California Commissioning Collaborative

Building Performance Tracking in Large Commercial Buildings: Tools and Strategies

Subtask 4.4 Research Report: Characterization of Building Performance Metrics Tracking Methodologies

Submitted to:
California Energy Commission

Prepared by:
Erik Greensfelder, PECI
Hannah Friedman, P.E., PECI
Eliot Crowe, PECI

November 2010

ABOUT THIS REPORT

This report is a deliverable under Task 4.4 of Project 4: “Building Performance Tracking in Large Commercial Buildings: Tools and Strategies”. This project is part of the integrated research program “Building Commissioning: Strategies and Technologies for Energy Efficiency”, funded by the California Energy Commission under agreement 500-08-039.

LEGAL NOTICE

COPYRIGHT NOTICE

Table of Contents

Executive Summary

The purpose of this research is to investigate building performance metrics that can be used by building owners, energy managers, and operators to track the performance of commercial facilities. While there is extensive literature on the subject of performance metrics, there is no single simplified source that provides guidance on which metrics an owner should track and how to track them. Further, the market adoption of energy and system metrics is fairly low. This research aims to clarify and simplify the options in order to promote market adoption. This report includes the methods and findings of this research, a discussion on important topics related to selecting, comparing, and tracking metrics, lists of recommended metrics, and conclusions and recommendations for achieving best practices in metric tracking.

This task is one of three research sub-tasks within the Building Performance Tracking project, funded by the California Energy Commission. The goal of the project is to facilitate a more rapid uptake of building performance tracking methods, tools, and strategies into the marketplace by providing and disseminating technical research, case studies, and a best practice guide to successful building performance tracking. The recommendations made in this report and the other sub-tasks of the project will help inform the primary deliverable: a best practice guide for owners and operators to select the best-fit building performance tracking management strategy and supporting technology for their buildings.

The primary research methods for this sub-task included 1) a comprehensive literature review and 2) phone interviews with professionals from the building controls industry. The team reviewed current literature related to the use of building performance metrics, including research reports, conference papers, and existing guidelines. The literature review provided a baseline understanding of current practices and available academic research. To supplement the literature review, the team conducted seven phone interviews with professionals in the controls industry. Findings from previous research were synthesized and combined with the findings from the literature review, interviews, and PECI's industry knowledge to provide a discussion on metric selection, benchmarking and baselining, and metric tracking. Additionally, the full array of performance metrics encountered were distilled to a list of recommended metrics with discussion around these individual metrics.

The literature review evaluated over 80 works and included a detailed review of 23. Of these documents three reports provide significant guidance on the tracking building performance data, including metrics:

- Barley et al (2005)
- Hitchcock (2002)
- Gillespie et al (2007)

These sources and others were used to inform the discussion and recommendations in this report.

Interviews were conducted with seven professionals in the controls industry to better understand current controls capability and typical industry practices. The individuals interviewed agreed that the methods of metric tracking in the industry are fragmented, and that the quantity of detailed information available from a BAS can complicate analysis. A resulting conclusion was that any information on metrics must be distributed in a simple and easily understood format.

The team defined a building performance metric as: ***a key performance indicator which may be compared to historical or expected values to describe building performance. A metric may indicate the energy cost per unit of service provided, indicate energy use during a period of time, or characterize system operation***. This report discusses and recommends a variety of metrics encompassing energy, comfort, and maintenance with a focus on energy-related metrics. Recommended metrics were divided into four categories:

- <u>Basic Energy Metrics</u>: Metrics that use whole building utility meter data. These metrics are relatively easy to track, and should be tracked by all buildings

- Advanced Energy Metrics: Metrics that use whole building utility meter data but require more advanced analysis than basic energy metrics, or metrics that require additional meters beyond whole building energy use meters.
- Basic System Metrics: Metrics that use existing points from the building automation system (BAS) or maintenance management system. These metrics are relatively easy to track.
- Advanced System Metrics: Metrics that require additional points to be added to the BAS or maintenance management system. This category also includes metrics that use both meter data and BAS data.

The basic energy metrics identified were:

System Type	Sub-system	Metric	Units
Whole Building	NA	Energy Use	kBtu / ft^2-yr
	NA	Energy Use	kBtu / annual operating hours-ft^2-yr
	Electric	Energy Use	kWh / ft^2-yr
	Gas	Energy Use	therms / ft^2-yr
	Electric	Utility Cost	\$ / ft^2-yr
	Gas	Utility Cost	\$ / ft^2-yr

The basic system metrics identified were:

System Type	Sub-system	Metric	Units
Whole Building	NA	% Hours uncomfortable	% hours outside of space temperature range
	NA	Comfort Index	Average comfort index (0-100)*

The basic metric lists are deliberately short to set a minimum achievable standard for building operators. The advanced metrics tables, presented in the body of the report, include more detailed metrics that can provide a more in-depth picture of building performance. Additionally, the full list of metrics considered is available in Appendix 8.3.

For this report a benchmark was defined as a comparison to one or more external points of reference while a baseline was defined as a comparison to past performance. The two most prevalent tools that can help make these comparisons are ENERGY STAR Portfolio Manager and Cal-Arch, which are based on the Commercial Buildings Energy Consumption Survey (CBECS) and California Commercial End-Use Survey (CEUS), respectively. Benchmarking should make comparisons across buildings with similar climate and energy use activity (schedules and plug loads). Since this is not always possible, energy use data can be normalized for different factors, such as weather and occupancy patterns. A discussion on normalization and possible variables is provided in the report.

The steps to selecting the appropriate metrics for a project were summarized as:

1. Determine goals and constraints
2. Identify stakeholder needs and talents
3. Determine high priority areas and unique needs
4. Identify metrics to track

The selected metrics can be tracked with a variety of different tools including the building's automation system or an energy information system (EIS). The chosen system must be able to perform some key basic functions:

- Gather necessary point data from the building
- Gather relevant meter and sub-meter data from the building or utility
- Calculate metrics from the collected data
- Store metrics in a database (ideally a SQL database)
- Process historical data into baselines
- Allow for the input of benchmarks
- Display and compare metrics to benchmarks and baselines in a clear format

We believe that the following information and standards will help ease market adoption of metric tracking: 1) broadly accepted procedures or standards for metric tracking, 2) a standard set of metric specifications that provides for easily accessible metrics in a user friendly display, and 3) more detailed benchmark data than is currently available in CBECS and CEUS.

1 Introduction

1.1 PIER Building Performance Tracking Research Project

Building performance tracking is the process of monitoring and analyzing facility data on a regular basis to meet energy and performance goals. The benefits include energy and cost savings, accurate measurement of energy savings from existing building commissioning (EBCx) or monitoring based commissioning (MBCx) utility rebate programs, and increased awareness of facility performance. Building performance tracking methods range in sophistication from monthly utility bill benchmarking to use of complex fault detection and diagnostic (FDD) tools (further information on FDD tools can be found in the Sub-Task 4.3 Report).

This project is funded by the California Energy Commission. The goal of this project is to facilitate a more rapid uptake of building performance tracking methods, tools, and strategies into the marketplace. This project will create a best practices Guide for owners and operators for selecting the best-fit building performance tracking management strategy and supporting technology for their buildings.

The primary objectives of this project are to:

1. Identify market and technical barriers to energy performance tracking, and create case studies to highlight identified best practices. (Task 4.2)
2. Characterize the rapidly evolving performance tracking software tools in the market to inform and guide owner selection. (Task 4.3)
3. Provide guidance for the implementation of performance metric tracking strategies in commercial and institutional buildings with best-practice analysis and easy-to-use guidance. (Task 4.4)
4. Provide building owners and key market players with a comprehensive, easy-to-use, practical Guide for selecting the best-fit energy performance tracking management strategy and supporting technology for their building(s). (Task 4.5)

The project was originally designed to focus on best practices to achieve persistence of energy savings from existing building commissioning (EBCx). The project later expanded to cover building performance tracking tools and approaches in general. The broadened scope reaches a wider audience, yet still achieves the goal of researching methods to track persistence of energy savings.

1.2 About this Sub-Task (Task 4.4)

This task, carried out between March and September of 2010, identifies and describes key building performance tracking metrics that can be used by building owners to maintain their building's energy performance over time. It targets owners who are less inclined to purchase expensive software tools, but have building automation systems where key tracking metrics and methods can be incorporated.

A literature review, interviews with controls professionals, and PECI's relevant experience in the field were used to identify methodologies for selecting and tracking key energy performance metrics and setting baselines and benchmarks. The literature review was particularly focused on how participants select key metrics, establish baselines and use benchmarking to manage and maintain energy efficient performance.

This research report identifies, describes, and prioritizes the key performance metrics building owners should track and manage. It also discusses methods for tracking benchmarks and setting baselines in order to maintain high levels of building performance. The outcomes of this task will be incorporated into a practical guide for selecting persistence strategies (Task 4.5 deliverable).

1.3 Definitions

A building performance metric can be defined as a key performance indicator which may be compared to historical or expected values to describe building performance. A metric may indicate the energy cost per unit of service provided, indicate energy use during a period of time, or characterize system operation. This report discusses a variety of metrics encompassing energy, comfort, and maintenance with a focus on building energy metrics. These metrics may be tracked through a building's energy information system (EIS), building automation system (BAS), a BAS overlay, or spreadsheet tools.

There are some differing views in the industry concerning how to define a metric. Many sources and practitioners define a point (such as chiller power or fan cfm) to be a metric. However, it is the belief of the authors of this report that to be defined as a metric, data must be able to provide significant information about the buildings performance and stand on its own without additional supporting data or context. Example metrics, by our definition, include building energy use intensity (EUI) which describes the energy use of a facility per unit area, or chiller plant efficiency (kW/ton). These metrics stand alone in their ability to clearly indicate performancewithout additional analysis.

This report assumes that building energy metrics will be evaluated by a human analyst to determine how the building is performing. In a closely related field, fault detection and diagnostics (FDD) uses automated tools to detect faults and diagnose their causes. A metric may be used in a FDD system, but it is not necessary. This report does not discuss FDD and the reader is referred to Task 3 of this project, Characterize Energy Performance Tracking Strategy Support Tools, for additional information.

For this report, metrics were broken into two different categories: **energy metrics** and **system metrics:**

- Energy Metrics – Only use data from energy meters or sub-meters
- System Metrics – Require additional data, such as inputs from the BAS, information from a maintenance management system, or user entered values.

There is some confusion in the industry around the terms 'benchmark' and 'baseline'; they are often used interchangeably. For this report a benchmark is considered a comparison to one or more external points of reference while a baseline is considered a performance measurement at a given point in time against which future performance can be compared. For example, a building could benchmark its EUI against other similar buildings using the Commercial Buildings Energy Consumption Survey (CBECS); it could also compare against a baseline of performance established during its first few years of operation.

2 Methodology

The work presented was developed through an extensive literature review, interviews with professionals in the building controls industry, and a review of other work conducted under the PIER Building Performance Tracking Project. Findings were assimilated and combined with PECI's in-house expertise to develop the discussion presented in Section 4.

2.1 Literature Review

A review of relevant literature was conducted focusing on research reports, conference papers, journal articles, and government documents. Over 80 documents were evaluated, and 21documents were chosen for review. Many of the resources were academic in nature; however, there were several resources that included practical examples in the form of case studies and guides focused on building owners.

Articles were reviewed to find information related to:

- Metric Selection:
    - Recommendations for key metrics to track to maintain performance

    - How a facility can determine which metrics are best to track for their situation
    - If certain metrics are more pertinent to certain stakeholders (eg. chief engineer vs. property manager)
- Benchmarks and Baselines: Establishing benchmarks and/or baselines
- Tracking and Analyzing Data: How the metrics data can be *used* (not just viewed) to maintain building performance

2.2 Interviews

Though the literature review provided pertinent information which metrics could be tracked, there was little information concerning *how* to track metrics or the current capabilities of tracking tools. To close this gap, interviews were conducted with seven individuals including performance contractors, controls contractors, a software developer, and an EIS business development team. The interviewees represented five different BAS and EIS platforms. The individuals were chosen to represent a wide variety of views in the industry and selected for industry experience based on recommendations from colleagues.

The interview questions, available in Appendix 8.1, were specifically designed to get perspectives from the field on:

- Metric Selection:
    - Which metrics should be tracked?
    - Which metrics are actually tracked?
- Benchmarks and Baselines: How benchmarks and baselines are established and used
- Tracking and Analyzing Data: How a BAS or EIS can be used to track metrics

2.3 Review of Sub-Tasks 4.2 and 4.3

Much of the work conducted under Sub-Tasks 4.2 and 4.3 is related to building energy metrics. The findings from those projects were reviewed for relevant information related to metrics.

3 Findings

This section summarizes the information gathered from the literature review, interviews, and review of previous work. Though it may identify gaps in knowledge, it will not seek to fill them. Section 4 provides a discussion of the findings along with analysis and commentary on how to best apply metrics in buildings.

3.1 Literature Review

All of the reviewed literature provided insight to this research, but three major works encompass much of the current published material on this topic. These key works examined during the literature review are specifically described below. The following sections discuss specific lessons learned from the literature review. Appendix 8.2 contains a summary table of all literature that was reviewed.

Barley et al (2005) present a procedure for measuring and reporting energy performance that aimed to standardize measurement and characterization. Though the paper is not specifically focused on metrics, many of the energy metrics that are discussed in Section 4 were presented in this paper. The authors provide a performance tracking procedure, including data collection and analysis procedures, as well as discussion of measurement tools and uncertainty. Additional discussion is provided on how to display data for visual analysis.

Hitchcock (2002) is a definitive work that was written to address the lack of standardization in monitoring and reporting building performance. The paper synthesizes many important works into a coherent hierarchical form that can help a user meet performance objectives. The author emphasizes that performance metrics can be used throughout the building life cycle and provides a comprehensive table of standardized performance metrics.

