A Study on Energy Savings and Measure Cost Effectiveness of Existing Building Commissioning

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Key Acronyms

A/C	Air conditioning
AHU	Air handling unit
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
CH	Chiller
CHW	Chilled water supply
CHWST	Chilled water supply temperature
CO_2	Carbon dioxide
CRAC	Computer room air conditioner
CWST	Condenser water supply temperature
Cx	Commissioning
DCV	Demand control ventilation
DDC	Direct digital controls
dP	Differential pressure
DSP	Duct static pressure
EBCx	Existing building commissioning
HVAC	Heating, ventilation, & air conditioning
HWS	Hot water supply
HWST	Hot water supply temperature
IEA	International Energy Agency
kBtu	Thousand British Thermal Units
kWh	Kilowatt-hour
OA	Outside air
PECI	Portland Energy Conservation, Inc.
RCx	Retrocommissioning
RTU	Roof top unit
SAT	Supply air temperature
Sq. ft.	Square foot
TDV	Triple duty valve
VAV	Variable air volume
VFD	Variable frequency drive

Executive Summary

Recent studies have examined the Existing Building Commissioning (EBCx) process and have determined EBCx projects to be a cost effective approach to achieve energy savings[1]. However, there is limited information available about costs and savings at the measure level. As more utilities engage in commissioning, there is a need to document and disseminate information about measure cost effectiveness and applicability to help guide future program design. This research meets this growing need by providing building owners, utilities and program implementers with an analysis of existing building commissioning measures implemented through programs across the country.

Information on commissioning measures implemented under utility programs across the United States was collected from 11 utilities known to conduct EBCx programs. In total, data on 122 commissioning projects and over 950 commissioning measures was received. From this, a data set was constructed representing a variety of building types, sizes, ages and climate zones, and contained data on measure types, savings, and costs. Gaps in the data set are addressed throughout the analysis.

The submitted measures were categorized into 44 measure types[2]. Energy savings (kBtu/sq.ft.yr) and simple payback[3] were calculated for each measure type. Controls measures constituted the most of the top savings measures and the majority (91%) of the 44 measure types had a simple payback of less than two years.

An analysis of simple payback for implemented measures by building attribute (building type, building location, building size, and building age) was conducted. The analysis indicates that implementing EBCx measures is cost effective for all building types, climate zones, building sizes, and building ages, as all categories had less than a two year simple payback with a median payback of eight months. While all climate zones had a payback less than two years, similar levels of savings among climate zones 3B and 3C (California) were achieved, indicating a similar opportunity for cost effective measure implementation despite the moderate temperatures in these regions. The data indicated that buildings under 200,000 sq.ft. have the highest savings per square foot and the quickest measure payback, which is an unexpected finding considering that most utility EBCx programs target larger buildings. Lastly, the results for building age, similar to building size, indicate that older buildings actually have the highest saving measures with the quickest payback. However, it was recognized that while the age of the building is important, the age of the equipment and the existing controls undergoing EBCx is also a factor and should be investigated in more detail.

Similarly to other industry studies[4], it was found that most of the measures (50%) affected air handling units. The boiler plant, chiller plant, cooling tower, and pumps account for another 25% of the measures.

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[1] EBCx includes both retrocommissioning and recommissioning.
[2] Measure types are defined in Table 10, in the Appendix.
[3] Simple payback, defined in 1.2, includes only implementation costs and excludes investigation, follow-up, and rebate/incentive costs.
[4] Portland Energy Conservation and Texas A&M University. "Subtask C Final Report: Commissioning Cost-Benefit and Persistence". Submitted to Lawrence Berkeley National Laboratory October, 2009.

By evaluating both the energy savings per square foot and the frequency of implementation of each measure, a "key measure mix" consisting of nine measures that contribute 75% of total cumulative savings was identified, as summarized below.

Top Cumulative Saving Measures and % of Savings

Key Measure Mix	% of Total Savings
Revise control sequence	21%
Reduce equipment runtime	15%
Optimize airside economizer	12%
Add / optimize SAT reset	8%
Add VFD to pump	6%
Reduce coil leakage	4%
Reduce / reset DSP setpoint	4%
Add / optimize optimum start/stop	3%
Add / optimize CWST reset	2%

For each building attribute (type, size, age, location), the top saving measures that account for 75% of the category's savings were identified. There was considerable overlap when the top saving measures for each building attribute were compared to the key measure mix (above).

The results from this study may be used to inform utility program design. For instance, a utility may require that all EBCx projects investigate the key measures, at a minimum, as a way to promote greater savings. Another option is for utilities to promote an operational tune-up program that only focuses on these most commonly found measures. While a tune-up program would likely reduce investigation costs, the full benefits of EBCx, such as well-integrated systems that deliver comfortable conditions, would not likely be realized.

The report concludes with recommendations for extending the data collection, where possible, to obtain additional data on building types, ages, and climate zones for which insufficient data to make valid conclusions was received. We also recommend that research is done to compare implemented versus non-implemented measures to determine the most important factors in choosing measures. We recommend that further research is done on smaller and older buildings to better understand the intricacies and opportunities of commissioning these buildings. As more utilities engage in EBCx, we recommend this study be refreshed in two to three years to capture new data and trends.

1.0 Goals, Methodology, and Accuracy of Data

1.1. Project Goals

PECI's overarching goal for this research is to conduct a cost benefit analysis of Existing Building Commissioning (EBCx) measures. An EBCx measure is the implemented solution to an operational deficiency in a building. While the cost-effectiveness of the EBCx process as a whole has been analyzed in-depth[5], there is a need to analyze individual measures implemented through the EBCx process in greater depth to inform utilities and building owners about measure cost effectiveness and the most commonly implemented measures in buildings. As such, the analysis focuses on the cost and benefit associated with individual measures, and does not consider project-level costs, such as the cost of investigation, or benefits.

Due to the lack of detailed and consistent data available, we focus this study on utility-incented EBCx programs with reporting requirements that made this level of data mining possible. Through this research, the value of collecting measure level data is illustrated, and a framework is provided for categorizing measures. This framework is based on the cost-benefit protocols developed through IEA Annex 47 Subtask C[6].

The research aims to address four main questions:

1. What are the most common measures being implemented through EBCx programs, and do these measures change based on building type, size, age, or climate zone? Is there a key set of measures that comprise the majority of potential savings that are always found?
2. What is the simple payback period of measures implemented through EBCx programs?
3. Which measures save the most energy per square foot?
4. Is implementing commissioning measures in older buildings and smaller buildings cost effective?

1.2. Methodology

To achieve our goals, PECI contacted the utilities across the country known to conduct EBCx programs. From each utility, we requested the following measure-level data for each completed commissioning project carried out through programs in their territory:

- *Building zip code-* used to determine climate zone
- *Building type*
- *Conditioned Square Footage-* floor area served by commissioned system, excluding parking
- *Year Building was Constructed*
- *Issue-* Identified problem found at the building
- *Measure-* Implemented solution to the problem

[5] Mills, Evan. "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions". California Energy Commission, Public Interest Energy Research, July 21, 2009.
[6] Portland Energy Conservation and Texas A&M University. "Subtask C Final Report: Commissioning Cost-Benefit and Persistence". Submitted to Lawrence Berkeley National Laboratory October, 2009.

- *Final Annual Electric Savings (kWh)*
- *Final Annual Natural Gas Savings*- any unit, specified by the utility
- *Final Annual Energy Cost Savings ($)*
- *Final Measure Cost ($)*- Cost of measure implementation, excluding utility incentives or rebates

While all the utilities agreed to participate in this study, one utility did not track measure level data. However, recognizing the value of this data, this utility is in the process of re-designing its program tracking tools to be able to monitor and record measure level data in the future. The amount of data received indicated a desire among utilities to increase the available information on measure level commissioning data and to contribute to studies that would help advance this knowledge in the industry.

Sample Sizes
For our analysis, we determined that measure sample sizes greater than 15 would be considered significant and included in the analysis. Sample sizes of less than 15 are represented in graphs and tables throughout the report, but are insufficient samples from which to draw valid conclusions.

Simple Payback
This report uses simple payback as the cost effectiveness metric. Since this analysis is limited to completed projects and implemented measures, only the cost of implementation is included; any investigation or follow-up costs are excluded. Implementation cost also excludes any utility-sponsored rebates or incentives, since we did not receive sufficient data on rebates to make any valid conclusions. Simple payback is calculated as:

$$\text{Simple Payback (Yrs)} = \frac{\text{Implementation Cost (\$)}}{\text{Total Annual Electric and Gas Savings (\$)}}$$

Data Analysis
In this report, median values were used for analysis purposes. To depict the spread of data for each measure, the lower (25%) and upper (75%) quartiles, which represent 50% of the data, are depicted as vertical lines. In instances where there is no vertical line, the sample size is less than three, which renders the spread incalculable.

1.3. Accuracy and Completeness of Data

All data was supplied by utility-sponsored EBCx programs and did not include building-sponsored or private EBCx programs. Savings and cost data are reported as submitted, recognizing that each utility uses a distinct quality assurance and technical review process for energy savings.

We received data on 122 completed EBCx projects and over 950 implemented measures. The measures were categorized into 44 measure types, as defined in Table 11 in the Appendix. The ‘Other” category contains measures that did not classify into one of the 44 measure types and are listed in Table 12, also in the Appendix. Two measures, ‘Control Calibration, non-Lighting’ and ‘Implementation, Other’, were submitted with significant savings (16 million kBtu) but were not included in the analysis as the measure description was too vague to be categorized.

Throughout this report the measure data will be analyzed based on the overall data set (all submitted data) and based on data categorized by four key building attributes; building type, building size, building age, and building location (represented by ASHRAE climate zone). Table 1 summarizes the sample sizes of data submitted for each building attribute. It should be noted that the sample size for each building attribute is not identical as every project did not include data on every building attribute. For example, a project could have submitted the building zip code but not enough information to determine building type. See the Measure Level Dataset and Project Level Dataset in Section 5.4 and Section 5.5 of the Appendix for a full list of projects, measures types, median savings, and the number submitted for each category.

Table 1. Sample Sizes of Submitted Projects by Category

	Large Office	Hotel/ Motel	Misc.	Hospital	Large Retail	K-12 School	Total Projects
Building Type	86	18	3	2	2	1	112

	< 200 sq.ft.	200 - 350 sq.ft.	350-550 sq.ft.	>500 sq.ft.	Total Projects
Building Size (in 1000s)	47	32	20	20	119

	<1920	1960-1969	1970-1979	1980-1989	1990-1999	2000 - Present	Total Projects
Building Age	16	9	11	54	11	18	110

	2B	3B	3C	4C	5A	5B	Total Projects
Climate Zone	3	68	28	6	8	5	118

2.0 RESULTS AND ANALYSIS

The analysis consists of four main sections. These include:

1. Measure Cost Effectiveness findings
2. Project Level Building Attribute Analysis: analysis of measures implemented by building type, age, size, and climate zone
3. Building System Analysis: findings on which building systems or equipment are most affected by the implemented measures
4. Measure Level Analysis: analysis of which key measures are found and implemented across all buildings

2.1. Measure Cost Effectiveness

The submitted measures were categorized into 44 measure types[7]. Energy savings (kBtu/sq.ft.yr) and simple payback were calculated for each measure type, shown in Figure 1. The vast majority of the measures are controls-based measures. Only 'Add small A/C unit', 'Add VFD to pump', and 'Add VFD to fan' and are retrofit measures. There is no apparent correlation between site energy savings and simple payback as measures with high energy savings and low energy savings

[7] Measure types are defined in Table 10, in the Appendix.

show both high and low paybacks. However, the majority (91%) of implemented measures individually had a payback of less than two years. Thus, existing building commissioning can be cost-effective on a measure level.

Several measure types had sample sizes of two or less. These categories were not included in Figure 1 as they are so infrequently implemented. However, several of these measures have high savings when implemented (Table 2).

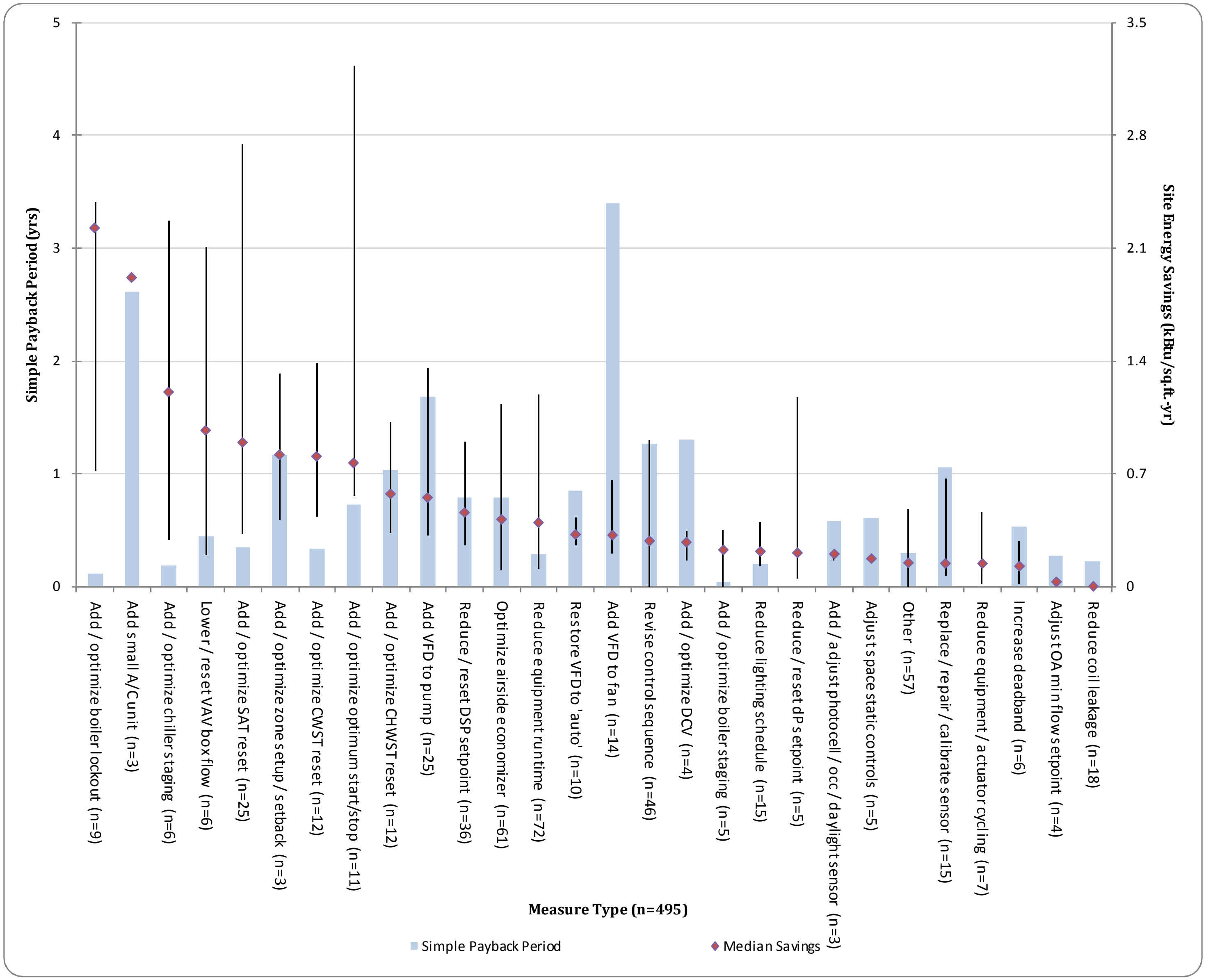

Figure 1. Site Energy Savings and Simple Payback Period by Measure Type

Table 2. High savings measures implemented infrequently.

