Key Performance Indicators

Final Report on:
Key Performance Indicators – Field Metering Study and Energy Performance Feedback

PIER Program: Evidence-based Design and Operations

Prepared for: California Energy Commission
Prepared by: New Buildings Institute (NBI)

The CEC is in the process of completing the final review of this report
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ABSTRACT

This report describes New Buildings Institute’s (NBI) investigation of metered key performance indicators (KPI) for commercial building energy use. These are indicators that can be observed or benchmarked using more detailed system-level meter data beyond whole-building energy data. This is the last stage of work that began with applying a whole-building approach for energy-use feedback including NBI’s monthly FirstView™ analysis which drives the greatest possible guidance from readily available monthly energy bills. Subsequent stages used more time- and labor-intensive onsite audits, along with computer modeling, to supplement the broad whole building findings. This report summarizes the installation of additional system metering downstream of the whole-building meters to investigate what KPIs can be observed and benchmarked, what they indicate, and how energy performance reviews can be enhanced while still using only limited additional metering.

The report describes the results from two office buildings outfitted with system-level metering to calculate KPIs. Designers are the primary audience, followed by operators and occupants. Where possible, KPIs were benchmarked using data from NBI’s building performance database to expand the comparisons.

The findings show that calculated system-level KPIs can reveal superior or inferior performance of certain aspects of design, operations and occupant behaviors. These KPIs can also be used to ensure that buildings compared using whole-building methods are similar in their design, operations and occupancy to improve the reliability of conclusions. Since the definition of each ‘system’ is crucial to the usefulness of the KPIs, or any other system-level metrics, the paper provides those used for the research and highlights the need for coordination among policymakers and practitioners on consistent definitions of metering, application and performance metrics. The report includes potential market intersection pathways for this useful set of system-level KPIs within a broader scope of indicators and building performance assessments.

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TABLE OF CONTENTS

1. Introduction .......................................................................................................................... 1

2. Driving from Whole-Building to System Meter Analysis ....................................................... 2

   2.1. Description of Analysis Methods and Meter Level ......................................................... 3

      2.1.1. Whole-Building EUI Analysis .............................................................................. 3

      2.1.2. FirstView Analytics ............................................................................................ 4

      2.1.3. System-Level KPI Analysis ................................................................................... 5

      2.1.4. Site Visits and Sensitivity Analysis ....................................................................... 6

3. Project Sites for System-Level KPI Development ................................................................. 6

   3.1. Oakland Office ............................................................................................................... 7

   3.2. Vancouver Office ......................................................................................................... 7

4. System-Level Metering, Capabilities and Definitions ....................................................... 8

   4.1. Whole-Building Electricity .......................................................................................... 10

      4.1.1. Whole Building: On-Site/Renewable Electricity Generation ............................... 10

   4.2. Lighting Electricity ....................................................................................................... 10

   4.3. Plug Load Electricity .................................................................................................... 10

   4.4. Direct Load Electricity ................................................................................................. 11

   4.5. Data Center Electricity ................................................................................................. 11

   4.6. HVAC and Net Electricity ............................................................................................ 11

   4.7. Whole-Building Gas ..................................................................................................... 12

5. System-Level Key Performance Indicator Results ............................................................ 12

   5.1. General Site Results ..................................................................................................... 12

   5.2. Design: Metered KPIs .................................................................................................. 13

      5.2.1. Design: Schedule Visualized System EUIs ............................................................. 14

      5.2.2. Design: Occupancy Stability Indicator ................................................................. 16

      5.2.3. Design: Occupant Energy Usage Indicator ............................................................ 17

      5.2.4. Design: Design and Operations versus Occupants Indicator ............................. 17

      5.2.5. Design: Daylight Effectiveness Indicator ............................................................... 19

      5.2.6. Design: Overall Lighting Design Indicators ............................................................ 20

      5.2.7. Design: Lighting and Plug Load Design Equivalence Indicator ........................... 21

      5.2.8. Design: HVAC and Net Electric Base Load Indicator .......................................... 22

      5.2.9. Design: Operational Consistency Indicator .............................................................. 23

   5.3. Operations: Metered KPIs ............................................................................................. 24

      5.3.1. Operations: Operational Schedule Consistency Indicator ...................................... 25

      5.3.2. Operations: Lighting and Common Area Indicators .............................................. 26

      5.3.3. Operations: Daylight Controls Effectiveness .......................................................... 26

      5.3.4. Operations: HVAC + Net Electric Usage on Unoccupied Days ............................. 27

      5.3.5. Operations: Operational Stability Indicator ............................................................ 28

   5.4. Occupants: Metered KPIs ............................................................................................. 29

      5.4.1. Occupants: Plug Load Performance Indicator ....................................................... 29

      5.4.2. Occupants: Lighting Performance Indicator ............................................................ 30

6. Site Conclusions .................................................................................................................... 30

7. Research summary ................................................................................................................ 32

   7.1. Whole Building Metrics ............................................................................................... 33

   7.2. A FirstView of Performance .......................................................................................... 33
7.3. System-level Metered KPIs .................................................................................................................. 34
  7.3.1. Overview of Submetering Issues ................................................................................................. 34
  7.3.2. Design: System-level KPIs ........................................................................................................... 35
  7.3.3. Operations: System-level KPIs ..................................................................................................... 35
  7.3.4. Occupants: System-level KPIs ..................................................................................................... 36
7.4. Expansion of System-level Metered KPIs .......................................................................................... 36
8. Market pathways........................................................................................................................................... 37
  8.1. Market Use ......................................................................................................................................... 37
  8.2. System-Level Meters and Design for Meterability (DFM) ................................................................. 38
9. Next Steps.................................................................................................................................................. 39
10. Appendix ............................................................................................................................................... 1
    A. Terminology and Metrics..................................................................................................................... 1
    B. References.......................................................................................................................................... 1

LIST OF FIGURES

Figure 1 Levels of Metering and Analysis Progressing from Whole Building to Systems ................. 3
Figure 2 Whole Building Annual Benchmarks for Oakland Office: National (Energy Star) and California (CEUS) ................................................................................................................. 4
Figure 3 FirstView Results Example for the Oakland Office .................................................................. 5
Figure 4 An Example of a System-Level KPI the “Schedule Visualized EUI Plot” ......................... 6
Figure 5 NBI System Diagram for the Two Sites .................................................................................. 9
Figure 6 Schedule Visualized System EUIs ....................................................................................... 15
Figure 7 A Plot that Demonstrates the Underlying Data in the Occupancy Stability Indicator .......... 16
Figure 8 The Metrics of Annual EUI Grouped to Indicate Design and Operations Versus Occupant Contributions for Each Office ................................................................. 18
Figure 9 Co-plotting Lighting Density and Night Length to Demonstrate the Daylight Effectiveness Indicator ........................................................................................................................................... 19
Figure 10 Lighting Metrics for Each Site Used as Overall Lighting Design Indicators ....................... 20
Figure 11 Active/Inactive Power Density Plots .................................................................................. 22
Figure 12 HVAC and Net Electric Monthly Energy Signature for Both Sites .................................... 22
Figure 13 HVAC and Net Electric System Monthly Energy Signatures ............................................ 23
Figure 14 The Lighting Occupied Energy Usage Rate Density and Night Lengths for Oakland ........... 27
Figure 15 Max Deviation Plot for the Oakland Office Used to Derive the Unoccupied Days Operation Indicator .................................................................................................................... 28
Figure 16 Co-plotted Data Underlying the Operational Stability Indicator for Both Sites ................. 29
LIST OF TABLES

Table 1  Summary of Stages in the KPI Project ................................................................. 1
Table 2: Important Building Attributes Per Site .......................................................... 7
Table 3  Comparing General EUIs to References ......................................................... 12
Table 4  Designers: 9 KPIs .............................................................................................. 13
Table 5  Annual System Energy Totals for Each Site ...................................................... 14
Table 6  Results of the Occupancy Stability Indicator ................................................... 16
Table 7  Summary of Metrics Used in the Occupant Usage Indicators ............................ 17
Table 8  Metrics for the Design/Operations and Occupant Indicator ............................. 18
Table 9  Design/Operations Versus Occupant Indicators for Both Sites and NBI Database Comparison for Similar Occupant EUIs ................................................................. 19
Table 10 Metrics for Daylight Effectiveness Indicator ..................................................... 19
Table 11 Metrics Used in the Overall Lighting Design Indicator ...................................... 20
Table 12 Active and Inactive Power Densities .................................................................. 21
Table 13 HVAC and Net Electric Base Load Comparison ................................................ 23
Table 14 Operational Consistency Indicator conclusions for both sites ......................... 24
Table 15 Operators: 5 KPIs ............................................................................................... 24
Table 16 Lighting, Plug Load, and HVAC and Net Electric Metrics Used as Occupant and Schedule Indicators .............................................................................................. 25
Table 17 Operator Lighting and Common Area Indicator Metrics ..................................... 26
Table 18 Occupied Energy Usage Rate Density for Oakland .......................................... 26
Table 19 Summary of the Unoccupied Days Operation Indicator for Both Sites ............... 27
Table 20 Operational HVAC and Net Electric Indicator for Three Months for Each Site .... 28
Table 21 Occupants: 2 KPIs ............................................................................................. 29
Table 22 Plug Metric Power Densities for Both Sites in One Month ................................. 30
Table 23 Occupant Lighting Metrics for Both Sites for One Month ................................. 30
Table 24 Design KPI Summary for Oakland and Vancouver ............................................ 31
1. INTRODUCTION

NBI conducted this research under Task 2.4 of the PIER Evidence-based Design and Operations Program to identify key performance indicators (KPI) representing major and consistent variables affecting building energy use. The research intent was to distinguish a set of KPIs that provide intuitive and impactful feedback from a minimum of metering points and develop a feedback format that is understandable and actionable.

In the preceding tasks we examined KPIs for commercial building energy performance using different methods: whole-building energy analysis, detailed sensitivity analysis modeling, and site visits and assessments. Table 1 shows a summary of this work. In each stage we gathered a greater level of detail, reducing the number of buildings from the initial analysis as the depth of analysis increased.

Table 1 Summary of Stages in the KPI Project

<table>
<thead>
<tr>
<th>Task</th>
<th>Analysis Type</th>
<th>Methods</th>
<th>Number of buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous Project Research:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Whole Building Energy Analysis</td>
<td>FirstView; Portfolio Manager</td>
<td>22</td>
</tr>
<tr>
<td>2.3</td>
<td>Site Visits</td>
<td>Owner Reports, Building Audits / Interviews</td>
<td>12</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Sensitivity Analysis</td>
<td>Energy modeling</td>
<td>n/a on bldg count: 28 energy features analyzed across 16 DOE climate zones (SF for CA)</td>
</tr>
<tr>
<td>This Report:</td>
<td>2.4.4 System Level KPIs</td>
<td>System metered analysis</td>
<td>2</td>
</tr>
</tbody>
</table>

Our conclusions from these earlier stages pointed to certain KPIs based on observations of commercial building attributes and the correlating monthly utility metered data or results of the sensitivity modeling. The current stage of work sought to use a greater level of detail through system-level metering on 2-4 buildings to expand the KPIs beyond whole-building metrics.

