re-enable AHU Night and Weekend Setbacks	AHU - 2	$7,595	$0	0.0	No cost	$1,142	283	1,066	6
EEM 17	De-lamp T8 Lamp Fixtures in Hallways and Offices	Hallway and Office Overhead Lamps	$5,639	$1,000	1.0	Capex	$998	20,250	-	17
EEM 18	Lower Compressed Air Pressure	AHU - 1	$4,583	$100	0.1	Low cost	$704	14,285	-	12
EEM 19	Replace T12 with T8 Fixtures in East and West Mechanical Rooms	East and West mechanical rooms	$509	$0	0.0	No cost	$77	1,553	-	1
	All In Progress Measures		**$97,119**	**$10,700**			**$16,213**	**161,358**	**7,803**	**175**

Source: EnerNOC

Recent analyses indicate that energy efficiency is indeed attractive from the perspective of NPV, payback, and IRR. McKinsey estimates a global average IRR of 17% from efficiency measures. In an analysis of approximately 1,000 efficiency projects, the UK's Carbon Trust Advisory Services found that the average IRR requirement set by businesses was 11.5%, and that 15% cost savings are possible by implementing projects which, on average, have an IRR of 48% and three-year paybacks.

References and Technical Resources

Carbon Trust Advisory Services. The business of energy efficiency: A paper from the Carbon Trust Advisory Services. October 2010. CTA001. Available from http://www.carbontrust.co.uk/Publications/pages/publicationdetail.aspx?id=CTA001&respos=0&q=the+business+of+energy+efficiency&o=Rank&od=asc&pn=0&ps=10.

This paper presents a financial analysis based on over 1,000 efficiency projects across the UK, including IRR, payback, and critical aspects of the business case for efficiency.

Farrell, D, and Remes, JK. How the world should invest in energy efficiency. Economic Studies; July 2008, The McKinsey Quarterly. McKinsey and Company. Available from http://salomonpechoconsultores.com/pdf/how-the-world-should-invest-in-energy-efficiency.pdf

Report documenting global financial opportunities associated with energy efficiency. Through the year 2020 efficiency represents 170B$/yr in potential investment opportunities, at an average IRR of 17%, although a number of policy and market barriers prevent realization of this potential.

Peretz, N. Growing the energy efficiency market through third-party financing. Energy Law Journal. 2009; 30:377-403. Available from http://www.felj.org/docs/elj302/15growing-the-energy-efficiency-market091020.pdf.

Article reviewing options to grow the US efficiency market, including a sector based analysis of opportunities. Energy efficiency projects are estimated to have 'illiquidity adjusted weighted average cost of capital' of 12.77%, which is lower than the average IRR of 17%, indicating financial attractiveness.

Peterson, PP, Fabozzi, J. Capital budgeting: theory and practice. Volume 10 of Frank J. Fabozzi Series; Wiley Finance. John Wiley and Sons, 2002, 243 pgs.

Reference book detailing capital budgeting techniques, decision processes, and limitations including IRR NPV and payback.

US Environmental Protection Agency. Revised July 2007. Energy Star Building Manual. Chapter 3 - Investment Analysis. Available from: http://www.energystar.gov/ia/business/EPA_BUM_CH3_InvestAnalysis.pdf.

Building-efficiency specific review of cash flow analysis metrics including payback period, net present value, and internal rate of return, with examples and investment decision making considerations.

US Environmental Protection Agency. Financial Evaluation: Energy Star. Available from http://www.energystar.gov/index.cfm?c=assess_value.financial_tools.

The Financial Value Calculator is a Microsoft Excel spreadsheet tool that presents energy investment opportunities in terms of key financial metrics.

The Cash Flow Opportunity Calculator is a Microsoft Excel spreadsheet tool to determine: the portion of efficiency investments that can be purchased from the anticipated savings; purchase timing for efficiency investments; whether money is being lost by waiting for lower interest rates.

The Building Upgrade Value Calculator in partnership with BOMA International and the BOMA Foundation, estimates the financial impact of proposed efficiency investments in office properties. It includes return on investment, internal rate of return, net present value, and other analyses. The calculations are based on data input by the user.

Technical and Analytical Details

The term "carbon accounting," or footprinting, is generally understood to include all six of the Kyoto greenhouse gases (GHGs). Since the six gases influence global warming differently, "carbon dioxide equivalents" based on each gas's global warming potential (GWP) are used as an international standard to compare or aggregate emissions. GWP is expressed on a scale relative to CO_2, which has a value of one. The 100-year GWP of each of the six Kyoto gases is published by the Intergovernmental Panel on Climate Change (IPCC), and is shown below. These values indicate, for example, that one ton of methane emissions has 25 times the warming impact of one ton of CO_2 emissions. Therefore, emissions of 1 ton of CO_2 and 1 ton of methane would amount to 26 tons of CO_2e emissions. The table includes the most recent GWP values from the 2007 IPCC assessment, which have not yet been adopted by the US EPA. The computation and programming example uses EPA values.

Gas	GWP
Carbon dioxide CO_2	1
Methane CH_4	25
Nitrous oxide N_2O	298
Hydrofluorocarbon HFC-134a	1,430
Hydrofluorocarbon HFC-23	14,800
Sulfur Hexafluoride SF_6	22,800

IPCC 2007 100-year GWP values

The Greenhouse Gas Protocol is an international accounting framework that is used as the basis of GHG standards and reporting programs. It defines three "scopes" of direct and indirect emissions. Building energy use contributes to an organization's Scope 1 and 2 emissions through fuel consumption: on-site emissions contribute to Scope 1, and purchased utilities contribute to Scope 2. Scope 3 is an optional reporting category that accommodates indirect emissions from sources beyond the organization's control or ownership, and therefore is not detailed in this handbook.

The U.S. EPA publishes electricity emissions factors that account for regional differences in utility generation, in its eGRID (Emissions and generation resource integrated database) database. For example, a region that relies heavily on hydropower will have lower emissions factors than one that relies heavily on coal. The U.S. Energy Information Agency publishes GHG emissions factors for the indirect emissions associated with purchased steam, hot and chilled water, natural gas, propane, and other fuels less commonly used in buildings.

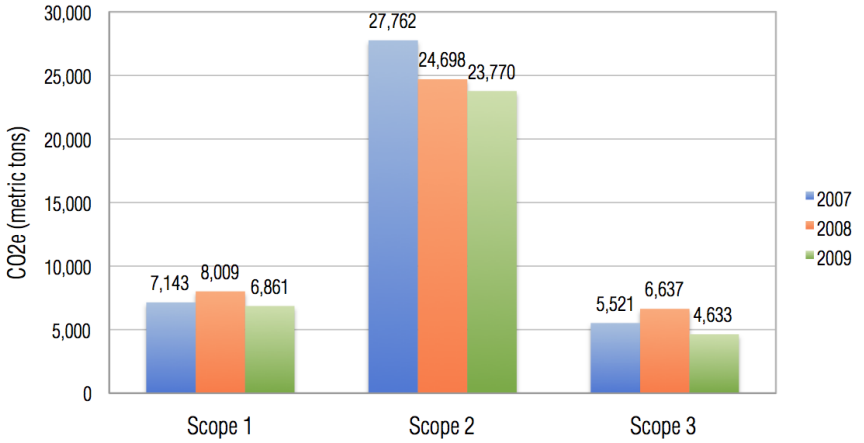
The primary greenhouse gas associated with building energy use is carbon dioxide, from electricity consumption and fossil fuel combustion. Combustion of fossil fuels such as natural gas and fuel oil also produces small quantities of methane and nitrous oxide. Electricity transmission and distribution can produce sulfur hexafluoride (SF_6) emissions, which are typically included in scope three. Hydrofluorocarbons (HFCs) are not associated with building energy use, though they may be found in commercial and industrial refrigerants, and can be emitted if there is a leak in the equipment.

While carbon dioxide equivalent (CO_2e) is the standard unit for international accounting and reporting, many voluntary reporting programs in the United States have used carbon equivalents (CE). Carbon equivalents account for only the mass of the carbon in the CO_2 molecule, while carbon dioxide equivalents account for the mass of the entire CO_2 molecule, including the oxygen. Thus, the CE is always lower than the CO_2e for the same quantity of emissions. The two units are directly related by the ratio between the atomic mass of carbon (12 amu) and the atomic mass of the carbon dioxide molecule (44 amu). To convert CE into CO_2e, multiply by 44/12. To convert CO_2e into CE, multiply by 12/44.

Use and Presentation

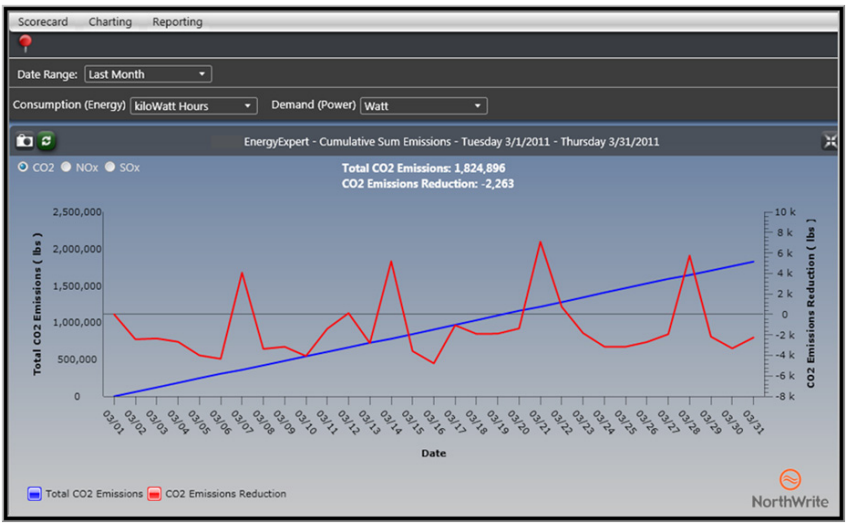
Carbon emissions calculators are widely and freely available from organizations like the Greenhouse Gas Protocol Initiative, the U.S. EPA, and Carbon Trust. Depending on the level of detail in your input, the calculators may apply national or regional utility generation and rate averages, or standard conversion factors to estimate carbon emissions. In general, the more you are able to specify regarding energy consumption, fuel properties, activity levels, and equipment, the more accurate the calculations will be. EPA's Portfolio Manager is a benchmarking tool that handles building carbon emissions as well as energy use, and provides a measure of your building emissions relative to similar, comparable buildings. This is a form of cross-sectional benchmarking, which is further detailed in the Reporting and Tracking chapter.

Carbon emissions can be tabulated, cited as a total quantity, or plotted in charts and graphs. You can disaggregate total emissions by scope or by GHG type. In the example below, an organization's total emissions are reported according to scope, and tracked for three years. In this particular example, the indirect Scope 3 emissions are attributed to employee business air travel. Summing scopes 1-3 gives the total corporate emissions, which were 35,000 metric tons in 2009, representing a 13% reduction from 2007 levels.



Source: Landis+Gyr

Commercial software tools may support additional views or representations of emissions, as shown in the image below. You can select CO_2, N_2O, or SO_2 with radio buttons on the upper left-hand portion of the screen, and can then view a trend of total emissions (shown in blue) and cumulative sum emissions (shown in red). The constant slope of the total to-date trend reflects approximately constant daily energy use. Cumulative Sum is an analysis method that is covered in the Advanced Methods chapter.



Source: NorthWrite

References and Technical Resources

Solomon, S, Qin, D, Manning, M, Chen, Z, Marquis, M, Averyt, KB, Tignor, M, and Miller, HL (eds.). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Available from http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

Defines and lists global warming potentials (GWP) used in convert greenhouse gases into carbon dioxide equivalents in Chapter 2.10.

World Resources Institute and World Business Council for Sustainable Development. Standards: Greenhouse Gas Protocol. Standards available from http://www.ghgprotocol.org/standards.

The Corporate Accounting Standard guides organizations in conducting GHG inventories, and the Project Accounting Protocol guides organizations in quantifying the reductions from mitigation projects.

The Climate Trust. Business and Organization Carbon Calculator. January 2009. Available from http://www.nextlife.com/media/IHA-carbon-calculator.pdf.

Simple calculator to estimate an organization's carbon footprint, accounting for electricity and natural gas consumption, vehicle use, air travel, and shipping.

The Global Reporting Initiative (GRI). The Sustainability Reporting Framework, Available from http://www.globalreporting.org/ReportingFramework/.

The Sustainability Reporting Guidelines and Technical Supplements publications provide cross-sector and sector-specific guidelines on disclosing economic, environmental, and social sustainability performance. The Technical Protocol documentation addresses the content and definitions included in a sustainability report.

US Energy Information Administration (EIA). Voluntary Reporting of Greenhouse Gases Program: Electricity Factors. January 2011. Available from http://205.254.135.24/oiaf/1605/coefficients.html.

Tables of emission coefficients for carbon dioxide, methane, and nitrous oxide for different fuel types, fuel grades, and vehicles.

US Energy Information Administration (EIA). Updated State-level Greenhouse Gas Emission Coefficients for Electricity Generation 1998-2000. April 2002. Available from http://www.eia.gov/pub/oiaf/1605/cdrom/pdf/e-supdoc.pdf.

Emission coefficients for the most commonly used fossil fuels and electricity.

US Environmental Protection Agency. Emissions & Generation Resource Integrated Database (eGRID): Clean Energy. 2010. Available from http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

Publically accessible database of the environmental characteristics and emission factors for US utility regions.

US Environmental Protection Agency. Metrics for Expressing Greenhouse Gas Emissions: Carbon Equivalents and Carbon Dioxide Equivalents. February 2005. Available from http://www.epa.gov/oms/climate/420f05002.htm.

Fact sheet on the conversion between carbon equivalent (CE) and the international standard of carbon dioxide equivalent (CO_2e).

Technical and Analytical Details

Longitudinal benchmarking requires the collection of energy data over fixed periods, the careful application of normalizations, and a useful visualization in the form of a plot or table.

Time periods

Longitudinal benchmarking is most often based on annual energy totals. Annual data is preferred because the seasonal variation of weather-dependent and weather-independent energy usage is duplicated in both years. For example, a school will have periods of high occupancy and periods of low occupancy. A full year of data allows the same variations to occur and effectively cancel out. A full year is also long enough so that any small variations that do occur will result in small changes in energy use relative to the annual total. The trade-off is that you must wait longer to get annual data for comparison.

In some cases, the benchmark period need not run from January through December, and may not include a full twelve months. For example, schools may choose an academic year, since this may result in more consistent energy use alignment from year to year. For example, a university may want to longitudinally benchmark data from the full-time academic season without the summer season, where building usage is erratic and may change dramatically from year to year. Government institutions might use the federal or state fiscal year.

Utility billing periods and meter reading dates may not align perfectly with 365-day calendar years. In this case, you must make certain assumptions to align the billing year with the benchmark period by adding or subtracting energy proportional to the difference in period length. As long as the adjustments are small relative to the annual energy usage, the assumptions will not cause significant error.

Seasonal periods, usually heating or air conditioning seasons, can be used to examine heating or cooling system or building performance. You can normalize energy use for a season with temperature data to establish a metric that will reveal more information. For example, buildings are sometimes benchmarked for heating system performance by comparing gas use per Heating Degree Day (HDD) on an annual basis. This accounts for warmer or colder winters when compared to annual gas use for other years. Another common normalization for whole buildings is to divide energy use by gross or conditioned square footage to facilitate comparisons to other buildings. These strategies are described in simple baselines. More advanced methods of correlation, as in model baselines and energy signatures, can be used for more complex analysis.