Gillespie et al (2007) present a specifications guide for performance monitoring systems intended to support ongoing commissioning. Though ongoing commissioning is outside of the scope of this research many of the ideas are still applicable. The work provides an overview of performance monitoring systems and discusses some key issues including scope, implementation approach, system rigor, data visualization, commissioning, and training. Other important topics in the report include:

- System performance capabilities and functional requirements
- Example specifications for every aspect of creating performance monitoring systems
- Accuracy of the measurement
- Network architecture, sampling, and data recording, archiving and storage.

Additionally, this work discusses the benefits of performance monitoring including:

- Understanding whole building energy and power use at different times
- Tracking and managing chiller peak load contribution and chiller health
- Monitoring growth of capacity requirements and finding anomalous loads
- Monitoring plant efficiency to find more efficient operations strategies, detect performance degradation, and determine if maintenance is needed.
- Tracking weather data to inform free cooling, cooling tower operation, and chilled water plant operation.
- Monitoring comfort performance
- Troubleshooting different parts of the HVAC system which can lead to early fault detection to lower costs and increase service quality

It is important to note that some authors take a broader definition of an energy metric that includes many data points that are outside of the definition presented in this report. The definition presented in the introduction intends for a metric to be able to stand on its own to describe building performance whereas many of the terms suggested in the literature may be important to track but require additional context to interpret. For example, an author might consider chiller power to be a metric, but the definition presented here would only consider this a metric if it were combined with a term describing the service provided, for example chiller power *per ton of cooling provided*.

Metric Selection

Most of the sources examined in the literature review provided one or more metrics that were evaluated for the metrics summary tables shown in Section 5. This section provides some treatment of general metrics, but focuses on the questions shown in the methods section of this report:

- Recommendations for key metrics to track to maintain performance.
- How a facility can determine which metrics are best to track for their situation.
- If certain metrics are more pertinent to certain stakeholders (e.g. Building engineers vs. Energy Manager).

Gillespie et al suggest that the level of detail to be monitored should be based on the number of buildings in a portfolio, system type, and the owner's desired level of detail and sophistication. The building should start its program with simple performance evaluation strategies and slowly add more complex strategies as owner confidence in the efficacy of the approach improves. The authors also caution readers to carefully scope a project in order ensure that the points necessary to calculate each metric are chosen, metering has appropriate accuracy, and data management structures are provided. The paper provides detailed guidance on each of these issues (Gillespie et al 2007).

While discussing the link between performance metrics and life cycle assessment, O'Donnell et al (2004) make several key points regarding metric selection. The authors suggest that metrics should be limited to clear and concise sets of information to ease industry adoption. Further metrics chosen must:

- "Measure, reflect or significantly influence a particular performance objective
- Be useful across the entire life cycle of a building
- Be either predictable or measurable at various stages of the building life cycle
- Be limited to a concise set of data that are easy enough to collect but robust enough to emulate the objectives in their entirety." (i.e. the metric must provide a simple mechanism to meet the project objective)

Further steps to programming are suggested:

1. Determine objectives in consultation with the architect and engineer
2. Reduce objectives to an appropriate hierarchy (e.g. an owner may have a whole building energy use goal that would encompass several system level goals)
3. Determine a metric that represents each objective

Sartor et al (2000) suggest a hierarchical approach to measurement and metrics that, using seven levels of metrics moves from gross annual energy use at the highest level down to disaggregated hourly end use data at the most detailed level. Metrics should start at the highest level and logically build to more specific detailed information about systems.

Tom (2008) reminds the industry that it is important to track comfort metrics as well as energy metrics. If a building is not meeting its intended purpose, to provide comfort, then energy savings are irrelevant. To meet this end he suggests the use of an arbitrary comfort index based on available data points such as temperature and humidity. The comfort index indicates a score of 100 when comfort criteria are met; the score drops as conditions degrade. Further details on this metric are given in Section 5.

Fowler and Dyer (2004) use a variety of metrics to compare the performance of facilities. They recommend metrics that include maintenance issues that are tracked through maintenance requests, time, and expenses and indoor environmental quality that is tracked through occupancy surveys, absenteeism, and turnover.

Pati et al (2009) focus on the use of quantified expressions to describe building performance through the life cycle of the building. Though most of their work focuses on specifying performance in the design phase of a project many expressions are analogous to performance metrics. Indicators are broken into hard and soft categories where hard indicators are directly measurable, such as energy use, and soft indicators contain some subjectivity, such as comfort. Post occupancy evaluation is used to evaluate soft indicators and is, unfortunately, too cumbersome to be considered in this project. The regular use of post occupancy evaluation can help structure the dialogue between tenants and facility managers.

Several papers discuss the use of mathematical tools to choose the appropriate variables to use in normalizing data (NBI 2009, Lee and Lee 2009). Further treatment is given to this topic in Section 4.3.

Benchmarks and Baselines

Most of the studies referenced in this report do not include discussion of benchmarks and baselines or assist the building owner in devising methods to compare metric data. Several studies do address this issue and, though benchmarking is a current gap in the field, some information is provided. Recall that, as explained in the definitions section baselining refers to comparing building performance to the historical performance of that building while benchmarking refers to a comparison to outside data sets. Identified techniques for baselining and benchmarking are:

Baselines:

- A running baseline can be created by saving building energy use data throughout its life cycle (Hitchcock 2002).
- Historical energy use data can be used in regression models to predict building performance (CEC).
- Building energy models (such as eQUEST or Energy Plus) created during the design phase can serve as a baseline, and that during the commissioning process the model can be updated to create an as-built baseline (Hitchcock 2002)
- A performance effectiveness ratio, based on work originally completed by Fiederspiel, can compare actual and modeled energy use (O'Donnell et al 2004).

Benchmarks:

- Statistical comparisons can be made to large data sets of other buildings (Sartor et al 2000). Examples of these include CBECS[1] and The California Commercial Energy-Use Survey (CEUS)[2].
- Performance can be compared against industry or company wide benchmarks or best practices (Sartor 2000)
- A code compliant building energy model can serve as a building specific baseline (O'Donnell et al 2004).
- Other benchmark values can be calculated using building codes (O'Donnell 2004) or manufacturer specifications (O'Donnell et al 2004, Sartor 2000) for specific building components.
- System level performance could be analyzed by comparing one system to another that, though not physically identical, provides the same benefit (Sartor et al 2000).
- Data could be compared against engineering rules-of-thumb and best practices (tons/cfm, cfm/ft2, etc.) (Sartor et al 2000).

Any energy metrics used in benchmarking should seek to reveal the technical efficiency of a building, in this case the technical efficiency of the building refers to a term that would remove the most confounding factors from a building energy metric, such as schedules and equipment type, and allow it to be equally compared to another building. When the building is then compared to a benchmarked number the difference indicates management performance (Lee and Lee 2009). Though the technique suggested to implement this is too complex for use in this research, the concept of using technical efficiency to evaluate management performance provides an excellent lens for considering benchmarks and baselines. Additionally, the mathematical approach used in their work can help guide future researchers as they seek to improve existing benchmarks.

Authors agree that when comparing metrics across different buildings some normalization must occur. The most commonly mentioned normalizing factors include building area and weather parameters, such as heating or cooling degree days. Additionally, many of the works cited suggest normalizing energy use by area and annual hours of operation.

Care must be taken when normalizing data and comparing to benchmarks so as not to inadvertently skew the results. Peterson and Crowther (2010) point out some of the many pitfalls that can be found when simply normalizing energy use by area without considering other factors. For example, if a parking garage is included in the area of an inefficient office building it may appear to use relatively little energy per area. Conversely if an efficient office building contains a large, well-run server facility, it may appear to be inefficient when compared against a traditional office space.

Section 5 provides a list of potential normalizing factors and several are briefly discussed here. Sabapathy et al (2010) put significant effort into benchmarking LEED buildings in India and, using regression models, determined significant factors to consider when comparing buildings. These include operating hours, occupant

[1] http://www.eia.doe.gov/emeu/cbecs/
[2] http://www.energy.ca.gov/ceus/, http://capabilities.itron.com/ceusweb/

density, area, and chiller type, the presence of VFDs, and whether audit recommendations had ever been followed. These results indicate that, at least for the buildings used in the study, benchmark data should account for these terms.

Benchmarking must make comparisons across buildings with similar climate and uses (such as schedules and plug loads). ENERGY STAR Portfolio Manager[3] and Cal-Arch[4] provide some tools to meet those goals. The ENERGY STAR Portfolio Tracker analyses the over 6,000 buildings in the CBECS data set and performs regression analyses on various building characteristics and weather normalization. These analyses allow the building owner to compare building energy performance to other similar buildings on a 0-100 point scale (ENERGY STAR 2010). Cal-Arch is based on the CEUS data set, which generated energy end-use information using calibrated building energy models based on a survey of 2,800 buildings in California. Mills et al suggest methods for using the data sets in benchmarking to evaluate energy efficiency opportunities (2008).

At this time there are limited options outside ENERGY STAR / CBECS and Cal-Arch / CEUS. A tool, EnergyIQ, is under development to help owners benchmark their buildings and assess performance based on either the CBECS or CEUS data sets (Mills et al 2008a). Other normative comparisons might be made against CIBSE Guide F and Dutch Code NEN 2916 (O'Donnell et al 2008), but these are outside the scope of most owners. The method used in NEN 2916 may need to be tweaked before it is used in the United States, but Pati et al (2009) discusses using NEN 2916 in the U.S. without modification for use in comparing building design.

Tracking and Analyzing Data

The literature review sought to find research that would indicate how the metrics data can be *used*, not just viewed, to maintain building performance. Unfortunately, little current information is available at this time. The three main papers references at the start of the literature review do provide details concerning how to calculate metric values.

Many authors discuss how data can be looked at graphically (Barley et al 2005, Hitchcock 2002, Gillespie et al 2007). Additionally, these studies discuss provide information on calculation details for the metrics presented.

To view this data, buildings must have strong data management and graphical display capabilities. Further a DDC system may be limited by bandwith, storage capability, and the database used. Further, DDC systems, as of 2007, can only generate X-Y plots. EIS systems can remedy some of these shortcomings (Gillespie et al 2007).

Any system used to track data will need careful commissioning to ensure proper function. Also, relevant building staff, contractors, and tenants should be trained in accessing, using, and making changes to the DDC/EIS as applicable (Gillespie et al 2007).

Metrics could be thought of in a hierarchical format where high level metrics are used to detect the existence of problems and more detailed metrics are used to diagnose the cause of the problem (Sartor et al 2000). Pati et al (2009) state that performance indicators are useful to facilitate dialogue between stakeholders, but that they should not supplant more sophisticated diagnostic tools.

[3] http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager
[4] http://poet.lbl.gov/cal-arch/

3.2 Interviews

Metric Selection

The interviewees agreed that building owners and engineers do not want detailed information and that controls systems can overcomplicate HVAC systems by presenting too much data and analysis. It is important that information be distributed in a simple and easily understood format. Though some buildings are pushing the envelope on building systems analysis, the majority of owners do not have a desire to track detailed metrics.

Throughout the interview process it was clear that there is not yet consensus on which metrics should be tracked and if so how. It was, however; apparent that the industry is experimenting with a variety of energy tracking tools, reports, and metrics; one interviewee predicted that 5-10 years of experience was needed before the industry will coalesce around a set of accepted practices.

Metrics suggested by interviewees will be presented in suggested metrics tables in Section 5. Most agreed that basic whole building energy use values, such as energy use intensity, should be tracked at all buildings. In keeping with the lack of cohesion in this area, there was little agreement surrounding more complex metrics. Most agreed on the need for efficiency terms for heating and cooling plants.

Many interviewees stressed the need to use metrics to not only track the energy performance of the building, but also comfort and maintenance. One interviewee in particular stressed that the purpose of a building is to deliver comfort and that owners see far more financial consequences of an uncomfortable building than an inefficient one. Additionally, maintenance metrics could help to preserve capital investments.

Interviewees disagreed on how often metrics should be analyzed. One stated that energy use should be looked at on a daily basis while others suggested that an analysis schedule should be tailored to each facility’s needs or checked monthly with annual reviews.

Benchmarks and Baselines

The interviews indicated that the lack of good benchmarking tools is a major hole in the industry right now. Most interviewees used data from CBECS to provide basic benchmark energy use data for their buildings. Some interviewees accessed this data through the ENERGY STAR Portfolio Manager, which has the benefit of providing a convenient interface. The perception amongst the interviewees was that CBECS data is not specific enough to account for different buildings characteristics, such as occupancy patterns. An examination of the CBECS data indicates that it is possible to sort building data based on many characteristics, but as more specific characteristics are identified the size of the data sets can become quite small and the statistical significance of the data is greatly reduced. Some of these problems are being addressed by industry specific groups such as the Association of Physical Plant Administrators (APPA) which is collecting data for universities.

Many respondents use their personal experience and in-house data to provide benchmarks for whole building and system performance. Comparing systems is particularly challenging and requires years of industry experience and engineering judgment. A portfolio of buildings would do well to benchmark outside of their holdings in case all of their buildings are performing badly. Modeling may also be used to provide an energy use benchmark, but it often misses inefficiencies that occur in the real world

New construction should specify measurement and verification (M&V) plans to establish baseline performance indicators.

Tracking and Analyzing Data

There are differences in opinion over whether the BAS should be used to track performance or not. Some felt that the BAS is built for control and that an overlay should be used, while others thought that an EIS was a redundant added cost and, with appropriate specifications, a BAS can provide good performance reporting. Some cautioned that with an EIS the building owner may lose ownership of data and may have to pay to view it.

Many BASs that are on the market or under development will have the capability of providing good metric reporting. But, currently, the capabilities of BAS software are underutilized. Many interviewees stated that if customers specified metric tracking that the BAS can provide it, but that barriers exist due to lack of standardization. In most cases power meters do not exist for system level analyses, but power use could be backed out in many cases. If system level metrics are desired it is much cheaper to specify additional metering during building design than to add it after construction.