Measure Type	Sample Size	Payback (years)	Savings (kBtu/sq.ft.yr)
Tune/Upgrade controls	2	2	15.4
Add/optimize HWST reset	2	0.08	4.2
Relocate/shield temp sensor	2	11.35	3.6
Add VFD to chiller	2	4.3	1.4
Optimize waterside economizer	2	1.27	1

2.2. Project Level Building Attribute Analysis

When grouping measures based on building attribute, all categories had a payback of less than two years, as shown in Figure 2 (building type), Figure 3 (building size), Figure 4 (building age), and Figure 5 (climate zone), regardless of the building attribute. Thus, our analysis demonstrates that EBCx may be cost effective for all building attributes[8]. In particular, it was found that EBCx is cost effective for all building sizes and for older buildings. These findings may disprove the myths that implementing EBCx measures in smaller buildings and older buildings are not cost effective.

Building Type

PECI received data on a total of 112 projects[9], as shown in Figure 2. However, only the sample sizes (n) for the Large Office and Hotel / Motel appear statistically significant. Therefore, our analysis focuses on Hotels and Offices. For the remaining building types, the data received is shown, but there is not enough data to draw significant conclusions.

[8] The sample sizes for hospital, large retail, schools, 1960-1969, 1970-1979, 1990-1999, and climate zones other than 3B and 3C were not large enough to draw statistically significant conclusions. More data is needed to conclude commissioning is cost effective for all building attributes.

[9] Data on 122 projects was submitted, but only 112 included data on building type.

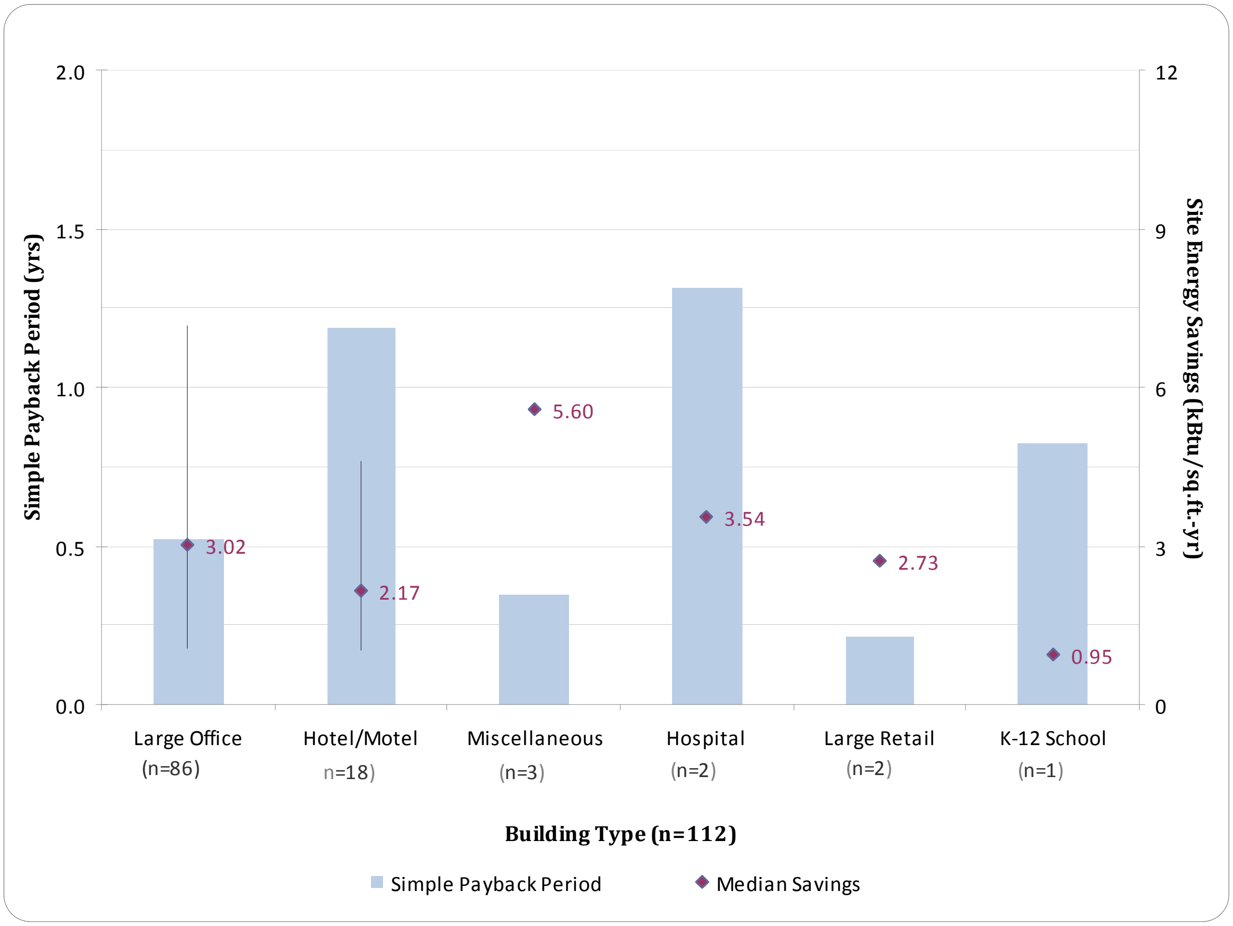

Figure 2. Site Energy Savings and Simple Payback Period by Building Type

As shown in Figure 2, all building types had a median payback less than two years. For the significant data sets, Large Offices have better payback and higher savings than Hotel / Motel. There are multiple possible causes for this difference, such as the different measure mix between the two building types (Table 5), number of rooms, and their hours of operation. Furthermore, Hotels/Motels have numerous zones where occupant comfort is critical. These factors make Hotel/Motels more complex to commission, making their implementation costs different from Large Offices.

As a whole, Figure 2 demonstrates that EBCx might be cost effective for all building types, if the data can be substantiated with larger sample sizes for Hospital, Large Retail, K-12 Schools, and Miscellaneous.

Tables depicting savings by measure type are provided in the Measure Level Dataset and Project Level Dataset in Section 5.4 and Section 5.5, respectively, of the Appendix.

Building Size

For all building sizes, sufficient data was received to be able to draw significant conclusions. The building size groupings represent the minimum to lower (25%) quartile, lower quartile to median, median to upper (75%) quartile, and upper quartile to maximum building size in the dataset.

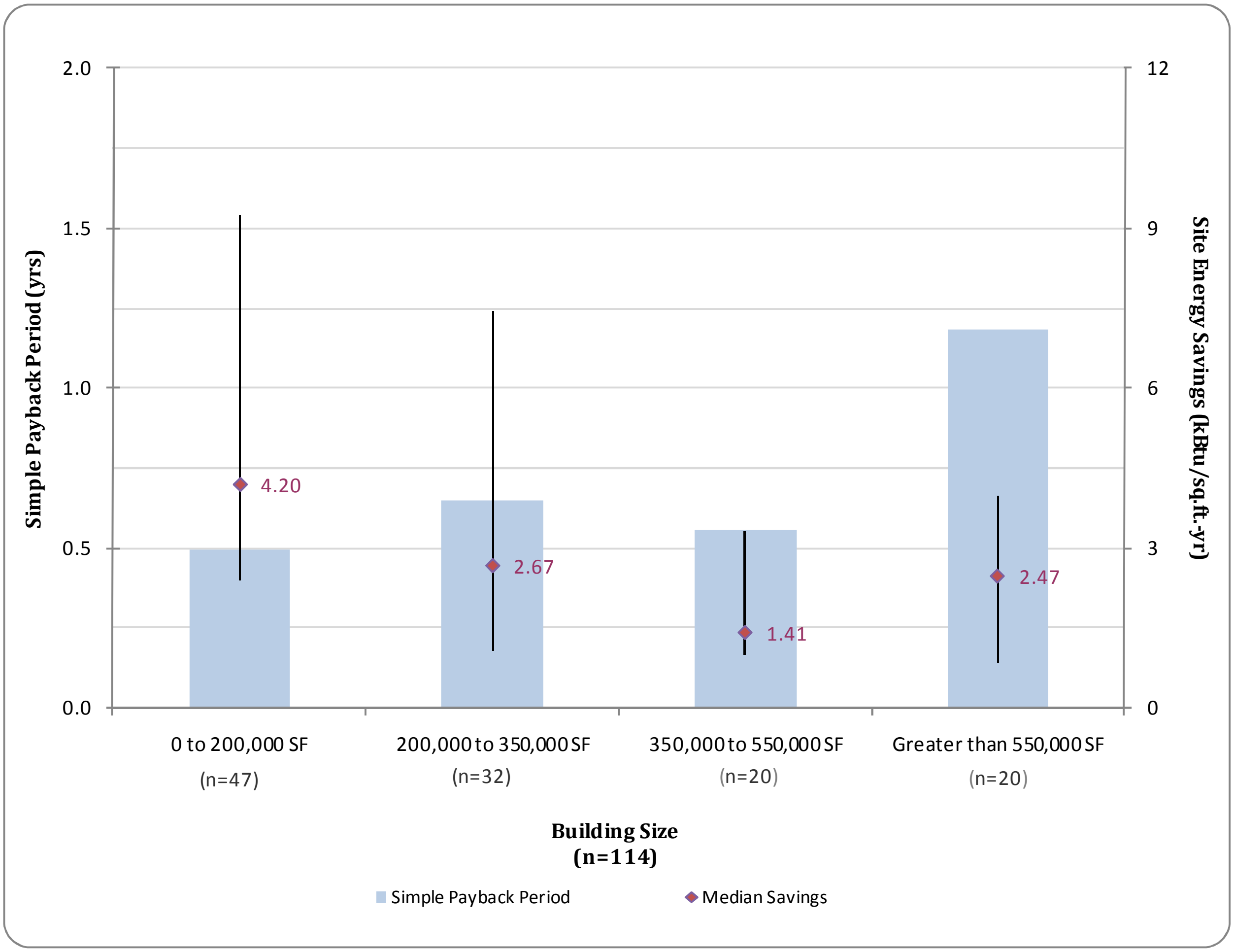

Figure 3. Site Energy Savings and Simple Payback Period by Building Size*

(*All building types and ages located in ASHRAE climate zones 2B, 3B, 3C, 4A, 4C, 5A, and 5B)

Figure 3 illustrates commissioning measure implementation is cost effectiveness for all building sizes, since the median payback for all sizes is less than two years.

It appears that measures in buildings smaller than 200,000 sq.ft were the most cost effective for building owners. However, buildings less than 200,000 sq.ft also showed the highest variation in energy savings. Investigation costs were not included in this analysis, which can be a significant portion of the overall project costs, especially for smaller buildings.

It is recognized that adding some granularity to determine if it is cost effective to commission buildings under 100,000 sq.ft is a need in the industry. Our data set only included three buildings smaller than 100,000 sq.ft with only four implemented measures. Based on the methods used in this analysis, it was found that the individual measures were cost effective as all four had a payback less than two years. It is interesting that two of the three measure types implemented in small buildings are the top two savings measures (Figure 9, discussed in measure level analysis), indicating significant savings potential. Assuming the utilities pay the investigation costs, commissioning is cost effective for small building owners. However, we can not conclude, based on this limited data set, that commissioning buildings under 100,000 sq.ft is cost effective to utilities without considering the investigation cost.

Tables depicting savings and payback by measure type are provided in the Measure Level Dataset and Project Level Dataset in Section 5.4 and Section 5.5, respectively, of the Appendix.

Building Age

Of the data received, only the sample sizes (n) for <1920, 1980 to 1989, and 2000 to present appear to be statistically significant. For the remaining building ages, 1960 – 1969, 1970 – 1979, and 1990 – 1999, the data received is shown, but there is not enough data to draw valid conclusions.

