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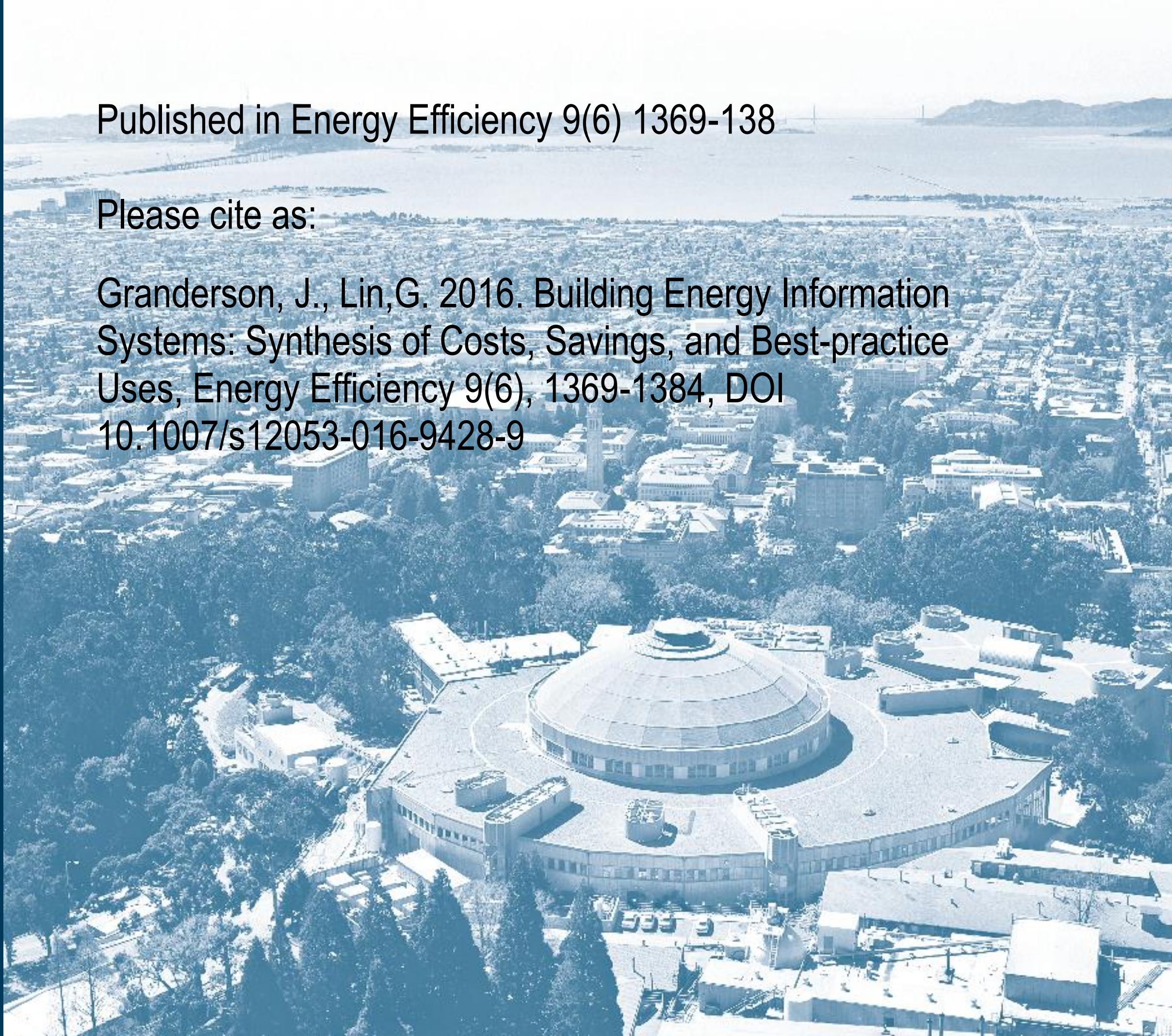

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Building Energy Information Systems: Synthesis of Costs, Savings, and Best-practice Uses

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Abstract

Building energy information systems (EIS) are a powerful customer-facing monitoring and analytical technology that can enable up to 20% site energy savings for buildings. Few technologies are as heavily marketed, but in spite of their potential, EIS remain an under-adopted emerging technology. One reason is the lack of information on purchase costs and associated energy savings. While insightful, the growing body of individual case studies has not provided industry the information needed to establish the business case for investment. Vastly different energy and economic metrics prevent generalizable conclusions.

This paper addresses three common questions concerning EIS use: what are the costs, what have users saved, and which best practices drive deeper savings? We present a large-scale assessment of the value proposition for EIS use based on data from over two-dozen organizations. Participants achieved year-over-year median site and portfolio savings of 17% and 8%, respectively; they reported that this performance would not have been possible without the EIS. The median five-year cost of EIS software ownership (up-front and ongoing costs) was calculated to be $1,800 per monitoring point (kilowatt meter points were most common), with a median portfolio-wide implementation size of approximately 200 points.

In this paper, we present an analysis of the relationship between key implementation factors and achieved energy reductions. Extent of efficiency projects, building energy performance prior to EIS installation, depth of metering, and duration of EIS were strongly correlated with greater savings. We also identify the best practices use of EIS associated with greater energy savings.

Introduction

Building energy information systems (EIS) are broadly defined as the web-based analysis software, data acquisition hardware, and communication systems used to store, analyze, and display whole-building, system-level, or equipment-level energy use (Granderson et al. 2009; Motegi et al. 2003). Fig. 1 shows the schematic diagram of an EIS. At a minimum, an EIS provides hourly or sub-hourly interval meter data with graphical and analytical capabilities. The data in an EIS comes primarily from electric and gas meters, but can also include other data, such as those from building automation systems (BAS); the data integrated into the system depends on the level of monitoring that is present at the site. A data acquisition system in the building gathers the data and transmits it to a server that is on-site or on the cloud. The server storages and analyzes the data. External data sources such as weather data, or utility price and demand response information may in some cases be integrated into the EIS to support its analytical capabilities. EIS users can view the data and analysis results in graphical or report format through the user interface. A key set of EIS analytical capabilities (Granderson, Piette, and Rosenblum 2011; Kramer et al. 2013) include:

- Time series load profiling: Provide plots of interval energy usage versus time
- Benchmarking: Compare energy use relative to a peer group, or compare current energy use against past performance
- Energy anomaly detection: Automatically identify abnormal energy consumption
- Peak load analysis: Monitor peak load and provide notification when the demand passes a threshold

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- Measurement and verification: Quantify the reduction in energy use from the pre-efficiency project baseline to the post-efficiency project energy use.

