Monitoring-Based Commissioning:

Benchmarking Analysis of 24 UC/CSU/IOU Projects

Evan Mills, Ph.D
Paul Mathew, Ph.D.

Lawrence Berkeley National Laboratory
Berkeley, California

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Disclaimer

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Executive Summary

Buildings rarely perform as intended, resulting in energy use that is higher than anticipated. Building commissioning has emerged as a strategy for remedying this problem in non-residential buildings. Complementing traditional hardware-based energy savings strategies, commissioning is a “soft” process of verifying performance and design intent and correcting deficiencies. Through an evaluation of a series of field projects, this report explores the efficacy of an emerging refinement of this practice, known as monitoring-based commissioning (MBCx). MBCx can also be thought of as monitoring-enhanced building operation that incorporates three components: 1) Permanent energy information systems (EIS) and diagnostic tools at the whole-building and sub-system level; 2) Retro-commissioning based on the information from these tools and savings accounting emphasizing measurement as opposed to estimation or assumptions; and 3) On-going commissioning to ensure efficient building operations and measurement-based savings accounting. MBCx is thus a measurement-based paradigm which affords improved risk-management by identifying problems and opportunities that are missed with periodic commissioning.

The analysis presented in this report is based on in-depth benchmarking of a portfolio of MBCx energy savings for 24 buildings located throughout the University of California and California State University systems. In the course of the analysis, we developed a quality-control/quality-assurance process for gathering and evaluating raw data from project sites and then selected a number of metrics to use for project benchmarking and evaluation, including appropriate normalizations for weather and climate, accounting for variations in central plant performance, and consideration of differences in building types. We performed a cost-benefit analysis of the resulting dataset, and provided comparisons to projects from a larger commissioning “Meta-analysis” database.

A total of 1120 deficiency-intervention combinations were identified in the course of commissioning the projects described in this report. The most common location of deficiencies was in HVAC equipment (65% of sites), followed by air-handling and distributions systems (59%), cooling plant (29%), heating plants (24%), and terminal units (24%). The most common interventions were adjusting setpoints, modifying sequences of operations, calibration, and various mechanical fixes (each done in about two-thirds of the sites). The normalized rate of occurrence of deficiencies and corresponding interventions ranged from about 0.1/100ksf to 10/100ksf, depending on the issue.

From these interventions flowed significant and highly cost-effective energy savings For the MBCx cohort, source energy savings of 22 kBTU/sf-year (10%) were achieved, with a range of 2% to 25%. Median electricity savings were 1.9 kWh/sf-year (9%), with a range of 1% to 17%. Peak electrical demand savings were 0.2 W/sf-year (4%), with a range of 3% to 11%.

The aggregate commissioning cost for the 24 projects was $2.9 million. We observed a range of normalized costs from $0.37 to 1.62/sf, with a median value of $1.00/sf for buildings that implemented MBCx projects. Per the program design, monitoring costs as a percentage of total costs are significantly higher in MBCx projects (median value 40%) than typical commissioning projects included in the Meta-analysis (median value of 2% in the commissioning database). Half of the projects were in buildings containing complex and energy-intensive laboratory space, with higher associated costs. Median energy cost savings were \$0.25/sf-year, for a median simple payback time of 2.5 years. Significant and cost-effective energy savings were thus obtained. The greatest absolute energy savings and shortest payback times were achieved in laboratory-type facilities.

While impacts varied from project to project, on a portfolio basis we find MBCx to be a highly cost-effective means of obtaining significant program-level energy savings across a variety of building types. Energy savings are expected to be more robust and persistent for MBCx projects than for conventionally commissioned ones. Impacts of future programs can be maximized by benchmarking energy use and targeting the commissioning towards particularly energy-intensive facilities such as laboratories.

Introduction

1.1 Context – A growing interest in measured energy performance

Buildings rarely perform as intended, with the result that energy use is often higher initially, or over time, than anticipated by the design and engineering estimates of savings. In recent years, building commissioning (see Box on terminology) has emerged as a highly cost-effective quality control and quality assurance strategy for remedying this problem in non-residential buildings. Complementing traditional hardware-based energy savings strategies, commissioning is a process of verifying performance and design intent and correcting deficiencies. A prior "Meta-analysis" of 224 diverse buildings across the United States found median savings of 15% and payback times well under one year [Mills et al. 2004].

Meanwhile, there are many strong drivers towards a measurement-based paradigm for evaluating the performance of energy-efficiency projects, including commissioning. Current paradigms based on stipulated or estimated energy savings invite significant uncertainty and thus risk of under-attainment of goals. Shifting to a measurement-based strategy affords better risk-management and also helps to identify problems and opportunities that are missed when only engineering estimates are used. Retro-commissioning is known to be vulnerable to persistence problems, and thus is a particularly good candidate for a measurement-based approach. Furthermore, certain commissioning opportunities cannot even be identified without the use of measurement.

California policies and laws such as the California Global Warming Solutions Act of 2006 (AB32) and non-residential energy benchmarking (AB1103) combined with the trend towards voluntary and mandatory markets for verifiable carbon trading and offsets will create a growing demand for verifiable energy and carbon reductions, as well as new metering and sensor technologies that make it easier and more productive to meter. There is also more research and evidence [Petersen, et al. 2007] showing that user behavior and motivation to reduce energy use is influenced by feedback on actual building performance. The growing interest in benchmarking also dovetails strongly with measurement-based analysis and opportunity assessment. For example, AB1103 will require that all California non-residential buildings provide a performance rating of their operational energy performance at the time of sale or lease. Many public sector buildings are being required to benchmark on a continuous basis, with goals to reduce energy use annually. New tools and methods are emerging in support of the growing interest in benchmarking [Mills et al. 2007; Mathew et al. 2007].

1.2 Monitoring-based Commissioning (MBCx)

Monitoring based commissioning (MBCx) combines ongoing building energy system monitoring with standard retro-commissioning (RCx) practices with the aim of providing substantial, persistent, energy savings [Brown et al. 2006, Brown and Anderson 2006]. There are three primary streams of additional energy savings from MBCx relative to traditional RCx (see Figure 1):

1. Savings from persistence and optimization of savings from RCx thanks to early identification of deficiencies through metering and trending. Several studies have shown that RCx savings can degrade without an explicit effort to monitor and maintain them [Mills et al. 2004, Bourassa, Piette, and Motegi 2004].

2. Savings from measures identified through metering and trending during the initial commissioning effort i.e. measures unlikely to be found from RCx alone. Haves et al. [2008] provide several examples of such measures, e.g. poor control of chilled water distribution to air handlers; unnecessary chiller operation due to disabled chiller lockout; poor VAV zone control due to inoperative actuators on air dampers and hot water valves.
3. Continually identified new measures. By virtue of the continuous nature of the monitoring, MBCx can identify new problems that emerge after the initial retro-commissioning investigation stage, such as equipment cycling and excessive simultaneous heating and cooling.

There are strong engineering arguments that improving due-diligence during and after the commissioning project can identify deficiencies that would otherwise go undetected (section 4.2.1 presents four such examples). As a case in point, the retro-commissioning of an existing hospital was initially projected to garner annual savings of just over $56,000. First-order calculation and inspection led to a revised savings estimate of under $53,000. The subsequent application of "retrofit isolation option B" per the IPMVP protocol identified additional savings opportunities, bringing the verified total to nearly $74,000, a 31% increase over the original estimate. The additional effort came at a price, but overall payback times remained well below one year [Chitwood et al., 2007].

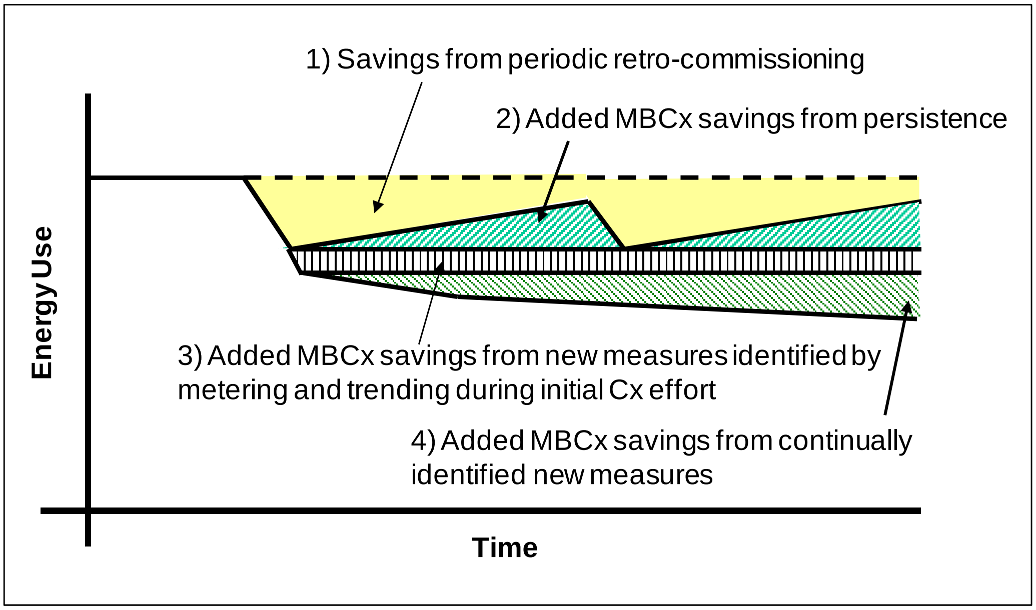


Figure 1. MBCx provides three streams of additional energy savings relative to RCx.

Commissioning Terminology

There has been a proliferation of terms used to describe various categories of commissioning activities. These include commissioning, new-construction commissioning, retro-commissioning, existing-buildings commissioning, re-commissioning, continuous commissioning, and monitoring-based commissioning. There do not appear to be any universally accepted definitions for these terms or for the scope of activities they represent. The California Commissioning Collaborative has made a focused effort to elucidate the terms and practices [Haasl and Heinemeier 2008a; 2008b]. To distinguish MBCx from other types of commissioning for the purposes of this discussion, we use these terms as follows:

New-construction commissioning: Single-instance commissioning of the systems in a newly constructed building (or major building addition), applied from project inception to initial occupancy.

Retro-commissioning (RCx) [or existing-buildings commissioning]: Single-instance commissioning of systems in an existing building.

Re-commissioning: Periodic commissioning of systems in an existing building to ensure that systems are operating as intended.

Continuous Commissioning (CCx): This term has been registered (SM) by Texas A&M University (TAMU), who defines it as “an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities.” Specific commissioning protocols are also associated with the term.

Monitoring-Based Commissioning (MBCx): This refers to the approach in the UC/CSU/IOU partnership. It involves three elements: 1) Energy Information Systems/Building Diagnostics; 2) Retro-commissioning; and 3) Ongoing commissioning and measurement-based savings accounting using the metered and monitored data.

As noted in Brown et al. [2006], MBCx builds on a significant body of research and experience from the field. In the 1990s, research and development on building monitoring and diagnostics included an approach employing extensive permanent energy system monitoring. This capability was shown to enable building operators to identify previously unrecognized dysfunction and energy waste [Piette et al 2000]. Also in the 1990s, Texas A&M University was prominent among those pioneering the practice of building retro-commissioning, with an emphasis on monitoring for baseline determination and diagnostics [Claridge et al. 2000]. Early in this decade, some early adopters on university campuses spontaneously combined these concepts in their energy management programs, establishing part of the model for development of the MBCx program [Haves et al. 2005].

1.3 UC/CSU/IOU MBCx Program Overview

The University of California (UC), California State University (CSU), and Investor-Owned Utility (IOU) Energy Efficiency Partnership is a California-wide energy efficiency program that establishes a permanent framework for a long-term, comprehensive energy management program at the 33 UC and CSU campuses served by California's four large IOUs (PG&E, SDG&E, SCE and SoCalGas) [UC/CSU/IOU EEP 2007]. The program employs three key strategies to meet its goals: 1) energy efficiency retrofits; 2) monitoring based commissioning (MBCx) for retrofitted and non-retrofitted buildings; and 3) training and education. The Partnership is funded by California's investor owned utility customers through Public Goods Charges (PGC), and administered by the utility companies under the auspices of the California Public Utilities Commission.

The Partnership has identified itself as an “innovative” program with all three elements supported by the California Energy Commission's Public Interest Energy Research Program (PIER). The retrofit component is supported by demonstration of PIER R&D products on participating campuses [Johnson, Bourassa, and Seaman 2008]. This has led to scaled-up proposals for deployment of these technologies with Partnership and campus funding. Course development for the training and education program was enhanced by the inclusion of the latest PIER program findings and technology information.

Development of the MBCx approach was enhanced by PIER program support [Piette et al. 2000]. The deployment of MBCx in the Partnership first received PIER support in the form of a campus case studies and needs assessments report [Haves et al 2005], them by an evaluation of EIS Architectures for MBCx implementation [Haves and Watson 2005]. The effort being reported on here developed and applied benchmarking methods to analyze and evaluate the performance of the first phase of campus MBCx projects. A new project will update a 2003 survey of web-based EIS systems [Motegi et al 2003] that could be used in conjunction with MBCx.

The MBCx program represented $5.2 million of the total program budget and was performed on 37 building projects and 9 plant systems, representing over seven million gross square feet. It has three components:

- Installation of permanent energy information systems (EIS) and diagnostic tools, at the whole-building and sub-system level including both hardware (meters), as well as software to analyze and display data. Telemetry and trending software are brought to bear to support the use of raw data generated by the monitoring infrastructure.
- Retro-commissioning of selected buildings and plants based on the information from the EIS and other tools.
- Ongoing commissioning to ensure persistently efficient operations, and measurement-based savings accounting using the metered data.

All three components are implemented by a team including campus facilities staff, working with private commissioning agents qualified by the program. The campus facilities staff received training to implement the MBCx program.

The program is also significant in that it is one of the earliest instances where the California Public Utilities Commission and the California investor-owned utilities have funded (with ratepayer “Public Goods Charges”) commissioning or the utilization of energy-monitoring and feedback as strategies for achieving statewide energy savings goals. The MBCx program is being managed by the UC/CSU/IOU Energy Efficiency Partnership, coordinated by Newcomb Anderson and McCormick (NAM). PECI was contracted to provide additional expertise for data analysis and research. The California Institute for Energy and Environment provided support as a part of the UC program team.

MBCx Benchmarking Project Overview

1.4 Motivation and Objectives

Benchmarking methods and tools can, in principle, inform and address several areas that are important to the UC/CSU/IOU MBCx Program. Following are examples of the role that can be played by benchmarking, as well as questions that framed the research described in this report:

Project screening:

The MBCx program screens and selects projects for funding based on several criteria, including projected savings, projected costs and payback times, qualifications of implementation team, equity across different campuses, etc.

- Can benchmarking could be used to check the reasonableness of baselines, savings, costs and payback, taking into account building type, location, and other characteristics?
- Does the use of benchmarking for project screening improve the overall performance of the MBCx portfolio?

Post-completion project evaluation:

- Which metrics are the key predictors of success? These could then be used to inform the screening process for the next phase of projects.