Use and Presentation

The results of longitudinal benchmarking can be displayed in many ways, including bar charts, line graphs, color-coded change plots, or simple data tables. Clearly label all charts, to identify the normalizations used and the periods of time compared.

Longitudinal benchmarking is available in most EIS software tools but is also very easy to calculate in spreadsheets. Utility bill tracking software tools and tools that are oriented toward managing large portfolios of commercial buildings will almost always have longitudinal benchmarking analysis. System or end-use equipment longitudinal benchmarking is more likely to require custom calculation in a spreadsheet.

An asset manager can use longitudinal benchmarking to quickly assess changes across a portfolio of buildings and systems. The data can also be viewed as a chart that summarizes only the difference or change in the energy usage for each building from one benchmark period to the next.

References and Technical Resources

Farnsworth, G. Performance benchmarking with energy bill data: Making the most of your energy accounting software. E SOURCE, Corporate Energy Managers' Consortium, CEMC-7, January 2006. Available from http://www.esource.com/esource/preview_list/20708.

Report reviewing energy accounting software tools in the context of benchmarking. Baseline considerations such as weather, production, and normalization are presented, with conclusions as to useful reporting, tool selection, and technical challenges.

Friedman, H, Crowe, E, Sibley, E, Effinger, M. The Building performance tracking handbook: Continuous improvement for every building. Prepared by Portland Energy Conservation for the California Energy Commission. California Commissioning Collaborative, 2011. Available from http://www.cacx.org/PIER/documents/bpt-handbook.pdf.

Handbook presenting basic concepts in tracking the energy performance of commercial buildings, including overall strategies, benchmarking, metrics, and a variety of tool types.

Garris, L. 8 Energy benchmarking hurdles (and how to get over them). Buildings, July 2008, pp 56-61. Available from http://hightech.lbl.gov/media/buildings-july08.pdf.

Article presenting eight common challenges encountered in building energy benchmarking, and ways to overcome them.

Lowenberger, A, Amann, J, Hinge, A, Lenihan, K. What drives energy performance scores: Benchmarking NYC high rise building stock. Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings 3-281. Available from http://eec.ucdavis.edu/ACEEE/2010/data/papers/1998.pdf.

Paper focused on cross-sectional benchmarking, which includes specific insights that can be gained from Longitudinal Benchmarking, and challenges in moving from longitudinal to 'apples to apples' cross-sectional approaches.

Lawrence Berkeley National Laboratory. Energy Benchmarking for Buildings and Industries. Available from http://energybenchmarking.lbl.gov.

Lawrence Berkeley National Laboratory website dedicated to research and development in building energy benchmarking including benchmarking techniques, services, and databases as well as the development and evaluation of specific benchmarking tools.

Technical and Analytical Details

There are four key considerations when selecting a cross-sectional benchmarking tool:

Is it able to benchmark your building use type? For example, ENERGY STAR can be used to benchmark 15 different building use types. If necessary, ensure that the tool can handle buildings with multiple use types.

What parameters does the tool normalize for? Most benchmarking tools normalize for floor area and weather. Some tools may normalize for additional variables, such as occupancy hours, number of computers, and others. Tools with more normalization parameters allow greater flexibility in obtaining an "apples to apples" comparison.

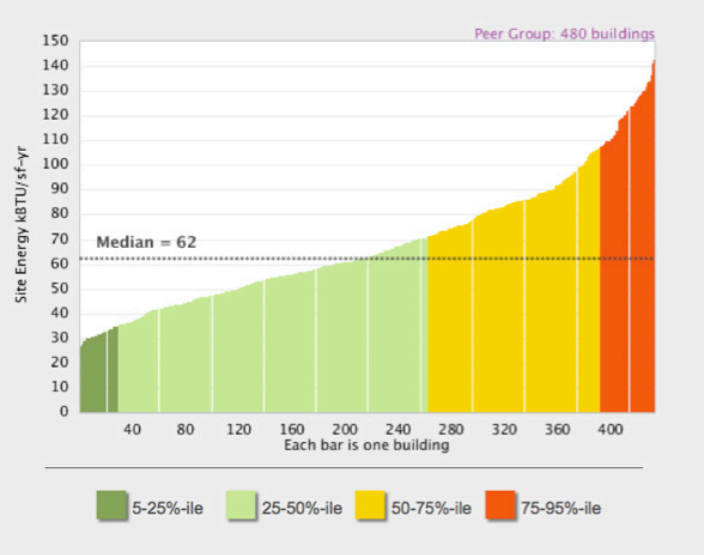
What technical method is used for normalization? Simple data filtering is the most basic method. Regression analysis and simulation are advanced methods that generally provide better "apples to apples" comparison, but are also more complex and maybe more difficult to understand and interpret the results.

What metrics are available to benchmark? Most benchmarking tools use site or source energy intensity. Some tools additionally provide metrics for different fuels, as well as system level-metrics.

Note that some tools will require the user to pre-process data into a format appropriate for input. For example, if the tool requires annual electricity use, the user may need to calculate the annual use by summing twelve monthly values from utility bills.

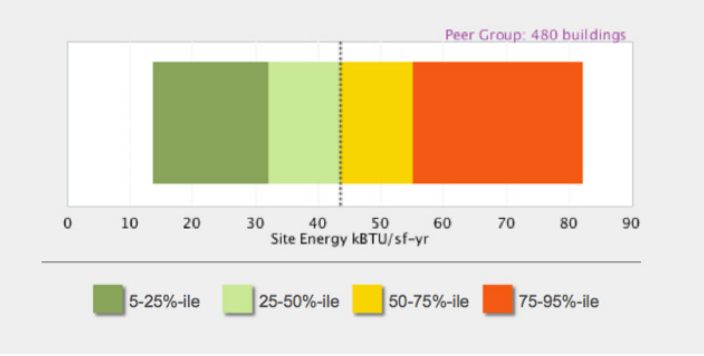
Use and Presentation

Cross-sectional benchmarking can be used to display and analyze the efficiency of building(s) relative to a peer group. There are several ways to display the results of benchmarking. One presentation method is a frequency distribution histogram, which shows the percentage of peer buildings that perform within each energy use intensity range, as in many of the application examples. Another option is a rank-ordered bar chart, which plots the EUI of each building in ascending order, as illustrated in the image below.



Source: Energy IQ

Color coding may be used to indicate ranges of percentiles, as in the images above and below.



Source: Energy IQ

References and Technical Resources

Energy Information Administration. Commercial Building Energy Consumption Survey. 2003. Energy Information Administration, U.S. Department of Energy. Available from http://www.eia.doe.gov/emeu/cbecs/contents.html.

The Commercial Buildings Energy Consumption Survey (CBECS) is a national data set for the stock of U.S. commercial buildings, their energy-related building characteristics, and energy consumption and expenditures. CBECS data is often used for benchmarking.

California Energy Commission, California Environmental Protection Agency. EnergyIQ: Action-oriented energy benchmarking. 2011. Available from http://energyiq.lbl.gov.

EnergyIQ is an action-oriented benchmarking tool for non-residential buildings that was developed by the Lawrence Berkeley National Laboratory with funding from the California Energy Commission and the California Environmental Protection Agency. Energy managers, building owners, architects and engineers use it to compare energy performance to peers, identify energy efficiency opportunities, and reduce energy costs and carbon emissions.

Friedman, H, Crowe, E, Sibley, E, Effinger, M. The Building performance tracking handbook: Continuous improvement for every building. Prepared by Portland Energy Conservation for the California Energy Commission. California Commissioning Collaborative, 2011. Available from http://www.cacx.org/PIER/documents/bpt-handbook.pdf.

Handbook presenting basic concepts in tracking the energy performance of commercial buildings, including overall strategies, benchmarking, metrics, and a variety of tool types.

Labs21 Benchmarking Tool. Laboratories for the 21st Century Program. Available from http://labs21benchmarking.lbl.gov.

This benchmarking tool is design for laboratory owners to compare the performance of their laboratory facilities to similar facilities and thereby help identify potential energy cost savings opportunities. The tool accommodates energy use metrics, e.g. Btu/sf/yr, as well as system efficiency metrics, e.g., W/cfm.

Lawrence Berkeley National Laboratory. Energy benchmarking for buildings and industries. Available from http://energybenchmarking.lbl.gov.

Lawrence Berkeley National Laboratory website dedicated to research and development in building energy benchmarking including benchmarking techniques, services, and databases as well as the development and evaluation of specific benchmarking tools.

Portfolio Manager Overview: ENERGY STAR. 2011. U.S. Environmental Protection Agency. Available from http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager.

The Portfolio Manager tool allows you to benchmark energy and water consumption, and receive EPA recognition for superior energy performance. For many facilities, you can rate their energy performance on a scale of 1–100 relative to similar buildings nationwide.

Technical and Analytical Details

The load profiling approaches that were presented in the application examples were qualitative inspections of load shape patterns, largely based on relative differences in magnitude and the time of day or season at which those differences occur. Essentially, they illustrate investigations that concern whether systems are on when they should not be.

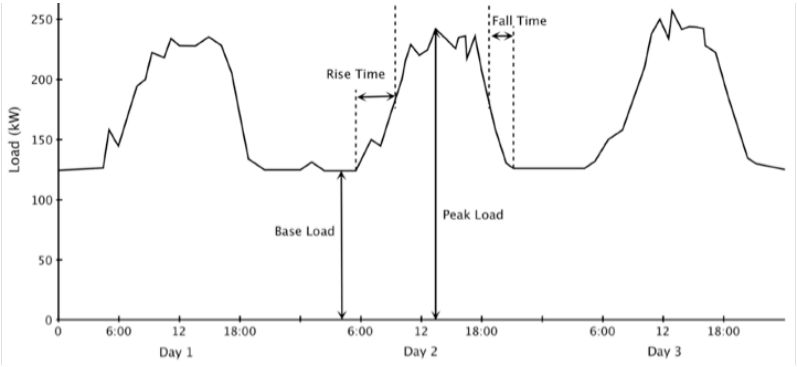
In addition to qualitative approaches, you can apply quantitative analyses, which are useful in understanding properties of the load that are either difficult to judge by eye or that are revealed by considering a collection of multiple 24-hour load profiles. You can compute the following five metrics for 24-hour load profiles, and plot them as their own time series, with days on the x-axis rather than time:

1. The near-peak load; defined as the third-highest load observed in the 24-hour set of interval data.
2. The near-base load; defined as the third-lowest load observed in the 24-hour set of interval data

Note: Discarding the absolute highest and lowest data points (the maximum load and the minimum load) removes data points that do not represent the building's general performance.

3. The high-duration period; defined as the amount of time during the day that the load is closer to the near-peak load than it is to the near-base load
4. The ramp-up time; an indicator of the time that it takes the building to go from its low loads to its middle loads. Low is defined as [near-base + 0.1*(near-peak–near-base)], and middle is defined as [near-peak + near-base)/2]
5. The ramp-down time; an indicator of the time that it takes the building to go from its high loads to its middle loads. Low is defined as [near-peak-0.1*(near-peak–near-base)], and middle is again defined as [near-peak + near-base)/2]

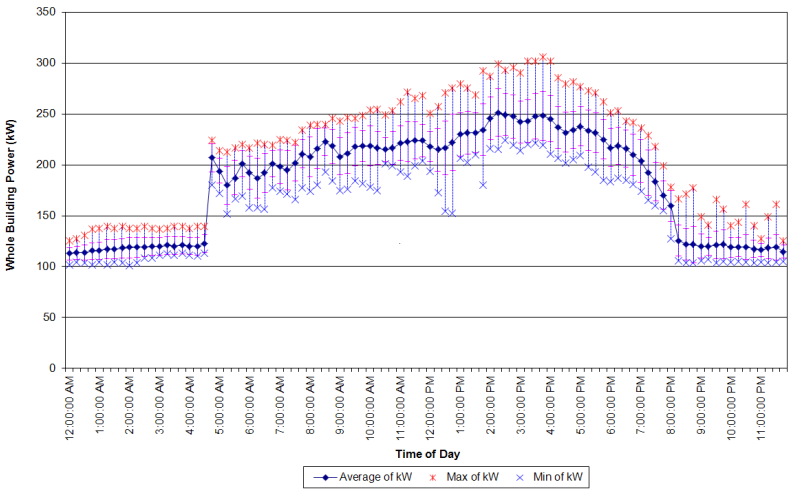
These five metrics are illustrated in the image below. Some buildings behave much more regularly than others, so it is not possible to give a general rule like "if the high-load duration changes by more than one hour, something is wrong." But by looking at these load-profiling parameters for one or two months of data, it is possible to gain an understanding of how much variation is expected from one day or week to the next; then, unusual behavior can be readily identified.



Source: Price, P. Methods for analyzing electric load shape and its variability. LBNL#3713-E, 2010.

You can aggregate collections of multiple 24-hour load profiles, for example, for a season or a year, and compute statistical summary metrics as another means of understanding characteristics of building load. Given a set of load profiles, for each time of the day, compute and plot the average, maximum, minimum, and standard deviation. Each point on the plot represents a statistical metric, taken over the total number of days in the set of load profiles.

The image below shows a load shape statistical summary for a campus. Here the inverted load shape, with minimum load in the daytime hours, is due to the use of a thermal energy storage system and daily load shifting. Points marked with an "X" indicate the maximum and minimum observed loads over a multi-month period, the diamonds mark the average load, and the bars indicate the deviation in metered load. These metrics reflect load timing, size, and variability.

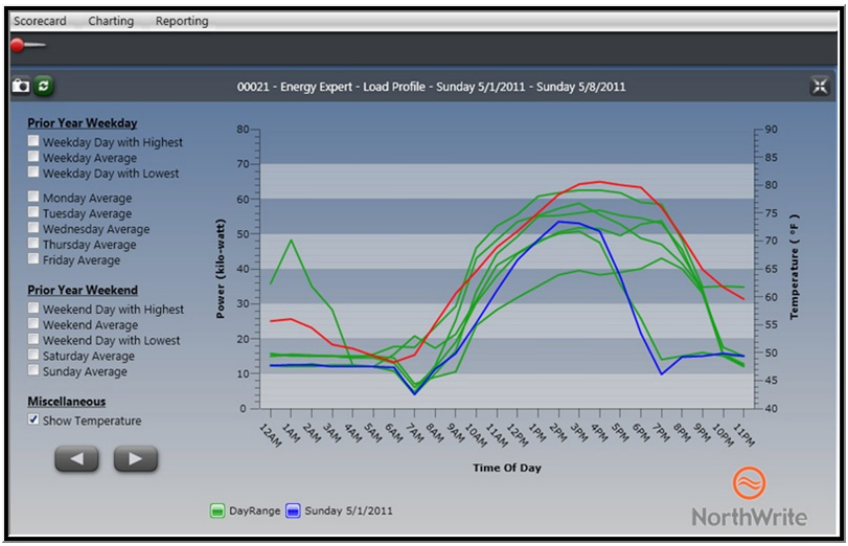


Source: Lawrence Berkeley National Laboratory

Use and Presentation

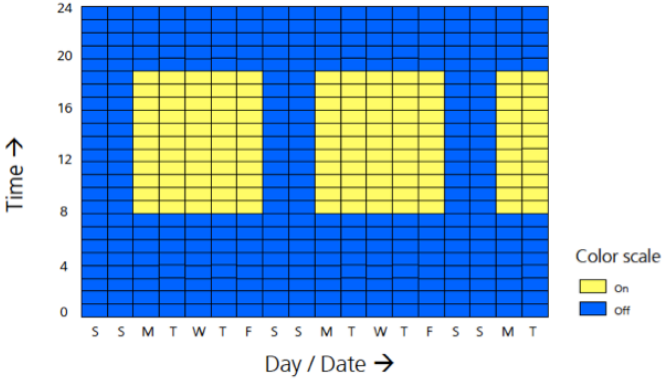
Many types of commercial energy monitoring software tools support load profiling, but with varying degrees of flexibility and computation of metrics. If building energy meters are integrated into your building automation systems, you can use the trending and visualization features to inspect load profiles, much in the manner provided in meter or panel visualization tools and portals. You can calculate maximum, minimum, and average loads. Energy information systems and demand response systems also support load profiling; the more advanced of which may offer increased levels of flexibility or sophistication in analyses. Very few commercial tools offer preprogrammed calculation of the quantitative load-shape metrics that were detailed in the previous section; you can compute and plot these metrics within a statistics software package, with a computer programming or scripting language, or with a spreadsheet program.