Energy information systems are a promising technology that can enable remarkable site energy savings, quick payback, and persistent low-energy performance when implemented as part of best-practice energy management programs (Capehart and Middelkoop 2011; Granderson, Piette, and Ghatikar 2011; Motegi et al. 2003; Smith et al. 2011; Henderson and Waltner 2013). The number of commercially available EIS has increased dramatically over the past ten years, driven by the increased availability of higher-granularity energy use data and the national trends towards federal- and city-level benchmarking disclosure and performance reporting requirements. In the Federal sector, the Energy Independence and Security Act of 2007 requires federal buildings to establish energy benchmarks for their facilities' portfolios. In the private sector, fourteen cities like New York, Austin, Seattle, Chicago, and Washington, D.C., have mandated benchmarking of energy use for large commercial buildings (IMT 2015). Despite of its potential and fast-growing availability, EIS are still in the early stage of adoption throughout the commercial building stock. The widespread adoption of EIS is hindered by the lack of information on its procumbent costs and energy and cost savings, as well as how to use the technology to achieve the maximum benefits.

The costs of different types of meters (e.g., electric meter, natural gas meter) are readily available in the publications (NBI 2009; FEMP 2011; NSTC 2011). In contrast, public domain information regarding EIS software costs is not widely available. CEC (2002) addressed the issue that EIS software costs were broken into single upfront costs and recurring ongoing costs. NBI (2009) characterized EIS costs which were limited to six offerings that appear to offer more basic functionality than today's more advanced enterprise-grade software tools. For example, basic functionality might include time series load profiling and simple reporting, whereas more advanced tools offer capabilities such as Portfolio Manager benchmarking and continuous energy anomaly detection. The 2009 study indicated that the upfront cost range of a "basic" EIS was $2,500–$4,000 for a building, with an annual ongoing charge of $0–$240. The cost data provided by a recent EIS customer's purchasing records, such as technology procurement invoices, would provide potential EIS users a better understanding of current, more-sophisticated EIS software costs.

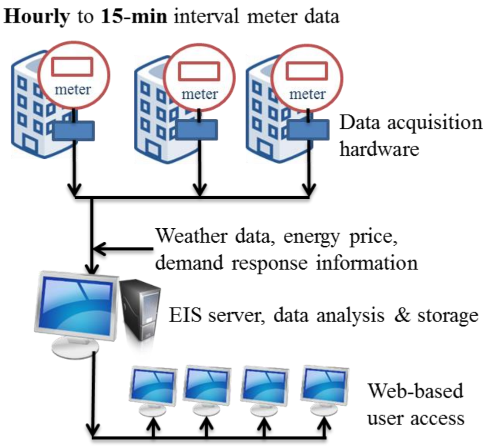


Fig.1 Schematic Diagram of an Energy Information System

Previous case study research has documented the value of EIS as tools for improving building energy efficiency; a sampling of this work is summarized in Table 1. While EIS functionality can range from more basic to advanced, these implementation cases in the literature are representative of the state of the art of the time of publication. Table 1 shows that energy saving potentials varies in different EIS implementation cases. These savings were reported in different metrics and narratives like whole-building energy savings, electricity savings, and energy cost savings, and others. It is difficult to generalize the findings from the number of case studies out there and use them to generate the business case to help EIS investment decision-making. Table 1 also provides some example actions or observations that facility operators have taken upon the information provided by EIS.

Table 1 Summary of savings and example actions with implementation of EIS reported in literature

Literature	Building Description	Savings	Example Action/observation
Smothers and Kinney (2002)	Office building	12% reduction in electricity use in 11 months 19% reduction in natural gas in 11 months	Steam valve replacement due to the identification of valve leakage HVAC schedule adjustment
Motegi et al. (2003)	University	14% reduction in summer electricity usage 10% reduction in summer gas usage	Fan nighttime reduction Closing fume hood at night
Owen et al. (2010)	Office building	12% lighting electricity savings in a week	Lighting campaign
Granderson, Piette, and Ghatikar (2011)	University	30% reduction in average daily gas use	Excessive overnight gas use due to non-zero pressure at steam boiler
	Refrigerated/dry warehouses	18% reduction in portfolio energy use in three years 36% reduction in whole-building energy use at a single site in three years	Retro-commissioning and refrigeration system tune-ups
	University	30% reduction in daily whole-building energy use	Lighting retrofit and ventilation schedule change
	Retail	$35,000/year avoided costs	Static 225 kW load at dimming control submeter
Smith et al. (2011)	Office buildings	Estimated over one million dollars of annual savings	--
Henderson and Waltner (2013)	Office buildings	13% annual electricity savings	HVAC equipment setbacks at night Free cooling temperature adjustment to season

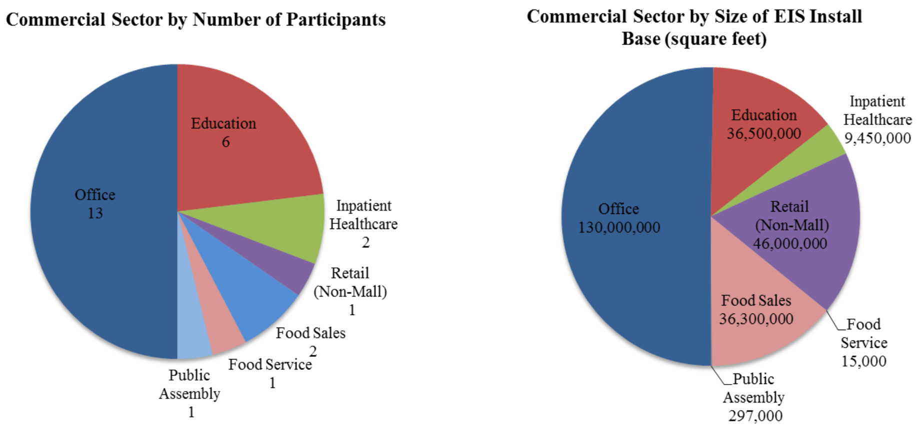
This paper presents a large-scale assessment of the value proposition for EIS use based on data from over two-dozen organizations. The overall objective is to provide organizational decision makers with the information they need to make informed choices on whether or not they should invest in an EIS. Specifically, it aims to answer the following three questions:

1. What are the technology costs of an EIS?
2. What are the energy- and cost-savings benefits of an EIS?
3. How should EIS technology be used so that maximum benefits are achieved?

