Title

Making the Most of Energy Data: A Handbook for Facility Managers, Owners, and Operators

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Making the Most of Energy Data: A Handbook for Facility Managers, Owners, and Operators

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ABSTRACT

Advances in information technology (IT) have brought an explosion of data to the modern world. Inexpensive storage, cloud-based services, networked communications, and systems integration have opened access to volumes of information that was not previously available. Commercial buildings are no exception, and the intersection of IT and analytics offers an enormous opportunity to improve energy efficiency and reduce costs.

Energy management efforts rooted in monitoring and performance analysis have been shown to save 10-20% in site energy use without significant capital upgrades, and the industry has begun to respond. The commercial market offers a diversity of tools to support the analysis of utility, and interval meter data; utilities have begun to pilot programs to incent such technologies, and the market is rapidly evolving. At the same time, most owners, managers, and operators have little experience in analysis, and need support to interpret the data and transform it into actionable information.

In response, the authors have developed the *Energy Information Handbook: Applications for Efficient Building Operations*. The target audience is commercial building owners, operators and energy and financial managers. The eighteen analysis methods presented in the handbook can be implemented to improve operational efficiency and may be automated in commercial tools such as building automation systems, and energy information systems. This paper presents the design and content of the handbook and associated analysis methods – e.g., load profiling, system efficiencies, and baselining. To conclude, best practice uses and associated energy savings are discussed, with dissemination plans and future directions.

Design Elements of the *Energy Information Handbook*

To target an audience with diverse backgrounds and little prior experience in energy analysis, simplicity in the design and content of the *Energy Information Handbook* was a key focus throughout the development process. The handbook does not assume prior knowledge in the analysis of building energy data, and emphasizes practical application examples over technical theory. In addition, it is written in an accessible language; the second person voice is used, technical jargon is minimized, and a base set of terms is defined in the glossary. For ease of navigation, each chapter is color-coded, quick-search tabs are included along the page borders, and the electronic PDF version of the handbook is extensively hyperlinked. A number of these graphical design elements are shown in Figure 1.

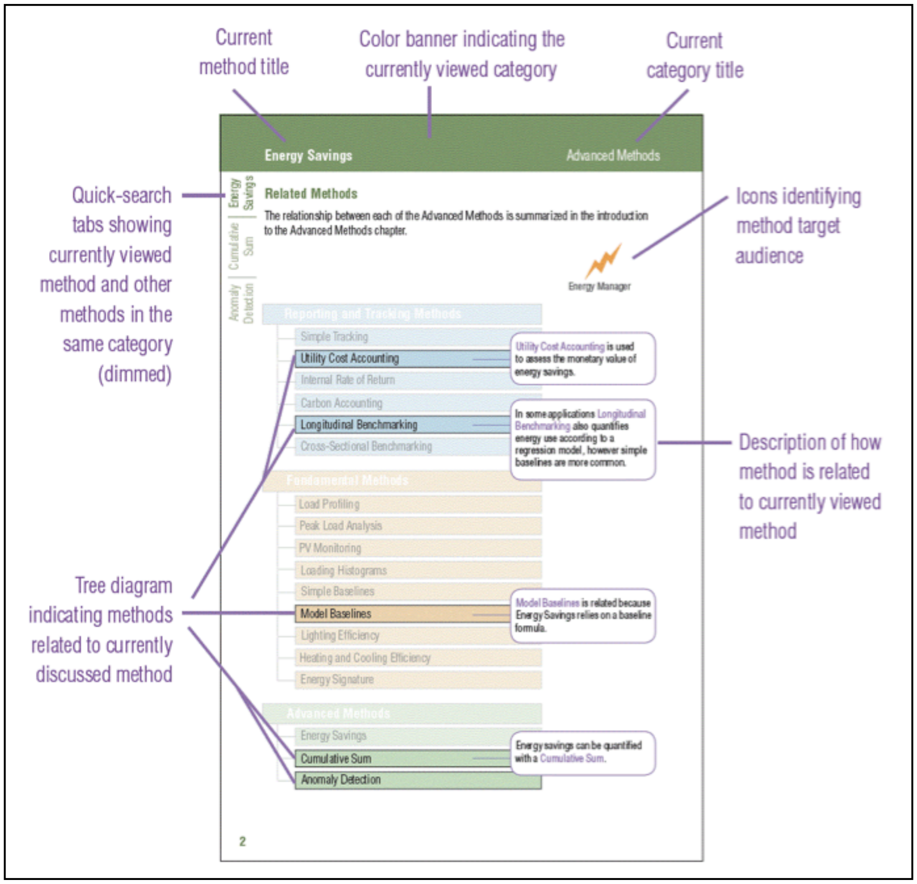

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Figure 1. Navigational and Design Elements of the *Energy Information Handbook*