Regardless of whether a building uses a BAS or EIS to track metrics the challenge is to turn all of the available data into useful information. Proper metric choice and communication is key to overcoming the barriers associated with operator time and education.

A barrier to widespread adoption of metric tracking is the lack of specific standards. Standards are needed around sending and receiving data. Additionally, it is hard for the industry to price dashboards due to a lack of standardization.

Certain capabilities must be present in the system in order to provide for metrics tracking. A system must be able to:

- Store all necessary data in a stable database, an SQL server is the preferred method
- Provide internet connectivity through an XML format
- Bring in all necessary information including points, meter data, weather data, and schedules
- Provide a method to calculate metric data (such as through virtual points)
- Present data in a simple graphical fashion that stakeholders can understand

It is an added bonus if the system can incorporate lighting metrics.

3.3 Review of Sub-Tasks 4.2 and 4.3

The sub-task research reports for tasks 4.2 ("Investigate Energy Performance Tracking Strategies in the Market") and 4.3 ("Energy Anomaly and System Fault Detection Toolsets") were reviewed for metrics-related information. The following information was gleaned from these sub-tasks, relevant to this sub-task 4.4.

Sub-Task 4.2: Investigate Energy Performance Tracking Strategies in the Market

Sub-task 4.2 identified one primary recommendation / best practice related to performance metrics: To meet the varying needs of different stakeholder groups, a variety of performance metrics may need to be monitored, and the performance tracking tool should be capable of generating these metrics. For example, higher-level metrics such as monthly whole building energy consumption may be sufficient for some stakeholders, while others may wish to see more detailed metrics such as chilled water plant efficiency.

Sub-Task 4.3: Characterize Energy Performance Tracking Strategy Support Tools

Sub-task 4.3 primarily focused on energy anomaly and system fault detection toolsets. It focused on the following categories, for evaluation and characterization of nine toolsets:

- Set Up and Installation
- Cost and Ongoing Resource
- Fault Detection and Diagnostics Capabilities
- Reporting

Even though the sub-task did not address selection of specific building systems for monitoring by these tools (e.g., HVAC systems, lighting systems), nor did it target metrics generated by the tools, it did include some metrics-related information that was gleaned from the vendor and end user interviews:

All of the interviewed tool users indicated a desire for energy information to be presented within a dashboard. Specifically, the energy cost per floor area ($\$ / ft^2$) was mentioned as a metric that would be useful for benchmarking against a company's portfolio as well as outside of their portfolio.

Another notable finding from sub-task 4.3 included a need for full acceptance of the tool across all levels of the organization. Tool users indicated that without support and full acceptance of the tool, a performance tracking program would not be successful, regardless of the tool's features and capabilities. Perhaps the primary recommendation related to performance metrics indicated in sub-task 4.2 - monitor a variety of performance metrics as needed to satisfy each stakeholder group - could help increase tool acceptance.

Normalization of data was also addressed in sub-task 4.3. Most of the tools covered by the sub-task detect faults via either a physical model (i.e., compare current performance to predicted performance as derived from calculations based on historical performance) or expert rules (e.g., "if-then" rules). Two of the tools that use physical models normalize both the historical and current energy usage by the driving independent variables (e.g., weather, building occupancy, day of week), for more meaningful comparisons and more accurate identification of performance anomalies. Different normalizing variables may be used for different depths of energy information, depending on the level of sub-metering at a particular site.

The sub-task also noted that sensor accuracy has a significant impact on the accuracy of performance metrics. Many vendors identified sensor inaccuracy as the number one problem in diagnosing faults accurately. One vendor mentioned that during tool setup, their first test run is sensor failure. They do this to ensure that the tool is receiving accurate sensor data, to prevent false alarms.

The sub-task found the users would prefer to use an energy tracking tool that could combine energy dashboard features, real time analysis of fault detection and diagnostics, and links to a work-order system. Users would like to be able to benchmark buildings inside of the tool against both a standard and high efficiency building.

4 Discussion

This section provides a synthesis of the findings described in Section 3 with the experience of the authors. It describes the use of building energy metrics in a format that can inform building owners and operators. It concludes with tables indicating recommended energy and system metrics.

4.1 How to Select Metrics

A building will choose which metrics to track based on its individual goals, equipment, budget, and management structure. In general, the building will be choosing which types of metrics to track and how detailed their tracking should be. For new construction, including metric tracking decisions early on in the process can significantly reduce the costs associated with installing additional meters and points.

This report breaks metrics into two major classifications, energy metrics and system metrics, where energy metrics require only energy meter or sub-meter data while system metrics include additional data points, such as from a BAS. System metrics include indicators concerning comfort and maintenance. Metric detail focuses on the level of monitoring to be completed; this can be considered from a whole building, system, or component perspective. The level of detail to be chosen fits in well with the monitoring hierarchy described by Hitchcock (2002). Examples of individual systems to monitor are chilled water plants and lighting systems. Component level monitoring includes individual pieces of equipment such as a chiller, pump, or fan.

Determine Goals and Constraints

The first step in selecting which metrics to track is to determine project goals. Goal setting provides a framework that will influence which metrics are chosen for tracking and how they may be tracked. O'Donnell et al (2004) notes that the metrics chosen must "measure, reflect, or significantly influence a performance objective." Goals should guide the categories and levels of detail of the metrics selected. These goals should be developed in a collaborative effort between the owner, maintenance staff, and building consultants. Tenants may also play a role in goal setting.

While setting project goals the building owner should also determine any factors that may constrain project development. The largest obvious constraint is project budgets. The level of metering and monitoring that can be completed can be significantly impacted by budgetary requirements. Beyond the cost of installing additional equipment and purchasing software upgrades metric tracking carries the additional cost of labor to analyze data and act on conclusions. Though hard to quantify, the additional costs associated with tracking metrics can pay for themselves in improved tenant satisfaction, reduced maintenance costs, and lower energy use.

Identify Stakeholder Needs and Talents

Along with identifying project goals and constraints, stakeholders' needs and talents should be evaluated. Upper level management may want to only see very high level metrics that provide a broad indication of building or portfolio performance while building engineers may want to be able to evaluate detailed metrics that can aid in diagnosing specific problems. If they are engaged tenants may also be interested in seeing various metrics.

Metrics should be chosen that provide information in a form that the intended stakeholder can understand. Metrics should be chosen that are as simple as possible to understand, while still meeting project goals. Additional training may be necessary to ensure that stakeholders can understand the information that is provided. It is also important to remember that staff will change throughout the life of the building and that new hires may not understand the data presented, or even know that it exists.

Determine High Priority Areas and Unique Needs

It is also important to evaluate the high priority areas in the building to be monitored. For many owners the decision of whether to track energy, comfort, and/or maintenance metrics will be based on potential cost savings, tenant retention, and environmental concerns. In certain market segments one or more these areas may be particularly important.

Additionally, the owner should determine if physical characteristics of the building indicate high priority metrics to track. For instance, a building may wish to focus special attention on those areas that use the most energy, such as the chiller plant and lights. Additional attention may be placed on defining metrics that can help mitigate persistence risks that exist in equipment such as economizers or controls systems. Specifically identifying these high priority areas will lead to the adoption of the most appropriate metrics.

While identifying the high priority areas of a building the unique needs of the facility should also be evaluated. Examples include hospital and laboratory spaces that might have high ventilation and IAQ needs, data centers with high cooling and computer energy use, or smaller buildings whose HVAC energy use is dominated by RTUs. Little information is available concerning metrics appropriate for RTUs, but a building owner, in consultation with the project engineer may be able to determine a series of metrics to help meet the individual project needs.

Identify Metrics to Track

After the unique project goals, constraints, stakeholder requirements, and high priority areas have been identified, the building team will identify metrics to meet these considerations. A variety of recommended metrics are shown in Section 5 which can be chosen based on the identified parameters. If additional metrics are needed the reader can consult Appendix 8.3. Additionally, site specific metrics may be devised if necessary. If additional metric are devised the team should ensure they can measure the data needed to create the metric and that a metric has more value if it can be compared against a good benchmark or baseline. Any metrics that are chosen must be as simple as possible to still meet project needs. Complex metrics that do not meet a clear need in connection with an engaged stakeholder will be ignored and quickly forgotten.

4.2 How to Set Benchmarks and Baselines

The value of metric data is greatly increased when it can be placed in the context of how other similar systems perform, or how the system has performed historically. The use of benchmarks and baselines help provide this context. A benchmark is a comparison to other similar buildings and systems, while a baseline compares a building and its systems to its own historical building performance. They can be used to provide tolerances for alarms, or simply a context for interpreting data. It is important to remember that as a building undergoes changes in use and equipment, benchmarks and baselines should be updated for more useful comparisons.

Whatever methods are chosen for benchmarking and baselining it is important that they be understood by the intended user and that they are easy to access and update. The lack of good benchmarks in the field provides a particular challenge and opportunity for the building team to use existing resources creatively.

Benchmarks

The use of benchmarks allows a building to compare to outside data sets to understand how the building is performing.

The most commonly used benchmark in the United States at this time is the Commercial Buildings Energy Consumption Survey (CBECS) which provides the data used in the ENERGY STAR Target Finder and Portfolio Manager. CBECS provides annual energy end-use data for typical building types and breaks out data by a variety of parameters including area, principal activity, vintage, region and climate, building construction parameters, number of occupants, typical schedules, energy sources, and HVAC equipment types. Unfortunately, when many building characteristics are examined at once the available data sets become quite small and a regression analysis may be needed to assess the data. The interviews conducted as part of this study found that many of the people working in the field found that the data do not provide enough detailed information concerning building characteristics. CBECS is; however, an excellent starting place to understand how a building generally compares to similar buildings.

The California Commercial Energy-Use Survey (CEUS), which can be accessed through the Cal-Arch front end, provides more detailed data then CBECS with a focus on California buildings. It provides annual end-use energy data by building area based on a variety of building types and climate zones in the state of California.

If metrics for individual pieces of equipment are being tracked, performance can be benchmarked against manufacturers published specifications, or more detailed information that may be available directly from the manufacturer. System efficiencies can sometimes be predicted from manufacturer's information to provide additional baselines. Using these data can be a challenging proposition since a variety of factors, such as equipment loading, can have a large impact on efficiency.

Further, a building energy model can provide a convenient building specific benchmark for a building. Models can provide benchmark energy consumption under typical climate conditions, or under the actual weather that the building encountered. Unfortunately, models can be expensive to create and update as the building's equipment and use changes. If a building model was created as part of the design process the annual energy use from this model can serve as a general benchmark and, if possible, the model could be updated to provide regular benchmarks for the current building design and weather conditions. It is important to remember that models may not be an accurate representation of the building due to the many errors that can occur during the modeling process.

In many cases there is a lack of formalized benchmarks for certain building types, operational patterns, or systems. The engineers working on the project may be able to provide rules of thumb, based on experience and proprietary data, to use as a rough baseline for comparison. Some of these values could be found in formal sources, such as chiller plant efficiencies shown in NBI (2009). Unfortunately, formalized numbers are often not available and owners will have to carefully evaluate any rules of thumb that are programmed into the system that is being used to track metrics.

BOMA's Experience Exchange Report (EER) can provide useful benchmarks on maintenance and operational performance. Additionally, though not a metric, results from post occupancy surveys, such as that produced by the Center for the Built Environment, can serve to help benchmark indoor environmental quality.

Baselines

The use of baselines allows a building to compare to internal data sets to understand how the building is performing. This term is commonly used in industry to define a building's performance before energy efficient upgrades are installed, for the purposes of measuring the impact of utility-sponsored projects/programs.

Baseline data will be created from past measured performance of a building and can help the operator understand if building performance is improving, degrading, or constant. This requires that historic utility and metric data be stored for future comparisons. As with benchmarks it is important to normalize data properly so that proper comparisons are made. In most cases the only normalization needed will be for climate, but it may also be necessary to normalize data for changing operational patterns or building physical characteristics.

Use and Updates

Building metrics can be compared to benchmarks to understand how the building is performing in relation to a similar set of buildings. It is important to understand how the data set used is defined so that erroneous conclusions are not made. Over time the building owner can determine if comparative performance is increasing or decreasing. Most whole building energy use baselines will require a whole year of energy data. This can make it challenging to quickly observe the effect of changes, though rolling averages could be used to mitigate this problem.

Baselines allow the building owner to determine if building performance is increasing or decreasing with time. They offer the benefit that, once established, they do not require a further full year of data in order to track against them. If energy use is normalized for temperature, current performance in a given month can be compared to historical performance on a regular basis. Of course, if a building's initial baseline performance is poor then all future metrics will be compared to poor performance which can lead to erroneous conclusions. Just because a building's metrics compare favorably with past performance there is no indication that the building couldn't be performing better. Benchmarks can be used to help evaluate the reasonableness of the baselines that are being used.

Once whole building performance has been quantified with appropriate metrics additional details can be determined by looking at system level metrics and comparing them to appropriate benchmarks and baselines. Here, a baseline can provide information regarding how system performance has drifted over time while a benchmark can set an industry average target for specific pieces of equipment. Identifying system level problems can guide a building operator to troubleshoot the proper area of the building to assess problems.

Though changes in whole building performance can indicate problems at the system level it can also mask problems. For example, if lighting energy is reduced due to decreased occupancy the savings may hide an increase in energy use at the chiller plant. For this reason system level metrics can provide a more detailed picture of building operation.

Metrics can be compared to baselines and benchmarks on a regular basis, such as monthly or annually to determine how the building is performing. In some cases, such as for sensitive equipment, or if the building owner wishes to test performance on a short time scale, such as to evaluate responses to schedules, metrics may be evaluated more frequently, perhaps daily, hourly or even sub-hourly. Frequent evaluation imposes an added cost both in operator time and by requiring a skilled operator that understands how the building should be performing on a short time scale.

Additionally, the metric data can be set to create alarms in the BAS when building metrics surpass defined boundaries. These boundaries may be defined based on benchmarks or baselines, including performance goals. The use of alerts can provide valuable information to the building operator, but they must be defined so as to not overwhelm the operator with too much information.

