



**U.S.–India Joint Center for Building Energy
Research and Development (CBERD)**

**Energy Information Systems:
From the Basement to the Boardroom**

Reshma Singh, Paul Mathew, and Jessica Granderson
Lawrence Berkeley National Laboratory, USA

Yash Shukla
Center for Environmental Planning and Technology, India

Aug 31, 2019

This page is intentionally left blank.

Acknowledgements

The U.S. Department of Energy (U.S. DOE) and the Department of Science and Technology (DST), Government of India (GOI) provided joint funding for work under the U.S.–India Partnership to Advance Clean Energy Research (PACE-R) program’s U.S.–India Joint Center for Building Energy Research and Development (CBERD) project. The Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, of the U.S. DOE under Contract No. DE-AC02-05CH11231 supports the U.S. CBERD activity. The DST, GOI, administered by Indo-U.S. Science and Technology Forum, supports the Indian CBERD activity.

Thank you to Dylan Cutler at the National Renewable Energy Laboratory, Dan Brown at Cascade Energy, and reviewers Sam Fernandes, Guanjing Lin, and Claire Curtin at Lawrence Berkeley National Laboratory (LBNL).

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California.

This page is intentionally left blank.

**Energy Information Systems:
From the Basement to the Boardroom**

Authors

Reshma Singh, Paul Mathew, and Jessica Granderson

Lawrence Berkeley National Laboratory, USA

Yash Shukla

Center for Environmental Planning and Technology, India

Technical Report

Aug 31, 2019

This page is intentionally left blank

TABLE OF CONTENTS

1. Introduction	10
1.1 Context.....	10
1.2 Target segment and audience for this report.....	11
1.3 Barriers.....	11
1.4 Opportunity in the office sector.....	13
1.5 General characterization of the office sector in U.S. and India	13
1.6 Triple bottom-line benefit of energy efficient, green offices.....	17
1.7 Overall objectives and our approach for packaged EIS.....	18
2. Methodology and Results	18
2.1. Transaction cost framework	19
2.2 Characterization of heterogeneity.....	21
2.2.1 Heterogeneity of the physical infrastructure	21
2.2.2 Heterogeneity of organizational characteristics	25
2.3 Analytics assessment	27
3. Results: Technical requirements for EIS-in-a-box packages for offices	29
3.1. The Entry EIS package	31
3.1.1 Organization type	31
3.1.2 Metering and data requirements	31
3.1.3 Included visualization and analysis.....	32
3.1.4 Required service levels	32
3.2 The Advanced EIS package	35
3.2.1 Organization type	35
3.2.2 Metering and data requirements	35
3.2.3 Included visualization and analysis.....	35
3.3. Software and user interface for the tiers	39
4. Conclusions	42
References and Literature Review	53

LIST OF FIGURES

Figure 1: Similarities and differences between U.S. and Indian Class A offices14

Figure 2. Energy Performance Index (EPI) using site energy data for various types of commercial facilities in India15

Figure 3: Electricity end-use consumption for a typical commercial office (left) and an IT office space (right) in India16

Figure 4: Average energy consumption by end use for typical commercial offices in United States17

Figure 5: Energy Information Systems (EIS) consist of data acquisition sensors and interval meters, communication gateways, and performance monitoring software with a user interface. These systems collect, analyze, and display building energy data19

Figure 6: Typical transaction cost framework for the specification, installation, and use of EIS.20

Figure 7: Office facility energy consumption, by energy source22

Figure 8: Typical list of Energy Sources and end uses in office facilities23

Figure 9: Decision framework for the picklist of loads. Please note that this graphic is illustrative, and is not the comprehensive suggested picklist.....25

Figure 10: Entry and Advanced tier functionality, built around prioritized support provided to business drivers.....26

Figure 11: A list of short-term questions that inform the facilities dashboard27

Figure 12: A list of high-level questions that inform the monthly/annual dashboard, targeted primarily for decision making at the owner/executive level. Additional facilities-level charts are also provided for the facilities staff28

Figure 13: Features and functionality of EIS Packages are mapped to office-specific business drivers29

Figure 14: Entry tier EIS package for office facilities33

Figure 15: Advanced tier EIS package for office facilities37

Figure 16: Facility Dashboard “Building Pulse at a Glance” for EIS Office packages: for daily or weekly use40

Figure 17: Annual Dashboard for EIS Office packages41

Figure 18: Range of organizational and technical factors addressed in the two tiers of EIS packages as compared to ‘no EIS’ and ‘custom EIS’ situations.....43

Figure 16(a): Details of Dashboard charts; Daily Chart #1 Energy Use Area Chart. Can be used for daily and weekly view using toggles. For both Entry Tier 1 and Advanced Tier 2 packages.....45

Figure 16(b): Details of Dashboard charts; Daily Chart #2. Power Demand Trendline chart. For both Entry Tier 1 and Advanced Tier 2 packages.46

Figure 17(a): Details of Dashboard charts; Monthly Chart #1. Fuel-type consumption and cost chart. For both Entry and Advanced tiers.47

Figure 17 (b): Details of Dashboard charts; Monthly Chart #2. Cost trending chart. For both Entry and Advanced tiers.48

Figure 17(c): Details of Dashboard charts; Monthly Chart #3. End-use breakdown chart. For both Entry and Advanced tier.49

Figure 17(d): Details of Dashboard charts; Monthly Chart #4. Benchmarking chart. For Advanced tier.50

Figure 17(e): Details of Dashboard charts; Monthly Chart #5. Average Loads chart. For both Entry and Advanced tiers.....51

Figure 17 (f): Details of Dashboard charts; Monthly Chart #6. Whole Building Power Heat map. For Advanced Tier 2 only.....52

LIST OF TABLES

Table 1: Metering and gateway requirements for EIS packages30

Table 2: Picklist of loads for the Entry Tier 1 EIS package based on end uses and physical spaces in an office facility34

Table 3: Picklist of loads for the Advanced Tier 2 EIS package based on end uses and physical spaces in an office facility38

Energy Information Systems: From the Basement to the Boardroom

1. Background

1.1 Introduction

The U.S.–India Joint Center for Building Energy Research & Development (CBERD) was created through the Partnership to Accelerate Clean Energy (PACE) agreement between the United States and India. CBERD was a research and development (R&D) center with over 30 institutional and industry partners from both nations. The U.S. Department of Energy and the Government of India jointly funded this five-year presidential initiative. CBERD aimed to build upon a foundation of collaborative knowledge, tools, technologies, and capabilities to increase the implementation of high-performance buildings (CBERD, 2012).

To reach this goal, the CBERD R&D focused on energy use reduction throughout a building's entire lifecycle—design, construction, and operations. During the operations phase of buildings, even with best-practice energy efficient design, actual energy use can be much higher than the design intent. Every day, much of the energy consumed by buildings is wasted, serving no purpose (Roth, 2005). Two of the CBERD research partners, Lawrence Berkeley National Laboratory (Berkeley Lab, U.S.) and the Centre for Environmental Planning and Technology (CEPT University, India) developed this study to identify solutions to close this gap and between the design intent and operational energy performance of commercial buildings.

One of the tools used in the U.S. to help reduce energy waste is a building energy information system (EIS). EIS are a component of a broad and rapidly evolving family of tools, called Energy Management and Information Systems (EMIS), that monitor, analyze, and in some cases, control building energy use and system performance. EMIS technologies include benchmarking and utility bill tracking software, energy information systems (EIS), building automation systems, fault detection and diagnostic (FDD) tools, and automated system optimization (ASO) software (U.S. DOE, 2016). Through an EIS one can use interval meter energy data to identify consumption patterns, track energy use, identify waste, and benchmark building energy performance against similar buildings. Owners, energy, and sustainability managers, and facility operators can use the data analytics provided by an EIS to drive energy efficiency and improve building performance.

Our research team identified potential operational energy savings of approximately 10 % in the U.S. commercial sector (~2 quads of primary energy in the U.S.), while industry building energy audits in India have indicated potential energy savings of up to 30 % in commercial buildings (~0.1 quads of primary energy in India) through energy monitoring and management (Singh, 2019). Additionally, offices, healthcare facilities (e.g., hospitals, clinics), and hotels are among the three highest-growth building typologies in India that

have significant energy consumption; and which could benefit most from the implementation of EIS. This study focuses on EIS in the office building typology.

There is a proliferation of EIS providers in the U.S. market alone, with varying levels of technical capability and cost (U.S. DOE Smart Energy Analytics, 2016). However, the adoption of such systems is largely limited to large enterprises, campuses, or buildings with large energy expenditures that justify the first and ongoing cost of using the EIS. These systems include diverse levels of software features, component and data integration, and analysis options, making them complicated to procure, install, and use. Price, security, and ease of use remain barriers to the adoption and pervasive use of such promising technologies (Accenture, 2016). These barriers are detailed further in Section 1.2.

We believe that these barriers can be addressed through the development of ready, simplified, consistent, commercially available, low-cost EIS packages, or “EIS-in-a-box”. These CBERD EIS packages would have a pre-defined set of hardware components and software features and functionality that are pertinent to a particular building sector. Simplified, sector-specific EIS packages can help to obviate the need for customization, and enhance ease of use, thereby enabling scale-up, in order to facilitate building energy savings. The CBERD EIS-in-a-box are adaptable in both the United States and India, and potentially beyond these two countries.

1.2 Target segment and audience for this report

This report focuses on EIS-in-a-box for new construction and retrofit of small and medium offices in both the U.S. and India. In India the primary target segment is new Class A¹ office buildings. There are two primary audiences for this publication: (1) commercial office building owners and managers, especially small and medium sized facilities and organizations and (2) EIS companies and vendors who can adopt these technical requirements into EIS product solutions to enable deeper market penetration in traditionally untapped markets, encouraging scale-up in both countries.

1.3 Barriers

Significant drivers exist for organizations to conduct building energy monitoring in office facilities. External drivers range from city energy disclosure ordinances, legislative acts, standards and guidelines for voluntary commitments to reduce energy efficiency. For instance, in the U.S. the Energy Policy Act of 2005 requires hourly electricity interval data; the ASHRAE 90.1-2013 standard incorporates a number of submetering requirements for buildings over 25000 sqft, and ISO 50001 energy management standard requires

¹ Per the Building Owners and Managers Association International (BOMA), Class A commercial buildings are the most prestigious buildings competing for premier office users with rents above average for the area. These buildings typically have high quality finishes and systems, good accessibility, and a definite market presence. Reference: <https://knowledge-leader.colliers.com/editor/how-a-is-your-class-a-building/>; accessed 25 May 2018.

organizations to use data to measure and monitor continual improvement of energy performance by integrating the management of energy into existing business practices.

In India, the Energy Conservation Building Code covers mandatory requirements for electrical power that includes 'check metering and monitoring' (Energy Conservation Building Code, 2007). Organizations conduct building energy monitoring in order to enable strategic energy management, reduce utility bills, deliver better occupant comfort, gain operational and maintenance efficiency (e.g. aging equipment needing upgrade) and ease of replication across the organization's building portfolio.

However widespread adoption of EIS is a challenge. We conducted stakeholder interviews with CBERD collaborators and identified several barriers that prevent wider adoption of EIS across the building sector through, such as:

1. **The high cost of building energy monitoring systems:** This high cost is the primary deterrent to the adoption of EIS products. The concern over pricing is amplified by the lack of a compelling value proposition provided to potential users
2. **The importance of cyber security and data privacy:** This is driven by sensitivity of enterprise and financial systems. Security is a significant barrier as consumers elect to abandon energy-related software products and services over cyber security concerns.
3. **Lack of stakeholder concurrence:** Since the energy information is confined to the facilities staff and management. Other stakeholders—such as the IT staff that deal with security, or investment decision makers such as executives and commercial real estate stakeholders are usually not brought on board early enough, do not get visibility into energy expenditures, or the insight into the impact that energy can have on the organization's carbon footprint.
4. **Lack of integration:** Since the building industry is siloed, with multiple vendors providing discrete building systems. The integration of data from legacy or new systems, meters, and controls is typically time consuming and can be prohibitively expensive. Even if companies install expensive building automation systems (BAS), accessing energy data from the system often means additional cost and complication.
5. **Heterogeneity within building typologies or sectors:** Unlike standardized vehicle models, office buildings are not standard, and require facility-wise customization. There is a wide diversity and complexity of spaces, loads, systems, and equipment in different types of offices, with diverse, tenancy, occupancy and unstandardized electrical circuitry. This leads to high level of transaction effort, time, and cost for the configuration and delivery of the EIS.

6. **Slow adoption in organizations:** This is owing to a legacy mindset in bidding and construction practices. Since EIS are not widgets, organizations may not know how to establish a roadmap of organizational activities to integrate the technology into processes and ramp up sophistication over time.
7. **Emphasis on non-energy imperatives:** For example, high-end offices are expected to provide high levels of service and comfort, exceptional tenant/occupant experience, and profitability; whereas, energy is a non-critical or missing value for decision makers.
8. **Lack of robust metrics to define building performance that may provide a link between productivity and operations:** The impact of employee productivity is much greater than energy savings on the bottomline; however current metrics are just only beginning to explore this important link. This is a missed opportunity for creating and delivering value.
9. **Lack of involvement of the building occupant:** For instance, office occupants and tenants do not feel connected to the way the buildings are operated or the energy use. They do not take ownership of their workplace as they do with their homes, where they would take action to make their residential spaces more comfortable and reduce utility bills.

1.4 Opportunity in the office sector

A substantial energy-reduction opportunity exists in the office sector, given that this market segment typically is an early adopter of new technology. There is a rising trend towards smart and connected offices through the internet of things (IoT) that provides new opportunities for operational efficiency, environmental sustainability practices, and corporate social responsibility. Leading commercial real estate companies have begun to shift from individual building automation systems (BAS) to partially integrated and automated systems such as energy management systems (Deloitte 2016). In both the United States and India, organizations are seeking operational excellence, enhanced tenant relationships, and topline growth. Hence it is imperative to engage the executives with decision-making power, by tapping into their interest in sustainability, corporate social responsibility, and innovation. This expansion of interest can enable data-driven decisions, strong energy investments, and deeper energy benefits, and would drive innovation in this field. However, none of this would be possible without robust, consistent building energy information to provide visibility across all the levels of decision making.

1.5 General characterization of the office sector in U.S. and India

We categorized office buildings based on the following aspects:

- Ownership: Tenanted versus owner-occupied buildings
- Occupancy schedule: Single-, double-, or triple-shift offices
- Stage of lifecycle: New construction or retrofit

For each feature, we investigated any energy use implications and key performance indicators; these findings are discussed in Section 2.2.

Next, we assessed the similarities and differences in Indian and U.S. office facilities (Figure 1) to understand how the context would impact EIS package design. We found that Class A buildings in both countries have an inherent similarity in functional and asset characteristics; however, there are significant differences, particularly with respect to stage of lifecycle, occupancy patterns, and space standards.

