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Building Commissioning Costs and Savings Across Three Decades and 1,500 North American Buildings

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ABSTRACT

Building commissioning (Cx) is a process for assuring efficient building operations that can be applied to new construction and existing buildings, resulting in energy and non-energy benefits. Quantifying the benefits of commissioning is challenging, but a 2009 study of 643 commercial buildings provided a solid initial data set to which we added 839 additional buildings for a significantly expanded and updated meta-analysis representing 34.7 million square meters (373 million square feet) of floor area. Since 2009 the commissioning industry has continued to grow, driven by building codes, utility programs, and rising awareness of commissioning benefits. In parallel, building controls have become more sophisticated, and analytics software has emerged to assist with commissioning. We find that delivery mechanism and market segment are key determinants of outcomes, although significant and cost-effective savings are found across the spectrum. Median primary energy savings for Cx projects in existing buildings ranged from 5 percent for those conducted under utility programs, 9 percent for monitoring-based commissioning utility programs (i.e., augmented with submetering and diagnostics), and 14 percent for Cx projects outside of utility programs. Across all project types, median savings ranged from 3 percent for the lodging market segment to 16 percent for public order and safety facilities. Outcomes did not vary significantly by building size or by market segment. Energy savings are rarely estimated for new construction commissioning. We found that the median costs of Cx were lower for the 2018 sample than for the 2009 sample—$2.85 per square meter ($0.26 per square foot) for existing buildings (a 33 percent reduction) and $8.78 per square meter ($0.82 per square foot) for new construction (a reduction of almost 50 percent). The median simple payback time for existing buildings was 1.7 years, with a 25th–75th percentile range of 0.8–3.5 years. This article summarizes these and other key findings, and discusses how the 2018 data reflects shifts in commissioning practice and outcomes.

Nomenclature

Cx	Commissioning (generic, representing applications to new as well as existing buildings)
EBCx	Existing Building Commissioning
MBCx	Monitoring-Based Commissioning (a sub-process of EBCx, employing data analytics software)
NCCx	New Construction Commissioning

1. Introduction

Commissioning (Cx) is a systematic process intended to verify and document that new and existing building systems operate according to the building design and the owner's operating requirements. For the current analysis, our focus is on energy-using systems and their performance. The practice of commercial buildings' Cx has evolved over the past three decades, spurred by market demand, utility program delivery, and the inclusion of Cx in codes and standards. Cx targeted at energy savings emerged in the early 1980s, with industry conversations regarding the definition and scope of the Cx process taking hold in the 1990s. Initially more commonly applied to new construction (NCCx), it later expanded to delivery through existing building commissioning (EBCx). In 1999 the first North American utility rebate program offered EBCx (BCxA 2019), increasing to 43 programs by 2016 (CEE 2016), adding significantly to EBCx market growth. Outside of utility programs, the last decade has seen a move toward more standardized approaches, driven by industry guidelines, building certifications such as LEED (USGBC 2019), standards such as ASHRAE 202 (ASHRAE 2013), and Cx provider training and certification.

Because Cx is a holistic approach affecting multiple interactive systems, it can be challenging to definitively quantify its benefits, in contrast to those arising from the application of a discrete piece of technology or efficient "widget." Moreover, most efforts to determine outcomes were focused on individual buildings or small samples of buildings. To address these challenges Lawrence Berkeley National Laboratory (Berkeley Lab) collected data from hundreds of projects in 2004 and 2009, publishing the largest studies at the time on the costs and benefits of Cx (Mills et al., 2004; Mills 2011). Mills 2011 reported median whole building source energy savings of 16 percent for EBCx and 13 percent for NCCx, with simple payback periods of 1.1 years and 4.2 years, respectively. Beyond the key headline metrics, Mills 2011 also characterized the breadth of Cx projects' scope of work, systems on which the Cx process was focused, building systems commissioned, non-energy benefits, and other qualitative aspects of the Cx process. Aside from these studies there have been few publications describing large-sample cost/benefit analyses for commissioning projects. An effort led by the National Institute of Standards and Technology (NIST) (Friedman et al. 2011) to gather cost/benefit data from international projects found median EBCx savings of 8 percent from a sample of 20 building commissioning projects, and did not receive any savings data for NCCx projects; the NIST report cited challenges with obtaining cost/benefit data as a major limitation. A retrospective on the NIST study highlighted an immediate global need for further investment in the collection of cost-benefit data for Cx to enable informed decision-making and realize cost-effective Cx (Milesi-Ferretti et al. 2017). A meta-analysis of 24 U.S. Building Retuning™ [1] projects reported a 15 percent median energy savings (Katipamula 2016). There *are* many published *individual* Cx case studies (such as Wang et al. 2013, SEDAC 2015, and Adighije et al. 2019), documented with widely varying levels of detail; while these case studies are useful as examples of potential savings of Cx and best practices there is typically an inherent bias, in that projects chosen for such efforts are generally the highest performing projects and/or subject to above-average implementation effort, and thus are not representative of the building stock as a whole. Disparate studies utilize varying assumptions (e.g., energy prices), complicating efforts to compare results.

Since Mills 2011 was published, the Cx industry has continued to grow, and its methods have evolved, through the introduction of code requirements, expansion of utility EBCx programs, and increased owner awareness of Cx benefits. The last decade has also seen development of Cx specialties that expand the scope and emphasis of Cx beyond its traditional focus on heating, ventilation, and air conditioning (HVAC) systems. Enclosure Cx, for example, targets a building's envelope, long recognized as a source of energy waste, and defects that can have significant non-energy consequences, notably moisture entry and damage. There are several ongoing industry efforts relating to this topic, for example the National Institute of Building Sciences published NIBS Guideline 3-2012 on enclosure Cx (NIBS 2012), and the U.S. Green Building Council has allowed the application of enclosure Cx to earn an "Innovation Credit" in the LEED rating system. Lighting-controls Cx is another area that has seen more focus over the past decade, targeting illuminance levels, sensor coverage patterns and placement, control zoning, control sequencing, and the intelligibility of controls to occupants and building managers (Welsh 2017). There are also recent examples of guidance on how the Cx process can apply to renewables and storage technology (Strand 2011; Dunn 2012; Salmon 2012), which is expected to become more important as more buildings target net zero energy and owners look to capitalize on incentives to shift peak demand.

Another area of Cx that has seen growing interest over the past decade is the application of sophisticated energy management and information system (EMIS) software to support monitoring-based commissioning (MBCx) processes. Early work documented 11 percent median source energy savings from MBCx approaches deployed in 24 higher education buildings in California in 2004/2005 (Mills 2014). A more recent study on building owners using comprehensive EMIS-based MBCx approaches found 7 percent median site energy savings, based on data from 687 buildings totaling 8.7 million square meters (m^2) of floor area (Kramer et al. 2019), and a subset of that data showed 8 percent median site energy savings based on data from 550 buildings where MBCx was implemented with the support of fault detection and diagnostics (FDD) software (Lin 2019).

Through the continued evolution of the state of art and knowledge in Cx practices over the past decade, several key research questions have emerged:

1) How has the scaling of Cx deployment due to codes, standards, utility EBCx programs, and other market factors affected its costs and benefits?
2) Is Cx still dominated by HVAC-related operational improvements, or has there been a shift toward other system types such as lighting and building enclosure Cx?