Organization and Content Overview

The *Energy Information Handbook* is broken into five chapters: "Introduction", "Reporting and Tracking Methods", "Fundamental Methods", "Advanced Methods", "Fault Detection and Diagnostics" (FDD), and an "Appendix". To first order, the chapters are organized from simpler to more complex content. The final two chapters, "FDD" and the "Appendix", contain the most advanced concepts and theoretical material emphasizing the technical foundation of the methods.

The eighteen analysis methods that are included in the handbook were defined and selected with critical feedback from a technical advisory committee comprised of industry professionals and technology owner and vendor stakeholders. These methods form a collection of analysis approaches deemed most useful to a target audience with little prior experience in the use of energy data. In defining and selecting the analysis methods that were included, special attention was devoted to ensuring that they methods only require commonly available data, that they be applicable to both whole-building and system investigations, and that they be able to reveal the most common sources of inefficiency in buildings.

The core content of the handbook *Energy Information Handbook* comprises overviews of the eighteen analysis methods, in three core chapters. Each method is presented according to a common template:

- *Summary* a page that describes the purpose, target audience (e.g., energy manager, operator, financial manger), and high-level description of the associated technical approach.
- *Calculation and Programming* a page that provides a summary of commercial tools that may offer the analysis method, and required data and step-by-step computational examples, for those who wish to program or configure their own analyses.
- *Related Methods* a page that informs the reader how the current method is similar to or different from the others in the handbook.
- *Application Examples* three to five annotated examples are provided for each method to:
  - instruct the reader in how to interpret the method output and associated plots
  - illustrate the energy and cost benefits of applying the methods in real buildings
  - demonstrate different investigations/questions that can be answered by applying the method

The next sections of the paper provide an overview of the "Introduction" chapter, the three chapters dedicated to the analysis methods, and the "Fault Detection and Diagnostics" chapter. These sections include six application examples that illustrate the specific ways in which selected analysis methods can be used. Rather than replicating the application examples in text, high-resolution, full-page screen shots are provided to communicate the instructional approach, illustrate insights that the methods can generate, and highlight associated energy and cost savings.

"Introduction" Chapter

The "Introduction" chapter serves as an orientation to the *Energy Information Handbook*. It covers the target audience, and descriptions of the chapters and associated analysis methods, and at-a-glance summary tables. The summary tables, shown in Figure 2, recognize the fact that readers may not immediately know which methods are most applicable to their buildings, and are not likely to read the handbook from cover to cover. They allow the reader to scan across the full set of analysis methods to identify minimum data requirements, applicable building systems, and the level of expertise needed to interpret or use the method.

Applicable Building Systems

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

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

Minimum Data Requirements

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

WB = whole-building.

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

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Figure 2. Summary Tables - Applicable Building Systems and Minimum Data Requirements

"Reporting and Tracking Methods" Chapter

The chapter titled "Reporting and Tracking Methods" includes approaches used to gauge financial, energy, and carbon performance. As indicated in Figure 2 they can be applied to specific building systems; however, they are most commonly used at the site or portfolio level. These methods can use utility billing information, and may not require interval meter data or sensor time series data.

Simple Tracking: Monthly or annual energy use is tracked to quantify changes over time and identify increases or decreases in consumption or costs. Energy use from one time period to another is inspected for increases or decreases, or for long-term upward or downward trends. Simple tracking is the starting point for the other analysis methods, and is the first step in measurement-based approaches to energy management.

Utility Cost Accounting: Energy use is converted into billed costs for use in budgets and financial projections, possibly including demand charges and specific tariff structures. Cost accounting based on utility bills attributes energy costs to the account holder; whereas, cost accounting based on submeters downstream of the utility meter can be used to pass utility charges on to tenants. Likewise, submeter cost accounting provides a means of valuing operational and efficiency changes to systems or components.