	U.S. Class A Office buildings	Indian Class A Offices buildings
Stage	Primarily retrofits	Primarily new construction
Size of facilities	Distributed across small, medium and large facilities	Bulk of office space is for small businesses, occupying 10-20K sf
Space standards	20 m ² occupant (U.S. General Services Administration regulations)	6–10 m ² /person
Working hours	Primarily single shift	Single, double, or triple shifts
Typology of space	Primarily indoor offices, meeting rooms, break rooms	Indoor offices and meeting rooms, break rooms are often outdoors or semi-outdoors
Construction materials	Glass towers with high levels of fenestration and solar exposure	
Mechanical systems	Heating based on electricity or natural gas, and less frequently fuel oil, district heat or propane; Cooling based on electricity or rarely, district cooling	Primarily cooling, based on electricity. Heating not required even in coldest months due to high occupancy density and clo values ² . Air conditioning (not fan-generated air movement) is becoming the norm in Indian offices that are conforming to ASHRAE cooling and ventilation standards
Smartness of buildings	BAS and smart meters; a small segment uses EMIS	BAS and EMIS are uncommon. Smart energy meters, if present, are at the whole building level
Energy Use intensity (EUI)	Average ~300 kWh/m ²	Average ~240 kWh/m ²

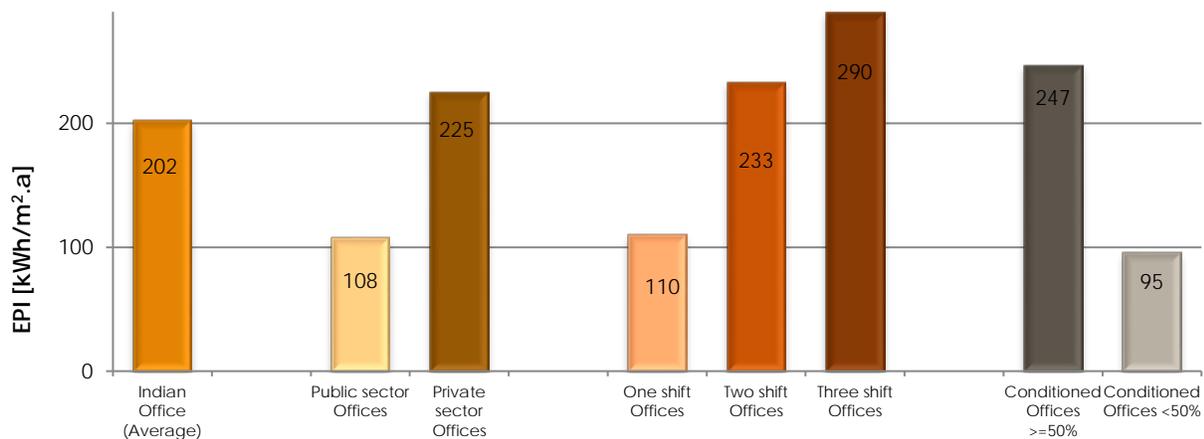
Figure 1: Similarities and differences between typical U.S. and Indian Class A office buildings.

² Relative measure of the ability of insulation to provide warmth. One clo is defined as the amount of clothing required by a resting (sedentary) person to be indefinitely comfortable at ambient conditions). Ranges from clo value (0) of a naked person, to (4) of cold weather clothing (fur pants, coat, hood, gloves, etc.). Reference: <http://www.businessdictionary.com/definition/clo.html#ixzz4CpRSOxw1>; accessed 25 May 2018.

1.5.1 Characterization of Indian offices

Commercial buildings in India were traditionally built with high thermal mass (brick, stone masonry) and punched windows with overhangs. These buildings used either natural ventilation or more recently mixed mode ventilation, with mini-split air conditioning systems as their principal ventilation and cooling strategy. Now, contemporary Class A office buildings are being designed and built as fully air-conditioned mid- to high-rise towers with glass facades incorporating information technology (IT) functions (Figure 2). These buildings have significant external and internal heat gains, and hence, high energy use intensity (EUI).³

A large share of existing and new Indian office space caters to high-density occupancy and multiple shift operations. While the average U.S. government and private sector offices have an occupant density of 20 square meters (m²)/occupant and 30 m²/occupant respectively, Indian offices have a typical density of ~6–8 m²/occupant in Tier 1 cities that have high real estate costs, and ~10 m²/occupant in Tier 2 cities. Business processing office (BPO) spaces have three-shift “hot seats”—a situation that conserves space because of its multiple usage but also leads to substantially higher EPI levels. Moreover, with the increased demand for multinational enterprise commercial office spaces and IT hubs, and the current privileges being accorded to Special Economic Zones (SEZs), the trend is towards larger buildings with fully conditioned spaces that are being operated with international standards. The EPI of various commercial buildings in India, normalized to three parameters- type (public/private), number of shifts, and amount of air conditioning is shown in Figure 2.



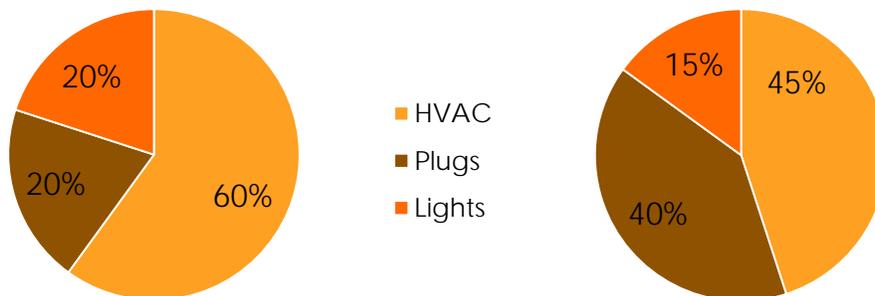
Source: Sarraf 2011

Figure 2. Energy Performance Index (EPI) using site energy data for various types of office buildings in India.

³ EUI is the energy use per square foot per year; the parallel measure in India is Energy Performance Index (EPI), which is energy use per square meter per year.

The increasingly higher energy use in Indian offices is potentially attributable to at least three factors (Singh, 2018):

- An exponential growth in the footprint of Indian office facilities.
- Aspiration towards primarily glass facades, leading to high external heat gain, coupled with a trend towards usage of primarily indoor, conditioned spaces with higher levels of climate control to avoid perspiration, odors, and outdoor pollution.
- A rapid increase in number of facilities with high plug loads and internal heat gain from IT equipment and multiple working shifts leading to a higher EPI. This is a shift from typical office facilities that have a different energy use profile. While the HVAC load remains the largest in Indian office buildings, at ~45%–60%, computing loads fluctuate between 20%–40% (Figure 3).



Source: Singh 2015

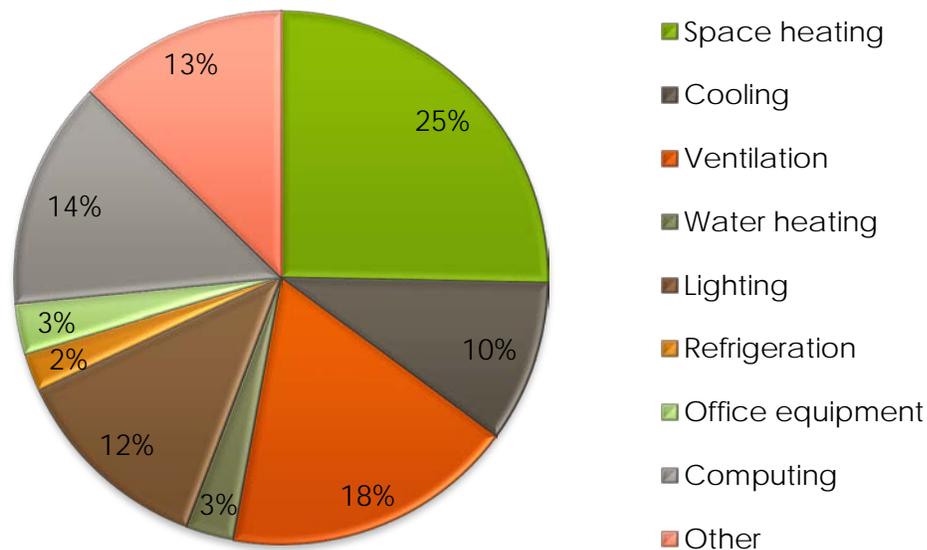
Figure 3: Electricity end use consumption for a typical commercial office (left) and an IT office buildings (right) in India.

Thus there are two intertwined effects: an increase in total building area and an increase in EPI. According to India’s Bureau of Energy Efficiency (BEE), electricity consumption in the commercial sector is rising at double the rate (11%–12% annually) of the average electricity growth rate of 5%–6% in the economy. To deliver a sustained rate of 8% to 9% through 2031–32 and to keep up with rising demand for electricity, India would need to add 15 gigawatts each year over the next 30 years (Bureau of Energy Efficiency, 2009). To manage and conserve the nation’s energy, it is imperative to aggressively manage building energy consumption.

1.5.2 Characterization of U.S. Offices

Energy represents 30% of operating expenses in a typical U.S. office building; this is the single largest (and most manageable) operating expense in offices (Kubba, 2010). According to the Commercial Buildings Energy Consumption Survey’s (CBECS, 2012), database of over 1,000 office buildings, heating, ventilating, and air conditioning consume over half the energy, followed by lighting, computing, and miscellaneous plug loads in 98% of offices (Figure 4). This is consistent with the Indian context as shown in figure 3 above.

Large U.S. office buildings have a high average EUI of ~80 kBtu/sf-yr (260 kilowatt-hours (kWh)/m²-yr), with an energy expenditure of \$2.42/sf in 2010 USD (CBECS, 2012). Monitoring, managing, and optimizing building loads can lead to lower first costs (through peak load reduction) and operating costs (through operational efficiency), both through energy saved and facilities maintenance. A study conducted at Berkeley Lab shows that EIS technologies enable median annual portfolio savings of 8% with up to 33% in portfolio savings in best-practice implementations (Granderson, 2013). A 30% reduction in energy consumption in office buildings can lower operating costs by 50 cents per square foot; in other words up to \$25,000 per year for every 50,000 square feet of office space (Energy Star, 2007). This value provided to the financial topline (gross revenue of a business) can elevate the energy conversation to the boardroom, leading energy savings through energy-oriented investment decisions.



Source: CBECS 2012

Figure 4: Average energy consumption by end use for typical office buildings in the United States.

1.6 Triple bottom-line benefit of energy efficient, green offices

This report considers a triple bottom-line framework for understanding benefit of energy efficient offices, i.e. economic, social, and environmental benefits. Apart from the direct first bottom-line financial benefit through operational savings, office spaces can command a premium based on the comfort and attractiveness of the environment. Optimizing daylighting and lighting can save energy, provide better views, and improve occupants' visual acuity. Similarly, well-designed mechanical systems can improve indoor air quality and reduce initial equipment and operating energy costs. Given that the bulk of working hours are being spent indoors, a better indoor environment can boost worker performance and reduce sick leave that could equate to monetary benefits to businesses. According to a study conducted by Berkeley Lab, green buildings can reduce

absenteeism by 40% and increase productivity by 5%. The same study shows that improving indoor temperature control and increased ventilation rates can provide benefit-cost ratios as high as 80 and annual economic benefits ~\$700 per person (Fisk, 2007). Hence, human health and productivity is a second bottom line that is important at the boardroom level. Human productivity provides the impetus to avoid costs and business disruptions by proactively addressing risks associated with poorly commissioned controls systems (Mills, 2015) that may impact human health and comfort. However, even though it is a strong driver, currently there are no rigorous measurement methods for measuring and acquiring data on the productivity and well-being of occupants. The third bottom line, natural capital, as environmental concerns are becoming an intrinsic part of corporate social responsibility. Triple bottom-line savings can be effectively realized through green, energy efficient buildings.

1.7 Overall objectives and our approach for packaged EIS

CBERD EIS packages are office sector specific and designed to be ready to install right “out of the box.” A simplified “EIS-in-a box” (Figure 5) product is conceptually geared towards owners and facility managers that are interested in understanding and reducing their property’s energy utilization but have minimal resources to research, procure, and configure a complex custom EIS solution such as those available currently.

It is also intended that vendors can integrate these technical requirements without needing to invent new or sophisticated components. The package is also intended for facility managers to conduct the first set of actions, easily operate and maintain the system, leading to reduced operating and service costs. Vendors and integrators with existing hardware, communications devices, and distribution channels should have fewer barriers to start selling in large quantities, which may lead to a lower price point.

2. Methodology and Results

To develop an EIS-in-a-box for offices, we followed three steps:

1. A **framing of typical transaction costs** for the initial installation, deployment, and use of EIS solutions.
2. A **characterization of heterogeneity** in the office sector in both countries, and its influence on hardware design and engineering.
3. An **assessment of required analytics**, to inform the user interface for the EIS packages.

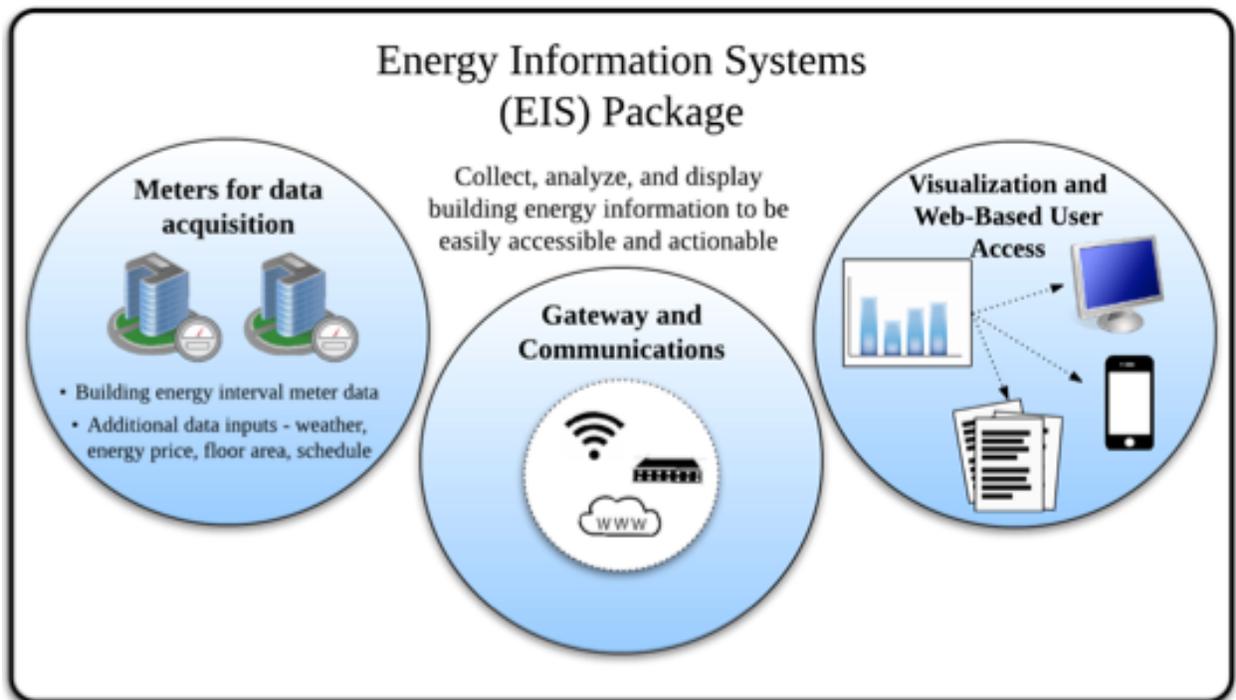


Figure 5: Energy Information Systems (EIS) consist of data acquisition sensors and interval meters, communication gateways, and performance monitoring software with a user interface. These systems collect, analyze, and display building energy data.

2.1. Transaction cost framework

Transaction cost is defined as costs other than the money price that is incurred in trading goods or services...activities (that) involve opportunity costs in terms of time, effort and money (Johnson, 2005).

The transaction process involves the time and effort required to deliver a product. For an EIS solution, this can typically be characterized as a four-step process, as shown in Figure 6. Each step takes time and effort that leads to overhead costs borne by the vendor, and presumably passed on to the client. Through vendor interviews, we determined that a significant portion of the cost is in implementing steps 1–3 (i.e., securing a client, system design, configuration and installation). These steps may be streamlined for a new facility, (e.g. the time taken for steps 2-3 may be shortened if the electrical circuitry of a new facility is designed to be viable for simple submetering). Through packaging of EIS, the intent is to streamline these steps to reduce the time and first cost incurred to the facility owner for installing and operating an EIS. The CBERD target is that within a compressed period of transaction time (on the order of a few days) the product requirement can be fulfilled and the installation completed.