The most common, basic graphical representation of a load profile is a plot of interval data for a single 24-period, with load plotted on the y-axis and time plotted on the x-axis. However, there is a wide variety in the ways that load profiles can be visualized. A week or a month of load might be shown on the y-axis, or multiple 24-hour load profiles might be overlaid on a single plot, or combined with other time series data. In the image below, a week of load profiles are plotted with temperature on a secondary axis. Colors are used to distinguish the day-in-question from the temperature trend and the comparative profiles that also appear in the plot. The menu options on the left allow you to filter the set of historic data according to specific days of the week, to compute summary averages and quickly plot specific 24-hour profiles from the days with the highest and lowest loads.



Source: NorthWrite

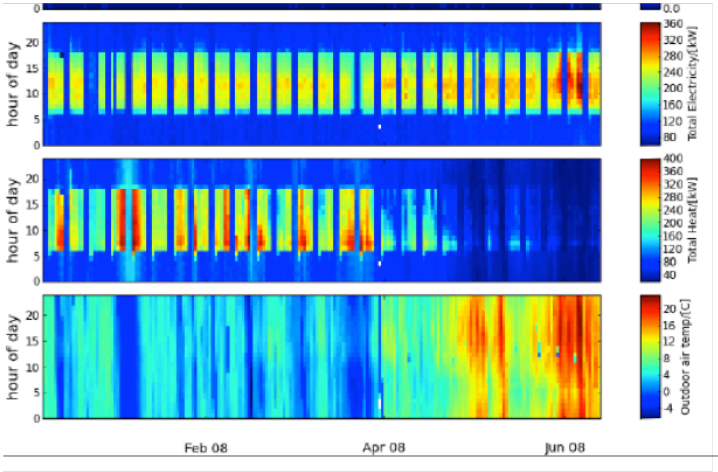
Another type of plot that can be useful in presenting load profiles places time of day on the y-axis, and day or date on the x-axis. Qualitative descriptions of load such as on/off or numeric ranges of load are color coded, resulting in a plot in which you can easily identify "hot spots." In the image below, a system's on/off status is plotted for a several-week period, making it easy to confirm that schedules are properly implemented.



Source: Neumann et al, eds. Results of the project Building EQ tools and methods for linking EPBD and continous commissioning. Fraunhofer Institute for Solar Energy Systems, Intelligent Energy Europe, 2010.

Similarly, the more dense example that follows shows whole-building electric and heating load profiles with outside air temperature, for the first half of a year.

For example, the user can quickly see that in the summer the heating load is low, while the air temperature is high. It is also clear that electric loads peak around the noon hour, fall on weekends, and are setback at night. Similar patterns are seen in the heating load during winter months.



Source: Neumann et al, eds. Results of the project Building EQ tools and methods for linking EPBD and continous commissioning. Fraunhofer Institute for Solar Energy Systems, Intelligent Energy Europe, 2010.

References and Technical Resources

Friedman, H, Crowe, E, Sibley, E, Effinger, M. The Building performance tracking handbook: Continuous improvement for every building. Prepared by Portland Energy Conservation for the California Energy Commission. California Commissioning Collaborative, 2011. Available from http://www.cacx.org/PIER/documents/bpt-handbook.pdf.

Handbook presenting basic concepts in tracking the energy performance of commercial buildings, including overall strategies, benchmarking, metrics, and a variety of tool types.

Granderson, J, Piette, MA, Ghatikar, G, Price, P. Building energy information systems: State of the technology and user case studies. Lawrence Berkeley National Laboratory, November 2009, LBNL-2899E. Available from http://eis.lbl.gov/pubs/lbnl-2899e.pdf.

Report containing a market characterization of energy information systems and related performance tracking tools, including common and advanced features and capabilities.

Hooke, JH, Byron, JL, Hart, D. Energy management information systems: achieving improved energy efficiency: a handbook for managers, engineers and operational staff. 2004. Office of Energy Efficiency of Natural Resources Canada, Cat. no. M144-54/2004E, ISBN 0-662-38024-X. Available from http://oee.nrcan.gc.ca/publications/industrial/EMIS.

Implementation handbook on energy information system technology, written for all levels of management and operational staff, including metering, data collection, data analysis, reporting and cost/benefit analyses.

Northwest Energy Efficiency Alliance. Performance indicators: Better Bricks. Available from http://www.betterbricks.com/building-operations/tools/performance-indicators-0.

Website with instructional information on building performance indicators, including best practices and concepts relevant to metrics, data and tools.

Price, Philip. Methods for analyzing electric load shape and its variability. May, 2010. Lawrence Berkeley National Laboratory, Report LBNL-3713E. Available from http://drrc.lbl.gov/system/files/LBNL-3713E_0.pdf.

Paper with details and advice on using various load profiling metrics.

Technical and Analytical Details

Depending on the specific analysis and context of application, various definitions may be associated with the word "peak." When used in a general context, the term "peak load" can refer either to the highest metered instantaneous load or the average load over a certain time interval. This average peak load is typically comprised of many instantaneous load measurements, and 15-minute intervals are common.

In the context of demand-response programs and specific utility tariffs, the phrase "peak demand" has a very specific definition, usually corresponding to the highest metered load during periods when customer usage is at a maximum. In this context, if the maximum load does not occur during the utility peak period, the maximum demand is not equal to the peak demand. However, for most system-level and whole-building loads, the maximum usage does fall within peak hours, and therefore the two quantities are frequently equal.

There are a number of ways to meter and measure peak demand. Block demand is simplest, and is based on the highest average demand in any single demand interval, e.g., a 15-minute period. Rolling demand or sliding window measurements divide the demand interval into a number of subintervals during which you can compute average demand. If you are using demand readings to compute energy consumption, accuracy may be of concern if the form of the data is instantaneous demand at a low-sampling frequency.

When using quantitative analyses for performance tracking rather than utility cost accounting or demand response, you may prefer quantities such as the "near peak" and "near base"'load. For example, in base to peak load investigations, and in certain aspects of load profiling, use of the "near-peak" and "near-base" may be appropriate. The "near-peak" load can be defined as the third-highest load observed in any 24-hour set of interval data, and the near-base load as the third-lowest. Discarding the absolute highest and lowest data points (the maximum load and the minimum load) removes potentially anomalous data points that are not representative of the building's general performance.

Use and Presentation

You can configure energy information systems, building automation systems, and advanced electrical metering tools to support peak load analysis at the building and system of submeter level. Investigations may be qualitative (using visualization features and user knowledge), quantitative, or a combination of the two. Demand response tools are tailored for analyses pertaining to utility load reduction incentive programs, and tend to offer flexible, robust analyses.

Many graphical presentations are used in peak load analysis. Time series overlays of load profiles are often used to visually inspect data for patterns or to compare days of interest such as holidays versus weekdays. Multi-week load profiles may be inspected to evaluate the magnitude of overnight peaks. You can plot and inspect time series of specific metrics

visually, as in the case of the near-peak and near-base load presented in the previous section; this approach is less commonly applied, but also useful.

Most peak load analyses compare the building or system to itself, or to others in a portfolio or campus; however, a limited set of performance data is available for peer-to-peer comparisons. In 1995, the U.S. national Commercial Buildings Energy Consumption Survey included average peak load data disaggregated by building characteristics and commercial sector. The Labs 21 benchmarking tool includes peak demand intensity (W/sf) for whole-building, lighting, and cooling systems in energy-intensive laboratory spaces. And the California Commercial End-Use Survey includes whole-building peak electric demand for California commercial buildings.

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National average peak loads in commercial buildings, disaggregated by building characteristics and commercial sector.

Hooke, JH, Byron, JL, Hart, D. Energy management information systems: achieving improved energy efficiency: a handbook for managers, engineers and operational staff. 2004. Office of Energy Efficiency of Natural Resources Canada, Cat. no. M144-54/2004E, ISBN 0-662-38024-X. Available from http://oee.nrcan.gc.ca/publications/industrial/EMIS.

Implementation handbook on energy information system technology, written for all levels of management and operational staff, including metering, data collection, data analysis, reporting and cost/benefit analyses.

Itron, Inc. California Commercial End-Use Survey (CEUS). Prepared for the California Energy Commission, March 2006. Publication # CEC-400-2006-005. Available from http://www.energy.ca.gov/ceus/index.html.

Survey of energy use in California commercial buildings, including peak electric demand, and stratified by utility service area, climate region, building type, and energy use level.

Laboratories for the 21st Century. Labs 21 benchmarking tool. Available from http://labs21benchmarking.lbl.gov.

A web-based benchmarking tool that contains energy use data from more than 200 laboratory facilities, including building and system level peak demands.

New Buildings Institute. Advanced metering and energy information systems. Prepared for US EPA, July 2009. Available from http://newbuildings.org/sites/default/files/metering-EPA%2083378201.pdf.

Paper documenting new technologies available in advanced, interval metering, and applications for performance monitoring and reporting.

Price, P. Methods for analyzing electric load shape and its variability. May, 2010. Lawrence Berkeley National Laboratory, Report LBNL-3713E. Available from http://drrc.lbl.gov/system/files/LBNL-3713E_0.pdf.

Report describing near-peak and near-base load metrics, and their application for building performance tracking.

Technical and Analytical Details

Monitoring and control of photovoltaic (PV) systems is essential to determine reliable functioning and maximum yield of any solar electric system. Knowing inverter performance is a basic requirement to verify electrical power production. Data loggers can provide basic energy monitoring, compared to more sophisticated, automated monitoring systems.

PV monitoring industry

PV energy monitoring is a highly evolved, commercialized industry with numerous devices and tools available to the owner/operator of a PV array. Many commercial devices have extensive monitoring, reporting, and data logging capabilities that can also provide real-time information in straightforward graphical displays. Some commercially available devices have enhanced reporting capabilities such as issuing status reports, providing automatic problem detection, alerting the owner/operator by e-mail or cell phone, and suggesting solutions to resolve problems. Extensive, quality PV monitoring solutions are readily available in the commercial market at reasonable cost.

Most commercial monitoring systems provide two basic measured parameters of the array's AC output in kWh and solar radiation (also known as irradiance) in watts per square meter. Beyond these two basic parameters, each additional measurement contributes to the ability of the owner/operator to understand and respond to the status of their PV system. Many PV array monitoring providers will include devices and sensors to measure an expanded set of parameters, in addition to a base-level monitoring package. The following parameters are usually of greatest interest for system monitoring:

- AC Energy Generation
- Irradiance
- Ambient Temperature
- Module Backsheet Temperature(s)
- Wind Speed

Inverter performance

You can perform the most simple check of inverter performance (PV monitoring) by reading values on the display of the grid-connected inverter. Important inverter (or grid) related parameters, such as PV array power, AC (grid) power, and PV array current . Remote control and monitoring can also be performed through remote connections such as analog modem, ISDN, and WiFi connections. Gathered data is logged and can be securely reviewed and analyzed at any time from almost any location.

Maximum Power Point Tracking (MPPT)

MPPT is a new technology used in some inverters that monitors, or tracks, the power output from an on-site PV array to maximize electricity power production. An inverter with MPPT technology automatically adjustments the electrical load to achieve the greatest possible

power harvest from the PV array by accounting for the complex relationship between solar irradiation, array temperature, and total electrical resistance, all of which produce a non-linear output efficiency. MPPT technology manipulates voltage in response to moment-to-moment variations of light level, shading, temperature, and photovoltaic module characteristics by sampling the output of the PV array and applying a resistance (load) to obtain maximum power for any given environmental conditions. Producing a time series plot of the MPPT provides valuable insight to the overall function of a PV array.

Microinverters

A microinverter is a new inverter technology that provides a new level of reliability, configurability, and overall improved economics by making the conversion from DC output power to AC output within each individual PV module. Consequently, an on-site PV module array benefits through increased energy output, improved electrical safety, ease of system design, reduced installation cost and complexity, and, importantly for this handbook, more precise and less costly monitoring capabilities. Microinverters achieve module-level monitoring by using power line carrier (PLC) signals that eliminate the need for additional communications wiring.

Data Accuracy Details

AC Energy Generation

ANSI C12.20 (0.2%) revenue-grade meters are recommended for the measurement of AC electrical components. These measurements are conducted between the inverter and the AC breaker panel, and are not collected from the inverter itself. It is not recommended to collect energy generation data directly from the inverter, since some articles have stated that inverter measurements may be inaccurate by as much as 8%. Modbus™ communications, if available, allow for the collection of tens of different electrical parameters beyond the typical energy values.

Irradiance

The measurement of incident irradiance is a critical parameter for the accurate analysis of a PV system. Irradiance is measured in watts per square meter (W/m^2) and may be accomplished through a variety of device types. The most common device is a silicon photodiode pyranometer, which has a long history, as a class of devices, for reliable field service and low cost. The other two device types include relatively expensive thermopile pyranometers and silicon reference cells. Thermopile devices require an annual recalibration and most silicon photodiode devices require bi-annual recalibration.

Regardless of the device selected, the following characteristics are recommended:

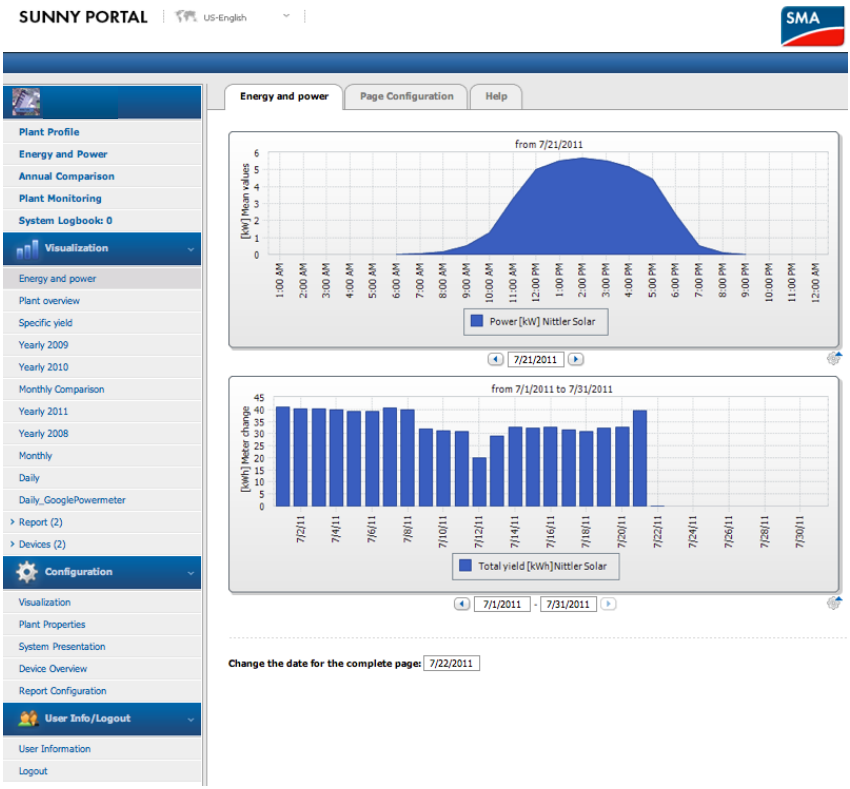
1. Orientations: Plane-of-array (POA) and global horizontal (GH)
2. Calibration: U95 < ± 5% under natural daylight conditions
3. Linearity: < ± 1% deviation from 0 to 1600 W/m^2
4. Stability: < ± 2% per year
5. Cosine Correction: Corrected to 80 angle-of-incidence

Use and Presentation

Data acquisition hardware can take many forms. The most common loggers contain internal storage memory, communications ports (such as RS-485, Ethernet, cellular modem, or Wi-Fi), and analog and pulse measurement channels. Many providers are configuring their offerings to automatically upload collected data to a central server at a periodic interval (most commonly hourly or daily intervals), which necessitates a stable connection to the Internet or the use of a cellular modem. When a connection is unavailable, most devices will retain their collected data for an extended period of time in internal memory (often for a month or greater) and then upload the data when a connection to the central server is re-established.