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[1] Building Retuning™ is a variant of EBCx developed by Pacific Northwest National Laboratory.

3) With the emergence of more sophisticated and user-friendly analytics tools to support MBCx, what data are available on the relative costs and benefits of MBCx compared to EBCx?

To address these key industry questions, we acquired and analyzed more recent data on North American Cx project costs and benefits; as a result, the total number of commissioned projects in the study data set increased almost threefold compared to Mills 2011, with a total of 1,185 projects represented (compared to 409 projects in Mills 2011). The new data enables a fresh meta-analysis of the Cx industry, describing typical practices and costs and savings, and showing how the practice of Cx has evolved over time, based on the largest Cx project data set in terms of building count and longitudinal coverage. In addition to creating the largest known data set and meta-analysis of commissioning project outcomes (representing a wide range of building types and climates), this work is unique in identifying comparative results for utility- and non-utility-sponsored projects, as well as those from MBCx projects.

This article describes the research methods (Section 2), data analysis results (Section 3), and discussion of the results and their implications (Section 4), and summarizes conclusions and recommendations for future work (Section 5).

2. Methods

The data collection and analysis for this study was designed to obtain cost, benefit, and qualitative data on individual EBCx/NCCx projects for a wide variety of commissioning projects implemented across the United States. Data collection and analysis progressed through several stages, as illustrated in Figure 1. The overarching approach was designed to prioritize trustworthy data sources, maximize the size and spread (e.g., market segment variety, building size range, geographical diversity) of the data set, and complement the data analysis with insights from a Building Commissioning Association (BCxA) national market survey that would help contextualize the analysis results. Data collection methods/instruments and analyses were consistent with those applied in Mills 2011, enabling synthesis into a single set of data covering Cx trends and changes over time.

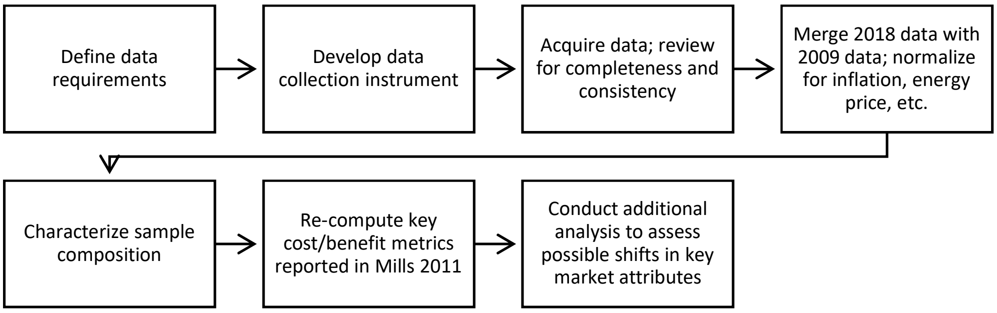

Figure 1. Data collection and analysis methodology

The data-collection and analysis steps are described in more detail below.

2.1. Definition of data requirements and development of the data collection instrument

To establish analysis findings that could be compared with prior Cx cost/benefit studies, data requirements for this study were kept consistent with Mills 2011. Data provided for the study were obtained from engineering records maintained for commissioning project reporting and documentation, enabling a large data set to be compiled within the resources available. This is preferred to primary efforts to assess project-by-project costs and benefits, which is not practical when a large sample is sought, as it would yield a relatively small data set, and would leverage similar industry-standard savings estimation approaches.

Starting from the spreadsheet-based data collection instrument used in Mills 2011, minor modifications were made to simplify data collection. Some data entries were removed if (1) they were considered less important to the current research questions, and/or (2) they received very low data submission rates in the prior study. Additional formatting edits were made to simplify the form and increase the likelihood of obtaining completed responses.

2.2. Project data collection and review

To allow for the collection of large amounts of project data with some assurance of data quality and consistency, the majority of the 2018 Cx project data set was drawn from two sources. First, the authors reached out to several utilities for EBCx data. The majority of this information came from two utilities, who provided data on all projects completed within a certain timeframe, i.e., they did not hand-pick projects for submission, thus minimizing potential bias. Costs and savings documentation for Cx projects sponsored by regulated utilities are expected to follow industry-standard protocols developed by third-party organizations, are subject to utility technical review, and are also sampled for independent review, providing further assurance of consistency and accuracy in the data received for this study. The two utilities providing the majority of EBCx data in the 2018 sample were electric-only utilities, though they provided data on natural gas savings where applicable and natural gas baseline consumption where available.

All 2018 NCCx project data were sourced from Cx firms affiliated with BCxA, a non-profit Cx membership organization that provides training and certification for its members. BCxA members are required to sign a commitment to follow the "Essential Attributes" defined by BCxA (BCxA 2018), which include general standards of record-keeping and documentation; this provides additional assurance of the reliability and quality of data that were received from BCxA members for this study. In the case of BCxA-affiliated Cx providers, project data came from 21 respondents, with each providing data for one to five projects. The authors conducted quality checks for data completeness and consistency, and reached out to data providers (Cx providers or utilities) for clarifications where needed (e.g., if data points were excessively high or low we reached out to the data provider to check if it was due to documentation error).

The subset of data originally reported by Mills (2011) also underwent significant quality assurance. Data were reviewed for completeness and potential errors, and clarifying information was collected from the primary data sources. This cohort included many projects originally published in peer-reviewed journals and conference proceedings. Five project cohorts were derived from independent rigorous research efforts by Texas A&M University (110 projects), the New York State Energy Research and Development Authority (NYSERDA) (1 project), the "UC/CSU" program spanning multiple colleges and universities in California (21 projects), the Minnesota Center for Energy and Environment (8 projects), and the Northwest Energy Efficiency Alliance (8 projects). Another subset (92 projects) was collected by Portland Energy Conservation Incorporated, a highly respected public-interest engineering organization considered to be a thought leader in the practice of commissioning. Los Angeles County rigorously commissioned 11 large projects. Three early quality-controlled utility programs in the data set include Colorado-based Xcel (38 projects), Southern California Edison (5 projects), and Sacramento Municipal Utility District (8 projects).

2.3. Sample composition

The Cx projects' sample is very diversified in terms of variety of market segments, vintages of buildings, building construction and HVAC system types, date of commissioning work, types of measures implemented, building ownership (public/private), climates, etc. The EBCx projects data collected in 2018 comprised 705 projects (738 buildings), covering 23.4 million m^2 (252 million square feet [ft^2]) When combined with the 2009 data set (as reported in Mills 2011) this yielded a total of 1,037 projects (1,299 buildings), covering 31.8 million m^2 (342 million ft^2) (see Table 1). The 2018 data set was dominated by data from two utilities: one in Illinois (61 percent of projects) and the other in British Columbia, Canada (21 percent of projects). An additional 8 percent of projects were drawn from California utility programs. For comparison, 37 percent of the 2009 EBCx data set comprised utility-sponsored projects. The top four market segments represented in the 2018 and 2009 data sets were the same: office, hospital (inpatient), higher education, and lodging. When pooled together, the combined EBCx project data set includes projects completed between 1984 and 2018. The EBCx projects are further divided into utility EBCx, EBCx projects implemented outside of utility programs, and utility MBCx projects.