Metrics can play a key role in reducing the risk of degradation of energy savings from commissioning or retrofits. By identifying how the whole building energy performance changes over time general trends can be observed that can guide an owner to identify persistence problems in individual systems or components. For example, a new building EUI baseline could be established following existing building commissioning, and future energy use numbers can be evaluated against this term. If the building is unable to meet this new baseline the operator must determine if performance has degraded or if the additional energy use is associated with providing additional services (such as increased occupancy).

Benchmarks and baselines will need to be periodically updated to ensure that metrics are always compared against appropriate numbers. Comparisons may be made at any time as long as sufficient building data is available, but the numbers used in the comparison may only need to be periodically updated. If calculated on a rolling basis baselines can be updated every time new utility data becomes available, otherwise it may only be necessary to update baselines on an annual basis. Baseline data should be updated every time significant changes are made to building operations or equipment, additionally, updates should occur after retrofits or following any major changes in how the building is used. Baselines may also be updated to reflect changing building performance goals. Benchmarks may be updated as updated information becomes available from the data source, or if a new data source becomes available. Even if metrics are regularly compared to updated baselines historical data should not be eliminated since it can be quite useful for evaluating the impacts and savings associated with changes to the building.

4.3 Tracking and Analyzing Data

Energy metrics are created from data gathered from the utility meters and possibly sub-meters while system metrics may also pull data from the BAS, maintenance management system, and other operator inputs. In some cases additional information may be entered by hand and gathered from other sources, such as occupant surveys. This data must be properly processed to create metrics which are then displayed to the user in an easily understood format. This section discusses the systems used to process and display data as well as some important concepts about around turning raw data into metrics.

Hardware and Software

A tool is needed to read in data gathered from points in the building by the BAS, meters, and sub-meters. This tool may be the BAS itself or an EIS. It will also need to accept benchmark information and any other data that may be needed to create and analyze metrics. The tool must then process this raw data and display it to the user.

Various options are available as to what sort of tool to use to serve these functions and opinions are divided as to what are the best options. A modern BAS can fill this role if properly specified. The option also exists to use an EIS or one of the various other overlays that are available. Many of the overlays that were encountered on this project were example tools that were created for research purposes.

Due to the lack of standards in the industry at this time there is no clear best option. Many modern BASs can provide for metric tracking as can many EISs. It is up to the building owner and consultants to determine which metrics will be tracked and how they will be used. With this information appropriate specifications can be developed, potentially with the help of the specifications guide created by Gillespie (2007). The specifications can then be brought to vendors to determine the systems that will best meet the projects needs. As of the writing of this document (2010) many of the BAS that are just coming onto the market can meet the needs of metric tracking; however, older systems may not be able to adequately track metrics. If metrics tracking is being added to an existing building the BAS should be evaluated as an option, but in most cases an EIS will be required.

No matter which type of system is chosen it must be able to perform some key basic functions:

- Gather necessary point data from the building
- Gather relevant meter and sub-meter data from the building or utility
- Calculate metrics from the collected data
- Store metrics in a database (ideally a SQL database)
- Process historical data into baselines
- Allow for the input of benchmarks
- Display and compare metrics to benchmarks and baselines in a clear format

Some facilities may also benefit from additional capabilities:

- Allow web connectivity, usually with XML scripts
- Allow the user to create additional metrics from existing points
- Display metric data for many facilities in a portfolio
- Compare multiple facilities
- User customized displays
- Alarm when metrics deviate from set tolerances

While determining what sort of system will be used, the owner should consider if he or she would like to retain ownership of data. In some cases where an EIS is used the service provider owns the information collected and the owner must pay to access it. If the EIS will be providing analysis services for the building this may make sense, but it can create a long term cost if the building owner must pay to access data on a regular basis.

Additionally, any system that is installed should be commissioned to ensure that it is working properly. Training should also be provided to any users to ensure that they can access the system and understand its outputs. More advanced users may also want to manipulate outputs to gain greater diagnostic capabilities. For example, an advanced user may wish to look at a metric on an hourly basis to help diagnose a problem.

Depending on the metrics selected additional metering may be required, such as if the building wanted to track chilled water plant efficiency it would need to include a separate sub-meter that tracked the energy use of the chiller and all related auxiliaries. For new buildings this should be determined as early as possible as it is much cheaper to include meters in the design than to add them later.

At a minimum the graphical display must be able to show the value of each metric and its corresponding benchmark or baseline. However, this is of limited utility since it doesn't show how values have changed over time. More useful graphical displays will be able to show time series plots of the metrics and their points of comparison. Additional calculations may show the variance between the metric and target. The ability to quickly toggle between viewing different sets of metrics may help to pinpoint trends in building operations.

Data Processing

There are several important concerns that must be addressed related to processing data into metrics and then displaying that data. Specific concerns exist about how data is normalized, the area that the data applies to, and how data is summed and averaged. Additionally, metric data can be viewed in a variety of ways to improve its functionality. There are a variety of caveats associated with different ways to process data and different approaches have different benefits. It is important that the building choose a calculation methodology that matches any data sets that will be used for benchmarking and that the methodology be consistent through the building's life to ensure meaningful baselining.

Data Normalization

In the context of building metrics, normalization describes the process of taking raw data, which only describes the performance of the building at a given point in time, and dividing it by one or more factors to create a more broadly comparable metric.   For example, if one wanted to compare the electrical energy use of two similar buildings of different sizes the total annual energy use of the two buildings would not provide a useful comparison, in this case one would be comparing kWh. However, if the total annual energy use was divided by the area of each building (normalized) the two facilities could be easily compared, in this case the term would be kWh/ft^2. Similar processes can be completed to account for operating hours, weather, and other building characteristics. A partial list of possible normalizing variables is shown in Table 1.

Table 1: Normalizing Variables

Factor	Source
Annual Hours of Operation	Bureau of Energy Efficiency (India)
Full-time Equivalent Workers	ASHRAE Standard 105
Full-time Eqivalent Students	ASHRAE Standard 105
Number Licensed Hospital Beds	ASHRAE Standard 105
Food Service Seating Capacity	ASHRAE Standard 105
Number of PCs	ASHRAE Standard 105
Weekly Hours of Operation	ASHRAE Standard 105
Annual Months of Operation	ASHRAE Standard 105
Area Computer Centers	ASHRAE Standard 105
Annual Average W/area Computer Centers	ASHRAE Standard 105
Percent Gross Floor Area Heated	ASHRAE Standard 105
Percent Gross Floor Area Cooled	ASHRAE Standard 105
Heating Degree Days	ASHRAE Standard 105
Cooling Degree Days	ASHRAE Standard 105
Area Parking Garages	ASHRAE Standard 105
Natatorium Space	ASHRAE Standard 105
Annual Peak Electic Demand	ASHRAE Standard 105
Electricity Generation Capacity	ASHRAE Standard 105
Annual Electricity Generation	ASHRAE Standard 105
Equipment Capacity	Strategies for Energy Benchmarking In Cleanrooms and Laboratory-Type Facilities
Average Monthly Temperature	NBI

The most common normalization term in the buildings industry is floor area. This term is more complicated than it might seem since the area may include large spaces that are unconditioned such as storage or parking garages, small unconditioned spaces such as hallways and restrooms, atriums that have a large volume but small floor area, and other unique concerns. Most definitions of building energy use intensity (EUI) use gross floor area, including ASHRAE standards 105 and 90.1, and CBECS, while a few, including ASHRAE standard 100 and California Title 42, use conditioned floor area (Peterson and Crowther, 2010). The use of gross floor area presents that challenge that it can make a building with a large amount of unconditioned space look more efficient than it really is. The problems with gross area can be rectified by further normalizing by the percent of floor area heated and cooled. Metrics that are calculated on the basis of rentable area can help indicate tenant specific costs.

Data can also be normalized by operational hours to account for varying schedules. An EUI adaptation being used in India normalizes energy use data by the weekly hours of operation multiplied by the number of weeks in the year (Ministry of Power, India). This could easily be adapted to be the weekly hours of operation times the number of weeks accounted for in the energy data set. ASHRAE Standard 105 also includes the weekly and monthly hours of operation as possible normalization terms.

Data can also be normalized against weather conditions, so that buildings in different climates can be compared, or that a building's performance can be compared to previous performance, when the weather was, of course, different. The most common terms used for this normalization is heating and cooling degree days (HDD and CDD respectively) for the time period in question. The challenge presented using HDD and CDD normalization is that it can be challenging to determine whether any given set of data should be considered part of the heating or cooling season. NBI, using energy signatures, avoids this issue by normalizing data to monthly temperatures. This method could be adapted to normalize based on the average temperature of the energy data set in question. If interval meter data is available a building should consider normalizing data on a daily or even hourly basis to reduce the opportunities for error present in monthly data sets.

Additional normalization factors address the number of people served in the facility, the presence of plug or data center loads, parking spaces, and energy production. One could easily imagine normalization factors that are also related to units of production or other factors that could be tailored for a specific facility.

Some academic and highly technical research work has been done to use multivariate regression analysis to determine the most relevant normalization variable for different building data sets. At this time the work is too specific to be considered for all but the most advanced applications, but it will surely be guiding future decisions about which normalization factors are most important.

ENERGY STAR Portfolio Manager includes weather normalization based on heating and cooling degree days when calculating a score. Additionally, the tool can be used to report a weather normalized energy use intensity term that normalizes the building's EUI for changes in weather patterns. Weather normalized energy use intensities may be computed for all building types, including buildings those that are not eligible to receive an ENERGY STAR score.   These outputs can be found in the tool's reporting functions. There does not appear to be other easy to use tools available to assist a basic user in weather normalization of utility data.

Facility and System Boundaries

It is also important to define the boundaries of the facility that will be addressed by metrics. For example, a large facility consisting of many several buildings may only be served by a single meter. If the goal of the project is simply to create facility-wide metrics, that won't help indicate which buildings are under or over performing, the facility fence line is an appropriate boundary. However, if there is a desire to understand how individual buildings and systems function then metrics will have to be defined and meters installed for each individual segment of the facility.

Metric Measurement Frequency and Aggregation

There are also different approaches concerning how data should be aggregated over time and how granular it should be.

Metrics can be calculated on coarse time intervals, such as on an annual basis or on a seasonal basis. On a smaller time scale they might be calculated monthly or weekly. Some metrics may lend themselves to daily, hourly, or sub-hourly time scales. Typically metrics that are calculated over a longer period of time (monthly or longer) serve to provide higher level insight about overall performance where those calculated with smaller time steps may be used to determine how the building or system responds to specific conditions, such as weather, schedules, or operational changes. Metrics calculated on shorter time scales provide a much more detailed picture of performance, and, if used properly, can help diagnose important issues. To be useful though they need to be viewed in a graphical display by a practitioner who has a good understanding of the both the physical building and how the metrics should reflect its performance.

Along with the time frame that a metric will address the way that data will be aggregated during that time frame. There are three common ways that metric data are aggregated:

- Summing over a time frame, for example total annual energy use
- Averaging over the whole time frame, for example annual average daily energy use

- Averaging over a subset of the time frame, for example monthly daily average energy use or averaging on weekdays and weekends

Typically the decision about how to aggregate data will be based on the need to conform to any benchmarks that are used and the specific needs of the facility. The larger the time interval used the less information is conveyed in the metric, but smaller time intervals require more analysis.

Metric Visualization and Comparison

Metric data have no value if they are not displayed in a useful and intuitive fashion. A good display will indicate the metric's past and present performance along with any benchmark or baseline terms. Graphical displays allow the user to quickly grasp the meaning of the data and should be a required output of whatever tool is used to process data into metrics.

For metrics that are collected on a long time scale, such as annual or quarterly EUI, a bar chart showing the actual metric data and comparison data set may be used. For metrics that are collected on a smaller time scale a time series plot should be used to display the metric values. If very small time steps are used (sub-hourly) it may be useful to also show a best fit line along with the metric data to indicate overall trends.

Comparison to baselines or benchmarks can be made by displaying these points as additional lines on a time series chart. If the facility has a goal of coming within a certain percentage of the comparison data then a shaded line or error bars indicating this range may be added to the time series plots. A more advanced comparison may include statistical terms, such as standard error, to describe the difference between metric data and the benchmark or baseline.

A wide variety of additional plotting techniques may be used, but the standard time series plot provides a simple view that can be understood by most stakeholders. Gillespie et al (2007) and Barley et al (2005) discuss many other different chart types that could be used, often plotting terms such as those discussed in the normalizing factors section, on the X-axis.

Other Data Processing Concerns

In some cases metric calculation methodology may be unclear, or a building will have special concerns related to on site energy production. Barley et al (2005) includes in depth discussion on metric calculation and includes recommendations on including energy production in calculations.

5 Recommended Building Performance Metrics

This study identified a wide variety of metrics that a building could track in order to ensure persistent high performance and distilled them down to lists of recommended metrics. The full list of metrics that were evaluated is available in Appendix 8.3.

Recommended metrics were broken into four categories:

- Basic Energy Metrics: Metrics that use whole building utility meter data. These metrics are relatively easy to track, and should be tracked by all buildings
- Advanced Energy Metrics: Metrics that use whole building utility meter data but require more advanced analysis than basic energy metrics, or metrics that require additional meters beyond whole building energy use meters.
- Basic System Metrics: Metrics that use existing points from the BAS or maintenance management system. These metrics are relatively easy to track.

- Advanced System Metrics: Metrics that require additional points to be added to the BAS or maintenance management system. This category also includes metrics that use both meter data and BAS data.

Metrics were categorized based on ease of measurement and interpretation. The lists show the metrics that PECI believes best indicate building performance while keeping the number of metrics to a minimum. Some researchers in this field have recommended the use of more detailed metrics, but we believe that these lists balance the benefits of tracking metrics with the resources required to track and analyze data.