Methodology

Information was collected from 26 organizations that have implemented energy information systems from 17 vendors. These organizations were recruited from the membership of the Department of Energy's Better Buildings Alliance, and from clients referred by EIS vendors. They all met the selection criteria: 1) the organizations should have at least one year of data before and after EIS installation and were willing to provide data; 2) the technology fitted the minimum EIS requirement that the system tracks hourly or sub-hourly interval meter data and provides graphical and analytical capabilities for users to identify opportunities to improve building operational efficiency. The study cohort represents a diversity of climates and commercial EIS technologies, as well as commercial subsectors that include office, education, healthcare, and retail. Each case investigation was conducted according to a common template as described below so that findings could be synthesized and analyzed for general conclusions. The study participants were asked to provide EIS software procurement costs, annual energy consumption of portfolio and representative building sites covered by EIS installation, and a record of major capital projects, retrofits, or other efficiency measures. The annual energy consumption and project records that were provided cover the time period from the year prior to EIS implementation through the most recent year of data. Building sites were taken as standard representatives from the EIS installation based on study participants' knowledge of the portfolios they maintain – that is not an extreme building that may have exhibited exceptionally high or low levels of efficiency, relative to the participant's overall portfolio.. The study participants were also interviewed to provide information such as building floor area and primary activity, depth of metering, EIS user engagement and empowerment, as well as typical EIS uses and benefits. The interviewees were mainly enterprise energy or sustainability managers who were organizational power users of the technology and could speak of others' use of the technology in their organizations. Appendix A contains key excerpts from the full set of information requested from each participant. The information-gathering strategy was to ask for high-granularity responses while accepting the level of resolution the participant was actually able to provide.

The 26 participating organizations represented 260 million square feet of EIS install base in a variety of commercial sectors and across more than ten states. Most of the participating organizations comprised enterprises and campus implementations, with a large number of buildings. The length of time an organization had used the EIS ranged from several months to as long as 10 years. From these organizations, annual energy consumption was acquired for nine portfolios and 28 individual sites; detailed technology uses and technology cost data were collected from 23 organizations. Participating organizations are further characterized in Fig. 2 and Fig. 3.



(a) (b)

Fig. 2 (a) Number of participants in each commercial sector, with 26 participants total; and (b) size of EIS install base in each commercial sector, with approximately 260 million square feet of EIS install base in total

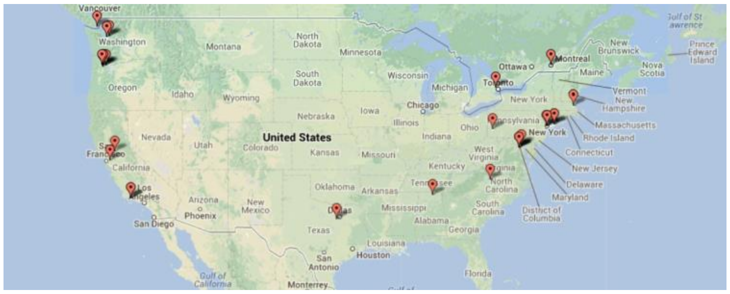


Fig. 3 Locations of the 28 individual buildings included in the annual data analysis

As shown in Fig. 1, the components of EIS implementation are generally broken into software, data acquisition system, and meters or sensors. The information presented in this study focuses on software costs; it does not include hardware costs like material and installation of metering and data acquisition hardware. The hardware costs can be identified from the guidelines published by New Building Institute (NBI 2009), Federal Energy Management Program, U.S. Department of Energy (FEMP 2011), and National Science and Technology Council (NSTC 2011), as well as manufacturer provided information in the public domain. In contrast, EIS software costs, are not readily available in the public domain. EIS software pricing models vary, therefore the study design accommodated many options; for example, up-front as well as ongoing costs, and itemized as well as bundled costs (Appendix Table A-2). After collecting the info, the software cost itemization in the analysis is based on the lowest common denominator across the cohort in terms of the information that could be provided to the research team – up-front and ongoing costs. Implementation details—such as the number of whole-building and submetered data points integrated into the EIS, the number of buildings, floor areas of the EIS install base, and whether the EIS was an on-premise or a cloud-based system—were also gathered and used to understand pricing differences and to synthesize case-specific findings into common terms for comparison.

Fig. 4 provides an example of annual energy use trends before and after EIS installation for a representative site. The data spanned year before implementation of EIS, to the most recent full year of data that each case could provide. Energy data from each site were converted to a common unit—annual, total combined fuels energy use per square feet (kBtu/sf)—which is often referred to as annual *energy use intensity* (EUI). Since EIS are an information and process tool, rather than energy efficient equipment, they enable energy savings, rather than directly producing them. As efficiency insights are gained from use of the EIS, and corrective action is taken, savings are visible in the building consumption trends. Therefore, in this study, the energy savings was determined by calculating the difference in EUI between the most recent year of data, and the year before the EIS installation. Energy consumption for individual buildings was not normalized for weather because total annual consumption was the resolution of data that was provided by study participants. Prior work has shown that for annual data, degree-day normalization in a format of Energy Use = BX (B-Heating or cooling scope, X-Heating or cooling degree days) can introduce more error than improvement (Eto 1985), as electricity is usually used for far more than just cooling in the buildings. Although occupancy rates can be a key driver of building energy consumption, occupancy data was not available for collection from the participants. The effect of fluctuations in occupancy is not able to be controlled for in the study, but likely less of an effect at the portfolio level. Once the quantity of energy saved is determined, the economic value depends on the assumed energy pricing and tariffs. Energy price varies for customers at different locations. To compare the cases from different places, computing energy costs using a single set of energy prices is desirable. In this study, energy cost savings were estimated using national electricity and natural gas prices ($0.03/kBtu for electricity and $0.008/kBtu for natural gas), according to 2012 national average energy price in commercial sector reported by U.S. Energy Information Administration (EIA 2013a; EIA 2013b).

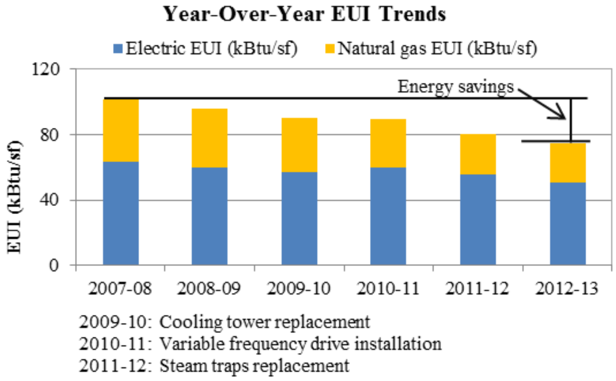


Fig. 4 Annual energy use trends for a single building, with annotations to indicate major projects and year of EIS installation