The NCCx data collected in 2018 comprised 71 projects (101 buildings), covering 2.1 million m^2 (22 million ft^2) When combined with the 2009 data set this yielded a total of 148 projects (183 buildings), covering 2.9 million m^2 (31 million ft^2) (see Table 1). Data on NCCx projects, all received from non-utility data sources, were more evenly spread geographically than EBCx projects. Market segmentation was significantly different in 2018 compared to 2009 data: in 2018 office buildings, hospital (inpatient), and K-12 schools represented 80 percent of total floor area, whereas the top three market segments by size in 2009 were public order/safety, laboratories, and office buildings (totaling 58 percent of the floor area). When pooled together, the combined NCCx project data set includes projects completed between 1993 and 2018.

Table 1. Sample composition for combined Cx data set

	EBCx	**NCCx**	**Total**
Number of projects	1,037	148	1,185
Number of buildings	1,299	183	1,482
Floor area in m^2 (ft^2)	31.8 million (342 million)	2.9 million (31 million)	34.7 million (373 million)
Median project floor area in m^2 (ft^2)	16,737 (180,158)	8,382 (90,228)	15,177 (163,363)
Date range of projects	1984–2018	1993–2018	1984–2018

2.4. Data analysis

The starting point for the data analysis was the set of primary cost and benefit metrics reported in Mills 2011:

- Cx whole building source energy savings percent (%): $E_s \div E_b$
- Cx energy savings in thousand Btu per square meter (kBtu/m^2): $E_s \div A$
- Cx energy cost savings per square meter (\$2017/m^2): $C_s \div A$
- Cx cost per square meter (\$2017/m^2): $C_p \div A$
- Cx project simple payback (years): $C_p \div C_s$

Where E_s is the calculated whole building source energy consumption savings (kBtu) including both electric and natural gas, E_b is the whole building baseline energy consumption (kBtu) including both electric and natural gas consumption (site electric savings/consumption were reported, and these values were converted to source energy values [U.S. EPA 2018]), A is the total building floor space served by the commissioned systems under the Cx project, C_s is the energy cost savings, and C_p is the Cx project cost including third-party Cx provider fees and the cost to remediate operational issues uncovered by the Cx project. For consistency of comparison between Cx project results from different data sources and regions, energy cost savings (C_s) are based on standardized electric (U.S. EIA 2018a) and natural gas prices (U.S. EIA 2018b), inflation-adjusted to 2017 U.S. dollars. Cx project cost (C_p) is also inflation-adjusted to 2017 U.S. dollars (U.S. Bureau of Labor Statistics 2018). Canadian dollars are converted to U.S. dollars where necessary (U.S. IRS 2018). These key metrics were established for the 2018 data set, and for the whole combined data set (including the data collected in 2009 and reported in Mills 2011).

For each key metric calculated for the Cx projects' data set, the median value was determined, and box/whisker plots were used to illustrate the sample distribution. Once median values were established for the whole data set, the data were divided to enable deeper analysis and exploration of three possible influencing factors: building size, market segment,[2] and project type. These three factors were chosen because, anecdotally, they are asserted to have an influence on project costs and achieved savings.

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[2] We chose to subdivide projects by "market segment" as opposed to "building type," as some project categories did not directly correlate to actual building types, e.g., "higher education" can include a mix of building types. It should be noted that our choice of building types aligns with that of the U.S. Department of Energy's Commercial Buildings Energy Consumption Survey, and these delineations are often used in national energy modeling and forecasting as well.

Data from the 2009 data set and 2018 data set were in some cases compared to explore possible changes in cost/benefit metrics, and in other cases metrics were developed for the combined data set ("all data") to establish overall aggregate values. Additional data analysis was centered on qualitative aspects of Cx, namely owners' motivation to perform Cx, activities included in the Cx scope of work, and types of corrective actions ("measures") performed in response to deficiencies identified during the Cx process. In the case of two utility programs providing measure-level data, we classified measures according to a single schema that allowed all data from both programs to be pulled into a single data set for analysis.

2.5. BCxA provider survey

To supplement the Cx projects' data collection, additional insights were drawn from an online survey of BCxA members ("BCxA provider survey"), conducted in late 2017, which covered a wide range of topics concerning the Cx market. The BCxA survey was designed to gather general information on Cx market dynamics (e.g., whether the Cx business was expected to increase, the profitability of offering Cx services, and the balance of business between EBCx and NCCx), as opposed to seeking data/results on individual projects. BCxA received survey responses from 120 Cx providers.

3. Results

Results of the Cx projects' data analysis, and selected insights from the BCxA provider survey and literature review, are presented below.

3.1. EBCx data analysis results

3.1.1. EBCx energy savings

As shown in Table 2, the median EBCx whole building energy savings for the 2018 data set was 6.0 percent (n = 283 projects). This compares to median savings of 10.0 percent in the 2009 data set[3] (n = 163 projects). The combined median savings for all data was 6.4 percent (n = 446). The typical savings range for the combined data set, spanning the 25th percentile to 75th percentile, was 3.4 to 12.4 percent.

Table 2. Comparison of median EBCx energy savings for data collected in 2009 and 2018

	2009 data set	2018 data set	All data
Median energy savings	10.0%	6.0%	6.4%
Number of projects	163	283	446

Market segment appears to have an influence on energy savings, as illustrated in Table 3, with median energy savings values among the 16 market segments ranging from 3 percent (Lodging) to 16 percent (Public Order & Safety).

Table 3. EBCx energy savings by market segment (All data, n = 446 projects)

Market segment	Median energy savings (%)	Sample size
Public Order & Safety	16	15
Laboratory	14	28
Food Sales	12	1
Food Service	11	1
Data Center	11	4

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[3] In the course of expanding the EBCx project data set, we augmented the 2009 cohort with additional pre-commissioning electricity use data for 64 utility-sponsored EBCx projects. This enabled an updated calculation of EBCx percentage savings for the 2009 data set. As these 64 projects collectively achieved substantially lower savings (3 percent electricity) than the median value for other projects in the 2009 data set, the weighted average median total energy savings for the 2009 cohort adjusts to 10%. One likely factor in the relatively low savings for the updated projects is that the utility program governing the projects capped EBCx investigation budgets at a relatively low $\$0.10/ft^2$.

Hospital (Outpatient)	11	9
Retail	10	3
Higher Education	9	101
K-12 School	9	41
Industrial	7	4
Office	6	105
Other	6	17
Public Assembly	6	2
Hospital (Inpatient)	5	88
Warehouse	4	3
Lodging	3	24

To assess the impact of the project type on percent savings, we divided the data into three project type categories: Utility EBCx, Utility MBCx, and "Other."

1) **Utility EBCx:** Characterized by a non-comprehensive scope, Utility EBCx is focused on energy savings for the fuel(s) provided by the utility. High rigor is applied to the savings estimates review, as utilities that provide a technical review of calculations and programs are subject to third-party evaluation. Typically, EBCx provider budgets are restricted compared to comprehensive EBCx, but some measures qualify for cash incentives to install the recommended improvement measures.
2) **Utility MBCx:** Similar to Utility EBCx in the measures targeted, but Utility MBCx includes additional budget/effort to install sub-metering and implement diagnostics, and possibly a longer engagement period to uncover more measures.
3) **"Other EBCx":** This category includes EBCx offered direct by Cx firms to their clients. There may be many targeted outcomes beyond energy savings (e.g., comfort and maintenance issues). Scrutiny of savings calculations varies. The budget and level of comprehensiveness is determined on a case-by-case basis.