Internal Rate of Return (IRR): The benefit of energy efficiency measures is quantified using a capital budgeting metric that accounts for the time value of money. IRR is an investment decision-making method based on cash flow, which quantifies the expected or achieved financial benefit of energy improvements. Using IRR, potential efficiency measures can be evaluated, and expected benefits can be confirmed. It can be applied to the energy cost savings associated with any efficiency project, and therefore to any building system, building, or collection of buildings.

Carbon Accounting: Building energy consumption is converted into carbon emissions for foot-printing and sustainability reporting. Emissions associated with building energy use include direct emissions from the fuel used to operate the building and indirect emissions to generate purchased utilities.

Longitudinal Benchmarking: Current energy performance is compared to past performance to identify trends and opportunities for improvement. Energy usage in a fixed period for a building, system, or component is compared to a to a baseline period of the same length, to determine if performance has deteriorated or improved, to set goals for a building or system, or to monitor for unexpectedly high usage.

Cross-Sectional Benchmarking: Building energy performance is compared to that of a comparable group of buildings to determine performance relative to peers. This type of benchmarking is the first step to determine if a building has the potential to improve its efficiency. It is usually done at the whole-building level, to assess a building's overall energy efficiency, using a metric such as kBtu/sf or kBtu/student (for a school).

Figure 3 contains application examples for Internal Rate of Return and Utility Cost Accounting. In these examples, IRR is used to select between 2 efficiency measures being considered for implementation, and simple tracking is used to reveal potentially inefficient buildings within a portfolio

"Fundamental Methods" Chapter

The "Fundamental Methods" chapter includes system-specific and whole-building analyses, and require relatively more user expertise than the "Reporting and Tracking or Advanced methods". They tend to require interval meter data or other time series, such as temperature data. This core set of analyses is used to reveal energy waste and opportunities for operational efficiency improvements.

Load Profiling: 24-hour periods of interval meter data are inspected on a daily or weekly basis to understand the relationship between energy use and time of day. Abnormalities or changes in load profiles can indicate inefficiencies due to scheduling errors, unexpected or irregular equipment operation, high use during unoccupied hours, or untimely peaks.

Peak Load Analysis: The size, timing, and duration of the peak load is analyzed to identify efficiency and cost-saving opportunities, including reductions in utility demand charges, the relationship between minimum and maximum loads, and system sizing.

Photovoltaic (PV) Monitoring: Time series of PV array generation are investigated to determine renewable electrical energy production, account for displaced conventional electricity, and "net" electrical energy use, and evaluate the overall condition, or "health" of the PV array.

Loading Histograms: HVAC system loading, and operational hours at each load are plotted to evaluate whether HVAC equipment is properly sized and staged, given the operated condition of the building. They are also used to identify potential retrofit solutions and optimizing control of multi-unit staging.

Simple Baselines: Simple normalization factors such as degree-days or square feet are applied to characterize and quantify standard energy performance for comparative or benchmarking analysis.

Model Baselines: Regression models are used to characterize energy performance according to weather and other variables that drive energy consumption; model baselines may also be used for anomaly detection and measurement and verification of energy savings. These baselines are typically not used independently, but as the fundamental underlying component of the Advanced Methods.

Lighting Efficiency: An 'as-operated' efficiency metric is computed from interval data and tracked to reveal excessive use or commissioning or control problems. The operational efficiency metric represents the percent of installed power that is in use at any point in time, and can be used to monitor the effectiveness of diverse control strategies.

Heating and Cooling Efficiency: The operational efficiency of heating or cooling systems is tracked to prevent degradation due to lack of proper maintenance or inefficient controls and to verify manufacturer performance specifications.

Energy Signature: inspect x-y pots of load vs. outside air temperature are inspected to identify weather dependencies and general potential for improved operations. The simple energy signature can be slightly modified to facilitate baselining, or over-time efficiency comparisons, or serve as a starting point for model baselines and more advanced analysis.

Figure 4 shows application examples for Load Profiling and Energy Signature. In these cases, load profiling is used to *visually* identify energy waste due to release of nighttime HVAC setbacks.

"Advanced Methods" Chapter

Each of the analyses in the Advanced Methods" chapter requires interval meter data and (in best practice cases) a baseline model that can robustly quantify expected or forecasted energy use. Although they are the most sophisticated and computationally intensive methods in the *Energy Information Handbook*, they involve less manual inspection than the Fundamental Methods, and therefore require minimal expertise to interpret.