To answer the question of how to use EIS technology to achieve the maximum benefits, six factors potentially associated with greater energy savings were investigated, including: (1) extent of efficiency projects, (2) building energy performance before the EIS was installed, (3) depth of metering, (4) user engagement, (5) user empowerment to take action based on information provided, and (6) total years of EIS installation, i.e., time of possession. The selection criteria for the six factors are different. Some factors are selected based on literature, some are based on intuition, and some are based on logic: (1) Extent of efficiency projects: This factor is selected based on logic. It is addressed in the paper as by definition that high extent of efficiency projects are the projects generating more savings (assuming correct implementation), so this factor is useful as a methodology and results sanity check. For example, retro-commissioning project or comprehensive retrofits that span HVAC and lighting are considered as high extent of efficiency projects, because both projects could achieve an average whole building savings of 15% (Mills 2004, PNNL 2011). Envelope retrofits such as window upgrades is considered as low extent of efficiency project as it is documented to save on the order of 1-7% in whole building energy (Gustav and Chris, 2014); (2) Building energy performance prior to EIS installation: This factor is selected based on literature. The study of benchmarking and energy savings (US EPA 2012) shows that the buildings started with higher energy use achieved the greatest savings; (3) Depth of metering: This factor is based on intuition and literature. Intuitively, we think that deeper granularity of data leads to deeper performance insights as in moving from whole-building to sub-building. Literatures (PG&E 2011, Zind 2013) also indicate that applying submetering to system, circuit, or device can allow users to flag poor performing systems/devices that were not distinguishable in a whole-building view; (4) User engagement: This factor is based on logic. Monitoring and analysis offered by EIS does not in and of themselves save energy, the user has to look at and act on the data; (5) User empowerment: This factor is based on logic that if you don't have ability to make changes, your improvement insights won't result in savings; (6) Total years since EIS installed: This factor is based on intuition. EIS is a process tool and the savings will achieve after the building operators took actions based on the information EIS provided. As a result, intuitively, we think that savings can accrue over time, as technology becomes more familiar and deeply ingrained into organizational practice.

A four-step analysis was conducted to study the extent to which each of these factors is associated with greater achieved energy savings. First, metrics were established to characterize the factors as low or high for each individual building, e.g., a low vs. high extent of an efficiency project. Second, the same set of individual buildings was divided into low and high groups for each of the six factors based on the characterization results. Third, savings achieved in the low vs. high groups were plotted and the differences in group medians were quantified. Fourth, the statistical significance of the observed differences in achieved median energy savings was analyzed. The strength of the association between that factor and the achieved savings was determined by the magnitude of the difference between the low group versus the high group.

Energy information systems are rarely implemented in isolation; most often being implemented as a critical element of a multi-faceted approach to energy management that also includes capital upgrades, retrofits, and commissioning. All of the cases in this study implemented a series of efficiency improvements over time, and participants were asked to provide a detailed accounting of these improvements and their energy impacts. The level of detail in this accounting varied from case to case, depending on the records that were maintained. The extent of improvement measures over time is, of course, a crucial aspect of contextualizing the annual energy consumption information, as reflected in the annotations in Fig. 4. The extent of efficiency improvements was characterized as high or low based on published data on the types of activities that yield deeper energy savings. The building energy performance before the EIS was installed was characterized as high or low based on regional average EUIs for the given commercial subsector. Specifically, if the EUI was higher than the regional subsector average (EIA 2003) the energy performance was characterized as high, and if it was lower than the regional average, the performance was characterized as low. The depth of metering was characterized based on the metering conditions in the buildings. If additional meters (even one) were installed in buildings to measure the energy consumption of subsystems like HVAC and lighting, or equipment like chillers and boilers, the depth of metering was characterized as high. User engagement with the EIS was determined based on the number of person-hours per month that each organization dedicated to use of the technology. The EIS users are building energy managers or operator across the organization. User empowerment to take action based on the information gained using the EIS was assessed based on a single question that asked on a scale of 1 to 3, how quickly the user is able to act to resolve energy problems that have been identified. The metrics of "low" and "high" for the six factors are summarized below.

- Extent of efficiency projects
  High = cases that conducted retro-commissioning of HVAC systems or that implemented comprehensive retrofit projects that included both lighting and HVAC end uses
  Low = all other cases like envelope retrofits or adding solar panels
- Building energy performance prior to EIS installation
  High = the EUI was higher than the regional average as reported in (EIA 2003)
  Low = the EUI was lower than the regional average
- Depth of metering
  High = presence of submetering and/or integration of trend logs from the building automation system
  Low = campus-level or whole-building metering only
- User engagement
  High = the reported person-hours per month was above the median for the cohort of cases
  Low = person-hours per month were below the median
- User empowerment
  High = response "1" (within a couple of days) when asked on scale of 1 to 3 how quickly they could take action based on insights gained through use of the EIS
  Low = responses "2" or "3"
- Total years since EIS installed
  High = total years since EIS installed was above the median for the cohort of cases
  Low = total years since EIS installed was below the median

Technology Costs

The technology procurement pricing information collected in this study was used to investigate common pricing models, as well as actual ranges of prices and total costs of EIS. This section summarizes the results of software costs of EIS from 18 organizations. In this study a "point" is defined as a single datum that is trended and stored in the EIS. In the studied cases, "points" corresponded to whole-building and submetered electricity and natural gas data. The cases where the energy data analysis was conducted by integrating meter data into a BAS with strong visualization and analysis capability were excluded in the cost analysis, as the cost of the analysis software was not separable from the cost of the control software (BAS). For the cost analysis, number of points was used as a primary common denominator, or normalization factor, across cases for two reasons. First, for software, it was reasoned that the number of points hosted, analyzed, and maintained is the actual service or product being purchased. Second, up-front costs in total dollars were found to scale linearly with the number of points, as opposed to other parameters such as the number of buildings.

Energy information system delivery and pricing models

Energy information systems are most commonly delivered as software-as-a-service offerings; however, on-premise implementations are possible, and were used in 4 of the 18 cases in this study. Software costs are most often broken into a single up-front cost and a recurring ongoing cost that is usually assessed annually. Up-front costs cover software licensing and initial system installation and configuration fee. Ongoing costs are charged for system usage, service, and maintenance with diverse frequency (e.g., monthly, quarterly, or annually) and according to diverse measures (e.g., per building or a single annual fee). Fig. 5 shows how vendors charge ongoing costs for the technology. For the cases in this study, annual fees were triple as common as monthly fees. Fees were typically assessed at the building or portfolio level, with per-meter or per-square foot charges much less common.