Most providers support the collection of measurements from both analog and digital sensors/devices. Digital sensors and devices (inverters, energy meters, and some weather stations) typically use the Modbus communications protocol to transfer their measurements to the data acquisition system. This allows for relatively long distances between the sensor and the data acquisition system, which is not possible with low-level analog signals. They are also less susceptible to signal noise, which may be introduced on long-length analog signal lines. Analog signals may be collected from a wide range of sources but are limited to relatively short lead lengths and have a resolution, which is limited to the characteristics of the analog-to-digital converter. We recommend that analog signals be measured using a 12 bit A-D converter or greater. A system with a greater number of bits will have a higher resolution.

Analogous to modern HVAC control systems, which offer data visualization and storage capabilities, PV systems increasingly offer analysis software layers. Continuously monitoring and evaluating AC generation, DC generation, inverter status and error codes, irradiance (both global horizontal and on the plane-of-array), ambient temperature, module backsheet temperature, and wind speed will ensure on-site PV array performance, maximize solar power harvesting, and reduce maintenance costs. The newest PV monitoring systems report on individual module power harvesting to increase system uptime and resolve faults more effectively.



Source: Anonymous user, SMA Solar Technology AG

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Barbose, G, Darghouth, N, Wiser, R. Tracking the sun IV: A historical summary of the installed cost of photovoltaics in the United State from 1998 to 2010. Lawrence Berkeley National Laboratory, Report LBNL-5047E, September 2011. Available from http://eetd.lbl.gov/ea/emp/reports/lbnl-5047e.pdf.

This report presents trends in the cost of grid-connected PV systems in the United States residential, commercial, and utility-sector systems.

US Department of Energy: Energy Efficiency and Renewable Energy. DSIRE SOLAR™ Portal. Available from http://dsireusa.org/solar/index.cfm?ee=1&RE=1&spf=1&st=1.

Website providing information on state, local, utility, and federal incentives and policies that promote solar energy.

US Department of Energy: Energy Efficiency and Renewable Energy. Energy Basics: Solar Energy Technologies. Available from http://www.eere.energy.gov/basics/renewable_energy/solar.html.

Multi-page website providing an introduction to of photovoltaics, including systems, cells, systems, and components.

National Renewable Energy Laboratory. A consumer's guide: Get your power from the sun. US Department of Energy; Energy Efficiency and Renewable Energy, DOE/GO-102003-1844, December 2003. Available from http://www.nrel.gov/docs/fy04osti/35297.pdf.

A booklet to guide businesses and home owners through the process of purchasing a photovoltaic system, not including design or installation considerations.

PV Watts: A performance calculator for grid-connected PV systems. Available from http://rredc.nrel.gov/solar/calculators/PVWATTS/version1.

An online calculator developed by the National Renewable Energy Laboratory to permit non-experts to quickly generate performance estimates for grid-connected PV systems, including an option to output hourly performance data.

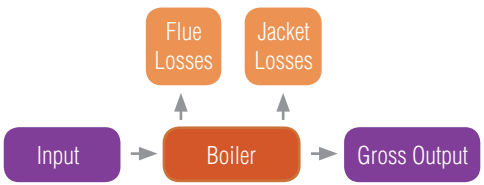
Technical and Analytical Details

Histograms of load versus hours of operation, also called "load frequency distributions," can be used for both heating and cooling systems. In either case there are multiple manufacturer ratings for both capacity and efficiency, and system size relative to actual building loads affects efficiency. If a unit is undersized, it will not be able to meet the building's conditioning needs; however, oversizing occurs more commonly.

Cooling system efficiency generally decreases as loads fall below full load to a part-load condition. Full load, or "cooling capacity" refers to the amount of heat that the unit can remove, and is commonly expressed in BTU/hr or tons. One ton of cooling capacity removes 12,000 BTU/hr of heat. However, most systems do not operate at full load for the majority of run hours. To accommodate a range of loads, multiple parallel units can be staged to improve efficiency by matching capacity to load.

Cooling system efficiency can be measured in several ways. One, "energy-efficiency ratio" (EER), is defined as the ratio of cooling rate to the power input at full-load conditions, including all compressors, fan motors, and controls. EER can be converted to kW/ton or to a coefficient of performance. There are also efficiency metrics that account for seasonal average conditions and part-load conditions, as detailed in Heating and Cooling Efficiency.

Boiler capacity and efficiency is characterized according to input and output ratings. The input rating is the firing rate of the burner. For gas-fueled systems, common units are BTU/hr or therms/hr; whereas, oil-fueled systems may provide the rating in gallons/hr. Gross output, or "capacity," refers to the heat output of the boiler, after jacket and flue losses, and therefore quantifies the heat in the fluid leaving the boiler. The boiler's overall efficiency is the ratio of gross output to gross input. As for cooling systems, there are also boiler efficiency metrics that account for seasonal average and part-load conditions.

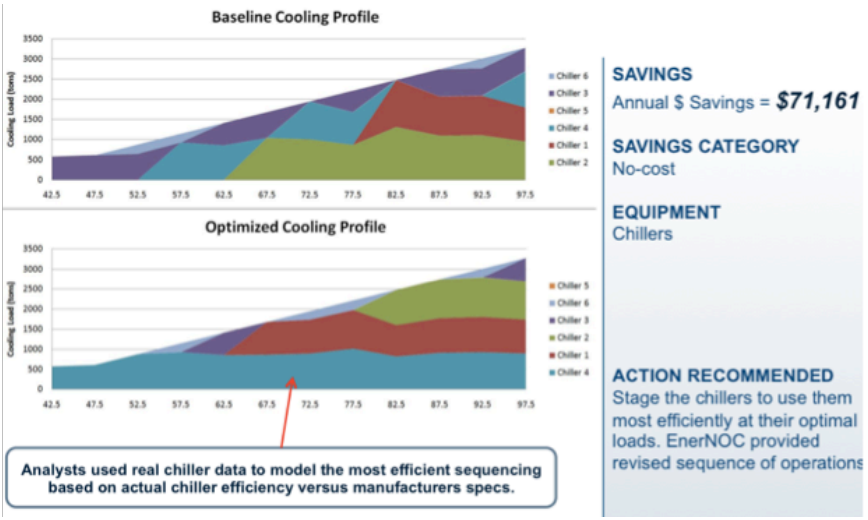


Procedures to determine both input and gross output of water heating equipment are published through the Hydronic Institute, which is also known as the Institute of Boiler and Radiator Manufacturers (IBR). The Hydronic Institute's testing and certification programs are administered by the Air Conditioning, Heating, and Refrigeration Institute (AHRI). IBR gross output applies to boilers over 300,000 BTU/hr. For boilers under 300,000 BTU/hr the Department of Energy defines standard test procedures for heat output called "DOE heating capacity."

Boiler input and output ratings correspond to full fire; however, boilers can also "turn down" to a low fire mode. Turndown ratio is another manufacturer rating, defined as the ratio between the full fire and low fire output, which for most boilers is 4:1. The low fire rate is the minimum at which the boiler operates; below that it will cycle off. Similar to cooling systems, boilers often operate at loads that are far less than their rated input capacity. If the system is oversized, it will frequently encounter loads beyond the limit of the turndown ratio, and the boiler will cycle on and off. Frequent cycling causes energy waste because air is purged in each cycle, introducing heat loss, and it also leads to mechanical wear. Since most boilers have a 4:1 turndown ratio, loads below 25% of capacity will induce cycling. Therefore boiler selection must take into account turndown ratio as well as capacity, so that seasonal variations are accommodated as efficiently as possible.

Use and Presentation

Loading histograms are most useful in verifying that anticipated load requirements from the design phase actually hold true once the building is occupied and operational. They can also be used on a continuing seasonal or annual basis, to ensure that system size or staging of parallel units remains well-aligned with conditioning need as building loads or uses change. As such, they effectively serve as first-cut commissioning and retrofit decision support. For example, the image below illustrates a case in which the staging of six chillers was optimized. Loading histograms could have been used as a simple, low-cost initial analysis to determine that the optimization exercise was indeed worth pursuing.



Source: EnerNOC

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Air-Conditioning, Heating, and Refrigeration Institute (AHRI). Available from http://www.ahrinet.org.

Information on HVACR industry standards, rating certifications, and guidelines.

American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Handbook. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Available from http://www.techstreet.com/lists/ashrae_handbook.html?ashrae_auth_token=

Four volumes comprise the handbook of the ASHRAE handbook; of direct relevance to HVAC efficiency, design, selection, and use are the 2011 HVAC Applications, the 2009 Fundamentals, and the 2008 HVAC Systems and Equipment.

Piette, MA, Carter, G, Meyers, S, Sezgen, O, Selkowitz, S. Model-Based chiller energy tracking for performance assurance at a university building. September 1997. Lawrence Berkeley National Laboratory, LBNL# 40781. Available from http://www.osti.gov/bridge/servlets/purl/645476-zScwVt/.../645476.pdf.

Report documenting the use of loading histograms in assessing chiller efficiency at a university campus building.

Rutkowski, H, Manual, N. Commercial Load Calculation, 5th Edition. 2008. Air Conditioning Contractors of America.

Publication that includes procedures for sizing HVAC equipment and for calculating design heating and cooling loads in small and medium commercial buildings.

Santamaria, C. Next generation energy efficient technologies: a case study demonstrating top operational performance. Journal of Green Building, 2009.

Chiller plant optimization case study in which loading histograms and efficiency plots are used for retrofit analysis.

Thomas, PC, Moller, S. HVAC system size: Getting it right - Right-sizing HVAC systems in commercial buildings. Cooperative Research Centre for Construction Innovation. 2007. ISBN 978-0-9803503-8-8. Available from http://www.construction-innovation.info/images/HVAC_system_size.pdf.

Publication documenting the symptoms and impacts of incorrect-sizing, barriers to right-sizing, and suggestions and solutions to reduce over-sizing.

Technical and Analytical Details

Simple baselines are best applied for high-level benchmarking and energy performance tracking. In contrast, analyses that focus on measuring savings and detecting energy waste and faults generally require more-sophisticated models. When developing simple baselines, be sure that the associated time period and data set are sufficient to address fluctuations in weather, occupancy, or operational characteristics that influence energy consumption. In addition, make sure that the normalization factors that best characterize consumption are measureable; for example, the number of occupants present for a given time period may be useful, but ultimately unavailable, given standard sensing systems.

Cooling systems are very difficult to characterize well with simple baselines, given that their energy performance depends in large part on temperature and humidity. Since simple baselines tend to rely upon coarse aggregates such as kWh/CDD that introduce significant uncertainty, and simple baselines may be limited. Heating systems may be decently characterized with simple baselines, provided that the time horizon is long enough and operations are sufficiently regular.

The most common simple baseline that is used to express whole-building energy use is the energy use intensity (EUI), or annual energy use per square foot per year [kWh/sf/yr]. The square footage used most often is gross square footage, which includes conditioned and unconditioned spaces, though usually excludes parking lots and underground parking garages. The type of services that a building delivers may form the simple baseline. For example, industrial activities may be characterized according to units of production, educational services according to number of students, or information technologies according to number of servers.

Use and Presentation

Many commercial energy analysis software tools accommodate the simple normalization that is required for the majority of simple baselines. This is typically done by providing arithmetic functionality, so that the tools can be configured to divide a metered energy total by constants such as square feet, or by other time series data, such as degree days. In this way, a normalized consumption metric is produced. Building automation systems, some utility tracking tools, and energy information systems are among the commercial tools that tend to accommodate normalization capability. The degree of flexibility built in to such computations differs from tool to tool. In some cases, changes can be made dynamically through the front-end graphical user interface (GUI) with user-accessible menu options; in other cases, you may easily be able to access computational parameters, and have to use direct system programming. Benchmarking tools may also apply significant data filtering and normalization to express a building's energy use in terms that are appropriate for performance comparisons.

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Carbon Trust. Degree Days: Accounting for weather effects on energy consumption. Available from http://www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/energy-metering-monitoring/pages/degree-days.aspx.

Website with information on the use of degree days in energy management, including publications and further online resources.

Farnsworth, G. Performance benchmarking with energy bill data: Making the most of your energy accounting software. E SOURCE, Corporate Energy Managers' Consortium, CEMC-7, January 2006. Available from http://www.esource.com/esource/preview_list/20708.

Report reviewing energy accounting software tools in the context of benchmarking. Baseline considerations such as weather, production, and normalization are presented, with conclusions as to useful reporting, tool selection, and technical challenges.

Friedman, H, Crowe, E, Sibley, E, Effinger, M. The Building performance tracking handbook: Continuous improvement for every building. Prepared by Portland Energy Conservation for the California Energy Commission. California Commissioning Collaborative, 2011. Available from: http://www.cacx.org/PIER/documents/bpt-handbook.pdf.

Handbook presenting basic concepts in tracking the energy performance of commercial buildings, including overall strategies, benchmarking, metrics, and a variety of tool types.

Northwest Energy Efficiency Alliance. Performance indicators: Better Bricks. Available from http://www.betterbricks.com/building-operations/tools/performance-indicators-0.

Website with instructional information on building performance indicators, including best practices and concepts relevant to benchmarking, and simple baselines, metrics, data and tools.

Technical and Analytical Details

The computational example that was provided in the main summary focused on modeling daily peak load based on day of week and peak daily outside air temperature. Fitting 15-minute data rather than daily load data uses the same procedure, but instead of daily maximum temperature, the 15-minute temperature is used (with interpolation if needed); and instead of an indicator variable for each day there is one for each 15-minute period of the week during which the building is occupied: Monday 7:00 AM, Monday 7:15 AM etc. This creates up to 672 different columns of indicator variables, although (as with daily data) any time in which the building is not operating should be excluded. At this scale of data analysis Excel may be unwieldy; you can use a statistical analysis software package instead.

Although our previous examples have used whole-building load, the regression approach can be used for any measured parameter (such as plug loads or lighting loads), as long as it can be predicted fairly accurately from available data such as time or day of week, temperature, humidity, etc. Also, although our examples have focused on time and outdoor temperature as predictive variables, other variables may be used as well. For example, if building occupancy is known as a function of time, this could be a very useful predictive variable (especially for plug load and/or whole-building electric load).