The report describes the results of the system-level metering in two office buildings: a 14,000 SF office in Oakland, California and a 5,500 SF office in Vancouver, Washington. NBI used gross square footage for analysis in both cases. The selection criteria was based on finding a suitable tenant with high performance systems in place, a good distribution between electric and fuel, and a suitable panel and metering points at the system level within the project budget. Although the design community considers it ‘good practice’ to disaggregate electric loads by system type (i.e. lighting, plug loads, HVAC), it remains common to have an intermingling of loads on shared circuits, resulting in many of the initial buildings requiring too many meters to realistically capture the defined system.

In a commercial building, the ‘system’ refers to an aggregate total of all usage, electric or fuel, by a particular class of equipment. Frequently used categories are plug loads, lighting and HVAC, with additional categories depending on the definer. We addressed this issue of defining system loads in Section 4. We collected system loads by installing submeters (advanced interval meters downstream of the main utility meter) at key points in the building where the system loads were aggregated.

---

1 The term “end use” is also sometimes used but we use “system” throughout this work.
The system-level KPIs in this stage of the project serve to inform the designers, operators and occupants and were looked at in two ways:

1. How do these KPIs directly inform designers, operators and occupants?
2. How do these KPIs help classify buildings for more accurate whole-building analysis?

As an example of item 2, Portfolio Manager and FirstView use monthly data which does not reveal how many hours per day the building is used or how much equipment is inside the building. Short-interval system-level data in theory can yield information about occupant schedule, amount of equipment and lighting, and overall what kinds of loads are in the building. This data can be used to ensure one is comparing “like-type” buildings when using whole-building analysis methods.

When looking at system-level KPIs to directly inform designers, operators or occupants, NBI focused on creating KPIs that could be benchmarked against other buildings, a design model, or compared against historical performance. We intentionally limited the detail of these KPIs to avoid replicating the functionality of more complex Energy Management Information Systems (EMS) that provide day-to-day feedback to building operators, or occupant dashboards that provide occupant feedback on usage. Instead, we sought to define KPIs that could be used in the absence of, or employed by, these platforms in addition to their highly specialized calculations to maintain operational performance.

As follow-on to this report, the graphics and narrative of the KPIs will be modified in market-centric presentation materials. These will be a part of the final stage of the research to develop feedback tools, methods and recommendations on building energy performance from the whole-building level through to KPIs.

To better understand the context of the research, we begin by describing how the analysis drives down through successive levels (i.e. whole building to system and potentially further to individual pieces of equipment) to enhance the performance conclusions for a particular building.

This report presents the research, findings and conclusions in the following sections:

1. Introduction
2. Driving from Whole-Building to System Meter Analysis
3. Project Sites for System Level KPI Development
4. System-Level Metering, Capabilities, and Definitions
5. System-Level Key Performance Indicator Results: Designer, Operator, Tenant
6. Site Conclusions
7. Summary and Market Pathways
8. Next Steps

2. DRIVING FROM WHOLE-BUILDING TO SYSTEM METER ANALYSIS

As shown in Table 1, NBI’s work under the PIER Evidence-based Design and Operations program has progressed from a low to a high level of detail to examine methods of summarizing useful findings of good or bad commercial building energy performance. NBI’s analysis has also progressed from whole-building analysis, using annual energy numbers, through the use of weather- and time-normalized analysis using the FirstView tool to peer past the whole-building meters into underlying heat transfer and
energy use. The system-level KPIs described below are the final stage but also seek to inform the higher level analysis.

The relationship of the various methods to one another and to market aspects of time and resources are shown in Figure 1.

**Figure 1 Levels of Metering and Analysis Progressing from Whole Building to Systems**

### 2.1. Description of Analysis Methods and Meter Level

The top-down approach to performance analysis begins with the whole-building annual benchmarks used in the initial stage of this PIER project. To display that continuum, this section presents the whole-building benchmarking for the Oakland office building that continued through to this KPI development stage.

#### 2.1.1. Whole-Building EUI Analysis

For the most basic benchmarks, a year’s worth of monthly energy bills was tested using EPA’s Energy Star tool, which provides a rating relative to the country’s existing building stock, adjusted to account for major impacts from climate and occupancy characteristics. The example case generated a rating of 84, well above the minimum of 75 required for an Energy Star label. Our initial reviews also benchmarked specifically against existing California office buildings, with performance ranges determined by the Energy IQ tool [LBNL, 2011] applied to California End Use Study (CEUS) data. Using this more local basis, this office’s EUI fell slightly below the median. These whole-building benchmarks are shown in Figure 2.
Clearly one limitation of this traditional benchmarking is that the ‘good’ or ‘bad’ determination depends greatly on the reference or peer group by which the benchmark is being determined. Even more limiting, these annual EUI benchmarks give no direction regarding which areas to pursue to improve building performance. A more analytic review of the monthly energy underlying the annual EUI total can help fill those gaps and more effectively point to specific areas worthy of more detailed investigation.

2.1.2. FirstView Analytics

Through this research NBI continued development of a monthly whole-building analysis tool (trademarked FirstView²) to provide building owners and operators actionable energy performance feedback from readily available billing and weather data. The tool generates a diagnostic physics-based analysis of energy consumption patterns, assessing performance characteristics in three broad categories: impact of physical and system characteristics, effectiveness of control operation, and characteristics of occupancy-related loads [Turner and Reichmuth, 2011]. Its automated diagnostic logic suggests specific performance areas that appear particularly effective or that may warrant investigation for possible savings. Examples include excessive reheat, poor heating or cooling efficiency, excessive ventilation or uncontrolled infiltration, unusually high plug loads and internal gains, etc. The tool also automates an estimate of the energy split by major end use based on the climate-normalized response of the building’s fuel usage.

Continuing with results for the Oakland office, FirstView’s automated analytics indicated:
- A high sensitivity to changes in temperature, suggesting excessive ventilation and/or a poorly insulated shell
- A relatively high gas baseload continuing throughout the summer
- Well-managed lighting and plug loads

Figure 3 shows four ways these results from the input of the monthly fuel use in FirstView can be displayed:

a) annual end use totals projected by the analysis
b) the automated analytics that represent performance indicators based on parameters in the tool
c) a temperature-based energy signature split by end use – filled plot
d) a temperature-based energy signature - trend lines for 12 months covering 2010 and 2011

Note that these end-use totals are derived by the FirstView model and do not represent the explicit system-level meter data referred to later in this paper.

2 FirstView was started in 2008 and has been jointly funded during development through EPA, USGBC, NBI, ERM and PIER.
From these FirstView results, and the results of the onsite visit, NBI sought to examine the system-level data from metering installed at this site and at another small office in Vancouver, Washington. The FirstView data is only compared to system-level data for the Oakland site.

2.1.3. System-Level KPI Analysis

NBI worked with system-level metering at the site to develop KPIs that would provide insights to designers, operators and occupants on how their actions may have impacted the building energy usage.

Installing submeters for energy tracking in commercial buildings, though far from common, is beginning to occur in newer projects. This trend is driven by the availability and affordability of equipment and also by a number of standards and guidelines (ASHRAE audit guidelines, M&V protocols, recent LEED NC and EBOM rating systems, etc.). However, the proliferation of submeters has progressed with no accepted framework to ensure comparable results from building to building. There is also no means to determine whether meters are being installed in ways that provide the most useful feedback in return for the costs incurred.
The term 'system level' is in common usage (though the term ‘end use’ is also used in some references to refer to this same level of energy usage aggregation); however, the definition of ‘system’ varies by project. There is no widely accepted framework for labeling a standard set of system definitions. Take a simple term like ‘lighting’ - there are gray areas: does this include parking lot lighting, common area, core and shell, tenant lighting? Emergency back-of-house lighting? Task lighting? Retail spaces?

Figure 4 An Example of a System-Level KPI the “Schedule Visualized EUI Plot”

Figure 4 shows an example of a system-level KPI derived for the Oakland office. In this example our intention was to show designers the annual energy contribution for each system. These are shown in the plot by the height of each section for plugs, lights, gas and HVAC including auxiliary equipment (labeled HVAC and Net Electric) along with the average hours per day (shown in the plot by the width of each section) that each system is in an ‘active’ state. This allows the designer to more clearly see how the building is being used and can be compared to the modeling assumptions. In Section 5 we describe this and other system-level KPI findings in detail.

2.1.4. Site Visits and Sensitivity Analysis

Along with the metered analysis of the site NBI conducted 12 site visits and a comprehensive prototype-based Sensitivity Analysis to provide additional KPI input. Summarized in other reports, these results were instrumental in guiding NBI in crafting the system-level KPIs. In particular we identified building parameters in the Sensitivity Testing that had great impact on the building energy use, such as plug loads, but that were not easily characterized in the site visits. This guided the system-level KPIs to also provide a role of assessing this unknown contribution more accurately rather than relying on subjective observations.

In summary, as we drove down from whole-building to system-meter level we tried to pull in all previous research to guide the derivation of useful and meaningful KPIs that represented a small but meaningful set. Some of these may not be useful to a widespread audience, but we felt a logical framework would provide a roadmap for industry collaboration. The results at the two project sites show more detailed system-level KPIs.

3. PROJECT SITES FOR SYSTEM-LEVEL KPI DEVELOPMENT

Two sites were selected for the research, a 14,000 SF office building located in Oakland, California, and a 5,500 SF office building located in Vancouver, Washington. We used gross square footage at each site.
The basis of the selection was driven first by access to the site and owner tolerance to allow for the multiple contractor visits. Additional criteria included the presence of high performance building systems and strategies in use, and review of the system wiring at the panel to assure the ability to install a small number of submeters to capture the system loads.

Meters were installed in 2010, and analysis continued through October 2011. Data analysis and results were conducted throughout the year.

### 3.1. Oakland Office

The Oakland office building is a 14,000 SF, two-story, concrete LEED Platinum renovation with a single owner/occupant. There are three gas-pack/DX Packaged Rooftop Units (PRTU) and one DX-only PRTU in a one-per-zone configuration with a Reliable Controls Building Automation System (BAS). Therma-Fuser™ diffusers manage zone balancing. Demand-controlled ventilation is enabled through a sensor in the return air and a wall sensor in one conference room. The building uses gas for service hot water (SHW) and heating. The envelope was designed for daylight, and the lighting system, controlled by manual zonal switches, has embedded daylight sensors that switch certain lights off when there is sufficient daylight. Plug loads are typical for a simple office space, and there is a large meeting space on the ground floor for public assembly and a server closet on the second floor. The building includes a 5.5kW nameplate PV system connected to the main distribution panel.

NBI used a NorthWrite data acquisition system with WattNode meters. Data was collected at 15-minute intervals from late 2010 through October 2011.

### 3.2. Vancouver Office

The Vancouver location is a 5,500 SF, single-story building occupied by a single tenant. There are two gas-pack/DX Packaged Rooftop Units (PRTU) in a one-per-zone configuration. Thermostats are wireless, utilizing a web-based interface that allows global control settings. A single conference room sensor provides Demand Controlled Ventilation (DCV). The building uses gas for heating and electric for all other end uses (including SHW). The structure is masonry with a wood-frame ceiling and four skylights above the main open office area. The lighting system uses manual zonal switches (no active daylight controls). At approximately 15 feet, the ceiling height is above average. Plug loads are as expected for an office, and the site has a small server closet for email and LAN storage.

NBI used a PowerMand data acquisition system with a DENT PowerScout 18 six-channel meter. Data was collected at 90-second intervals from late 2010 through October 2011.