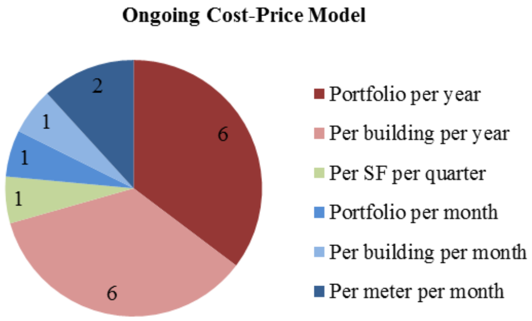


Fig. 5 Pricing models for ongoing EIS software costs, reported by 17 study participants

Energy information systems software costs

Table 2 and Table 3 summarize the ranges and median values of up-front and annual ongoing software costs across 18 total cases, in four metrics including total dollars, dollars per point, dollars per building, and dollars per square feet. Across all cases, the number of points hosted within the EIS ranged from 6 to 1,000, and the median was 200 points; the number of buildings in the EIS install base ranged from 1 to 560, and the median was 17 buildings; the size of the EIS install base ranged from 0.2 to 22 million square feet, and the median was 3 million square feet.

Fig. 6 and Fig. 7 provide a graphical representation of some of the information provided in Table 1, showing the relationship between up-front or ongoing software costs ($/pt) and the number of points. Up-front per point costs ranged from $0/pt (no up-front costs) to $10–$3,400/pt, with most cases falling in the $100–$500/pt range. They did not trend significantly downward with an increase in the number of points, indicating an absence of strong economies of scale in up-front software costs in dollar per point. Annual ongoing per point ranged from $5–$3,100/pt. In contrast to up-front costs, some economies of scale were observed; software costs per point decreased as the number of points increased. Above ~300 pts, ongoing costs were $5–$50/pt. The highest ongoing cost—$3,000/pt—corresponds to a case in which the actual vendor pricing model was assessed on a dollar per square foot basis. In Fig. 7, annual ongoing costs are extrapolated and added to up-front costs, to determine a calculated five-year ownership cost. The median five-year total cost calculated for the cases in this study was approximately $1,800/pt.

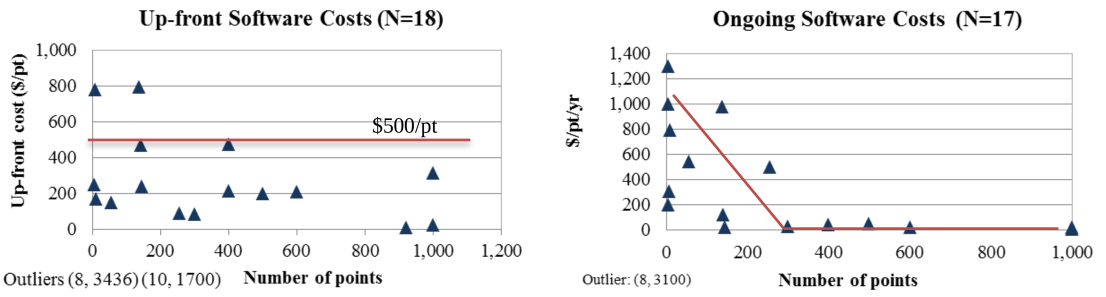
Table 2 Ranges in EIS software costs: up-front, ongoing, and five-year total costs of ownership

Type of Costs	**Range**			
	($)	**($/pt)**	**($/building)**	**($/sf)**
Up-front (N=18)	0* to 1,700–300,000	0* to 10–3,400	0* to 15–120,000	0* to 0.0008–0.77
Annual ongoing (N=17)	1,000–140,000	5–3,100	12–25,000	0.0004–0.15
5-yr ownership (N=14)	31,000–790,000	140–16,000	300–130,000	0.02–1.1

* For two organizations in the study, there were no up-front charges - only an annual software subscription fee

Table 3 Median EIS software costs: up-front, ongoing, and five-year total costs of ownership

Type of Costs	**Median**			
	($)	**($/pt)**	**[$/building]**	**($/sf)**
Up-front (N=18)	23,000	230	1,400	0.01
Annual ongoing (N=17)	16,000	200	400	0.01
5-yr ownership (N=14)	150,000	1,800	3,600	0.06

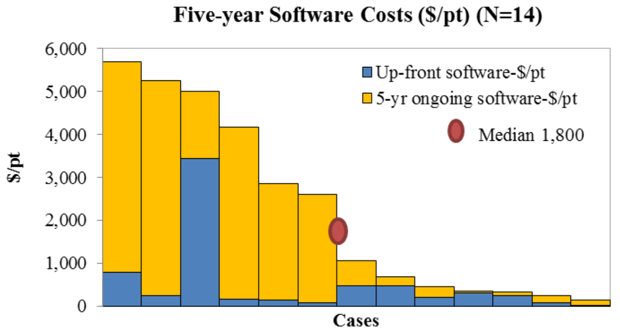


Outliers (8, 3436) (10, 1700)

Outlier: (8, 3100)

(a) (b)

Fig. 6 Up-front (a) and ongoing (b) software costs of energy information systems, as reported by study participants



Not plotted but included in the calculation of median:16,000

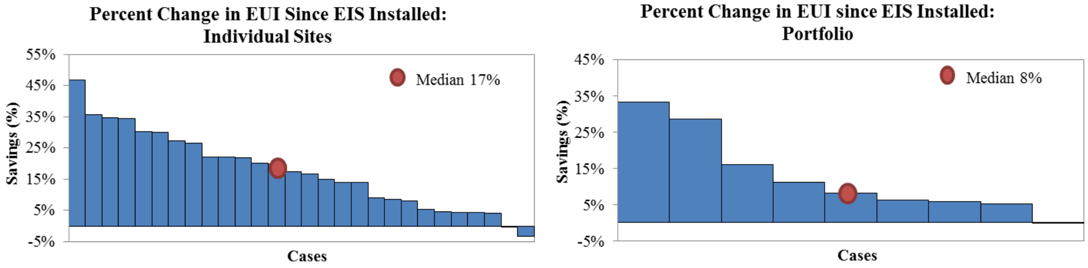
Fig. 7 Distribution and median of total cost of EIS ownership, calculated over a five-year period

Overall, these findings indicate that for the cases in this study, the total costs of EIS software ranged over two to three orders of magnitude. These large ranges are driven in part by the size of the implementation; ongoing costs ($/pt) did decrease significantly as the number of points exceeded approximately 300. However, there remains significant diversity in costs. For example, for the five cases that maintained approximately ten total points, the ongoing costs still ranged over two orders of magnitude (Fig. 6). This variation is believed to be due to differences in pricing *models*, and maturity of this rapidly evolving market. .