The lists strived to incorporate metrics that indicate energy use, comfort, and maintenance. The units presented in the tables are example units for a typical building in the US, users can, of course, use whichever metrics best fit their needs. Metrics in these lists represent an amalgamation of many different metrics from different sources and include the industry experience of PECI, for this reason citations are not given for each metric, but citations are included with the original full list in Appendix 8.3.

Based on the considerations discussed above in Section 4.1 the owner will need to determine which metrics are best for his or her facility. In general, all buildings should consider tracking basic energy and system metrics and buildings that are seeking to achieve higher performance should also include some or all of the advanced metrics. If a building has special needs additional metrics should be considered. Though the full list presented in the Appendix can serve as a starting point the building may create their own metrics to suit their unique equipment and goals.

As discussed in Section 4.3 a variety of different normalization factors and time scales can be used for these metrics. Common additional normalizing factors are heating and cooling degree days, operating hours, and number of occupants. The most common factors are given here as well as suggestions to improve granularity, but a facility should adapt the metrics as needed.

Basic Energy Metrics

The basic energy metrics, shown in Table 2, are intended to provide a general picture of building energy use. Metrics from this list indicate the whole building gas and electric energy use as well utility costs. They do not require any more data than what can be gathered from a typical utility bill, and though a metric tracking tool would simplify calculation and analysis, it is not required. Metrics are normalized by building area and, for whole building energy use, operating hours.

The metrics presented show annual metric calculation as a minimum standard, but it is recommended that these metrics be looked at on a monthly basis with a bi-annual in-depth review. At a monthly review the owner should calculate the metric for the previous 12 months (e.g. kBtu / ft^2-yr) and also calculate it on a monthly basis (e.g. kBtu / ft^2-month) for the preceding months. Metrics of this sort can be easily benchmarked against CBECS or CEUS and an ENERGY STAR Score could be generated when the building is benchmarked.

Table 2: Basic Energy Metrics

System Type	Sub-system	Metric	Units
Whole Building	NA	Energy Use	kBtu / ft^2-yr
	NA	Energy Use	kBtu / annual operating hours-ft^2-yr
	Electric	Energy Use	kWh / ft^2-yr
	Gas	Energy Use	therms / ft^2-yr
	Electric	Utility Cost	$ / ft^2-yr
	Gas	Utility Cost	$ / ft^2-yr

Advanced Energy Metrics

The advanced energy metrics, shown in Table 3, provide a more in-depth look at how a building is using energy. Many of these metrics require additional energy sub-meters, a more detailed review of utility bills, or additional calculations. As in other sections the building owner may consider analyzing these metrics on smaller time scales or using other normalizing factors.

Some of these metrics allow the building to analyze electric use and demand as well as associated costs. These can point to opportunities for a building to reduce peak demand and further reduce costs. In particular the facility load factor can help indicate if the peak demand is considerably different than typical demand.

The emissions metric can help quantify the carbon emissions associated with gas and electric use, the California Climate Action Registry[5] and Greenhouse Gas Protocol Initiative[6] can provide additional guidance on calculating these terms. Electric emissions factors are available in the U.S. from the EPA[7].

Heating and cooling metrics that are calculated on a monthly basis will see significant month-to-month changes due to seasonal weather variations. These metrics, in particular, should consider normalizing based on ambient conditions and should be compared to benchmarks and baselines that account for seasonal variation. Other metrics, such as lighting and plug loads, will, in most cases, only have marginal variation across seasons.

Other metrics require sub-metering and indicate the performance of total HVAC, components of HVAC, and lighting systems. Note that these metrics combine gas an electric energy use (such as for heating or in an absorption chiller), but that metrics could be further broken down to include separate gas and electricity terms. Metrics are also provided for plug loads and people movers (such as elevators and escalators). The CEUS database can help users in California benchmark their energy end-uses.

[5] http://www.climateregistry.org/
[6] http://www.ghgprotocol.org/
[7] http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

Table 3: Advanced Energy Metrics

System Type	Sub-system	Metric	Units
Whole Building	NA	Energy Use Cost (excluding demand)	\$ / ft^2-yr
	Electric	Electric Demand - Peak	kW / ft^2-month
	Electric	Electric Demand Cost	\$ / ft^2-month
	Electric	Net facility load factor	kW(ave) / kW(peak)
	NA	Atmospheric emissions	ton / ft^2-yr
HVAC	Heating	Energy Use	therms / ft^2-yr
	Heating	Energy Use Cost	\$ / ft^2-yr
	Heating	Electric Demand - Peak	kW / ft^2-month
	Heating	Electric Demand Cost - Peak	\$ / ft^2-month
	Cooling	Energy Use	kWh / ft^2-yr
	Cooling	Energy Use Cost	\$ / ft^2-yr
	Cooling	Electric Demand - Peak	kW / ft^2-month
	Cooling	Electric Demand Cost - Peak	\$ / ft^2-month
	Ventilation	Energy Use	kWh / ft^2-yr
	Ventilation	Energy Use Cost	\$ / ft^2-yr
	Fans and pumps*	Energy Use	kWh / ft^2-yr
	HVAC Eqpm + common auxiliaries**	Energy Use	kBtu / ft^2-yr
Lighting	NA	Energy Use	kWh / ft^2-yr
	NA	Energy Use Cost	\$ / ft^2-yr
	NA	Electric Demand - Peak	kW / ft^2-month
	Exterior	Energy Use	kWh / ft^2-yr
	Interior	Energy Use	kWh / ft^2-yr
	Interior - Daylit Zones	Energy Use	kWh / ft^2-yr
	Interior - Non-Daylit Zones	Energy Use	kWh / yr
	Interior	Electric Light Reduction Ratio	kWh(daylit area)/yr-ft^2 / kWh(non-daylit area)/yr-ft^2
Plug Loads	NA	Energy Use	kWh / ft^2-yr
Plug Loads	NA	Energy Use Cost	\$ / ft^2-yr
People Movers	NA	Energy Use	kWh / ft^2-yr
	NA	Energy Use Cost	\$ / ft^2-yr
Domestic Hot Water	NA	Energy Use	kBtu / ft^2-yr
	NA	Energy Use Cost	\$ / ft^2-yr

*If not covered in cooling, heating, and ventilation.
**Auxiliaries include equipment that serves multiple HVAC systems. E.g., control air compressors.

Basic System Metrics

The basic system metrics, shown in Table 4, use information already available in the BAS to expand the owner's understanding of building performance. Based on the complexity of most system metrics we believe that only two metrics belong in this table, both of which are methods of tracking comfort. The facility may choose to track one or both of these metrics. It is recommended that these metrics be assessed on a monthly basis. The comfort metrics will likely be compared to internal targets.

The 'Percent of Hours Uncomfortable' metric can be used to track how frequently zones deviate from an acceptable setpoint range. This metric should be tracked on a zone-by-zone basis to pin point problem areas and may be averaged over the building to indicate general performance. As displayed in the table a score of zero indicates excellent performance, the metric could be changed to indicate 'Percent of Hours Comfortable' to reverse the scale.

The 'Comfort Index' metric was developed by Tom (2008) and uses an arbitrary 100 point scale, with 100 considered perfect, to describe comfort based on the points available in the building. For example, if a zone only had a temperature sensor the building may decide to score hours where the zone temperature is between 72 and 76°F with 100 points. Perhaps temperatures between 70 and 71 or 77 and 78 would score 90 points, and so on. If the room had humidity sensors and/or CO_2 sensors scores could be developed for different temperature and humidity conditions. In this way the building can measure how far outside of comfort conditions it is. The metric should be calculated at all zones and may be averaged across the building and time frame of interest.

Table 4: Basic System Metrics

System Type	Sub-system	Metric	Units
Whole Building	NA	% Hours uncomfortable	% hours outside of space temperature range
	NA	Comfort Index	Average comfort index (0-100)*

*Based on at least space temperature, may include other factors like CO2 and humidity

Advanced System Metrics

The advanced system metrics, shown in Table 5, contain more detailed information concerning building energy use, comfort, and maintenance. Some metrics will require additional sub-metering and points; other will require data entry from other sources. A notable metric in this table, chiller plant efficiency, indicates the performance of a highly energy intensive process. The environmental quality and maintenance metrics should be evaluated at least annually, if not more frequently. It is recommended that the plant and ventilation metrics be evaluated monthly.

The indoor environmental quality (IEQ) metric describing absenteeism provides a basis for understanding occupant health, which can be linked to building comfort and can be compared to past performance and goals. The availability of this sort of data may vary from facility to facility depending on the willingness of human resources departments to share this data.

The maintenance metrics will require data entry from a computerized maintenance management system (CMMS) or other source of maintenance records. They indicate the resources devoted to maintenance and help to show how efficient the maintenance program is. These metrics may be more interesting when correlated with other metrics, for example if maintenance costs increase while comfort metrics improve the trade off may be worth while, but if maintenance costs increase while energy use is also increasing it is likely that equipment is not being run properly. The maintenance cost metric can be benchmarked against data available in the BOMA Experience Exchange Report (EER). The maintenance metrics will likely be compared against past performance and goals.

The heating and cooling plant efficiencies require additional sub-metering and points, and provide a clear indication of plant performance. These efficiencies include all equipment associated with the plant, such as chillers and pumps. NBI (2009) provides a chart that can be used to benchmark chiller plant performance and ASHRAE Guideline 22-2008 provides additional information on monitoring chiller plant efficiency. In calculating these metrics the building will need to track not only energy in to the chiller and boiler plant equipment (determined with sub-meters) but also the energy delivered by the plant. To determine energy delivered the facility must be able to monitor supply and return water temperatures and flow. These metrics should be evaluated monthly with at least an average efficiency and potentially charts showing daily or hourly efficiency.

With additional sub-metering and points fan efficiency can also be monitored. In this case a flow meter will be necessary to determine air flow delivered. This metric could be compared against manufacturer's data or past performance.

Additionally, the outside air (OA) cfm delivered per person can be analyzed to indicate ventilation to the space. Analyzing outdoor airflow will require either a flow meter or a virtual point correlating fan speed with a fan curve to produce a flow rate. Occupancy can be estimated and updated as the building's use changes. The cfm per person metric will not deliver an exact measurement, but can help approximate air delivered in a simple fashion, it will likely be around 15 cfm. The term may be averaged during occupied hours for the time period being evaluated.

Table 5: Advanced System Metrics

System Type	Sub-system	Metric	Units
Whole Building	NA	IEQ	# sick absences / occupant-yr-ft^2
	NA	Maintenance	$ spent on maint / yr
	NA	Maintenance	hrs spent on maint / yr
Whole Building	NA	Maintenance	# maint requests (by type) / yr
HVAC	Heating	Heating Plant Efficiency	Btu/h(out) / Btu/h(in)
	Cooling	Cooling Plant Efficiency	kW / ton*
	Ventilation	Fan System Efficiency	kW / cfm**
	Ventilation	Outside air ventilation	OA cfm / person‡

*kW of entire plant, not just chiller.
**kW of all fans combined (e.g., supply, return, exhaust), cfm of supply air
‡Average monthly OA cfm / person, during occupied hours operating in minimum outside air (non-airside economizer) mode.

Considerations for Atypical or Small Buildings

Many of the metrics discussed above can be applied to small buildings that are served by roof top units (RTUs), but several, especially those that relate to plant efficiency are not applicable. This study did not identify any literature with recommended metrics for RTUs. It would, however, be feasible to consider adding a sub-meter to track the collective performance of the RTUs on a building. Monthly energy use could be compared against weather data to evaluate long term performance.

Many other buildings, especially medical facilities, laboratories, and industrial facilities, may need to use more specialized metrics than are presented in this report. Sartor et al (2000) provides guidance directed specifically at laboratories and clean rooms.

6 Conclusion and Recommendations

6.1 Conclusion

This report has synthesized existing literature, interviews of controls professionals, and PECI's engineering experience to create lists of recommended metrics that building owners can track to understand performance in the areas of energy, maintenance, and comfort. The metrics were broken into categories, **energy metrics** and **system metrics**, largely delineated by whether they derive from utility meter data or from other sources, including the BAS.

Despite the existence of literature for recommended system metrics, market adoption appears to be very low and there is no single simplified source that provides guidance to narrow down the options of which metrics to track and how to track them. Though determining the reasons for low adoption were outside of the project's scope, it appears as though building owners need clear direction in how to specify those metrics that most meet their needs. The use of building EUI and comparisons against data provided by the ENERGY STAR Portfolio Manager is gaining some market penetration.

Industry feedback suggested that there were no technical limitations to implementing a range of metrics (modern BAS and EIS are very capable), but there are resource limitations for building owners such that they would only reasonably track a small number of metrics.

Based on the literature search and interviews, this report resulted in tables of key metrics broken into the following categories:

- <u>Basic Energy Metrics</u>: Metrics that use whole building utility meter data. These metrics are relatively easy to track, and should be tracked by all buildings
- <u>Advanced Energy Metrics</u>: Metrics that use whole building utility meter data but require more advanced analysis than basic energy metrics, or metrics that require additional meters beyond whole building energy use meters.
- <u>Basic System Metrics</u>: Metrics that use existing points from the BAS or maintenance management system. These metrics are relatively easy to track.
- <u>Advanced System Metrics</u>: Metrics that require additional points to be added to the BAS or maintenance management system. This category also includes metrics that use both meter data and BAS data.

The metrics presented in this report sought to provide enough information for an owner to understand performance without providing so much information as to overload the owner. Using the resources presented in the report ambitious owners with well trained staff can consider tracking metrics that indicate a detailed level of building performance.

6.2 Recommendations

The creation of a broadly accepted procedure or standards for metric tracking will speed its adoption across the buildings industry. Such a document must not only focus on the technical issues of developing metrics, but also on the need to turn the developed metrics data into information that can be easily analyzed and acted upon by building owners. A standard set of metric specifications that provides for easily accessible metrics in a user friendly display would help to move the industry forward.