Table 2 shows a summary of building attributes that were identified as important by the Sensitivity Analysis testing (identified by the Building Parameter Type) and determined during the site visits. Ideally, given a larger selection of buildings to compare, we would use these criteria to better define ‘like-type’ comparisons.

<table>
<thead>
<tr>
<th>Building Attribute</th>
<th>Vancouver, WA</th>
<th>Oakland, CA</th>
<th>Building Parameter Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation/Lower Floor Type</td>
<td>Slab-on-grade</td>
<td>Slab-on-grade</td>
<td>Thermal Mass</td>
</tr>
<tr>
<td>Construction Type</td>
<td>Masonry</td>
<td>Concrete</td>
<td>Thermal Mass</td>
</tr>
<tr>
<td>WWR - %</td>
<td>12</td>
<td>20</td>
<td>Glazing</td>
</tr>
<tr>
<td>Est. Avg. Wall Insulation – R</td>
<td>15</td>
<td>30</td>
<td>Envelope Insulation</td>
</tr>
</tbody>
</table>
### 4. SYSTEM-LEVEL METERING, CAPABILITIES AND DEFINITIONS

NBI used the two project sites to create definitions of building systems based on wiring design and lessons learned in metering other existing buildings, keeping in mind analysis methods such as FirstView. The definitions below were selected to represent a next step past the whole-building level and remain as broad as possible while still providing meaningful detail. NBI determined that ongoing discussion is needed to create widely accepted standards for system definitions, including detail on what end-use equipment should be included in which system, especially when considering different building use types.

Figure 5 shows a diagram of the system meter defined points used in this project. The sections below discuss each point in more detail. As a reminder, this level of analysis does not seek to preclude more detailed metering, such as chiller kW per ton, but rather serves as a framework for defining the system level as the next level of detail past whole building.
The dashed lines in Figure 5 indicate a meter point that would most likely be ‘virtual’, meaning that the reading is found by addition or subtraction of other physically metered points.

Today nearly all off-the-shelf electrical submeters, and many utility meters, are capable of storing or transmitting usage at least once per hour, thereby providing interval data as part of an Energy Information System. The analysis in this report is based on having at least hourly interval data for electricity at the whole-building level and at each system meter. Natural gas and other fuel meters are also frequently capable of interval measurements, though the intervals are generally less frequent due to greater installation expense and more doubts over cost versus benefit.

At the whole-building level interval, Advanced Meter Infrastructure (AMI), meters are becoming more and more common. The latest Federal Energy Regulatory Commission report [FERC 2011] shows that interval utility meters have a penetration of 13.4% nationwide with California seen as a leader in AMI installations. In PG&E territory for example, all residential and commercial customers now have AMI meters in place [Vasnaik, 2012].

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3 The general topic of meter and data acquisition system selection has been reviewed in several publications [NBI 2009], [PNNL 2005], [LBNL 2010].
4.1. Whole-Building Electricity

To successfully implement system-level KPI analysis, the whole-building electric measurement must be interval data and include all electrical energy use of the building and immediate site. It is important to understand the total loads on a whole building meter and ensure the ‘whole building’ definition includes just those uses and systems attributable to the occupants and building energy use. A common problem with whole-building analysis is the inclusion of large, unrelated electric loads from site activities which distorts a like-type comparison. NBI recommends these large unrelated loads be categorized in the Direct Load system (described below).

4.1.1. Whole Building: On-Site/Renewable Electricity Generation

Whole-building energy use should include the consumption of renewable energy to ensure the KPIs account for all site energy consumption. This may become complicated when the building is a net producer and the whole-building utility meter runs backwards, or in cogeneration when fuel is consumed to create electricity and waste heat used onsite.

The accounting of onsite energy generation and its impact on building energy use is a broad topic covered in more detail in other references. This definition is a broad catch-all to ensure that whole-building energy usage is properly accounted for by including any generation from onsite sources. If co-generation is used, the metering requirements can become quite extensive; metering strategies are discussed in some detail in NREL publications [Torcellini et al 2006].

Only the Oakland site included renewable energy generation (in the form of 5.5 kW of Photovoltaic panels). This was metered to arrive at the proper whole-building electrical usage.

4.2. Lighting Electricity

The lighting energy is ideally the total facility internal lighting energy that serves the occupants. Common area and exterior lighting, and any retail lighting that is not the primary building use (e.g. ground floor of a high-rise office) should be included in the HVAC and Net Electric system. This allows for a more direct measurement of the occupants’ direct lighting needs and excludes lights that operate outside the thermal envelope or serve common areas which relate more to the operator’s or owner’s responsibility.

In small commercial buildings the distinction between internal and external/common is difficult to discern. This was the case with the two KPI sites where the lighting definition includes all lights on separated lighting panel.

In larger buildings the electrical distribution is often subdivided for common area/core area lighting and/or egress emergency lighting or back of the house lighting. This can make it easier to measure internal occupant lighting energy, allowing the remainder to be included in HVAC and Net Electric system (described below).

4.3. Plug Load Electricity

In our analysis we rely heavily on the plug load to infer the behavior of occupants. Similar to lighting, there is a natural operator versus occupant advantage to separating plug loads into those that serve occupant spaces from those that serve common and exterior areas. Inclusion of possible large common area loads such as white goods (laundry and central kitchen equipment), auxiliary heating and unmetered common area retail space reduces the usefulness of the feedback and obscures the occupant schedule. Further, separation of occupant and non-occupant plug loads allows the responsible agent (i.e. occupant
or owner/operator) to have more direct feedback on measures to improve efficiency, especially in large buildings, and will benefit from having all the lighting and plug load that they can influence on one meter.

For designers, knowing occupant plug loads is important as this is an area of significant uncertainty when planning and modeling new construction projects. NBI research has shown that the annual energy usage of plug loads in office spaces is often three times that of lighting loads. Further increasing occupant plug loads are the growing numbers of server closets [Koomey 2009] - small installations of a few servers, switches and UPS equipment that may or may not have dedicated cooling equipment. The same report shows large data centers with dedicated cooling are also growing and NBI recommends these have separate metering as described in the Data Center system (described below).

As with the lighting system, since the two of the projects studied were small commercial buildings plug loads from all areas were included in the definition. Also, these spaces are offices; in other use types the logic of using plug loads as an occupancy indicator may need to be reexamined and the definition changed accordingly.

Both sites included a small server closet. The Oakland site used a temporary auxiliary 1.0 kW cooling system to augment the central HVAC system though the AC unit did not reject heat outside the building.

### 4.4. Direct Load Electricity

Direct load electricity represents an auxiliary category that could capture electric usage in buildings of very unusual use-types or mixed-mode situations such as first-floor retail or upper-floor tenant space. This ‘system’ may include plugs and lights, as well as HVAC if the situation warrants. Segregating this energy usage allows assessment of its impact on overall building energy use and provides feedback to the third-party entity responsible for its management.

### 4.5. Data Center Electricity

There is extensive activity regarding performance metrics for data centers, a rapidly growing use of electricity [EPA 2012], [Koomey 2009]. In the analysis of building energy signatures, and particularly with the FirstView tool, data centers can change the relationships of internal and external gains in dramatic ways that confuse analysis. EPA’s Portfolio Manager also separates analysis for buildings that report a data center; submetering for data centers will be a requirement of Energy Star in 2012.

When data centers are large, centralized, and have dedicated cooling via split HVAC systems, the data center and its accompanying HVAC should be metered in total as a separate system. While this may not be in line with current performance management practices in data centers, NBI found that it would facilitate thermal inverse modeling. Neither of the KPI sites had a data center installation that needed submetering by the definition above. Both sites did have server closets, and their electricity use was included in the plug load system.

### 4.6. HVAC and Net Electricity

The HVAC and Net Electric system measures what is left once plug loads, lighting, data center and direct loads are totaled and subtracted from whole-building electrical use. This includes all components used in the HVAC system, miscellaneous pumps, elevators and even common area lighting and plug loads that do not fall into the lighting or plug load categories described above, which we define as occupant lights and plugs.
The broadness of this system definition is deliberate and anticipates situations, especially existing buildings, where components of the HVAC system are widely distributed or are too numerous to easily meter in a handful of meter points. Also the breadth of the definition, along with restrictions on the lighting and plug load systems, allows for a high-level comparison of how the building uses energy relative to how the occupants use energy. There is a temptation to meter all aspects of the HVAC system (fans, pumps, RTUs, exhaust fans, etc.) to arrive at total HVAC electrical (and perhaps gas or fuel) usage, but in large built-up systems the number of meter points would be considerable. Further, benchmarking becomes more difficult given the more specific nature of the system definitions.

While the use of HVAC and Net as a catch-all category may be easier to implement in the field, more specific measure of heating and cooling outside simple BAS data could be useful. NBI considered using a sub-definition of the primary heating and cooling equipment - equipment like packaged rooftop units, larger RTUs for built-up systems, chillers, boilers (electric powered). This should be further examined in follow-on projects.

Because both KPI sites were small offices with packaged rooftop equipment and little or no common areas, they had relatively similar HVAC and Net definitions. One distinction was that the Vancouver office has an electric water heater, while the Oakland office uses gas. Gas water heat transfers the service hot water usage to the whole building gas system from the HVAC and Net Electric system.

4.7. Whole-Building Gas

This system consists of the whole-building gas or other fuel, preferably with interval data, consumed at the building or site. NBI wanted to acquire gas interval data at each site, but this was not possible due to utility meter and time constraints. Both sites instead used monthly utility meter gas data for KPI development.

In California commercial office buildings gas accounts for 25% of total building energy use on average4. Based on anecdotal feedback from building analysts, gas interval metering is not a high priority for energy management and consequently is rare. Since gas use is usually only associated with heating, and in some cases also with SHW, the cost may outweigh the benefit of interval metering.

5. SYSTEM-LEVEL KEY PERFORMANCE INDICATOR RESULTS

5.1. General Site Results

Table 3 shows the simple purchased and produced energy comparisons per building and also against published benchmark data from CEUS and CBECS. These benchmark comparisons suffer from the definition bias problem but are presented here to give some anchor of reference to put the buildings’ energy use in perspective.

<table>
<thead>
<tr>
<th>Whole Building Data</th>
<th>Annual EUI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vancouver</td>
</tr>
<tr>
<td>By Fuels</td>
<td>kBTU/ft²</td>
</tr>
<tr>
<td>Purchased Electric</td>
<td>11.9</td>
</tr>
</tbody>
</table>

---

4 Itron 2006 California Energy Use Survey
The Oakland site appears to outperform CBECs but not CEUS. The Vancouver site appears to meet the CBECs average though the underlying fuel data shows fundamental differences with electric and gas usage.

### 5.2. Design: Metered KPIs

Designers and asset raters need high-level feedback for a portfolio of buildings to track which individual building reflects a superior design. KPIs for designers should answer questions like “Is the design working well despite operations and occupant choices? Which part of the design in particular? Is the HVAC system I chose better than the one from the other building?”

To avoid being trapped in highly detailed findings that are hard to benchmark, these indicators examine long periods of time but at the same time leverage the underlying interval data to roll up useful trends.

Table 4 shows a summary of 10 Design KPIs derived by NBI, along with a brief explanation of purpose and target value. These indicators should be based on a full year of data, though less than a year’s worth can be used if careful methods are used to annualize the data.