It should be noted that most of the cases in this study comprised enterprises and campus implementations, with a large number of buildings, and it is unknown whether they are equally applicable to smaller implementations. These results do not include metering or other hardware costs, nor do they include instances where energy data analysis was conducted by integrating meter data into a BAS with strong visualization and analytics capability. The cost info in this study is from prices paid by EIS customers from several years ago to more recently. The market is rapidly changing, and it is expected that the costs will continue to fall due to market competition, and data measurement and acquisition advances.

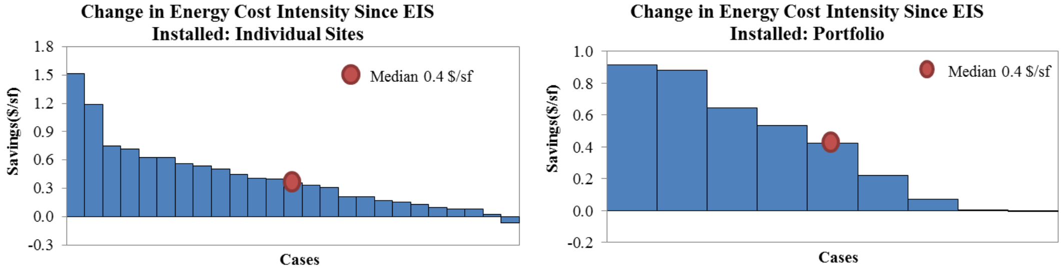
Achieved Energy and Cost Savings

This section presents findings focusing on observed energy and cost savings derived from the use of EIS. Among 21 participating organizations, annual energy consumption before and after EIS installation was acquired for 28 individual sites and nine portfolios which covers over 1,700 buildings installed with an EIS. Impressive reductions between the most recent year for which data were available, and the year before the EIS installation are exhibited in both portfolio and site energy use. Fig. 8 and Fig. 9 show the distribution of percent energy savings and energy cost savings across the same 28 buildings and nine portfolios. The percentage energy savings range from -3% to 47% with a median of 17% for individual buildings, and from 0% to 33% with a median of 8% for portfolios. The range of cost savings is \$0–\$1.5/sf for individual buildings and \$0–\$0.9/sf for portfolios. The median cost savings was \$0.4/sf for both individual sites and portfolios. Study participants were not generally able to provide annual utility costs and associated tariff changes. Therefore, utility cost savings were estimated using national average energy prices, as described in the Methodology section.



(a) (b)

Fig. 8 Distribution of percentage energy savings that were achieved in 28 buildings (a) and in nine portfolios (b)



(a) (b)

Fig. 9 Distribution of estimated energy cost savings (\$/sf) in 28 buildings (a) and in nine portfolios (b)

In addition to total savings, the savings for each year of 28 individual buildings was plotted in Fig. 10. Here, each line represents a building, and the y-axis represents percent savings relative to the year before the EIS installation; the "base year." The x-axis represents savings relative to the base year, for each year that the EIS was in place. This plot shows that in most cases, savings increased over time.

Efficiency projects and other energy management activities were conducted in parallel with EIS use over multi-year time periods. Therefore the relative impacts of each cannot be decoupled, and direct attribution of the total savings exclusively attributable to the EIS technology is not possible. Even so, a full 19 of 21 cases reported that they could not achieve these performance levels and efficient operations without the use of the EIS. Dividing the 28 individual buildings into low extent and high extent efficiency project groups based on the metric in the Methodology section, a median of five percent energy saving was achieved even in cases with low extent of efficiency projects.

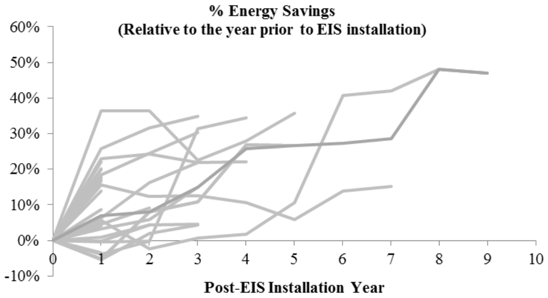


Fig. 10 Percent change in EUI, relative to year of an EIS installation; the gray lines indicate savings for each of 28 individual buildings

Factors Associated with Greater Energy Savings

As noted in the methodology section, the factors that may be related to achieved energy savings include EIS-specific factors such as depth of metering, user engagement, user empowerment, and total years since the technology was installed. In addition, building- or organization-specific factors such as the energy use intensity before the EIS was installed, and extent of efficiency projects, can also have an impact. This section presents an analysis of the extent to which each of these factors is associated with greater achieved energy savings.

Fig. 11 contains plots that show the absolute energy savings (kBtu/sf) that were achieved relative to each potential factor of influence. In these plots, energy savings are shown on the y-axis, and box-and-whisker plots represent the distribution of achieved EUI reductions for cases in which the factor of influence was characterized as low, and for cases in which it was characterized as high. The horizontal bars, or "whiskers," indicate the minimum and maximum savings; the bottom and top of each box indicate the 25th and 75th percentiles; and the transition from green to blue indicates the 50th percentile, or the median savings.

The plots in Fig. 11 provide a visual summary of each potential factor of influence that was considered in the study. Instances in which the savings for the low group are obviously offset from, or different than the high group, indicate factors that appear to have a significant effect on achieved savings. For example, extent of efficiency projects and EUI prior to EIS installation, located in the top row of plots, stand out as having a greater potential effect on achieved savings. Conversely, instances in which the distributions for the low and the high group show extensive overlap indicate a less clear relationship with achieved energy savings. For example, there is little difference in the energy savings achieved in cases with low versus high user engagement (see plot on bottom right).

In addition to visual inspection of the data, a statistical analysis was conducted to determine the size and significance of the relationship between each factor and achieved site energy savings. For each factor, the difference in median energy savings from the low and high group was evaluated using the Wilcoxon-Mann Whitney (WMW) test (Mann and Whitney 1947). This test is a non-parametric equivalent of the independent means t-test, and is applicable to cases in which the dependent variable (in this study, achieved energy savings) does not follow a normal distribution. The achieved energy savings in the "low" and "high" groups are from individual building sites, which are independent of one another, and therefore meet the statistical assumption for Wilcoxon-Mann Whitney test. The effect size for each factor was calculated based on the z-score obtained from the results of the WMW test and the sample size, according to Field (2009).