Figure 2 illustrates the variation in percent savings by project type, with median values ranging from 5 percent (Utility_EBCx) to 14 percent (Other_EBCx). Key insights derived from review of savings by project type included the following:

- The 2018 data set contained two large cohorts of utility projects; when analyzed individually these cohorts showed median energy savings of 4 percent (n = 94) and 7 percent (n = 156).
- The largest cohort of utility-sponsored EBCx from prior studies was from the 2009 data set, showing 4 percent median savings (n = 47), so the 2018 data set shows a higher overall energy savings percent than that achieved by utility programs in the 2009 data set.
- Utility MBCx projects show higher median savings (9 percent, n = 41) than those from utility EBCx projects, as might be expected with higher investment in the project and a longer engagement period for uncovering savings and implementing improvements.
- EBCx projects outside of utility programs show the highest median savings (14 percent, n = 107) and a very wide distribution of savings when compared to other project types.

Prior Cx cost-benefit studies did not report savings by project type, only overall median values. Given the variation in median savings shown in Figure 2, project type appears to be a significant factor and should be considered when setting expectations for EBCx project savings. We can see that in the most favorable circumstances—presumably a combination of significant baseline deficiencies together with thorough, effective commissioning measures—that savings can surpass 50 percent. Under disadvantageous circumstances, or in circumstances where comfort or maintenance issues were the sole priority of the Cx project, no savings may occur.

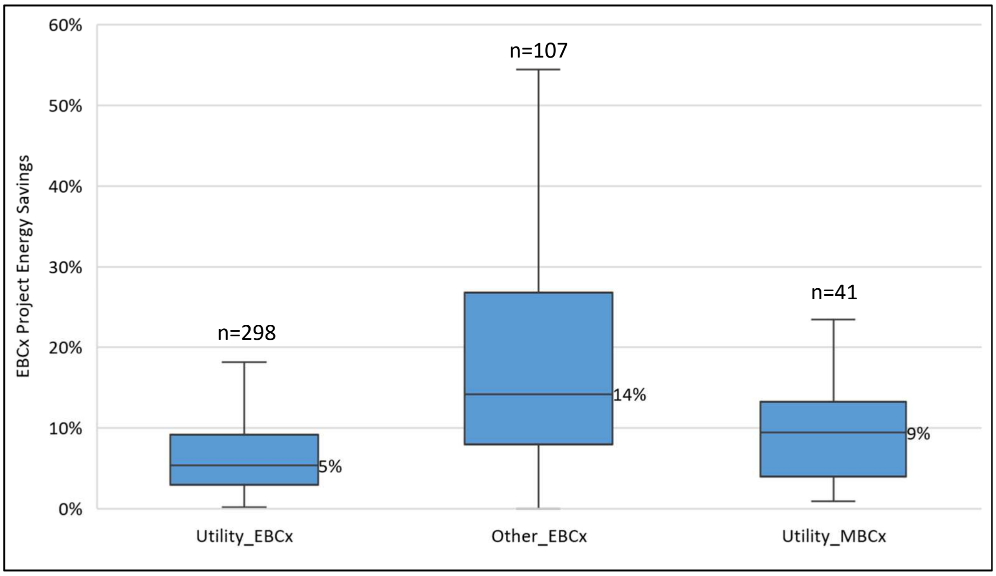

Figure 2. EBCx percent source energy savings by project type (all data)

In addition to market segment and project type, we also considered the impact of building size and date of project on EBCx energy savings. Building size was not shown to have a strong correlation with energy savings, even when isolating data from single market segments. Similarly, project completion year (ranging from 1984 to 2018) did not show a strong correlation with energy savings.

3.1.2. EBCx cost and simple payback

Based on data from 985 projects, the median EBCx project cost was \$2.84 per m^2 (\$0.26 per ft^2) (all data, \$2017), as shown in Table 4. The 2018 data set has a significantly lower median cost, \$2.65 per m^2 (\$0.25 per ft^2), compared to the 2009 data set (\$3.93 per m^2 [\$0.36 per ft^2]). Project cost data included the cost of third-party Cx provider services to identify deficiencies and the cost paid by building owners to implement the recommended remedial measures.

Table 4. Comparison of median EBCx cost per square meter for data collected in 2009 and 2018

	2009 data (\$2017)	2018 data (\$2017)	All Data (\$2017)
Median cost per m^2 (Median cost per ft^2)	\$3.93 (\$0.36)	\$2.65 (\$0.25)	\$2.84 (\$0.26)
Sample size (projects)	325	660	985

Figure 3 provides a breakdown of EBCx cost by project type, and several observations can be made based on these data. For example, utility MBCx median costs of \$15.57 per m^2 (\$1.45 per ft^2) far exceed and have broader distribution than the costs for other project types. This presumably reflects additional costs for installing metering hardware, the possible inclusion of additional retrofit measure types beyond traditional EBCx measures, or other factors. Also, the median cost for Utility_EBCx (\$2.65 per m^2 [\$0.25 per ft^2]) and Other_EBCx (\$2.57 per m^2 [\$0.24 per ft^2]) are very similar. One unknown factor in EBCx cost comparisons is the possible impact of cash incentives offered under utility EBCx programs (incentives were not factored into this study's data analysis). However, the similarity in cost between Utility_EBCx and Other_EBCx may suggest that expected overall EBCx project costs are similar, irrespective of whether the owner is partially reimbursed through incentives.

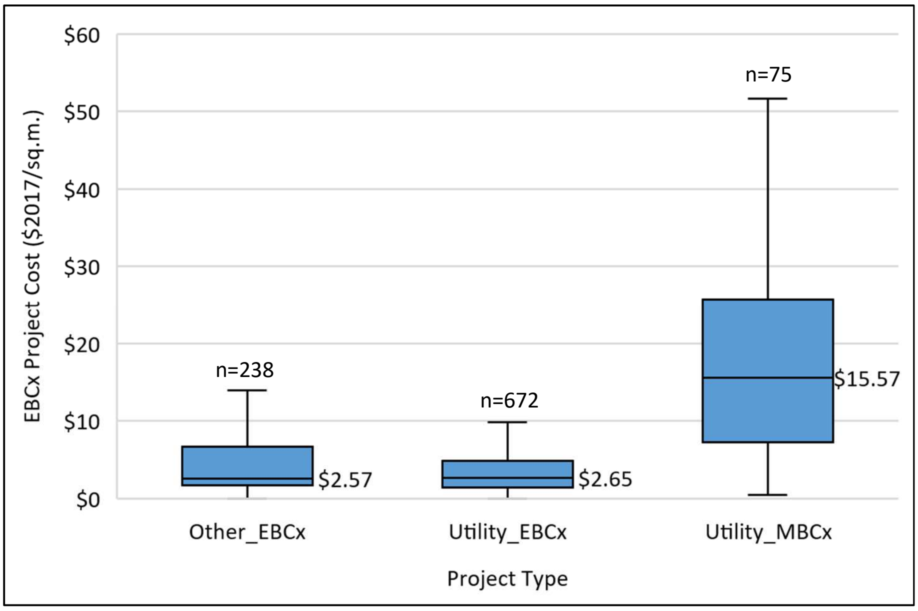

Figure 3. EBCx project cost per square meter ($2017), by project type, with median values indicated (all data). Values shown include cost of third-party Cx provider services and the cost paid by building owners to implement the recommended remedial measures.