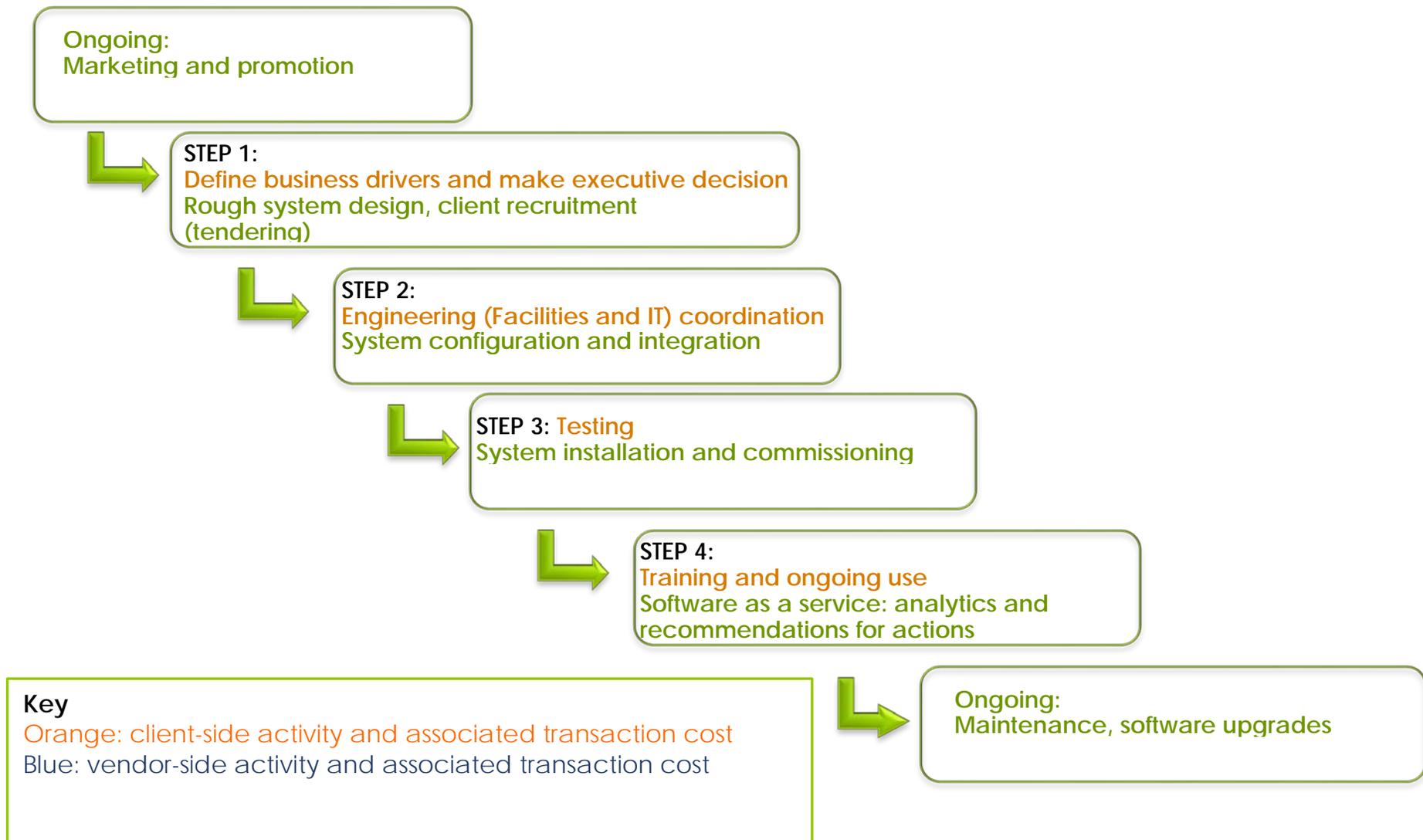


Figure 6: Typical transaction cost framework for the specification, installation, and use of EIS.

2.2 Characterization of heterogeneity

After establishing that there is a technical opportunity in streamlining the transaction cost in conducting the system design and configuration we investigated the variety of office facilities. The goal is for an EIS package to be relevant across a range of office facilities by recognizing and accommodating the heterogeneity within the target segment. Two aspects make the office sector highly varied: (1) the wide range of physical buildings, and (2) the diversity in characteristics of organizations; as described below.

2.2.1 Heterogeneity of the physical infrastructure

2.2.1.1 Mapping physical infrastructure

There is particularly significant diversity in Indian buildings, which range from small, naturally ventilated municipal offices using ceiling fans to private sector high-rise offices with central air-conditioning. This study focused on higher-end Indian Class A office facilities with mechanical cooling and ventilation, and where an EIS could impact energy use. We also assessed the differences between owner-occupied and tenanted offices in relation to the physical systems, as well as what would be possible in new construction, and what limitations would be entailed in installing in a retrofit.

2.2.1.2 Identifying relevant information and metrics for various enterprise decision makers

We started by identifying the business drivers most relevant to decision makers on both the owner and tenant side, such as facilities executives and sustainability managers. While facilities staff consider building automation systems important for primarily building operations and management, the value of energy efficiency to be appreciated and be perceived as being business-relevant. Recognizing this, we mapped performance metrics to the business drivers; these include both bottom-up metrics relevant to the facilities staff, as well as top-down investment-oriented metrics that tie back to the topline revenue and profit relevant to executives.

We identified the following business drivers for offices:

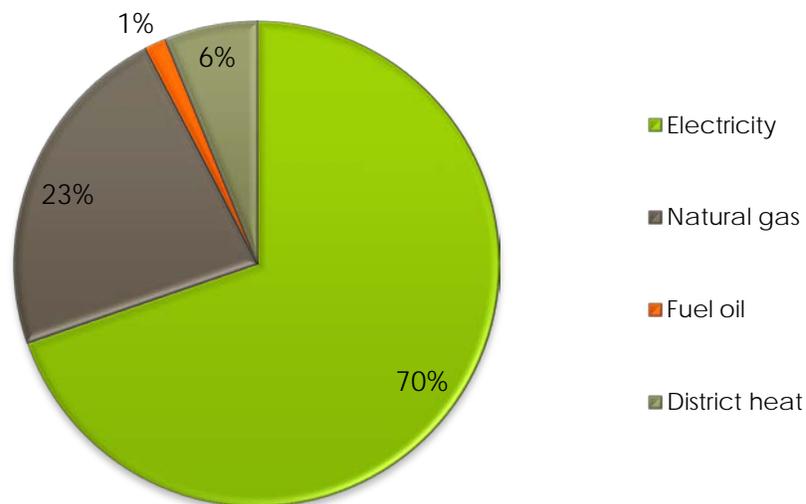
1. **Monitor energy performance.** To glean near real-time time-series information on facility energy use and to quantify changes in energy use over time.
2. **Track cost and demand.** To understand the financial implications of energy use, and wastage; identify base and peak demand, and assess system size and efficiency. To support establishing and monitoring utility budgets and costs, and develop annual energy reports.
3. **Benchmark energy performance.** To have an effective yardstick for demand, efficiency, and energy use targets by comparing the facility's energy performance against a peer (cross-sectional benchmarking). Second, to benchmark the facility against itself, (i.e., validate the energy performance against the design intent, initial commissioned operations, or base period of performance).

4. **Identify and track energy efficiency projects.** To identify, understand and mitigate risks of undertaking energy efficiency measures, track persistence in savings through any implemented projects,⁴ and track improvements over time.
5. **Environmental sustainability.** To track greenhouse gas emissions, for instance if required for benchmarking or carbon disclosure programs, and city energy disclosure ordinances.

Once we identified the business drivers for office organizations, we mapped the energy data needed to address the drivers, how to assess those data through consistent metrics, and how best to make the resultant energy information accessible and actionable. This is detailed in the next subsection.

2.2.1.3 Generating a pick list of loads through a load selection framework

To identify which measurements would most effectively inform metrics relevant to the business drivers identified above, we started with a comprehensive list of all typical loads in an office facility, building energy sources (Figure 7), and potential end uses (Figure 8), which included all non-critical end-uses, as well as emergency and standby end uses. Then we charted the possible end uses to various space types in an office building. These results are shown in loads matrices in tables 2 and 3 in Section 3.



Source: CBECS 2012

Figure 7: Office building energy consumption, by energy source.

⁴ Opencompute (Opencompute.org) is a movement in the datacenter space to publicly track and disclose energy intensity of datacenters. This is not matched by similar efforts in the office segment.

Typical List of Energy Sources and End Uses in an Office Facility

Energy Sources

1. Electricity Supply

- 1.1 Grid raw power
- 1.2 On-site renewables

2. Natural Gas Supply

3. Fuel Oil Supply such as on-site diesel generators (standby power)

4. District Heat

End Uses

1. Electricity Consumption

- Central cooling (chiller plant, cooling towers)
- Individual cooling (if packaged ACs / mini splits / window ACs / heat pumps)
- Air handler fans
- Pumps (hot water, heat recovery, water booster, chilled water, condenser water)
- Indoor lighting
- Outdoor lighting
- Emergency lighting
- Miscellaneous electric loads (MELs) / Plug loads (receptacles, computers, faxes, printers, etc.)
- UPS system (conditioned power)
- Special equipment (individual space heaters, gym, etc.)
- Process loads (elevators, escalators, water and sewage treatment plants)
- Water heating

2. Natural Gas Consumption (U.S. only)

- Central heating (furnace)
- Central heating (boiler: gas or fuel oil)
- Reheat (separation, if done at terminal units)
- Water heating

Figure 8: Typical list of Energy Sources and end uses in office buildings.

The ASHRAE standard 90.1-2013 *Energy Standard for Buildings Except Low-Rise Residential Buildings* for buildings over 25,000 sf requires the monitoring of electrical energy use for total electric energy; heating, ventilating, and air-conditioning (HVAC) systems; interior lighting; exterior lighting; and receptacle circuits *separately*, at a minimum interval of 15-minutes. It also requires the monitoring of other energy sources supplied by a utility, energy provider, or plant that is not within the building, including natural gas, fuel oil, propane, steam, chilled water and hot water (ANSI/ASHRAE/IES, 2013). *The Standard for the Design of High-Performance Green Buildings* incorporates additional metering and sub-metering requirements for building energy resources that extend beyond the ASHRAE Standard 90.1-2013, including electricity, natural gas, district energy, geothermal energy, onsite renewable electric energy, onsite renewable thermal energy. Within the building, it identifies a number of sub-metering requirements for various end uses and tenants (ANSI/ASHRAE/USGBC/IES, 2014).

If one had to measure every point in the loads matrix, that would require hundreds of submetering points, which would be neither practical nor cost effective.

Hence, only prioritized loads are monitored, to provide the relevant data to feed into the pertinent metrics required for the business drivers. In other words, our aim was to reach an 80/20 solution, i.e., select say, 20% of core measurement points in an office building necessary to provide 80% of the most critical information necessary for energy-based decision making.

In order to select the core submetering points to measure loads or end-uses, we developed a decision framework consisting of the three questions below (see Figure 9)

1. **Does the load (or end-use) have high energy use?** Answering this question helps to identify the most significant loads by size in an office facility. For example space heating and cooling loads typically account for a third to half of a building's energy use. IT loads are especially significant in information technology-enabled services (ITES) buildings.
2. **Is it a discretionary load/end-use?** It is important to characterize loads in a facility that can be controlled, managed, or scheduled by the facility manager (or even the occupant) versus those that are too indispensable to be flexibly controlled or optimized. Some loads are too regulated by standards and regulatory bodies, while others may be too distributed to be easily controlled or managed. For instance, in triple-shift Indian office buildings such as business processing operations (BPOs), critical IT demand requires continuity of service at all times through access to standby power, such as uninterrupted power supply (UPS) to the datacenter or server spaces. Hence this is a non-discretionary load. Class A office facilities provide several hours of backup emergency power (through diesel generators) given the unreliability of the electric grid, in order to provide continued operations and ensure tenant retention.
3. **Is the load measurable?** Analyses must determine whether the electrical design provides an opportunity to submeter certain points, or even disaggregate data through subtraction or back-calculation, i.e. virtual load. While there is more variability in the wiring design in Indian office facilities, U.S. office facilities are required to follow the standardized guidelines for electrical design, which allow predetermination of standardized points for energy monitoring.

Using the decision framework, we assessed which electrical points scored high on all three decision criteria. An example is space-cooling loads in office spaces: cooling loads typically account for a significant contribution to the energy use (45 to 60 % in a typical Indian Class A building), and cooling is potentially able to be scheduled in an office with

variable occupancy, thus making it discretionary. Finally, HVAC loads are often on an independent circuit, making it meterable. Hence space cooling is prioritized as a core monitoring point. Another example is lighting, which is responsible for 10 to 20 % of energy use in a typical office and is potentially schedulable or controllable, especially if there is a dedicated lighting panel. In cases where there are several lighting panels, several submeters are required. Even in situations where lighting is not disaggregated from plug loads at the panel level, there still is value in obtaining data from the mixed lighting-plus-plugs panel.

Using this method, we derived a picklist of loads (see tables 2 and 3 in Section 3). This picklist is a set of core recommended energy-monitoring points for an office building. This picklist would be further used to inform technology users of the types of meters and gateways and the associated analysis and visualization that all contribute to an EIS package definition. By creating this predefined package of EIS components, we aim to reduce the usual transaction costs borne from developing custom EIS configurations on a facility-by-facility basis.

	CONTRIBUTION Is the load a major contributor to energy consumption?	DISCRETIONARY Is the load available to control, manage, schedule?	MEASURABLE Can the load be sub metered or disaggregated?	SELECTED For pick list of loads
Load 1 e.g. chiller plant	✘	✘	✘	Yes
Load 2 e.g. plug loads	✘	✘	—	No
Load 3 e.g. UPS	✘	—	✘	No

Figure 9: Decision framework for the picklist of loads. Please note that this graphic is illustrative, and is not the comprehensive suggested picklist.

2.2.2 Heterogeneity of organizational characteristics

Organizations can be heterogeneous, with varying levels of skills and motivation of their staff. To address this heterogeneity, we developed two distinct tiers of EIS packages: Entry (Tier 1) and Advanced (Tier 2). These tiers are based respectively on a light-touch and medium-touch approach, and are commensurate with the skill and motivation levels of the organization. The differentiation between the two tiers lies in their objective, type of

user/audience, functionality, and the usability of the packages. Going from Entry to Advanced tiers also increases their relative complexity, cost, and energy savings potential. Compared to custom EIS tailored to each buildings (that is the typical business-as-usual process of procuring, installing and using EIS), both the Entry and Advanced tiers of EIS packages have reduced functionality and complexity (Figure 10).

Entry Tier 1 provides organizations that traditionally have no visibility into their building energy footprint, and whose building managers who have extremely limited time and resources, to obtain only the most important information. In such organizations, their monthly utility bill may be the only available energy use information, which they receive post-facto. On the other hand, organizations that recognize the value of energy and provide relatively more time and resources for their building managers to more closely monitor their building’s energy usage may be better served through an Advanced Tier 2 solution. Users could start with Tier 1 and “graduate” to Tier 2 over time, as their needs change. The EIS packages are designed so that the features and functionality of each tier are built around prioritized support targeted to the organization types and business drivers important to their organizational goals, as shown in Figure 10.

Business drivers / Package Levels	1. Monitor energy consumption	2. Track cost and demand	3. Benchmark performance	4. Identify and track project performance	5. Track emissions
Tier 1: Entry package	●	●	○	○	—
Tier 2: Advanced package	●	●	●	○	○
Custom EIS	●	●	●	●	○

Priority — None ○ Low ● Medium ● High

Figure 10: Entry and Advanced tier functionality, built around prioritized support provided to business drivers, compared to custom EIS.