Performance of MBCx projects relative to other commissioning projects:

- How do MBCx projects perform relative to the cohort of projects documented in the LBNL commissioning Meta-analysis database [Mills et al 2004]?
- Does MBCx yield a different set of efficiency measures?
- How can the data from the MBCx program be used to inform related efforts such as California-wide benchmarking efforts?

Data Analysis:

- What are the protocols used to account for missing data or poor data quality?
- What are the appropriate ways to normalize for building type, climate, weather and other factors?
- What are the appropriate methods to normalize and account for the buildings served by central utilities versus those that aren’t?

1.5 Scope of Work

In order to explore these areas further, LBNL was commissioned by the PIER Technology Demonstration Program and the California Institute for Energy and Environment to pursue two broad objectives:

- Develop practical benchmarking processes that can be implemented given existing constraints in terms of UC/CSU staff time, skills, and data availability.
- Conduct a benchmarking analysis of the results from the first phase of projects.

Task 1. Benchmarking methods

1a. Develop a quality assurance (QA) checklist for data provided by sites, prior to and after completion of project implementation

1b. Develop a practical benchmarking process that can be used to screen projects during selection, and evaluate their performance after completion.

Task 2. Perform benchmarking analysis of Phase-1 projects

2a. Assist NAM in developing QA'd dataset of Phase-1 projects, using the QA checklist developed in Task 1a.
2b. Analyze and benchmark QA'd project data using benchmarking process developed in Task 1b.
2c. Compare outcomes to those of non-MBCx projects

These tasks were performed largely in parallel, with interim results from each task iteratively informing the other. Section 3 describes the results of Task 1, and Section 4 describes the results from Task 2.

Benchmarking Methods

1.6 Data Quality Assurance Checklist

Data collected on site for benchmarking is error-prone for several reasons, including outdated or non-existent building drawings and specifications, lack of EIS systems for energy data, lack of staff time and expertise to collect and review data, lack of motivation or incentives to ensure data quality for benchmarking, deviation from pre-defined data definitions, whether “empty cells” represent zeros or missing data, etc. These issues are widespread in the building industry, and are likely to remain so for the foreseeable future. Benchmarking processes need to take these factors into account and cannot assume good data quality.

Quality assurance can, of course, be performed at various levels, depending on the desired level of assurance and resources available. A comprehensive and robust quality assurance process would include independent on-site verification of data. This was beyond the scope of this project and arguably may not even be necessary. Rather, the intent here was to conduct some basic “sanity checks” that highlight irregularities that could then be explored further with the site as needed. It is recommended that these simple checks carried out for all future phases of the project. In some cases, they can be built into the data reporting forms to prevent erroneous input. Table 1 indicates simple QA checks that we performed for various data items, and recommendations for how to execute the QA checks. In almost all cases, QA requires a technical reviewer to evaluate reasonableness. The benchmarking results in Section 4 can be used to aid this process. In a few cases, the QA check can be automated within the reporting form, which would flag errors at the time of input. Many of the QA checks require metrics calculated from the reported data. This also can be automated within the database.

Table 1. Simple QA checks for MBCx project data.

Data Item(s)	QA Check(s)	QA Execution
All descriptive fields (free form text)	Ensure that text is in appropriate field	Technical Reviewer
Building Area	Is it reasonable by order of magnitude?	Technical reviewer
	Calculate difference between proposal and final report? If yes, is it explained?	Calculation in database; Technical reviewer
Area with 100% outside air	Calculate lab area ratio. Is it reasonable based on building description?	Calculation in database; Technical reviewer
Number of fume hoods (in the case of laboratories)	Calculate # hoods/ 5000 gsf. Is it reasonable based on building description? (Figure 16)	Calculation in database; Technical Reviewer

Data Item(s)	QA Check(s)	QA Execution
Building electricity: baseline, post-retrofit	Ensure non-zero value	Auto validation in report form
	Calculate building kWh/gsf. Is it reasonable? (Figure 10)	Calculation in database; Technical reviewer
	Calculate % savings. Is magnitude reasonable based on description of ECM?	Calculation in database; Technical reviewer
Building on-peak electricity: baseline, post-retrofit	Ensure non-zero value	Auto validation in report form
	Calculate ratio of on-peak to total. Is it reasonable?	Calculation in database; Technical reviewer
	Calculate % savings. Is magnitude reasonable based on description of ECM?	Calculation in database; Technical reviewer
Building natural gas: baseline, post-retrofit	Ensure non-zero value if building served by natural gas, and vice versa	Auto validation in report input form (report should explicitly ask if there is building natural gas)
	Calculate building BTU/gsf. Is it reasonable? (Figure 12)	Calculation in database; Technical reviewer
	Calculate % savings. Is magnitude reasonable based on description of ECM?	Calculation in database; Technical reviewer
Central plant steam/hotwater: baseline, post-retrofit	Ensure non-zero value if building served by central plant steam/hot water, and vice versa	Auto validation in report input form (report should explicitly ask if there is central plant steam/hot water)
	Calculate steam/hot water BTU/gsf. Is it reasonable? (Figure 13, Figure 14)	Calculation in database; Technical reviewer
	Calculate % savings. Is magnitude reasonable based on description of ECM?	Calculation in database; Technical reviewer
Central plant chilled water: baseline, post-retrofit	Ensure non-zero value if building served by central plant chilled water, and vice versa	Auto validation in report input form (report should explicitly ask if there is central plant chilled water)
	Calculate chilled water ton-hr/gsf. Is it reasonable? (Figure 15)	Calculation in mastersheet; Technical reviewer
	Calculate % savings. Is magnitude reasonable based on description of ECM?	Calculation in mastersheet; Technical reviewer
Max 15 min. demand: baseline, post-retrofit	Ensure non-zero value	Auto validation in report form
	Calculate W/sf. Is it reasonable? (Figure 11)	Calculation in mastersheet; Technical reviewer
Central plant electricity savings	If non-zero, ensure building served by central plant chilled water generated from electric chillers	Auto validation in report form
	Calculate implied efficiency (kW/ton) for electric chillers. Is it reasonable? (Between 0.5 and 2.0 kW/ton)	Calculation in mastersheet; Technical reviewer

Data Item(s)	QA Check(s)	QA Execution
Central plant natural gas savings	If non-zero, ensure building served by central plant steam/hot water or gas-driven chillers	Auto validation in report form
	Calculate implied efficiency (BTU output/ BTU input) for boilers. Is it reasonable? (Between 50-98%)	Calculation in mastersheet; Technical reviewer
Metering and monitoring costs: Contracted out, in-house	Ensure that one or both fields are non-zero, and that zero value indicates no cost (and not missing data)	Auto validation in report input form (report should explicitly ask if metering was in-house and/or contracted out)
	Calculate total metering $/gsf. Is it reasonable?	Calculation in mastersheet; Technical reviewer
Baseline and Cx costs: Contracted out, in-house	Ensure that one or both fields are non-zero, and that zero value indicates no cost (and not missing data)	Auto validation in report input form (report should explicitly ask if baseline and Cx was in-house and/or contracted out)
	Calculate total baseline and Cx $/gsf. Is it reasonable? (0 b)	Calculation in mastersheet; Technical reviewer

These QA checks identified over 20 items in the Phase 1 project data that required further investigation, many of which resulted in corrections to the reported data.

1.7 Benchmarking Approach – Metrics and Data

As noted earlier, there are two primary applications of benchmarking in the MBCx program:

- Proposal screening
- Post-completion evaluation

Toward this end, we developed a set of metrics based on the analysis framework developed for the Cx Meta-analysis [Mills et al. 2004, with some additional metrics for portfolio level analysis and diagnostics. Table 2 lists the metrics and their application for proposal screening and post-completion evaluation. Note that many of these metrics are used for data QA during both proposal screening and post-completion evaluation.

Three data sets were used for benchmarking the MBCx projects:

1. MBCx portfolio i.e. comparison across the MBCx project portfolio itself
2. RCx Meta-analysis – all data points, which includes over 100 projects across the U.S.
3. RCx Meta-analysis – West Coast cohort, defined as the subset of projects in California, Oregon, and Washington.

Table 2. Benchmarking metrics for MBCx proposal screening and post-completion evaluation

Metrics	Proposal screening	Post-complete evaluation	Available in Cx Meta-Analysis?
Baseline			
Source energy kBTU/sf-yr	√		√
Electricity kWh/sf-yr	√		√
Peak elec kWh/sf-yr	√		
Fuel kBTU/sf-yr	√		√
Historical vs. revisedP[1] Elec kWh/sf-yr		√	
Historical vs. revised[1] Peak kWh/sf-yr		√	
Historical vs. revised[1] Fuel kWh/sf-yr		√	
Savings			
Electricity %, kWh/sf-yr	√	√	√
Bldg Elec %, kWh/sf-yr	√		
Peak elec %, kWh/sf-yr	√	√	[2]
Bldg Peak %, kWh/sf-yr	√		[2]
Fuel %, kBTU/sf-yr	√	√	√
Bldg Fuel %, kBTU/sf-yr	√		√
Chilled water %	√	√	√
Hot water/steam %	√	√	√
Total source %, kBTU/sf-yr	√	√	√
Total site %, kBTU/sf-yr	√	√	√
Total cost $/sf-yr	√	√	√
# Deficiencies		√	√
# Measures		√	√
Proposed vs. reported Elec kWh/sf-yr		√	
Proposed vs. reported Peak kWh/sf-yr		√	
Proposed vs. reported Fuel kBTU/sf-yr		√	
Implementation Costs			
Simple payback (yrs)	√	√	√
Project cost $/sf	√		√
Metering cost (% of total)		√	[3]

Notes:

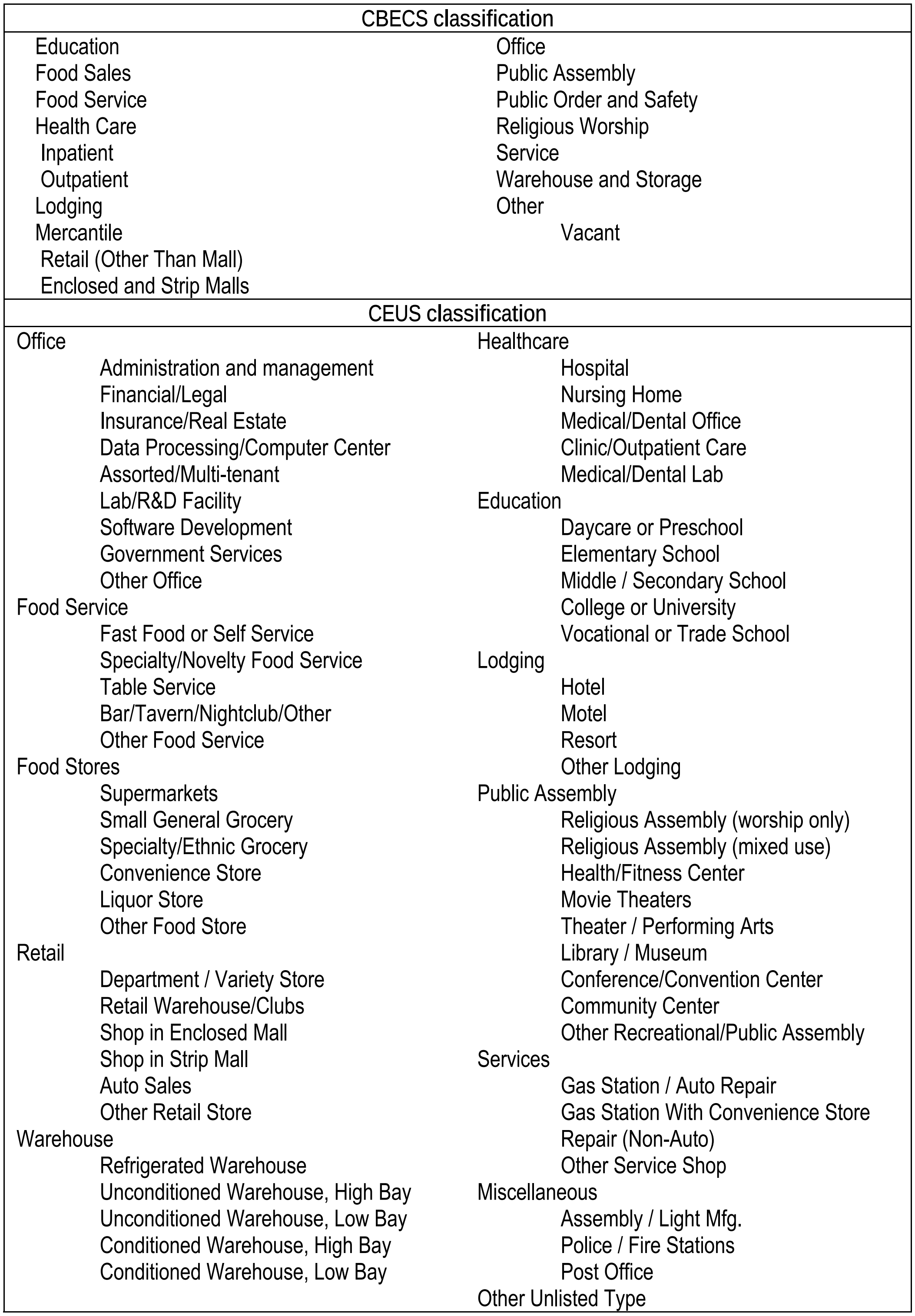
1. "Revised" refers to the baseline after the installation of any metering equipment
2. Power densities only
3. Includes related category called "Verification & Persistence Tracking"

1.8 Special Considerations

A key to meaningful benchmarking is defining the appropriate peer group against which the subject building should be compared. In this project, we considered building type, climate and weather, utilities/services provided and whether or not a given building is served by a central plant. We suggest a hierarchical classification scheme that allows classification at different levels of granularity based on data availability i.e. while it is generally preferable to benchmark with a classification that is as fine-grained as possible, data limitations may require a more coarse classification [Mathew et al. 2008].

1.8.1 Building type classification

Building type classification is a key issue in energy benchmarking. There is no standard way to classify non-residential buildings in the US. Figure 2 shows the classification in the CBECS database [EIA 2003] and the CEUS database [CEC 2006]. CEUS has a two- tier classification that is more fine-grained, with 62 sub-types.