As we did when analyzing energy savings data, we also analyzed the impact of building size on EBCx cost. Figure 4 shows the median EBCx project costs for buildings within five size ranges, and clearly illustrates the general trend that cost per square meter decreases as building size increases, although there is significant overlap across the broader sample, particularly for buildings under 20,000 m^2 (215,000 ft^2). Figure 4 also illustrates the reduction in distribution of costs as building size increases; for buildings less than 5,000 m^2 (54,000 ft^2), the range from the 25th to 75th percentile is $4.58 to $12.23 per m^2 ($0.43 to $1.14 per ft^2), whereas the corresponding range for buildings over 40,000 m^2 is just $0.95 to $2.23 per m^2 ($0.09 to $0.21 per ft^2).

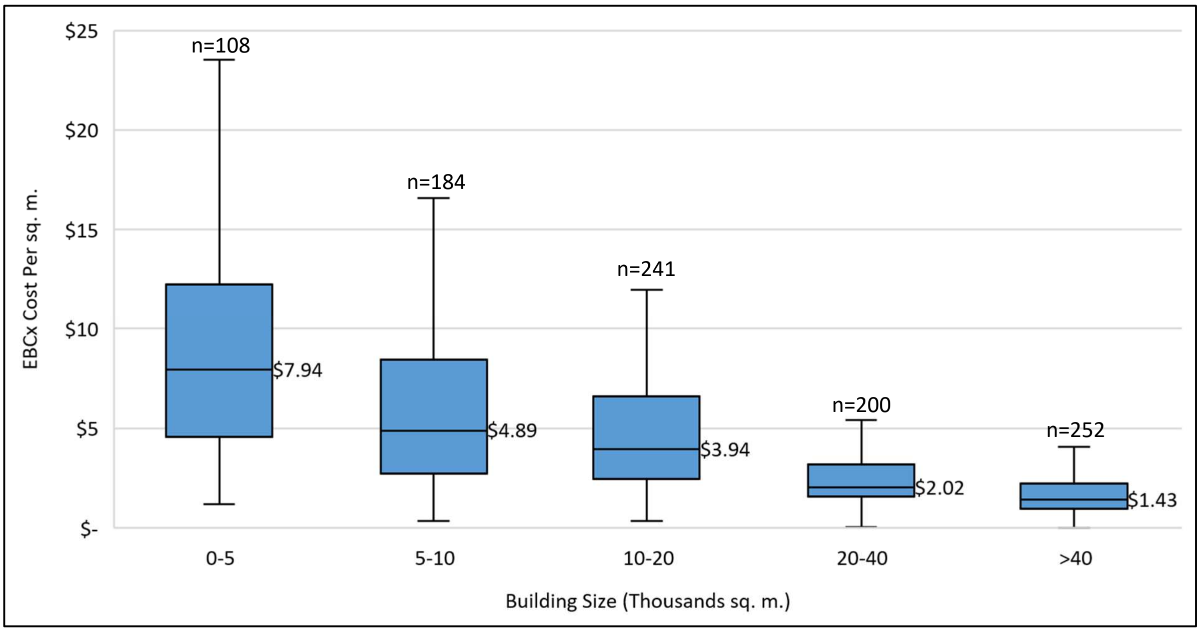

Figure 4. EBCx project cost per square meter ($2017), by building size, with median values indicated (all data)

We also reviewed the impact of market segment on EBCx cost. While variation in median values was observed, the data were not considered conclusive. First, it was difficult to interpret whether cost differences were due to building type, project type, or building size differences; for example, the majority of K-12 schools were drawn from one utility cohort, while the majority of office buildings were drawn from a different utility's cohort. Second, nine of the building type categories had small sample sizes. Building type is understood to have a strong influence on EBCx cost (due to differing mechanical system complexity), but the study data do not give a strong basis for quantifying the influence.

As shown in Table 5, the median simple payback time for the 2018 data set was 2.2 years (n = 356)—double the 1.1 years' median simple payback reported in Mills 2011 (n = 300). When all data are combined, the median simple payback is 1.7 years, with a 25th–75th percentile range of 0.8–3.5 years.

Figure 5 illustrates simple payback by project type. Median simple payback for the three project types ranged from 1.1 years (Other_EBCx) to 3.2 years (Utility_MBCx), indicating that all three project types continue to offer relatively short payback periods when compared to capital investments in energy efficiency.

Table 5. Comparison of EBCx project median simple payback for data collected in 2009 and 2018

	2009	2018	All Data
Median simple payback	1.1 years	2.2 years	1.7 years
Sample size (projects)	300	356	656

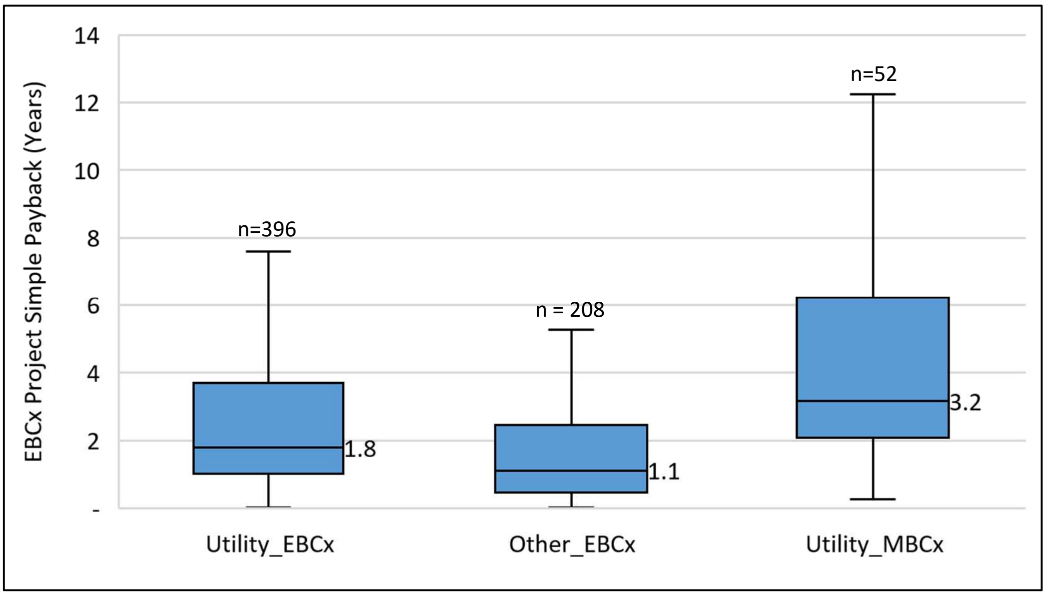

Figure 5. EBCx simple payback by project type (all data)

3.1.3. Other findings

Analysis of 2018 study data on 3,695 EBCx measures implemented through two utility programs[4] (from 503 projects) shows that five measure types account for 95 percent of all measures implemented: scheduling, operations & control (other), advanced resets, setpoint modifications, and sequence of operations modifications (see Figure 6). These top measures are consistent with typical EBCx project findings (Effinger 2010) and were overwhelmingly targeted at HVAC systems (87 percent of measures were HVAC-related, 3 percent concerned lighting, and 10 percent were denoted as "other"). It is noteworthy that mechanical fixes, maintenance, and calibration did not feature among the top five measure types. It is possible these types of maintenance activity are performed prior to or concurrent with EBCx; if so, it may not be reported through the programs, since the savings are difficult to calculate and often these measures are not allowable for utility program savings claims. Sufficient

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[4] Similarly-detailed EBCx measure information was not available from other Cx cost/benefit studies for comparison, nor from non-utility projects in the 2018 data set.

data were not available to draw conclusions as to whether the scope of EBCx had become more or less comprehensive over time.