We illustrate time-of-week regression with an example based on several weeks of 15-minute interval data. Consider a building that operates in "occupied" mode for 8 hours per day, Monday through Friday. The occupied period thus includes 160 15-minute periods per week. Let *i* be an index from 1-160 that identifies the 15-minute period during the week. Let *T(ti)* be the outdoor air temperature at time t, which occurs in time interval *i*. If there are several weeks of data, there will be several data points for each index *i*: one from the first week, one from the second, and so on. The projected load at time *t* is

$$\hat{L}(t_i;T(t_i)) = a_i + b_T[T(t_i) - 60F]$$

Linear regression is used to determine the a_i values (the "time of week" coefficients, one for each of the 160 periods in this example) and b_T (the temperature coefficient), so as to minimize the root-mean-squared difference between the predicted and measured load. As in the computational example in the main summary, the entire term in [brackets] should be replaced by zero when the outdoor temperature is below 60 °F. An outdoor temperature of 60 °F is often near the point below which there is no temperature-dependent load, but this exact point depends on the internal loads in the building, as well as its temperature setpoint, so a temperature such as 55 °F or 65 °F might work better for any individual building.

More complicated temperature dependence, such as non-linear behavior at high temperature or increased load at low temperature due to heating, can also be included through small changes to the model. Also, you can add linear terms to the right side of the equation to handle explanatory variables such as humidity or occupancy.

In this example, we have assumed that the quantity of interest is the whole-building electric load. You can use the same general approach of regression modeling for other parameters such as lighting load, plug loads, etc. In some cases, such as lighting loads the outdoor air temperature would not be expected to play a substantial role, and can be left out of the regression, which, in its minimal form, would include only the time-of-week coefficients.

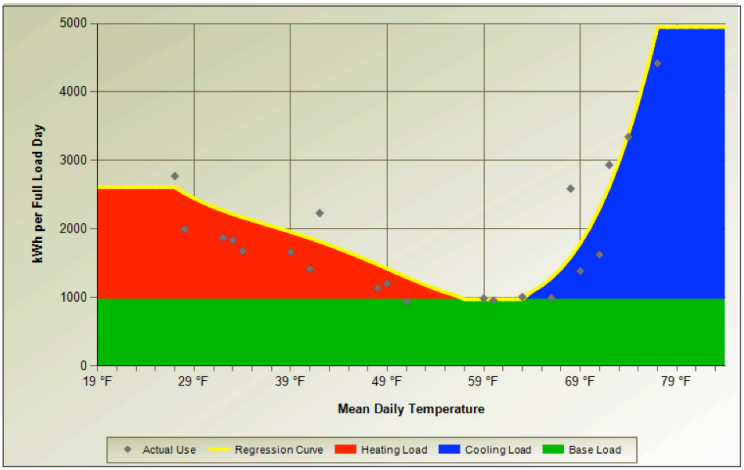
Temperature-Dependent Loads

An approach that is sometimes used to quantify the effect of temperature on load is to plot load versus temperature and find the best-fit regression line that describes the relationship, without using "time of week" coefficients, as presented in the Energy Signature method. However, that approach does not completely account for a crucial dependency, and carries associated inaccuracies. Namely, in most buildings the load is higher in the afternoon than in the early morning for two reasons: (1) the occupancy is higher (bringing higher plug and lighting loads), and (2) outdoor temperatures are higher, so cooling energy use is higher. Simply performing a regression of load on outdoor temperature completely ignores item (1), and can substantially exaggerate the dependence of load on temperature. For instance, even buildings that do not have air conditioning will usually have a higher load when the temperature is high than when it is low, simply because both the load and the outdoor temperature are usually low in the morning and evening and high in the afternoon. In a more typical case, a building might consume (on average) 500 kW more when the temperature is 85 °F than when it is 55 °F, but 100 kW or 200 kW of this increase is actually due to the time of day, with the causal effect of temperature being only 300-400 kW.

A regression that includes time-of-week coefficients and a temperature coefficient can separate reasons (1) and (2) above. The resulting temperature coefficient captures the temperature dependence that remains after accounting for the regular variation that occurs every day. For this to work effectively, the data must include days with a range of outside air temperatures: if every day has the same temperature profile, the regression will not be able to distinguish temperature-dependent load from time-dependent load.

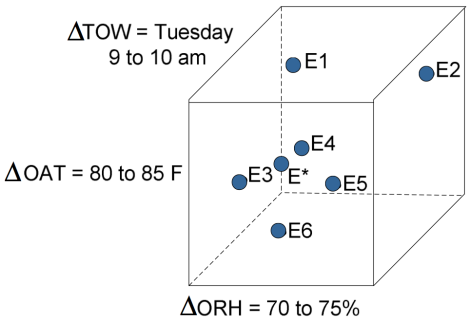
Use and Presentation

The robustness of baselining in commercial energy analysis tools varies widely. Many tools offer ranges of projected loads generated from baselines that can be significant, depending on the fitness of the underlying model. A common set of graphical presentations tends to be used in baseline-related analyses; however, the underlying modeling approaches may be quite different. For example, the image below shows a case in which actual daily electric usage (gray diamond markers) is overlaid with the regression baseline model (yellow curve) in an energy signature presentation of load vs. outside air temperature. Both the baseline model and the graphical display apportion the load into a base load shown in green and temperature-dependent loads for the cooling and heating seasons, shown in blue and red respectively.



Source: Interval Data Systems

Regression models were the focus of the computational example and much of the technical discussion; however, you can also use other techniques to good success. Bin methods predict the energy consumption at a given time to be equal to the average consumption at times when conditions were similar. Consider the case in which air temperature, relative humidity, and time of week are the explanatory variables used to model energy. The three-dimensional space of explanatory variables is "binned," or broken into mutually exclusive volumes. For example, temperature might be binned into five-degree intervals, time of week into weekend and weekday, and relative humidity into five-percent intervals. Energy consumption data are placed into the appropriate bins, as in the image below, and the explanatory variables are used to identify which bin corresponds to the current conditions. Modeled energy consumption for the current conditions is then taken as the average of the historic data in the bin.



Source: NorthWrite

Weighted-average methods apply the same basic principle as the bin method: the predicted energy consumption is the average consumption during similar periods. Create a metric to describe the degree of similarity between current conditions and similar conditions at other times. As the basis of the model, use a weighted average of the energy performance at these similar times; the weights used in calculating the average depend on the degree of similarity, with highly similar conditions receiving a high weight.

Neural networks are also used in commercially available energy analysis tools. Artificial neural networks are so named because they simulate some of the behavior of neurons in the central nervous system. Input variables such as outdoor temperature and humidity are mathematically processed to create a potentially large number of secondary, or "hidden," values. These hidden values are then processed to generate a (usually small) number of output values, such energy consumption. The mathematical functions that process the input values and the hidden values have adjustable parameters known as weights, so that the effect of every input value on every hidden value is adjustable, as is the effect of every hidden value on every output value. Neural networks "learn" by adjusting the weights so that the outputs are as close as possible to their desired values, for a large set of "training" data. For example, you can use data from several weeks or months of building operation to train the network to model energy consumption, from variables such as temperature, humidity, and time of day.

References and Technical Resources

Granderson, J, Piette, MA, Ghatikar, G, Price, P. Building energy information systems: State of the technology and user case studies. Lawrence Berkeley National Laboratory, November 2009, LBNL-2899E. Available from http://eis.lbl.gov/pubs/lbnl-2899e.pdf.

Report containing a market characterization of energy information systems and related performance tracking tools, including a review of baseline modeling approaches in Appendix C.

Kissock, JK, Haberl, JS, Claridge, DE. Development of a toolkit for calculating linear, change-point linear and multiple-linear inverse building energy analysis models. Final Report for ASHRAE Research Project 1050-RP. November 2002. Energy Systems Laboratory, Texas A&M University. Available from http://repository.tamu.edu/handle/1969.1/2847.

Report summarizing a FORTRAN 90 application for developing regression models of building energy use, to be used in measurement and verification of energy savings.

Komhard, S, Neumann, C. Black box approach for energy monitoring of commercial buildings. 2008. Proceedings of the International Conference for Enhanced Building Operations, Berlin. Available from http://repository.tamu.edu/bitstream/handle/1969.1/90820/ESL-IC-08-10-52.pdf?sequence=1.

Description of a baseline modeling approach to develop a multiple linear regression model based on energy signatures. In addition to measured building data, a clustering process is added to the regression to isolate the building's day-types.

Montgomery, DC, Peck, EA, Vining, G. 2011. Introduction to linear regression analysis, 5th edition. Wiley Series in Probability and Statistics. Wiley, 710p.

Book describing both the conventional and less common uses of linear regression, including a general introduction, typical applications, and more advanced modeling concepts.

National Productivity Council. Book-1: General aspects an energy management and energy audit; Chapter 8 Energy Monitoring and Targeting. 2004. Guide books, 2nd edition, National Certification Examination for Energy Managers and Energy Auditors. Bureau of Energy Efficiency, Ministry of Power, Government of India. Available from http://emt-india.com/BEE-Exam/GuideBooks_QB.htm.

Guide to energy monitoring and targeting, with extensive review of the use of baseline models and cumulative sums for detecting energy use anomalies.

Office of Energy Efficiency, Natural Resources Canada. Monitoring and targeting techniques in buildings. 2007. Office of Energy Efficiency, Natural Resources Canada. Available from http://oee.nrcan.gc.ca/publications/commercial/m144-144-2007e.cfm.

Fact sheet presenting approaches to monitoring buildings and targeting operational improvements, including model baselines, and the use of cumulative sum calculations.

Price, Philip. Methods for analyzing electric load shape and its variability. May, 2010. Lawrence Berkeley National Laboratory, Report LBNL-3713E. Available from http://drrc.lbl.gov/system/files/LBNL-3713E_0.pdf.

Paper with details on the construction of regression model baselines.

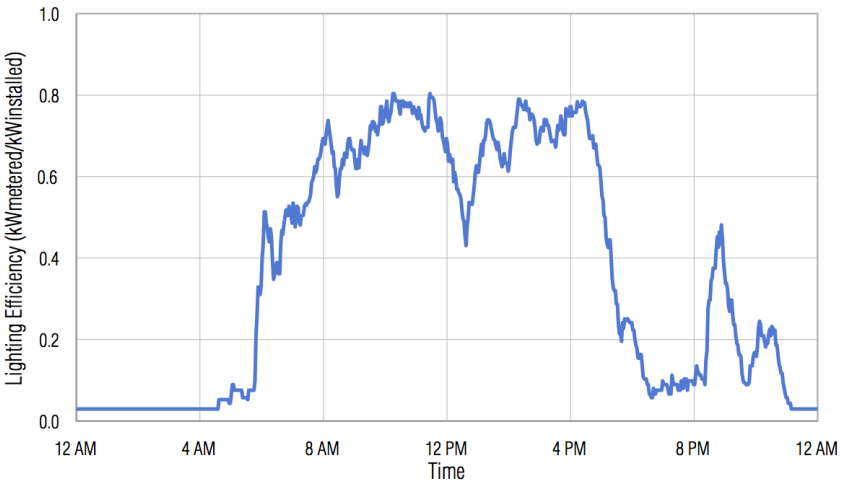
Technical and Analytical Details

Lighting efficiency normalizes the actual lighting load by the installed capacity, and therefore is an indication of the proportion or percentage of the installed load that is on at any given time. This insight into actual usage is not reflected in traditional lighting metrics such as lighting power density (LPD), which is the total installed load normalized by the floor area [W/sf]. Given only the LPD, a building that used the lights very conservatively appears equal to a building in which the lights are routinely left on unnecessarily.

The savings from advanced controls are often not fully realized because they are set up incorrectly, are defeated by occupants, or stop working over time. Therefore, in buildings with advanced lighting controls, continuous tracking of the lighting operational efficiency metric is particularly useful in exposing problems. In most cases, interpretation of the value of the metric is straightforward; however, it becomes more difficult if the submetering includes areas of the building with more than one control strategy, for example, some daylight dimming zones and some scheduled zones with no manual control.

Use and Presentation

The application examples presented in the main method summary were comprised of investigations of time series of the lighting operational efficiency metric, with time of day plotted on the x-axis and the value of the metric plotted on the y-axis. Similar to load profiling, operational efficiency can be aggregated over a collection of many 24-hour periods to understand the "average" operational performance of the lighting system at each hour of the day. In the example below, 32 days of operation are aggregated for a control zone with occupant sensing and set-point tuning. Therefore, each point on the plot represents the average value of the metric for a given time of day, over the 32-day period.



Source: Lawrence Berkeley National Laboratory

In this case, the operational efficiency increases from the near-zero nighttime value, between the hours of 6-9 AM, reflecting the variability in the arrival time of the occupant each morning. A marked dip occurs around noon with the lunch hour, and by 6 PM the occupant tends to be gone, with the lights on a very low percentage of the time. The spikes between 8 PM and midnight reflect security and cleaning crews.

In contrast to HVAC control systems, lighting control systems do not typically report control status or time series of load that are accessible to external building performance monitoring tools. Those that do may offer visualization and load profiling, but do not commonly trend operational efficiency as defined in this handbook. In some cases it is possible to monitor lighting loads through panel-level metering, which may be accessed through BAS, or commercial energy information systems. In either case it is a straightforward programming task to compute the operational efficiency metric, but ensure that the total installed lighting power has been carefully accounted for, and that the panel-based submetering does not include other non-lighting miscellaneous loads. While it may be possible to submeter some of the lighting loads at the panel level, it is particularly unlikely that loads are sufficiently separated to be able to capture all of the lighting loads though panel-level metering.

References and Technical Resources

Granderson, J, Gaddam, V, DiBartolomeo, D, Li, X, Rubinstein, F, Das, S. Field-measured performance evaluation of a digital daylighting system. 2010. Leukos 7(2): 85-101.

Paper describing additional metrics to evaluate the as-operated performance of controlled lighting systems, including occupancy detection errors, daylight regulation, and energy savings.

Heschong Mahone Group, Inc. November 2005. Sidelighting photocontrols field study. Final Report submitted to Southern California Edison Co., Pacific Gas and Electric Company, and Northwest Energy Efficiency Alliance. Available from http://www.h-m-g.com/Projects/Photocontrols/sidelighting_photocontrols_field.htm.

Study of the performance of daylight-responsive lighting controls, including expected vs. achieved energy savings, and functionality relative to design intent.

Illuminating Engineering Society of North America. 2011. The IESNA Lighting Handbook, 10th Edition. Illuminating Engineering Society of North America, 1328 pgs. Available from http://www.iesna.org/handbook/

Technical lighting reference that includes practical applications, and selected topics on controls, energy management, sustainability, and economics.

Jennings, J, Rubinstein, F, DiBartolomeo, D, Blanc, S. Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed. 2000. Leukos 29(2): pgs 39-60.

Paper documenting the potential energy savings from occupancy, switching, and dimming control in private offices.

National Electrical Contractors Association. Guide to Commissioning Lighting Controls. National Electrical Contractors Association. 2006. Available from http://www.necanet.org/files/ACF363E.pdf.

Describes the commissioning of lighting controls and calibration of associated sensors.

Rubinstein, F and Enscoe, A. Saving energy with highly-controlled lighting in an open-plan office. 2010. Leukos7(1): 21-36.

Field study to determine energy savings of a workstation-specific controls retrofit.

Technical and Analytical Details

In quantifying the efficiency of heating or cooling systems, first define the system boundaries. This summary does not include ventilation systems, or extend into the distribution systems and coils where losses are difficult to measure and quantify.

Efficiency calculations depend on two primary quantities: the energy consumed to produce the heating or cooling, and the heating or cooling load produced. Heating systems are commonly supplied by electricity or natural gas, and cooling systems are typically supplied by electricity. Note that purchased steam or oil heating systems and gas adsorption cooling are outside the scope of this discussion. In analyzing the efficiency of water-cooled chiller systems, the electric consumption includes the power used to run all fans, pumps, and cooling towers, as well as the chillers themselves.