Energy Savings: Total energy savings associated with an efficiency improvement are quantified using a baseline model to characterize use before and after the improvement. The Energy Savings method allows building owners, energy service companies, and financiers of energy-efficiency projects to verify the energy-savings performance of energy conservation measures or efficiency programs.

Cumulative Sum: Running totals of energy savings or increases are computed relative to a baseline, and accumulated over time. The total accrued energy savings or losses are used to gauge energy waste or performance relative to operational changes.

Anomaly Detection: Abnormal energy use is automatically identified based on the difference between the expected use indicated by a baseline model, and actual metered energy use. Anomaly detection may be paired with alarming and used as part of monitoring-based commissioning routines. Abnormal energy use can be isolated to a specific system or zone, based on a combination of user knowledge and supplementary data such as submetered loads, equipment schedules, and outside air temperature.

Figure 5 shows application examples for the use of Cumulative Sums to identify gas waste and totalize energy savings, and for the use of Anomaly Detection to *automatically* flag waste due to relaxed HVAC setpoints. This is in contrast the visual approach used in Figure 4.

Example 2: Measure Selection with IRR and NPV

(A) Either occupancy sensors or time clock scheduling could be implemented.
(B) Estimated annual savings and initial costs differ in each case.
(C) IRR is above the typical cost of capital in both cases, so either is a good investment.
(D) To determine which of the two options should be selected, NPV is considered.
(E) Since occupancy sensing carries a higher NPV, it is the better investment.

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

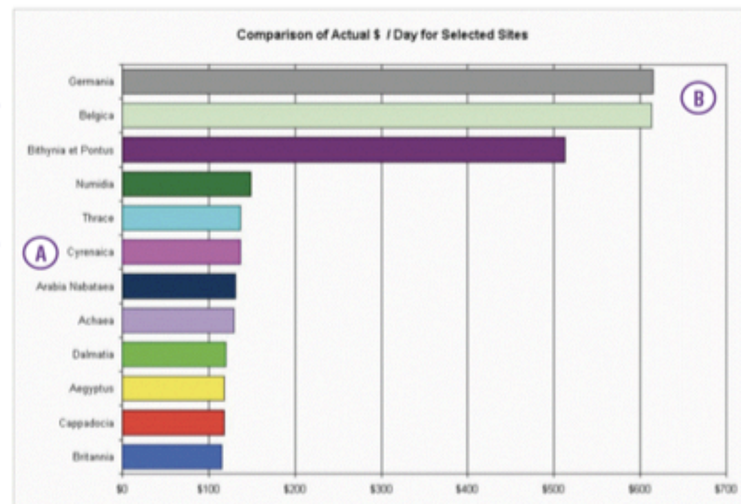
Option A: occupancy sensors ← (A) → Option B: central time clock

Year	Initial investment ($)	Energy savings ($)	Initial investment ($)	Energy savings ($)
0	–42,000	—	–9,000	—
1	—	12,200	—	3,550
2	—	12,200	—	3,550
3	—	12,200	—	3,550
4	—	12,200	—	3,550
5	—	12,200	—	3,550
6	—	12,200	—	3,550
7	—	12,200	—	3,550
8	—	12,200	—	3,550
9	—	12,200	—	3,550
10	—	12,200	—	3,550
IRR		**26.2%** ← (C) →		**37.9%**
NPV (10% discount rate)		**80,000** ← (D-E) →		**26,500**