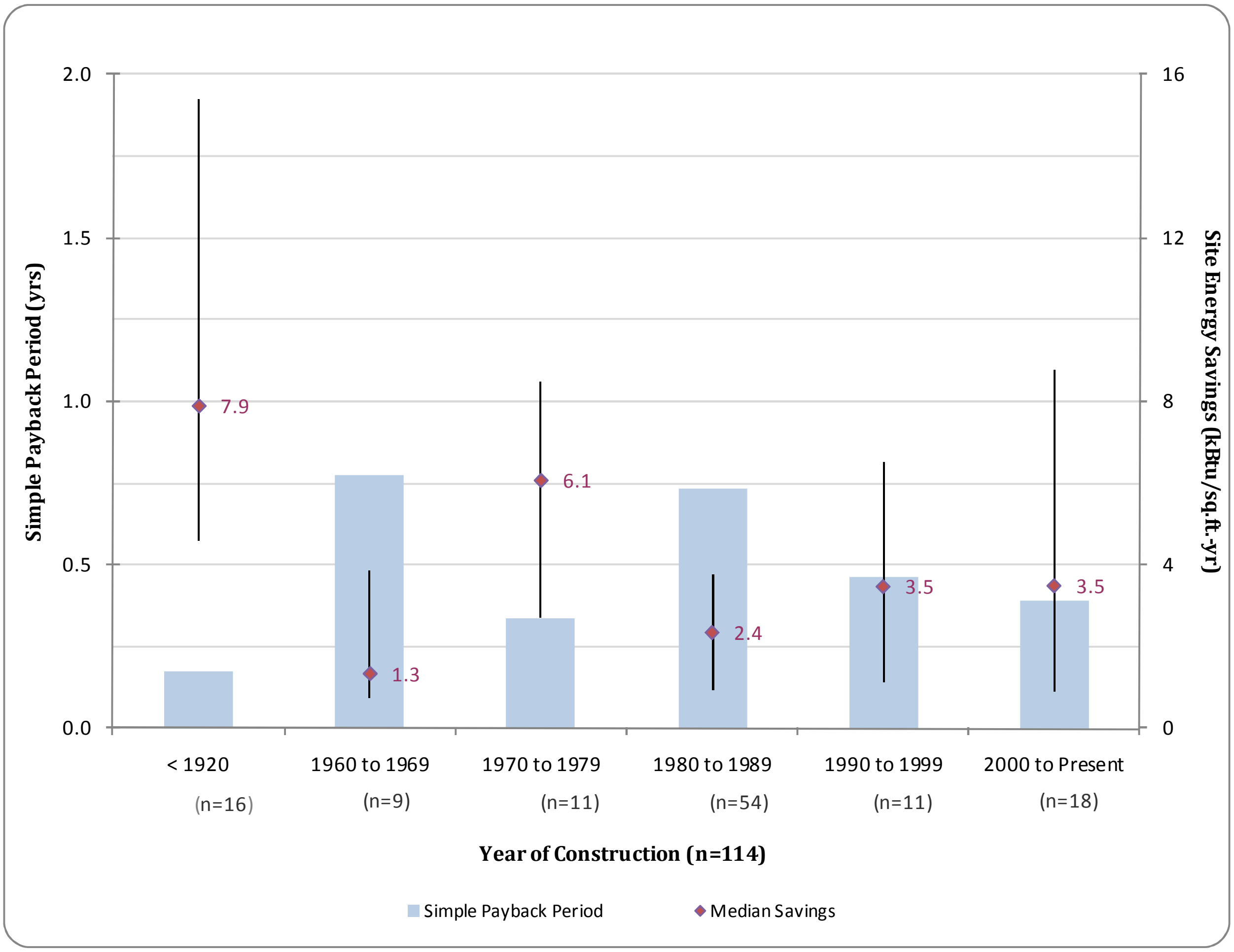

Figure 4. Site Energy Savings and Simple Payback Period by Year of Construction

Figure 4 illustrates that it can be cost effective to implement commissioning measures in buildings of all ages, as all groupings have under a 2 year payback. The results also imply that buildings that were built prior to 1920 are actually relatively more cost effective commissioning candidates, contrary to the myth that older buildings are not cost effective to implement commissioning measures.

We recognize that while the age of the building is important, the age of the equipment undergoing EBCx is also a factor. The age of the equipment does not necessarily correlate with the age of the building. For example, at the time commissioning took place, buildings older than 1920 may have already had relatively new equipment installed as part of a recent retrofit, whereas buildings constructed in 1985 may still be operating with the original equipment in need of replacement. The former is a good candidate for EBCx, while the latter is more applicable for retrofit. Additionally, the data did not contain any information about the control systems in these older buildings, which could also have an impact on the types of measures implemented and their associated simple payback.

When considering EBCx, which includes both retrocommissioning and recommissioning, of older buildings we expect to see more retrofit measures. Of the data submitted, 2 measures ('Tune / Upgrade controls' and 'Add small A/C unit') are retrofits. However, we did not receive enough data to be able to draw a conclusion if implementing EBCx measures in older building are cost effective.

Tables depicting savings and payback by measure type are provided in the Measure Level Dataset and Project Level Dataset in Section 5.4 and Section 5.5, respectively, of the Appendix.

Climate Zone

Since many EBCx measures relate to optimizing building HVAC systems and the outdoor climate can have a significant impact on a building's heating and cooling load profile, the data was analyzed on a climate-zone basis. Of the data received, ASHRAE climate zones 3B and 3C, which primarily cover California, have statistically significant sample sizes. For the remaining climate zones, 2B, 4C, 5A, and 5B, the data received is shown, but there is not enough data to draw valid conclusions. As we targeted known utility EBCx programs and achieved a 91% response rate, the lack of data from other climate zones, in particular, the southeast, northeast, and Montana / Dakota regions, is probably due to the lack of utility programs in those climate zones. A map depicting the ASHRAE Climate Zones is provided in the Appendix.

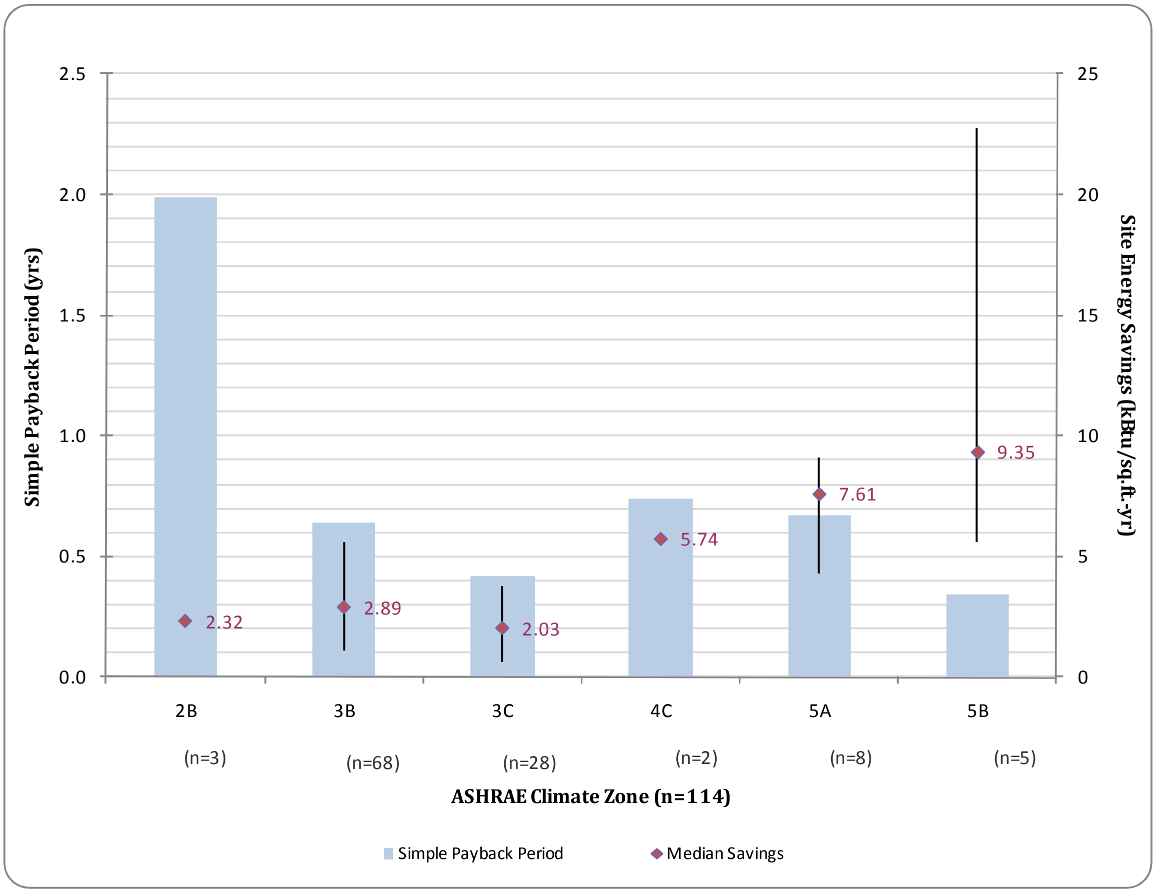

Figure 5. Site Energy Savings and Simple Payback Period by ASHRAE Climate Zone

Figure 5 suggests that EBCx is cost effectiveness across multiple climate zones, as the median simple payback of every climate zone was less than a two years. The data also shows a similar level of savings among climate zones 2B, 3B, and 3C, all of which contain California utility program data. Furthermore, 3B and 3C have similar savings and low payback, indicating a similar opportunity for cost effective commissioning despite the moderate temperatures in these regions of California. Climate zone 5B covers Colorado, Nevada, and eastern Oregon and Washington. The data received indicates that there is higher energy savings potential in this climate zone, which is expected as this area has a harsher climate than the California climate zones. However, not enough data was collected to make a significant conclusion. Also, the high simple payback in zone 2B appears to be an anomaly, especially since we received such a small amount of data. 2B is a small zone in southeast California with climates similar to 3B and 3C. Thus it is expected that its savings and simple payback would be similar to 3B and 3C.

Tables depicting savings and payback by measure type are provided in the in the Measure Level Dataset and Project Level Dataset in Section 5.4 and Section 5.5, respectively, of the Appendix.

2.3. Building System Analysis

Each measure was categorized by the system, or equipment type, affected. Figure 6 shows that the main system affected are air handling units, accounting for 50% of the measures. The boiler plant, chiller plant, cooling tower, and pumps account for another 25% of the measures. This is similar to the previous Annex study[10] which also found the air handling units were the primary system affected.

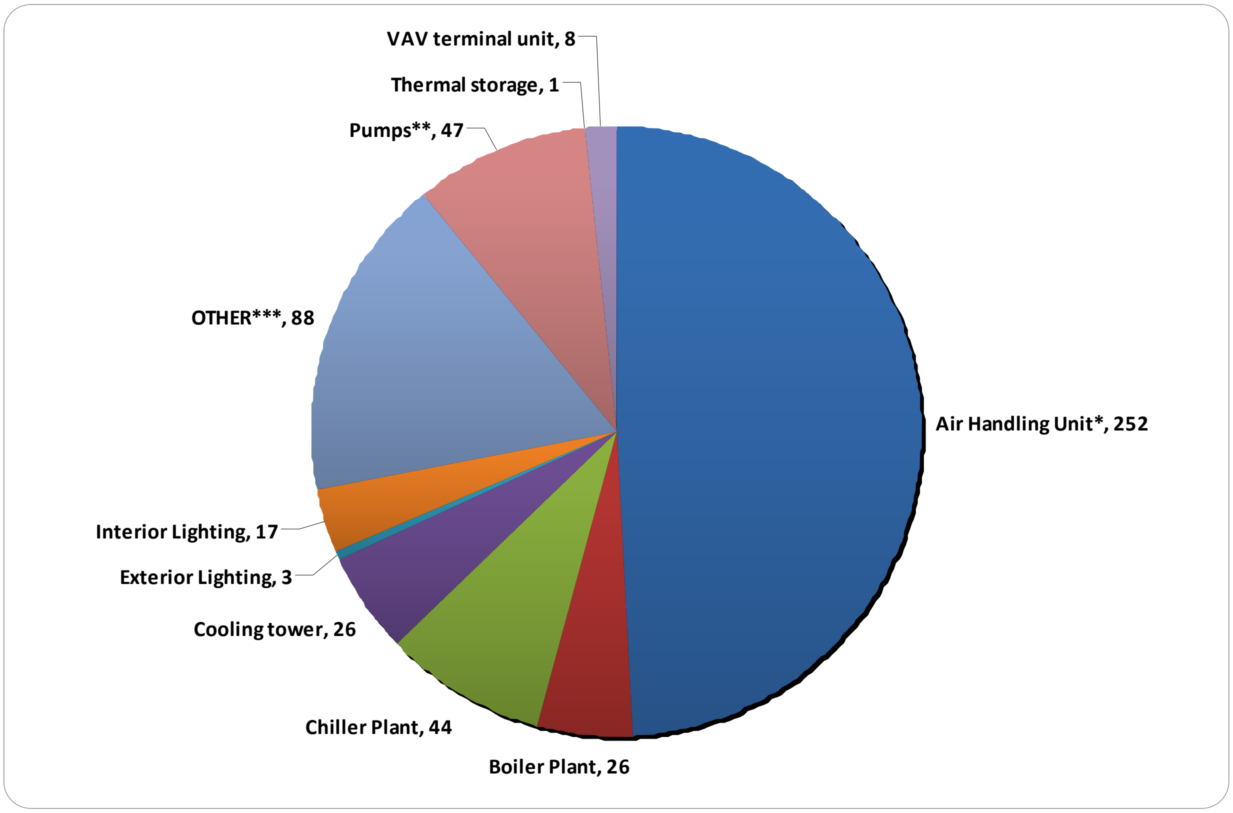

Figure 6. Systems and Equipment Affected by Implemented EBCx Measures

*A chart representing the types of air handling units is included under Building System Analysis – Charts in the Appendix

**A chart representing the types of pumps affected by implemented measures is included under Building System Analysis – Charts in the Appendix

*** The "Other" category includes garage and exhaust fans, equipment/system control sensors (e.g., outdoor air temperature sensors), plate and frame heat exchangers, and smaller unitary equipment such as unit heaters and CRAC units. The "Other" category also served as the default equipment type when insufficient information regarding the affected equipment was received.

2.4. Measure Level Analysis

Cost effectiveness, as defined in this analysis, is limited to implementation costs. However, we recognize that the cost of the investigation to utilities can be significant and can affect overall EBCx cost effectiveness. While Mills[11] found that EBCx is cost effective with investigation costs

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[10] Portland Energy Conservation. "IEA Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings". Submitted to Lawrence Berkeley National Laboratory June, 2009.
[11] Mills, Evan. "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions". California Energy Commission, Public Interest Energy Research, July 21, 2009.

included, PECI hypothesized, based on our experience implementing EBCx programs, that the cost of the EBCx investigation could be reduced significantly by using a more targeted building investigation approach. Such an approach would require a complete program design to help ensure it aligns with the budgets, energy savings goals, market characteristics, resources, and regulatory requirements for a given utility or building owner wishing to implement it. However, a central component of that program design would include a baseline list of measures that would be consistently investigated for all buildings participating in the program.