The load produced in heating and cooling systems is calculated from a flow measurement, a temperature delta between system supply and return, and unit conversion factors. Heating loads are typically expressed in Btu/hr, with boiler loads computed from measures of water flow, and furnace loads from measures of airflow. Analogously, cooling loads are also typically expressed in Btu/hr or tons, with water-cooled chiller loads computed from measures of water flow, and direct expansion chiller loads from measures of airflow.

Modern control systems typically trend and store the supply and return temperatures from boilers and chillers. However, hot or chilled water flow meters are less common, and may need to be installed and integrated to obtain the load produced by the equipment. Flow measurements are more difficult in air-based systems, and you may have to use specified airflow rates as a proxy. System-level gas or electric submetering is necessary to determine the energy used to produce the heating or cooling. Accurate gas and water flow measurements require straight runs of pipe several times the pipe diameter, which is often challenging given the typical plant configurations.

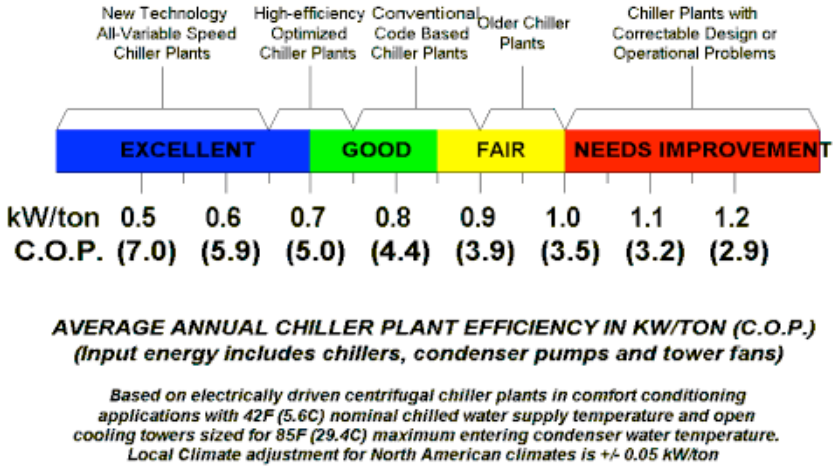
Use and Presentation

As with input and output ratings, discussed in loading histograms, there are numerous efficiency ratings and procedures for heating and cooling equipment. As described in the following table, the performance of heating and cooling equipment is rated at a single set of full-load design conditions, as well as across a hypothetical range of 'seasonal average' conditions that account for partial loading. The coefficient of performance (COP), energy-efficiency ratio (EER), and kW/ton each quantify the power input at full-load, relative to the rate of cooling that is generated. You can apply unit conversion factors to convert from one metric to another.

Equipment Type	Design Rated Conditions	Seasonal Average Conditions
Cooling	COP, EER, kW/ton	COP, IPLV, SEER
Heating	COP, combustion efficiency, thermal efficiency	AFUE, COP

Source: Engineering Toolbox

The table below presents a high-level, rough guide to interpreting COP and kW/ton for plant efficiency, given electric centrifugal chillers.



Hartman, T. Improve chiller plant efficiency! AutomatedBuildings.com, January 2001. Available from: http://www.automatedbuildings.com/news/jan01/articles/hartman/hrtmn.htm.

The seasonal energy-efficiency ratio (SEER) is a weighted average of EERs over a range of outside air conditions, and carries units Btu/Wh. SEER is typically applicable to systems with a capacity of less than 60-65,000 Btu/hr. The range of outdoor conditions is intended to capture the seasonal effects over a hypothetical typical year. Analogous to SEER, the integrated part load value (IPLV) is a rating based upon a weighted average of performance at 100%, 75%, 50%, and 25% load.

For heating systems, COP, thermal efficiency, and combustion efficiency are each rated at standard design conditions. Seasonal average ratings include the DOE's annual fuel utilization efficiency (AFUE) for boilers under 300 kBtu/hr input, as well as COP. The American Society of Mechanical Engineers Power Test Code details processes for determining boiler efficiency.

X-y scatter plots of efficiency metrics vs. percent load or total produced heating or cooling

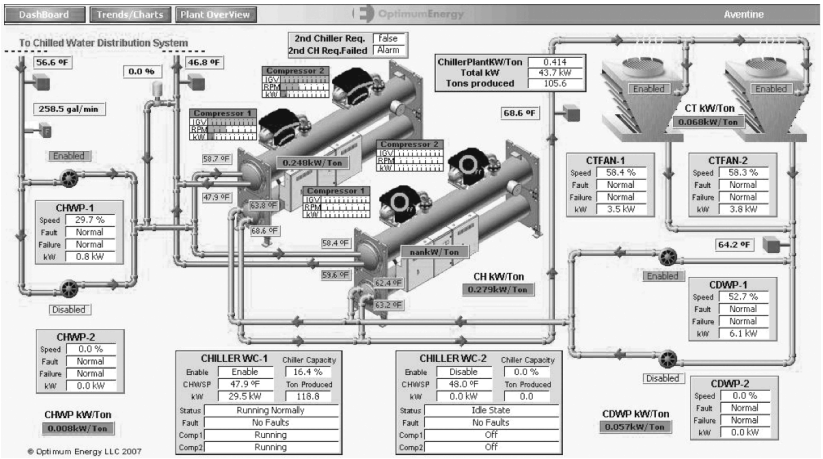
are commonly used to monitor efficiency and identify savings opportunities. For cooling systems and chillers, the following guidelines can assist in interpretation of the kw/ton vs. tons (or percent load) efficiency curves that were reviewed in the Application Examples of the main summary. If your efficiency curve not does not reflect specifications, or has deteriorated over time, a number of causes may be investigated, including:

- Design flaws
- System changes (such as cooling tower down time)
- Poor water flow characteristics (perhaps you need multiple chillers)
- Component malfunctions (like condenser fan cycling)
- Fouling of chiller tubes
- Loss of refrigerant charge
- Poor full-load or part-load performance (may be related to weather conditions)
- Over- or under-sizing of components

Loss of efficiency is not the only thing to look for on your cooling system efficiency or chiller curve. You also want to look at where you're operating on this curve, and for how long. Watch out for:

- Excessive "on" time
- Short cycling
- Heavy system use at low efficiencies
- Excessive on time at full-load or part load (over or undersizing)
- Improper function of the delivery system
- Suboptimal setpoints or control schedules
- Malfunctioning temperature gauges or thermostats

In addition to efficiency curves, commercial software packages may offer graphical visualizations of system configuration and components overlaid with performance metrics computed from measured data. An example is provided in the image below.



Source: Optimum Energy

References and Technical Resources

Air-Conditioning, Heating, and Refrigeration Institute (AHRI). Available from http://www.ahrinet.org.

Information on HVACR industry efficiency standards, rating certifications, and guidelines.

American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE Handbook. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Available from http://www.techstreet.com/lists/ashrae_handbook.html?ashrae_auth_token=

Four volumes comprise the handbook of the ASHRAE handbook; of direct relevance to HVAC efficiency, design, selection, and use are the 2011 HVAC Applications, the 2009 Fundamentals, and the 2008 HVAC Systems and Equipment.

Piette, MA, Khalsa S, Haves, P, Rumsey, P, Kinney, K, Lock EL, Sebald A, Chellapilla, K, Shockman, C. Performance assessment and adoption processes of an information monitoring and diagnostic system prototype. October 1999. Lawrence Berkeley National Laboratory, LBNL# 44453. Available from http://escholarship.org/uc/item/6zb5417g.

Report evaluating the use of a monitoring and diagnostic system for improved building operations, with measurement and analysis examples including HVAC efficiency.

Santamaria, C. Next generation energy efficient technologies: a case study demonstrating top operational performance. Journal of Green Building, 2009. Available from http://www.optimumenergyco.com/pdf/Journal%20of%20Green%20Building%20-%20Next%20Gen%20Technologies%20-%20JGB%20FINAL.pdf.

Chiller plant optimization case study in which loading histograms and efficiency plots are used for retrofit analysis.

Showers, G. Boiler operation efficiency insights and tips: Debunking five common myths about boiler-system operation. Heating/Piping/Air Conditioning Engineering, 2002. Available from http://lattnerboiler.com/Boiler%20Operation%20Efficiency%20-%20Operations%20and%20Tips.pdf.

Article reviewing basic engineering and operating principles based on actual curves from efficiency tests performed over a number of multi-boiler plants.

Technical and Analytical Details

When plotting load versus OAT you must first choose interval of analysis (e.g., hourly, daily, monthly). For this interval, average or measure the OAT as a point, and then plot it on the x-axis, and plot the corresponding average power or instantaneous power on the Y-axis. Plotting many points leads to a relationship that you can compare against historical performance or against published numbers or a model output for expected performance. This method represents a simple regression analysis that can be fit with a mathematical curve to create a predictive model of building or system performance. An advantage of the Energy Signature method is that it is relatively simple and informative, due to a reliable correlation of dry-bulb outdoor air temperature with other climatic variables that also commonly influence performance: wet bulb temperature (relative humidity), solar radiance, and wind speed. An advantage of the energy signature is that you can create it using billing data from a utility and temperature data from a reference weather station, rather than relying on more-advanced meters and larger data sets.

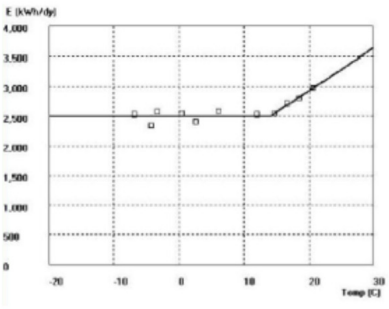
The relationship that defines the energy signature is also present in the Model Baseline Method, when applied to temperature-dependent loads. The Model Baseline Method uses further categorization to separate like-type days, and even time of day/week, to create the rigorous final model, while the energy signature relies on averages across times and day types to smooth out the relationship.

The interval selected should be short enough to create a useful analysis, but long enough to eliminate transient effects, so that the correlation is precise and orderly. For whole-building energy, daily and monthly plots are more common. You can still create these plots by aggregating interval data taken at hourly (or less) intervals. The example below shows a whole-building electric energy signature with monthly intervals at the left and daily intervals at the right, with the corresponding R^2-value of correlation (higher is better). The monthly interval is suitable to describe building behavior, and it provides a lower error. The daily energy signature provides analysis more promptly but is less accurate.

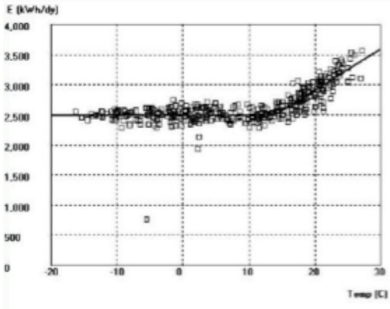
Cooling or heating system energy signatures can be considered in an hourly, daily, or monthly interval. The hourly data may not provide consistent results, depending on the definition of the cooling or heating system; that is, whether or not it includes auxiliary equipment such as pumps, fans, and other distribution equipment). End-use equipment like Air Handler Units (AHU) or chillers can be examined at shorter intervals (daily, hourly, or less) though the relationship may not be complex enough to be an accurate tool. Heating and cooling system performance is reviewed more comprehensively in the Heating and Cooling Efficiency section, in Fundamental Methods.

Change Point Models

Change point analysis is used when the correlation of energy usage versus OAT changes for different regimes of OAT. Graphs (a) and (b) in the figure below demonstrate a general three-point model, where the heating (left) or cooling (right) energy signature has a flat (base load) period, where the change in OAT does not affect the electric usage and a sloped (heating or cooling slope) period where the energy use is linearly related to energy use. These three points: base load energy; balance point temp (T_b); and the heating or cooling slope are sufficient to characterize the relationship.

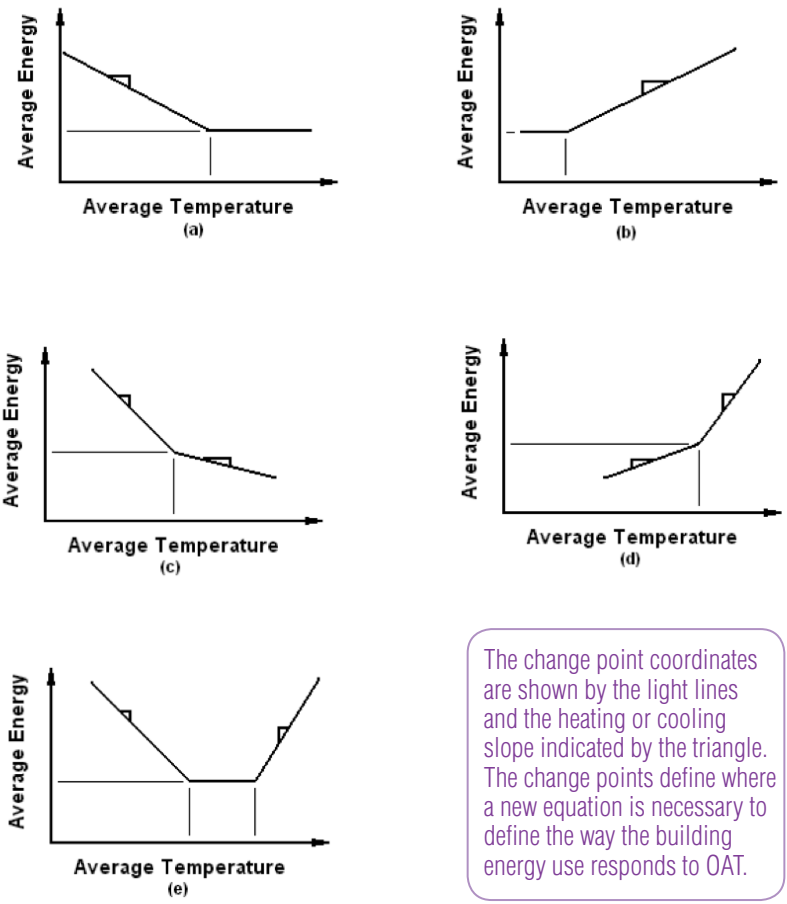


Monthly Regression
$R^2 = 0.89$



Daily Regression
$R^2 = 0.69$

Source: Kissock, K., Improving model calibration using inverse modeling. Presentation to the International Building Performance Association, 2010.



The change point coordinates are shown by the light lines and the heating or cooling slope indicated by the triangle. The change points define where a new equation is necessary to define the way the building energy use responds to OAT.

Source: Adapted from Kissock, K., Improving model calibration using inverse modeling. Presentation to the International Building Performance Association, 2010.

As the number of regimes of behavior increase, additional points are added to characterize the relationship between energy and OAT. As shown above, three- (top row), four- (middle row), or even five-point models (third row) are used in the same way as all energy signatures by comparing changes against a baseline period, comparing against modeled expectations, or benchmarking against similar buildings within a portfolio or national reference set.

Energy and Temperature Metrics

The energy signature can plot energy as the Y-axis coordinate or average power. Using energy requires that all the intervals be of the same duration to be meaningful. Average power (or average rate of energy use) allows for intervals of differing lengths to be used, which is often the case when using billing data for the creation of an energy signature. As an alternative, other calculations such as kWh/day or kWh/h can be used.

In order to make whole-building energy signatures easier to compare from building to building, the Y-axis point is often further normalized by the Gross Square Footage (GSF) of the building, typically excluding parking. Heating or cooling energy signatures may be normalized by Conditioned Square Footage (CSF).