These KPIs are like any other numerical calculation of energy usage in that they are usually only useful when placed in context of comparisons to expected or historical behavior. Broadly these comparisons are: (1) a large data set of similar buildings – benchmarking, (2) a private portfolio of similar buildings, (3) historical data and (4) design model expectations. We provide comparisons when data exists but this project seeks to explore a framework that hopefully will eventually lead to more data for comparisons.

Each indicator provides a piece of evidence. The intention is that they be used together as a set to make overall design determinations and then combined with other analysis like FirstView and non-metered building attributes to reveal a final assessment. (This combination is examined in the Site Conclusions).

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Purpose</th>
<th>Target Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Schedule Visualized Annual System Energy Use Index (EUI)</td>
<td>Quickly indicates what system is responsible for the most usage and what is its approximate schedule of typical activity</td>
<td>Verify in line with expected values from design or portfolio benchmarks. Ensure HVAC and Net Electric is not far outside lighting or plug load.</td>
</tr>
<tr>
<td>2 Occupancy Stability</td>
<td>The designer can see if occupancy changed during the year of performance.</td>
<td>Used as a check for other indicators to ensure that occupancy was not the cause of variations.</td>
</tr>
<tr>
<td>3 Occupant Usage</td>
<td>Provides more details and an assessment of how the occupant’s usage impacts the building.</td>
<td>Used as a check for other indicators and a way to assess the magnitude of occupant usage compared to benchmarks.</td>
</tr>
<tr>
<td>4 Design and Operations versus Occupants</td>
<td>Provides a simple numerical assessment of annual design and operations usage versus occupant</td>
<td>Strive to make the ratio of Design and Operations to Occupant Usage as small as possible or in line with high</td>
</tr>
</tbody>
</table>
These indicators will likely be used very infrequently by the designer, perhaps as an assessment made once the building has been occupied for a significant period of time, or perhaps a few times in the life of the building. Yet, they replace a complete void of building energy feedback to design teams.

Calculations of energy use over a period of time at a certain interval create metrics (defined in Appendix A) used in the indicators. Each of these 10 metrics are discussed and demonstrated below.

### 5.2.1. Design: Schedule Visualized System EUIs

NBI created the Schedule Normalized System EUI to allow designers to quickly see how each system is contributing to the overall EUI while also providing a visual indication of the schedule of each system. This addresses a weakness of benchmarks based on long intervals, such as annual periods for EUI or monthly data for energy signature/FirstView analysis, with which the usage schedule of the building is obscured. One building may have a high EUI but is used for twice as many hours per day as a comparable building with low EUI. This condition does not automatically represent poor performance from an operations or design standpoint. Short interval meter data allows for the evaluation of characteristics of the daily usage profile without examining the data in detail.

Table 5 shows the annual system EUI results for each site. Note the similarity in the lighting energy use but the much lower plug load and HVAC and net electric in Vancouver, yet the very high gas use in Vancouver.

**Table 5 Annual System Energy Totals for Each Site**

<table>
<thead>
<tr>
<th>System</th>
<th>Vancouver Office</th>
<th>Oakland Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>kBTU/ft²</td>
<td>kBTU/ft²</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>5.3</td>
<td>4.6</td>
</tr>
</tbody>
</table>
The schedule-visualized EUI, shown in Figure 5, quickly assesses the EUI contribution of each system while also examining the number of active hours per typical workday across a year. The determination of active status is made through a simple algorithm for active versus inactive [Reid et al 2006] based on hourly deviation from a baseline condition on non-holiday weekdays.

Figure 6 is a stacked chart where the schedule-visualized EUI of each system type is stacked on top until the total annual EUI is reached at the top. The active hours of each system type are then shown on the x-axis. Note that the overall area of each system has no meaning, only the height on y-axis which represents the contribution to EUI and the width on the x-axis which represent the average active hours. Since there was no interval data for the gas usage, the active hours are made equivalent to the HVAC and Net Electric.

Figure 6 shows the Oakland building may be occupied 12 hours per day, though the plug-load schedule infers there is significant use only 8 hours per day. One can see that even though the lighting has a longer schedule, the plug load is significantly larger. It is difficult to say if any aspect is unusual without comparisons, but the designer may get a quick feel for the use of the building in the context of the system usages.

The Vancouver site shows an obvious issue with gas usage, perhaps due to the low levels of lighting and plug load which customarily serve as internal gain to supplement heating. We know from the building attributes that the SHW is electric not gas. Note also the HVAC and Net electric seem small, and the schedule averages only 6 hours per workday.
5.2.2. Design: Occupancy Stability Indicator

In the absence of more direct measurements, plug loads are an important indicator as a proxy for occupancy, either as an assessment of occupancy magnitude or as a test in variation of occupancy in a given year. A designer cannot determine how much emphasis to place on results without first knowing if the performance data for a particular building is from a year with stable occupancy. NBI used the intensity and schedule of the plug load data for each site (as shown in Figure 7) to make a qualitative assessment of occupancy. The assessment is shown in Table 6 along with one of the plug load metrics for each site. (As a reminder, metric terminology is defined in detail in Appendix A.)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
<th>Oakland</th>
<th>Vancouver¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Plug Load Workday Energy Use Rate</td>
<td>W/SF</td>
<td>0.48</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Occupancy Stability Indicator</strong></td>
<td>-</td>
<td>Moderately Stable</td>
<td>Stable</td>
</tr>
</tbody>
</table>

¹ The Vancouver site uses a metric of average monthly lighting energy use density for data clarity

Lighting loads may also be considered a proxy for occupancy, though as was seen in Oakland, the building was regularly used after hours as a community meeting space, a use that would employ lighting but not much plug load use. In addition, after-hours cleaning often results in a lot of lighting with little actual occupancy. Lastly, many buildings are controlled by master sweep systems that do not reflect the actions and schedule of actual occupants.

For reference Figure 7 is a graphical representation of the underlying data used in the determination of occupancy at each site. The intention is to highlight any behavioral changes that may have impacted building energy use. The green line shows the average value of plug load workday use rate over the year while the blue diamonds show the monthly data. The red squares are plotted against the right side axis and show the average ‘active’ hours in each month.

This indicator shows that the magnitude of the plug loads (diamonds) in the Oakland office was decreasing slightly while the schedule hours (squares plotted on Right Y-axis) remained the same. This suggests occupancy was moderately stable, though this is a subjective assessment at this point; we decided there were no drastic changes (e.g., a large tenant moving out). The Vancouver office shows very stable behavior in schedule and plug load magnitude. These observations led to the qualitative assessments shown in Table 6.

![Figure 7 A Plot that Demonstrates the Underlying Data in the Occupancy Stability Indicator](image-url)
This indicator tells the designer the data represented stable or unstable occupancy; the next indicator establishes how the occupants use energy against other comparison cases.

5.2.3. Design: Occupant Energy Usage Indicator

The manner in which occupants use energy via plug loads can be expressed through metrics of performance to indicate how occupants are using energy relative to similar buildings. The occupant energy use directly impacts HVAC energy use by requiring more heat to be rejected but also serves as a partial proxy for the number of occupants in similar building use-types. The designer or owner can use this more detailed look to assess the success of the overall building energy usage in terms of occupant choices and also look at the energy usage of other systems relative to this occupant usage.

NBI calculated a plug load energy metric using protocols developed for the Office of the Future (OTF) project, an analysis and demonstration of high performance offices. We compared the OTF results to make a qualitative assessment of occupant usage. Table 7 shows the numbers for each office and some benchmarked comparison data from the OTF sites and research sources including a median performance case and a ‘high performance’ (i.e. lowest energy) case.

The data show the Oakland occupant uses more than the median case in all metrics. Particularly notable are the Off Hours and Weekend Ratios which demonstrate how much energy is used at night and on weekends. The designer can infer that the occupant is partially responsible for increased energy usage and even determine by how much against the comparison case. The designer’s next project can strive to enable occupant feedback or plug load measures to drive this downward.

| Table 7 Summary of Metrics Used in the Occupant Usage Indicators |
|---------------------|----------|-----------------|----------------|-----------------|
| Plug Load Metric     | Unit     | Oakland Office  | Vancouver Office | Lowest Energy Case | Median Energy Case |
| Occupied Energy Use Rate Density | W/SF | 0.62 | 0.15 | 0.12 | 0.55 |
| Peak Energy Use Rate Density      | W/SF | 1.01 | 0.45 | 0.39 | 0.86 |
| Workday Energy Use Rate Density    | W/SF | 0.48 | 0.11 | 0.10 | 0.41 |
| Off Hours Ratio                  | W/SF | 70% | 48% | 39% | 59% |
| Weekend Ratio                   | W/SF | 78% | 55% | 50% | 70% |
| Occupant Energy Usage Indicator Assessment | - | High | Very Low | - | - |

The effects of those design elements can be evaluated in terms of the impact on the same building. The designer may also use the Occupant Usage Assessment or its underlying data to decide which other buildings make good comparisons for other KPIs.

5.2.4. Design: Design and Operations versus Occupants Indicator

NBI found a simple indicator that compares at a high level the impact of design and operations as opposed to occupant behavior within buildings. In comparing total plug load and lighting system EUI against the HVAC and Net Electric plus Whole-Building Gas usage, we intended to draw a distinction between energy used by occupant activities and the amount of energy used to operate the building to support occupant activities. As a fundamental driver of performance, the amount of energy used to support occupant activities should be as small as possible. Figure 8 uses stacked charts that graphically reflect the ratio of design and operations impacts versus occupant impacts. The top portion shows the annual EUI attributed to the systems HVAC and Net Electric and the Gas use (Design and Operation),
while the bottom section shows the annual EUI for the plug load and lighting systems (Occupants). Since the Oakland office also had annual EUI data from its design model, we plotted this for comparison.

![Image of EUI comparison](image-url)

**Figure 8 The Metrics of Annual EUI Grouped to Indicate Design and Operations Versus Occupant Contributions for Each Office**

The Vancouver office at right shows a large imbalance of Design and Operation EUI compared to Occupant EUI. When used to compare buildings from a similar region and for a similar year this KPI can indicate inferior design or operations.

NBI compared these results with data from our buildings database and national sources. Table 8 shows the Design and Operations versus Occupants as a ratio along with the same ratios from the CBECS and CEUS data shown in Table 3. For the Oakland site, design data was available for comparison and included in the table.

<table>
<thead>
<tr>
<th>Metric Set</th>
<th>Oakland Office</th>
<th>Vancouver Office</th>
<th>CEUS</th>
<th>CB ECS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and Operations versus Occupants Ratio</td>
<td>Metered</td>
<td>1.49</td>
<td>6.07</td>
<td>0.81 - 0.93</td>
</tr>
<tr>
<td>Design Data</td>
<td>0.46</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ideally the ratio would be zero, meaning the building used no additional energy outside what the occupants needed to perform their productive work. Since the ideal is rarely the reality, some method of benchmarking the measured results is needed. In Oakland the design appears to miss its target, though this may be due partly to different occupant load assumptions.