We hypothesized that utilities or program implementers could, within the context of their program designs, define a key measure mix that would account for most of the savings potential—roughly 75%—in any building. This key measure mix could be used to develop programmatic guidelines that could streamline the EBCx process into an operational tune-up approach while still achieving the majority of the potential savings. This assumes that the cost to investigate each building would be reduced by focusing on these commonly found measures instead of conducting a fully comprehensive investigation. PECI recognizes that an operational tune-up approach would no longer be considered an EBCx project, since the scope of the investigation would be reduced compared to the traditional, comprehensive EBCx investigation. With this in mind, we examined the hypothesis further to determine its feasibility and applicability across the four building attributes identified in this report.

This measure analysis includes:

- Identification of the most frequently implemented measures and the definition of a key measure mix that accounts for 75% of total savings in this data set
- Analysis of the applicability of the key measure mix to the four building attributes (type, size, age, and climate zone)
- Comparison of the key measure mix to the measures with the highest individual energy savings
- Discussion of the potential for a operational tune-up that would achieve the majority of potential savings at reduced cost

Key Measure Mix Identification

It would be inadequate to use the highest savings measures as the key measure mix because some measures are implemented too infrequently to be applicable in most EBCx projects; for example, 'Add small A/C unit' only applies in a few rare instances, despite having high savings per square foot. Furthermore, the measures that are implemented the most frequently (Figure 7), for instance, optimize airside economizer, reduce equipment runtime, and reduce/reset DSP setpoint, are not the measures that have the most savings per square foot. While these measures individually may not be top saving measures, cumulatively they contribute significantly to total energy savings. Therefore, the key measure mix needs to account for both energy savings ($/sq.ft) and frequency of implementation.

Thirteen measures accounted for 75% of the total number of measures implemented, which points to the surprisingly consistent nature of findings in various building types, ages, and climate zones (Figure 7). One explanation for this consistency is that with constrained EBCx budgets, these measures are the easiest to identify and implement solutions. For example, zone level improvements were rarely implemented through the EBCx projects in this study, likely due to the relatively high level of effort and control system functionality that needs to be present to address what otherwise might be cost effective energy savings.

To determine which measures are the biggest energy savers for the EBCx programs in this study while still factoring in the frequency of implementation of each measure type, the cumulative energy savings (kBtu/yr) for each measure type was calculated and its percent contribution to total savings determined (Figure 8). Nine measures contributed 75% of the cumulative savings. These nine measures are defined as the "key measure mix" (Table 3). The applicability of this key measure mix to buildings in general depends on how the measure mix vary by building attribute, and is analyzed in the next section.

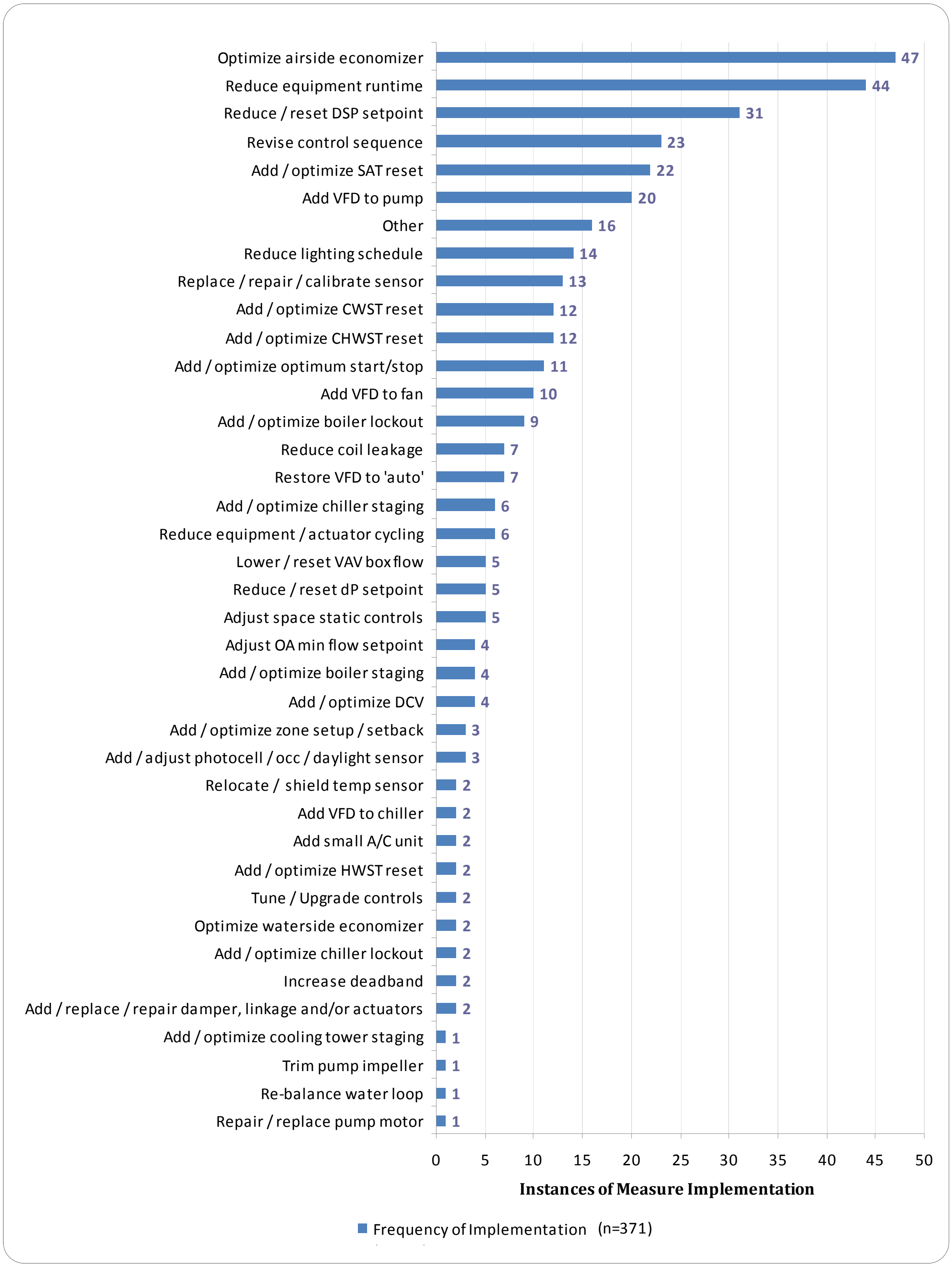

Figure 7. Frequency of Implemented Measures

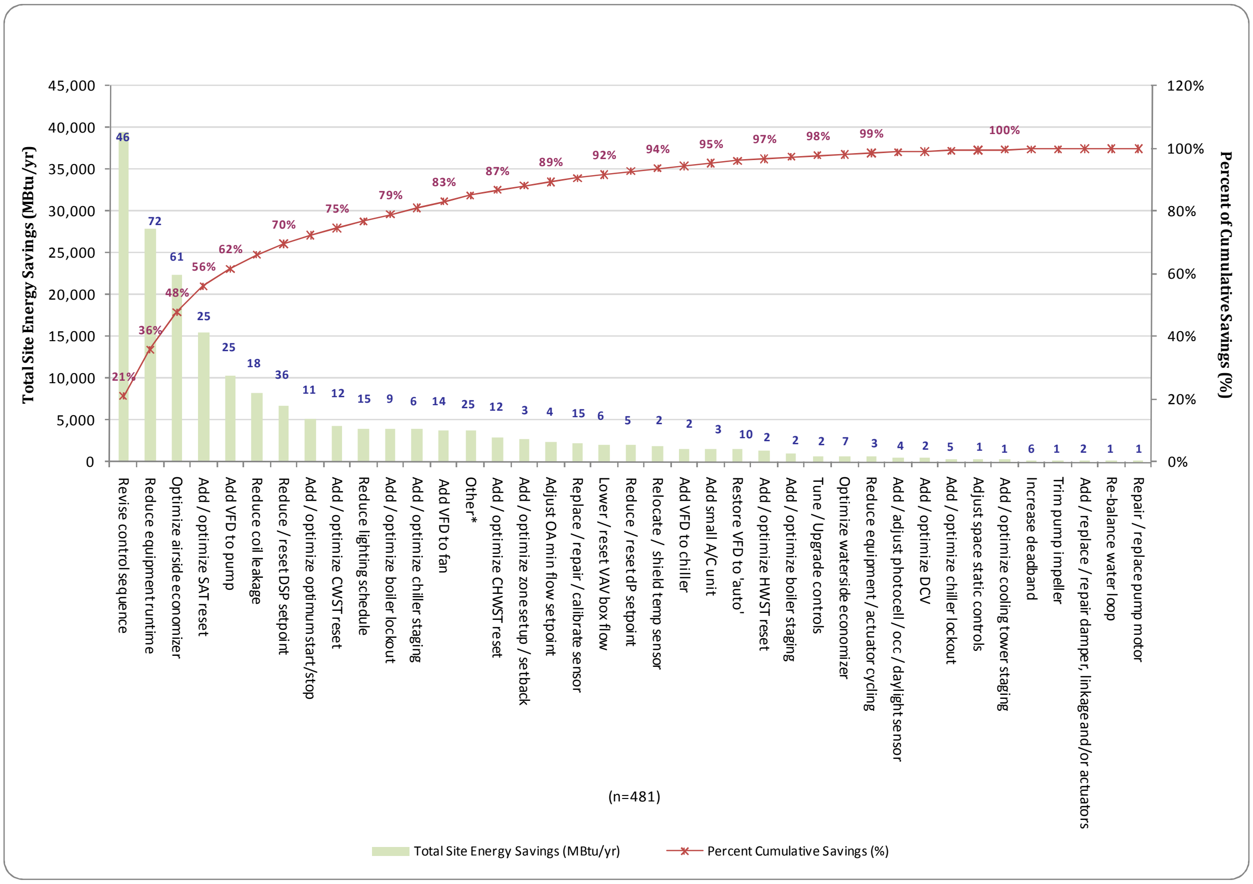

Figure 8. Total Energy Savings by Measure Type[12].

***Other – the list of measures included in the "other" category is in Table 12 in the Appendix**

Table 3. Top Cumulative Saving Measures and % of Savings

Key Measure Mix	% of Total Savings
Revise control sequence	21%
Reduce equipment runtime	15%
Optimize airside economizer	12%
Add / optimize SAT reset	8%
Add VFD to pump	6%
Reduce coil leakage	4%
Reduce / reset DSP setpoint	4%
Add / optimize optimum start/stop	3%
Add / optimize CWST reset	2%

12 The following project level charts show combined electricity and gas site energy usage in kBtu. For charts showing only electric or only gas usage, see Figure 10, Figure 11, and Figure 12 in the Appendix.

Comparison of the Key Measure Mix by Building Attributes

Measures were grouped by building attribute (type, size, age, climate zone) and attribute sub-category (hotel, hospital, <1920, 0-200,000 sq.ft, etc) to determine, for each sub-category, what measures cumulatively (kBtu) save the most energy. The measure mixes for building type are shown in Table 5, for building size in Table 6, for building age in Table 7, and for building location in Table 8[13]. The measures listed in Table 5 through Table 8 for each sub-category are the top measures in order of cumulative savings that add up to 75% of the total savings for that category. The measures that save the most energy in a sub-category and are a measure included in the key measure mix are shaded for easy identification. For instance, in Large Offices revise control sequence is shaded as it is also on the key measure mix, while add optimize boiler lockout is not shaded as it is not in the key measure mix.

In comparing the measure mix for each sub-category with the key measure mix it can be seen in Table 5 through Table 8 there is considerable overlap. In fact, the key measure mix accounts for the majority (66%) of potential savings for eight of the eleven sub-categories, including large offices (Table 5), buildings sized 0-200,000 sq.ft, 350,000-550,000 sq.ft., and greater than 550,000 sq.ft (Table 6), buildings constructed 1980-1989 and 2000 – present (Table 7), and climate zones 3B and 3C (Table 8). For the hotel/motel (Table 5) and buildings sized 200,000-350,000 sq.ft (Table 6) adding one additional measure, 'Add VFD to fan', would achieve the majority of the savings. For the remaining sub-category, adding the measure 'Add small AC unit', would achieve the majority of the savings. The results of this comparison analysis are summarized in Table 4. Thus, the analysis illustrates that use of a customized key measure mix as one component of a customized program design could help utilities and program implementers achieve a significant portion of potential savings for a given building. If designed appropriately, the approach could be used to conduct an operational tune-up program that has the potential to be more streamlined and cost effective than a comprehensive EBCx program.

For example, as a starting point a large office that is 350,000-550,000 sq.ft constructed after 2000 and in climate zone 3C could use the key measure mix. A large office that is 200,000-350,000 sq.ft constructed before 1920 and in climate zone 3C could use the key measure mix plus 'Add VFD to fan', depending on the building characteristics. The level of investigation into additional opportunities could then be tailored to the building's characteristics or other specific program factors. Of course, this analysis still assumes that looking at a limited group of measures would reduce investigation costs, making implementation of operational improvements more cost effective to utilities and program implementers.

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[13] The prevalent measures for all sub-categories are included for reference purposes only. Only those with significant sample size (n) should be used in any analysis.