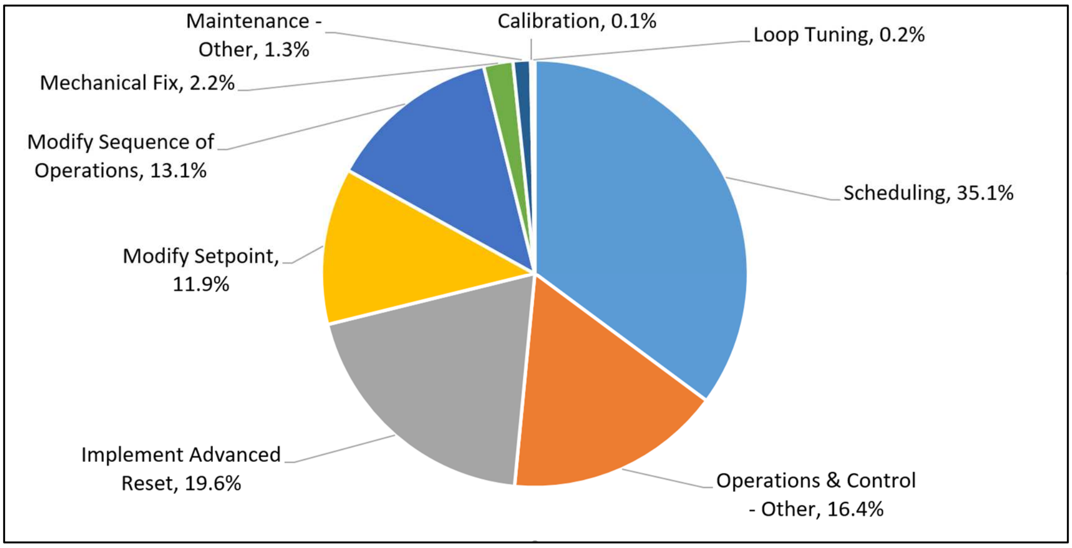

Figure 6. EBCx measure types implemented through two utility programs (n = 3,695 measures, from 503 projects; 2018 data set)

To understand owner motivations for pursuing EBCx projects, Cx providers were asked to indicate, from a list of 15 possible reasons for performing EBCx, which reasons applied to the projects they submitted to this study. For owner-initiated projects conducted outside of utility programs (n = 32 projects), the 2018 data returned the same top five reasons as reported in Mills 2011: (1) Obtain energy savings, (2) Ensure system performance, (3) Ensure or improve thermal comfort, (4) Ensure adequate indoor air quality, (5) Train and increase awareness of operators or occupants (see Table 6).

Table 6. Owners' reasons for implementing EBCx, 2009 vs. 2018

	Fraction of reporting projects with reason indicated (%)		
Reason for pursuing an EBCx project	**2018**	**2009**	**Difference**
Obtain energy savings	100	90	+10
Ensure system performance	91	47	+44
Ensure or improve thermal comfort	78	65	+14
Ensure adequate indoor air quality	47	57	-10
Train and increase awareness of operators or occupants	38	32	+5
Qualify for rebate, financing, or other services	38	18	+20
Participation in utility program	31	28	+3
Comply with LEED or other rating system	28	3	+25
Extended equipment life	25	3	+22
Comply with organizational mandate/policy	25	0	+25
Increase occupant productivity	22	23	-1
Reduce liability	3	0	+3
Research/demonstration/pilot	3	20	-17
Comply with existing buildings ordinance	3	0	+3
Other	9	0	+9

3.1.4. Supplementary findings from the BCxA provider survey

Given the limited recent data on EBCx savings and costs for non-utility EBCx projects (the 2018 data set included 13 such projects, with a median 19 percent savings and a median one-year simple payback), the BCxA provider survey responses were reviewed for additional insights on industry trends. Out of 82 responses, 70 percent of respondents self-reported that their projects' EBCx whole building savings were at least 10 percent, and 58 percent of respondents indicated fewer than two years' simple payback (based on a multiple-choice survey, no actual project data provided). Isolating non-utility EBCx projects in the combined data set gives a median savings of 14 percent and a simple payback of 1.1 years. Taking all these data points into consideration, there is strong evidence to suggest that EBCx implemented outside of utility programs might reasonably achieve 10 to 20 percent whole building savings with a simple payback of one to two years.

The project data collected in 2018 provided no data on MBCx projects conducted outside of utility programs, but the BCxA provider survey indicated that 43 percent of Cx providers included Ongoing Cx[5] in project scopes "sometimes," "very often," or "always." Market survey responses also indicated that 53 percent of Cx providers had offered ongoing Cx services for three years or longer.

Beyond MBCx, another area of interest for the 2018 Cx study was EBCx for high-tech facilities. Mills 2011 identified facilities such as laboratories, data centers, cleanrooms, healthcare, and specialized research facilities as the "commissioning mother lode" due to the high energy intensities of these facility types. The 2018 data set included many hospitals within the utility programs' data (94 projects, median 4 percent energy savings) but little data beyond that for quantifying the benefits of EBCx in high-tech facilities. More effort needs to be invested in gaining a recent picture of Cx outcomes in these energy-intensive building types.

3.2. NCCx data analysis results

3.2.1. NCCx Costs

The median NCCx cost reported for the 2018 data set was \$8.78 per m^2 (\$0.82 per ft^2), significantly less than the \$16.69 per m^2 (\$1.55 per ft^2) reported in Mills 2011 (see Table 7; all data inflation-adjusted to \$2017). When all data are combined, the median cost is \$11.08 per m^2 (\$1.03 per ft^2), and the range from 25th–75th percentile is \$5.71–\$23.76 per m^2 (\$0.53–\$2.21 per ft^2). While there are differences in data set composition there is anecdotal evidence that NCCx costs have been reduced through market competition, and also that there have been efficiencies in the application of NCCx through the use of software and improved skillsets due to a more experienced and qualified workforce (sourced from discussions during a Town Hall discussion session at the 2018 BCxA Conference). A second cost metric applied to NCCx is cost as a percentage of overall construction cost, and in this respect the 2018 data set also reflected a reduction versus 2009; 2018 data showed the NCCx cost was 0.25 percent of the overall construction cost, compared to 0.57 percent in the 2009 data set (see Table 7). This may reflect overall construction costs increasing more rapidly than commissioning costs.