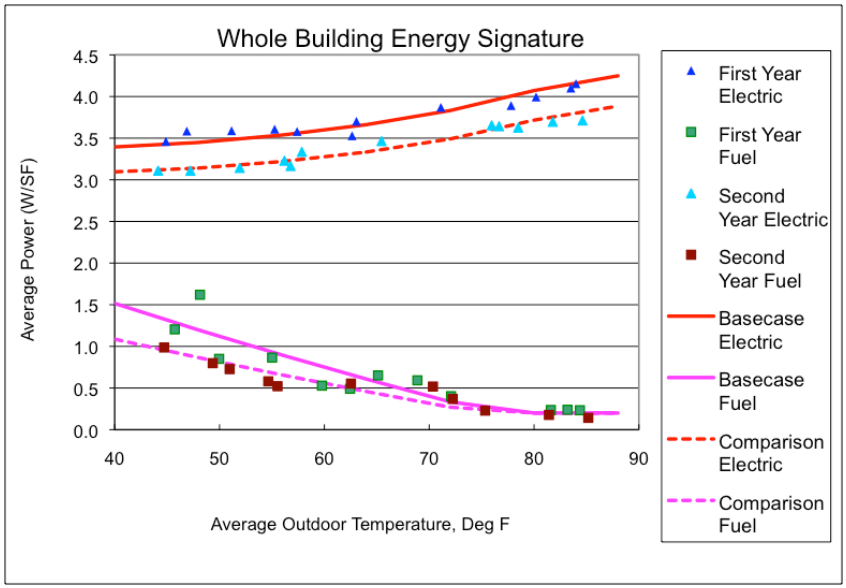
You can make a slight modification to an energy signature if average OAT data is not available but degree days are available. Degree days, expressed as Heating Degree Days (HDD) or Cooling Degree Days (CDD) are a way of making temperature information into an algebraic quantity. Heating Degree Days (HDD) are counted daily as the difference between the daily OAT and the reference. For example, a daily OAT of 35 °F using a HDD-60 reference results in 25 heating degree days for that day. An average OAT of 65 °F would count as 0 HDD. In this way, a monthly or annual total can be established and used as the X-axis coordinate in an energy signature, with energy or power as the Y-axis coordinate. Likewise CDD are calculated by a similar method, but for OATs that exceed the reference temperature.

High temperature extremes in a monthly period, or seasonal variations of solar gain, can cause scatter in the plotted energy signature points that may be falsely interpreted as control-related problems. Currently there are no fixed procedures for dealing with these variations.

The energy signature does not normalize for occupancy, and this can cause plotted data points, especially in the electric energy signature, to vary when operations have not changed. There are no fixed procedures for dealing with occupancy variations in the energy signature analysis at this time.

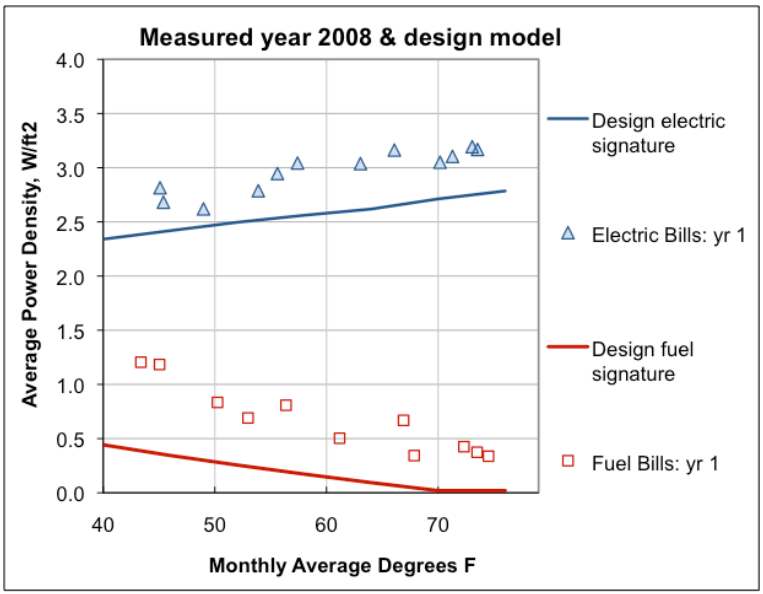
Use and Presentation

You can use energy signatures in several ways. You can compare them to a reference signature such as a design energy model, or to reference characteristics such as specific change point regimes. You can also compare them over time or between peers, as is done in Longitudinal and cross-sectional benchmarking. You can directly inspect the energy signature to identify unusual traits such as high base loads, slopes, or data scatter. In the example below, electric and gas signatures are plotted for two years. In the upper portion of the plot, the electric signature for Year 2 (dashed line) is lower than that for Year 1 (solid), reflecting improved efficiency due to a server virtualization project in the site's data center. The fuel signatures from Year 1 (solid) to Year 2 (dashed) show the effect of an improvement in the control and efficiency of the heating system, and perhaps a reduction of loss to the heavily air-conditioned data center space. Note that the gas base load (representing the heating of service water) remains relatively unchanged, since the server virtualization does not affect SHW usage.



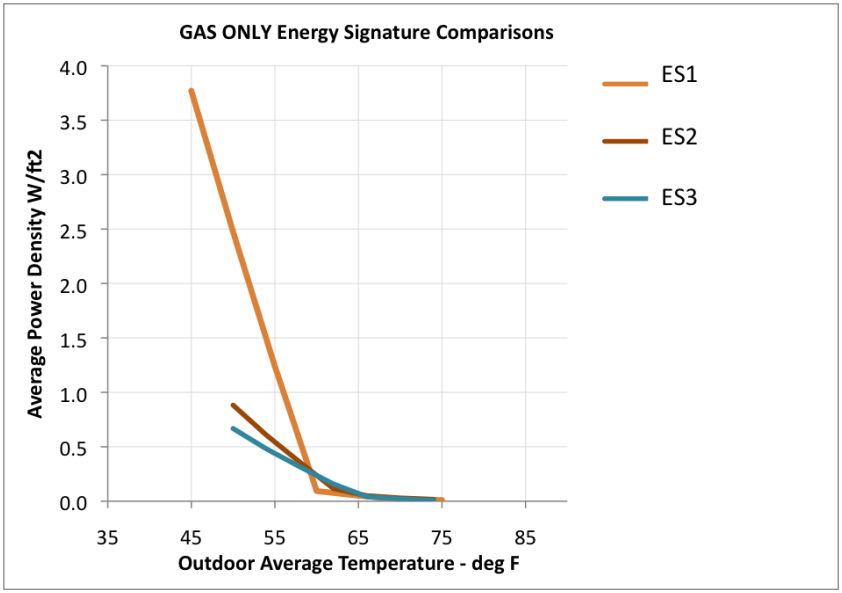
Source: New Buildings Institute

In the next example of use and presentation, monthly whole building energy signatures for electric (blue triangles) and gas (red squares) are overlaid with the signatures from design energy models (blue and red lines). Such analyses can reveal instances in which modeling assumptions were incorrect, or where operational decisions have led the building to stray from the design intent.



Source: New Buildings Institute

The final example of use and presentation shows an overlay of monthly heating system energy signatures for three like-type buildings, in this case elementary schools (ES1,ES2, and ES3) of a similar construction and gas-heating HVAC type. The Y-axis on these energy signatures is normalized for GSF, allowing for a valid comparison between buildings. The energy signature of ES1 is significantly different from the other two schools, revealing much higher energy use and potential for energy savings.



Source: New Buildings Institute

References and Technical Resources

Kissock, K. Improving model calibration using inverse modeling. August 13, 2010. Presentation to the International Building Performance Association, New York, NY. Available from http://www.ibpsa.us/pub/simbuild2010/invitedPresentations/SB10-PPT-IS09C-02-Kissock.pdf.

Presentation documenting the use of energy signatures, including change point models and errors.

Kissock, JK, Haberl, JS, Claridge, D. 2003. Inverse modeling toolkit: Numerical algorithms. ASHRAE Transactions, 109(2). Available from http://ecalc.tamu.edu/SupportFilesPub/Inverse%20Modeling%20Toolkit%20-%20Numerical%20Algorithms.pdf.

Paper describing the numerical models in the Inverse Modeling Toolkit, developed in ASHRAE Research Project RP 1050. Details include the algorithms used to find general least squares regression, variable-based degree days, change-point, and combination change-point multi-variable regression models, as well as uncertainties for determination of energy savings.

Komhard, S, Neumann, C. Black box approach for energy monitoring of commercial buildings. 2008. Proceedings of the International Conference for Enhanced Building Operations, Berlin. Available from http://repository.tamu.edu/bitstream/handle/1969.1/90820/ESL-IC-08-10-52.pdf?sequence=1.

Description of a baseline modeling approach to develop a multiple linear regression model based on energy signatures. In addition to measured building data, a clustering process is added to the regression to isolate the building's day-types.

Neumann, C, et al, eds. Results of the project Building EQ: Tools and methods for linking EPBD and Continuous Commissioning. January 2010. Fraunhofer Institute for Solar Energy Systems, Intelligent Energy Europe. Available from http://www.buildingeq-online.net/fileadmin/user_upload/Results/BEQ_publishable_results_report_final_rev_100624.pdf.

Report with examples of energy signatures used for energy performance monitoring and analysis.

Piette, MA, Khalsa, S, Rumsey, P, Lock, LE, Sebald, A, Shockman, C. Early results and field tests of an information monitoring and diagnostic system for commercial buildings. September 1998. Lawrence Berkeley National Laboratory, LBNL 42238. Available from http://gaia.lbl.gov/btech/papers/42238.pdf.

Report evaluating the use of a monitoring and diagnostic system for improved building operations, including an overview of diagnostic plots such as cooling system energy signatures.

Turner, C, Reichmuth, H. Using measured whole-building performance for green building program evaluation. 2009. Proceedings of the Energy Program Evaluation Conference, Portland, OR, pp 751-763. Available from http://www.newbuildings.org/sites/default/files/MeasuredWholeBuildingPerformanceForGreenBuilding.pdf.

This paper presents several examples of the use of energy signatures, identifying some of the key observed performance factors, and demonstrating that useful insight into measured building performance is possible with a relatively simple set of data.

Technical and Analytical Details

The International Performance Measurement and Verification Protocol (IPMVP) presents a framework of methodologies and definitions for determining the savings gained through energy-efficiency improvements. A detailed description of best practices and all aspects of implementing the various options in the IPMVP are outside the scope of this handbook; however, two of the options are particularly relevant for analyzing energy savings.

"Option B" requires short-term or continuous metering/measurement that captures the full energy impact of the improvement measure. You can apply it at the system or component level, and use it to individually assess the savings from multiple measures that are implemented in parallel. Option B is recommended in cases where: savings are too small to be measured at the whole-building level; interactions with other equipment or systems are measureable or negligible; independent variables such as baseline parameters are easily identified and monitored; the necessary submeters are already in place; isolation of the measure precludes the need for complicated baseline adjustments due to facility changes.

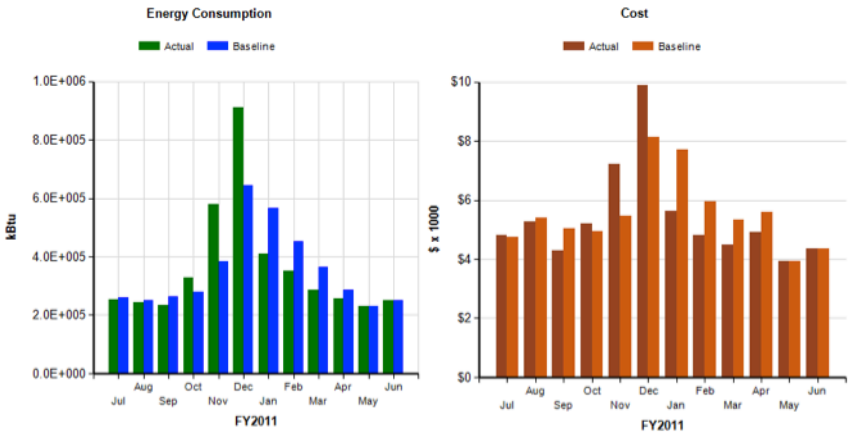
"Option C" relies on whole-building utility meters or utility billing data. It quantifies the total energy savings from all improvement measures included in the meter. Option C is recommended in cases where: many improvements have been implemented; site energy savings are of more interest than system-level savings; the savings are roughly 10% or greater and therefore robust to noise in the baseline monitoring period; at least one full year can be devoted to measurement in the post-measure period, with 2 or 3 years preferred. Further, hourly meter data should be aggregated to at least a daily total, to reduce the number of independent variables required to accurately characterize energy use in the baseline period.

ASHRAE Guideline 14 also addresses methods for the calculation of energy savings for different system types.

Use and Presentation

Verifying a project's energy savings using the IPMVP requires a detailed agreement between the parties involved (owner, facilities, energy service provider) and a description of the regression model that will be employed, the required monitoring period, and treatment of variable aspects of the financial transaction. The analysis is often referred to as Measurement and Verification (M&V), and specialized contractors can be hired to perform this analysis.

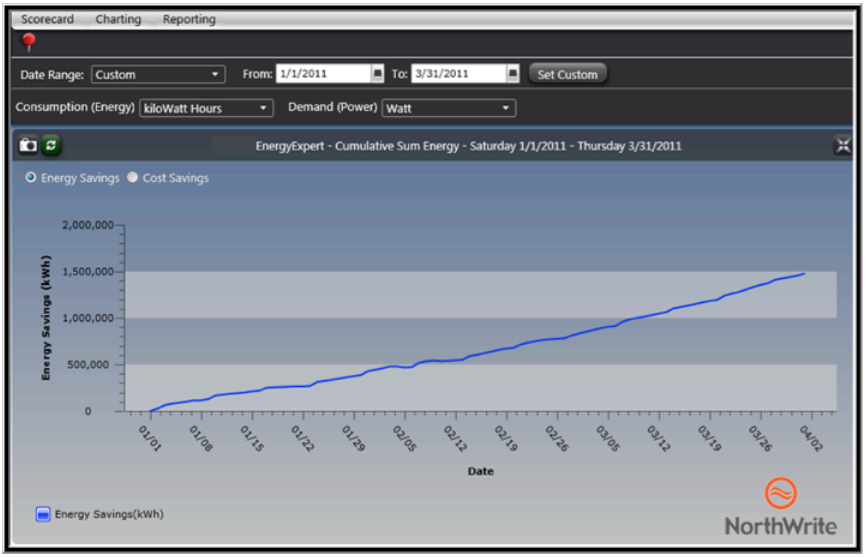
As in many of the application examples, the results of the baseline model and ongoing avoided energy calculations are often displayed in a co-plot of actual metered data and baseline model projected data, with notations indicating the baseline and performance periods and the ECM installation. You can also combine this co-plot with a table of the avoided energy use projections, with associated metered data and adjustments. For example, in the image below, baseline and actual energy use and energy costs are plotted monthly in a bar graph. Below the graph, the same information is summarized in a table, with the calculated difference (the "variance") between actual and baseline use. Note that the "Year-to-Date Variance" shown in this example is equivalent to a cumulative sum, and in this example reflects usage above the baseline.