CBECS classification

- Education
- Food Sales
- Food Service
- Health Care
  - Inpatient
  - Outpatient
- Lodging
- Mercantile
  - Retail (Other Than Mall)
  - Enclosed and Strip Malls
- Office
- Public Assembly
- Public Order and Safety
- Religious Worship
- Service
- Warehouse and Storage
- Other
  - Vacant

CEUS classification

- Office
  - Administration and management
  - Financial/Legal
  - Insurance/Real Estate
  - Data Processing/Computer Center
  - Assorted/Multi-tenant
  - Lab/R&D Facility
  - Software Development
  - Government Services
  - Other Office
- Food Service
  - Fast Food or Self Service
  - Specialty/Novelty Food Service
  - Table Service
  - Bar/Tavern/Nightclub/Other
  - Other Food Service
- Food Stores
  - Supermarkets
  - Small General Grocery
  - Specialty/Ethnic Grocery
  - Convenience Store
  - Liquor Store
  - Other Food Store
- Retail
  - Department / Variety Store
  - Retail Warehouse/Clubs
  - Shop in Enclosed Mall
  - Shop in Strip Mall
  - Auto Sales
  - Other Retail Store
- Warehouse
  - Refrigerated Warehouse
  - Unconditioned Warehouse, High Bay
  - Unconditioned Warehouse, Low Bay
  - Conditioned Warehouse, High Bay
  - Conditioned Warehouse, Low Bay
- Healthcare
  - Hospital
  - Nursing Home
  - Medical/Dental Office
  - Clinic/Outpatient Care
  - Medical/Dental Lab
- Education
  - Daycare or Preschool
  - Elementary School
  - Middle / Secondary School
  - College or University
  - Vocational or Trade School
- Lodging
  - Hotel
  - Motel
  - Resort
  - Other Lodging
- Public Assembly
  - Religious Assembly (worship only)
  - Religious Assembly (mixed use)
  - Health/Fitness Center
  - Movie Theaters
  - Theater / Performing Arts
  - Library / Museum
  - Conference/Convention Center
  - Community Center
  - Other Recreational/Public Assembly
- Services
  - Gas Station / Auto Repair
  - Gas Station With Convenience Store
  - Repair (Non-Auto)
  - Other Service Shop
- Miscellaneous
  - Assembly / Light Mfg.
  - Police / Fire Stations
  - Post Office
- Other Unlisted Type

Figure 2. Building type classification in CBECS and CEUS.

Both CBECS and CEUS have the type “College or University” but do not provide further sub categories for the large diversity of types of buildings that are found on college and university campuses (although some of these building types, such as administrative offices are represented separately).

At the top level, buildings can be simply classified as ‘complex’ (i.e. energy intensive) or ‘non-complex’ (i.e. not energy-intensive). This classification was also used in developing benchmarks for design loads for the UC Merced campus (Brown 2002). Table 3 shows the proposed classification as well as the corresponding building types in CEUS and CBECS. Buildings that are mixed use could be classified based on predominant type or simply as “mixed”. Given the limited number of data points for the current analysis, it was only possible to define use separate cohorts for ‘Laboratories’ and ‘Non-Complex’.

Table 3. Suggested building-type classification for Campuses in MBCx Program

Building Type	Related CEUS building type (* indicates aggregate type)	Related CBECS building type (* indicates aggregate type)
Complex	-	-
Laboratories	Lab/R&D Facility	Laboratory
Dense lab	-	-
Light lab	-	-
Healthcare	Healthcare*	Healthcare*
In-patient	Hospital; Nursing home	Out-patient healthcare
Out-patient	Clinic/Outpatient care	In-patient healthcare
Food Sales	Convenience Store	Food sales
Food Service	Fast food or self service	Food service
Non-Complex		
Office	Office (non-medical)*	Office
Classroom	-	-
Library	Library/Museum	-
Dormitories	-	-
Retail	Other retail store	Retail other than mall
Sports facilities	Health/Fitness center	-
Warehouse (ex. refrigerated)	Warehouse* (ex. refrigerated)	Non-refrigerated warehouse
Conditioned	Conditioned warehouse	Non-refrigerated warehouse
Unconditioned	Unconditioned warehouse*	Non-refrigerated warehouse

Laboratory sub-types: Dense vs. light:

Given their high energy intensity and prevalence in colleges and universities, laboratories are an especially significant building type for this program. Furthermore, since this building type is more diverse compared to other building types, we explored the possibility of further sub-categorizing laboratories as “dense” or “light” to improve comparability in benchmarking.

There are three key factors that individually or in combination can be used to characterize lab intensity:

- Lab area ratio (ratio of area requiring 100% outside air to the total building area)
- Fume hood density
- Laboratory equipment plug load intensity

Ideally, the benchmarking process for laboratories should normalize for these three parameters. The rigor with which this is done would depend on the purpose of benchmarking. For first order screening, we propose simple threshold criteria, as follows:

A laboratory may be categorized as “dense” if it meets one or more of the following criteria:

- Lab area ratio greater than 0.5. This is the approximately the median value for lab area ratio in the Labs21 database (http://labs21.lbl.gov/).
- Fume hood density greater than 0.75/ 1000 sf gross building area. This roughly corresponds to the threshold value above which ventilation rates become fume hood driven. The calculation and assumptions for this value are as follows: General exhaust requirements range from 1.0 to 1.3 cfm/sf of lab area. A six-foot fume hood is typically 1200 cfm at full flow, and therefore 1 fume hood / 1000 sf of lab area would result in 1.2 cfm/sf. So 1 fume hood/1000 sf of lab area is a threshold for a fume hood driven lab, assuming no sash management. Since the minimum flow for fume hoods is typically about one-quarter of full flow, the threshold with perfect sash management would be 4 fume hoods/ 1000 sf. of lab area. Since sash management is generally average to poor, we assume 1.5 fume hoods/1000 sf of lab area as threshold for a fume hood-driven lab. Assuming 0.5 lab area ratio this translates into 0.75 fume hoods / 1000 sf of gross building area.
- Plug load intensity: Since quantitative data (equipment W/sf) is unlikely to be available, a qualitative judgment should be made based on the usage of the laboratory i.e. labs that that are equipment intensive (e.g. laser labs) should be characterized as dense labs.

Each of the labs in the present analysis was classified as dense or light based on this approach, although data gaps and quality precluded rigor in this classification. The limited number of data points also precluded the use of separate dense and light lab cohorts for the benchmarking analysis.

1.8.2 Climate and weather normalization

Climate normalization refers to the normalization for differences in climate across different geographical locations. This allows buildings in different climate zones to be compared to each other. Weather normalization refers to the normalization for differences in weather from one year to another in the same location. Depending on the intent of the benchmarking either or both climate and weather normalization may be required. The extent to which normalization matters and therefore the rigor with which it should be done depends on the purpose of the benchmarking analysis. To be done rigorously, normalization requires an adequate data set for regression analysis. In particular, weather normalization typically requires monthly data energy use data. In the context of MBCx, where benchmarking is primarily being used for project screening and post-completion evaluation, it could be argued that a rigorous regression-based analysis may not be worth the additional data collection requirements and loss of transparency inherent in regression-based approaches. There are some additional considerations that support this view:

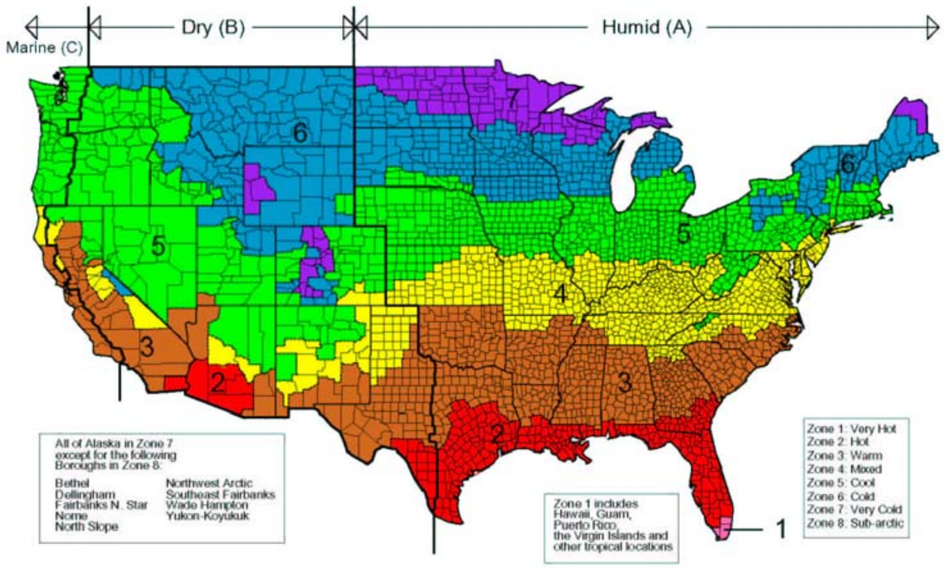
- Since the phase-1 MBCx projects were executed within the same time frame, weather normalization (i.e. accounting for year-to-year differences) is largely not an issue for comparing projects within a given phase. Note however, that the savings for each MBCx project were normalized to account for differences in baseline and post-retrofit conditions.

- A regression-based analysis of weather normalization for various EPA laboratory buildings [Mathew 2007] showed very strong correlations between energy use and monthly average temperatures. Despite these strong correlations, year-to-year differences in weather were not significant enough to affect conclusions about the impact of savings.
- Piette [2008] suggests that accounting for variations in climate may not be that critical for non-laboratory buildings in many regions of California, because the weather-dependent portion of building energy-use may be relatively small for non-laboratory buildings in mild climates. However, many of the State's population centers have considerable cooling loads.

Nevertheless, to the extent that regression-based normalization can improve the quality of benchmarking at a reasonable "cost" (in terms of data requirements and analysis time) it should continue to be an option – especially as more data is obtained from future phases of the MBCx program. Where the requirement is to quantify energy savings in the single-digit percentage range, weather-normalization can make a material difference in findings.

For the present, we recommend using a climate zone classification to compare buildings in similar climates. There are two options: a) DOE national classification; and b) California Title 24 climate zones.

The DOE climate zone classification was developed by Pacific Northwest National Laboratory, and has been adopted by ASHRAE [Briggs et al. 2002], the International Energy Conservation Code (IECC), the Labs21 benchmarking tool, and others. This classification has 15 major climate zones for the United States, based on temperature and humidity, and assigns a climate zone for each county and territory in the US (Figure 3).



Briggs, R., Lucas, R., Taylor, Z, Climate Classification for Building Energy Codes and Standards, Technical Paper, Pacific Northwest National Laboratory. March 2002

Figure 3. DOE climate zone classification

There are three relevant zones for the UC/CSU system:

- Warm Marine (Zone 3C)
- Warm Dry (Zone 3B)
- Mixed Marine (Zone 4C)

Since the DOE classifications are based on county, some adjustments are needed for counties that have significant microclimates. The warm dry region (3B) includes the central valley and the south coast (Los Angeles, San Diego). If using this classification, we recommend a separate Warm Dry Coastal sub-region to include UCLA, UC Irvine, UC San Diego, CSU Dominguez Hills and CSU Long Beach.

The California Title 24 Climate classification, with 16 climate zones for California, offers much more resolution than the DOE classification. The EnergyIQ benchmarking tool (http://EnergyIQ.lbl.gov), which builds on the CEUS database, provides an aggregated version with seven climate regions (a further level of resolution, while technically possible, was not available for reasons related to data confidentiality). In the present analysis, the limited number of data points precluded the use of separate cohorts based on climate zone.

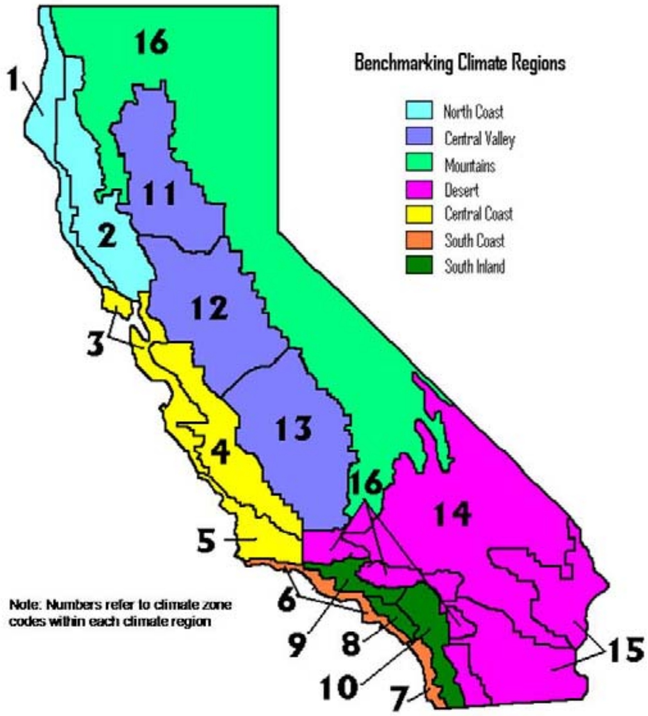


Figure 4. California climate zones and regions

1.8.3 Comparing buildings with and without central plant services

Buildings in the benchmarking peer-group may have any combination of building utilities and central plant systems that serve these utilities, as listed in Table 4.

Table 4. List of building utilities and plant systems

Building utilities	Plant systems
Electricity	Electric chillers
Natural gas	Gas-fired chillers
Other Fuel	Cogeneration
Plant chilled water	Thermal Energy Storage
Plant steam	Boilers
Plant hot water	
Plant condenser water	

Depending on the purpose of the benchmarking analysis, the following approach is recommended for computing the energy use of plant utilities in plant-served buildings:

- To assess and compare buildings in terms of their energy efficiency *at the building*, use uniform efficiency rates for plant utilities, as indicated in Table 5.

Table 5. Standard efficiency rates for central plant utilities

Central Plant Utility	Efficiency
Chilled Water	1.0 kW/ton
Steam	80%
Hot water	80%
Condenser water	0.4 kW/ton

- To compare the cost-effectiveness and report energy and cost savings on completed projects, use reported (i.e. "actual") efficiency rates for plant utilities. This is the approach used for comparison to the Meta-analysis.

1.8.4 Other considerations

There are a host of more qualitative factors that also merit special attention in data gathering and analysis. These include records of the specific deficiencies discovered and measures implemented to correct them, verification of measure installation, nature of energy savings data (measured versus estimated), and completeness of cost data (a common problem is that only commissioning agent fees are included). Commissioning documentation often fails to make clear whether the entire facility and all of its sub-systems were commissioned, or whether specific areas and/or systems were targeted. Floor area definitions should also be transparent as to the handling of net versus gross areas, unconditioned spaces, parking areas, etc.

Benchmarking Results

1.9 Summary of Program Portfolio Results

Table 6 summarizes the overall performance of the 24 Phase-1 MBCx projects in terms of key savings and cost metrics. This set of projects is a subset of the overall portfolio of the MBCx Phase-1 program in that it excludes projects that had capital retrofits and/or central plant projects. However, as it is intended as an overall assessment of the program it does include three MBCx projects that received funding but which did not report any savings and may not have been fully implemented as of the time data were collected. As a result of including these zero-savings projects in the analysis, the portfolio results are more conservative than if they were to be excluded. For each metric, three different values are presented: median; project average (obtained from averaging the values of the metric for all projects); and aggregate (obtained from computing the metric at the portfolio level i.e. essentially a weighted average). For comparison, Table 6 also shows the values of the savings metrics for the two Meta-analysis cohorts i.e. all projects, and west coast projects only.