Table 4. Comparison of key measure mix to building attributes

Building Attribute Sub-Category	Percent of savings achieved through key measure mix	Prevalent measure(s) to add to key measure mix	Percent of savings achieved with additional measure
Building Type			
Large Office	72%	-	
Hotel/Motel	64%	Add VFD to fan	76%
Building Size			
0-200	73%	-	
200-350	55%	Add VFD to fan	67%
350-550	69%	-	
>550	69%	-	
Building Age			
<1920	63%	Add small AC unit	72%
1980-1989	72%	-	
2000-Present	71%	-	
Climate Zone			
3B	77%	-	
3C	78%	-	

Table 5. Key Measure Mix Comparison by Building Type

	Large Office (n=86)		Hotel Motel (n=18)		Miscellaneous (n=3)		Hospital (n=2)		Large Retail (n=2)	
Key Measures	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings
Revise control sequence	Revise control sequence	26%	Optimize airside economizer	18%	Optimize airside economizer	40%	Optimize airside economizer	44%	Reduce coil leakage	29%
Reduce equipment runtime	Reduce equipment runtime	16%	Add / optimize SAT reset	15%	Reduce equipment runtime	32%	Reduce equipment runtime	25%	Reduce equipment runtime	27%
Optimize airside economizer	Add / optimize SAT reset	9%	Add VFD to pump	14%						
Add / optimize SAT reset	Optimize airside economizer	9%	Add VFD to fan	12%						
Add VFD to pump	Reduce / reset DSP setpoint	5%	Reduce equipment runtime	8%						
Reduce coil leakage	Add / optimize optimum start/stop	4%	Add / optimize CWST reset	8%						
Reduce / reset DSP setpoint	Add VFD to pump	3%								
Add / optimize optimum start/stop	Add optimize boiler lockout	3%								
Add / optimize CWST reset										
Top Measures Subtotal		75%		75%		70%		69%		56%
Key Measures as % of Total Savings		**72%**		**64%**						
Measures Required To Achieve at least 66% of Total Savings			Add VFD to fan	12%						
Revised: Key Measures as % of Total Savings				**76%**						

Table 6. Key Measure Mix Comparison by Building Size

Key Measures	0 to 200,000 sq.ft. (n=47)		200,000 to 350,000 sq.ft. (n=32)		350,000 to 550,000 sq.ft. (n=20)		Greater than 550,000 sq.ft. (n=20)	
	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings
Revise control sequence	Reduce equipment runtime	24%	Optimize airside economizer	23%	Reduce equipment runtime	29%	Revise control sequence	35%
Reduce equipment runtime	Add / optimize SAT reset	19%	Reduce equipment runtime	18%	Optimize airside economizer	12%	Add VFD to pump	9%
Optimize airside economizer	Revise control sequence	12%	Add VFD to fan	6%	Add / optimize SAT reset	9%	Optimize airside economizer	8%
Add / optimize SAT reset	Optimize airside economizer	9%	Other	5%	Revise control sequence	8%	Add / optimize SAT reset	8%
Add VFD to pump	Reduce / reset DSP setpoint	6%	Add VFD to pump	5%	Add VFD to fan	7%	Reduce equipment runtime	5%
Reduce coil leakage	Add / optimize optimum start/stop	4%	Revise control sequence	5%	Add / optimize CWST reset	5%	Other	5%
Reduce / reset DSP setpoint			Relocate / shield temp sensor	4%	Reduce / reset DSP setpoint	5%	Add / optimize optimum start/stop	3%
Add / optimize optimum start/stop			Reduce / reset DSP setpoint	4%				
Add / optimize CWST reset			Add / optimize boiler lockout	4%				
Top Measures Subtotal		73%		63%		71%		71%
Key Measures as % of Total Savings		**73%**		**55%**		**69%**		**61%**
Measures Required To Achieve at least 66% of Total Savings			Add VFD to fan	6%				
			Relocate/shield temp sensor	4%				
Top Measures Subtotal (at least 75% of Total Savings)				**65%**				

Table 7. Key Measure Mix Comparison by Building Age

Key Measures	<1920 (n=16)		1960-1969 (n=9)		1970-1979 (n=11)		1980-1989 (n=54)		1990-1999 (n=11)		2000 to Present (n=18)	
	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings
Revise control sequence	Revise control sequence	22%	Reduce / reset DSP setpoint	16%	Reduce equipment runtime	29%	Revise control sequence	33%	Optimize airside economizer	21%	Reduce equipment runtime	31%
Reduce equipment runtime	Add / optimize SAT reset	16%	Reduce equipment runtime	11%	Revise control sequence	12%	Optimize airside economizer	15%	Reduce equipment runtime	19%	Add / optimize SAT reset	24%
Optimize airside economizer	Reduce equipment runtime	13%	Add / optimize boiler lockout	11%	Adjust OA min flow setpoint	10%	Reduce equipment runtime	8%	Add / optimize SAT reset	17%	Optimize airside economizer	11%
Add / optimize SAT reset	Add / optimize optimum start/stop	12%	Add / optimize CWST reset	10%	Add VFD to pump	10%	Add VFD to pump	7%	Add / optimize optimum start/stop	15%	Add / optimize chiller staging	6%
Add VFD to pump	Add small A/C unit	9%	Optimize airside economizer	10%	Reduce / reset dP setpoint	8%	Add / optimize SAT reset	5%			Reduce / reset DSP setpoint	6%
Reduce coil leakage			Other	8%	Reduce / reset DSP setpoint	6%	Add VFD to fan	4%				
Reduce / reset DSP setpoint			Add VFD to fan	5%			Reduce / reset DSP setpoint	3%				
Add / optimize optimum start/stop												
Add / optimize CWST reset												
Top Measures Subtotal		72%		59%		69%		68%		72%		77%
Key Measures as % of Total Savings		**63%**						**72%**				**71%**
Measures Required To Achieve at least 66% of Total Savings	Add small A/C unit	9%										
Revised: Key Measures as % of Total Savings		**72%**										

Table 8. Key Measure Mix Comparison by Climate Zone

Key Measures	2B (n=3)		3B (n=68)		3C (n=28)		4C (n=6)		5A (n=8)		5B (n=5)	
	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings	Prevalent Measures	Savings
Revise control sequence	Add / optimize CWST reset	31%	Optimize airside economizer	19%	Reduce equipment runtime	26%	Other	53%	Revise control sequence	20%	Revise control sequence	26%
Reduce equipment runtime	Add VFD to pump	24%	Reduce equipment runtime	18%	Add / optimize SAT reset	22%	Revise control sequence	19%	Adjust OA min flow setpoint	16%	Add / optimize SAT reset	23%
Optimize airside economizer	Optimize airside economizer	16%	Add / optimize SAT reset	7%	Reduce / reset DSP setpoint	9%			Reduce equipment runtime	16%	Reduce equipment runtime	18%
Add / optimize SAT reset			Add VFD to pump	7%	Add VFD to pump	7%			Reduce / reset dP setpoint	12%		
Add VFD to pump			Revise control sequence	5%	Add VFD to chiller	5%			Optimize airside economizer	10%		
Reduce coil leakage			Reduce coil leakage	5%	Optimize airside economizer	4%						
Reduce / reset DSP setpoint			Add / optimize optimum start/stop	4%								
Add / optimize optimum start/stop			Add VFD to fan	4%								
Add / optimize CWST reset			Add / optimize boiler lockout	3%								
			Reduce / reset DSP setpoint	3%								
Top Measures Subtotal (75% of Total Savings)		71%		44%		57%		72%		51%		66%
Key Measures as % of Total Savings		**71%**		**67%**								
Measures Required To Achieve at least 66% of Total Savings												
Revised: Key Measures as % of Total Savings												

Comparison of the Key Measure Mix to the Top Savings Measures

The preceding analysis focused on the top measures that contribute to total potential energy savings, taking into account both individual measure savings and the frequency of measure implementation. However, uncommon top saving measures are still applicable in some EBCx projects and could result in significant savings. The savings for each measure type was normalized by square foot and the top eight measures contributing 75% of the savings are shown in Figure 9. Comparing the key measure mix to the top individual savings measures reveals that no measures are on both lists (Table 9). This means that the top individual savings measures are uncommon and not widely applicable.

In addition to the key measure mix, an operational tune-up approach could seek to expand its scope and savings opportunities by investigating additional measures, where they are found to be applicable. However, these additional, targeted measures should be prioritized such that the investigation can optimize the balance between investigation costs and energy savings opportunities per program goals. In our analysis, the eight additional measure types listed in Figure 9 appear to have significant potential.

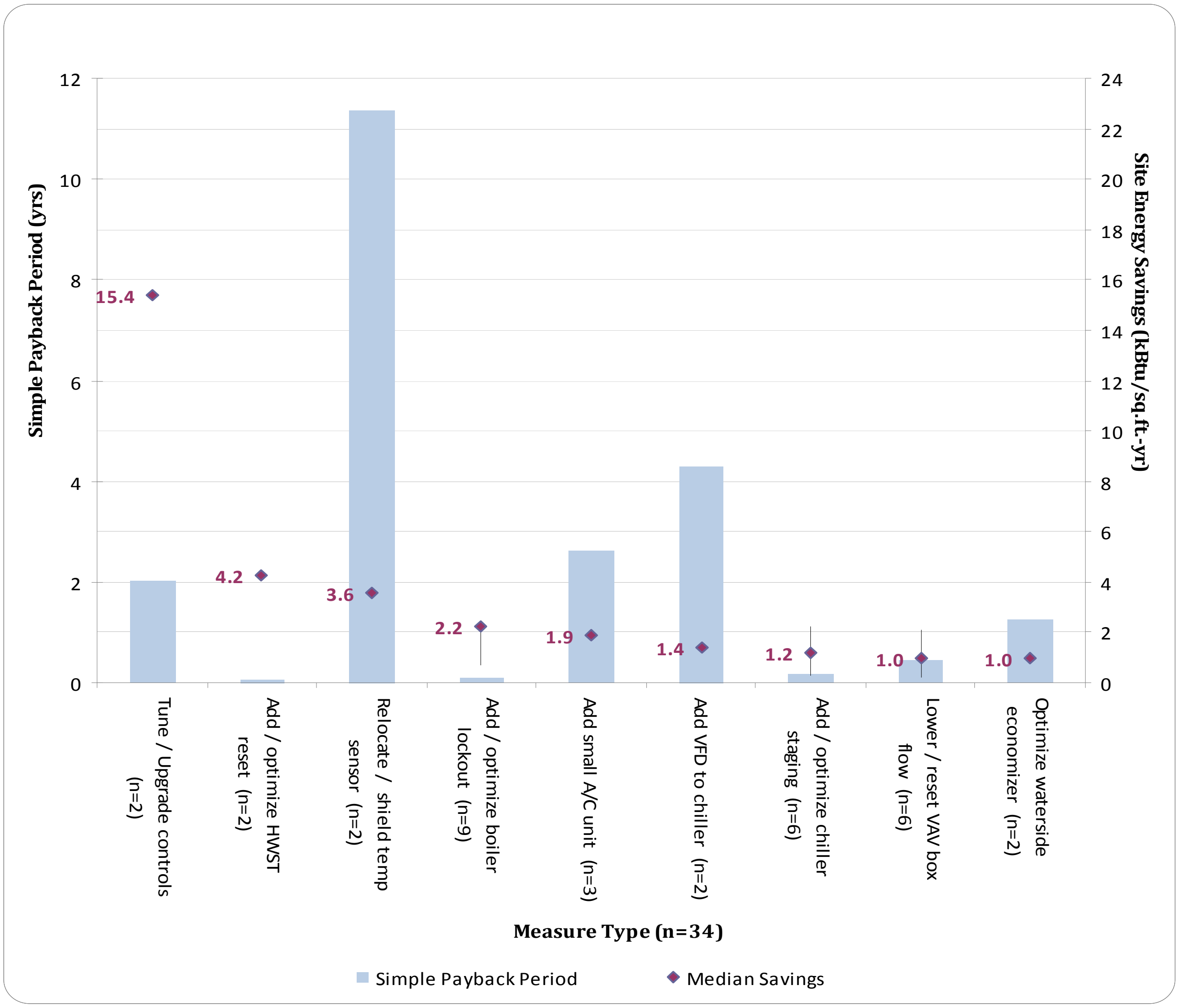


Figure 9. Site Energy Savings and Simple Payback Period by Measure Type – Measures with the Highest Individual Savings*

*(*Includes all building sizes and ages located in ASHRAE climate zones 2B, 3B, 3C, 4A, 4C, 5A and 5B)*

Table 9. Comparison of the key measure mix to the measures with the highest savings per square foot.

Key Measure Mix	Top Individual Savings Measures
Revise control sequence	Tune / Upgrade Controls
Reduce equipment runtime	Add / Optimize HWST reset
Optimize airside economizer	Relocate / shield temp sensor
Add / optimize SAT reset	Add /optimize boiler lockout
Add VFD to pump	Add small A/C unit
Reduce coil leakage	Add VFD to chiller
Reduce / reset DSP setpoint	Add / optimize chiller staging
Add / optimize optimum start/stop	Lower / reset VAV box flow
Add / optimize CWST reset	Optimize waterside economizer

Potential for an Operational Tune-Up Approach

From the preceding analysis it is concluded that there is potential for utilities and program implementers to use the "key measure mix" / "top individual savings measure" approach in the design of a streamlined EBCx program. Customized use of this approach as a component of a well-designed program could have the potential to address the majority of the savings opportunities while reducing investigation costs, streamlining projects, and helping to ensure more consistent building investigations across programs. This operational tune-up approach would base the majority of its investigation time and costs on a pre-defined set of high priority measures.

The analysis in this report suggests two sets of measures appear to be significant both in terms of frequency of occurrence and energy savings impact, across the programs investigated. Program designers considering adopting a "key measure mix" / "top individual savings measure" approach should consider these lists along with their specific market characteristics and program parameters to develop a customized list for use in their program. It should be recognized that a tune-up approach would not likely be as successful in overall system integration as EBCx, since the tune-up approach inherently does not look at the whole building as an integrated system.

3.0 CONCLUSIONS

The data collected in this research expands the industry knowledge by:

- Providing a cost benefit analysis of individual EBCx measures
- Investigating EBCx projects' and measures' cost effectiveness by four building attributes (type, size, age, climate zone)
- Investigating the most frequently implemented measures
- Identifying a key measure mix that could be leveraged and customized in an operational tune-up program design

This research found that the implementation phase of EBCx is cost effective on a project level. Project cost effectiveness was not impacted by building type, building size, building age, or building location (climate zone). Based on this limited data, it appears that it can be cost effective to implement commissioning measures smaller and older buildings.