An additional barrier to increased effective adoption of the use of performance metrics is the lack of good benchmark metric data. It is imperative that more detailed data sets that account for variations in building use (both building type and varying internal loads, such as from data centers), climate, and scheduling be developed. Further, developing solid benchmark data for systems, such as chiller and boiler plants, will help building owners to better understand how their plants perform. Without improved baseline data, buildings will be unable to accurately assess the performance of their building and take appropriate actions to address it.

7 Bibliography

ASHRAE Standard 105: Standard Measures of Measuring Expressing, and Comparing Building Energy Performance. ASHRAE. 2007.

Augenbroe, G., and C. Park. 'Quantification Methods of Technical Building Performance', Building Research & Information, 33: 2, 159-172. 2005

Barley, D., M. Deru, S. Pless, and P. Torcellini. Procedure for Measuring and Reporting Commercial Building Energy Performance. National Research Energy Laboratory. NREL/TP-550-38601. October 2005

Benchmarking the Performance of Building Energy Management Using Data Envelopment Analysis. Wen-Shing Lee and Kuei-Peng Lee. 2009.

BetterBricks. The High Performance Portfolio: Engineering Metrics Checklist. Available at www.betterbricks.com/graphics/assets/documents/EngineeringChecklist.pdf

Bureau of Energy Efficiency. Scheme for Star Rating for Buildings – BPO. Ministry of Power, Government of India. December 2009

ENERGY STAR Performance Ratings – Technical Methodology. U.S. Environmental Protection Agency. June 2010.

Fowler, K.M. "Building Cost and Performance Measurement Data." PNNL-SA-43119. Greenbuild 2004 International Conference and Expo, Portland, Oregon. 2004

Gillespie, K., P. Haves, R. Hitchcock, J. Deringer, and K. Kinney. A Specifications Guide for Performance Monitoring Systems. California Energy Commission Public Interest Energy Research Program. March 2007.

Haves, P., R. Hitchcock, K. Gillespie, M. Brook, C. Shockman, J. Deringer, and K. Kinney. Development of a Model Specification for Performance Monitoring Systems for Commercial Buildings. LBNL. May 2008.

Hitchcock, R. High-Performance Commercial Building Systems Program: Standardized Building Performance Metrics. LBNL. California Energy Commission Public Interest Energy Research Program. October 2002

Mills, E., P. Mathew, M.A. Piette, N. Bourassa, and M. Brook. Action-oriented Benchmarking: Concepts and tools. Energy Engineering, Vol. 105, No. 4. 2008.

Mills, E., P. Mathew, N. Bourassa, and M. Brook. Action-oriented Benchmarking: Using the CEUS Database to Benchmark Commercial Buildings in California. Energy Engineering, Vol. 105, No. 5. 2008.

Morrissey, E., J. O'Donnell, M. Keane, and V. Bazjanac. Specification and Implementation of IFC Based Performance Metrics to Support Building Life Cycle Assessment of Hybrid Energy Systems. National University of Ireland. LBNL. Conference Paper: IBPSA-USA SimBuild 2004 Conference. August 2004.

New Buildings Institute. Advanced Metering and Energy Information Systems. US Environmental Protection Agency, Grant 83378201. July 2009.

O'Donnell, J, M. Keane, and V. Bazjanac. Specification of an Information Delivery Tool to Support Optimal Holistic Environmental and Energy Management in Buildings. LBNL-918E. Conference Paper: SimBuild 2008 Conference, Berkeley CA. August 2008.

Pati, D., C. Park, and G. Augenbroe. Roles of Quantified Expressions of Building Performance Assessment in Facility Procurement and Management. Building and Environment Journal, 773-784. 2009.

Peterson, K. and H. Crowther. Building EUIs. High Performing Buildings. Summer 2010.

Piette, M., J. Granderson, G Ghatikar, and P. Price. Building Energy Information Systems: State of the Technology and User Case Studies. LBNL. Presentation Slides: California Energy Commission Public Interest Energy Research Program. October 2009.

Sabapathy, A., S. Ragavan, M. Vijendra, and A. Nataraja. Energy Efficiency Benchmarks and the Performance of LEED Rated Buildings for Information Technology Facilities in Bangalore India. Energy and Buildings Journal, 2206-2212. 2010

Sartor, D., M. Piette., W. Tschudi, and S. Fork. Strategies for Energy Benchmarking In Cleanrooms and Laboratory-Type Facilities. LBNL No. 45928. Conference Paper: 2000 ACEEE Summer Study on Energy Efficiency in Buildings. August 2000.

Sullivan, G.P., R. Pugh, and W.D. Hunt. Metering Best Practices: A Guide to Achieving Utility Resource Efficiency. U.S. Department of Energy. October 2007.

Tom, S. Managing Energy and Comfort. ASHRAE Journal. June 2008.

8 Appendices

8.1 Interview Questions

Intro:
Ask if the contractor has incorporated metrics tracking into a facility's BAS before. If they have, ask them to share their experiences with that – how they selected the metrics to track, what was involved in setting it up in the BAS, and if the owner is tracking the metrics (if they aren't, ask why not).

Metric Selection: (25% of interview)

What metrics should every building track to ensure persistent high performance?

> If this list of metrics if >5, please prioritize a top 5.
>
> Would this list be different for varying system and building types (central plant vs. packaged, office vs. hospital)?
>
> Are their particular systems (boiler plant, chilled water plant) or equipment (pumps, economizers) that warrant particular attention?

Given a resource constrained environment, how should a building choose which metrics to track? If a building operator has a long list of metrics that *could* be tracked, how would you guide him to choose the most important metrics?

<u>Benchmarks and Baselines</u>: (10% of interview)

Once a building is tracking metrics, what would you compare them against? Its own past performance, or the performance of its peers? For example, a building may compare EUI to CBECS data, chiller performance to a rated EER, or established rules of thumb.

Do you have specific benchmark recommendations for certain metrics?

<u>Methods for Tracking Metrics</u>: (65% of interview)

A building may use a BAS, EIS, or some other software overlay to track metrics. What type of system do you find most owners gravitate towards? What type of system would you recommend? Please discuss hardware and software.

> Specifically related to metrics, what are some limitations of the different systems? Can they be overcome, if so, how?
>
> *Probe at these* c*oncerns: Data storage, processing data to metrics, metric visualization, comparing metrics to baselines/benchmarks*
>
> Are their particular benefits to different systems?

Do you have any recommendations on how metrics should be viewed by the user? Do you recommend particular visual displays? How often should metrics be updated and checked?

8.2 Literature Review Summary Table

The following tables summarize the findings of the literature review. The first table provides an overview of each document while the second table provides more detailed information on metrics, benchmarks and baselines, and monitoring.

#	Title; author; year	Format	Intended Use / Audience	Overview of Study
1	Procedure for Measuring and Reporting Commercial Building Energy Performance; D. Barley, M. Deru, S. Pless, P. Torcellini; 2005	NREL Technical Report	Researchers and Building Energy Professionals	This report aims to standardize the measurement and characterization of building energy performance. It notes that previous research reports are either too broad or too specific. • Method demands a minimum of one year of data in order to see building performance in all seasons. • Gives performance tracking procedure descriptions (including project definition, measurement system design, data collection and analysis, and reporting). • Data collection and analysis procedures: o Recommends conducting energy balances to verify data or find immeasurable points, outlines procedures to deal with missing data. o Provides directions for standardizing months (12 approximately equal periods, or follow billing cycle) and addressing other incongruities in time intervals. o Provides estimation methods to track data that may be hard to measure (plug loads, task light loads, equipment that may be used for multiple end uses such as a heat pump, thermal energy storage, pump and fan energy assignment). o Provides examples for reporting, including diagrams of data acquisition strategy, data display (monthly total, monthly daily average, and peak day profiles). • Gives recommendations for data loggers as well as measuring AC Power, DC Power, temperature, relative humidity, and flow. • Appendices provide valuable information: a sample project, uncertainty analysis, and demand and load factor performance metrics.
2	High-Performance Commercial Building Systems Program: Standardized Building Performance Metrics; Robert Hitchcock; 2002	LBNL Technical Report	Researchers and Building Energy Professionals	Written to address the lack of standardization in monitoring and reporting building performance. • Emphasizes that performance metrics can be used through the entire building life cycle, from planning through operation, to help realize performance objectives. • Performance metrics can be thought of in a *hierarchical context*; metrics identify the performance of systems or subsystems which all converge towards monitoring a stated higher level objective, like 'optimize energy performance' or 'improve occupant comfort'. • To address variation over time, use a structured data model to track and archive metrics. • The ability to track metrics has been incorporated into IFC/IAI specifications which smoothes exchange of data across software tools; some problems still exist in technical import/export capabilities. Metrics discussed can be represented using extended IFC model. • Discusses a variety of performance frameworks (CIB, ASTM, ICC, LEED, US-DOE), which are outside of the scope of this project. • Provides a table of standardized performance metric sets.

#	Title; author; year	Format	Intended Use / Audience	Overview of Study
3	A Specifications Guide for Performance Monitoring Systems; Kenneth Gillespie, Philip Haves, Robert Hitchcock, Joseph Deringer, Kris Kinney; 2007	LBNL Technical Report	Commissioning Providers and Building Owners and Operators	This document is a specifications guide for performance monitoring systems intended to support ongoing commissioning. • Provides an overview of performance monitoring systems • Discusses general issues impacting "scope, implementation approach, system rigor, data visualization, commissioning, and training." • Appendices provide additional information on: system performance capabilities and functional requirements, example specifications for measurements • Includes discussion of accuracy of the measurement, network architecture, sampling, and data recording, archiving and storage. Additionally, provides detailed example specifications for every aspect of creating performance monitoring systems (description of work, monitoring system, instrumentation and data requirements, sensor inputs by virtual points and calculated values, naming, trends, archives, display requirements, monitoring system commissioning, and training) • Discusses the benefits of performance monitoring including: o Main meters: use by time of day, manage peak loads, operation during unoccupied periods, and power quality and power factor. o Chilled water plant: track and manage chiller peak load contribution and chiller health o Chilled water flow and temperatures and plant power to find heating and cooling energy delivered: monitor growth of capacity requirements, find anomalous loads, monitor plant efficiency to find more efficient operations strategies, detect performance degradation, and determine if maintenance is needed. o Weather station for wet and dry bulb ambient temperature: inform free cooling, cooling tower operation, and chilled water plant operation. o Data calculation and display: view HVAC energy and comfort performance, monitor and troubleshoot different parts of the HVAC system which leads to early fault detection to lower costs and increase service quality.
4	Building Energy Information Systems: State of the Technology and User Case Studies; Mary Ann Piette, Jessica Granderson, Girish Ghatikar, Phil Price; 2009	CEC / LBNL Presentation	Researchers and Building Energy Professionals	This presentation describes energy information systems and the state of the technology. It is included here to describe three potential benchmarking options that are described below.
5	Metering Best Practices: A Guide to Achieving Utility Resource Efficiency; G. Sullivan, R. Pugh, W. Hunt; 2007	DOE / FEMP Report	Building Operators and Managers	This document is a broad guide to metering building systems. Of particular relevance to this report is that it breaks metering down to four levels: whole building, panel, circuit, and end use. A facility may use a mix of meters at varying levels. Higher levels can be useful to alert that a problem exists, even if it does not identify the problem.
6	Specification and Implementation of IFC Based Performance Metrics to Support Building Life Cycle Assessment of Hybrid Energy Systems; James O'Donnell, Elmer Morrissey, Marcus Keane, Vladimir Bazjanac; 2004	SimBuild Article	Researchers and Building Energy Professionals	This paper describes a methodology for storage and utilization of performance metrics. It is included here to show benchmarking options, the idea of a performance effectiveness ratios, and comments on the metric selection process.

#	Title; author; year	Format	Intended Use / Audience	Overview of Study
7	Strategies for Energy Benchmarking In Cleanrooms and Laboratory-Type Facilities; Dale Sartor, Mary Ann Piette, William Tschudi, Stephan Fork; 2000	LBNL Report	Researchers and Building Energy Professionals	This article is focused on benchmarking the energy performance of cleanrooms and laboratories which have high energy use, but the findings can be applied to other building types as well. Comparisons can be made against: • Similar buildings • Historical (baseline) energy use for the building • A set of similar systems or components The number of confounding factors makes it easy to draw improper conclusions from benchmark data. Production metrics (kW/unit production) can mask inefficient systems or components. Benchmarking methods include: • Statistical comparisons • Point based rating systems • Model based techniques • Hierarchical end use and performance metrics evaluations
8	Managing Energy and Comfort; Steve Tom; 2008	ASHRAE Journal Article	Building Energy Professionals	The author argues that the primary purpose of HVAC systems is to provide comfort to occupants, and that energy efficiency must come as an important secondary goal. If comfort is not tracked it cannot be evaluated and improved, so a comfort index is suggested.
9	Quantification Methods of Technical Building Performance; Godfried Augenbroe, Ceol-Soo Park; 2005	Building Research and Information Article	Researchers and Building Energy Professionals	The paper presents a web-based toolkit that was developed to quantify building performance. The toolkit contains several performance indicator with categories including energy, lighting, thermal comfort, and maintenance. The toolkit was successfully used to evaluate several buildings in the US.
10	Energy Efficiency Benchmarks and the Performance of LEED Rated Buildings for Information Technology Facilities in Bangalore India; Ashwin Sabapathy, Santhosha Ragavan, Mhima Vijendra, Anjana Nataraja; 2010	Energy and Buildings	Researchers and Building Energy Professionals	The authors benchmarked four LEED-India IT facilities against 22 similar non-certified buildings in Bangalore, India.
11	Scheme for Star Rating for Buildings – BPO; Bureau of Energy Efficiency, Ministry of Power, Government of India; 2009	Government Document (India)	Building Owners	The document presents a star rating system for energy use in Business Process Operations (BPO) buildings (buildings that provide IT-related services). Buildings are benchmarked on an Annual Average hourly Performance Index (AAhPI).
12	Building Cost and Performance Measurement Data; Kim Fowler, Beverly Dyer; 2004	DOE Technical Report	Researchers and Building Energy Professionals	This DOE study was designed to provide federal decision makers data demonstrating the benefits of sustainable building design. The study generated high-level metrics to be used in identifying cost and performance differences between sustainable and traditional buildings. Metrics were developed through a literature review, audience evaluation, TAG review, and pilot test. Metrics selected were evaluated on ease of collection, usefulness, and data quality. A more detailed article “Building Cost and Performance Metrics: Data Collection Protocol” can be found as PNNL Report #15217.