Table 6. Overall performance of MBCx phase -1 projects

Savings/Cost Metric	MBCx Phase-1 projects median/proj avg/ aggregate	Cx Meta-analysis [5] median/proj avg	Cx Meta-analysis [5] CA/OR/WA Only [6] median/proj avg
Total source energy savings %	10% / 9% / 10% (N=24/24/22) [1]	13% / 16% (N=46)	8% / 9% (N=24)
Total site energy savings %	11% / 11% / 11% (N=24/24/22)[1]	15% / 19% (N=46)	8% / 9% (N=24)
Simple Payback Period	2.2 / N/A / 2.1 (N=21/24) [2,3]	1.0 / 2.1 (N=98)	1.5 / 2.7 (N=36)
Electricity savings %	9% / 8% / 9% (N=24/24/22) [1]	9% / 11% (N=46)	
Peak electricity savings %	5%/ 6% / 6% (N=23/23/21) [1]	2% / 7% (N= 3)	
Fuel savings %	9% / 15% / 13% (N=24/24/22) [1]	6% / 13% (N=19)	
Chilled water savings %	17% / N/A / 22% (N=10) [4]		
Hot water/Steam savings %	12% / 23% / 18% (N=13)		
Total Thermal		36% / 37% (N=16)	

Notes:

1. The number of data points for the aggregate value is less than the number of data points for median and project average because baseline data were not available for two of the un-implemented projects, and therefore they were excluded for calculating the aggregate values.
2. Project average was not calculated for simple pay back because the portfolio includes zero-savings projects for which simple payback could not be calculated.
3. The second value of N refers to the number of data points for the aggregate value. The number of data points for the median is lower because it excludes the zero savings projects, for which simple payback cannot be calculated.
4. One project resulted in a large shift of energy use from the building to the plant, rendering the average of values for chilled water meaningless.
5. Values for Meta-analysis include the subset with weather-normalized data, and assume the same energy prices and electric-conversion heat rate adopted for the MBCx analysis.
6. The western cohort primarily distinguishes the Meta-analysis projects that are not in high-humidity (summer) climates. It is notable that the cohort of projects in the high humidity climate is dominated by one provider (Texas A&M University).

1.10 Detailed Results

We analyzed and compared performance among the MBCx cohort. In addition, we compare the cohort as a whole to the outcomes of other retro-commissioning projects that have been analyzed as part of the Lawrence Berkeley National Laboratory database of commissioning and retro-commissioning costs and benefits. We refer to this as the "LBNL Meta-analysis Database".

This analysis seeks to normalize diverse retro-commissioning data to standard energy prices, and correct for inflation so that projects costs and savings in various years can be more readily compared. Per the discussion of defining meaningful peer groups for benchmarking and analysis purposes, we adopted the following conventions and normalizations:

- Building types: To distinguish among services, we provide separate analyses for laboratory facilities and other (less energy intensive) facilities.
- Weather and climate: Weather-normalization is achieved by short-term monitoring of energy and actual weather and then scaling to annual values based on normalization per long-term data. For climate normalization, we

compare non-laboratory MBCx projects to other retro-commissioned projects in the states of California, Oregon, and Washington. This primarily distinguishes the Meta-analysis projects that are not in high-humidity (summer) climates. It is notable that the cohort of projects in the high humidity climate is dominated by one provider (Texas A&M University). Due to lack of data from CA/OR/WA climates, for laboratory-type spaces we compare those in the MBCx sample to other labs wherever they occur in the U.S. (predominantly at Texas A&M University).

- Central plant utilities: We used reported (i.e. "actual") efficiency rates for plant utilities.
- Economics: We use standardized commercial energy prices, and inflation-correct all cost data to 2007 levels.

1.10.1 Deficiencies and Interventions

We applied a framework for tabulating the deficiencies identified and corresponding interventions (measures) implemented to correct them. This framework was previously used in the LBNL Meta-analysis (Mills et al. 2005) with refinements and clarifications for the present version. Various metrics can be used to characterize deficiencies and measures. These include total number, number normalized by floor area, and occurrence by percentage of buildings.

A total of 1120 deficiency-intervention combinations were identified in the course of commissioning the 24 UC/CSU projects described in this report (see Table 7 and key in Appendix A). The most common location of deficiencies was in HVAC equipment (65% of sites), followed by air-handling and distributions systems (59%), cooling plant (29%), heating plants (24%), and terminal units (24%). The most common interventions were adjusting setpoints, modifying sequences of operations, calibration, and various mechanical fixes (each done in about two-thirds of the sites). The normalized rate of occurrence of deficiencies and corresponding interventions ranged from about 0.1/100ksf to 10/100ksf, depending on the issue (Figures 5 and 6).

The choice of metric is important. For example, while a very high number of lighting-related deficiencies were identified (and a correspondingly high number per unit floor area), they were found in a relatively small fraction (just over 10%) of all sites. Conversely, while the number of deficiencies in heating and cooling plants was a small, fraction of the total, they were relatively common (being found in 25% to 20% of sites).

Table 7. Deficiencies and Interventions in MBCx Projects.

		Commissioning Measures Implemented																		
		Design, Installation, Retrofit, Replacement				Operations & Control									Maintenance					
		Design change	Installation modifications	Retrofit/equipment replacement	Other	Implement advanced reset	Start/Stop (environmentally determined)	Scheduling (occupancy determined)	Modify setpoint	Equipment staging	Modify sequence of operations	Loop tuning	Behavior modification/manual changes to operations	Other	Calibration	Mechanical fix	Heat transfer maintenance	Filtration maintenance	Other	SUM
Component being Commissioned		D1	D2	D3	D4	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8	OC9	M1	M2	M3	M4	M5	
HVAC (combined heating and cooling)	V	2	2	1	0	11	9	12	47	0	29	17	0	0	97	123	0	7	0	**357**
Cooling plant	C	1	1	0	0	2	4	0	1	2	2	2	0	2	2	0	0	0	1	**20**
Heating plant	H	0	2	1	1	1	3	1	9	6	1	1	0	0	1	6	0	0	2	**35**
Air handling & distribution	A	0	0	6	1	30	2	17	12	9	23	4	0	2	29	38	9	9	0	**191**
Terminal units	T	0	0	0	0	0	0	0	5	0	6	5	0	0	136	10	0	0	0	**162**
Lighting	L	1	1	1	0	1	286	49	0	0	0	0	3	0	0	0	0	0	0	**342**
Envelope	E	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
Plug loads	P	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
Facility-wide (e.g. EMCS or utility related)	F	0	0	0	4	0	0	0	0	0	0	0	0	3	0	0	0	0	0	**7**
Other	O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
SUM		**4**	**6**	**9**	**6**	**45**	**304**	**79**	**74**	**17**	**61**	**29**	**9**	**7**	**265**	**177**	**9**	**16**	**3**	**1120**

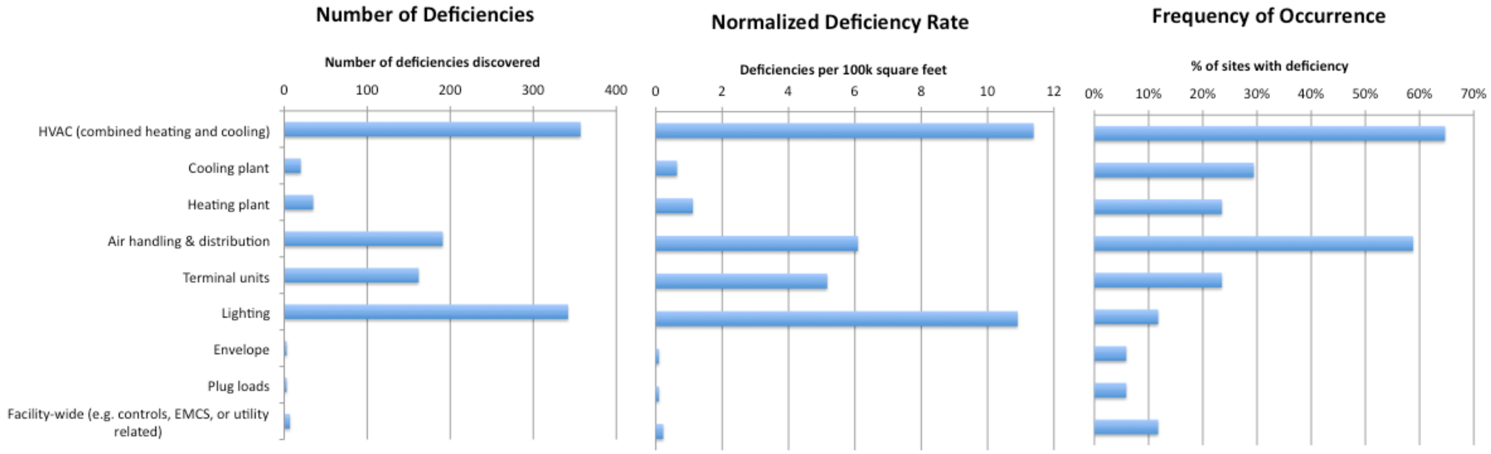


Figure 5. Frequency of deficiencies found through MBCx

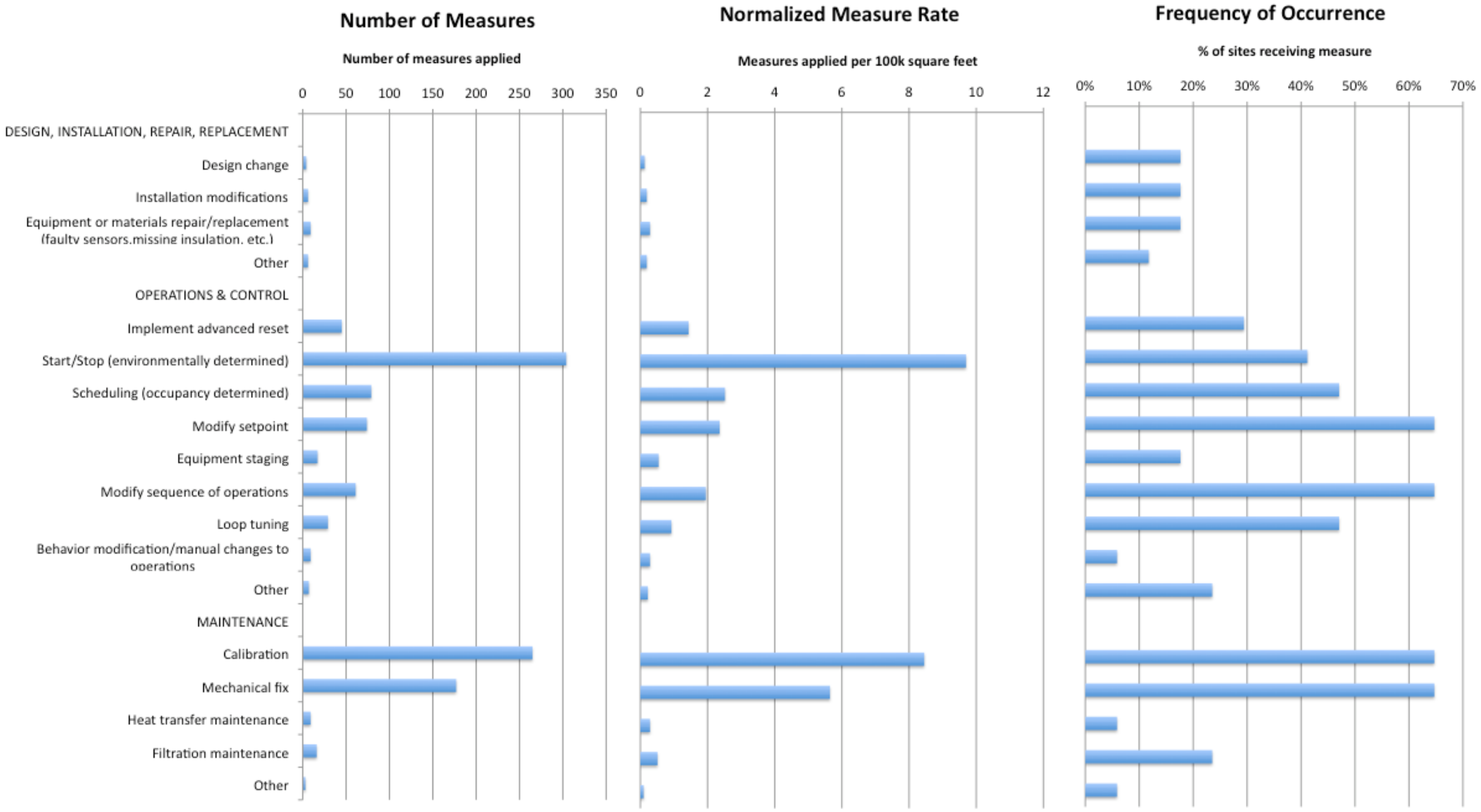


Figure 6. Frequency of measures implemented in MBCx projects

Four examples of how MBCx helped identify and address deficiencies

Monitoring reveals instability in digital controls and excessive valve cycling.

The MBCx monitoring for project #2005.10 identified significant instability in the direct digital control system's control of supply air temperatures in two air handlers. The trending data showed that the preheat valve cycled every 15 minutes between 75% open and full closed. This resulted in a variation in supply air temperature of 9 or 10 F in the heating mode for the air handlers which serve the biological sciences building. The chilled water valve was found to have a similar though smaller control instability, causing the supply air temperature to vary by 4 or 5ºF every 15 minutes in the cooling mode. This cyclic variation in supply air temperature makes control of space temperatures difficult, and potentially causes unnecessary heating and cooling.

When tied to EMCS, previously ignored electric and gas meters revealed inefficient nighttime operation, simultaneous heating and cooling, and excessive lighting. New scheduling program resulted in nighttime energy savings.

The MBCx metering for project #2005.12 provided some immediate results. When the existing electric and gas meters at the building were tied into the campus energy management system and their energy use was trended, high nighttime electricity and natural gas use were immediately obvious. Further investigation revealed that the air handlers operated continuously although the building was empty at night. The chiller also operated at night, as well as the boiler, performing simultaneous heating and cooling. Much of the lighting was also found to operate after hours. Once identified, the nighttime operation was easily addressed by reprogramming the EMS.

The building has had electric and gas meters for a number of years. If the meters were manually read monthly, the total usage readings apparently had not triggered any alarms, and would not have revealed the simultaneous heating and cooling. This seemingly obvious problem was not identified until the MBCx monitoring was in place.

The MBCx project also included installation of a Btu meter on the hot water output of the building boiler. The readings from this meter revealed that the calibration factor used for the gas meter was not properly corrected for gas pressure. All of the historical gas meter readings were incorrect. The new gas readings that are based on the correct multiplier now compare properly with the metered hot water use.

Temperature sensors reveal faulty thermostats, broken VAV actuators. Planned chiller upgrade deemed unnecessary.

The building in project #2005.08 has 28 zones served by rooftop units and a single boiler and chiller. The zone temperatures are controlled by VAV RH boxes using pneumatic thermostats and actuators. The presence of pneumatic controls means there was no monitoring available for temperatures in the spaces, VAV box airflow, or reheat coil position.

The MBCx project installed temperature sensors in multiple rooms in the building, tied back into an energy management system. Large variations in temperatures were trended in the various rooms. One room might be 79ºF while another similar room was 70ºF. This led to an investigation of the pneumatic thermostats and VAV boxes. Roughly 80% of the zones were found not to be controlling temperature properly. A number of thermostats were found to be out of calibration. A number of VAV boxes were found to have inoperative actuators on the air dampers or hot water valves. There was a significant amount of unproductive energy use in heating, cooling and distributing air unnecessarily. Discomfort in the building led to the chiller being manually started during some hours when comfort could have been maintained without chilled water, given properly operating zone controls. The controls were calibrated and malfunctioning actuators replaced where they could be. The recommendation was made to convert to direct digital controls at the zone level in the future.