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

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

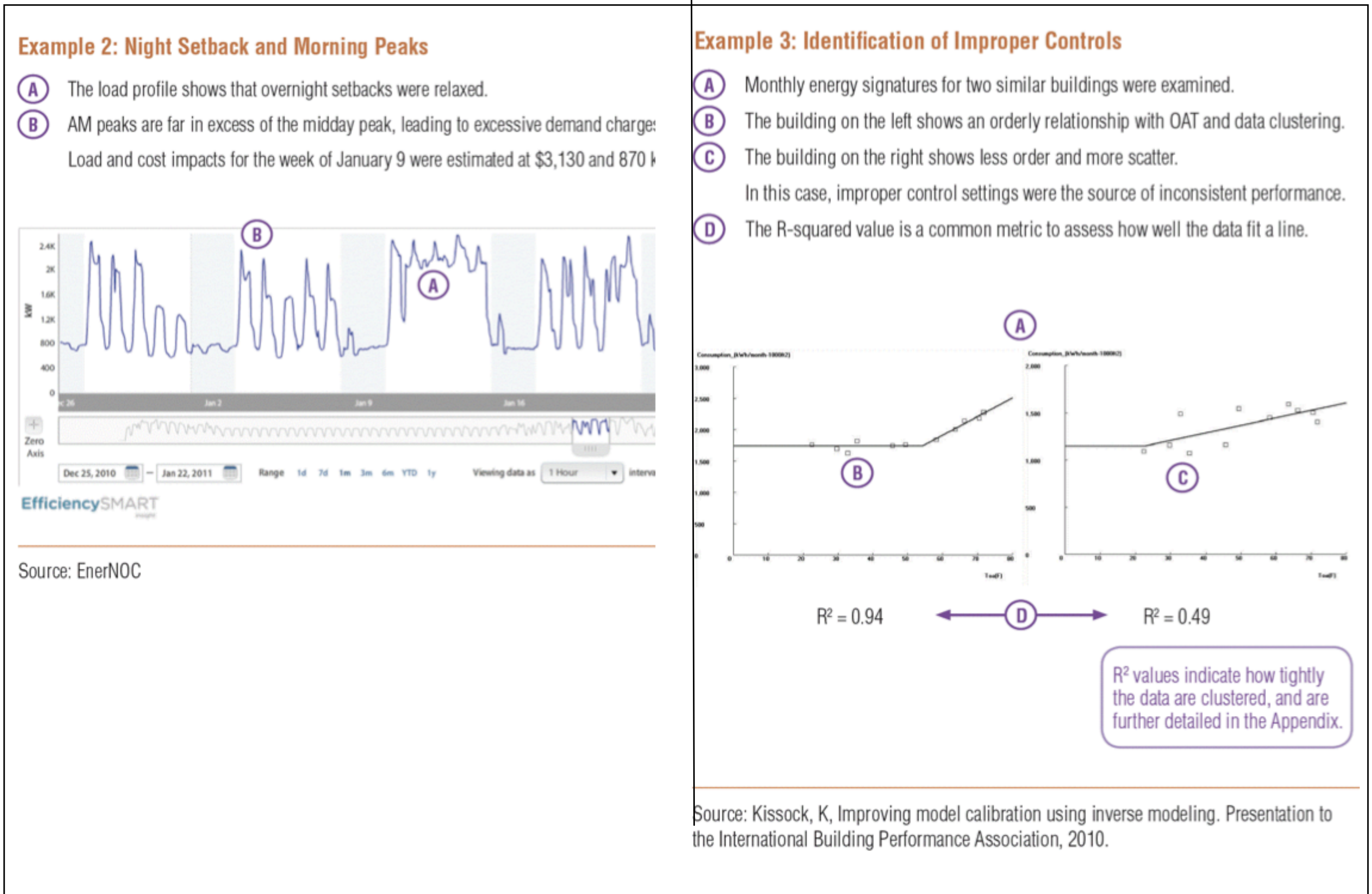
(A) Daily energy costs are tracked for each building in a portfolio.
The buildings have similar use-types and HVAC systems, making comparisons valid.
Billed utility costs for gas and electric are totaled for each site.
(B) The three buildings with high costs should be further investigated.
A simple model that normalized by sq ft would support more refined investigations.