Thirteen measures accounted for 75% of the total number of measures implemented, which points to the surprisingly consistent nature of findings in various building types, ages, and climate zones (Figure 7). One explanation for this consistency is that with constrained EBCx budgets, these measures are the easiest to identify and implement solutions. For example, zone level improvements were rarely implemented through the EBCx projects in this study, likely due to the relatively high level of effort and control system functionality that needs to be present to address what otherwise might be cost effective energy savings

It was also found that the majority (91%) of implemented measures were cost effective. While building attribute did not have an effect on cost effectiveness it did have an effect on the measure mix that achieves the majority of the potential savings in each category. However, a key measure mix that is applicable to all buildings was identified. Therefore, there exists a potential for an operational tune-up approach utilizing this key measure mix that could achieve the majority of the savings at reduced cost. Utilities seeking a more streamlined approach to EBCx might consider leveraging the key measure mix to guide to their customized building investigation processes.

However, such an approach would require careful considerations of the unique characteristics of the utility's customer base, program budgets, resources, goals, and objectives as well as the potential drawbacks of a limited-scope EBCx approach.

4.0 FUTURE RECOMMENDATIONS

Resulting from this analysis, PECI has several recommendations.

Expand the Data Set
First, we recommend this study be extended in order to fill the gaps in our dataset (below) to be conclusive in the cost effectiveness analysis for more building types, ages, and climate zones, when possible. We recognize EBCx programs may not exist for certain building types and climate zones, limiting the ability to collect data for those buildings and regions. In this case, we encourage EBCx of all building types across the country through pilot studies or programs

Table 10. Building Attribute Categories Requiring Additional Data Collection

Building Types	
Hospitals	Large Retail
Schools	Industrial
Universities	
Building Ages	
1920 – 1929	1960 – 1969
1930 – 1939	1970 – 1979
1940 – 1949	1990 – 1999
1950 – 1959	
ASHRAE Climate Zones	
1A	5A
2A	5B
2B	6A
3A	6B
4B	7A
4C	8

Research Building Equipment Age
Secondly, we recommend future studies more closely examine the correlation between building equipment age, controls, and measure cost effectiveness. Since the age of the equipment does not necessarily correlate with the age of the building, more research is needed into whether the age of building equipment influences the cost effectiveness of EBCx measures.

Research Implemented vs. Non-Implemented Measures
Secondly, PECI recommends a future study that compares data on implemented and non-implemented measures. This type of study would reveal key insights into what measures building owners and/or utilities chose and may identify reasoning behind those decisions. It would also conclusively determine if cost effectiveness is the most important factor in choosing measures, as this analysis implies.

Further Research EBCx in Smaller and Older Buildings

Thirdly, we recommend more closely examining the two EBCx myths: building age and small buildings. In particular, the correlation between building equipment age, which has a significant impact on commissioning applicability, and cost effectiveness should be investigated. Also, further study to gain a better understanding of the intricacies and opportunities of commissioning smaller buildings (smaller than 100,000 sq.ft) should be conducted.

5.0 APPENDIX

5.1. Definition and Description of Measure Types

Table 11. Measure Types used in this research

Measure Type #	Measure Type	Description
1	Reduce equipment runtime	Changing an equipment availability schedule to reduce its runtime relative to the building occupancy schedule (i.e., time-based reduction in availability time)
2	Add / adjust photocell / occ / daylight sensor	Installing or adjusting a photocell (exterior lighting daylight sensor), occupancy sensor and/or daylight sensor (interior lighting) to reduce lighting levels and runtime
3	Add / optimize boiler lockout	Add or optimize control of a heating water system to disable the boiler when the outside air dry-bulb temperature exceeds a specified temperature setpoint
4	Add / optimize chiller lockout	Add or optimize control of a chilled water system to enable the chiller when the outside air dry-bulb temperature exceeds a specified temperature setpoint
5	Add / optimize chiller staging	Add or optimize control of the chilled water system by modifying the chiller staging control (i.e., turning chillers on to meet the building cooling load while maintaining optimum part-load performance)
6	Add / optimize CHWST reset	Add or optimize control of the chilled water supply temperature based on either outside air temperature or cooling load.
7	Add / optimize CWST reset	Add or optimize control of the condenser water supply temperature based on either outside air wet-bulb temperature or chiller load
8	Add / optimize DCV	Add or optimize the minimum outdoor air method control in the AHUs to be based on the difference between outdoor air CO2 and return/space air CO2. This is called Demand Control Ventilation (DCV).
9	Add / optimize HWST reset	Add or optimize control of the heating water supply temperature based on either outside air temperature or heating load.
10	Add / optimize optimum start/stop	Add or optimize optimum start/stop controls of the AHUs to allow the supply fans and cooling and heating equipment to be enabled based on the minimum time needed to restore space temperatures to occupied setpoints.
11	Add / optimize SAT reset	Add or optimize control of the supply air temperature based on either outside air temperature or space loads.
12	Add / optimize zone setup / setback	Add or optimize controls of the zone VAV or other terminal units to provide better control of space temperatures or allow spaces temperatures to drift more during unoccupied hours. (e.g., convert pneumatic VAV controls to DDC, adjusting zonal setpoints to affect AHU fan performance, etc...)
13	Add small A/C unit	Add a small AC unit to a space that is assigned to a main AHU, but has a different space occupancy or conditioning requirement than the other spaces.
14	Add VFD to chiller	Add a variable frequency drive (VFD) to a chiller compressor.
15	Add VFD to fan	Add a variable frequency drive (VFD) to an AHU/RTU supply fan.
16	Add VFD to pump	Add a variable frequency drive (VFD) to a pump.
17	Adjust OA min flow setpoint	Adjust the minimum outdoor air ventilation rate setpoint to reduce heating and cooling loads.
18	Adjust room temp setpoint	Adjust the temperature setpoints in a room or thermal zone.
19	Adjust space static controls	Adjust the space static pressure setpoint to reduce fan energy consumption (not the same as reducing duct static pressure setpoint).
20	Increase deadband	Increase the space temperature deadband (range of temperature acceptable without cooling or heating conditioning) to reduce the heating and cooling loads
21	Lower / reset VAV box flow	Modify the air flow rates through a VAV terminal unit.

Measure Type #	Measure Type	Description
22	Optimize airside economizer	Repair/optimize the mixed air economizer control in an AHU (e.g., fix mixed air dampers, replace damper actuators, modify economizer control sequence, etc…)
23	Optimize waterside economizer	Repair/optimize the waterside economizer to allow process chilled water return to reject heat directly to the condenser water loop (saves energy by keeping the chiller disabled at lower outdoor air temperatures).
24	Other	Any measure not described by any of the other 36 measure types in this list.
25	Re-balance water loop	Having a contractor balance a water loop to ensure that water flow rates through the loop are to design specifications
26	Reduce / reset dP setpoint	Reduce/reset the differential pressure (dP) setpoint across a water loop pump to reduce the load on the pump
27	Reduce / reset DSP setpoint	Reduce/reset the duct static pressure setpoint to reduce the load on the supply fan motor
28	Reduce coil leakage	Make repairs to a leaking coil
29	Reduce equipment / actuator cycling	Make repairs to equipment/actuator controls to reduce cycling (turning on and off).
30	Reduce light levels	Reduce the lighting levels in overlit spaces
31	Reduce lighting schedule	Reduce the lighting runtimes
32	Relocate / shield temp sensor	
33	Relocate photocell / occ / daylight sensor	
34	Replace / repair / calibrate sensor	
35	Restore VFD to 'auto'	Restore automatic control of a VFD
36	Revise control sequence	Modify or change an AHU control sequence to better suit the current facility requirements
37	Trim pump impeller	
38	Add / replace / repair damper, linkage and/or actuators	
39	Add / optimize boiler staging	Add or optimize control of the heating or hot water system by modifying the chiller staging control (i.e., turning boilers on to meet the building heating load while maintaining optimum part-load performance)
40	Add / optimize cooling tower staging	Add or optimize control of the condenser water system by modifying the cooling tower staging control (i.e., turning cooling tower fans on to meet the building heating load while maintaining optimum part-load performance)
41	Repair / replace pump motor	
42	Repair / replace fan motor	
43	Tune / Upgrade controls	General building-wide controls tune-ups, modifications or upgrades (i.e., AHUs, Chillers, Boilers, pumps and/or VAV boxes are all included in the same measure).
44	Lighting retrofit / redesign	Lighting fixtures are being replaced with more efficient fixtures (If the measure recommends changing the lighting schedule also, then this is most likely a product of replacing the existing fixtures).

Table 12. Definition and Description of the 'Other' Category

Measure Type	# of Measures Implemented	Cumulative Site ΔE (kBtu/yr)
Other	14	2,327,250
Repair Chilled Water Valves on Three AHUs	1	159,344
Insulate return air duct in the Lower House.	1	100,756
Implement the filter replacement program for ACS /RS units based on actual pressure drop across the filter rack to avoid fan energy loss to overcome additional filter resistance	1	137,313
Eliminate the opening from outside to suction plenum of return fans # 4-6 at the 35th floor to prevent infiltration of higher enthalpy outside air to return air.	1	83,034
Insulate painted windows at the Upper House on 35th and 36th floors.	1	240,812
Remove orifice plate from abandoned condenser flow meter located between basket strainer and Trane chiller (CH-3)	1	139,486
Repair/correct the controls for the five unit heaters that are operating 24/7 (used as freeze protection in air handling unit mixed air section) so that the unit heater turns on only to meet the mixed air setpoint in the unoccupied mode.	1	33,107
Correct Hybrid Heating Function	1	254,688
Leaks in compressed air system	1	290,135
Open TDVs on HWS and CHWS	1	34,970
Four space unit heaters run if < 90 degrees inside	1	0
Control Calibration, non-Lighting	22	13,586,580
Implementation, Other	10	2,656,038

5.2. Electric and Natural Gas Savings by Measure Type

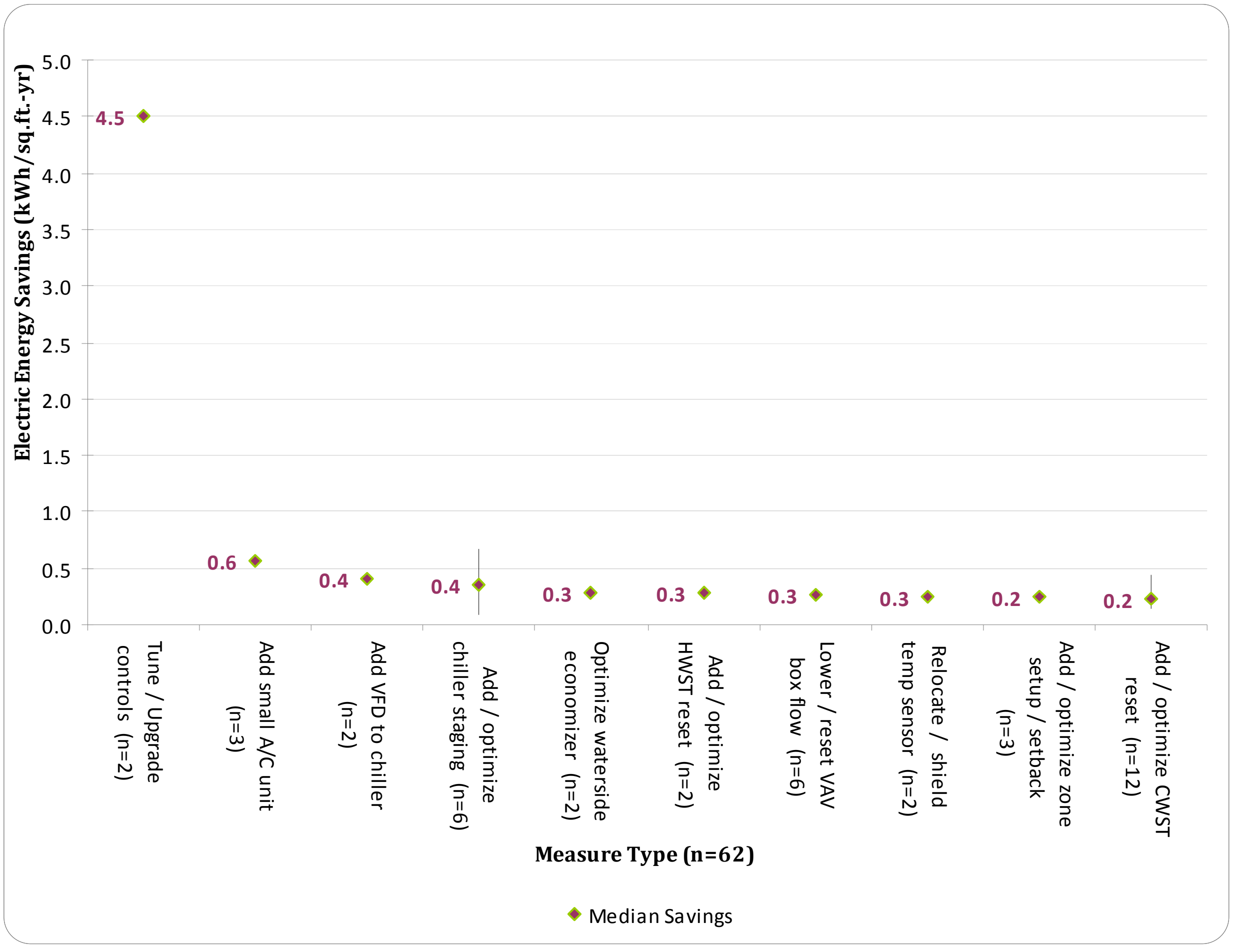


Figure 10. Electric Energy Savings by Measure Type – Measures with the Highest Individual Savings