For a more relevant comparison we analyzed data from the internal NBI database of commercial office buildings for similar climate zones. We also only compared the Oakland and Vancouver ratios against ratio ranges of like-type office buildings (Climate Zone and Use-Type) where the absolute magnitude of lighting and plug load were similar (using FirstView Internal Gain results). Table 9 shows the results.
Table 9  Design/Operations Versus Occupant Indicators for Both Sites and NBI Database Comparison for Similar Occupant EUIs

<table>
<thead>
<tr>
<th>Building</th>
<th>2010/2011 Design-Occupant Indicator</th>
<th>NBI Data Average</th>
<th>NBI Data Maximum</th>
<th>NBI Data Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver Office</td>
<td>6.07</td>
<td>2.09</td>
<td>2.76</td>
<td>0.98</td>
</tr>
<tr>
<td>Oakland Office</td>
<td>1.49</td>
<td>1.53</td>
<td>3.05</td>
<td>0.41</td>
</tr>
</tbody>
</table>

In Table 9 the Oakland office is in line with the average while the Vancouver office is clearly out of bounds. Note that the Schedule-Normalized EUI provides some measure of reassurance that the building schedule is normal and the Occupancy indicator showed that occupancy did not change drastically throughout the year. This provides feedback to the designer who made choices regarding the HVAC system and common area loads and might further use this data to compare choices made in other buildings with similar attributes.

5.2.5. Design: Daylight Effectiveness Indicator

Designers often specify daylighting in designs through skylights, lightshelves or dimming controls. As a result, the lighting system energy use should be impacted by daylight choices made by the design team either through the inclusion of daylight design in the envelope, causing occupants to manually respond to light, or through the use of lighting controls that automatically respond to daylight, or both.

NBI derived a KPI for daylight effects using a lighting energy metric correlated to the number of hours from sunset to sunrise (referred to as the ‘night length’) for both sites. Figure 9 is an expressive demonstration of the correlation. It clearly shows that lighting energy use in Oakland responds to daylight; in the Vancouver office that response is muted, implying that the lighting design characteristics in Oakland are superior though specific conclusions on why are not possible.

Figure 9 Co-plotting Lighting Density and Night Length to Demonstrate the Daylight Effectiveness Indicator

Table 10 show the metrics and observations used to generate that Daylight Effectiveness Indicator. The numerical calculations support the indicator which we express as a qualitative assessment.

Table 10 Metrics for Daylight Effectiveness Indicator

<table>
<thead>
<tr>
<th>Metered Data</th>
<th>Units</th>
<th>Oakland</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy Assessment</td>
<td>-</td>
<td>Moderately Stable</td>
<td>Stable</td>
</tr>
</tbody>
</table>
KPI Field Metering and Performance Feedback  
NBI PIER Evidence-Based Design Program 500-08-049

<table>
<thead>
<tr>
<th>Metered Data</th>
<th>Units</th>
<th>Oakland</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Occupied Energy Use Rate Density</td>
<td>W/SF</td>
<td>0.38</td>
<td>0.19</td>
</tr>
<tr>
<td>Maximum annual deviation</td>
<td>W/SF</td>
<td>0.11</td>
<td>0.03</td>
</tr>
<tr>
<td>Daylight Effectiveness Assessment</td>
<td>-</td>
<td>Excellent</td>
<td>Poor</td>
</tr>
</tbody>
</table>

Vancouver office data used the monthly energy use rate. A slightly different basis as some of the daily data was not present to calculate the occupied use rate.

The building attributes show the use of embedded daylight controls in Oakland; the Vancouver office has skylights and manual controls only. There is too little data to draw conclusions on the superiority of either method, but given enough data this KPI may serve as an indicator of the relative success of each strategy while the Occupancy Assessment can be used to account for occupancy effects on these trends.

5.2.6. Design: Overall Lighting Design Indicators

With further examination of the lighting data in comparison to OTF metrics, NBI revealed an overall lighting performance KPI that is useful to compare actual energy performance across platforms. The designer can use this assessment to determine the field effectiveness of the occupant-serving lighting system compared to other lighting systems or strategies for like-type buildings, particularly taking into account occupancy-related indicators and envelope design choices.

Figure 10 shows a bar chart of the lighting energy calculations from each site. The installed capacity (LPD) in W/SF is shown compared to the Peak Energy Use Rate Density, which is the highest electric demand seen in the monitoring period, and the Average Occupied Energy Use Rate Density, which is the average energy use rate on workdays during the day. Neither of the two sites appears to perform dramatically well, and we qualitatively assessed each site with a comparison to reference data in Table 11.

Table 11 Metrics Used in the Overall Lighting Design Indicator

<table>
<thead>
<tr>
<th>Lighting Metric</th>
<th>Unit</th>
<th>Oakland Office</th>
<th>Vancouver Office</th>
<th>Low Energy Office</th>
<th>Median Energy Office</th>
</tr>
</thead>
</table>

Figure 10 Lighting Metrics for Each Site Used as Overall Lighting Design Indicators

Table 11 shows metrics of performance and comparisons, again derived from the OTF protocols, for both sites. The metrics represent the average value seen across the year, except in the case of the peak demand which is a maximum value seen throughout the year.
One can see that the lighting energy performance for either site does not correlate to particularly high performance and is closer to median performance.

**5.2.7. Design: Lighting and Plug Load Design Equivalence Indicator**

Many design choices are made based on assumptions of the internal load contributions of plug and lighting loads. These assumptions are sometimes modeled and sometimes expressed as a typical load density and an hourly schedule of an expected fraction of the nominal density. The occupancy and lighting indicators above do not necessarily reflect this format, and annual EUI data do not help designers or modelers understand how accurate their assumptions are. Consequently NBI analyzed the data for the plug load and lighting systems to create a graphical and tabular indicator that reports average energy use rates for lights and plugs while active or inactive using the definition discussed in Section 5.2.1 - Design: Schedule Visualized System EUIs.

We looked at the schedule of when lighting or plug loads are ‘on’ versus ‘off’ and then calculating an average energy use rate density for that state. Table 12 shows the numbers for the annual period. These numbers can be examined for weekends as well.

<table>
<thead>
<tr>
<th>Lighting Metric</th>
<th>Unit</th>
<th>Oakland Office</th>
<th>Vancouver Office</th>
<th>Low Energy Office</th>
<th>Median Energy Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Installed Lighting Capacity</td>
<td>W/SF</td>
<td>0.81</td>
<td>~1.0</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Peak Energy Use Rate Density</td>
<td>W/SF</td>
<td>0.74</td>
<td>0.56</td>
<td>0.29</td>
<td>0.71</td>
</tr>
<tr>
<td>Average Occupied Energy Usage Rate Density</td>
<td>W/SF</td>
<td>0.33</td>
<td>0.30</td>
<td>0.10</td>
<td>0.39</td>
</tr>
<tr>
<td>Overall Lighting Usage Indicator Assessment</td>
<td>-</td>
<td>Median</td>
<td>Median</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 11 shows a stacked plot of the plug load and lighting active and inactive average energy use rates. The x-axis corresponds to the active and inactive average hours per day (note this is centered on 12:00 noon and not representative of the exact schedule. Ideally, the exact schedule would be represented.). The y-axis represents total energy use density from both plug loads and lights. Note that the Oakland data reflects the difference in the lighting and plug load schedule seen in the indicators above.

**Table 12 Active and Inactive Power Densities**

<table>
<thead>
<tr>
<th>Metric</th>
<th>System</th>
<th>Oakland</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inactive</td>
<td>Active</td>
</tr>
<tr>
<td>Average Weekday Active/Inactive Energy Use Rate Density</td>
<td>Plug Load</td>
<td>0.4</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Lighting</td>
<td>0.05</td>
<td>0.34</td>
</tr>
</tbody>
</table>
The detailed lighting and plug load design assumption data were not available for either site. Without this comparison these indicators only serve as a further representation of the relative magnitudes and schedules of the lighting and plug loads.

5.2.8. Design: HVAC and Net Electric Base Load Indicator

Heating and cooling performance, and the HVAC and Net electric and Gas system usage, are much tougher to leverage using benchmarked annual EUIs. More useful are energy signature comparisons to references, benchmarks or an automated analysis similar to the FirstView tool. This is because HVAC energy usage is heavily dependent on thermostat settings, equipment condition, and indoor and outdoor temperature for HVAC usage.

NBI focused on the baseload of the HVAC and Net Electric monthly energy signature to derive a metric that can indicate the magnitude of the electrical loads in the system in the monthly (28-day) period and to a certain extent the success of the HVAC system in combating unnecessary reheating of conditioned air. Designers can use this metric and the HVAC and net electric energy signature to compare HVAC and common area lighting and plug load performance against other buildings. The Occupancy metric from Table 6 and the schedule data from can support comparison between buildings.
Figure 12 shows the monthly HVAC and Net Electric energy signature for both sites. The y-axis shows the average energy use rate in W/SF for each monthly period, and the x-axis is outdoor average temperature. The increase in the colder months (left side in each graph) represents the increased fan energy to blow heated air into the building, while the warmer months (right side of each graph) represent fan and air conditioning energy. The Vancouver site clearly shows this pattern, while the Oakland site is less clear. This trade-off of heat and cooling is shown more expressively in Figure 3c. in the FirstView Analytics Section.

Table 13 shows the resulting values for the two sites. Note that the common area baseload is much higher in the Oakland office despite the similarity of the HVAC system. Unfortunately NBI had no comparison data set to use to create a qualitative assessment. The sites use a similar HVAC type and have similar equipment in the common areas and so might be compared against each other. A high HVAC and Net Electric baseload could be due to poor operation or a high level of common area usage. In either case a lower baseload is desirable.

Table 13 HVAC and Net Electric Base Load Comparison

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Unit</th>
<th>Oakland Office</th>
<th>Vancouver Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy Assessment</td>
<td>-</td>
<td>Moderately Stable</td>
<td>Stable</td>
</tr>
<tr>
<td>HVAC and Net Electric Baseload</td>
<td>W/SF</td>
<td>0.29</td>
<td>0.08</td>
</tr>
</tbody>
</table>

5.2.9. Design: Operational Consistency Indicator

As a complement to the Baseload Indicator, NBI examined the HVAC and Net electric energy signature in monthly and weekly (7-day) increments for an indication of whether the HVAC system is well controlled.

Figure 13 demonstratively shows the monthly period energy signature (solid line) with an overlay of the weekly interval data (hollow squares). Note how the Vancouver office co-plots well while the Oakland office is very erratic. This implies that control-related issues might be contributing to the overall energy signature and potentially increasing heating and cooling energy use beyond what is called for by the well-operated design. It is still difficult to determine what is attributable to design and what is attributable to operation, but this indicator shows there is reason to doubt the Oakland Office EUI represented its best possible performance for the given occupancy.

Figure 13 HVAC and Net Electric System Monthly Energy Signatures
In Oakland the FirstView tool indicated, shown in Figure 3b, high gas use in general as well as a high summer gas baseload. The Design/Operations versus Occupant Indicator suggested HVAC and Net Electric and Gas were only average compared to other offices and much higher than design intent, despite a lower occupant usage. The “Erratic” Operational indicator and somewhat high HVAC and Net Electric baseload indicator (compared to the Vancouver office case) suggest HVAC operation is the culprit rather than shell. Further, the occupancy schedule and relative stability suggest the occupant actions are not to blame.

Table 14 summarizes the qualitative assessment indicator for each site based on observation as no comparison data is available. While the Vancouver office shows a stable pattern of weekly/monthly average energy use rate, the Oakland office is quite erratic.

<table>
<thead>
<tr>
<th>Table 14 Operational Consistency Indicator conclusions for both sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Occupancy Assessment</td>
</tr>
<tr>
<td>Operational Consistency Assessment</td>
</tr>
</tbody>
</table>

The Vancouver site shows expected performance for an HVAC system with consistent performance and stable common area usage. The designer may wish to interpret the data as an endorsement of the HVAC design approach taken in this case versus the Oakland case or perhaps wait until operations have settled before using other KPIs to determine the success or failure of the building design. Further, in the Vancouver case the stability of the HVAC system may indicate that the high gas usage is not a result of poor operation of the HVAC system but more the envelope of the building.