A project under consideration initially was the replacement of the chiller with a more efficient unit. The metering determined that the annual load on the chiller was lower than expected and that it was likely to be lower still after repair of the zone controls. As a result it was determined that there was an inadequate annual electric load to justify the replacement of the chiller on the basis of energy savings.

Data trending uncovers non-delivery of chilled water. Comfort improved and energy saved.

The MBCx team for project #2005.03 trended all of the points available on the Building Management System for the building. The evaluation of data from the first air handler in May 2005 identified supply air and chilled water temperatures outside of the expected performance range. The team investigated and found that chilled water from the central plant was not being drawn into the building loop. As a result, the building air handlers were delivering air at an elevated temperature, causing them to operate at high speeds to meet the cooling load of the building. In June 2005 the team modified the setpoints on the loop pressure control and the VFD controller, resulting in a proper air handler supply air temperature and an appropriately high chilled water temperature returning to the campus loop. The metering system observed a reduction in the building electric load and an increase in the building chilled water load. The effect of the increased load on the chiller plant was calculated to offset about 20% of the fan savings. The increased chiller electricity use occurs at night because the campus uses a Thermal Energy Storage system at the central plant. This is an example of the analysis of trended building energy performance data leading directly to reduced energy use at the building and increased comfort. The MBCx project also included installation of a Btu meter on the hot water output of the building boiler. The readings from this meter revealed that the calibration factor used for the gas meter was not properly corrected for gas pressure. All of the historical gas meter readings were incorrect. The new gas readings that are based on the correct multiplier now compare properly with the metered hot water use.

1.10.2 Benchmarking analysis of energy use, costs, and savings

Table 8 presents the benchmarking analysis of various energy use, cost and savings metrics. The analysis includes comparison to the Meta-analysis, using the cohorts as defined in the introduction to this section 4.2. Note that this analysis divides the dataset into more cohorts than the portfolio summary analysis provided in Table 6. Additionally, this analysis excluded three MBCx projects that received funding but which did not report savings and may not have been fully implemented.

For the MBCx cohort, source energy savings of 22 kBTU/sf-year (10%) were achieved, with a range of 2% to 25%. Median electricity savings were 1.9 kWh/sf-year (9%), with a range of 1to 17%. Peak electrical demand savings were 0.2 W/sf-year (4%), with a range of 3% to 11%. It is worth noting that these savings numbers are based on a greater degree of measurement than is typically found in many savings calculations.

The aggregate commissioning cost for the 24 projects (26 buildings; 3.4 million square feet) analyzed was $2.9 million. We observed a range of $0.37 to 1.62/sf, with a median value of $1.00 for buildings that implemented MBCx projects. Half of the projects were in buildings containing complex and energy-intensive laboratory space, with the higher costs associated with these projects. Median energy cost savings were $0.25/sf, for a median simple payback time of 2.5 years. Significant and cost-effective energy savings were thus obtained. The greatest absolute energy savings and shortest payback times were achieved in the subset of laboratory-type facilities.

Table 8. Benchmark outcomes for Meta-Analysis (MA) and Monitoring-Based Commissioning (MBCx) for full samples and for climate- and building-type cohorts (median values).

	All Sites		By Climate		By Building Type	
Sample	MA*	MBCx**	MA - non-Lab	MBCx - non-Lab	MA - Lab	MBCx - Lab
Location	US	CA	CA/OR/WA	CA	US	CA
Number of projects	84	21	36	14	13	12
Number of buildings	128	26	72	9	15	12
Median building size (square feet, sf)	154,000	121,214	197,953	117,607	139,361	106,592
Total Source Energy						
Pre-cx (kBTU/sf, source)	323	335	231	189	543	534
Savings (kBTU/sf, source)	31	24	15	18	119	40
Savings (%)	12%	11%	9%	10%	16%	12%
Building Electricity						
Pre-cx (kWh/sf-year)	23	21	16	14	29	35
Savings (kWh/sf-year)	1.7	1.6	1.2	0.9	1.5	1.7
Savings (%)	8%	7%	9%	8%	5%	6%
Building Peak Power						
Pre-CX	4.2	3.7	4.2	2.7		4.4
Savings	0.5	0.2	0.1	0.3		0.2
Savings	2%	4%	9%	8%		3%
Building Fuel						
Pre-cx (kBTU/sf, source)	89	153	89	50		195
Savings (kBTU/sf, source)	7	12	3	2		20
Savings (%)	9%	7%	5%	5%		10%
Central Thermal* **						
Pre-cx (kBTU/sf, source)	211				388	
Savings (kBTU/sf, source)	56				142	
Savings (%)	32%				24%	
Central Hot Water						
Pre-cx (kBTU/sf, source)		42		19		68
Savings (kBTU/sf, source)		8		8		16
Savings (%)		25%		36%		23%
Central Steam						
Pre-cx (kBTU/sf, source)		98		24		213
Savings (kBTU/sf, source)		32		2		41
Savings (%)		19%		12%		19%
Central Chilled Water						
Pre-cx (kBTU/sf, source)		45		27		95
Savings (kBTU/sf, source)		8		6		9
Savings (%)		19%		29%		16%
Economics						
Project costs ($/sf)	$ 0.29	$ 1.00	$ 0.24	$ 0.72	$ 0.31	$ 1.15
Cost savings ($/sf)	$ 0.33	$ 0.32	$ 0.16	$ 0.22	$ 1.65	$ 0.46
Simple payback time (years)	0.6	2.5	1.4	2.7	0.1	1.9

Values should not be compared between rows as the number of datapoints in each subset varies in many cases.

The following assumptions and normalization factors are applied in normalizing data to 2007 price levels, and to reflect CA conditior

Commercial-sector energy prices: $0.10/kWh; natural gas price $10.00/MBTU (Notes to table 1 in Brown et al. 2006).

Peak demand savings valued at $120/kW.

Labor cost index. June 2007 values. (Engineering News Record, McGraw-Hill).

GDP deflator: All values adjusted to 2007 currency levels.

Heat rate for electric power production 9,215 BTU of source energy input per kilowatt-hour generated.

Note: Assumed energy prices and heat rates reflect California conditions. In other published reviews of the MA data, assumptions are reflective of national conditions are used.

* Analysis using subset of projects with weather-normalized energy data

** MBCx cohort excludes three projects that were funded but not implemented.

*** For MA, energy use in central plant is broken out into hot water, steam, and chilled water.plant conversion losses. All centrally prepared energy is counted at the point of delivery to the building, i.e. excluding plant conversion losses.

We compared the outcomes for the MBCx cohort with those for the LBNL Meta-analysis, disaggregating the analysis by climate and building type (0 a&b). The disaggregation of impacts highlights the importance of examining peer groups. Although small in number, the more energy-intensive buildings skew most values upwards for the all-inclusive sample. In particular, as expected pre-commissioning energy intensities and savings were higher among lab than non-lab facilities.

Examining the subgroups also narrows the observed variance in results (particularly for non-lab facilities).

The samples were quite consistent in terms of building source energy intensities prior to commissioning. The median building size was smaller for the MBCx cohort. The MBCx lab facilities were more electricity intensive than their counterparts in the Meta-analysis.

Across the MBCx sample, monitoring costs were much higher proportion of the total than for the comparison group, representing 40% of total. Some projects in the national Meta-analysis sample also involved a degree of monitoring (up to 47%, characterized as “verification and persistent tracking), but the median value for the 30 Meta-analysis projects for which we have data is only 2%.

The high metering cost fraction for the MBCx program is per program design. Sites that hosted the UC/CSU MBCx program tend to be thinly metered, as they are usually on campuses that are centrally metered, with individual buildings often not having the building level metering emphasized by the MBCx concept. Thus, particularly high investments in new metering were required at these sites. In addition, many of the campuses have chilled water, hot water, and/or steam distribution systems. Building-level metering ("BTU meters") for these energy streams has significant costs that are higher than for stand-alone buildings (e.g. steam or hot water metering can be more expensive than gas metering, chilled water metering is in addition to electricity metering).

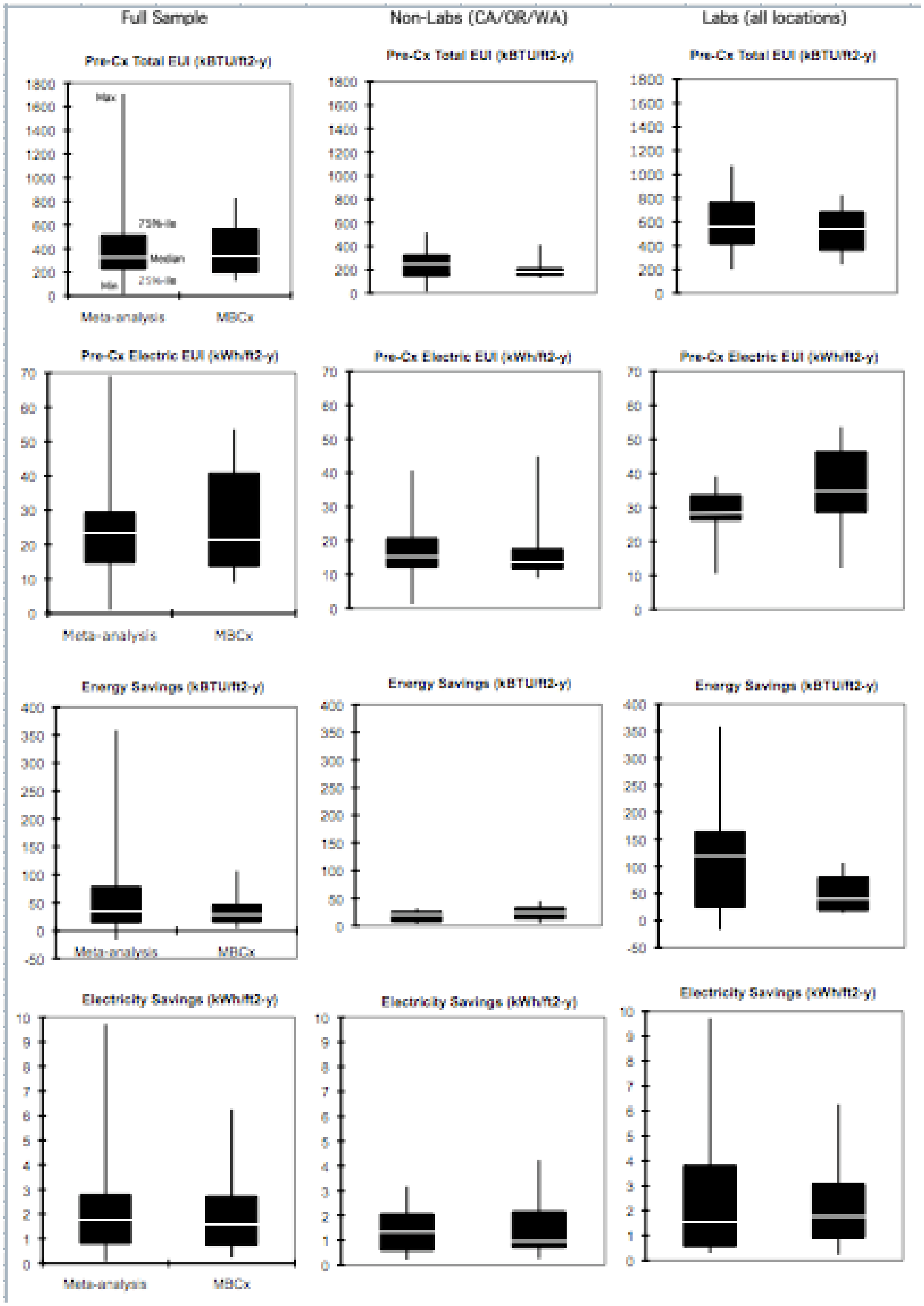


Figure 7. (a) Portfolio comparison of MBCx and Meta-analysis in terms of preCx EUI, pre-Cx electrical EUI, energy savings, and electricity savings for three cohorts: full sample (left column); non-lab buildings in CA/OR/WA (middle column); labs in all locations (right column).

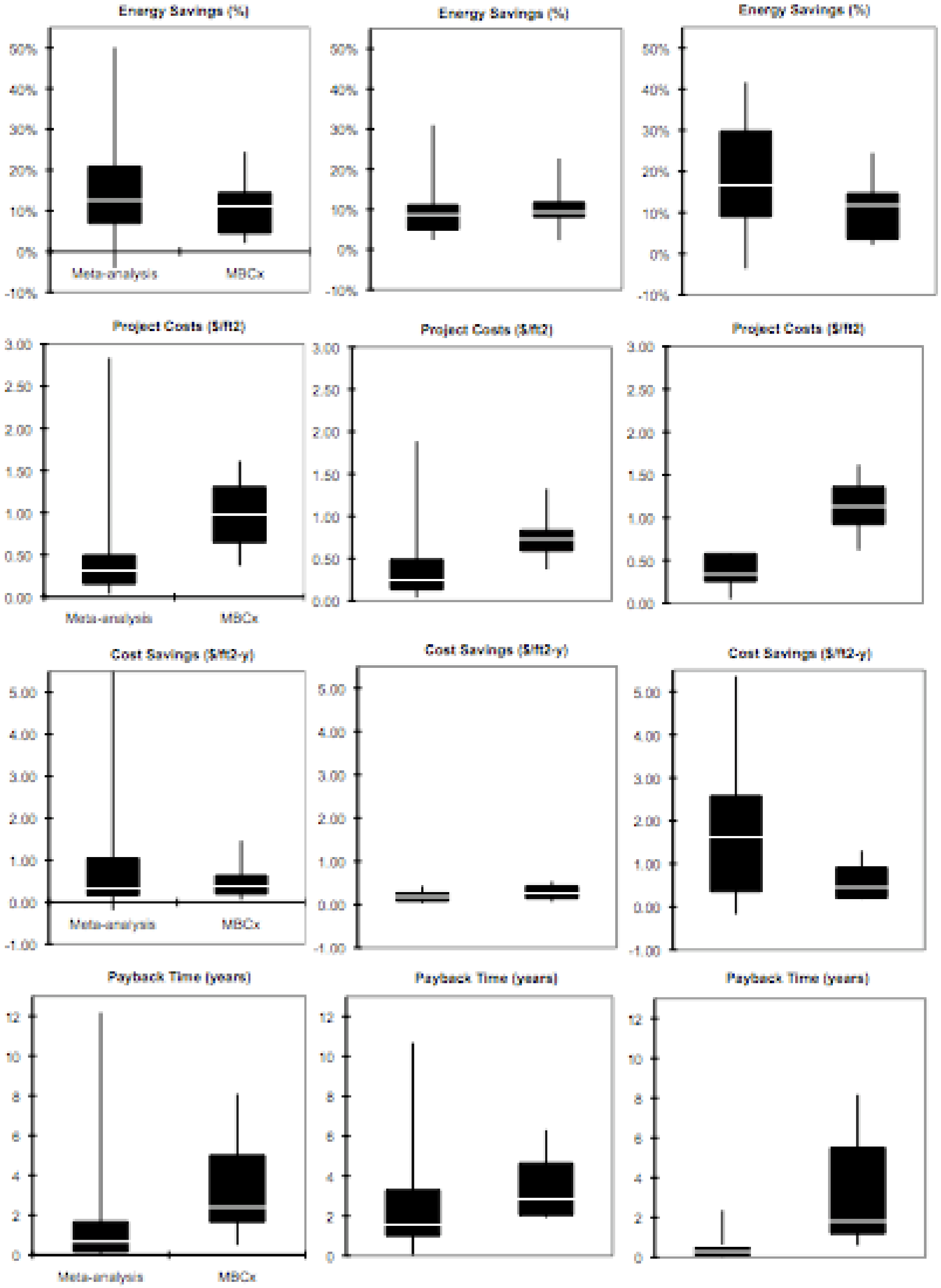


Figure 7 (b). Portfolio comparison of MBCx and Meta-analysis in terms of energy savings %, project costs, cost savings, and payback times for three cohorts: full sample (left column) ;non-lab buildings in CA/OR/WA (middle column); and labs in all locations (right column).