#	Title; author; year	Format	Intended Use / Audience	Overview of Study
13	Benchmarking the Performance of Building Energy Management Using Data Envelopment Analysis; Wen-Shing Lee, Kuei-Peng Lee; 2009	Applied Thermal Engineering Journal Article	Researchers	This study uses a mathematical model to argue that benchmarks should be scaled in such a way as to distinguish scale factors (area, occupancy, climate) and management factors (policy, equipment efficiency, temperature settings). Most common benchmarks are scaled on floor area. The study concludes for a case study in Taiwan that building energy performance should be calculated using the floor area, number of occupants, and climate-adjusted energy consumption in order to reveal the technical efficiency of a building. Comparisons of technical efficiency would then indicate the effect of management performance.
14	Advanced Metering and Energy Information Systems; New Buildings Institute; 2009	US EPA Research Report	Researchers, Building Energy Professionals, Building Owners	This article focuses on the use of energy metering (whole building, system, or component level) and EIS to track energy use. Costs of using these systems include costs related to components and costs related to analysis (either in house or through a service provider) and acting on findings. An EIS consists of meters and sensors, a data acquisition system, a communication service, remote database, and software tools for analysis. Specific details are given regarding the features and costs of these components. A discussion of existing research showing the cost effectiveness of EIS is given as well as considerations for drivers and barriers for increased adoption.
15	Specification of an Information Delivery Tool to Support Optimal Holistic Environmental and Energy Management in Buildings; James O'Donnell, Marcus Keane, Vladimir Bazjanac; 2008	LBNL / Simbuild Paper	Researchers, Building Energy Professionals	The paper presents some excellent discussion of the state of the industry and focuses on specifying a tool to deliver metrics to owners. Benchmarking information is provided in the next section.
16	Roles of Quantified Expressions of Building Performance Assessment in Facility Procurement and Management; Debajoyti Pati, Cheol-Soo Park, and Godfried Augenbroe; 2009	Building and Environment Journal Article.	Researchers, Building Energy Professionals	This paper focuses on using performance indicators as a quantifiable tool to facilitate dialogue between various building stakeholders during building design and operation. The primary target of the paper is the design process, but many of the indicators could be adapted to assess ongoing operation.
17	Building Energy Use Intensity; Kent Peterson and Hugh Crowther; 2010	High Performing Buildings Journal Article.	Building Energy Professionals	The authors focus on some important distinctions that should be made when calculating the energy use intensity of a building. These include the definition of floor area and energy used as well as suggestions for other possible normalizing factors.
18	ASHRAE Standard 105: Standard Measures of Measuring Expressing, and Comparing Building Energy Performace; ASHRAE; 2007	ASHRAE Standard	Building Energy Professionals	This standard provides detailed guidance on calculation of building energy use intensity. It also provides an extensive list of possible normalizing factors.
19	Action Oriented Benchmarking: Concepts and Tools; Evan Mills, Paul Matthew, and Mary Ann Piette; 2008	Journal Article	Building Energy Professionals	This article, part one of a two part series, describes a process called action oriented benchmarking which allows users to evaluate different energy efficiency measures. They introduce a web-based tool that uses CEUS and CBECS data, called energyIQ, to accomplish this goal. The tool is still in beta test mode. http://energyiq.lbl.gov/
20	Action Oriented Benchmarking; Paul Matthew, Evan Mills, Noman Bourassa, and Martha Brook; 2008	Energy Engineering Journal Article.	Building Energy Professionals	This paper, part of a two part series, discusses the development of the CEUS database and how it can be used to benchmark buildings and for end-use and component level energy use and evaluate individual energy savings opportunities.

#	Title; author; year	Format	Intended Use / Audience	Overview of Study
21	ENERGY STAR Performance Rating Technical Methodology; 2010	Technical Report	Building Energy Professionals	This report provides an overview of the technical methodology employed in the ENERGY STAR Performance Ratings. Individual detailed discussions are too specific to address here.

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
1	Procedure for Measuring and Reporting Commercial Building Energy Performance; D. Barley, M. Deru, S. Pless, P. Torcellini; 2005	The report addresses many possible metrics that could be used. Metrics may be normalized against building gross area or against functional areas (area of office space, labs, parking garages, etc.). The report does not indicate which metrics are the key ones to track, nor does it give recommendations for how a facility can determine which metrics are best to track for their situation. Metrics include: • Whole Building (or Facility) Monitoring: o Energy: use and cost as total and per unit area o Power: demand and cost as total and per unit area, load factor • HVAC o Total HVAC energy use o Cooling energy use o Heating energy use o Ventilation air distribution energy use • Lighting o Energy use o Installed and task lighting energy use o Façade lighting energy use • DHW o Energy use o Load (thermal energy delivered) o Efficiency (load/energy supplied) • Process and Plug Loads energy use • Zones o Temperatures by zone, average, or deviations The report also addresses metrics related to generation, cogeneration, and thermal storage.	Does not provide benchmarking numbers. Does not present methods for a facility to establish their own benchmarks or baselines.	Discusses ways to display metric data for analysis: • Energy and Currency o Monthly totals (tabular) o Monthly daily averages (graphical) o Monthly values o Annual totals o Peak day in billing period (graphical) o Graphs that show deviation across points • Power o Monthly values (tabular or graphical) o Annual maximum of monthly values (can show separated by heating and cooling season, include date and time of peak) • Temperature o Monthly and annual averages, CDD, HDD

[8] Note whether or not the study makes recommendations for key metrics to track to maintain performance (not just a list of which metrics *could* be tracked). Also note whether or not the study outlines how a facility can determine which metrics are best to track for their situation. Note if any metrics are more pertinent to certain stakeholders.
[9] Note whether or not the study outlines how to establish benchmarks and/or baselines.
[10] Note whether or not the study indicates how the metrics data can be *used* (not just viewed) to maintain building performance. I.e., who acts on the data / analysis? What's the process?

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
2	High-Performance Commercial Building Systems Program: Standardized Building Performance Metrics; Robert Hitchcock; 2002	Reviews and summarizes the various metrics presented in: US DOE High-Performance Buildings Metrics Project, ASHRAE Standard 105, Laboratories for the 21st Century, and a case Study of the Oakland Administrative Building. The report does not indicate which metrics are the key ones to track, nor does it give recommendations for how a facility can determine which metrics are best to track for their situation. Summarizes metrics from these studies in easy to read tabular format.	Recommends several benchmarks: • The building energy model, from the design phase, serves as a baseline and informs commissioning. • During commissioning the initial metric data are updated to create an as-built benchmark. • Through the building's life data are archived to keep a running record for use in comparisons.	• Discusses ways to collect and display data for analysis o Collect data from BAS and other sources. o Aggregate data to show specification, tracking, and visualization of performance objectives. o Statistical web tools can be used for assessing whole building energy use intensity. • Discusses prototype software, Metracker o Aggregates data from different sources to show the specification, tracking, and visualization of performance objectives o Tool shows data as bar charts, 2-D XY charts, and time series and frequency distributions.
3	A Specifications Guide for Performance Monitoring Systems; Kenneth Gillespie, Philip Haves, Robert Hitchcock, Joseph Deringer, Kris Kinney; 2007	Recommends metrics based on a three-tier scale (basic, intermediate, and advanced). The level of detail to choose is based on: the number of buildings, system type (simple built up systems or more complex arrangements), owner's desired level of detail and sophistication. The building(s) should start with simple metrics and slowly add more complex metrics as operations ability improves. Provides list of metrics, points, and describes calculation methodologies. Detailed descriptions of the metrics are given in the appendix. A project should be properly scoped to ensure that the proper points and metrics are chosen as well as the necessary accuracy and data management is provided.	NA	• Need to have strong data management and graphical display capabilities. A system should include: "unique point names, animation and hot links, defined data tables, trend plots with multiple X and Y axes scales, group trend plots, multiple group trend plots on a single screen, special plot types: X-Y, carpet, load frequency distributions." • Mentions many display options and includes examples in the appendices. Describes an open source program, VizTool, to "graph building performance information from different data sources." • Discusses the use of an upgraded DDC vs. EIS. A DDC may be limited by the available bandwith, storage capability, and database type. DDC systems can only generate X-Y plots. EIS systems can remedy some of these shortcomings. • Points should be carefully named • The performance monitoring system will need to be commissioned to ensure proper function and accuracy. • Relevant building staff, contractors, and tenants should be trained in accessing, using, and making changes to the DDC/EIS as applicable. • Provides an Excel based tool to acquire data from WebCTRL.

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
4	Building Energy Information Systems: State of the Technology and User Case Studies; Mary Ann Piette, Jessica Granderson, Girish Ghatikar, Phil Price; 2009	NA	Bin Method: Date is binned based on parameters such as "outdoor air temperature, time of week, relative humidity," etc. Performance is predicted based on average of other points in the bin. Another option is to weight binned data toward more similar conditions. Neural Networks: Building performance is predicted based on various inputs using a mathematical model that "learns" from historical data.	NA
5	Metering Best Practices: A Guide to Achieving Utility Resource Efficiency; G. Sullivan, R. Pugh, W. Hunt; 2007	NA	NA	NA

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
6	Specification and Implementation of IFC Based Performance Metrics to Support Building Life Cycle Assessment of Hybrid Energy Systems; James O'Donnell, Elmer Morrissey, Marcus Keane, Vladimir Bazjanac; 2004	This paper expands on Federdspiel's work using model-based benchmarking and an effectiveness ratio. It proposes two performance ratios: • The idealized effectiveness ratio, which is the benchmark metric value over the measured metric. • Performance Effectiveness Ratio, which is the simulated metric over the measured metric. As this report includes a comparison to calibrated model results it suggests that some metrics be chosen to facilitate model calibration. It is suggested that metrics be limited to clear and concise sets to ease industry adoption. A performance metric must:" • Measure, reflect or significantly influence a particular performance objective; • Be useful across the entire life cycle of a building; • Be either predictable or measurable at various stages of the building life cycle; • Be limited to a concise set of data that are easy enough to collect but robust enough to emulate the objectives in their entirety." One should only use one metric for each performance objective to avoid confusion in the BIM. Steps to programming: 1) Determine objectives in consult with the architect and engineer 2) Reduce objectives to an appropriate hierarchy 3) Determine a metric that represents each objective	Benchmarks may be based on building codes or manufacturers' equipment catalogs. Additionally, building energy simulation programs may be used as points of comparison. A code compliant model may serve as a benchmark while a calibrated model can be used to calculate the performance effectiveness ratio.	NA

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
7	Strategies for Energy Benchmarking In Cleanrooms and Laboratory-Type Facilities; Dale Sartor, Mary Ann Piette, William Tschudi, Stephan Fork; 2000	A hierarchical approach should be taken to measurements and metrics. Metrics should start at a higher level (whole building) and build to more specific detailed information about systems. Whole building data may be misleading. Describes 7 levels of metrics: • Gross Annual (ex energy/area) • Additional Annual and HVAC Sizing (ex energy/capacity) • Add monthly data and weather normalization (baseload, energy/HDD) • Refined with hourly data • Refined with disaggregated end-use data • Refined with disaggregated hourly end-use data • Other Disaggregated data allows for comparison across many buildings, but can be expensive to obtain.	Comparison options may include: • One type of system to a similar or different system that provides the same benefit • Component performance to specifications • Industry or company-wide benchmarks or best practices Mentions weather normalization as important to some facilities. Statistical comparisons and point based rating systems focus on whole building comparisons to large data sets of other buildings. Discusses effectiveness metrics (modeled bench mark energy use over actual). Allows for comparison between different buildings. In this case uses a specific modeling tool, but this could be applied to other models. Discusses the use of metrics, but benchmark discussion is limited to stating that disaggregated data can be used to compare different buildings. Data could be compared against engineering rules-of-thumb and best practices (tons/cfm, cfm/ft2, etc.).	Discusses the possibility of using a hierarchical tool to compare metrics across different buildings. The tool would start with a whole building metric and then narrow down to equipment specific metrics to identify problem areas.

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
8	Managing Energy and Comfort; Steve Tom; 2008	Since it is hard to track comfort this article suggest that each building establish a comfort index to express zone comfort. The building would need to arbitrarily establish scores for various conditions. For example, if the building only measured temperature it may give zones between 72 and 78F a perfect score of 100 while zones that are 79-80 and 70-71F would receive a score of 90 and so on. The score is arbitrary but provides a convenient means to track comfort in the building. Additional scores can be developed for combinations of temperature, CO_2, and humidity.	NA	This metric can be used to provide baseline data for building performance or to benchmark against other buildings in a portfolio that use the same index definitions.
9	Quantification Methods of Technical Building Performance; Godfried Augenbroe, Ceol-Soo Park; 2005	All of the metrics discussed are recommended and included in the toolkit. Energy: The study suggests that the Dutch Energy Performance Norm (NEN 2916) be used to quantify energy us. Lighting: Energy efficiency (energy/area-year), efficacy (lumens/watt), and daylight autonomy. Other light indicators include view to outside, task lighting and visual comfort. Thermal Comfort: Includes metrics related to air diffusion, thermal radiation, cold draft caused by glazing, occupant variation, zoning, and system capacity and response time. Maintenance: Includes metrics related to efficiency, business organization, failure frequency, and policy.	NA	Metrics will be monitored with the web-based toolkit. Details are not provided.