	Actual Bill	Baseline	YTD Variance	Actual kBTU	Baseline kBTU	YTD Variance
Jul 2010	$ 4,814	$ 4,743	$ 71	254,611	260,167	-5,556
Aug 2010	$ 5,268	$ 5,401	-$ 133	242,360	250,454	-8,094
Sep 2010	$ 4,301	$ 5,056	-$ 755	233,597	263,499	-29,902
Oct 2010	$ 5,196	$ 4,940	$ 256	328,297	277,724	50,573
Nov 2010	$ 7,209	$ 5,467	$ 1,742	579,763	384,786	194,977
Dec 2010	$ 9,898	$ 8,139	$ 1,759	911,025	643,028	267,997
Jan 2011	$ 5,628	$ 7,723	-$ 2,095	410,389	564,955	-154,566
Feb 2011	$ 4,813	$ 5,941	-$ 1,128	349,646	452,836	-103,190
Mar 2011	$ 4,494	$ 5,337	-$ 843	285,523	363,177	-77,654
Apr 2011	$ 4,915	$ 5,600	-$ 685	255,671	287,401	-31,730
May 2011	$ 3,936	$ 3,936	$ 0	229,871	229,871	0
Jun 2011	$ 4,341	$ 4,341	$ 0	249,541	249,541	0
Total	$ 64,813	$ 66,624	-$ 1,811	4,330,295	4,227,439	102,856
	$ 64,813	$ 66,624	-$ 1,811	4,330,295	4,227,439	102,856

Source: Interval Data Systems

Cumulative sums are commonly computed to quantify the running total, or aggregate savings since the beginning of an efficiency project, as shown in the image below. Note the radio button that allows you to toggle between energy and cost savings. Here, the relatively straight slopes indicates steady, or near-constant daily energy savings relative to the baseline period.



Source: NorthWrite

References and Technical Resources

American Society of Heating, Refrigerating and Air-Conditioning Engineers. Guideline 14, Measurement of energy and demand savings. 2002. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

This M&V guideline was developed by ASHRAE to provide guidance on the acceptable level of M&V of energy and demand savings for commercial transactions; it does not address water efficiency projects.

Energy Valuation Organization. International performance measurement and verification protocol: Concepts and practices for determining energy and water savings, Volume 1. 2010. Energy Valuation Organization. Available from http://www.evo-world.org.

Volume I of the IPMVP defines basic terminology and general procedures to achieve reliable and cost-effective determination of energy and water savings in buildings and industrial plants.

Haberl, JS, Culp, C. Review of methods for measuring and verifying savings from energy conservation retrofits to existing buildings. April 2005. Energy Systems Laboratory, Texas A&M University, ESL TR-03/09-01. Available from http://repository.tamu.edu/handle/1969.1/2049.

This paper covers a brief history of M&V in the United States, an overview of M&V Methods, a cost benefit analysis, and cost-reduction and M&V sampling strategies.

Jump, D. Guidelines for verifying existing building commissioning project savings - Using interval data energy models: IPMVP Options B and C. 2008. California Commissioning Collaborative. Available from http://resources.cacx.org/library/holdings/VoS%20Guide%20111308_final.pdf.

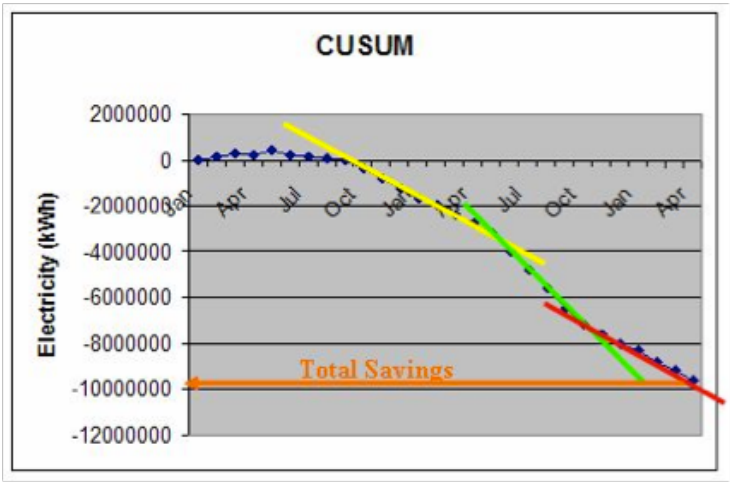
This guideline describes how to apply diverse measurement and verification concepts to determine the savings from existing building commissioning projects and programs.

Webster, L, Bradford, J. M&V guidelines: Measurement and verification for federal energy projects, Version 3. April 2008. Prepared by Nexant, Inc. for the US Department of Energy, Federal Energy Management Program. Available from http://www1.eere.energy.gov/femp/pdfs/mv_guidelines.pdf.

This document provides guidelines and methods for measuring and verifying energy, water, and cost savings associated with federal energy savings performance contracts.

Technical and Analytical Details

The slope of the CUSUM trend over an interval of time explains the rate of energy savings or losses. In the example below, the yellow, green, and red lines have three different slopes marking different periods of energy performance relative to the baseline (blue). A steeper slope, represented in the image in green, indicates a greater rate of energy savings. Distinct slopes at different time periods often indicate changes in energy consumption brought about by particular changes in equipment operations or energy-efficiency measures. As defined by the CUSUM equation, a positive slope and y-value indicate energy use greater than that suggested by the baseline. Some performance monitoring tools use a reversed sign convention in which negatives slope and y-value usage above baseline.



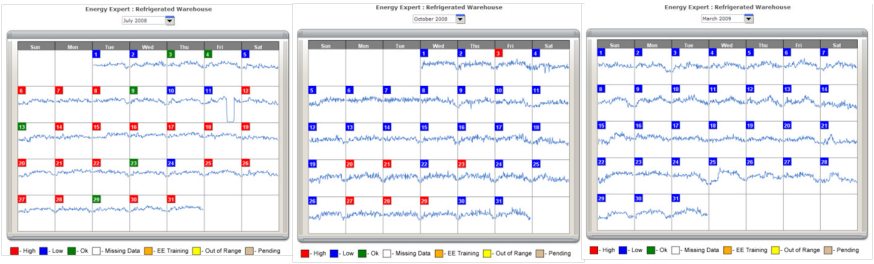
Source: Wikipedia

A poor baseline model will lead to incorrect predictions of energy consumption, so the CUSUM will not reliably represent actual savings or waste. Measured data must be sampled at a rate less than or equal to the interval of the underlying baseline model. For example, if the baseline quantifies monthly consumption, you must gather meter data at least monthly, but you could sum hourly data to monthly totals.

One technical question that arises in the application of CUSUM analysis is when to "reset" the baseline. For example, after you implement a set of efficiency measures, the CUSUM should grow increasingly negative, as energy savings accumulate. However, after a period of time it makes sense to establish a new, more current baseline that accurately reflects this improved level of efficiency.

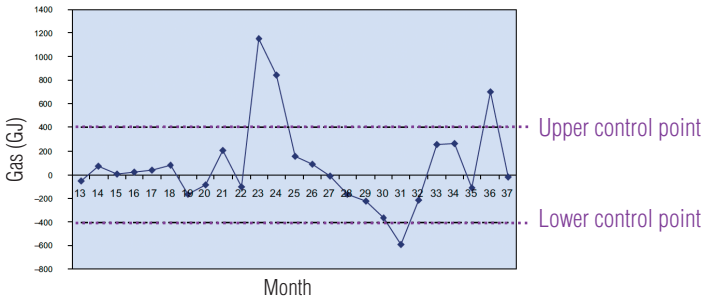
Use and Presentation

A calendar view, showing daily progression of CUSUM calculations, is one means of assessing, in one glance, days where savings or losses occurred. In the following example, red indicates cumulative energy losses, green reflects no change in performance, and blue indicates energy savings. During the first month, the building experienced cumulative energy losses, but improved, so that by the third month there were daily cumulative energy savings.



Source: NorthWrite

CUSUM control charts, as shown below, mark upper- and lower-bound thresholds to indicate when deviations from baseline performance are large enough to require attention. You can couple some CUSUM implementations with automated alarming or alerts, which can be triggered when control limits are surpassed. Control limits may be determined analytically or according to user preference or experience. If the trend moves above the upper control limit, it means that an event occurred to cause a substantial increase in energy consumption; if the lower control limit is surpassed, then energy savings of a given magnitude were realized. Note that the upper and lower control lines are CUSUM thresholds (use relative to baseline) as opposed to absolute measured load thresholds (kW).



Source: Natural Resources Canada

Some tools permit the user to record events in text format, and associate those events with particular time series data streams, or with dates and times. This ability to annotate quantitative data with supplementary qualitative information is useful in tracking the source of performance changes.

References and Technical Resources

Hooke, James H, Landry, B, and Hart, D. Energy Management Information Systems: Achieving Improved Energy Efficiency. A Handbook for Managers, Engineers, and Operational Staff. 2004. Office of Energy Efficiency, Natural Resources Canada.

Implementation handbook on energy information system technology, written for all levels of management and operational staff, including metering, data collection, data analysis, reporting and cost/benefit analyses, and two examples of the use of cumulative sums.

National Productivity Council. Book-1: General aspects an energy management and energy audit; Chapter 8 Energy Monitoring and Targeting. 2004. Guide books, 2nd edition, National Certification Examination for Energy Managers and Energy Auditors. Bureau of Energy Efficiency, Ministry of Power, Government of India. Available from http://emt-india.com/BEE-Exam/GuideBooks_QB.htm.

Guide to energy monitoring and targeting, with extensive review of the use of Baseline Models and cumulative sums for detecting energy use anomalies.

Office of Energy Efficiency, Natural Resources Canada. Monitoring and targeting techniques in buildings. 2007. Office of Energy Efficiency, Natural Resources Canada. Available from http://oee.nrcan.gc.ca/publications/commercial/m144-144-2007e.cfm.

Fact sheet presenting approaches to monitoring buildings and targeting operational improvements, including model baselines, and the use of cumulative sum calculations.

Puranik, VS. CUSUM quality control chart for monitoring energy use performance. 2007. Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management. Available from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4419388&tag=1.

Paper discussing the application cumulative sums to monitor energy use data, with comparisons to the use of traditional control charts.

Stuart, G, Fleming, P, Ferreira, V, Harris, P. Rapid analysis of time series data to identify changes in electricity consumption patterns in UK secondary schools. 2007. Building and Environment 42:4, pp. 1568-1580. Available from http://www.sciencedirect.com/science/article/pii/S0360132306000199.

Paper documenting the use of cumulative sums with interval electric data from 37 secondary schools, with multiple application examples.

Technical and Analytical Details

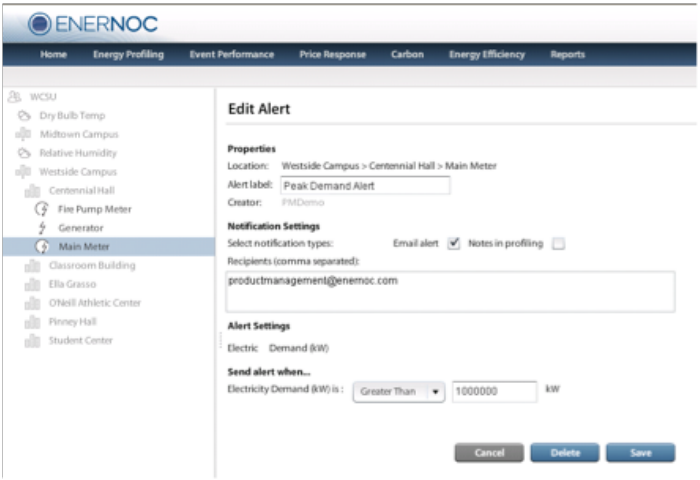
The robustness of automated energy anomaly detection methods depends most critically on how robust the underlying baseline method and accuracy of predicted values are. A poor baseline model will lead to unrealistic predictions, and therefore false, undetected consumption anomalies. Similarly, methods that generate predictions with large uncertainty could also compromise its usefulness. In some implementations, you may have the option to select or add independent variables to the analysis, which requires that you understand well which factors influence your building's load. Energy anomaly detection methods may be challenged in cases where building operations are extremely inefficient or variable. In the case of long-term inefficiency the method may not actually be able to discern waste, because the baseline will reflect consistently high usage. If building loads are highly variable, predictions may include enough uncertainty that the method becomes susceptible to false negatives and positives in the anomalies it does detect.

Research applications may entail a more sophisticated determination of thresholds based on knowledge of system operational characteristics, dynamic states and rates of change, or more advanced mathematical techniques. These approaches are not found in commercial analysis tools, and begin to mark a transition into an area of fault detection and diagnostic methods.

Use and Presentation

Automated whole-building energy anomaly detection is offered in some of the more sophisticated commercial analysis tools, such as advanced EIS. Non-commercial calculation modules, offered by researchers, do exist, and these can be constructed in analysis tools that offer regression modeling and arithmetic programming functionality. In the non-commercial case, the user must explicitly address data acquisition and quality assurance, which are non-trivial concerns.

Automated anomaly detection relies upon a combination of interval energy use data, system-level points that may be trended in existing BAS, and weather data acquired through weather feeds or stand-alone sensors at the building site. Whole-building energy anomaly detection methods are most powerful in cases where the building has modern BAS with robust trending and storage capabilities, and can therefore provide additional information to be used in isolating the sources of the anomaly, as described above. The ability to easily configure the data source, adjust threshold levels, and alert delivery settings is often integrated into analysis tools, as shown in the configuration screen below.



Source: EnerNOC

The energy anomaly detection threshold and projected load can be expressed visually in a number of ways. In the example below the projected load +/-10% is indicated by the green band. The yellow line shows the actual building load, which on the day shown, is within the expected range. If energy consumption exceeds the threshold, an energy anomaly is detected, and the yellow line will appear in the red area of the plot. Energy consumption below the expected range would lie within the blue area. Users can modify the +/-10% threshold for anomaly detection.

Source: NorthWrite

References and Technical Resources

Friedman, H, Crowe, E, Sibley, E, Effinger, M. The building performance tracking handbook: Continuous improvement for every building. Prepared by Portland Energy Conservation for the California Energy Commission. California Commissioning Collaborative, 2011. Available from: http://www.cacx.org/PIER/documents/bpt-handbook.pdf.

Handbook presenting basic concepts in tracking the energy performance of commercial buildings, including overall strategies, and a review of anomaly detection as offered in commercial performance monitoring tools.

Granderson, J, Piette, MA, Ghatikar, G, Price, P. Building energy information systems: State of the technology and user case studies. Lawrence Berkeley National Laboratory, November 2009, LBNL-2899E. Available from http://eis.lbl.gov/pubs/lbnl-2899e.pdf.

Report containing a market characterization of energy information systems and related performance tracking tools, including features and capabilities such as energy anomaly detection, as well as baseline modeling approaches.

National Productivity Council. Book-1: General aspects an energy management and energy audit; Chapter 8 Energy Monitoring and Targeting. 2004. Guide books, 2nd edition, National Certification Examination for Energy Managers and Energy Auditors. Bureau of Energy Efficiency, Ministry of Power, Government of India. Available from http://emt-india.com/BEE-Exam/GuideBooks_QB.htm.

Guide to energy monitoring and targeting, with extensive review of the use of Baseline Models and cumulative sums for detecting energy use anomalies.

Office of Energy Efficiency, Natural Resources Canada. Monitoring and targeting techniques in buildings. 2007. Office of Energy Efficiency, Natural Resources Canada. Available from http://oee.nrcan.gc.ca/publications/commercial/m144-144-2007e.cfm.

Fact sheet presenting approaches to monitoring buildings and targeting operational improvements, including model baselines, and the cumulative summation of the energy impacts of anomalies.

Puranik, VS. CUSUM quality control chart for monitoring energy use performance. 2007. Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management. Available from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4419388&tag=1.

Paper discussing the application cumulative sums to detect anomalies in energy consumption.

Stuart, G, Fleming, P, Ferreira, V, Harris, P. Rapid analysis of time series data to identify changes in electricity consumption patterns in UK secondary schools. 2007. Building and Environment 42:4, pp. 1568-1580. Available from http://www.sciencedirect.com/science/article/pii/S0360132306000199.

Paper documenting the use of cumulative sums to identify energy use anomalies in 37 secondary schools, including multiple application examples.