2.3 Analytics assessment

In the last step of the study, we identified the three dimensions for the user interface: (1) type of user, (2) tenant or owner/occupier, and (3) frequency of analysis . In the spirit of making energy visible from basement to boardroom, we identified the two primary audiences for the user interface: (1) facility managers who track energy granularly at a daily or sub-daily basis, and (2) management/executives who view energy quarterly or annually

Further, we identified critical questions and metrics for the facility manager to track and report on rapid, short-term level (daily/weekly) (Figure 11) and a long-term (quarterly/annual) basis (Figure 12). In these figures, references are made to charts such as “area charts”, and “bar charts” that are a part of recommended daily and annual dashboards of easy-to-use charts. Our recommended dashboards targeting these two audiences are shown in Section 3: Results.

Building Pulse at a Glance: Facilities Dashboard with Five Metrics
Primary Audience: facility managers, engineering staff; Time scale: daily, weekly

1. What is my whole-building **Absolute Energy Consumption**?
 - kWh or kBtu (or therm) per day or per week
Area chart (Chart 1)
2. What is the **normalized Energy Use Intensity**?
 - kWh or kBtu (or therm) per unit square area
 - kWh/occupant or full-time equivalent (FTE)
Area chart (Chart 1 toggles)
3. How is my building performing compared to past performance, i.e., **longitudinal benchmarking**?
 - kWh or kBtu (or therm) use for given day or week versus a previous time period
Area chart (Chart 1 variation)
4. What is the **load demand per end use** of my building, and are the end-uses operating efficiently?
 - kW or kBtu/hour per time period
 - % portion of the total energy use*
Trendline chart (Chart 2)
5. What is the **fuel consumption and cost**?
 - kBtu/fuel per time period
 - USD/INR per time period
Pie chart (Chart 3)

*Tier 2 only, using building occupancy inputs

Figure 11: A list of short-term questions that inform the facilities dashboard

High-level Picture: Executive Dashboard with Five Metrics, with additional Facilities Charts

Primary Audience: executives, facilities managers

Timescale: monthly, quarterly or annually

1. What is the **fuel consumption and cost**?

- kBtu/fuel per time period
- \$ or INR per time period

Pie chart (Chart 1)

2. What are the trends for my facility's energy costs?

- \$ or INR per time period

Trend chart (Chart 2)

3. What is my building's **energy performance**, and how is it performing over time compared to baseline, i.e. **longitudinal benchmarking**?

- kWh or Btu per month, quarter, or year
- kWh or kBtu/unit square area
- kWh/occupant (e.g., full-time equivalent [FTE])*

Stacked bar chart (Chart 3)

4. How is my building performing compared to other similar facilities in my portfolio, or benchmarks, i.e. **cross-sectional benchmarking**?

- kBtu/fuel per time period, or per unit square area, or per FTE occupant*
- \$ or INR per time period

Cross-sectional Benchmarking (Chart 4)

5. What is **the carbon footprint** of my facility?

- Metric tons or pounds of carbon dioxide (CO₂) per year

Cross-sectional Benchmarking (Chart 4)*

Additionally, for facilities staff

6. What is the **load demand per end use** of my building, and are the systems operating efficiently?

- kW or kBtu/hour per time period
- % portion of the total energy use
- kW/ton*

Average loads line chart (Chart 5)

7. What does an **annual snapshot** of my facility look like? Is it performing well throughout the course of a month/year

- kW or kBtu/hour per time period

Whole Building Heat map (Chart 6)

* Tier 2 only

Figure 12: A list of high-level questions that inform the monthly/annual dashboard, targeted primarily for decision making at the owner/executive level. Additional facilities-level charts are also provided for the facilities staff.

3. Results: Technical requirements for EIS-in-a-box packages for offices

This section describes the results of our analysis based on the methodology described in Section 2. We derived the technical requirements for two tiers of packages: Entry and Advanced. As explained earlier, each tier is mapped to the business drivers for the office sector, and has an associated set of pre-defined configuration of (i) sub- meters (Table 2), (ii) communication gateways (Table 2), and (iii) software to access and analyze data, front-end visualization charts, metrics and and notifications.

The following is an example of the rationale for the package. Lets consider a critical business driver for the office sector, *continuous monitoring of energy performance*. At the Entry tier 1, two metrics that address this driver are: tracking energy consumption per time period (kWh or kBtu-hr), and power demand (kW or kBtu). Data inputs are required to generate the metrics. These are continuously acquired from hourly (for Tier 1) or 15-minute (for Tier 2) interval data from both the whole-building meters and specific submetered loads. Data on continuous loads and peak loads are also collected. The EIS software then performs tasks such as simple tracking of energy consumption and loads, trend analysis of historical data going back to recommended intervals, and whole-building/critical-load daily or weekly load profiling with daytime and nighttime demand loads. For the same business driver, two specific charts addressing its purpose are displayed on a dashboard: an Energy Use Area Chart, and a Power Demand Trendline. Figure 13 shows the logic mapping the business driver to the EIS features and functionality. The dashboard charts are presented Section 3.3.

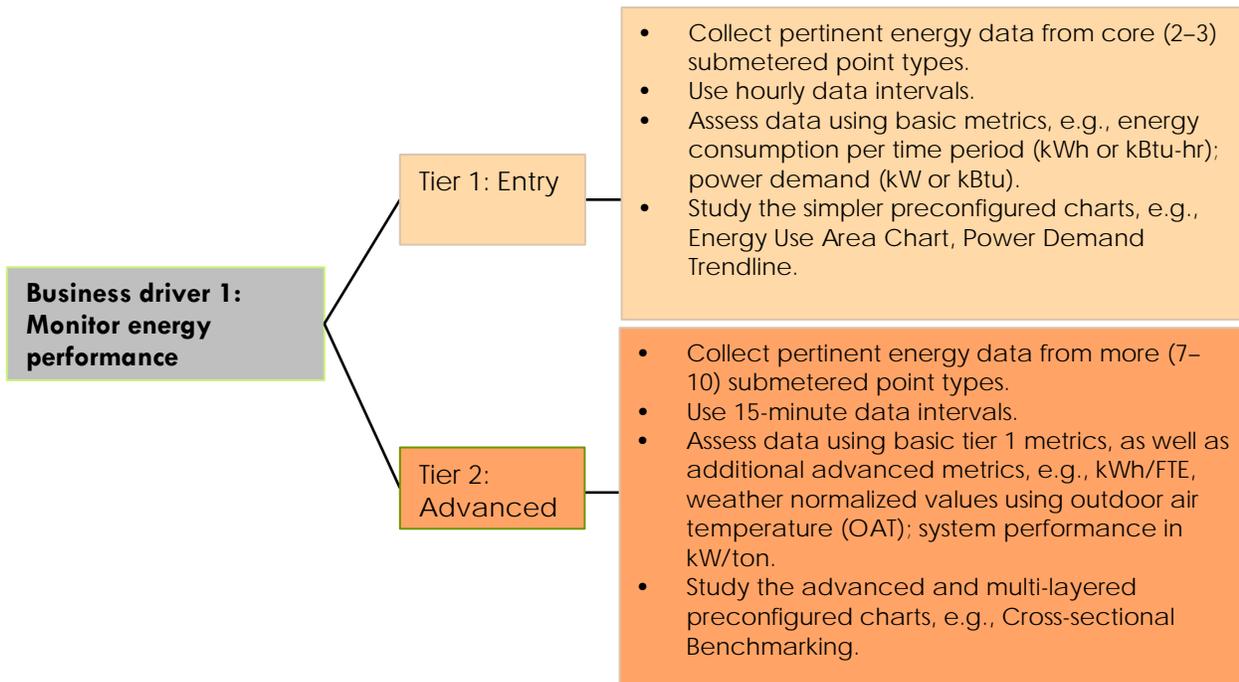


Figure 13: Features and functionality of EIS Packages are mapped to office-specific business drivers

Meters	Submetering Points	Physical Location	Communication Gateways	Measured Parameters	Accuracy and Turndown (U.S. and India)	Additional inputs
Tier 1: Electric submeters*	Whole Building, 2-3 major loads (spaces or end uses) such as chiller plant, fan energy	1 Main distribution board (DB)	Wired between submeter and gateway, Wi-Fi between gateway (1) and remote database RS-485 (Modbus and BACnet) output standard for India; TCP/IP for U.S.	kWh, V, A	Class 1 according to IS13779 (India standard); 1% with 10:1 turndown (U.S. requirement)	~ Bldg./space areas ~ fuel supply cost
Tier 2: Electric submeters*	Whole Building, 7-10 major loads (spaces or end uses) such as: - chiller plant - fan energy - emergency equipment/plugs/lights	1 Main DB + Representative Spaces / Floor DB	Wired between submeter and gateway, Wi-Fi between gateway (1) and remote database RS-485 (Modbus and BACnet) output standard for India; TCP/IP for U.S.	kWh, kW, V, A, Power Factor, For WB: current and voltage harmonics	Class 1 according to IS13779 (India standard); 1% with 10:1 turndown (U.S. requirement)	Tier 2 ~ Bldg./space areas ~ fuel supply cost ~ operating schedules ~ outdoor air temperature (OAT) from weather data
Tiers 1 and 2: Gas submeters Primarily U.S.	Whole Building gas; 1 major space heating load (boiler or furnace)	1 main piping location, at all boilers/furnaces	Pulse output counting using a twister pair to gateway (e.g., pulse counting and convert to therms)	Submeter reads out in cubic ft, data required as therms	U.S. ANSI B109 standard; 1% with 100:1 turndown	
Tier 2: Btu submeter	Water cooling and heating	At chiller and boiler plant	Scaled pulse or RS-485 (Modbus and BACnet) output standard	Btu/h	Precision matched temp. sensors, 2% accuracy 10:1 or 4% accuracy with 100:1; Standard EN 1434	

Table 2: Metering and gateway requirements for EIS packages

The following parameters should be measured and displayed by electric submeters:

- Instantaneous phase voltage (V); phase-to-phase, phase-to-neutral
- Instantaneous phase current (A)
- Instantaneous apparent power (VA), active power (W), and reactive power (VAR)
- Maximum demand (W) over a specific time interval
- Power factor
- Frequency (Hz)
- Active energy (kWh)

As mentioned earlier, an EIS has three components: meters, gateways, and software with a user interface. The hardware components, i.e., sub-meters and gateway are specified for each tier, selected from off-the-shelf products that comply with the specifications (Table 1). An important first-order task for understanding the overall consumption is by metering whole-building electric, natural gas, other fuel and standby power. This should be followed by identifying the location and types of points for submeters identified through the 'picklist of loads'. This whole building and systems/ end-use submetering information can help trigger action towards delving further into a certain fuel or end-use. For this, software analysis and visualization is required that is also defined for each tier.

Section 3.1 and 3.2 below describe the Entry Tier 1 and Advanced Tier 2 EIS packages in more detail.

3.1. The Entry EIS package

The Entry Tier 1 (Figure 14) is a "foot in the door" package to familiarize the user with the installation and use of the EIS. It provides information about when and how much total energy is being consumed. This is the simplest and cheapest solution beyond utility bill analysis, assumptions or manufacturers specification, or spot measurements and site gauges. It primarily provides visibility into whole-building energy use trends using interval time-series data. The appeal of this approach is that it is simple, requires minimum hardware, and takes less time than other approaches to identify low-hanging fruit for energy savings. The energy savings potential is estimated to be as much as 3–5 % at a whole-building level through best practices in both U.S. and India; each situation will vary based on the types of actions and interventions taken.

3.1.1 Organization type

The Entry Tier 1 package is targeted towards office facility owners and managers who have an interest in understanding their building's energy utilization, but with limited skill, resources, and time.

3.1.2 Metering and data requirements

The Entry Tier 1 package includes interval meters for whole-building loads and a prioritized, recommended set of 2–3 types of critical loads selected based on the load selection

framework. These loads can be at the system level (e.g., a boiler or furnace for heating) or for a particular area (e.g., offices, conference rooms, cafeteria). Our analysis showed that in both in India and the U.S, HVAC consumed over half of the building energy. This is followed by lighting and computing, and plug loads (Figures 3 and 4), together comprising the majority of office facility demand. Hence, these loads (as determined with the decision framework shown in Figure 9) are given priority in the tier 1 package (Table 2). Additional user-supplied information that needs to be input to the software is limited to the gross floor area (square feet or square meters) to express energy consumption as normalized energy use intensity (EUI often expressed as kBtu/sf, or EPI expressed as kWh/sqm).

3.1.3 Included visualization and analysis

Visualization of the data is presented in seven preconfigured views—three in the daily dashboard and four in the quarterly/annual dashboard (Figures 16–17)—that provide the following:

- Identification of trends and potential electricity waste from the basic charts to inform energy efficiency actions. Charts include simple tracking of energy consumption (kWh) and load profiling of critical loads (kW).
- Tracking of whole-building energy reductions after implementation of an energy efficiency project. The chart shows longitudinal benchmarking to provide visibility into long-term trends about the building's energy performance
- Reconciliation of energy billing cost (INR/\$) and identification for discrepancies between billed costs and metered consumption.
- Notifications, such as threshold-based alerts and alarms, those have additional programming needs. Stock recommendations to the facility manager, and standard monthly reports to executives.

For examples of the dashboards, see Section 3.3.

3.1.4 Required service levels

The installation would be provided by a systems integrator or vendor in consultation with the client organization's in-house facilities and IT staff. The simpler levels of analyses can usually be carried out in-house after staff training. A limited amount of vendor support required for recalibration of meters, software upgrades, etc. The availability of monitoring and visualization of energy consumption (in kWh or kWh/floor area), energy fuel cost, and hourly load profiling of critical loads (kW) enables users to analyze energy consumption patterns. The identification of high energy consumption and anomalies enables users to identify large energy users to target to implement energy efficiency options in a building, and eventually across a portfolio or campus of buildings. It then provides long-term visibility into the building's energy performance that can be used for benchmarking.