Figure 8 through Figure 15 benchmark at the individual project level the energy and demand intensities prior to the retro-commissioning activity versus savings attributable to MBCx. The individual peer groups defined in 0a – b are used here as well, and indicated in the figures to facilitate comparisons. Laboratory-type facilities consistently stand out as having relatively high pre-project energy use as well as subsequent savings. Where comparable data are available, the MBCx projects are compared with projects from the LBNL Meta-analysis database. Similar qualitative patterns of savings emerge for both data sets.

While the scatter is significant, most of the comparisons suggest that targeting high-EUI projects would, not surprisingly, improve the likelihood of attaining higher absolute savings. (However, note that there that there is not a strong correlation between EUI and % savings, as shown in Figure 9. Though perhaps counter-intuitive, a correlation would not be expected as total energy use is in both the denominator of the dependent y variable and the numerator of the independent x variable.). Particularly high savings were obtained from hot water, chilled water, and steam provided to the buildings by central plants. (A similar result to the high-savings Texas A&M cohort from the Meta-analysis.)

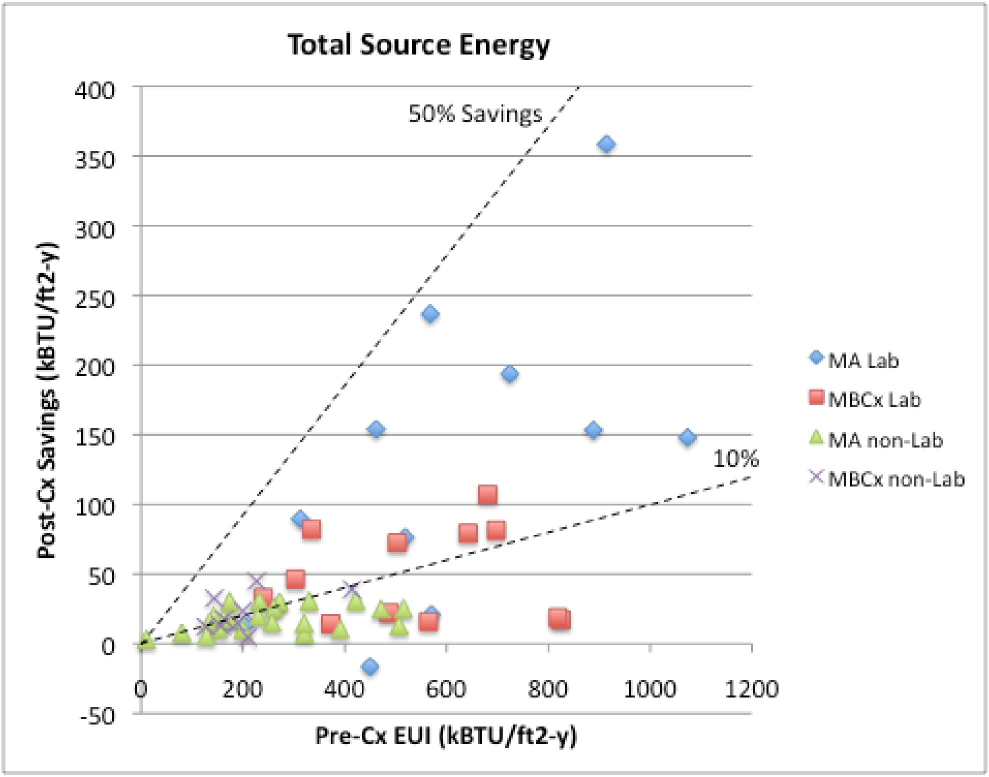


Figure 8. Total source energy pre-Cx energy use intensity vs. post-Cx savings

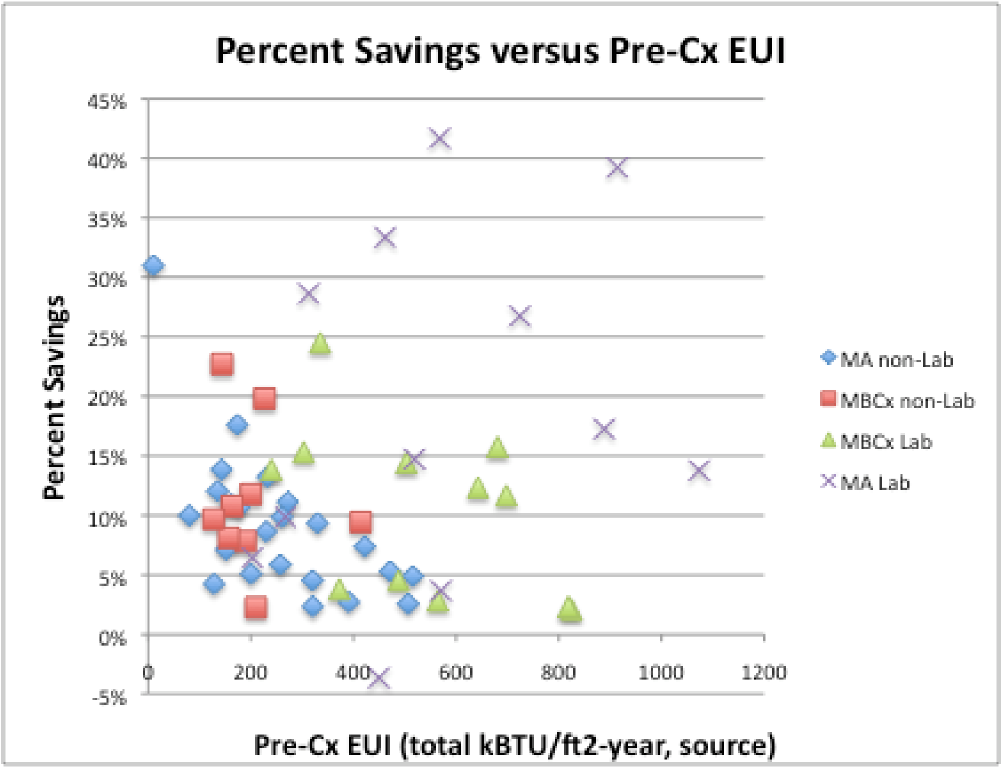


Figure 9. Total source energy pre-Cx energy use intensity vs. post-Cx % savings

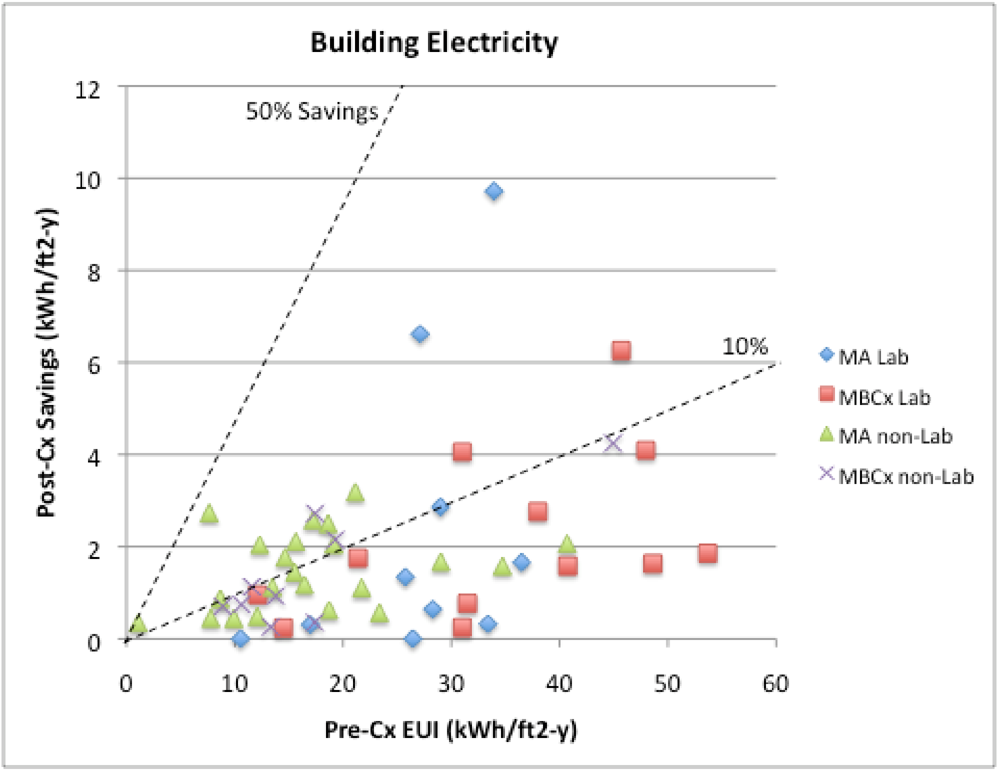


Figure 10. Building electricity pre-Cx energy use intensity vs. post-Cx savings

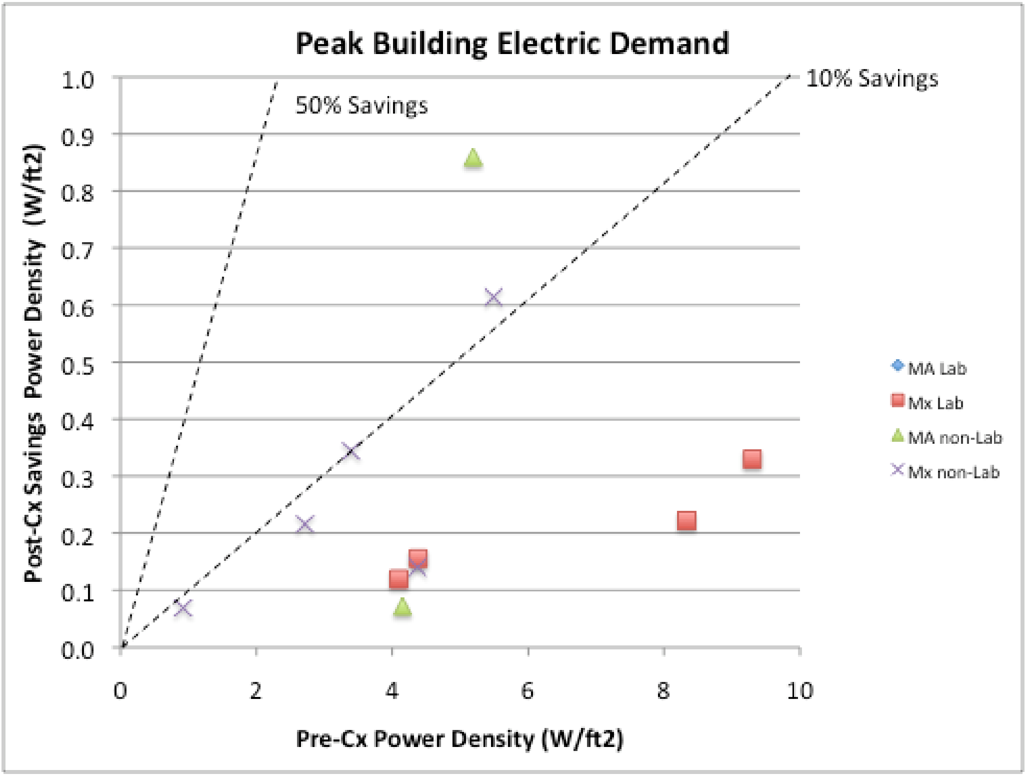


Figure 11. Peak building electric demand pre-Cx power density vs. post-Cx savings

