The Cost-Effectiveness of Continuous Commissioning® Over the Past Ten Years

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ABSTRACT

Continuous Commissioning® data including savings, costs, and implemented measures from over 60 buildings and sites commissioned by staff from the Energy Systems Laboratory at Texas A&M University are presented. Measured annual whole building data is included and is used to calculate indicators describing energy savings, commissioning cost, and the relationship between the two. The measures are organized by component and type and analyzed for frequency of implementation. The average unit area savings for the data set is \$0.51/(ft^{2}a) (\$5.52/(m^{2}a)) with an average annual energy cost savings of 14%. The average cost of commissioning is \$0.43/(ft^{2}a) (\$4.60/(m^{2}a)) resulting in an average simple payback of 1.6 years. Just over half of the measures implemented are related to air handling and distribution and 13% of the total number of measures implemented are advanced resets of air side systems. Overall, the analysis reinforces previous studies demonstrating the effectiveness of Continuous Commissioning®.

INTRODUCTION

Continuous Commissioning®[1] (CC®) is an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities. The intent of CC is not to return the building to original design specifications but to meet the current needs of the facility by focusing on overall system control and operations (Liu et al. 2002). The CC process was developed at the Energy Systems Laboratory (ESL) and since 1993 has been implemented in over 300 buildings and central plants nationwide. Past reviews of this body of work have shown average energy cost reductions of 10-25% with simple paybacks typically less than two years (Wei et al. 2006). The following analysis of commissioning projects is intended to increase the certainty of statistics related to the cost effectiveness of building commissioning, specifically the CC process, by increasing the number of buildings analyzed.

Many previous analyses of the benefits of the CC process have been conducted utilizing a small number of buildings as case studies; however fewer have included a large number of buildings. One such large scale analysis focused on the results of implementing the CC process at the Texas A&M campus over a ten year period (Deng et al. 2006). Since 1996, the CC process has been systematically implemented on the Texas A&M University campus in College Station. During that ten year period, the campus building inventory grew by over 3 million ft^2 (278,710 m^2) but the Energy Use Index (EUI, MBtu/(ft^{2}a) or kWh/(m^{2}a)) decreased from 426 MBtu/(ft^{2}a) (1,344 kWh/(m^{2}a)) in 1996 to 276 MBtu/(ft^{2}a) (871 kWh/(m^{2}a)) in 2006. In terms of the investment made in the program, the campus wide effort saw a positive cash flow in less than two years.

The methodology utilized in this study was developed at Lawrence Berkeley National Laboratory (LBNL) and implemented in 2004 as part of a nationwide study encompassing projects from multiple commissioning providers across the nation (Mills et al. 2004). This particular study included 224 new and existing building commissioning projects from 21 states for a total of 30.4 million square feet of commissioned floor area (73% percent from existing buildings). Over 40 buildings commissioned by the ESL utilizing the CC process were included in the earlier study. This analysis does not include any of the ESL buildings from the original 2004 study but adds over 60 buildings to the previous work using the LBNL study's methodology. The Excel based database which includes space for general building information, project cost, reasons for commissioning, savings, and persistence of savings will be referred to as the CxMatrix.

[1] Continuous Commissioning and CC are registered trademarks of the Texas Engineering Experiment Station.

During the process of gathering the information that is relevant to the established methodology, three items were viewed as required information for inclusion in the database: the building area (ft^2), the CC project cost ($), and the savings resulting from the CC process. In the case of the building area and CC project cost, there is no additional level of detail and the information was either available or not. In the case of the CC savings, varying levels of detail were available from project to project meaning not all of the buildings in the database are included in the following savings analysis. The number of buildings the stated results pertain to is included in the following analysis. Since the results for all of the following analysis do not refer to the exact same group of buildings but the ones for which the relevant information is available, the results will not necessarily agree with each other at the overall level.

GENERAL DESCRIPTION OF DATA SET

The following data set includes information from 71 sites and 222 buildings for an average of 3.13 buildings per site. Site refers to a collection of buildings at a single location while building refers to an individual building. It is also important to note that for some of the sites with multiple buildings, the savings and cost were reported for the site as a whole and not for the individual buildings. The data set includes buildings from 14 states across the United States from the east coast to the west coast and from the Mexican border to the Great Lakes region. Over three quarters of the sites are in Texas (77.5%) with over 90% of the buildings at these sites. The data set also represents buildings of many ages; the oldest was built in 1910 while the newest was built in 2002. The average age is 33 years (built in 1975) and the median age is 29 years (built in 1979). The total commissioned building area for the entire data set is approximately 21.82 million ft^2 (2.03 million m^2).