EIS Tier 1 (Entry) Package: Office Facilities

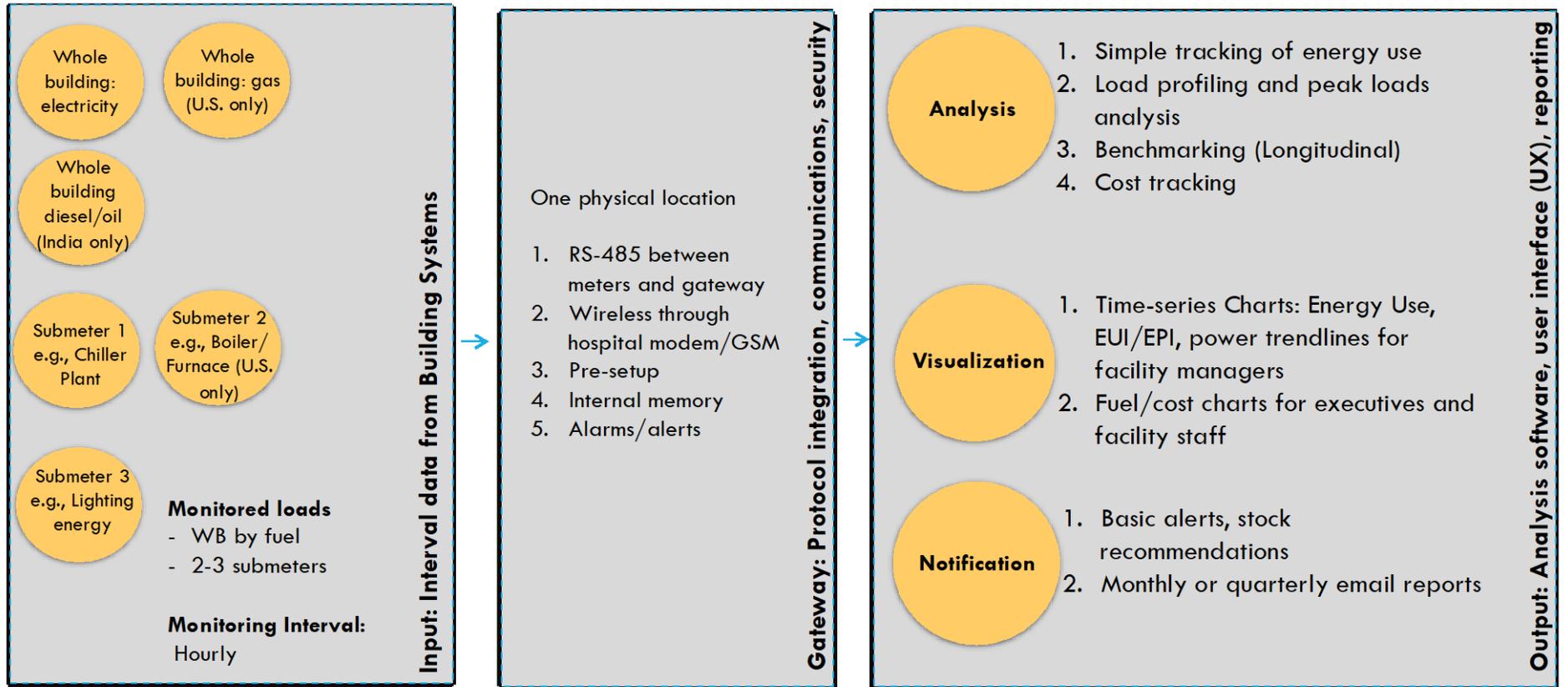


Figure 14: Entry Tier1 EIS package for office buildings.

		Whole Building	Occupant Offices		Schedulable Common Spaces	24 x 7 Spaces	Service Spaces	Support Spaces
			Open cubicles	Private rooms	Conference rooms, break rooms, lobby	Server room	Kitchen, restroom	Cafeteria, recreation rooms, gyms
Loads picklist: Entry Tier 1								
All electricity from the grid		X						
All electricity from on-site source		X						
All gas		X						
HVAC	Central chiller plant power consumption (chiller, pump, and boiler if any, cooling tower if any)	X						
	Individual units, if any (split units or packaged units or heat pumps) ¹							
	Heating (furnace)	X						
	Fan energy (air handling unit, AHU) ¹							
Lights	Indoor Lighting ¹	X						
	Outdoor Lighting							
Plugs	Controllable Plug loads (MELS)							
	Computing loads (UPS) ²							
Process	Kitchen equipment							
	Process Loads (transportation) ³							
¹ Multiple locations possible, ² Uninterrupted power service: IT, data network, emergency/alarms, intercom, CCTV; ³ Elevators, escalators X Tier 1 electric/gas meter								

Table 2: Picklist of loads for the Entry Tier 1 EIS package based on end uses and physical spaces in an office building.

3.2 The Advanced EIS package

More complex than the Entry tier 1 package, the Advanced Tier 2 EIS package (Figure 15) consolidates more granular data from a larger number of interval meters and provides deeper visibility and granularity in terms of *when*, *how much*, and *where* energy is being consumed. This goes beyond the primarily whole-building metrics provided by the Entry Tier 1 package, so that it provides more actionable information that can lead to specific pathways towards energy savings, since you can better pinpoint the reasons for use and waste. An Advanced Tier 2 package provides deeper benefits of EIS, to provide savings up to 10 %. The cost is correspondingly higher because of additional metering, upfront software cost, and ongoing software services (analysis, data storage) cost, although the increase in number of points can potentially bring down the cost of the per-point metering cost.

3.2.1 Organization type

The Advanced Tier 2 package is targeted towards office facility owners and managers who have a higher awareness and interest in the benefits of energy efficiency and carbon accounting and the ability to invest funds and staff resources commensurately.

3.2.2 Metering and data requirements

In addition to whole-building meters, the advanced tier EIS requires interval data from 7–10 critical end uses or major areas (Table 3). It considers submetering nuances between owner-occupied and tenanted offices. For instance, for an owner-occupied facility, the owner may opt to submeter and pay for just the chiller plant (high-side of HVAC), while the tenanted spaces may have separate submeters for individual AHU fan energy (low-side of HVAC), if disaggregated by tenant. Additional user-supplied information needs to be configured into the EIS, such as operating schedules, building/zone areas, and occupancy that allow normalization and superior analytics.

3.2.3 Included visualization and analysis

The Advanced Tier 2 EIS consists of 10 preconfigured visualization screens: four in the daily/weekly dashboard and six in the monthly/annual dashboard (Figures 16 and 17). In addition to the charts from the Entry EIS package, there are charts depicting cost accounting, carbon accounting, heat maps, and end-use pie charts. See Figure 15 (a)–(d) and Figure 16 (a)–(f), which provide the following:

- Higher granularity and visibility into energy consumption (kWh) for load profiling (kW) of 7–10 major loads drawn from the picklist of prioritized loads. Their selection is based on the primary loads, such heating furnace/boiler and the chiller plant, or major areas that may be actionable. These include the submetering points provided in the tier 1 package, as well as additional submeters such as a Btu meter for central heating and cooling.
- Simple baseline modeling through integration with additional user-provided data such as weather and occupancy data. This makes the tier 2 EIS package a

powerful tool to provide that provides normalized baselines to identify when and where the energy-saving opportunities are (i.e., scheduling, anomalies, changes in load profile).

- Cross-sectional benchmarking with respect to a peer group such as a portfolio or other similar office facilities. Benchmarking provides comparative information that reveals the need for improvement in energy performance, helps set energy targets, prioritizes energy efficiency projects, and tracks progress towards those targets.
- Sustainability/greenhouse gas (GHG) tracking, by providing carbon accounting analysis and reports.
- Cost accounting in terms of reporting energy costs against the budget, indicating surplus or deficit.
- Notifications, such as threshold-based alerts and alarms that have additional programming needs, including e-mail/phone notifications. Some custom recommendations to the facility manager and monthly reports to executives.

Since the Advanced Tier 2 package relies on data acquisition from a larger set of 7–10 recommended metering locations and provides more granular information, it has enhanced capabilities.

This Advanced Tier 2 package can provide simple baseline normalization to ascertain where energy savings opportunities exist through scheduling opportunities, anomaly detections, and changes in load profile. Additional advanced graphics include carbon accounting, cross-sectional benchmarking with peer groups, and energy cost accounting.

EIS Tier 2 (Advanced) Package: Office Facilities

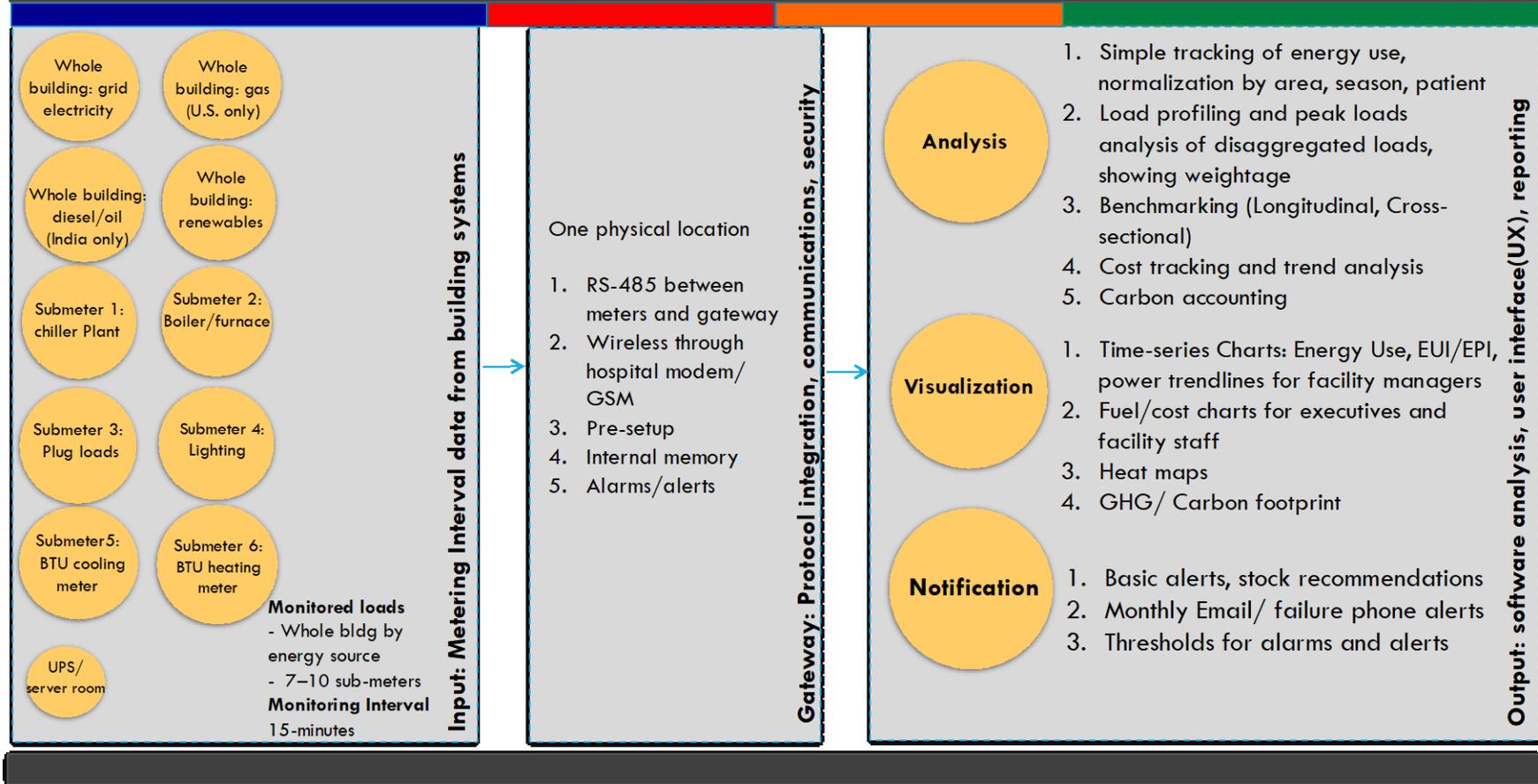


Figure 15: Advanced Tier 2 EIS package for office buildings.

Loads picklist: Advanced Tier 2		Whole Building	Occupant Offices		Schedulable Common Spaces	24 x 7 Spaces	Service Spaces	Support Spaces
			Open cubicles	Private rooms	Conference rooms, break rooms, lobby	Server room	Kitchen, restroom	Cafeteria, recreation room, gym
All electricity from the grid		X						
All electricity from on-site source		X						
All gas		X						
HVAC	Central chiller plant (chiller, pump, boiler, cooling tower if any)	X X						
	Individual units, if any (split units packaged units or heat pumps) ¹		X	X	X			X
	Central Heating (furnace)	X X						
	Fan energy (air handling unit, AHU) ¹				X			X
Lights	Indoor Lighting ¹	X	X	X	X		X	X
	Outdoor Lighting	X						
Plugs	Plug loads (MELS) ¹	X						
	Computing loads (UPS) ²	X						
Process	Kitchen equipment							
	Process Loads transportation ³							
¹ May be multiple locations; ² Uninterrupted power supply including IT, data network, emergency/alarms, intercom, CCTV; ³ Elevators, escalators X: Tier 2: electric/gas meter; X: Tier 2: Btu meter; X: Multiple locations for the same type of submeter								

Table 3: Picklist of loads for the Advanced Tier 2 EIS package based on end uses and physical spaces in an office facility

3.3. Software and user interface for the tiers

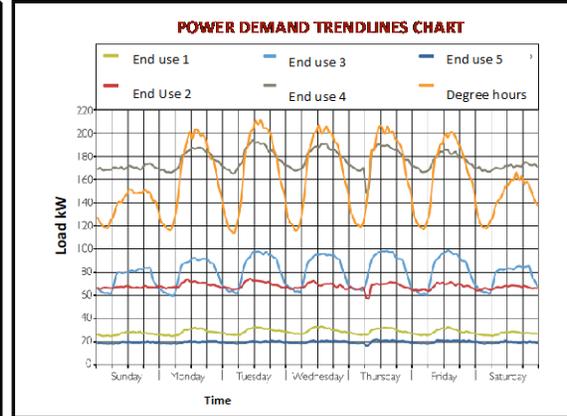
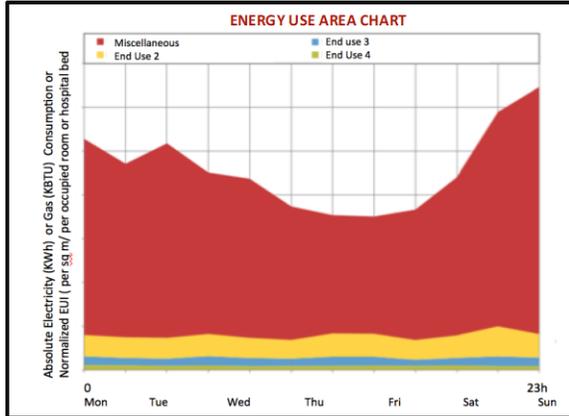
Based on the questions to be answered in the short-term (Figure 11), we developed a daily/weekly dashboard with four possible charts. For the Entry Tier 1 package, three charts should be included (Figure 15). And for the Advanced Tier 2 package, a fourth additional chart will be included. (See Figures 15 (a)–(d)). Based on the questions to be answered in the long-term (Figure 12), we developed a quarterly/annual dashboard. For the Entry level, four charts will be included, and for the Advanced tier 2 package, all six will be included (Figure 16) and Figures 16 (a)–(f).

These dashboards enable facility staff to monitor and answer pertinent questions quickly and succinctly, and to send reports up the management chain to the executive level. Each package provides guidance on how to interpret and relay information from each energy consumption analysis. Flexibility is built in for the suggested picklist of loads, as well as incremental configuration of charts and associated notifications based on pertinence to an Entry Tier 1 or Advanced Tier 2 package.

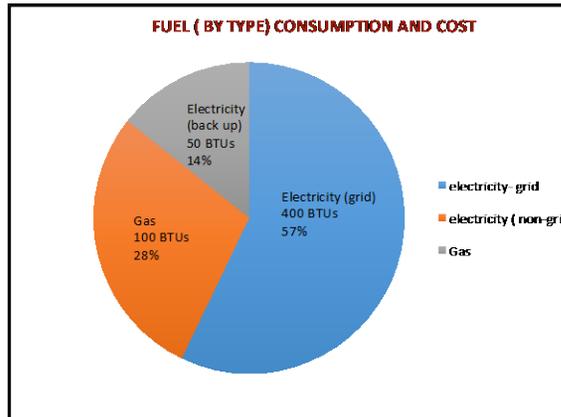
Facility Daily Dashboard: Building Pulse at a Glance

How much energy (by fuel) and cost is my building consuming, where and when?