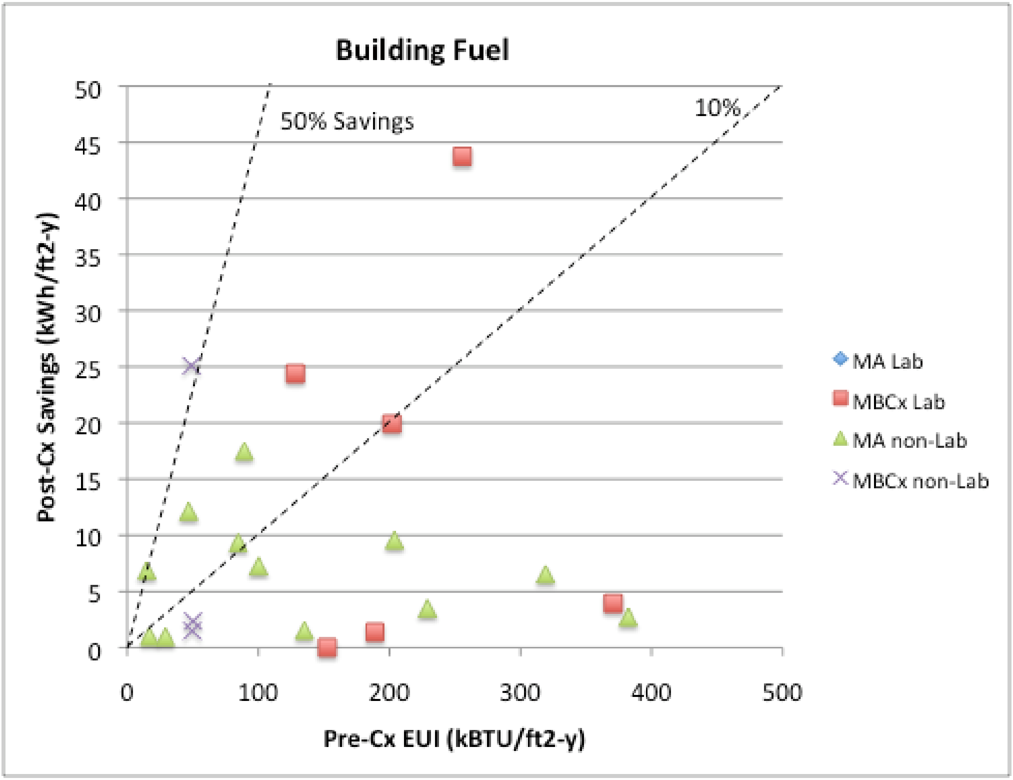


Figure 12. Building fuel pre-Cx energy use intensity vs. post-Cx savings

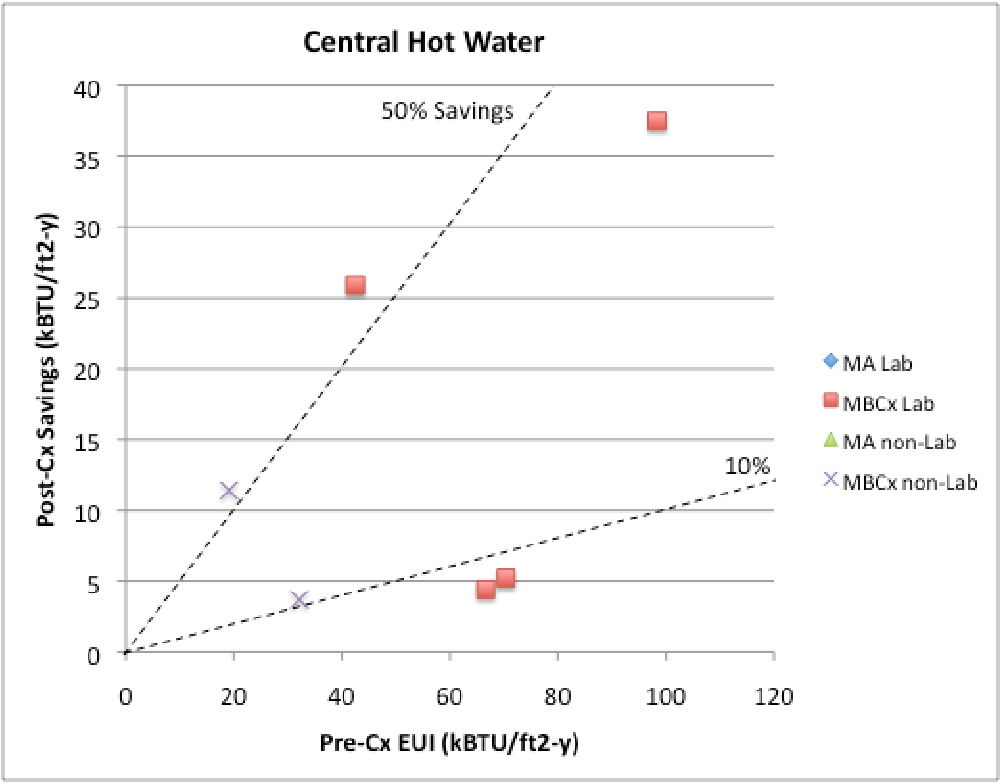


Figure 13. Central plant hot water pre-Cx energy use intensity vs. post-Cx savings

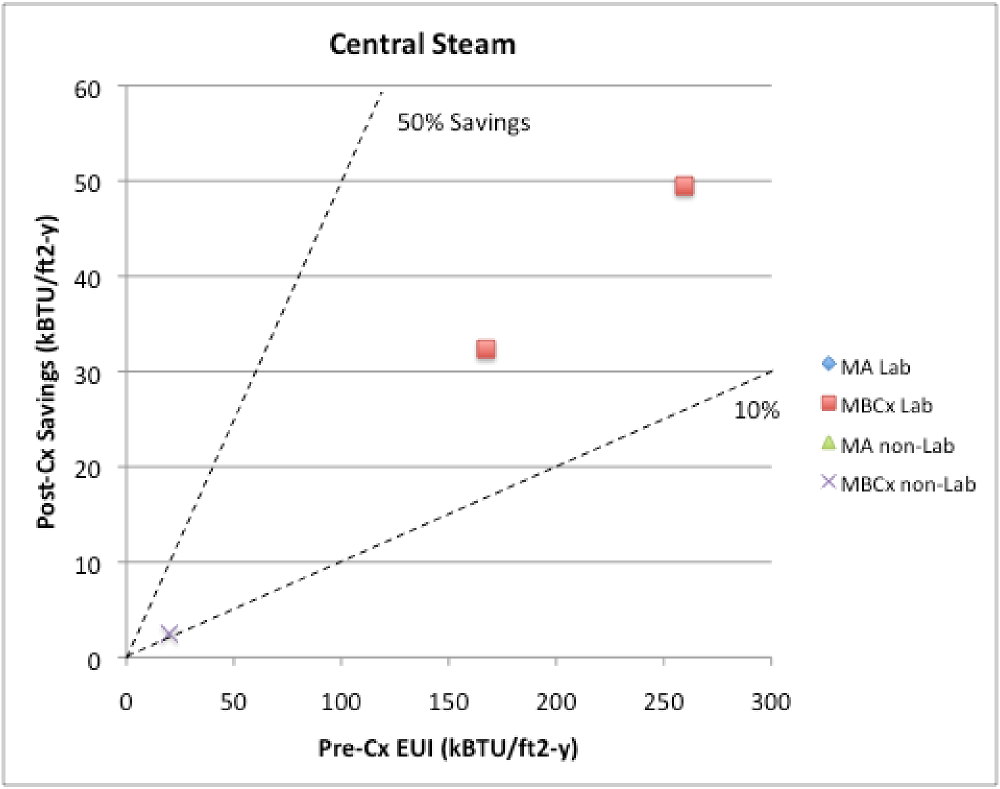


Figure 14. Central plant steam pre-Cx energy use intensity vs. post-Cx savings

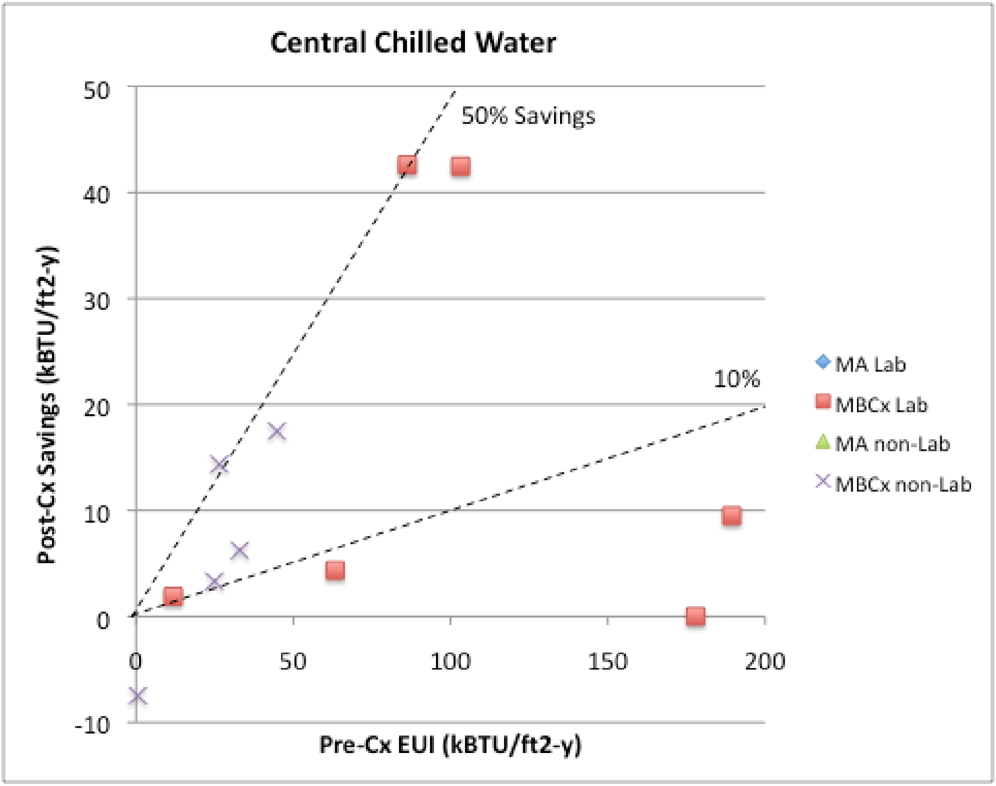


Figure 15. Central plant chilled water pre-Cx energy use intensity vs. post-Cx savings

1.10.3 QA and other Diagnostics

In addition to the analysis of the key performance metrics shown above, additional analyses were used as part of the data QA process.

Figure 16 shows the fumehood density for various laboratory buildings in the MBCx project portfolio. This chart can be used in the data QA process to check the fumehood data. In the future, as the dataset grows, it can also be used to filter the benchmarking peer group for labs with similar hood density.

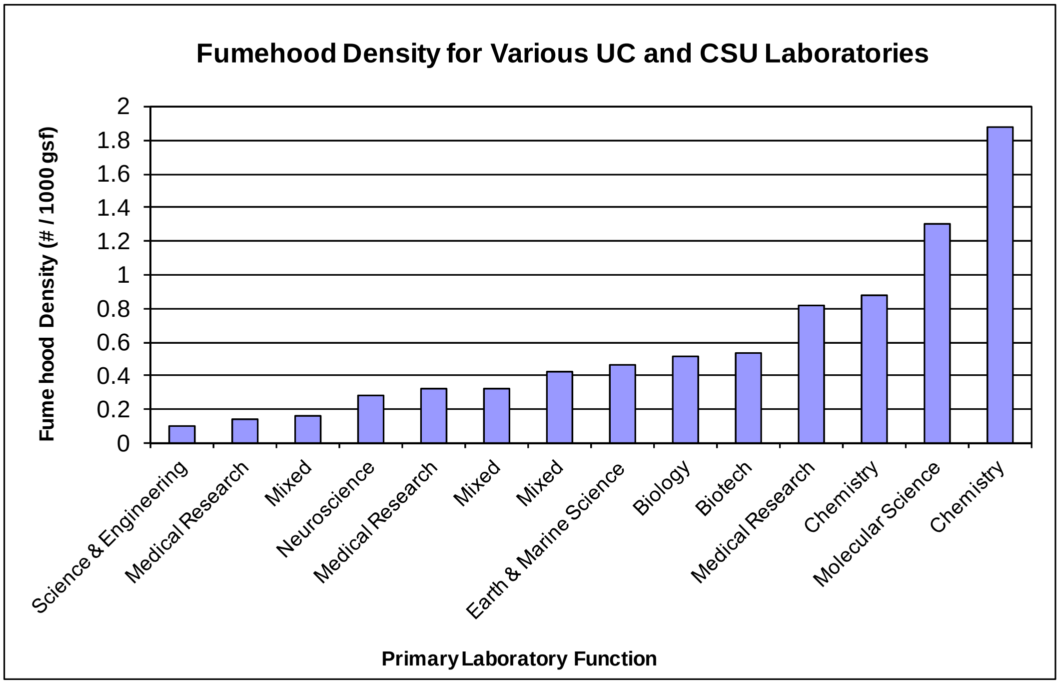


Figure 16. Fumehood density for various laboratories in the MBCx phase-1 project portfolio

Figure 17 compares savings using reported plant efficiencies vs. savings using standard (i.e. uniform) central plant efficiencies. With one exception, there were little or no differences, suggesting that the reported plant efficiencies were likely based on assumptions of typical efficiency that have been used for standard plant efficiencies.

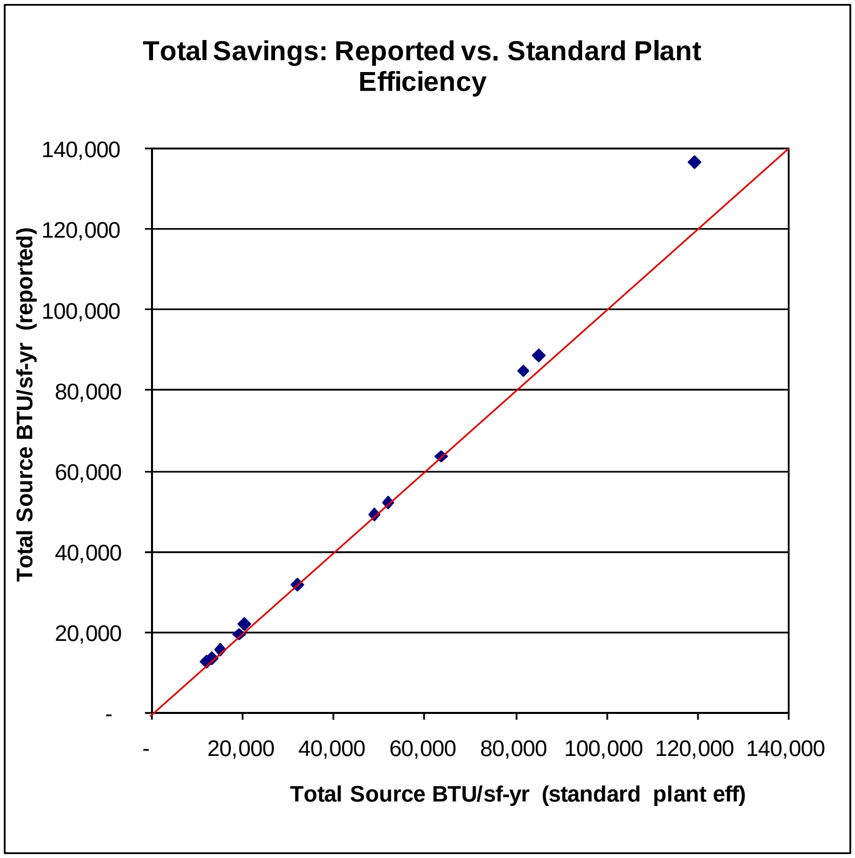


Figure 17. Total source energy savings using reported plant efficiencies vs. standard (i.e. uniform) central plant efficiencies for MBCx projects that had central plant savings.

Figure 18 and Figure 19 compare the historical baseline (prior to installation of metering equipment) vs. the revised baseline (after installation of metering equipment) for building electricity and gas respectively. The data show that in most cases, the historical baseline was revised based on metered data, thereby affirming one of the initial benefits of metering i.e. better baseline data.