To properly characterize the buildings by usage type, the U.S. Department of Energy's Commercial Buildings Energy Consumption Survey (EIA 2001) definitions are used in the LBNL methodology as well as in this analysis. Since the majority of the buildings in the data set do not fall completely under one single category, the approximate area associated with each function has been entered separately. The approximate nature of the area breakdowns must be considered when looking at the composition of the entire data set based on building area. Three space types make up over 79% of the total commissioned building area: health care including both inpatient and outpatient (30.8%), education including both K-12 and higher education (27.9%), and office space (20.9%). The full area breakdown by space type may be found in Figure 1 below.

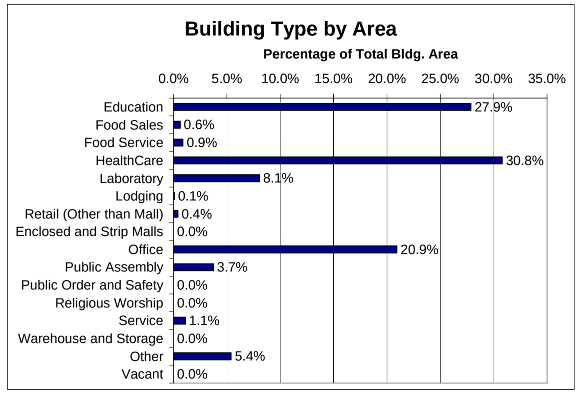

Figure 1. Building type by area

For purposes of the following analysis, the buildings are categorized based on their primary function, which is the function comprising the largest portion of the total building or site area. When the data set is organized in this manner, four types comprise 88% of the total number of sites: education (28.4%), office (28.4%), health care (16.4%), and laboratory (15.0%). The reason for the large difference between the breakdown when given by area or by site is simply the difference in the average area per site. For example, the health care sites have an average area of 539,285 ft^2 (50,101 m^2) per site while the education sites have an average area of 282,550 ft^2 (26,250 m^2).

No analysis of the buildings in this set is undertaken in regards to the savings potential of buildings built to different technical standards such as naturally ventilated versus fully air-conditioned. This is not done first because the technical details such as system type, design standard, etc. of the buildings was not part of the data gathering form this study is based upon. Further, detailed system information was simply not provided in the available sources for many of the buildings. Second, in terms of natural ventilation versus fully air-conditioned buildings, the buildings in the study are typical of most commercial buildings in the United States where most buildings are fully air-conditioned and natural ventilation is not common for a number of reasons. Given that 77% of the sites and 90% of the buildings in the study are located in Texas where the ambient temperature is continuously above 75°F (24°C) for about four months of the year, natural ventilation would not be feasible for the majority of the sites. Furthermore, many of the Texas sites are located in a hot and humid zone where moisture control also prohibits the use of natural ventilation.

SAVINGS

CC savings were recorded in the CxMatrix as given in the reports along with the year(s) the savings were measured. The savings were then adjusted to current year dollars using the EIA implicit price deflator as given in Appendix D of the EIA's 2006 Annual Energy Review (AER) (EIA 2007). For a number of projects, the CC savings was incurred in 2007. Since the 2006 AER does not include an implicit price deflator for 2007, a 2.5% change from 2006 to 2007 was assumed based on the average percent change of the previous 5 years. For many of the sites the given savings were calculated using data from more than one year. For purposes of applying the deflator, the year at the end of the period analyzed is used as the year the savings were obtained. All savings presented below are given in 2006 dollars ($2006). Savings are not analyzed based on the actual energy savings (kWh, MMBtu, etc.) due to the limited amount of the required information available.

Savings per Unit Area

A simple way to compare savings across many buildings of various sizes and types is to look at the CC savings on a unit area basis. Overall, the average savings per unit area is $0.5132/($ft^2$a) ($5.52/(m^2a)) and the median is $0.3605/($ft^2$a) ($3.88/(m^2a)). The maximum savings is $1.7620/($ft^2$a) ($18.97/(m^2a)) and the minimum is $0.0202/($ft^2$a) ($0.22/(m^2a)). Approximately 80% of the sites have savings greater than $0.1/$ft^2$ ($1.08/$m^2$) and 10% have savings greater than $1.5/$ft^2$ ($16.15/$m^2$). The savings per unit area distribution is presented in Figure 2 below.