- 1. Energy Use Area Chart**
 (2 versions, for tier 1 and 2)
Energy Consumption
- Electricity (kWh or kBtu)
 - Gas (therms or kBtu)



- 2. Power Demand Trendlines Chart**
 (2 versions, for tier 1 and 2)
- Electrical Loads (kW)
 - Gas Load (kBtu/hour)

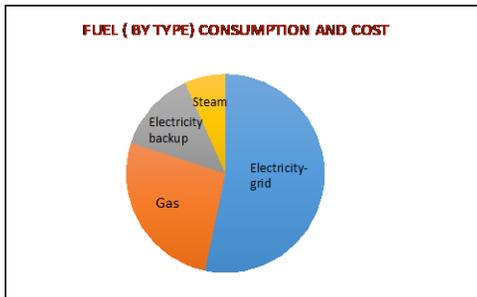


- 3. Fuel Cost and Consumption Chart**
 (similar for tier 1 and 2)
- Consumption (kBtu):
 Electricity (grid, off-grid),
 Natural Gas
 - Cost (INR/USD)

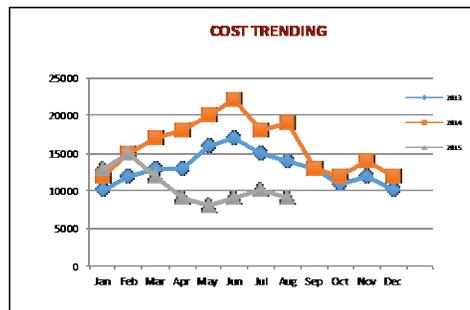
The Facility Daily Dashboard can be used by the facility staff on a daily or weekly basis

Figure 16: Facility Dashboard "Building Pulse at a Glance" for EIS Office packages: for daily or weekly use.

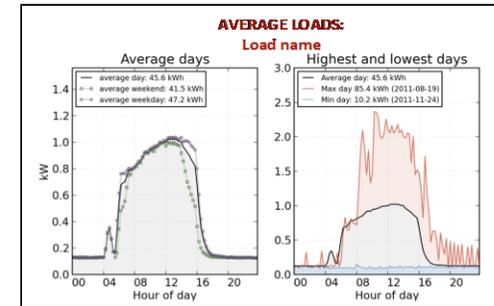
Monthly/Annual Dashboard



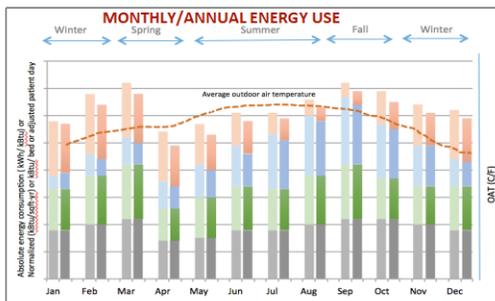
1. Consumption and cost per fuel type
(Similar for Tier 1 and 2)
USD/INR or kBtu/ time period



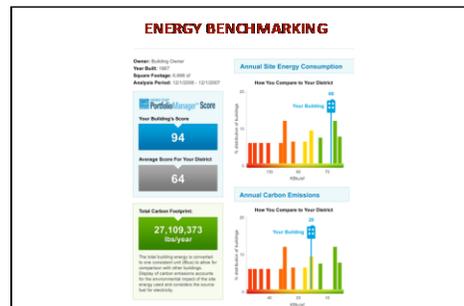
2. Cost trending
(Similar for Tier 1 and 2)
USD or INR/ time period



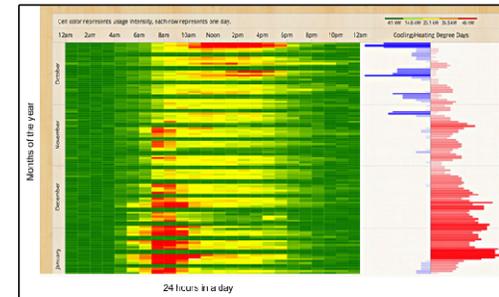
5. Average Loads line chart
(Similar for Tier 1 and 2)
- Electrical Loads (kW)
- Gas Load (kBtu)



3. Monthly/Annual energy use and longitudinal benchmarking
(Similar for Tier 1 and 2)
Electricity (kWh), Gas (kBtu)



4. Cross-sectional Benchmarking (Tier 2 only)
- Portfolio Manager score
- Carbon footprint
- Comparisons with peer buildings in the district or nation



5. Whole Building Heat Map: (Tier 2 only)
- Electrical Loads (kW)

Executive-level charts

Facility manager charts

Figure 17: Annual Dashboard for EIS Office packages.

4. Conclusions

Energy Information Systems (EIS) are a relevant technology for driving energy savings in office facilities where a significant portion of the annual operating costs are energy related. CBERD office EIS technical requirements are intended to address the following:

- 1. Cost-effectiveness**, by helping to reduce first costs (i.e. transactional costs, hardware costs) as well as ongoing operational costs. This can help ease the sales cycle for vendors (especially for new or tough-to-penetrate markets) and make procurement and operations cost effective for users.
- 2. Scalability**, by development of an optimum EIS that takes into account the specificity of the office sector rather than being too generic (all types of buildings) or too specific (customized on a per-building basis). By engineering EIS packages to accommodate heterogeneity across office buildings and yet be valuable, scalability establishes a broader market applicability of the systems.
- 3. Simplicity**, through ease of use, procurement, and installation. EIS packages are engineered for the uncomplicated integration of the three main components (i.e., meters, gateways, and software) into pre-set configurations as two recommended tiered EIS packages. The uncluttered hardware and just-enough data helps curtail unnecessary data management needs. Technical simplification of products and their usability is a real need and path towards .scalable deployment.
- 4. Actionability in the organization**, by being mapped to business drivers and metrics that are relevant across various levels of organizational decision making. For the facilities staff in the basement checking the near-time, daily, or weekly pulse, it allows data-derived actions in the facilities operations. For executives, valuable energy information presented with the relevant energy and sustainability metrics at quarterly/ annual time frame can help inform facility and energy investments within their larger decision-making framework.

The CBERD EIS package technical requirements presented here provide details for the three components—metering, gateways, and software/user interface—and integrate them into two tiers for EIS packages. The recommendations are specific, but allow flexibility in the prioritized selection of points for energy monitoring, reporting, and granularity of data acquisition, analysis, and actionable information display.

EIS packages provide a significant improvement over the business-as-usual practice for energy measurement of post-facto utility bill information, or single-point-in-time information such as spot measurements, site gauges, manufacturer specifications and assumptions. The core EIS information is intended to provide knowledge that is actionable across various types of decision makers in an organization, as well as across organizations in the offices sector. The packages rely on buy-in across various stakeholders including upper

management commitment for investment in these packaged solutions, as well as early involvement of IT staff to help overcome security, data maintenance, big data management and installation hurdles. The packages are based on training of in-house staff while leveraging the technical skills of systems integrators as necessary in the process. In this way, the design of the packages consider the EIS vendor, integrator, and client organization’s facilities and IT staff as crucial partners in the successful installation of an EIS and persistent savings through its use.

The range of organizational and technical factors addressed in the two tiers of EIS packages is shown in Figure 18 below. We believe that Entry Tier 1 EIS package is a minimum requirement and Advanced Tier 2 EIS package is best practice within a certain cost range.



Figure 18: Range of organizational and technical factors addressed in the two tiers of EIS packages as compared to 'no EIS' and 'custom EIS' situations.

This work considers best practices in ensuring maximum benefit for organizations, referencing other work conducted through the U.S. Department of Energy such as the Better Buildings Alliance organizational primer on the use of energy management and information systems (LBNL 2015). Also, its value is intentionally for the packaged and standardized end of the EIS spectrum, as compared to the Better Buildings procurement specifications that are geared in contrast, to non-packaged, custom EIS solution (LBNL, 2015). Finally, advantages may be derived in the future by building upon the current work.

One is the ability for asset digitization– intelligence is built into critical pieces of equipment that can tie back into the system. In addition, standardization of packages also may help with interoperability and security standards down the line.

While EIS packages do not provide all of the features available through more complex, custom-built EIS solutions, they represent a cost-effective option for stakeholders interested in increasing their property's energy efficiency. The sector-specific packages are a factor in market transformation that could allow building owners and managers to easily install and monitor their energy usage, as well as identify areas for improvement and cost savings, and encourage market adoption of the technology.

Facility Dashboard Chart #1: Energy Use Area chart (time series charts, separate for electric and gas consumption)

Description

1. Simple tracking of energy use totals.
2. Visualization at whole building level and selected end uses as different colored bands on hourly/ daily/weekly basis.
3. Can be potentially reconciled with utility meter readings.
4. Energy baseline overlaid
5. Occupied and unoccupied hours or days can be overlaid
6. Provides baseline energy use, target energy use, and actual energy use

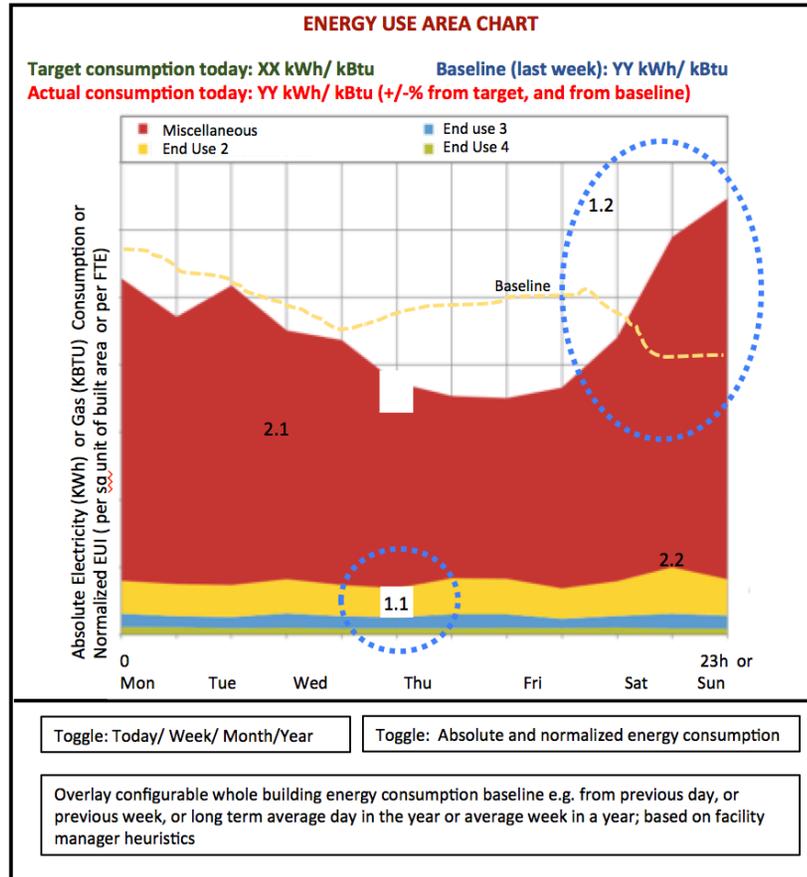
Inputs

- (i) Automated energy use interval data from whole building meter or utility/ shadow meter (kWh/ kBtu) (Tier 1)
- (ii) Automated energy use interval data from specific end use/ area submeters (kWh/kBtu) (Tier 1)

- Interval:
Hourly (Tier 1) ; 15-min (Tier 2). Keep data interval consistent.

Additional inputs

- (i) Normalization:
 - Area footprint (one-time) (Tier 1);
 - Real time occupancy e.g. number of FTEs in the building (Tier 2 only)



Analyses and Interpretation

1. Energy Consumption: kWh or kBtu/ time period
2. Normalized Energy Use Intensity (EUI): (Tier 2 only)
kWh or kBtu/soft; kWh or kBtu /FTE or hospital bed or hotel room

1. **Qualitative simple tracking view of whole building load:** Shape of load reflects expected use of building wrt occupancy, schedule

1.1 **Diagnostics:** Look for any data gaps in chart that indicate missing data. That may indicate measurement fault, broken equipment, etc (software can automatically fill in small pieces of missing data).

Action: Rectify any reasons for data gaps, else contact EIS vendor

1.2 Look for any irregularities in the shape e.g. unexpected spikes or troughs, excursions such as increased area under curve that indicates potential inefficiencies and energy wastage from baseline

Action: Identify potential reasons for excursions such as change in schedule or occupancy. Check controls/ BAS. If not corrected, then fix the malfunctioning equipment

2. **Qualitative Disaggregation view of end uses indicated through colored bands** showing their relative contribution and weightage

2.1 Identify highest energy consuming end uses and watch those to ensure they don't deviate from expected baseline

2.2. Determine if relative proportion of end-uses (colored bands) changing, and which end use is responsible for any increase or decrease.

Actions: Make observations such as:

- Cooling plant panel is highest among all loads. Unexpected, hence investigate further

- Service hot water energy usage is lower than usual- great job!

3. **Quantitative rule-based alerts:** Screen/e-mail/ text alerts to facility manager about missing data, expected failures, excursions from expected energy use.

- If within 5% variance from baseline (previous (un) occupied day or week) or trend then on-screen notification. Low risk of energy waste

- If 5-10% variance, then text/email alert

- If 10-30% variance, then audio alarm

- Emergency alerts for critical pieces of missing data or variance >30%

Additional value :

- Identification of energy saving opportunities and projects

Figure 16(a): Details of Dashboard charts; Daily Chart #1 Energy Use Area Chart. Can be used for daily and weekly view using toggles. For both Entry Tier 1 and Advanced Tier 2 packages.

Facility Dashboard Chart #2: Power Demand Trendlines chart (time series, separate for electricity and gas loads)

Description

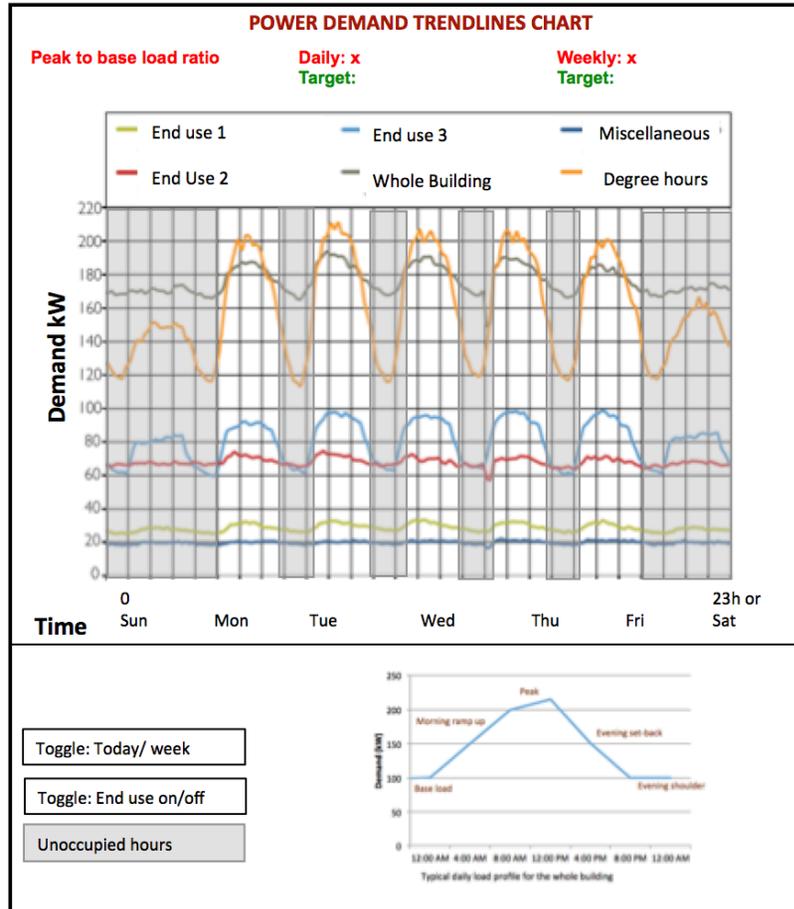
Presents whole building interval meter data overlaid with selected end-use submeter data, showing the contribution of end-uses in different colors. This time series chart presents loads (in kW) on a daily (day/night) or weekly (weekday/weekend) basis

Inputs

- (i) Automated energy use interval data from whole building meter sub-hourly or hourly: (kW)
- (ii) Automated load data from end uses (kW)
- Interval
Hourly (Tier 1) ; 15-min (Tier 2).
Keep data interval consistent.