Source: Abraxas Energy Consulting

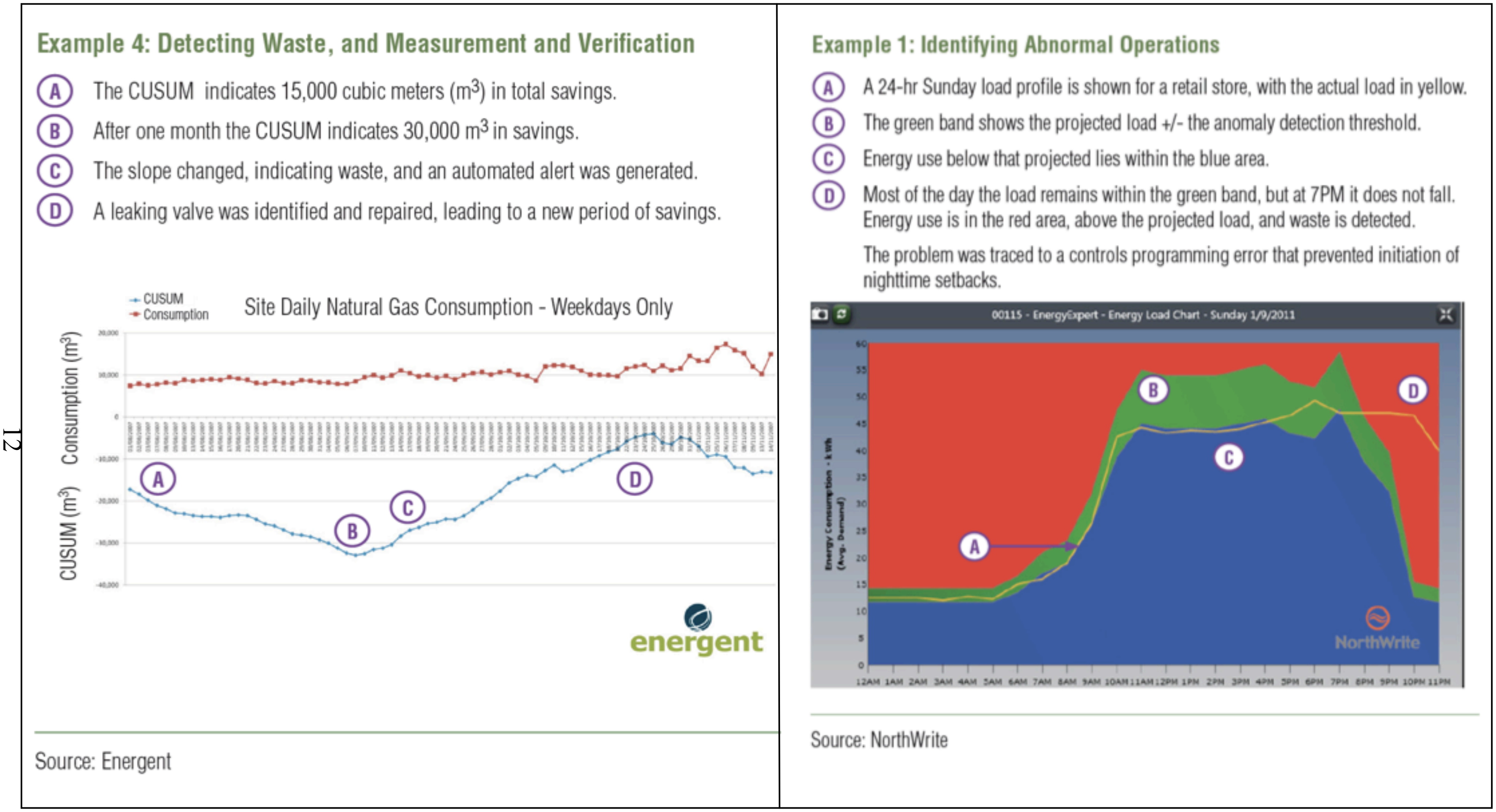
Granderson et al. 2011. Images provided by E Source Companies L.L.C, Boulder CO, and Abraxas Energy Consulting

Figure 3. Internal Rate of Return and Utility Cost Accounting, Application Examples



Granderson et al. 2011. Images provided by EnerNOC and (Kissock 2010)

Figure 4. Load Profiling and Energy Signature, Application Examples



Granderson et al. 2011. Images provided by Energent and NorthWrite

Figure 5. Cumulative Sum, Anomaly Detection, Application Examples

"Fault Detection and Diagnostics" Chapter

The last chapter introduces fault detection and diagnostic methods, which are used to detect system equipment faults early, and to identify their causes. This enables building managers to correct the faults and prevent energy waste, additional damage to the system, or loss of service. FDD can be performed "manually" through visual inspection of charts and trends or can be fully automated. In the automated case, algorithms use measured time-series data and set-up data that describe the equipment and system characteristics (such as setpoints and type of control) to generate actionable information for operational staff. Automation streamlines the FDD process and enables continuous performance tracking. Many methods exist for automated FDD, but rule-based methods, broadly classified as first-principle qualitative models, are most commonly employed in commercial FDD tools. With this approach, qualitative relationships or "rules", are derived from knowledge of the underlying system operation. Application examples for both manual and automated FDD are provided in the handbook.