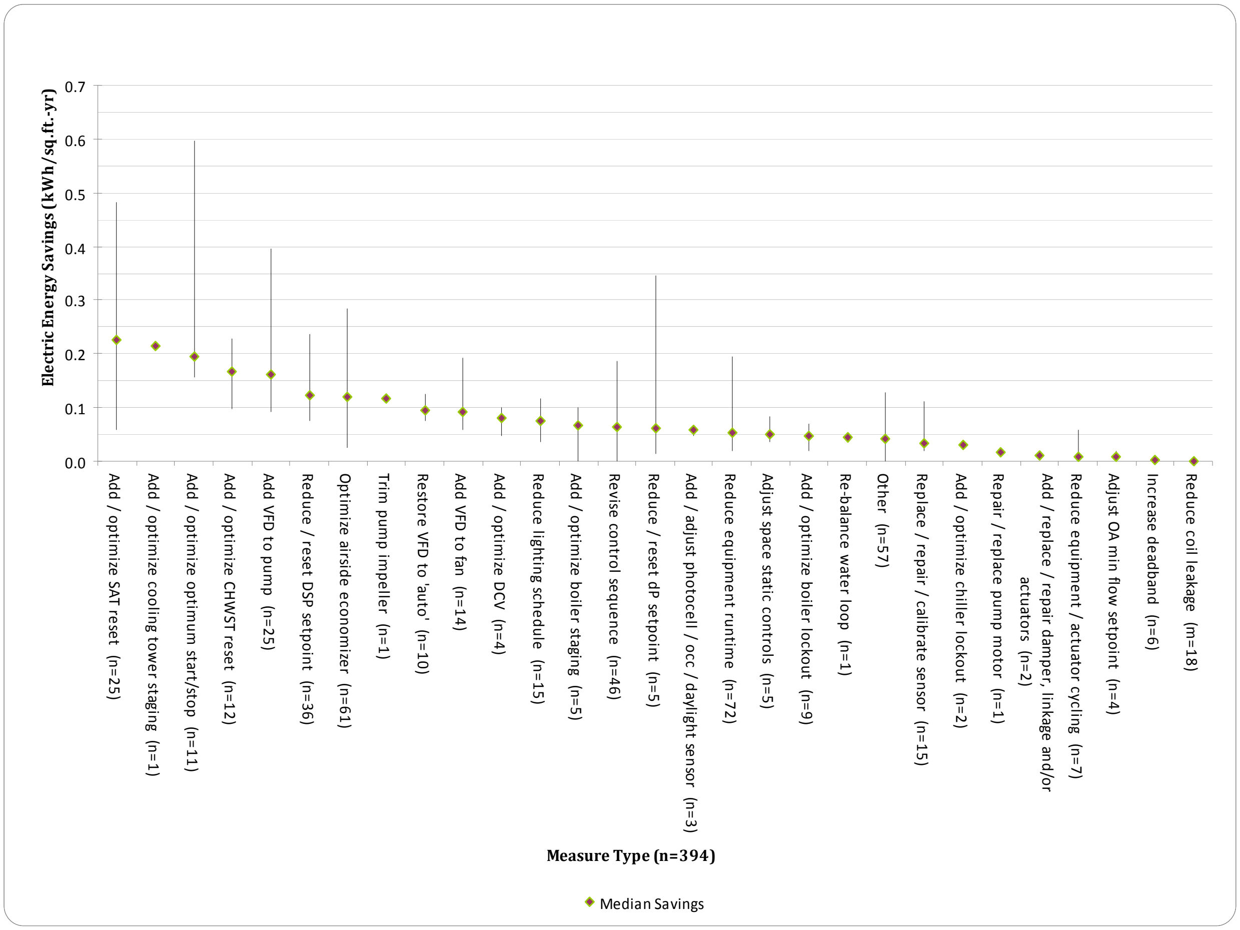


Figure 11. Electric Energy Savings by Measure Type

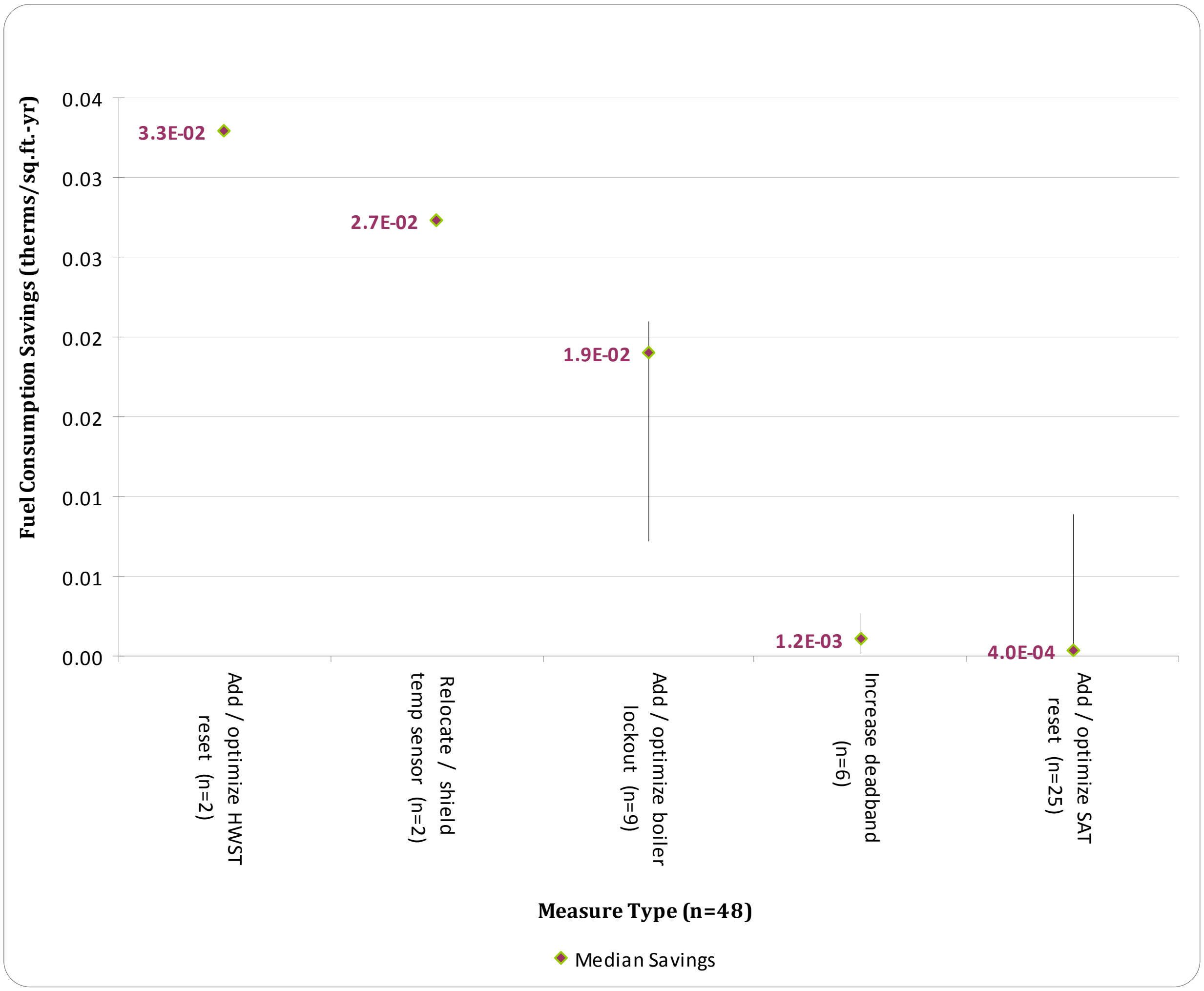
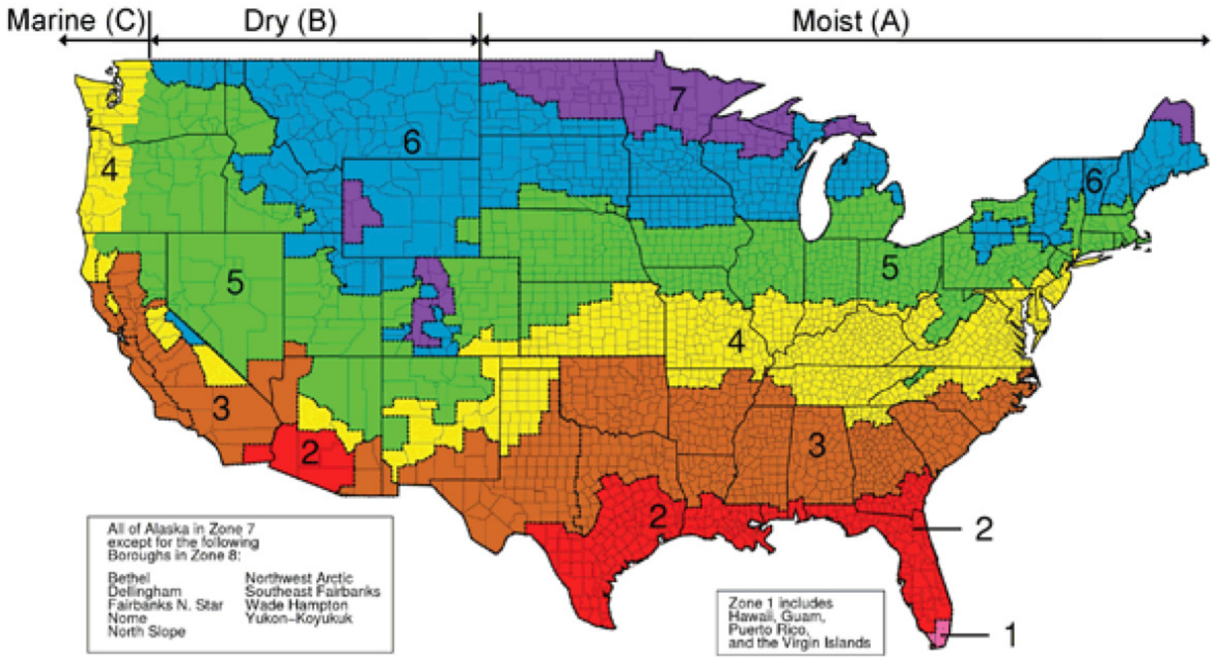


Figure 12. Natural Gas Consumption Savings by Measure Type – Measures with the Highest Individual Savings

5.3. ASHRAE Climate Zones

ASHRAE Climate Zones Map[14]



N.B. PECI received data for climate zones 2B, 3B, 3C, 4C, 5A, and 5B.

[14] *Energy Standard for Buildings Except Low-Rise Residential Buildings.* ANSI/ASHRAE/IESNA Standard 90.1-2007. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2007. Print.

5.4. Measure Level Dataset

Median Site Energy Savings (kBtu.sq.yr.) and Frequency per Measure Type and Building Attribute

	Building Type										Building Size							
	Large Office		Hotel Motel		Miscellaneous		Hospital		Large Retail		0 to 200,000 sq.ft.		200,000 to 350,000 sq.ft.		350,000 to 550,000 sq.ft.		Greater than 550,000 sq.ft.	
Measure Type	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency
Add / adjust photocell / occ / daylight sensor	0.23	2							0.13	1							0.20	3
Add / optimize boiler lockout	2.22	9									2.24	4	2.38	3	0.72	1	1.47	1
Add / optimize boiler staging							0.23	1					0.38	2			0.23	1
Add / optimize chiller lockout	0.21	1													0.21	1		
Add / optimize chiller staging	5.45	2	1.23	1							8.27	1	1.93	2			1.17	1
Add / optimize CHWST reset	0.60	7	0.57	5							1.24	2	1.13	3	0.60	1	0.32	6
Add / optimize cooling tower staging	0.73	1													0.73	1		
Add / optimize CWST reset	0.70	9	0.91	3							1.36	3	0.91	3	0.61	4	0.78	2
Add / optimize DCV	0.27	4											0.38	1			0.22	3
Add / optimize HWST reset	7.03	1			1.47	1					7.03	1	1.47	1				
Add / optimize optimum start/stop	0.77	11									0.77	7	2.15	2	0.12	1	3.75	1
Add / optimize SAT reset	1.71	18	0.87	6							2.66	10	0.83	5	0.33	7	4.31	3
Add / optimize zone setup / setback	1.32	2									0.82	1					1.82	1
Add / replace / repair damper, linkage and/or actuators	0.08	1															0.08	1
Add small A/C unit	2.23	2	0.12	1									2.23	2			0.12	1
Add VFD to chiller	0.73	1	2.02	1									2.02	1			0.73	1
Add VFD to fan	0.31	8	0.87	5							0.23	1	0.68	5	0.42	5	0.04	2
Add VFD to pump	0.46	12	0.72	9			0.88	2	1.01	1	1.35	3	1.38	7	0.49	3	0.55	11
Adjust OA min flow setpoint	0.03	4									0.04	1			0.02	1	1.33	2
Adjust space static controls	0.15	4	0.29	1							0.50	2	0.04	1	0.21	2		

	Building Age												Climate Zone											
	< 1920		1960 to 1969		1970 to 1979		1980 to 1989		1990 to 1999		2000 to Present		2B		3B		3C		4C		5A		5B	
Measure Type	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency	Median	Frequency
Add / adjust photocell / occ / daylight sensor					0.13	1	0.20	1			0.26	1			0.13	1	0.23	2						
Add / optimize boiler lockout	0.48	2	2.38	1	2.96	1	2.42	2	2.22	1	1.47	2			2.24	8	1.47	1						
Add / optimize boiler staging	0.23	1																	0.17	4			0.23	1
Add / optimize chiller lockout	0.21	1													0.11	2								
Add / optimize chiller staging							2.62	1	1.23	1	8.27	1			2.62	3			0.00	3				
Add / optimize CHWST reset			1.13	1	0.78	2	0.46	6	1.29	1	0.31	2	0.43	2	0.98	5	0.34	5						
Add / optimize cooling tower staging							0.73	1													0.73	1		
Add / optimize CWST reset	2.64	1	1.62	2			0.54	7	0.53	1	0.92	1	1.46	1	0.70	7	0.53	3			2.55	1		
Add / optimize DCV			0.38	1			0.33	1	0.22	1	0.00	1			0.22	1	0.33	3						
Add / optimize HWST reset											4.25	2			7.03	1					1.47	1		
Add / optimize optimum start/stop	3.75	3	0.12	1	2.24	1	0.61	2	0.77	3	0.34	1			0.63	8							3.75	3
Add / optimize SAT reset	21.84	1	0.83	1	0.08	1	0.84	14	2.59	2	2.21	6			0.83	15	2.57	9					21.84	1
Add / optimize zone setup / setback	0.82	1					1.82	1							0.00	1							0.82	1
Add / replace / repair damper, linkage and/or actuators							0.08	1							0.00	1								
Add small A/C unit	2.23	2					0.12	1							1.91	3								
Add VFD to chiller							0.73	1	2.02	1							1.37	2						
Add VFD to fan			0.42	2	0.87	1	0.32	8			0.31	2	0.09	1	0.61	7	0.31	6						
Add VFD to pump			0.36	2	1.18	2	0.72	15	1.22	3	0.42	2	1.72	1	0.63	16	0.31	7			1.35	1		
Adjust OA min flow setpoint	0.04	1			0.40	1	0.02	1			0.01	1			0.02	1	0.01	1			0.19	1	0.04	1
Adjust space static controls	0.04	1	0.13	1			0.23	2			0.84	1			0.23	4	0.13	1						