5.3. Operations: Metered KPIs

A building operator will find value in the FirstView output as well as the Design KPIs mentioned above but will need more frequent feedback than designers to optimize building performance. For this analysis we suggest a quarterly inspection interval. The operator or auditor will likely use other data and intervals than these to diagnose and resolve specific issues underlying the indicators. The operator wants to know “Is the building still doing well? Are the changes in energy usage due to my actions or the occupants? How am I doing with the equipment I can influence, e.g. common area lights, HVAC equipment?”

Table 15 describes the Operator KPIs NBI derived using system-level metering. The underlying metrics of these indicators are similar to the Design metrics but are different in subtle ways that provide feedback more specifically to the operator in areas they can influence through efficiency measures.

Small to medium-sized commercial buildings may not have an active operator. This was the case in both Oakland and Vancouver, so the information relevant to the operation of the building may be utilized by a building energy auditor or even a responsible site occupant rather than a separate local or remote operator working on behalf of the owner.

<table>
<thead>
<tr>
<th>Table 15 Operators: 5 KPIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>1 Operational Schedule Consistency</td>
</tr>
</tbody>
</table>
In general, “operational” problems may be the fault of the original design, e.g. oversizing equipment or poor zoning. Use of these Operations KPIs may be useful to identify designs or equipment that are difficult for the average operator to utilize.

5.3.1. Operations: Operational Schedule Consistency Indicator

Occupant schedule and usage patterns can affect performance and should be tracked periodically through quarterly or monthly KPIs. Table 16 shows data for a three-month period with monthly metrics of plug, lighting, and HVAC and Net Electric. The metrics in Table 16 inform the operator of how well the HVAC and common area equipment schedule align with occupant schedules.

This indicator is comprised of metrics that let the operator know if the building schedule exceeds occupant usage and whether the occupancy is stable in the inspection interval. For example, as established above the lighting schedule at the Oakland office appears longer than the regular office occupant schedule as determined by the plug loads. The HVAC system should be “active” to address the needs of whomever is in the building but should not exceed this usage to avoid unnecessary conditioning.

The data in Table 16 shows both sites look to be in line with these expectations. The operator may want to be certain that the lighting schedule length is needed or if it is a failure of the control system. Table 16 also shows a qualitative assessment of the numbers. The Oakland site has both lighting and HVAC and Net Electric schedules that are longer than the occupant plug load schedule. The operator may want to investigate the reason for this.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
<th>Oakland</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Month 1</td>
<td>Month 2</td>
</tr>
<tr>
<td>Average Plug Load Weekday Energy Use</td>
<td>W/SF</td>
<td>0.54</td>
<td>0.51</td>
</tr>
<tr>
<td>Rate Density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug Load Schedule</td>
<td>Hours</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Lighting Schedule</td>
<td>Hours</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>HVAC Schedule</td>
<td>Hours</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Operational Schedule</td>
<td>-</td>
<td>Lighting and HVAC Schedules</td>
<td>Normal</td>
</tr>
</tbody>
</table>
5.3.2. Operations: Lighting and Common Area Indicators

The operator has influence over the occupant lighting system in off-hours and weekend periods, as well as common-area lighting and plug loads. The inactive power for the lighting and HVAC and Net Electric systems provides a measure of improvement that tracks to efficiency measures an operator might employ. For lighting, the off-hours and weekend ratios provide a measure of the impact of these operator lighting actions relative to typical occupied use.

Table 17 shows values for the metrics at each site. Note that the inactive power is a direct electrical power average, not a density per SF. There is no qualitative assessment in Table 17.

Table 17 Operator Lighting and Common Area Indicator Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
<th>Oakland</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting Inactive Power</td>
<td>kW</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Off-Hours Ratio Ratio</td>
<td></td>
<td>36%</td>
<td>36%</td>
</tr>
<tr>
<td>Weekend Ratio Ratio</td>
<td></td>
<td>11%</td>
<td>30%</td>
</tr>
<tr>
<td>HVAC and Net Electric Inactive Power</td>
<td>kW</td>
<td>2.0</td>
<td>1.6</td>
</tr>
</tbody>
</table>

The data for each site appears stable, though there was increased weekend lighting usage in Month 2 in Oakland. The operator may also want to address the lighting inactive power in the Vancouver site to reduce off-hours and weekend ratios.

5.3.3. Operations: Daylight Controls Effectiveness

The operating condition of daylight controls can be examined using historical data and monthly interval occupied energy usage rate metrics in a manner similar to the Design KPI.

The lighting occupied energy use rate density for Oakland for three months is shown in Table 18. The indicator is not applicable to Vancouver because though there are skylights there are no active daylight responsive controls for the operator to maintain or change.

Table 18 Occupied Energy Usage Rate Density for Oakland

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
<th>Oakland</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting Average Occupied Energy Use Rate Density</td>
<td>W/SF</td>
<td>0.38</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Figure 14 shows the Oakland data points co-plotted with the expected curve based on historical data. A curve from another building may be used if the designs are similar enough and the curve is adjusted for magnitude. The yellow squares represent the monthly energy use rate points in W/SF, and the red line and squares show the night lengths in hours. The single black line is the historical or expected trend.
5.3.4. Operations: HVAC + Net Electric Usage on Unoccupied Days

Energy is wasted when the HVAC system is operated as normal on holidays and weekends, when the building is closed or unoccupied. NBI created a metric to detect the number of days in the period where HVAC and Net Electric usage was normal while plug and/or lighting energy were much below expected.

Table 19 shows the summary of the analysis indicating operation on unoccupied days. The operator might examine the data periodically to ensure that the HVAC schedule is up to date.

Table 19 Summary of the Unoccupied Days Operation Indicator for Both Sites

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Unit</th>
<th>Oakland</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unoccupied Days Operation</td>
<td>W/SF</td>
<td>Month 1</td>
<td>Month 2</td>
</tr>
<tr>
<td>Indicator</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 15 below shows a plot of the data for Month 3 from the Oakland office. The grey shaded area is the plug deviation measurement, and the yellow is lighting. The red squares are the HVAC and Net Electric deviation. The large highlighted red square point indicates unnecessary operation of the HVAC system (or perhaps some other large common area load) on that day. Notably, the day is Memorial Day, 5/30/2011, when the Oakland office was likely unoccupied but the HVAC system ran as normal.
5.3.5. Operations: Operational Stability Indicator

The use of the monthly and weekly overlay of HVAC and Net Electric is useful to reveal erratic control conditions. Similar to the design KPI, regular monitoring of this KPI should reveal operational issues in commercial buildings where the HVAC and Net Electric usage characteristics are not dominated by the non-heating and cooling base load (comprised of non-direct loads, like common areas, lighting, elevators, etc.).

Table 20 Operational HVAC and Net Electric Indicator for Three Months for Each Site

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
<th>Oakland</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC and Net Electric Control Indicator</td>
<td>-</td>
<td>Erratic</td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erratic</td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erratic</td>
<td>Stable</td>
</tr>
</tbody>
</table>

The HVAC and Net Electric stability Indicator is shown in Table 20 as a qualitative assessment of the data plotted in Figure 16 of monthly and weekly energy signature data from each site. Unsurprisingly the data reveal the same underlying erratic pattern at the Oakland site. The operator can use this indicator to maintain consistent operations.
5.4. Occupants: Metered KPIs

Occupant actions regarding plug load controls, lighting settings and (in some buildings) thermostat settings can have a big impact on overall EUI. Occupant KPIs provide feedback on energy use trends in a way that makes for easy comparison to other similar sites.

Occupants want to know, “How are my choices impacting the building energy use? Is this considered good or bad? If I take action then what changed?”

Occupant KPIs shown in Table 22 and Table 23 are intended to be presented to the occupants regularly, perhaps trended continuously with a trailing window to allow occupants to take actions that reduce their energy usage and result in better metrics. The use of regular metrics will make comparisons to other facilities easier.

Table 21 Occupants: 2 KPIs

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Purpose</th>
<th>Target Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupant Plug Load</td>
<td>Provide a means to show occupants how their plug load usage compares to other like-type occupants and track performance</td>
<td>As low as possible for all metrics or in-line with benchmark targets</td>
</tr>
<tr>
<td>Occupant Lighting</td>
<td>Provide a means to show occupants how their lighting usage compares to other like-type occupants and track performance</td>
<td>As low as possible for all metrics or in-line with benchmark targets</td>
</tr>
<tr>
<td>Off Hours Ratio</td>
<td>Demonstrate the periods of occupancy highlighting the energy use in unoccupied time periods as a ratio of full occupancy.</td>
<td>The ratio should be very low with little to no energy use during unoccupied schedules.</td>
</tr>
</tbody>
</table>

Since both sites were offices, NBI worked with the OTF data for comparison. NBI showed this as an example of how occupants can be provided numerical KPIs for which some data exists for a benchmarking comparison.

In large office buildings where the usage of many tenants’ is combined, presentation of the aggregate data in this format may not be compelling for individual offices. In those buildings further submetering (perhaps through existing utility allocation metering) could provide data that would allow for more specific feedback to a particular office space or tenant.

5.4.1. Occupants: Plug Load Performance Indicator

The occupant plug load KPIs derived for each site from a single month’s worth of data are shown in Table 22, along with corresponding benchmark comparison data from the OTF data set.

For example, a tenant may undertake a company-wide effort to shut off equipment at night, change settings and employ timers. The ratios in Table 22 will show the effectiveness of the measures taken while the annualized energy density will reflect the impact of those measures on EUI.
Table 22 Plug Metric Power Densities for Both Sites in One Month

<table>
<thead>
<tr>
<th>Plug Metric</th>
<th>Unit</th>
<th>Oakland Office</th>
<th>Vancouver Office</th>
<th>High Performance Reference Office</th>
<th>Benchmark Median Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annualized Energy Density</td>
<td>kWh/SF</td>
<td>4.71</td>
<td>0.86</td>
<td>3.03</td>
<td>4.52</td>
</tr>
<tr>
<td>Average Occupied Energy Use Rate Density</td>
<td>W/SF</td>
<td>0.69</td>
<td>0.15</td>
<td>0.12</td>
<td>0.44</td>
</tr>
<tr>
<td>Peak Energy Use Rate Density</td>
<td>W/SF</td>
<td>1.01</td>
<td>0.39</td>
<td>0.39</td>
<td>0.86</td>
</tr>
<tr>
<td>Inactive Power</td>
<td>kW</td>
<td>6.4</td>
<td>0.38</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Ratios

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-Hours Ratio</td>
<td>-</td>
<td>69%</td>
<td>48%</td>
<td>39%</td>
<td>59%</td>
</tr>
<tr>
<td>Weekend Ratio</td>
<td>-</td>
<td>76%</td>
<td>61%</td>
<td>50%</td>
<td>70%</td>
</tr>
<tr>
<td>Occupant Plug Load Performance Assessment</td>
<td>-</td>
<td>High</td>
<td>Very Low</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
the system-level metering at the two office locations to derive KPIs for designers, operators and occupants that form meaningful indicators of good performance. These KPIs were calculated to independently inform these three audiences as well as enhance evaluations that use whole-building methods.