- Additional inputs

- (i) Degree hours or Outside Air Temperature (OAT) (Tier 1)
- (ii) Optional (Tier 2): operational hours, building schedules (one-time, reconciled with building automation system (BAS) control sequence from from the operations manual or control drawings or BAS programming



Analyses and Interpretation

Metrics: kW/day, kW/week electric; kBtu/hour or kBtu/week gas

1. Qualitative load profiling on a daily or weekly basis to understand the relationship between energy use and time of day/ day of week. Inspect plots of at least 24-hour periods of interval meter data, or "profiles," and evaluate that information in the context of your building's operational hours and building schedules, or intended system control schedules. How is the building performing in occupied and unoccupied hours or days? Consider changes in load size and shape against time of day, day of week, or season.

1.1 Check if the load shape has the 5 typical: base load, morning ramp up, peak, evening set back, and evening shoulder.

1.2 Check if the start up and shut down is similar

1.3 Flat demand profiles from day to night are indicative 24-hour operation, occupancy, or a disabled nighttime setback control feature.

1.4 Check if the base load remains high despite a night time or/and weekend setback

Action: Check control sequences for setback periods. If high base load persists then perform quantitative analysis.

2. Quantitative Peak Load analysis peak-to-base load ratio (Daily, weekly) calculated to assess the after-hour setback. A "good" versus "poor" value of base-to-peak load depends on the specific building operations and characteristics; ratios <0.33 indicate that significant loads are shut off for parts of the day.

~ Low ratio (**on screen notification**): look for loads are being left on continuously e.g. phantom loads;

~ Medium ratio (**alert**): indicates good controls e.g. holiday/weekday setbacks are 50% lower than weekday operations;

~ High ratio (e.g.>300%) (**alert**) indicates very high peaks (bad) ; or extremely deep shut-offs (good). Drill down further on the cause

~Ideal 25-33% ~ Aggressive: 75-80% on nights and weekends.

Actions:

1. Turn off end uses or equipment that are not in use
2. Consider approaches to deepen set-back or shut down opportunities,
3. Shorten operating hours of building systems to better reflect actual building occupancy schedule and service needs
3. Implement unoccupied (night, weekend, and holiday) setback strategies in HVAC building automation system to minimize air conditioning during the unoccupied period
4. Reduce or turn off lighting, office equipment, and garage and exhaust fans during the unoccupied period. Occupancy sensors can be utilized to automatically turn lights off when occupancy is not detected.

Figure 16(b): Details of Dashboard charts; Daily Chart #2. Power Demand Trendline chart. For both Entry Tier 1 and Advanced Tier 2 packages.

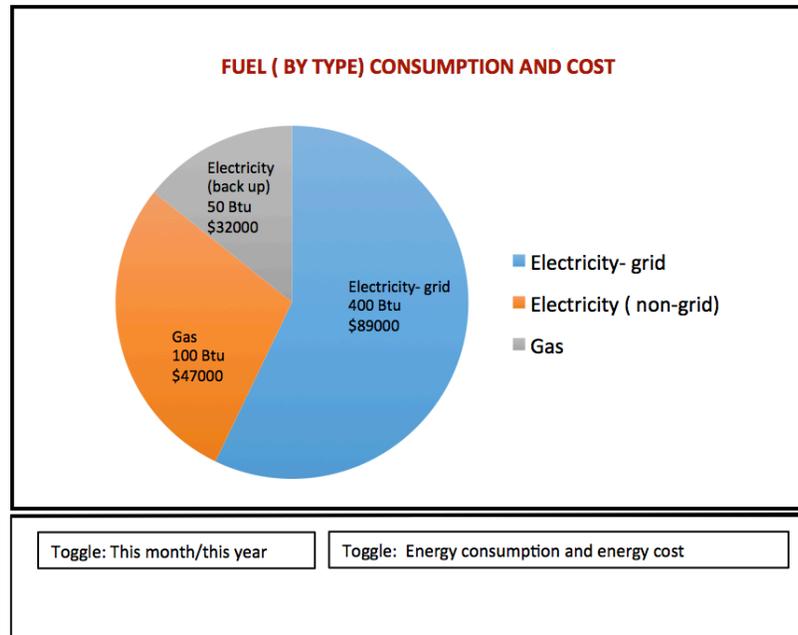
Long Term Dashboard Chart 1: Fuel-type consumption and cost

Description:

Fuel breakdown: How much fuel of what type is being consumed over the course of a month or a year

Inputs:

Automated fuel meter data, or utility meter reading over a selected period (kWh/ kBtu)



Interpretation:

KPI: kBtu per fuel type per month or year

Look for energy consumption per fuel type and as a portion of the total consumption

Check consumption against the the monthly utility readings

2. KPI: Cost per fuel type per month or year

Total cost for the month or year broken down per fuel type

Additional value :

Proportion of back up power utilization for critical functions, UPS etc

Figure 17(a): Details of Dashboard charts; Monthly Chart #1. Fuel-type consumption and cost chart. For both Entry Tier 1 and Advanced Tier 2 packages.

Long-term Dashboard Chart 2: Cost trending

Presentation:

Line graph revealing the monthly energy cost. Also shows previous years cost profile

Inputs:

Cost, reconciled with utility bills

Interpretation:

KPI: \$ or INR/month

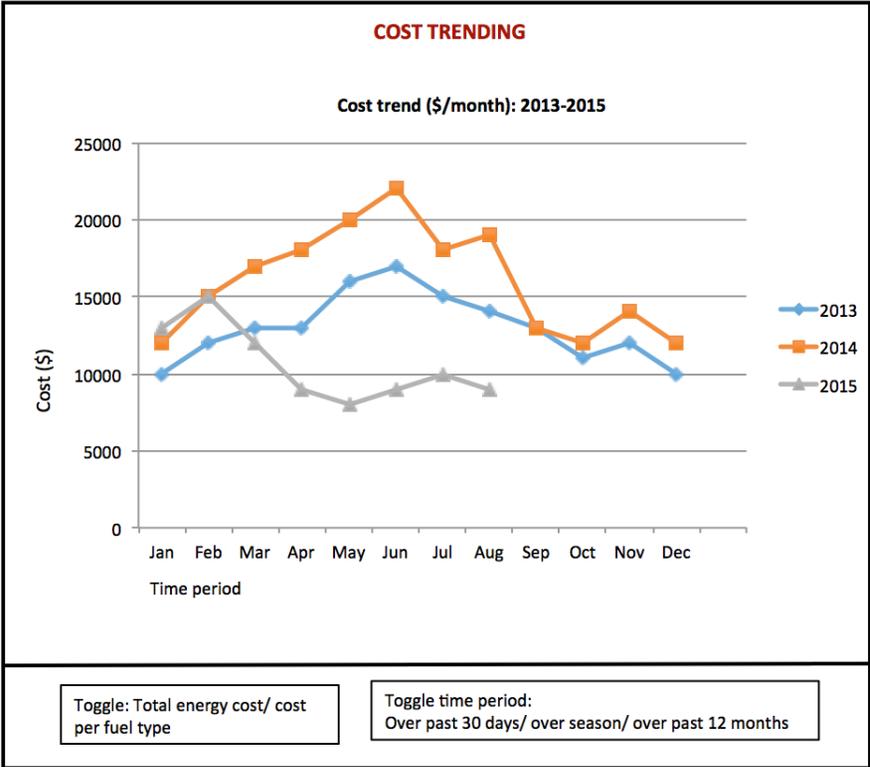


Figure17 (b): Details of Dashboard charts; Monthly Chart #2. Cost trending chart. For Entry Tier 1 and Advanced Tier 2 packages.

Long-term Dashboard Chart 3: Monthly/ Annual Energy Use Bar Chart

Description

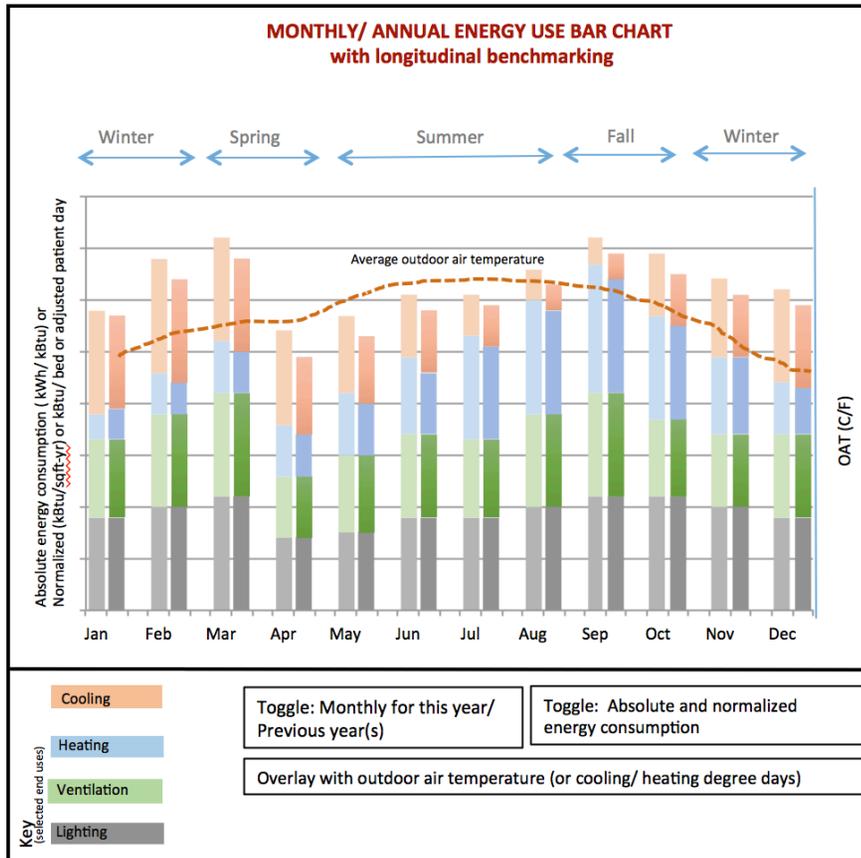
- Calendar view of whole building and submetered end use energy use plotted in a stacked bar chart. Each end-use is a different color, and heights of each bar show comparative weightage
- Baseline energy use from the previous year if available

Inputs:

- Automated energy use interval data from whole building meter or utility/ shadow meter (kWh/ kBTU)
- Automated energy use submetered interval data from a building area or end-use (kWh/ kBTU)
- Interval
Hourly (Tier 1) ; 15-min (Tier 2).
Keep data interval consistent.

Additional input

- Normalization: Outdoor air temperature (Tier 1) or degree days (Tier 2);
- Trend logs from previous years (Tier 2)



Interpretation:

1. KPI:

Energy Consumption: kWh or KBTU per month or year

- **Simple tracking** to view energy use from one time period to another and inspect for increases or decreases, or long term upward or downward trends. Monthly usage bars indicate monthly/ seasonal variations.

- Inspect end use bars for irregularities or large increases or decreases in use that may indicate operational or efficient problems. Observations such as: per expectation, Water heating stays consistent throughout the year, while cooling and heating fluctuates by season.

- Compare to baseline period to see if there are any increases and drill down for causes. Decreases are good.

2. KPI: Normalized Energy Use Intensity (EUI): kWh/sqft or kWh/hotel room, occupied hospital bed or adjusted patient day

Additional value that may be derived:

- Normalization based on OAT or, cooling/ heating degree days

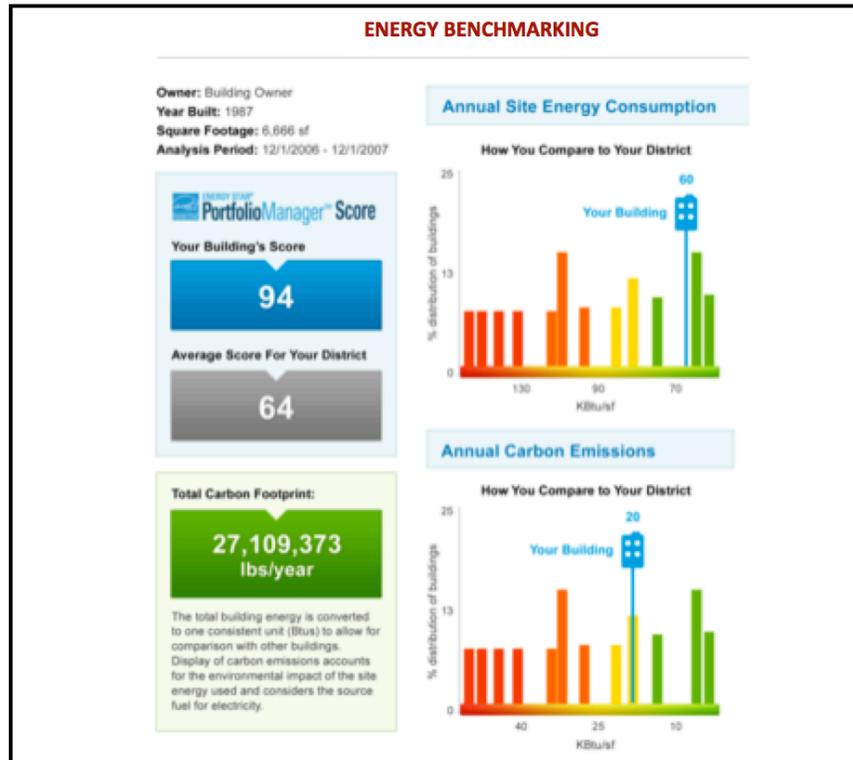
Figure 17(c): Details of Dashboard charts; Monthly Chart #3. End-use breakdown chart. For both Entry Tier 1 and Advanced Tier 2 packages.

Long-term Dashboard Chart 4: Cross-sectional Benchmarking and Carbon Footprint

Presentation:

Inputs:

Energy Star Portfolio Manager data



Interpretation:

1. KPI:

Annual Site Energy Consumption $kBtu/sf$, $kWh/sq\ m$

Annual Carbon emissions: pounds or metric tons of $CO_2/year$

Portfolio Manager score

- Carbon footprint

- Comparisons with peer buildings in the district or nation

Figure 17(d): Details of Dashboard charts; Monthly Chart #4. Benchmarking chart. For Advanced Tier 2 package.

Long-term Dashboard Chart 5: Average Loads Chart

Description: Power intensity

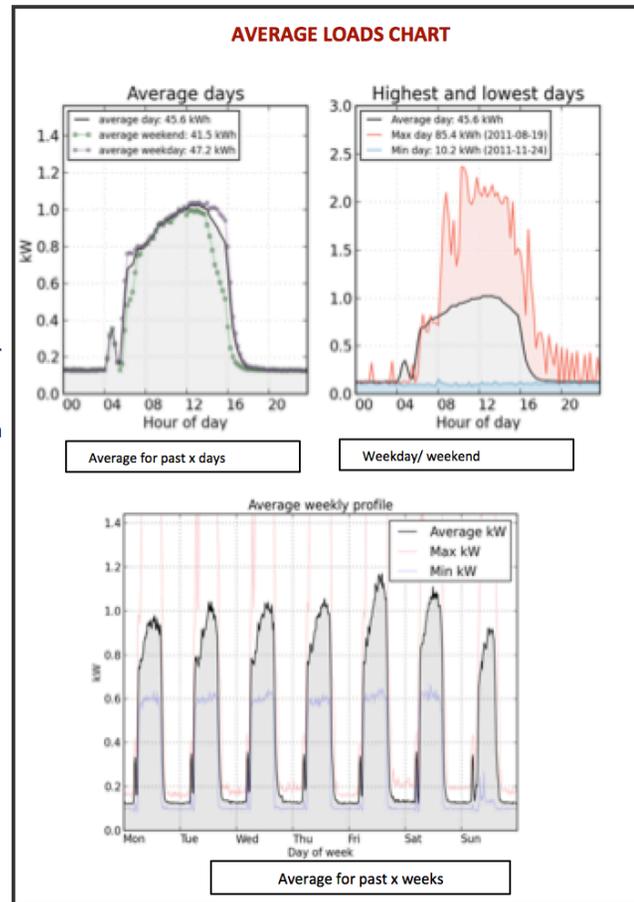
-This chart displays the typical average daily weekly load profile (in kW) corresponding to the buildings occupancy and use for each hour if day or day of the typical week. Loads are shown on the vertical axis, and hours of the day or day of the week are shown on the horizontal axis.