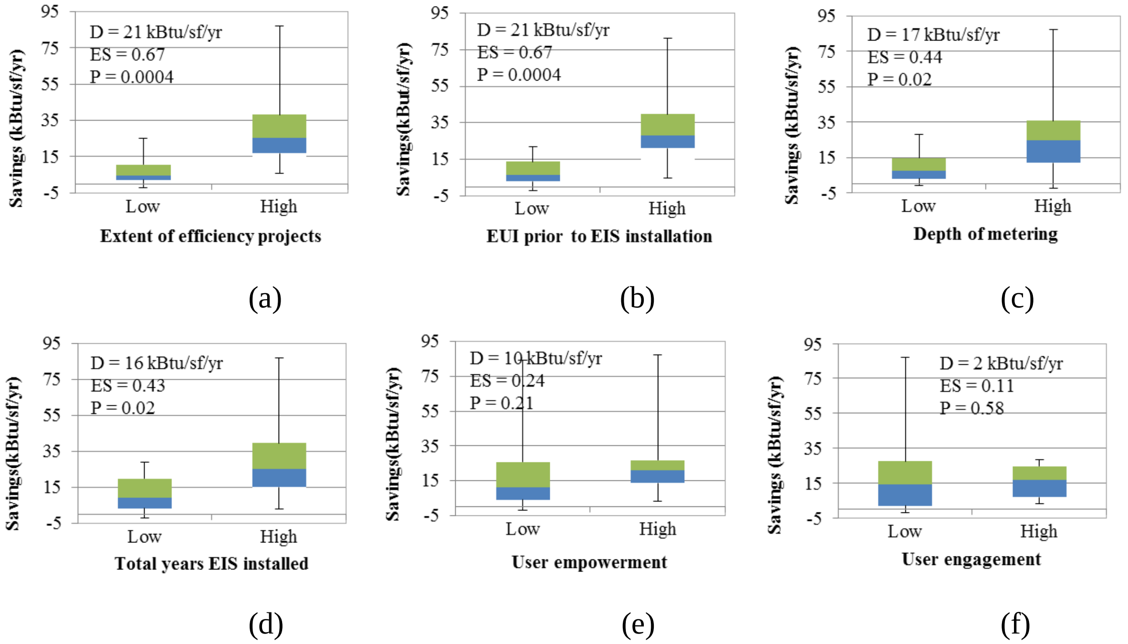
For those unfamiliar with statistical hypothesis testing, the effect size can be interpreted as a normalized representation of the magnitude of the different savings achieved in the low group versus the high group. For the effect sizes reported in this study, any value between .1 and .3 is considered "small correlation," while .3–.5 is "medium correlation," and greater than .5 is "large correlation" following the conventions established in (Cohen 1988). The p value provides insight into the association between the factor considered and achieved energy savings. It shows whether the difference in achieved energy savings between the low group and the high group was statistically significant (consider significant if p value less than 0.05)—that is, whether the difference is truly distinguishable, or a simple artifact of the sampling of study participants. The results of this statistical analysis are shown on Fig. 11.

Fig.11 shows that extent of efficiency projects and EUI prior to EIS installation are most strongly associated with high energy savings; with large significant differences between cases in the low and high groups, large effect size (greater than 0.5), and p values less than .05. Depth of metering and total time that the EIS was in place were the next factors strongly associated with increased energy savings. For these factors, the difference between cases in the low and high groups is modest, the effect size was medium (between 0.3 and 0.5), and the significance of the result was high, with p values less than .05. User engagement and user empowerment were not strongly associated with greater energy savings, as there was little difference in the savings achieved in the high and low groups, small effect size (less than 0.3), and p values more than .05.

Since the cases characterized as 'high extent of efficiency projects' are those that have conducted the projects known to produce deeper energy savings, the extent of efficiency projects factor should have a direct causal impact on the depth of achieved energy savings. The fact that this factor was found to be the most significant in the statistical analysis serves as a validation point for the study methodology and findings. Similarly, EUI is intuitively recognized as a strong indicator of the amount of energy that can be saved using commonly available solutions and practices.

In contrast to efficiency projects, metering alone does not result in energy savings. However it does make sense that implementations with more granular levels of monitoring information have the potential to provide deeper performance insights and greater savings over time. While the study findings show that deeper metering was associated with deeper savings, they do not reveal the ideal maximum depth or level of submetering; that is, the point at which the value of additional information begins to fall off or plateau. Total years of EIS installation may have resulted in a strong association because most cases had installed their EIS within the last one to two years. Over time, operational inefficiencies can be resolved, and the building can reach a point of persistent efficient operation, where further savings require more aggressive retrofits and other improvement measures.

Considered individually, user-specific engagement and empowerment were not associated with deeper energy savings. This should not be interpreted as definitive evidence that these factors are not important. It is possible that while there were relative differences in engagement within this cohort, the cohort may represent high engagement in an absolute sense. In addition, there could have been bias in self-reported levels of empowerment that obscured this factor's true importance. It is also possible that these factors become more important when considered in combination with other factors such as depth of metering. This is a topic for further exploration in future work.



(a) (b) (c)

(d) (e) (f)

Fig. 11 Reductions in EUI for each factor considered, for 28 individual buildings and results from Wilcoxon-Mann Whitney assessment: (a) Extent of efficiency projects; (b) EUI prior to EIS installation; (c) Depth of metering; (d) Total years EIS installed; (e) User empowerment; (f) User engagement; D is difference in median savings between *low* and *high* groups, ES is effect size, and p is Wilcoxon-Mann Whitney p value

Best Practice EIS Uses

The statistical analysis of potential factors of influence showed that depth of metering was associated with greater savings. Although the presence of metering does not directly cause savings, the association was strong, and the difference in savings achieved was large. Based on these findings, implementation of metering beyond the whole-building or whole-campus level is a recommended best practice. In addition to more granular information for issues of operational efficiency, submetering can enable meter-based recovery of utility costs for campus recharges or tenant billing. Additional data from the case studies supplemented the results from the statistical analysis. The ten organizations that achieved the largest energy savings were qualitatively assessed as a subgroup, and the following additional best practice technology uses were identified from the detailed EIS use (Appendix TableA-1) reported by these organizations. The number of organizations that implemented a specific activity is listed after the description of that activity:

Operational Efficiency

- Load profiling on a regular basis (ten out of the top ten): Inspection of time series plots of interval energy consumption data, at least weekly, and at a minimum at the whole-building level. Inspection of submetered building- or equipment-level load profiles can generate further performance insights.
- Use of automated energy anomaly detection features (nine out of the top ten): As opposed to simple threshold-based alarming, use of a mathematical baseline consumption model to automate identification of a typical energy use. Baseline models account for key drivers of energy use such as outside air temperature, time of day, and day of week. Automation and interval metering enable continuous performance assessment and timely identification of energy waste.
- Use of x-y scatter plots of load versus outside air temperature to assess efficacy of the control and operation of temperature-dependent loads, such as whole-building energy, or chiller power (six out of the top ten).