At the individual building level the metering and feedback provide a succinct set of conclusions that demonstrates the way the KPIs can inform a target audience. In Table 24 the Design KPIs are used as an example KPI summary, but the same can be done, as shown within the report, with customized information and KPIs for the operators, etc. The metered assessment is shown with performance indicators of each building against comparison sets followed by an explanatory paragraph on the buildings.

Table 24 Design KPI Summary for Oakland and Vancouver

<table>
<thead>
<tr>
<th>Design KPI</th>
<th>Oakland Assessment</th>
<th>Vancouver Assessment</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule Visualized Annual System Energy Use Index (EUI)</td>
<td></td>
<td></td>
<td>CEUS, CBECS</td>
</tr>
<tr>
<td>Occupancy</td>
<td>Moderately Stable</td>
<td>Stable</td>
<td>Inspection</td>
</tr>
<tr>
<td>Occupant Usage</td>
<td>High</td>
<td>Very Low</td>
<td>NBI</td>
</tr>
<tr>
<td>Design and Operations vs. Occupant</td>
<td>Median</td>
<td>Very High</td>
<td>Design data, CEUS, CBECS, NBI</td>
</tr>
<tr>
<td>Occupant Usage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daylight Effectiveness</td>
<td>Excellent</td>
<td>Poor</td>
<td>Inspection</td>
</tr>
<tr>
<td>Overall Lighting Performance</td>
<td>Median</td>
<td>Median</td>
<td>NBI</td>
</tr>
<tr>
<td>Lighting Model Equivalence</td>
<td>n/a</td>
<td>n/a</td>
<td>no comparison data</td>
</tr>
<tr>
<td>Plug Load Model Equivalence</td>
<td>n/a</td>
<td>n/a</td>
<td>no comparison data</td>
</tr>
<tr>
<td>HVAC and Net Electric</td>
<td>0.28 W/SF</td>
<td>0.08 W/SF</td>
<td>no comparison</td>
</tr>
</tbody>
</table>
At the 14,000 SF Oakland site the plug load schedule indicates the occupants have a normal schedule (9 hours per average workday), though their energy usage is higher than typical compared to the NBI data set. The lighting and HVAC schedules appear to be longer than normal (12 hours), though no data is available for comparison. The lighting system appears to be very responsive to daylight though occupants or visitors usage of the lighting system is at a median level compared to NBI data. The amount of energy used for Design and Operations versus Occupants is at a median level though it is notably higher than the design. HVAC and Net Electric Baseload also appear very high compared to the Vancouver office despite the similarity of their HVAC typologies. Further, the HVAC and Net Electric appear erratic, indicating the HVAC system may not be operating properly. As a result, the designer may not want to trust the annual energy performance from this site without being assured by the operator that the building is operating in accordance with the design. If several sites with the same design have similar problems, it is likely that the design itself may be flawed.

The 5,500 SF Vancouver office has an obviously high gas energy use that does not seem to be driven by a longer-than-normal schedule by the occupants or the HVAC schedule. This may be in part to the low level of Occupant Usage (requiring more heating), though it is extremely high compared to buildings with a similar internal gain in the NBI set, causing a Design and Operations versus Occupant ratio of 6. The lighting system is not very responsive to daylight despite consistent occupancy, and the overall usage level for lighting is median. The HVAC and Net Electric Baseload appears very low, and the Operational Consistency is stable, which may indicate the gas usage is an envelope rather than operational issue as there are no large gas Direct Loads or gas water heating at the site. The designer should reexamine and upgrade the methods used in the envelope design for the next project.

7. RESEARCH SUMMARY

This research focused on evidence-based (metered) performance feedback to guide understanding of, and improvements to, the performance of a building by various parties involved in its energy use. NBI found that certain combinations of metrics of whole-building and system energy usage formed meaningful indicators of good performance. The metered Key Performance Indicators suggested in this report are intended to serve as a next-level approach after whole-building feedback methods for designers, operator/auditors and occupants while remaining well short of the advanced algorithmic FDD type methodologies of many commercially available software tools.

The KPIs in this research report represent the sixth step in the following research progression:

1. A whole-building review of energy bills of 22 California buildings.
2. A FirstView analysis of the of 22 California buildings.
4. A sensitivity analysis of the relative impact of energy use features through extensive modeling data.
5. **Site visits** with audits and interviews at 12 of the 22 research buildings to establish the minimal set of priority metrics on energy performance and accompanying options for plotting that further reveal information about the building.

6. **System-level metering** at two building sites to explore real-time and trending energy use at a system and a whole building level in a known commercial environment.

The sections below briefly summarize aspects of the Whole-Building and FirstView approaches as initial levels of performance review and show examples followed by the research conclusions on system-level metering.

### 7.1. Whole Building Metrics

All building energy reviews, and the most common market and industry understanding, begin with whole-building metrics. Some considerations of whole-building metrics are:

- **Whole-building data review** is the **first, and still largely absent**, step toward market improvements of energy performance.

- **Energy cost** is the most widely considered metric by the market (owners and property managers) because it is a metric universally delivered and quickly understood but it can represent more than just energy consumption (base fees, taxes etc.). **Total energy** use by month or by year, **ENERGYSTAR score**, and energy use intensity (EUI) per year, in that order, are other commonly used whole building performance metrics.

- Establishing an **ENERGYSTAR score** through Portfolio Manager has gained significant market use over the past ten years, and new disclosure ratings requiring it will further increase this simple level of whole-building energy performance.

- **LEED and Green/Energy Program Ratings** of performance are considered a market metric and are now being used as policy metrics (e.g. achieve LEED Silver, Savings by Design) with energy as a portion of these ratings.

- **Feedback on energy use** through whole-building metrics and comparisons with like buildings is a **primary starting point** for increasing the initial understanding of performance and helps move toward more specific feedback on metered systems and KPIs.

### 7.2. A FirstView of Performance

Whole building monthly fuel data and a few building characteristics can be further analyzed to provide first-level KPIs on broad building areas of energy use. This hybrid approach of ‘whole-building data in and broad KPIs out’ is a next step toward deeper understanding of energy performance as was done in this PIER research. Some considerations of energy signatures and FirstView are:

- The **easiest next step** for an initial deeper view of performance and areas of possible improvement comes from analyzing energy use correlated with outside temperature via a tool like FirstView.

- **Simple tools** built on sophisticated analysis platforms like FirstView can be widely scaled and provide feedback, trending and simple initial diagnostics.

- A significant **increase in performance understanding** and direction for improvements can come from applying energy signature and analysis tools prior to investing in metering and/or audits.
The FirstView tool relies only on input of the most fundamental and accessible level of data at little cost and automates the performance results into a heating curve, a cooling curve, domestic hot water and baseload energy. These correspond to three target feedback areas:

- **Design** - heating and cooling slopes and amounts can indicate shell issues and equipment selection and efficiency
- **Operations and Controls** - the slopes for heating and cooling and the overlap of these, as well as the volume of energy use in the baseload, can indicate control issues or operational failures
- **Tenants** – the baseload profile indicates the lights and plugs (internal gains) that are in the control of the tenants (although setbacks on lights can be a control issue)

Feedback from FirstView and other whole building analysis tools require intuitive graphics, simplified and automated messaging, and clear introductory explanations to the user.

This next step of screening performance requires a modest cost compared to a whole building metric and greater attention and action.

### 7.3. System-level Metered KPIs

This next level of useful guidance comes from: (1) assuring that the whole-building electric meter records interval data and (2) submetering a few major end use categories. The conclusions provide an overview on the submetering and the KPI Findings by audience with examples.

#### 7.3.1. Overview of Submetering Issues

- Performance improvement must incorporate several ‘layers’ of approaches starting from simple through to deeper knowledge and opportunities as shown in this research.
- A small set of key performance indicators, represented graphically, can provide insights on the majority of energy use within a building in the absence of, or in addition to, a full energy information or management control system.
- To assess performance, the evidence-based KPIs need to have comparisons of other like buildings, targets and/or the building over time.
- Benefits of submetering come from the greater specificity of how energy is being used and from the additional analytics available from interval data. Both help inform the individual DOT groups.
- Submetering can be done at relatively low cost if planned for at the time of initial wiring.
- Adding two additional meters to an existing building – on lights and plug loads – allows for a reasonable level of disaggregation of energy use into the major areas and informs which audience impacts that use.
- Metering need not be permanent. A “meter-in-a-box” could be developed and loaned through utilities or contractors thereby reducing the cost.
- System-level metering of existing buildings is dependent on the wiring independency of the systems. Cost and accuracy can vary widely due to the unknown state of the panel and wiring.
- Interval whole-building data are critical to system-level load KPI analysis because one of the system energy uses, in this research case the HVAC and Net System load, is calculated by a deduction of the metered lighting and plug loads from the whole-building energy use.
• Related research\(^5\) suggests that one of the **largest areas of saving** in an existing leased building is **tenant-level submetering** rather than whole building or by system. This, along with correct lease pricing signals (tenant pays for power) can drive significant attention to operating schedules and occupant use.

• Improved **clarity of the KPIs** is needed and presentation should **vary by audience** (improvement on these aspects is a part of the final stage of this research).

### 7.3.2. Design: System-level KPIs

Designers and asset raters need high-level feedback at an individual building and for a portfolio of buildings to track the building attributes that reflect a superior design. KPIs for designers should answer questions like “Is the design working well despite operations and occupant choices? Which part of the design in particular? Are there poor performance issues driven by design choices? Is the HVAC system I chose better than one from another building?” Each indicator provides a piece of evidence. The intention is that they be used together as a set to make overall design determinations and then combined with other analysis like FirstView and non-metered building attributes to reveal a final assessment. The list below provides the research determination of the top ten metrics to inform the design team regarding building energy performance. Many of these overlap with other audiences and provide KPIs for operators or tenants as well. Generating intuitive names and graphics beyond those used in this research report is the next stage of this research.

1. **Schedule Visualized Annual System Energy Use Index (EUI)** - Quickly indicates what system is responsible for the most usage and its approximate schedule of typical activity.

2. **Occupancy Stability** - The designer can see if occupancy changed during the year of performance.

3. **Occupant Usage** - Provides more details and an assessment of how the occupant’s usage impacts the building.

4. **Design and Operations versus Occupants** - Provides a simple numerical assessment of annual design and operations usage versus occupant usage.

5. **Daylight Effectiveness** - Determines if the daylight design or daylight controls are effective.

6. **Overall Lighting Design/Performance** - Determines the performance of the lighting design and usage compared to other lighting designs.

7. **Lighting and Plug Load Design Equivalence** - Checks the performance of the lighting and Plug Load system in metrics similar to those of a design model.

8. **HVAC and Net Electric Balance Point** - Determines the magnitude of the HVAC and Net Electric contribution towards the building energy use as well as track the change in simultaneous heating and cooling.


### 7.3.3. Operations: System-level KPIs

A building operator will find value in the FirstView output as well as the Design KPIs mentioned above but will need more frequent feedback than designers to optimize building performance. Small to medium-sized commercial buildings may not have an active operator, as was the case in the two research sites, and the information relevant to the building operation may be utilized by an energy auditor or even a responsible site occupant. Based on this, for this analysis we suggest a minimal of a quarterly inspection interval.