Table 7. Comparison of NCCx cost data, comparing 2009 and 2018

	2009 Data	2018 Data	All Data
Median cost per m^2 (\$2017) (Median cost per ft^2) (\$2017)	\$16.69 (\$1.55)	\$8.78 (\$0.82)	\$11.08 (\$1.03)
Median cost as a percentage of overall construction cost	0.57%	0.25%	0.37%
Sample size (projects)	73	67	140

3.2.2. NCCx Energy savings and simple payback

The 2018 data set had very limited data on NCCx savings (and of the few data points collected, half were in non-U.S. currency), so it was unfeasible to establish a savings percent or savings per square meter for the data added in 2018. In the absence of new data, the savings reported in the 2009 data set remains the best available (median 13 percent whole building energy savings, at a simple payback of 4.2 years).

3.2.3. Other findings

To complement the NCCx cost analysis it was useful to review changes in typical scope of work between the 2009 and 2018 studies, e.g., if cost has fallen, has the scope of work also been reduced? For each submitted project survey, respondents noted the presence or absence of up to 16 different scope items (this analysis was not conducted

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[5] MBCx is a major component of ongoing Cx (Stum et al. 2017).

for the EBCx data set due to lack of data on implemented scope items). Twelve scope items were selected in 75 percent or more of the projects (see Figure 7), compared to the 2009 data set where only five scope items were included in 75 percent or more of the projects. It is also noteworthy that the 2018 data indicates greater involvement in many of the early steps in the construction process (e.g., design review, reviewing submittals, construction observation), which has been a long-term objective for Cx providers wanting to improve NCCx project outcomes. This suggests that the 2018 data set represents projects completed to a more comprehensive scope of work for NCCx, and at lower cost, compared to the 2009 data. Identifying and correcting design deficiencies at the pre-construction stage can of course be expected to be more cost-effective than addressing construction defects later in the process.

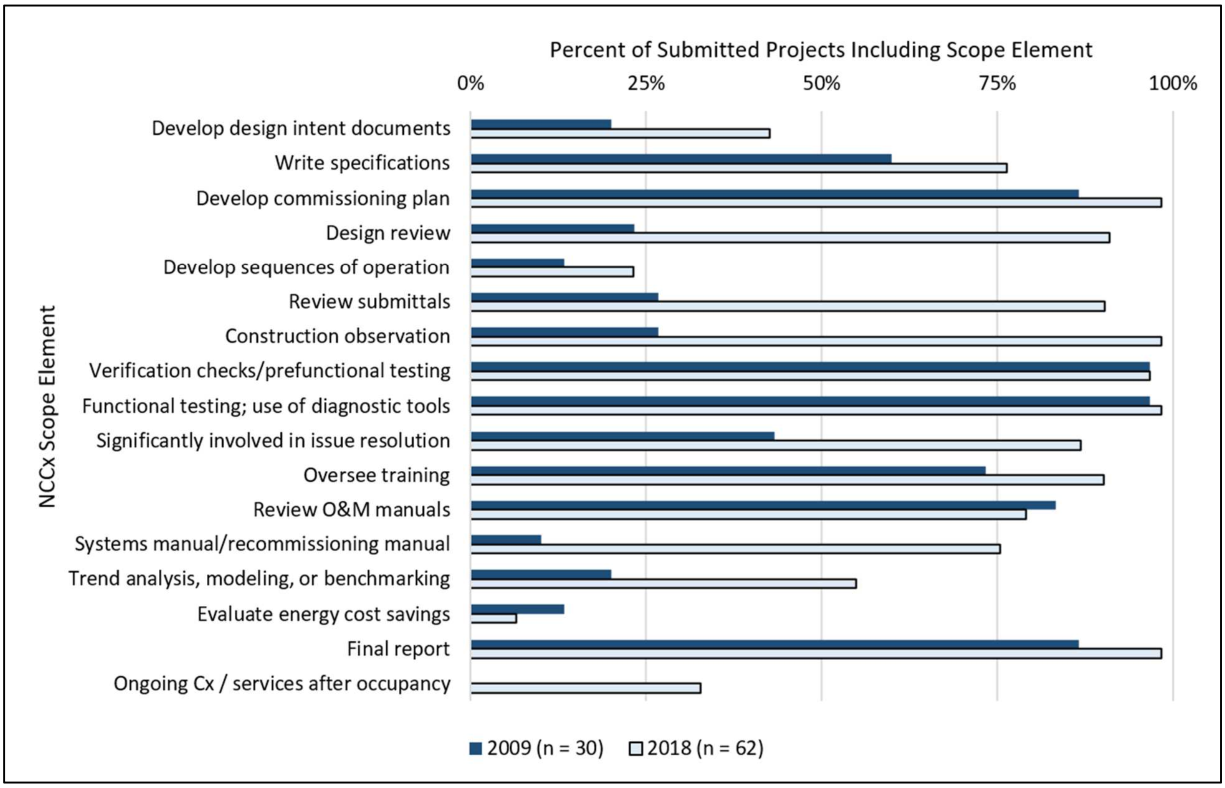

Figure 7. Percentage of NCCx projects including specific scope items.

As indicated in Figure 7, quantifying energy savings is rarely included in the NCCx project scope (included in only 6 percent of projects in the 2018 data set). Energy savings are likely important to building owners but may be secondary to a host of non-energy benefits and, in any case, determining savings requires costly modeling to estimate, given the lack of pre/post measured data for newly constructed buildings. To assess the significance of non-energy benefits, 2018 survey respondents indicated the presence or absence of up to 16 non-energy benefits that occurred as a result of a given project, and the following seven benefits were indicated for 75 percent or more of the projects: (1) construction project on schedule, problems detected and corrected earlier; (2) occupied on schedule; (3) improvements to system design, equipment sized correctly; (4) improved thermal comfort; (5) ease of maintenance improvements; (6) improved operations; and (7) facility staff training and education. These non-energy benefits are highly valuable to building owners and developers.

3.2.4. Supplementary findings from BCxA provider survey

In the context of reduced NCCx costs and increasing comprehensiveness of the project scope, we were interested in exploring whether NCCx is becoming less profitable as a business offering. The BCxA provider survey asked if NCCx is increasingly profitable, to which 82 percent of respondents indicated they were maintaining or increasing profitability (based on responses of "Neutral," "Agree," or "Strongly Agree"). Respondents were also optimistic about future business, with 78 percent expecting to be doing more NCCx in five years, and 18 percent expecting to maintain the same level of NCCx business. Thus, in the context of growing competition we are encouraged to report increasing profitability and optimism among Cx practitioners.

3.3. Results summary

Table 8 summarizes key cost/benefit metrics when combining data from Mills 2011 and the current study.