- **Average kW** is the average of all power readings calculated separately for each hour of the week, **Max kW** is the maximum power reading calculated separately for each hour of the week, and **Min kW** is the minimum power reading calculated separately for each hour of the week.

Inputs:

- Automated energy use interval data from whole building meter sub-hourly or hourly: (kW)
- Automated load data from end uses (kW)

Note: Data of any resolution may be used as long as it is consistent.



Interpretation:

KPI: kW/ month or season

- **Peak load analysis:** Presents daily or weekly average, min and max loads and daily range. Daily or weekly max- to-min ratio provides an estimate of how much total load is turned off and on every day or weekly. Usage is observed during non-working hours, and investigated using hourly data
 - Low ratio: indicates that loads are being left on continuously e.g. phantom loads; analysis may provide opportunities for turning off end uses or equipment
 - Medium ratio: indicates good controls e.g. holiday/weekday setbacks are 50% lower than weekday operations; analysis may present opportunities to extend or deepen shut-off periods, and reduce peaks
 - High ratio (e.g.>300%) indicates very high peaks (bad) ; or extremely deep shut-offs (good). Drill down further on the cause for high ratio Provides the range in load across the year, for any time of the year . e.g. at noon, the load varies between 0.2 and 2.3 kW

- **Peak load analysis-** informs the utility cost expectation. Take actions to reduce the peak demand and reduce utility bills

- Calculates load variability. Low load variability implies the loads can be predicted well using historic data

Additional value that may be derived:

- **Improving Load planning:** e.g. Higher base loads imply non-implementation of night time schedules. Reveals energy savings potential even though day-night differential in hotels and hospitals may not be as high as in offices
- **Peak load analysis** reveals magnitude of peak, including "Most likely maximum load". Can help inform system sizing in retrofit projects

Figure 17(e): Details of Dashboard charts; Monthly Chart #5. Average Loads chart. For both Entry Tier 1 and Advanced Tier 2 packages.

Long-term Dashboard Chart 6: Whole Building Power Heat map

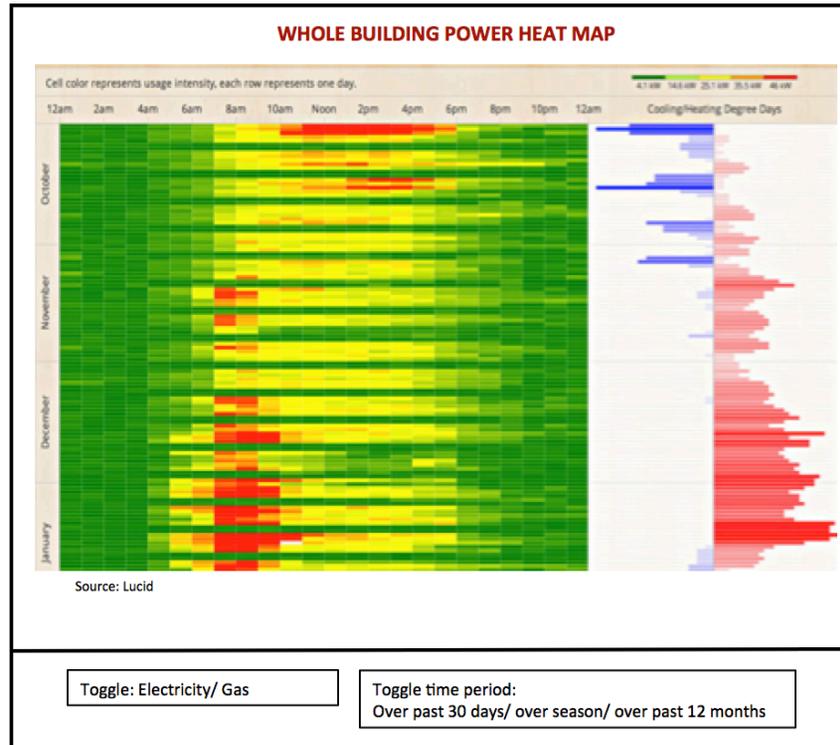
Presentation:

Power Heat Map:
View a macro-level snapshot of energy use at a high level, that reveals usage patterns, weather sensitivity, and opportunities for scheduling and controls refinements. Each row is one day, and each column is an hour of the day; the Heat Map can plot an entire year of hourly data — 8,760 data points — in one screen.

Inputs:

- Power demand of every end use/ load meter

Note: Data of any resolution may be used as long as it is consistent.



Interpretation:

KPI: Power intensity: kW

Chart color codes through a pixel grid the power demand of every meter reading, Pixel color indicates high or low power demand- greens are low, yellow/orange are medium, red is high. Weather is plotted.

- Horizontal bands indicate change in consumption
 - Energy use be highest at midday say for an office when the building is fully occupied and the impact of weather conditions is most pronounced, while off-hours should see reductions in consumption
 - Weekly horizontal bars reveal weekend setbacks with building systems maintaining nighttime set points through the unoccupied weekend. Vacations surface as larger horizontal bars.
 - Lack of vertical band implies poor nighttime shutoff
 - Lack of horizontal banding implies poor weekend shutoff
 - Small horizontal bands implies shutoff during consecutive days e.g. weekends
 - Wider horizontal bands indicates seasonality of energy use
- Vertical bands show consistency of scheduling and tight controls
 - Make observations such as:
 - December and January the heating loads are high because of high heating degree days
 - If control schedules are disrupted or changed, changes in the colors or 'hot spots' will encourage further investigation. Sudden high consumption during hours that are normally low may suggest changes in building settings if there aren't any occupancy or weather related factors to explain the increase in consumption. Executives can ask Facility managers to provide reports for hot spots and how they were dealt with.

Figure 17 (f): Details of Dashboard charts; Monthly Chart #6. Whole Building Power Heat map. For Advanced Tier 2 only.

References and Literature Review

Björnsjö, Agneta, Mélina Viglino, and Georgina Lovati. *Igniting Growth in Consumer Technology*. Rep. Accenture, 2016. Web. Accessed on 15 Apr 2016.

https://www.accenture.com/t20151231T013104_w_us-en_acnmedia/PDF-3/Accenture-Igniting-Growth-Consumer-Technology.pdf.

Building Owners and Managers Association International. *Building Class Definitions*. n.d. Web. Accessed on 14 Feb 2016.

<http://www.boma.org/research/pages/building-class-definitions.aspx>.

Bureau of Energy Efficiency. *The Action Plan for Energy Efficiency*. Ministry of Power, Government of India. 2009. Web. Accessed on 15 April

2016. http://beeindia.in/content.php?page=miscellaneous/useful_download.php.

Center for Building Energy Research and Development (CBERD). 2012. Web. Accessed on 15 November 2017. www.cberd.org.

Energy Conservation Building Code 2007. Bureau of Energy Efficiency. Ministry of Power, Government of India, New Delhi, India. Web. Accessed on 25 Apr 2016.

<http://www.bee-india.nic.in/sidelinks/ECBC/DRAFTECBC27MARCH2006.pdf>.

Energy Standard for Buildings except Low-rise Residential Buildings. ANSI/ASHRAE/IES Standard 90.1-2013. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2013.

Evans, Meredydd, Bin Shui, and Sriram Somasundaram. *Country Report on Building Energy Codes in India*. Pacific Northwest National Laboratory. Apr 2009. PNNL-17925. Web.

Accessed on 15 April

2016. https://www.pnl.gov/main/publications/external/technical_reports/PNNL-17925.pdf.

Fisk, William, and Olli Seppanen. *Providing Better Indoor Environmental Quality Brings Economic Benefits*. Proc. of Clima 2007 Well Being Indoors, June 10-14, 2007, Helsinki. N.p., n.d. Web. Accessed on 25 Apr 2016.

<http://energy.lbl.gov/ied/sfrb/pdfs/performance-1.pdf>.

Granderson, Jessica, and Guanjing Ling. *Energy Management Information Systems (EMIS) Specification and Procurement Support Materials*. Rep. Lawrence Berkeley National Laboratory. Feb 2015. Web. Accessed on 25 Apr 2016.

https://betterbuildingsolutioncenter.energy.gov/sites/default/files/attachments/emis_proc_spec_BBA_FINAL_021815_508.pdf.

Granderson, Jessica, Guanjing Lin, and Mary Ann Piette. *Energy Information Systems (EIS): Technology Costs, Benefits, and Best Practice Uses*. Rep. Lawrence Berkeley National Laboratory. Nov 2013. LBNL-6476E. Web. Accessed on 15 April 2016.

https://betterbuildingsinitiative.energy.gov/sites/default/files/attachments/EIS_costs_benefits_report.pdf.

Granderson, Jessica, Mary Ann Piette, Benjamin Rosenblum, Lily Hu, et al.. *Energy Information Handbook: Applications for Energy-Efficient Building Operations*. Lawrence Berkeley National Laboratory. 2011. LBNL-5272. Web. Accessed on 15 April 2016.

<https://betterbuildingsolutioncenter.energy.gov/sites/default/files/attachments/energy-information-handbook.pdf>.

ISO 50001. International Standards Organization, n.d. Web. Accessed on 25 Apr 2016. <http://www.iso.org/iso/home/standards/management-standards/iso50001.htm>.

Johnson, Paul M. *Transaction Costs. A Glossary of Political Economy Terms*. Auburn University Department of Political Science, 2005. Web. Accessed on 15 Feb 2016.

http://www.auburn.edu/~johnspm/gloss/transaction_costs.

Kejriwal, Surabhi, and Saurabh Mahajan. *Smart Buildings: How IoT Technology Aims to Add Value for Real Estate Companies*. Rep. Deloitte, 19 Apr 2016. Web. Accessed on 25 Apr 2016.

<http://dupress.com/articles/internet-of-things-iot-commercial-real-estate-intelligent-building-systems/>.

Kubba, Sam. "P. 263." *Green Construction Project Management and Cost Oversight*. Burlington, MA: Architectural, 2010. N. pag.

Lawrence Berkeley National Laboratory. *A Primer on Organizational Use of Energy Management and Information Systems (EMIS)*. Rep. U.S. Department of Energy Better Buildings. Dec 2015. Web. Accessed on 25 Apr 2016.

https://betterbuildingsolutioncenter.energy.gov/sites/default/files/attachments/A_Primer_on_Organizational_Use_of_EMIS_V1.1.pdf.

Mills, Evan, Jessica Granderson, Rengie Chan, Richard Diamond, Phil Haves, Bruce Nordman, Paul Mathew, Mary Ann Piette, Gerald Robinson, and Steve Selkowitz. *Green*,

Clean, & Mean: Pushing the Energy Envelope in Tech Industry Buildings. Lawrence Berkeley National Laboratory, May 2015. LBNL-1005070. Web. Accessed on 15 April 2016.
<https://eta-publications.lbl.gov/sites/default/files/1005070.pdf>.

Parker, SA, WD Hunt, KM Fowler, WF Sandusky, GP Sullivan, BK Boyd, KL McMordie Stoughton, TM Koehler, and R. Pugh. *Metering Best Practices: A Guide to Achieving Utility Resource Efficiency, Release 3.0*. Pacific Northwestern National Laboratory, Mar 2015. PNNL-23892. Web. Accessed on 15 April 2016.
https://www.wbdg.org/FFC/DOE/NLCRIT/mbpg_2015.pdf.

Roth, Kurt W., Detlef Westphalen, Michael Y. Feng, Patricia Llana, and Louis Quartararo. *Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential*. 2005. Web. Accessed on 15 April 2016.
<https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2006100567.xhtml>.

"S.535 - 114th Congress (2015-2016): Energy Efficiency Improvement Act of 2015." *Congress.gov*. N.p., n.d. Web. Accessed on 25 May 2016.
<https://www.congress.gov/bill/114th-congress/senate-bill/535>.

Sarraf Saket, Shilpi A.Saboo, and S. Gupta. *ECO III Report 1042 - Benchmarking Energy Consumption in Buildings: Preliminary Data Analysis*. USAID India Energy Conservation and Commercialization. 2011. Web. Accessed on 25 Apr 2016.
http://eco3.org/wp-content/plugins/downloads-manager/upload/Data_Analysis-Report%20No.%201042.pdf.

Singh, Reshma, Mary Ann Piette, Ashok J Gadgil, Rajan Rawal, Narendra Bansal, Vishal Garg, Jyotirmay Mathur, Philip Haves, Paul A Mathew, Christian Kohler, Mahabir Bhandari, Gail Brager, Vivian Loftness, Narendran Nadarajah, Ronnen M Levinson, Richard E Brown, Andre Desjarlais, Milind Rane, Sanyogita Manu, Yash Shukla, and Mona Doctor-Pingel. *R&D and Implementation Outcomes From The U.S.-India Bilateral Center For Building Energy Research And Development Program*. Rep. Lawrence Berkeley National Laboratory. August 2019. DOI: 10.20357/B74G69. Web. Accessed on 15 Aug 2019.
https://eta-publications.lbl.gov/sites/default/files/reshma_final_whole.pdf.

Singh, Reshma, Baptiste Ravache, and Dale A Sartor. *Building Innovation: A Guide For High-Performance Energy Efficient Buildings In India*. Rep. Lawrence Berkeley National Laboratory. May 2018. LBNL-2001147. Web. Accessed on 15 April 2019.
https://eta-publications.lbl.gov/sites/default/files/final_cover_lbni-2001147pdf.pdf

Singh, Reshma, Dale Sartor, and Girish Ghatikar. *Best Practices Guide for High - Performance Indian Office Buildings*. Rep. Lawrence Berkeley National Laboratory. April 2013. LBNL-6230E. Web. Accessed on 15 April 2016.
<https://eta.lbl.gov/sites/all/files/publications/lbni-6230e.pdf>.

Standard for the Design of High-performance Green Buildings: Except Low-rise Residential Buildings. ANSI/ASHRAE/IES/USGBC Standard 189.1-2014. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2014.

United States Congress. Public Law 109–58 109th Congress. Congressional Record, 2005. Web. Accessed on 15 Apr 2016.

http://energy.gov/sites/prod/files/2013/10/f3/epact_2005.pdf.

U.S. Department of Energy, *Smart Energy Analytics Campaign*. 2016. Web. Accessed on 24 June 2016.

<https://smart-energy-analytics.org/glossary>.

U.S. Energy Information Administration. "Building Characteristics Summary Tables." *Commercial Buildings Energy Consumption Survey*. 2012. Web. Accessed on 20 May 2016.

<https://www.eia.gov/consumption/commercial/data/2012/>.

Zatz, Mike, and Leslie Cooke. "Leading the Way to Climate-Friendly Buildings." Kentucky, Louisville. Dec. 2007. *Energy Star*. Web. Accessed on 15 Feb 2016.

https://www.energystar.gov/sites/default/uploads/buildings/old/files/3_Presentation_Private_Kickoff.pdf.