Median Site Energy Savings (kBtu.sq.yr.) and Frequency per Measure Type and Building Attribute

Building Type

Measure Type	Large Office Median	Large Office Frequency	Hotel Motel Median	Hotel Motel Frequency	Miscellaneous Median	Miscellaneous Frequency	Hospital Median	Hospital Frequency	Large Retail Median	Large Retail Frequency
Increase deadband	0.12	6								
Lower / reset VAV box flow	2.26	3	0.22	2						
Optimize airside economizer	0.42	32	0.55	15	1.04	4	0.10	3	0.35	1
Optimize waterside economizer	0.96	2								
Other	0.31	20	0.40	2			0.02	3		
Re-balance water loop	0.15	1								
Reduce / reset dP setpoint	0.21	5								
Reduce / reset DSP setpoint	0.54	31	0.12	4	0.42	1				
Reduce coil leakage	0.37	2	0.05	1					1.14	1
Reduce equipment / actuator cycling	0.14	5	0.13	2						
Reduce equipment runtime	0.40	54	0.45	8	2.94	3	1.21	1	0.78	2
Reduce lighting schedule	0.22	11	0.30	3						
Relocate / shield temp sensor	3.59	2								
Repair / replace pump motor	0.05	1								
Replace / repair / calibrate sensor	0.56	7	0.12	7						
Restore VFD to 'auto'	0.32	7	0.25	3						
Revise control sequence	0.51	28	0.19	2	1.30	1			1.28	1
Trim pump impeller	0.40	1								
Tune / Upgrade controls	15.39	2								

Building Size

Measure Type	0 to 200,000 sq.ft. Median	0 to 200,000 sq.ft. Frequency	200,000 to 350,000 sq.ft. Median	200,000 to 350,000 sq.ft. Frequency	350,000 to 550,000 sq.ft. Median	350,000 to 550,000 sq.ft. Frequency	Greater than 550,000 sq.ft. Median	Greater than 550,000 sq.ft. Frequency
Increase deadband	0.49	1	0.02	5				
Lower / reset VAV box flow	2.53	2	0.91	2			0.28	1
Optimize airside economizer	0.91	19	0.94	14	0.55	9	0.24	15
Optimize waterside economizer			0.37	1	1.55	1		
Other	0.63	6	0.50	13	0.31	4	0.15	16
Re-balance water loop					0.15	1		
Reduce / reset dP setpoint	1.18	1	0.05	3			1.98	1
Reduce / reset DSP setpoint	0.83	13	0.54	9	0.39	6	0.12	8
Reduce coil leakage	0.74	1					0.05	3
Reduce equipment / actuator cycling	0.67	1	0.14	3			0.00	3
Reduce equipment runtime	1.47	18	0.48	20	0.29	26	0.62	6
Reduce lighting schedule	3.00	2	0.44	4	0.18	2	0.24	6
Relocate / shield temp sensor			7.17	1	0.01	1		
Repair / replace pump motor							0.05	1
Replace / repair / calibrate sensor	1.12	3	0.14	7	0.41	2	0.31	2
Restore VFD to 'auto'	0.32	3	0.32	5	0.36	2		
Revise control sequence	3.61	5	0.59	11	0.92	3	0.10	20
Trim pump impeller			0.40	1				
Tune / Upgrade controls	15.39	2						

Building Age

Measure Type	< 1920 Median	< 1920 Frequency	1960 to 1969 Median	1960 to 1969 Frequency	1970 to 1979 Median	1970 to 1979 Frequency	1980 to 1989 Median	1980 to 1989 Frequency	1990 to 1999 Median	1990 to 1999 Frequency	2000 to Present Median	2000 to Present Frequency
Increase deadband							0.12	6				
Lower / reset VAV box flow							1.65	1	2.26	3	0.28	1
Optimize airside economizer	0.37	6	1.10	2	0.33	2	0.41	27	0.99	6	0.89	12
Optimize waterside economizer							0.37	1			1.55	1
Other	0.20	5	0.65	2	0.16	3	0.29	11	0.09	3	0.69	1
Re-balance water loop							0.15	1				
Reduce / reset dP setpoint					2.28	1	0.12	2			0.61	2
Reduce / reset DSP setpoint	0.55	2	0.42	5	0.81	3	0.37	17			0.50	9
Reduce coil leakage					1.14	1	0.05	3				
Reduce equipment / actuator cycling							0.20	4			0.00	3
Reduce equipment runtime	2.95	2	0.08	5	1.19	9	0.34	19	0.15	21	0.32	14
Reduce lighting schedule			0.40	2	3.26	2	0.22	7			0.06	3
Relocate / shield temp sensor							7.17	1			0.01	1
Repair / replace pump motor							0.05	1				
Replace / repair / calibrate sensor	0.06	1	0.77	1	0.11	2	0.56	7	0.07	3		
Restore VFD to 'auto'			0.42	1	0.56	4	0.30	5				
Revise control sequence	1.52	4			0.33	8	0.28	17			1.08	3
Trim pump impeller							0.40	1				
Tune / Upgrade controls	15.39	2										

Climate Zone

Measure Type	2B Median	2B Frequency	3B Median	3B Frequency	3C Median	3C Frequency	4C Median	4C Frequency	5A Median	5A Frequency	5B Median	5B Frequency
Increase deadband					0.12	6						
Lower / reset VAV box flow			1.65	5	0.28	1						
Optimize airside economizer	0.40	2	0.55	29	0.22	10	0.00	6	0.97	7	0.10	5
Optimize waterside economizer			0.37	1	1.55	1						
Other			0.63	10	0.29	5	0.00	32	0.10	2	0.11	4
Re-balance water loop			0.15	1								
Reduce / reset dP setpoint			0.21	3	0.05	1			2.28	1		
Reduce / reset DSP setpoint			0.47	16	0.61	14			0.40	3	0.55	2
Reduce coil leakage			0.00	5	0.05	1	0.00	11	0.00	1		
Reduce equipment / actuator cycling	0.25	1	0.41	4	0.00	2						
Reduce equipment runtime			0.31	54	0.37	12			2.56	4	2.95	2
Reduce lighting schedule	0.18	1	0.42	7	0.23	6			0.32	1		
Relocate / shield temp sensor			7.17	1	0.01	1						
Repair / replace pump motor												
Replace / repair / calibrate sensor	0.06	1	0.19	12	0.00	1						
Restore VFD to 'auto'			0.32	9					0.22	1		
Revise control sequence	0.28	1	1.00	8	1.85	2	0.00	13	0.06	15	1.73	3
Trim pump impeller			0.40	1								
Tune / Upgrade controls									15.39	2		

If cell is blank no data was submitted for inclusion in this analysis.

5.5. Project Level Dataset

	Project-level Median Site Energy Savings (kBtu/sq.ft.yr.) and Frequency				
	Project Attribute	**Median Savings**	**Upper Quartile**	**Lower Quartile**	**Frequency**
Building Type	Large Office	3.02	7.19	1.08	86
	Hotel Motel	2.17	4.62	1.04	18
	Miscellaneous	5.60	5.60	5.60	3
	Hospital	3.54	3.54	3.54	2
	Large Retail	2.73	2.73	2.73	2
	K12 School	0.95	0.95	0.95	1
Building Size	0 to 200,000 sq.ft.	3.61	8.88	0.80	47
	200,000 to 350,000 sq.ft.	2.67	7.46	1.07	32
	350,000 to 550,000 sq.ft.	1.41	3.31	0.98	20
	Greater than 550,000 sq.ft.	2.47	4.00	0.87	20
Building Age	< 1920	6.37	2.54	9.46	16
	1960 to 1969	1.35	0.67	2.53	9
	1970 to 1979	3.24	1.23	3.98	11
	1980 to 1989	2.56	0.64	6.07	54
	1990 to 1999	2.01	0.52	3.47	11
	2000 to Present	3.01	0.83	4.02	18
Climate Zone	2B	2.32	2.32	2.32	3
	3B	2.89	5.59	1.13	68
	3C	2.03	4.15	0.62	28
	4C	5.74	5.74	5.74	6
	5A	7.61	9.14	4.33	8
	5B	22.74	24.52	7.47	5

5.6. Building System Analysis – Charts

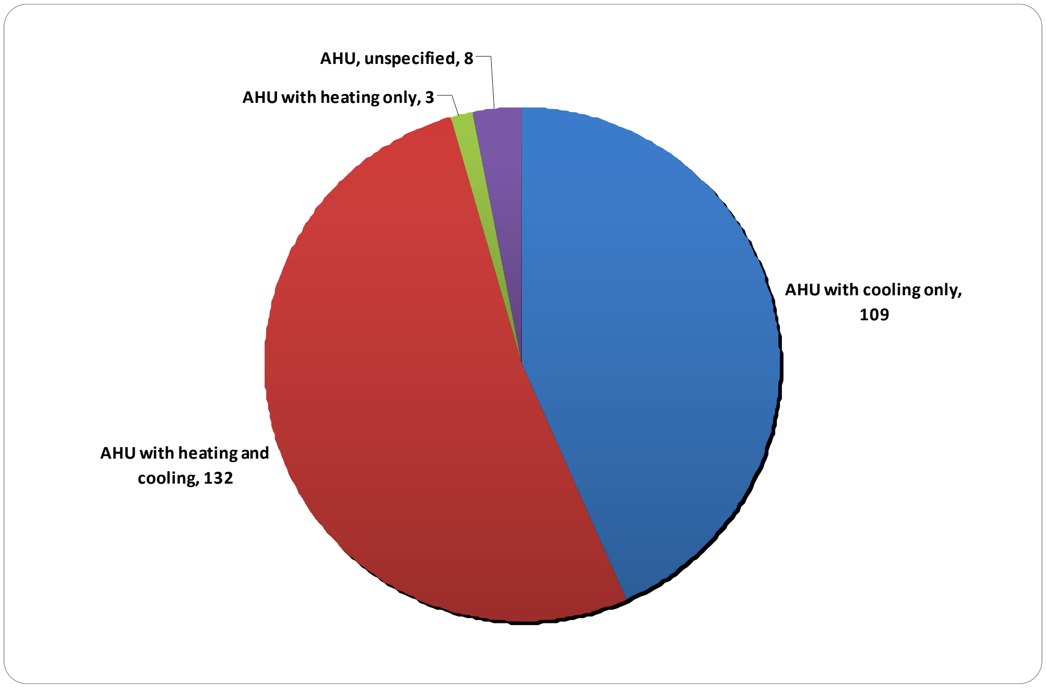


Figure 13. Types of Air Handling Units Affected by Implemented EBCx Measures

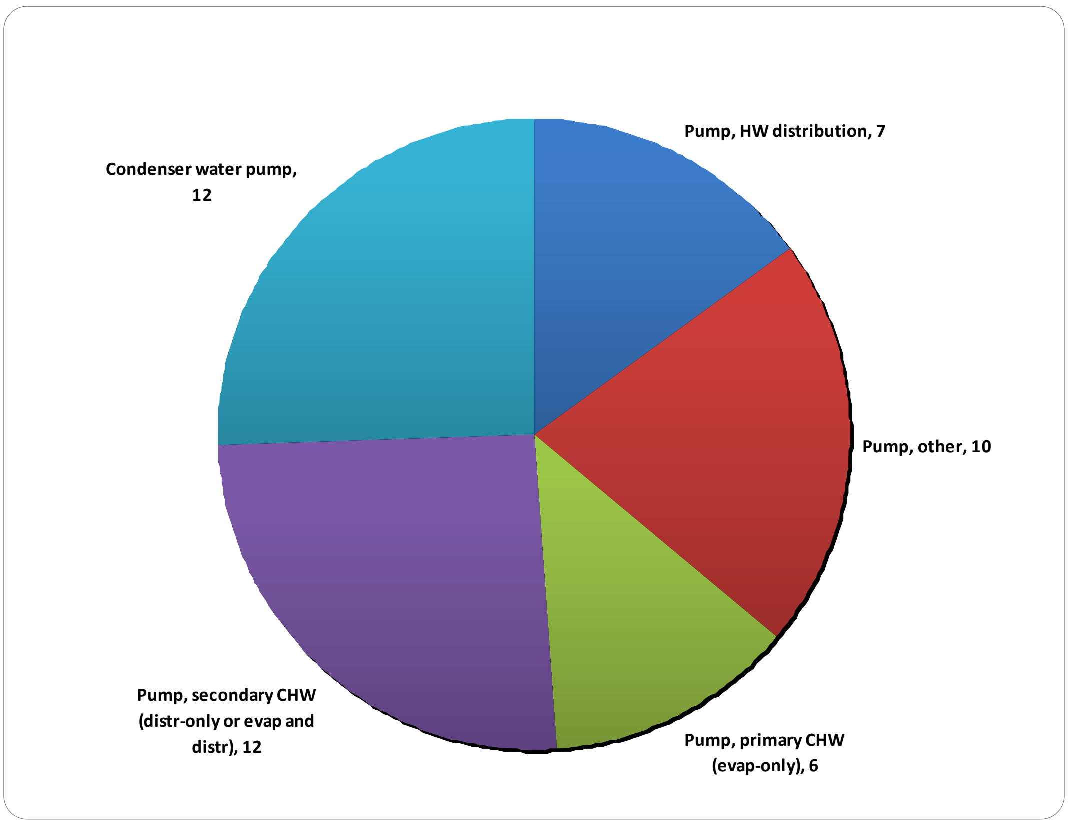


Figure 14. Types of Pumps Affected by Implemented EBCx Measures