Best Practice Uses of the Analysis Methods in the *Energy Information Handbook*

This collection of methods in the *Energy Information Handbook* span multiple levels of analysis, from portfolio to whole-building and system investigations, and there is considerable overlap between them. For example, Lighting Efficiency is effectively a system-level application of normalized load profiling. Used in combination with one another, the collection of methods can be used to generate multiple insights into a common set of "root" aspects of energy performance. For those who are new to continuous energy performance monitoring and data analysis it is useful to highlight best practice applications. In general, it is best to first focus on monthly or annual energy tracking, and then move into whole-building interval analyses and system- specific investigations. This approach recognizes that skill will increase with experience, and that resources may need to be expanded gradually, as budgets and human resources permit.

The first investigations that a reader performs should leverage universally available utility billing data, to develop a habit of routine energy tracking and to understand how the building's energy performance ranks relative to peers. Simple Tracking, Utility Cost Accounting, Carbon Accounting, and Cross-Sectional Benchmarking all support these initial investigations. Next, the reader should focus on whole-building interval data to understand how much energy is used at different times of day and to identify opportunities related to the scheduling and control of major systems. Longitudinal Benchmarking, Load Profiling, Peak Analysis, and Anomaly Detection are especially useful for gaining insight into whole-building aspects of operation.

Once the reader has a solid understanding of whole-building behaviors and energy performance, system-specific analyses can be incorporated into the continuous energy management approach. Lighting Efficiency, Sizing Histograms, PV Monitoring, Longitudinal Benchmarking, and Load Profiling are the simplest methods to apply and interpret. HVAC Efficiency and Energy Signatures can be applied to continuously monitor heating and cooling system operations once sizing is verified and simple load profiles are thoroughly reviewed. Methods such as Internal Rate of Return, Utility Cost Accounting, Energy Savings, and Cumulative Sum should be used to explicitly quantify the financial and energy benefits of performance improvements. These can be applied to capital projects and to monitor continuous energy management initiatives.

Conclusions and Future Directions

The energy savings that are achievable through continuous performance monitoring and analysis depend on several factors, including how poorly the building performed before tracking was initiated, the availability of and depth of metered data, the level of engagement of the operator or facility manager, and their ability to take action once problems are identified. Research on the costs and benefits of commissioning has shown that existing buildings waste 16% on average, due to inefficient operations [Mills 2009]. The system-level and FDD analysis methods presented in the *Energy Information Handbook* can expose many such inefficiencies. *Monitoring-based* commissioning, or the use of permanent metering for continuous performance analyses is documented to save 9% in energy use [Mills and Mathew 2009]. Moreover, performance analyses applied at the whole-building level can reveal inefficiencies in heating and cooling systems, as well as in lighting and plug loads, and loads that may not be individually submetered. Case studies have shown 5-25% site or portfolio energy savings, quick payback, high return on investment, and persistent low-energy performance in cases where an organization has implemented a continuous energy monitoring and analysis program, in combination with enabling software tools and accountable staff [Capehart and Middelkoop 2011; Granderson 2010; Motegi 2003; Smith 2011].

This paper provided an overview of the development and content of a new resource to assist energy managers, operators, and owners in applying data analysis methods to save energy. These methods, initially created by energy engineers and domain experts, are available in commercial performance monitoring tools, or can be applied using programmable data analysis tools, such as spreadsheets. The technical literature documents the value of these methods, and their application to buildings, however the use of data for operational efficiency is still not business-as-usual in today's buildings. Development of the handbook was therefore motivated by a desire to make existing technical knowledge widely accessible and usable by non-engineers.

To increase awareness of this resource, the authors have distributed release announcements to a number of building energy professional organizations, consortiums, newsletters, and blogs. They have also begun to include the Handbook in webinars and workshops sponsored by organizations such as the California Commissioning Collaborative, Department of Energy, and Consortium for Energy Efficiency. After four months release, the Handbook has been downloaded approximately 900 times, indicating solid public interest. Moving forward, opportunities to publish hard copies of the handbook will be explored, and for maximum impact, the authors will create modular instructional material for inclusion in educational courses and seminars. Early adopters are expected to include federal agencies striving to meet building energy reduction mandates; participants in utility programs that target monitoring-based and continuous commissioning; participants in DOE's Commercial Building Energy Alliances; and campuses pursuing efficiency improvement initiatives.

Future research will target 1) making analytics accessible to small and medium commercial sites, with energy expenditures that are often too small to justify the first costs of commercial monitoring and analysis tools; 2) providing standard methods for authoring, sharing, testing, and improving advanced analytical methods to enhance operational efficiency; 3) creating market demand for building energy analytics and technologies such as energy information systems.

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