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
10	Energy Efficiency Benchmarks and the Performance of LEED Rated Buildings for Information Technology Facilities in Bangalore India; Ashwin Sabapathy, Santhosha Ragavan, Mhima Vijendra, Anjana Nataraja; 2010	NA	The paper focused on benchmarking buildings using an Energy Performance Index (similar to EUI) and an Annual Average hourly Energy Performance Index (AAhEPI). The work, using several benchmarking studies as a foundation, explored normalizing the indexes for each facility based on age, years of occupancy, ownership, area, employment density, operating hours, indoor temperature setpoint, occupant awareness, whether an energy audit had been done and implemented, power factor, chiller type, occupancy based lighting, illuminance based lighting, temperature based HVAC controls, VFDs, and HVAC compressor type. They found significant variables to be operating hours, area, occupant density, and the presence of VFDs. Other papers cited in the study found significant factors to include occupant density, number of computers, number of operating hours, and whether is the building is owner occupied.	NA

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
11	Scheme for Star Rating for Buildings – BPO; Bureau of Energy Efficiency, Ministry of Power, Government of India; 2009	NA	Buildings are benchmarked on a Average hourly Energy Performance Index (AAhEPI) which is equivalent to EUI / (daily hours of operation x weekly days of operation x 52)	NA
12	Building Cost and Performance Measurement Data; Kim Fowler, Beverly Dyer; 2004	Metrics recommended to compare the performance of facilities include: • Site gas and electric energy per area, total energy cost per area • Monthly source energy production and emissions • Peak demand • Maintenance issues including cost, hours, and number of requests • IEQ measured with CBE survey rating, absentees per occupant year, and turnover per year.	NA	NA
13	Benchmarking the Performance of Building Energy Management Using Data Envelopment Analysis; Wen-Shing Lee, Kuei-Peng Lee; 2009	NA	Benchmarked building energy use should seek to reveal the technical efficiency of the building so that comparisons can indicate building management performance. For a case study in Taiwan technical efficiency was calculated using building area, occupancy and climate-adjusted energy use. The techniques employed are too complex for this study, but are worth noting for future work.	NA

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
14	Advanced Metering and Energy Information Systems; New Buildings Institute; 2009	Metrics can be normalized against degree days or average temperature data to allow for easier comparison. An energy signature can be created by plotting EUI against mean monthly temperature. Multi-variable change point regression (MVR) models can be used to normalize energy use data for different variables. The variables that MVR uses are building specific and can point to certain problem areas in the building. Key performance indicators are chiller performance (kW/ton) and boiler efficiency (BTU/BTU). A figure showing expected kW/ton values for different building types is presented.	Portfolios of buildings can be tracked using that EUI. Benchmarking must make comparisons across comparable buildings. Comparable buildings are defined to have similar climate and activity (schedules, plug loads) energy use ENERGY STAR and Cal-Arch are available options. Some energy management software tools can automatically upload data to ENERGY STAR Portfolio Tracker.	The EIS may be installed by the owner, a service provider, or a utility. The paper discusses the differences between an owner installed and utility installed system.
15	Specification of an Information Delivery Tool to Support Optimal Holistic Environmental and Energy Management in Buildings; James O'Donnell, Marcus Keane, Vladimir Bazjanac; 2008	NA	Normative comparisons of building energy use can be made against CIBSE Guide F, ENERGY STAR, and Dutch NEN 2916. It also, citing Federspiel, cautions that each building in a data set is unique and that all of them might be inefficient.	NA

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
16	Roles of Quantified Expressions of Building Performance Assessment in Facility Procurement and Management; Debajoyti Pati, Cheol-Soo Park, and Godfried Augenbroe; 2009	Indicators are broken into two categories: hard indicators (indicators backed by objective science) and soft indicators (indicators backed by 'less objective cultural and personal factors, and subjective interpretations'). The indicators are discussed with a focus on predicting performance and facilitating the design process. Comfort metrics could be expressed in terms of the number of hours that a temperature setting is not met or using predictive mean vote (PMV). Performance indicators cited are those from the "GSA Building Performance Assessment Toolkit" (see Article #9). Calculation details are provided in the report. Hard indicators (above) are considered to be static with time, as they are predictive of building performance when designed. Post occupancy evaluation (POE) is used to quantify soft indicators. POE identifies mismatch between user needs and those provided. POE data for courthouses was evaluated to determine a variety of predictive indicators. Their specificity, complexity, and role in prediction as opposed to measurement render them outside of the scope of this study. Regular POEs can help structure facility management dialogue.	NA	The performance indicators are designed to present a simplified method that facilitates dialogue between stakeholders, but should not supplant more sophisticated measures.

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
17	Building Energy Use Intensity; Kent Peterson and Hugh Crowther; 2010	This paper focused on the energy use intensity metric and made some pertinent observations about how to calculate it. Definitions of terms used in the calculation can have a large impact on the final EUI. The article cautions users to be careful about how they define EUI for their building and how their benchmark may define it. Notes internal and external factors that impact building energy use include weather, occupancy schedules, maintenance, occupancy rates, plug loads, and others. Depending on the what the EUI term will be used for the building area might be calculated based on gross building area, conditioned building area, or occupied buildings area. The decision about which term to use will be based on the standards for the data that the user is comparing to. Note if the EUI definition includes parking garages then two otherwise identical buildings would have very different EUIs. Some building types may consider different denominators, such as the number of occupants or power use effectiveness in data centers. Power use effectiveness is the power that enters the data center over the power used to run computers. The energy term can also be calculated in different ways such as source or site and energy content or energy cost. Site energy would usually include gas, electric, and energy purchased from central sources. Note that using site energy could make electric resistance heating (COP=1) look better than purchased hot water, which is an undesirable outcome. Calculating EUI with source energy is complicated by the use of site-to-source multipliers that may not account for variations between regions, time-of-day, and generation mixture. Energy cost could be used in lieu source energy, but inconsistent rates make this difficult.		

#	Title, author, year	Performance Metrics Discussed, Recommended, and Selection Process[8]	Establishing Benchmarks and Baselines[9]	Monitoring of Metrics to Maintain Performance[10]
18	ASHRAE Standard 105: Standard Measures of Measuring Expressing, and Comparing Building Energy Performace; ASHRAE; 2007	Building energy use intensity is specified to use gross floor area and calculates total and net energy indices as well as a net cost index. Additional expressions (normalizing factors) for energy performance are: Full time equivalent workers/students Number of licensed hospital beds Food service seating capacity Number of PCs Weekly hours of operation Annual months of operation Computer center area or annual average energy/area Percent gross area heated or cooled HDD or CDD Parking space Natatorium space Annual peak electric demand Electricity generation capacity Annual electric generation		
19	Action Oriented Benchmarking: Concepts and Tools; Evan Mills, Paul Matthew, and Mary Ann Piette; 2008	NA	NA	NA
20	Action Oriented Benchmarking; Paul Matthew, Evan Mills, Noman Bourassa, and Martha Brook; 2008	NA	NA	NA
21	ENERGY STAR Performance Rating Technical Methodology; 2010	NA	NA	NA

8.3 Table of Metrics

The following table shows all of the metrics considered in the study.

System Type	Sub-system	Metric	Units
Whole Building	NA	Energy Use	kBtu / ft2-yr
Whole Building	NA	Energy Use	KBtu / yr
Whole Building	NA	Energy Use	KBtu / ft2
Whole Building	NA	Energy Use	kBtu / annual operating hours-ft2-yr
Whole Building	Electric	Energy Use	kWh / ft2-yr
Whole Building	Electric	Energy Use	kWh / ft2
Whole Building	Gas	Energy Use	therms / ft2-yr
Whole Building	Gas	Natural Gas Heat Rate	therms / hr
Whole Building	Electric	Utility Cost	$ / ft2-yr
Whole Building	Gas	Utility Cost	$ / ft2-yr
Whole Building	NA	Total Utility Cost	$ / ft2-yr
Whole Building	NA	Energy Use Cost (excluding demand)	$ / ft2-yr
Whole Building	Electric	Electric Demand - Peak	kW / ft2-month
Whole Building	Electric	Electric Demand - Peak	kW / ft2
Whole Building	Electric	Electric Demand Cost	$ / ft2-month
Whole Building	Electric	Net facility load factor	kW(avg) / kW(peak)
Whole Building	Electric	Load Factor	kWh / kW
Whole Building	NA	Atmospheric emissions	ton / ft2-yr
Whole Building	NA	Atmospheric emissions	$ / ft2-yr
Whole Building	NA	Energy effectiveness	Idealized Btu / Actual Btu*100
Whole Building	NA	Building purchased energy cost intensity	Currency / ft2-yr
HVAC	Heating	Energy Use	therms / ft2-yr
HVAC	Heating	Energy Use Cost	$ / ft2-yr
HVAC	Heating	Electric Demand - Peak	kW / ft2-month
HVAC	Heating	Electric Demand Cost - Peak	$ / ft2-month
HVAC	Heating	Total boiler output	kBtu / hr
HVAC	Heating	Boiler efficiency	therms(out) / therms(in)
HVAC	Heating	Heating Plant Efficiency	[Btu / h(out)] / [Btu / h(in)]
HVAC	Cooling	Energy Use	kWh / ft2-yr
HVAC	Cooling	Energy Use Cost	$ / ft2-yr
HVAC	Cooling	Electric Demand - Peak	kW / ft2-month
HVAC	Cooling	Electric Demand - Peak	kBtu / hr-ft2
HVAC	Cooling	Electric Demand - Peak tons	tons / ft2

System Type	Sub-system	Metric	Units
HVAC	Cooling	Electric Demand Cost - Peak	$ / ft2-month
HVAC	Cooling	Electric Demand Cost - Peak	$ / ft2-month
HVAC	Cooling	Electric Demand efficiency	kW / ton
HVAC	Cooling	Chiller efficiency	kW / ton
HVAC	Cooling	Cooling Plant Efficiency	kW / ton
HVAC	Ventilation	Energy Use Cost	$ / ft2-yr
HVAC	Ventilation	Energy Use	kBtu / ft2-yr
HVAC	Ventilation	Electric Demand - Peak	kW / cfm
HVAC	Ventilation	Outside air damper fraction	% actual / % expected
HVAC	Ventilation	Outside air ventilation	OA cfm / person
HVAC	Ventilation	Air handler specific power	kW / cfm
HVAC	Ventilation	Total air handler specific power	kW / cfm
HVAC	Ventilation	Average daily total air handler system specific power	kW / cfm
HVAC	Fans and pumps	Energy Use	kWh / ft2-yr
HVAC	Fans and pumps	Energy Use	kBtu / yr
HVAC	Heat HVAC + common aux	Energy Use	kBtu / ft2-yr
HVAC	Cool HVAC + common aux	Energy Use	kBtu / ft2-yr
HVAC	HVAC + common aux	Energy Use	kBtu / ft2-yr
HVAC	HVAC + common aux	Energy Use	kBtu / yr
Lighting	NA	Energy Use	kWh / ft2-yr
Lighting	NA	Energy Use	kBtu / yr
Lighting	NA	Energy Use	kBtu / ft2-yr
Lighting	NA	Energy Use Cost	$ / ft2-yr
Lighting	NA	Electric Demand - Peak	kW / ft2-month
Lighting	NA	Electric Demand - Peak	W / ft2
Lighting	Exterior	Energy Use	kWh / ft2-yr
Lighting	Interior	Energy Use	kWh / ft2-yr
Lighting	Interior - Daylit Zones	Energy Use	kWh / ft2-yr
Lighting	Interior - Non-Daylit Zones	Energy Use	kWh / yr
Lighting	Interior	Electric Light Reduction Ratio	[$kWh_{daylit\ area}$ / yr-ft2] / [$kWh_{non\text{-}daylit\ area}$ / yr-ft2]
Whole Building	Plug Loads	Energy Use	kWh / ft2-yr
Whole Building	Plug Loads	Energy Use	kBtu / ft2-yr
Whole Building	Plug Loads	Energy Use Cost	$ / ft2-yr
Whole Building	Plug Loads	Electric Demand - Peak	kW / ft2
Whole Building	People Movers	Energy Use	kWh / ft2-yr
Whole Building	People Movers	Energy Use	kWh / yr

System Type	Sub-system	Metric	Units
Whole Building	People Movers	Energy Use Cost	$ / ft2-yr
Whole Building	People Movers	Electric Demand - Peak	kW / ft2
Whole Building	Domestic Hot Water	Energy Use	kBtu / ft2-yr
Whole Building	Domestic Hot Water	Energy Use	kBtu / yr
Whole Building	Domestic Hot Water	Energy Use Cost	$ / ft2-yr
Whole Building	Domestic Hot Water	Electric Demand - Peak	kW / ft2
Whole Building	Process Loads	Process Loads Energy Use	kBtu / ft2-yr
Whole Building	Process Loads	Process Loads Energy Use	kBtu/ yr
Whole Building	Process Loads	Process Loads Energy Use Cost	$ / ft2-yr
Whole Building	Process Loads	Electric Demand - Peak	kW / ft2
Whole Building	Miscellaneous Equipment	Misc. Eqpt. Energy Use	kWh / ft2-yr
Whole Building	Miscellaneous Equipment	Misc. Eqpt. Energy Use	kWh / yr
Whole Building	Miscellaneous Equipment	Misc. Eqpt. Energy Use Cost	$ / ft2-yr
Whole Building	Miscellaneous Equipment	Electric Demand - Peak	kW / ft2
Whole Building	Comfort	% Hours uncomfortable	% hours outside of space temperature range
Whole Building	Comfort	Comfort Metric	Average comfort index (0-100)
Whole Building	Comfort	Comfort	# sick absences / occupant-yr-ft2
Whole Building	NA	Maintenance	$ spent on maint / yr
Whole Building	NA	Maintenance	hrs spent on maint / yr
Whole Building	NA	Maintenance	# maint requests (by type) / yr
Whole Building	Domestic Water	Consumption	ft3 / ft2-yr