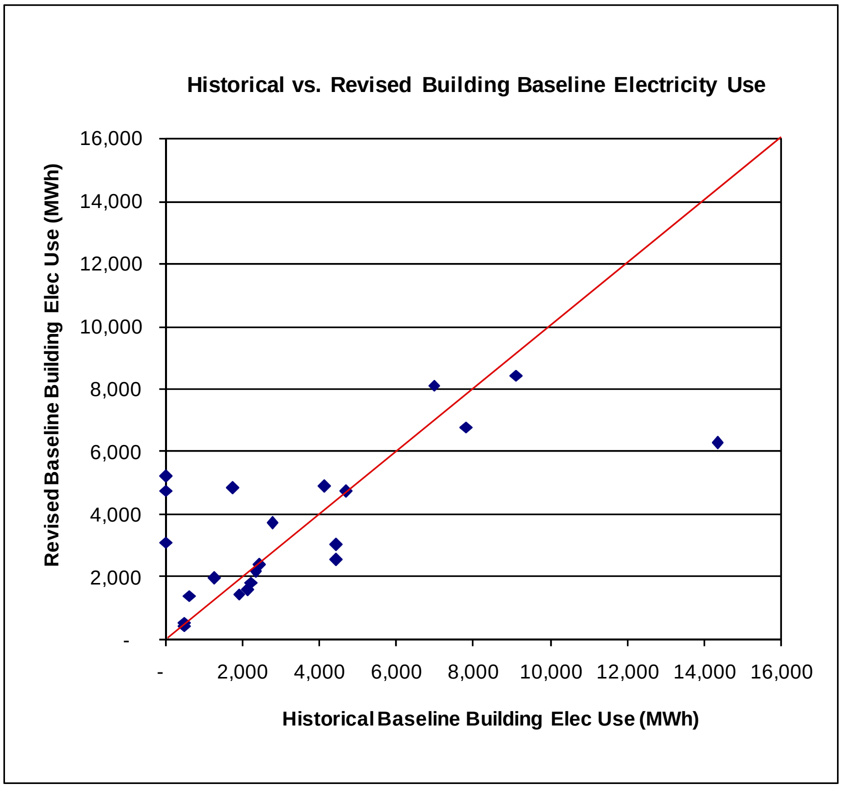


Figure 18. Historical vs. revised baseline building electricity use

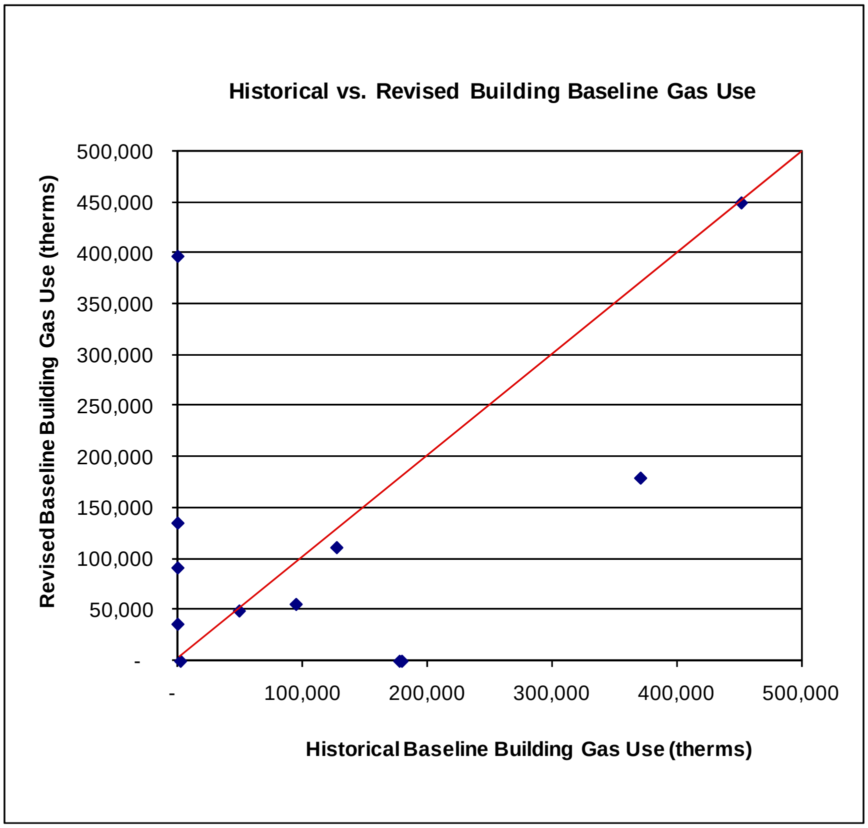


Figure 19. Historical vs. revised baseline building gas use

Figure 20 through Figure 22 compare the target vs. reported savings for total electricity, gas, and peak demand respectively. The data show that a majority of projects exceeded their targets. The portfolio of projects exceeded both the program goal and the higher sum of the individual project targets.

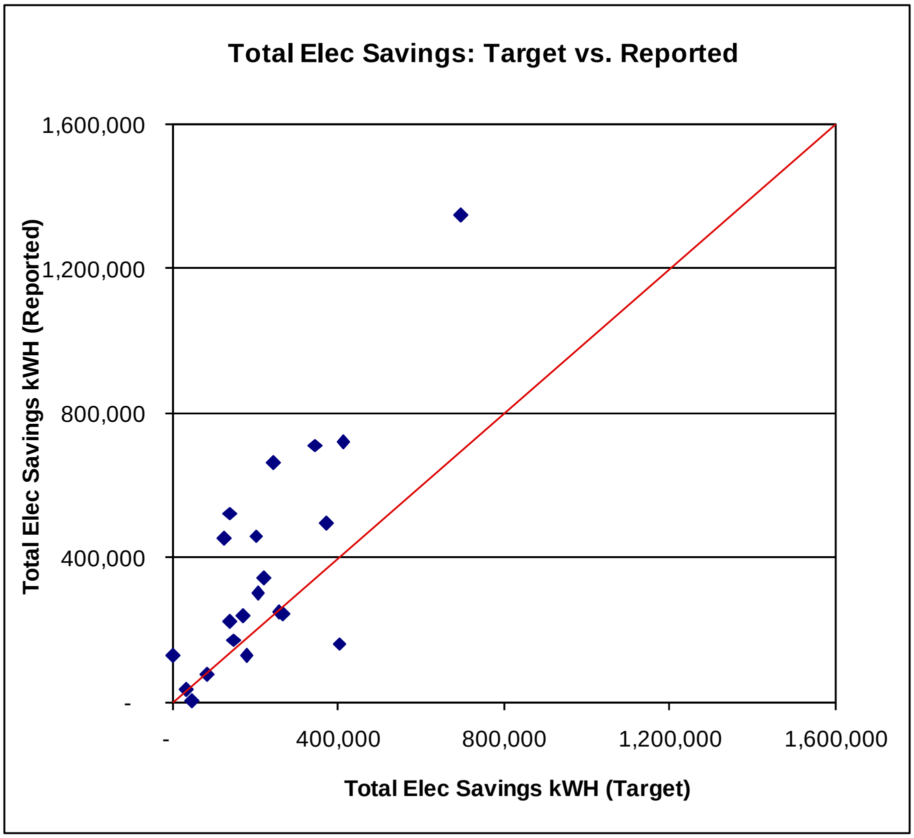


Figure 20. Target vs. reported total electricity savings

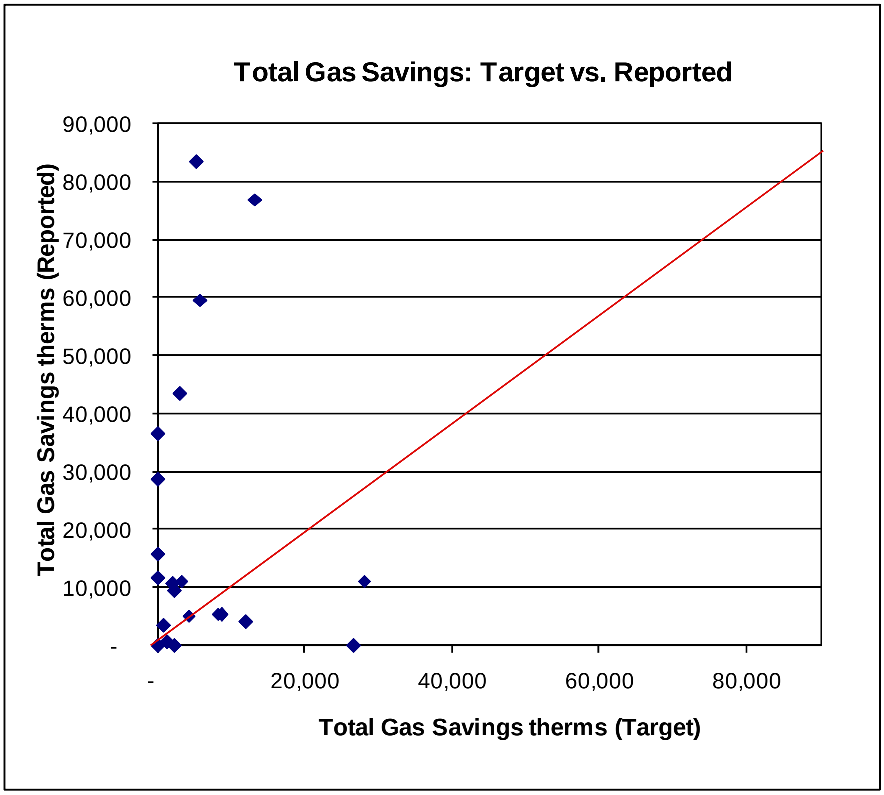


Figure 21. Target vs. reported total gas savings

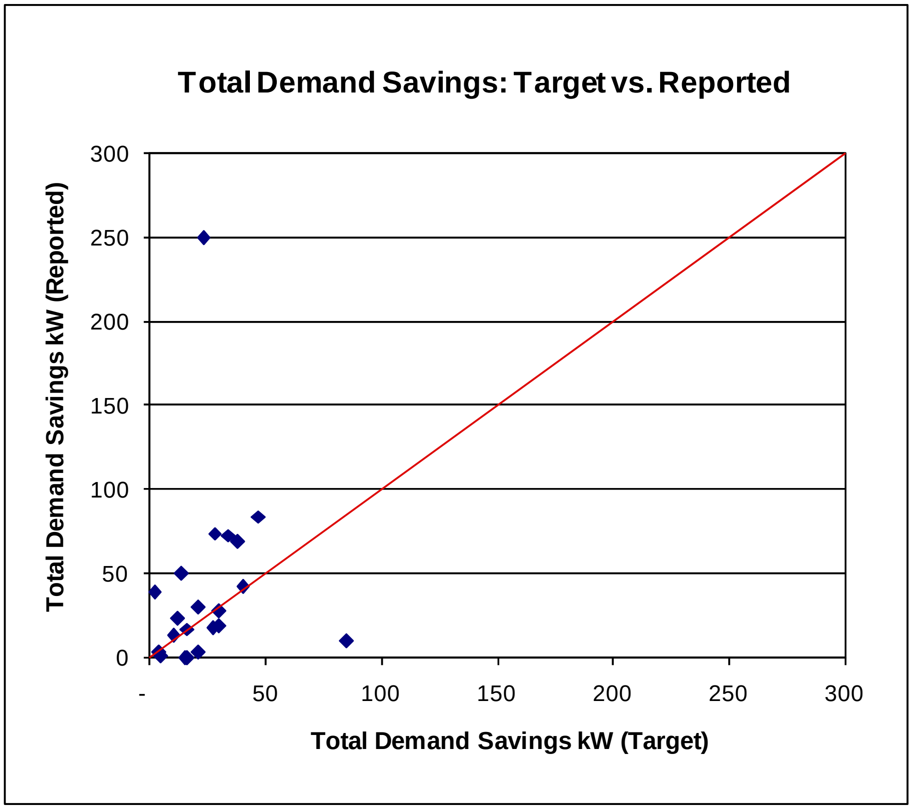


Figure 22. Target vs. reported total demand savings

Conclusions

Overall performance of MBCx Projects

While impacts varied from project to project, on a portfolio basis we find MBCx to be a highly cost-effective means of obtaining significant portfolio/program-level energy savings across a variety of building types. The greatest absolute energy savings and shortest payback times were achieved in the subset of laboratory-type facilities.

MBCx helped identify a very wide range of deficiencies. Anecdotal evidence shows the value of monitoring in identifying savings opportunities that would not otherwise have been identified.

Energy savings are expected to be more robust and persistent for MBCx projects than for conventionally commissioned ones, due to the level of metering and monitoring. MBCx affords a very high level of M&V. More savings and greater persistence of savings for these projects are anticipated over time, but it is too early to confirm and quantify these benefits. MBCx thus represents an important risk-management strategy for policymakers and program managers who seek verifiable and durable energy demand reductions.

It is possible that the incentive structure limited savings in that some project teams may have been "satisfied" to meet the pre-defined project target and not go further in identifying measures. There was no mandate to identify all possible measures in a building. Moreover, the scope of the diagnostics and commissioning was sometimes limited to certain systems.

Application of benchmarking for project screening and post-completion evaluation

During the course of this project, we developed a quality-control/quality-assurance process and protocols for gathering and evaluating raw data from project sites. This helped identify errors in the field-reported data and it is recommended that all future project data should be checked with these protocols. During the course of this project, we also developed recommendations on how to develop a peer group and appropriate metrics for benchmarking, taking into account building type, climate, weather, utilities/services provided and whether or not a given building is served by a central plant.

Benchmarking can be used to check the reasonableness of baselines, savings, costs and payback. The use of benchmarking for project screening can help identify the most promising projects and thereby improve the overall performance of the MBCx portfolio. Targeting projects to high-EUI sites is a reliable way to maximize the absolute level of savings.

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Appendix A: Key for Deficiencies-Measures Matrix

Design, Installation, Retrofit, Replacement

	Code
Design change (design detail, improper equipment, improper system, etc.) Design problems found and corrected during design review of a new building (Cx), a design problem physically corrected or circumvented (during Cx or RCx). [Problems with the design of control sequences are accounted for under "Operations & Control".]	**D1**
Installation modifications (construction out of spec, equipment out of spec, O&M access, etc.) To address out-of-spec or improper installation of equipment, sensors, distribution systems, etc. Could also include corrections to ensure future access for O&M.	**D2**
Retrofit/equipment replacement (faulty sensors, etc.) RCx strategies to improve the performance of a system, as distinct from a change in design [treated above]. Major capitol retrofits are not considered part of commissioning and should not be included in this analysis.	**D3**
Other Other design, installation, retrofit, or replacement measures.	**D4**

Operations & Control

Implement advanced reset (air, water, lighting) Recommended modifications to reset schedules of HVAC processes. E.g., Supply Air Temperature reset based on Outside Air Temperature; corrections to fan/pump speeds or lighting levels.	**OC1**
Start/Stop (environmentally determined) Recommendations that affect environmentally determined equipment control settings (e.g., chiller or boiler lockouts that based on outside air dry bulb temperature or seasonally determined equipment operation).	**OC2**
Scheduling (occupancy determined) - equipment or lighting Recommendations affecting the control of equipment availability as a function of building occupancy (e.g. lighting sweeps; temperature setbacks; morning warm-up).	**OC3**
Modify setpoint (high VAV setpoint minimum, setpoint suboptimal) Recommendations that modify the setpoint of a control loop. E.g., Supply air temperature setpoint, thermostat setpoint, or static pressure setpoint.	**OC4**
Equipment staging	**OC5**

Recommendations that affect control settings for the availability or staging of duplicate equipment, e.g., Chiller staging and loading sequence or lead-and-lag pumping sequences.

Modify sequence of operations **OC6**
Recommendations that propose changes significant enough to be considered a major modification to the building's existing sequence of operations.

Loop tuning **OC7**
Modify control loop parameters to improve control (reduce cycling, hunting, oscillations).

Behavior modification/manual changes to operations **OC8**
Recommendations that seek to modify the behavior of the building staff or occupants or instruct building staff or occupants on the proper use of equipment (e.g. turning off lights upon leaving a room, correctly manipulating the system in response to complaint calls).

Other **OC9**
Other operations & control measures.

Maintenance

Calibration **M1**
Recommendations that address calibration problems with equipment or systems.

Mechanical fix (flow obstructions, leaky valves, leaky ductwork, etc.) **M2**
Replacing belts, broken linkages, motor maintenance, etc.

Heat transfer maintenance (dirty heat transfer component, improper refrigerant charge, etc.) **M3**
Coil cleaning, cooling tower water treatment, correcting refrigerant charge

Filtration maintenance **M4**
Changing filters, modifying filter racks, changing filter type, etc.

Other **M5**
Other maintenance measures.