\(^5\) Do Green Buildings Make Dollars and Senses? Miller, Norm UC San Diego, Pogue, David CBRE 2012
The list below summarizes the Operator KPIs derived using system-level metering. The underlying metrics of these indicators are similar to the Design metrics but are different in subtle ways that provide feedback more specifically to the operator in areas they can influence through efficiency strategies and measures. The operator wants to know “Is the building still doing well? Are the changes in energy usage due to my actions or the occupants? How am I doing with the equipment I can influence, e.g. common area lights, HVAC equipment?”

1. **Operational Schedule Consistency** - Compares lights, plugs, and HVAC schedule to ensure alignment and also establish occupancy stability.

2. **Lighting and Common Area Usage** - Compares metrics of common area and lighting base load usage to reveal savings opportunities that the operator can address or track.

3. **Operational Daylight Effectiveness** - Compares occupied lighting performance with night lengths to establish daylight controls functionality.

4. **HVAC and Net Electric on Unoccupied Days** - Provides an indicator of unnecessary HVAC operation when no occupants are present.

5. **Operational Stability** - Similar to the design KPI this indicator reveals operational inconsistency through a comparison of monthly and weekly data.

### 7.3.4. Occupants: System-level KPIs

Occupant actions regarding plug load controls, lighting settings and (in some buildings) thermostat settings can have a big impact on overall EUI. Occupant KPIs provide feedback on energy use trends in a way that makes for easy comparison to other similar sites.

Occupants want to know, “How are my choices impacting the building energy use? Is this considered good or bad? If I take action then what changed? Are we leaving things on at night?”

The two primary occupant KPIs are shown in below. The schedule of plugs and lights energy use is represented directly within these two KPIs as “off hours ratio” whereby a high ratio shows energy use during unoccupied periods and flags potential savings. Occupant KPIs shown in Table 22 and Table 23 are intended to be presented to the occupants regularly, perhaps trended continuously with a trailing window to allow occupants to take actions that reduce their energy usage and result in better metrics. The use of regular metrics will make comparisons to other facilities easier.

1. **Occupant Plug Load** - Provides a means to show occupants how their plug load usage compares to other like-type occupants and track performance.

2. **Occupant Lighting** - Provides a means to show occupants how their lighting usage compares to other like-type occupants and track performance.

   **Off Hours Ratio** (a component of the two KPIs for occupants) - Demonstrates the periods of occupancy highlighting the energy use in unoccupied time periods.

### 7.4. Expansion of System-level Metered KPIs

The expanded use of system-level KPIs in the market requires the following:

- Close coordination on fuel **distribution and wiring design** issues. Detailed design guidance to support codes.

- The design community needs directly useable **guides** on how to **specify system level wiring** requirements for contractors.
• Benchmarking and interpretation of submetered data needs consistent definitions of what is included in the broad end use categories

• Submetering systems needs to move to a standard practice for green certifications and an eventual requirement through codes.

• Slow and steady progress to arrive at solid consistency in design by 2030.

8. MARKET PATHWAYS

Analysis of building energy use through system-level KPIs is a valuable tool to assist in the evaluation, operation and energy monitoring of commercial buildings, representing a next step past the whole-building meter. The market for evaluation of commercial building energy performance is dominated by the whole-building annual metric and regression analysis comparisons to other like-type buildings using a large national or state data set. More advanced methods like FirstView are changing the possibilities for energy performance assessment and can drive performance-based efficiency programs and new financing strategies. The system-level KPI approach using consistent definitions and approaches for existing buildings can take the simple initial whole building methods one step further using metered data.

8.1. Market Use

The value of this set of metrics is greatest for small to medium-sized buildings which don’t typically have full-time operators or advanced energy information systems. Aligning with the previous stages of this project, a research intention is to “connect the DOTs” (designers, owners, operators, tenants) so that each metric relates to specific feedback needs of these various players in energy performance. Often single metrics address the needs of multiple audiences, each of which will derive different types of actions from the feedback provided. From selected KPIs of actual energy performance the DOTs can do the following:

• **Designers** can review or create comparable “as-designed” metrics from the initial energy modeling for the building, thus gaining more insight into areas where results differ from expectations. The results can directly support improving future designs of the same firm. The separation of energy use attributed to occupant loads and schedules from that for conditioning the tenant space is also directly aligned with the designers’ need for feedback on the chosen structure and systems. These KPIs would also allow designers to improve the way they serve occupants by providing consistent metrics to enable occupants to improve their own efficiency.

• **Owners** can readily see areas worthy of additional investigation on the part of operators or contractors. The package of metering and KPIs can provide the next layer of specificity without (or before) any onsite audit, and will thus be able to more effectively target onsite audits or investigations.

• **Operators**, energy auditors and energy managers can get an initial look at how the building uses energy and where the big problems lie and use these high-level metrics to prioritize issues and areas for attention - even in larger buildings with more complex EIS systems. For smaller buildings the KPIs reduce the time to identify areas of deviant performance which helps increase the likelihood that improvements can be pursued.

• **Tenants** (Occupants) can be informed of the impact of their equipment and lighting use. With trends toward tenant-level metering and green lease guidelines, simple KPIs can help tenants manage their use and costs and serve as the basis for negotiations on energy-related lease aspects.

In addition, this level of performance feedback supports other market players:
• **Utility** energy efficiency program managers can integrate a short set of KPIs and the associated system metering as a measurement and verification component of incentive programs. Utilities also begin with the whole building data necessary to benchmark the building at the highest level and an enormous set of data on comparable buildings. Utilities have a unique and critical role in providing access to performance data that can facilitate target setting and feedback.

• **Policy** managers can establish a whole building metric and a set of KPIs with metering requirements within existing or reach codes, to inform asset and operational ratings, and as a reporting requirement to guide policy development. KPIs also serve as a more complete M&V set of data to correlate savings attributable to efficiency changes versus changes in occupancy usage or schedule. The potential for KPI-based evaluation and analysis with temporary metering is very real and could be cost effectively scaled if integrated into standard practice at key transaction times such as sales or permits.

• **Modelers** can apply simple system-level metering to enhance inverse modeling tools by providing a monthly measure of Occupancy or Internal Gain. The evidence-based KPIs allow a modeler to calibrate the original model for a building, if one existed, or to establish a benchmark for next phase changes.

• **New tool developers** are setting a furious pace of development of metering and data acquisition products, particularly in California. FirstView and System-level KPIs can provide evidence-based data for inverse modeling products, databases for comparison building sets, to improve diagnostics, and to inform the depth and approach to delivering performance information to the market.

### 8.2. System-Level Meters and Design for Meterability (DFM)

Some emerging commercial building projects are placing a focus on the segregation of electrical and gas system-level loads to facilitate energy metering, but even among these projects there is no definition reference that results in metered energy metrics that can be compared from building to building, or in energy metrics that align with direct or inverse energy models. Further, there is a lack of guidance in the design community on methods that result in easily metered buildings with little or no added design/construction cost.

Successful implementation of the metered KPI approach requires an energy distribution layout that can capture the relevant system energy usage information in a reasonable number of meter points. The layout can be accomplished relatively easily in new construction with proper attention to electric panel layout in the design stage.

Widespread coordination of a Design for Meterability (DFM) approach would facilitate the coordination of projects that will permit permanent or temporary meter installation to gather KPI data. The idea of DFM is making inroads in codes like IgCC which has system segregation requirements. Further market intersection can occur through design firms with awareness and design guidelines to meet a standard that allows cost-effective system-level meters.

The DFM practice should assist designers through codes and design guidance documents to create a building that can be easily metered at any time or for any length of time to improve the cost benefit proposition of measured performance at the system level.
9. NEXT STEPS

Through the PIER Evidence-based Design and Operations research project, NBI has worked to forge a measured performance pathway from whole-building energy analysis using annual benchmark comparisons and the monthly inverse modeling FirstView through hourly interval analysis at the system level. Naturally the methods become more complex as intervals are shortened, meter points added, and the audiences stretched to separate design, operator and occupant/tenant-relevant feedback.

NBI sees a need for further integration between the FirstView tool and the indicators and system data discussed in this document. In particular to enhance the underlying logic of the FirstView tool to accept more direct, shorter interval measurements of energy use parameters. The meter-based KPIs discussed in this report should be examined in a broader context of KPIs from other sources. Within this PIER project the planned next steps include:

- Beta test and functionality / market impact of the FirstView tool with architects, operators and utilities.
- We are working to reach out to code experts and designers who have tried system-level meters to gather information on the current state of progress and successes and failures.
- Follow up with existing energy feedback tool vendors in California to share findings from this research and influence the customer information.
- Publish and present findings, including using definitions suggested as a platform for industry adoption of a common vocabulary on system level energy performance topics.

Additional work and research in the area includes:

- A more detailed and collaborative effort on DFM should be arranged among the stakeholders discussed in this report, especially among architects and mechanical and electrical professionals in the design community, to begin the process of defining systems that will serve as a cohesive framework for evaluation and assessment of buildings. Additionally, more detailed studies of cost and benefits of DFM projects involving real firms should be conducted.
- More exploration of the state of electrical and gas distribution in commercial buildings is needed to get a more representative sample of whether the definitions discussed herein will serve existing buildings or whether changes or broadening may be necessary. In buildings with extreme blending of circuits, the cost benefit of wiring changes or temporary application of granular metering can be explored and reported.
- Convene a forum of experts and stakeholders to work on system level definitions. This may begin with an interim level that separates out the occupants from the rest of the building so that operators and designers can reach industry-level agreement. This is more realizable in existing buildings. By settling on standard definitions there can be greater harmonization of data from existing projects conducted in many locations.
- The system level metering described here could then be the basis for new construction.
- Lastly, a pilot project based on system-level analysis should be introduced into a currently operating new construction incentive program to test the viability of the approach, especially regarding the “black box” approach or a temporary metering-based approach. Yes, utilities need a mechanism to intersect this market and have the metering and installation expertise. A pilot project or two might answer cost questions and reveal where the utility can support its programs for new construction and create a potentially new revenue stream included in the rate base.
10. APPENDIX

A. Terminology and Metrics

**Active/Inactive Power or Energy Use Rate:** The active or inactive state is determined using an algorithm for deviation from an average during the day which indicates equipment being “on” or in use by occupants/operators. The power or energy use rate in the inactive or active state is an average of the values in that state in the interval studied.

**Base load:** An amount of power or energy use rate that is a constant minimum.

**Occupied Energy Use Rate:** The rate of energy use in a system from 6AM to 6PM on a workday (i.e. not a Saturday, Sunday or Holiday).

**Off Hours Ratio:** A ratio of the Occupied Energy Use Rate to the Unoccupied Energy Use Rate. Expresses the amount of lighting or equipment left on at night on workdays.

**Peak Energy Use Rate Density:** The maximum energy use rate for an hourly interval seen in the period of time analyzed. This provides a good measure of installed capacity for lighting and plug loads as well as a tracking metric for performance management.

**Unoccupied Energy Use Rate:** The rate of energy use in a system from 6PM to 6AM on a workday (i.e. not a Saturday, Sunday or Holiday).

**Weekday Energy Use Rate:** The rate of energy use in a system over a 24-hour period on a workday (i.e. not a Saturday, Sunday or Holiday).

**Weekend Energy Use Rate:** The rate of energy use in a system over a 24-hour period for Saturdays, Sundays or Holiday.

**Weekend Ratio:** A ratio of the Weekend Energy Use Rate to the Weekday Energy Use Rate. Expresses the amount of lighting or equipment left on the weekends or Holidays.

B. References


[CEC] California Energy Commission, *California Energy End-Use Study (CEUS).*