Table 8. Key cost/benefit metrics (all data)

Cost/Benefit Metric	EBCx			NCCx		
	Median	**25th–75th Percentile Range**	**Sample Size (Projects)**	**Median**	**25th–75th Percentile Range**	**Sample Size (Projects)**
Energy savings	6.4%	3.4%–12.4%	446	13%	9%–30%	7
Cost per m^2 (Cost per ft^2)	\$2.84 (\$0.26)	\$1.60–\$6.03 (\$0.15–\$0.56)	985	\$11.08 (\$1.03)	\$5.71–\$23.76 (\$0.53–\$2.21)	140
Simple payback	1.7 years	0.8–3.5 years	656	4.2 years	1.5–10.8 years	36

While Table 8 indicates differences from the 2009 data set (most notably, reduction in EBCx median savings), the overall finding is that Cx for new construction and existing buildings remains a strong proposition for achieving significant whole building energy savings with reasonable payback.

4. Discussion

In this study we took a quantitative approach to understanding Cx costs and benefits and how they have changed since the last major study was published, established updated benchmark metrics for an expanded data set of Cx projects, and sought to gather evidence of how Cx practice has evolved in terms of systems commissioned and the use of advanced analytics. In the course of this work, we have assembled the largest repository of measured data on Cx project outcomes.

For EBCx the most significant shift from the 2009 data set was toward lower overall median energy savings, although when looking deeper we found a more nuanced story by dividing the data set into different project types (EBCx and MBCx, both within and outside of utility programs). Utility EBCx programs comprised the largest portion of the 2018 data set (85 percent of buildings), versus just 37 percent of the buildings in the 2009 data set. Another possible factor is the increasing implementation of energy efficiency improvements (prior to commissioning), i.e., a falling baseline energy use. A much higher proportion of the 2018 cohort was LEED-compliant, suggesting higher efficiency and commissioning conducted during construction. Conversely, the 2009 sample had an older building stock and a higher incidence of energy-intensive market segments (e.g., laboratory-type facilities and hospitals) which also achieved high percentage savings. The maximum-achieved savings in both samples was in excess of 50 percent.

Our database comprises a large enough repository of information to show that utility EBCx programs reliably produce whole building energy savings in the 3 to 9 percent range, cost-effectively (typically with a one- to four-year simple payback) and at scale. The first known EBCx utility program was launched in 1999, and the first large scale programs were launched in 2006, so reaching cost effectiveness at scale for a complex EBCx process is a significant success. Utility MBCx programs show potential to achieve higher savings than EBCx programs, and though the 2018 data showed relatively high project cost, the median simple payback was still reasonable, at four years. Additional data on MBCx programs would be helpful in determining whether the outcomes we have observed reflect MBCx in general or just the specific program design represented in the 2018 data set, and whether persistence of savings is greater.

The EBCx energy savings achieved outside of utility programs appear appreciably higher (14 percent) than those within utility programs (5 percent), and those projects are particularly cost effective. Though the data set is smaller and the quality control is less consistent compared to utility program applications, the available project data, published literature, and the BCxA provider survey all suggest energy savings in the 10 to 20 percent range, with typical simple payback of less than two years. Our study data do not explain why EBCx energy savings were higher outside of utility programs but, anecdotally, utility program payments to EBCx service providers are typically lower and a larger portion of that payment needs to be allocated to meet strict regulatory requirements for savings calculations and documentation, meaning EBCx providers would have less budget for identifying energy-saving improvements. Other possible factors are lowest-bidder rules, restricted allowable measures and commoditization, and that programs sponsored by "single-fuel" utilities will not target all end uses.

A similarly positive picture is seen in the NCCx portion of the 2018 data set. Median NCCx cost was significantly reduced for the 2018 data set compared to the 2009 data set (\$8.78 per m^2 compared to \$16.69 per m^2, adjusted for inflation), and yet the BCxA provider survey suggested that NCCx is growing more profitable and that Cx providers expect the market to grow. Further, the 2018 data set suggested a more comprehensive NCCx scope of work being implemented compared to the 2009 data. These data, taken together, might suggest productivity improvements in the delivery of NCCx, although we cannot state that categorically. Anecdotally, two sources of productivity improvements are the emergence of Cx process management software tools and a workforce that is gaining in experience over time. In the absence of new data on potential savings of NCCx, the median 13 percent reported in 2009 remains the most comprehensive data set available, reflecting a median simple payback of 4.2 years.

While the 2018 data were a significant addition to the previous set of Cx cost/benefit data (particularly for utility EBCx programs), some Cx-related activities remain under-represented in the data set. There is a lack of available data (and market activity) on practices such as enclosure Cx and lighting controls Cx, as well as for emerging technologies and practices such as renewable energy systems, energy storage, and demand-response technologies and software, or integrated systems such as those marshaled to achieve net zero energy buildings. These gaps reflect the continuing rarity of commissioning beyond HVAC systems. There are also limited recent data on EBCx outside of utility programs, and for both EBCx and NCCx, the 2018 data set contained data solely sourced through BCxA-affiliated providers—who may not be fully representative of the market at large. However, the 2009 sample includes large numbers of non-utility-sponsored EBCx projects. For NCCx projects the 2018 data did not contain any estimates of savings; given that quantification of energy savings is rarely included in NCCx project scope, this gap in recent data may not be resolved unless a primary research effort is initiated to address that specific question.

Owner motivations for commissioning have evolved significantly. We observed some key changes in reasons for owners implementing commissioning in existing buildings. The most dramatic increases were associated with ensuring system performance, with other notable examples being improving occupant comfort, qualifying for financial incentives, and complying with "green" rating systems. Complying with organizational mandates and policies was not invoked at all in the 2009 Cx cost-benefit data set, but by 2018 was a reason given by a quarter of the project participants. Reducing liability was mentioned rarely within the 2018 cohort, and not at all in the 2009 cohort. Further, participation in research/demonstration/pilot projects was cited far less often as a driver in the 2018 data set. Surprisingly, ensuring or improving indoor air quality was cited less often, although it was still a factor in almost half the cases.

5. Conclusions and future work

The 2018 expansion of the largest known database of Cx project results reaffirms the savings potential and cost-effectiveness of Cx, and illustrates the ongoing maturation of Cx delivery models. In this study we uncovered and quantified the differing cost/benefit potentials for different types of Cx project delivery for existing buildings. Cost-effective savings are achieved across all types of delivery mechanisms, market segments, and building sizes. We also identified a trend toward delivering more comprehensive NCCx services at a lower cost, which has significant potential impact for the Cx industry and for raising the energy performance of the commercial building stock.

In the 1990s and 2000s the Cx industry was focused on defining the process of Cx and the Cx provider profession. As large-scale EBCx programs grew, standards and guidelines emerged, and more firms saw the business potential, some concerns emerged over whether competition and price pressures would erode the quality and profitability of Cx. Our comparison of the 2009 and 2018 data sets suggests that the market has been able to grow and mature, delivering reliable verified savings and supporting a profitable industry. Despite this maturity there remains great potential, with the emergence of enclosure Cx, lighting controls Cx, and MBCx supported by sophisticated analytics software. Further research on costs and benefits of these emerging Cx practices would help Cx providers communicate their value to building owners. Also, efforts to quantify energy savings and non-energy benefits of NCCx on recent projects would provide valuable insights into the long-term trends for NCCx impacts. As building systems become more integrated, with deployment of optimized dynamic control algorithms, and with the call for buildings to be more grid-interactive to balance generation needs, large-scale deployment of Cx will become even more critical in ensuring that buildings can satisfy occupant needs and attain aggressive sustainability goals.

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