- Benchmarking portfolio and site performance (nine out of the top ten): “Triage” of the worst-performing buildings, and referral for deeper investigation to resolve problems. This is a particularly effective strategy in managing the efficiency of a large portfolio of buildings.
- Tight integration between the energy analyst and building operations (five out of the top ten): Regular communication and information-sharing to close the loop between problem identification and resolution.
- Conversion of energy consumption information into monetary information (five out of the top ten): Use of utility tariffs or cost estimates to explicitly represent the cost of energy used. This was noted as an important motivational technique that can communicate the tangible dollar value of energy savings or waste.

Utility Billing Validation and Payment

- Continuous monitoring of peak load to manage demand charges (nine out of the top ten): Use of whole-building and sometimes submetered data to control the magnitude of peak loads. Especially in larger buildings, electric demand charges can comprise a significant portion of total utility costs, so that peak load management is an effective means of reducing total costs of operation.
- Use of software features to streamline utility-related processes (eight out of the top ten): Minimization of personnel resources required for bill payment and cost reporting, particularly for portfolios with a large number of utility accounts.
- Identification of billing and metering errors (eight out of the top ten): Energy use totals and peak loads that are monitored and tracked in the EIS can be used to identify mistakes in utility charges.

Use of Data for Additional Analyses

- Verification of project savings (five out of the top ten): Historic records of whole-building or submetered data can be exported to quantify achieved energy savings (some advanced EIS automate this capability). This can serve two purposes: (1) validation that efficiency measures are indeed generating the expected level of savings, and (2) hard evidence for financial groups, to confirm the utility cost savings from completed projects.
- Sustainability reporting (five out of the top ten): Energy use records are increasingly used by enterprises to streamline the aggregation of data into quantities required for corporate or organizational reports. In some cases the EIS reporting features were used directly, and in other cases the data were exported for further manipulation.

Summary and future research

This work provides important insights as to the value proposition for implementing and using energy information systems, and provides answers to one of the most critical questions being asked by prospective users – Is the cost of an EIS worth the benefits in utility cost savings, and persistence in efficient operations? Prior to this study the energy savings enabled by EIS were reported in different metrics and narratives, and as a result, it was difficult to generalize the findings. Information on technology costs was especially difficult to find, and limited to a small number of older or more narrowly scoped studies. The results from this work indicate that in several dozen mostly enterprise or campus-level deployments, site and portfolio savings of 17 and 8 percent, and utility cost savings of 0.4 dollar per square feet, respectively, could not have been achieved without the use of the energy information system. The extent of efficiency projects, site EUI before EIS installation, depth of metering, and total years since EIS installation were found to be strongly associated with greater savings. A median of five percent saving was achieved even in cases with low extent of efficiency projects. Best practices associated with greater energy savings included metering beyond the whole-building level; benchmarking to prioritize operational improvement efforts; regular load profiling and continuous anomaly detection; peak demand monitoring; and establishing strong communications between operations and analysis teams. Median five-year costs of ownership (excluding hardware) for these large implementations were $150,000, or approximately $1,800 per monitoring point and $.06/sf. Some economies of scale were observed, with per-point costs decreasing as the number of points hosted in the EIS increased.

Future work should continue to explore the relationship between energy savings and the use of EIS, particularly focusing on additional tracking of the analyses that are most valuable to motivate actions that result in greater energy savings. The work presented in this study focused on large enterprise-wide EIS implementations; solutions to reduce EIS costs also are needed so that the technology can be deployed to small- and medium-sized buildings. The calculated savings in this study didn’t take into consideration the effect of weather as normalization for weather is not recommended when comparing annual EUI values. Additional insights could be gained from analysis of monthly energy data, and that in that case, weather normalization would be critical for rigor in assessment of over-time tends. Finally, understanding new and emerging business models, particularly those that include analytical services, will be important in increasing the adoption of these tools.

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Appendix A Detailed Description of Key Questions Addressed in Case Investigations

Table A-1: Questions those were included in the study to address the general information of EIS and how participants use the EIS

EIS Use
EIS Overview
EIS Vendor:
Year Acquired:
Portfolio or site size covered by EIS installation (sf):
What are approximate person hours per month using EIS (hours)?
How quickly can you act to resolve identified issues? [1 = immediately, 2 = within acceptable delay, 3 = very slowly]
Would you be able to achieve your current levels of energy performance without this tool?
Detailed EIS Use
Please indicate which of the following analyses are you conducting with EIS:
1. Simple tracking (Energy use from one time period to another is inspected for increases or decreases, or for long term upward or downward trends without normalization)
2. Utility cost accounting (Are they converting energy costs to $ in the tool?)
3. Utility billing validation, i.e. identify mistakes in billing
4. Assessing recharges and/or meter-based tenant utility billing
5. Capital budgeting, e.g. payback, return of investment
6. Longitudinal benchmarking (compares the energy usage in a fixed period for a building, system, or component to a baseline period of the same length)
7. Cross-sectional benchmarking (compares a building’s energy efficiency relative to a peer group.)
8. Load profiling (is used on a daily or weekly basis to understand the relationship between energy use and time of day.)
9. Peak load analysis
10. Photovoltaic (PV) monitoring
11. Energy signature (is a plot of energy use versus the outdoor air temperature for a certain period of time. It is used to monitor and maintain the performance of temperature dependent loads such as whole-building gas and electric use or heating and cooling)
13. Quantify and verify energy savings of energy-efficiency projects
14. Anomaly detection (is used to automatically identify abnormal energy consumption against a baseline (regression or other))
15. Carbon accounting or sustainability accounting
16. Encouraging occupant accountability or behavior change

Table A-2 Questions those were included in the study to address technology costs

Technology Costs
Up-front Costs: Software
Per-Point Cost ($)
Per-User Cost ($)
Feature or Module Specific cost ($)
Configuration Labor ($)
Integration Labor Costs ($)
Other Software Costs (specify type and $)
Ongoing Costs: Software and Operations
Software Recurring Costs ($)
Other Ongoing Costs (specify type and $)

Table A-3 Questions those were included in the study to address depth of metering and monitoring

EIS Meters and Sensors
Whole-Building Fuel Meters
Whole-building electric:
Whole-building gas:
Whole-building other:
System-Level Meters
System-level electric:
System-level gas:
System-level other:
Equipment-Level Meters
Equipment-level electric:
Equipment-level gas:
Equipment-level other:
Other
Other Sensors Used in the EIS [Type, Vendor - temp, flow, occupant]
End Use Load disaggregation
Integration
Is the EIS integrated with any points from the building automation system?
Scale of Monitoring
What is the approximate total number of points monitored in the EIS?
What is the approximate total number of buildings monitored with EIS?