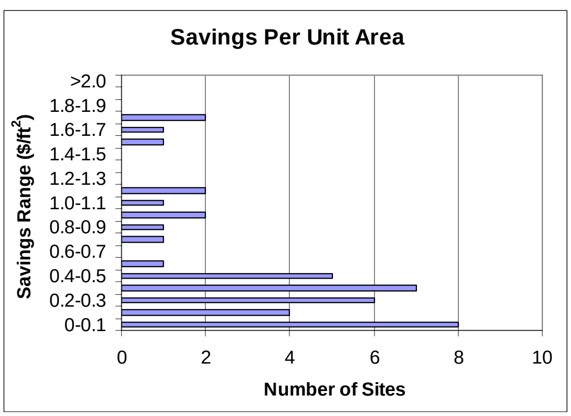

Figure 2: Savings per unit area distribution

To put these savings in perspective, the average annual energy use on a unit area basis before CC was completed for sites with the required data (12 sites) is 451 kBTU/(ft^2a) (1,422 kWh/(m^2a)). The average annual energy use on a unit area basis after CC was completed (14 sites) is 292 kBTU/(ft^2a) (921 kWh/(m^2a)). These average values may seem misleading at the overall level when compared to the average % savings because the group of sites used to calculate each of these averages is different.

Savings by Building Type

The average savings for buildings of a specific type may be useful for quickly estimating the CC potential of a site, if based on a large enough sample of buildings. The average annual savings per unit area and the number of buildings in each category are presented in Table 1 below. Clearly the building type with the greatest measured savings is the public assembly type which has an average saving per unit area that is 181% greater than the overall average. It must be noted however, that this value is based on only two sites. The next best performers are the laboratory buildings with an average savings that is 97% greater than the overall average. On the other end of the spectrum, the education and health care average savings are 41% and 26% less than the overall average, respectively.

Table 1. Savings per unit area for each building type

Building Type	**Number of Type**	**$2006/sq.ft. (Avg)**	**$2006.sq.m. (Avg)**
Education	11	$0.3023	$3.2534
Health Care	9	$0.3806	$4.0969
Laboratory	5	$1.0133	$10.9074
Office	12	$0.5112	$5.5029
Public Assembly	2	$1.4431	$15.5329
Other	2	$0.1663	$1.7903

Savings as Percent of Annual Energy Cost

Although the number of buildings or sites with detailed savings data is not large, it is still useful to analyze the percent annual energy cost savings of the relevant buildings since this metric is one that is often quoted. The average overall savings for the 26 sites with detailed savings data is 14.27% and the median is 12.75% savings. The minimum savings is 2.5% and the maximum is 39.8%. The distribution of the percent annual energy cost savings is shown in Figure 3 below. Approximately two thirds of the buildings have savings greater than 10% and 92% of the sites have savings greater than 5%.

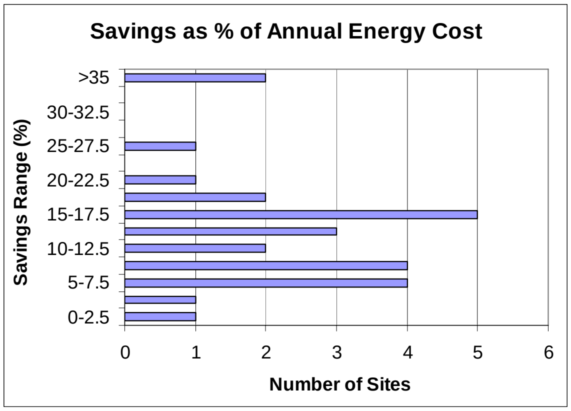

Figure 3: Annual % cost savings distribution

Also useful is the typical percent savings for different types of buildings. The average percent savings for each building type is presented below in Table 2. Clearly, laboratory facilities have the largest percent savings which is 112% greater than the overall average. Office buildings are also good performers with savings that are 31% greater than the overall average. On the other hand, education facilities are the poorest performers of all with savings 39% less than the overall average. Health care facilities savings are approximately equal to the average (4% greater).

Table 2. Annual % cost savings by building type

Building Type	Number of Type	% Savings (Avg)
Education	10	8.71%
Health Care	8	14.87%
Laboratory	3	30.38%
Office	3	18.66%
Other	2	8.86%

Savings by Location

As previously stated, the majority of the sites in this study are located in Texas. In terms of the sites with savings data available, 74% of them are located in Texas with no more than 3 buildings in any other single state. Given this geographic distribution, it is not feasible to draw substantive conclusions based on geography other than by comparing the buildings in Texas to the buildings outside of Texas. The average savings per unit area for sites in Texas (31 sites) is $0.5526/($ft^2$a) ($5.63/(m^2a)) while the average for sites outside of Texas (11 sites) is $0.4867/($ft^2$a) ($5.24/(m^2a)). The percent difference between the average savings for sites in and outside of Texas is only 7% which does not suggest any significant difference between the savings potential from implementing the CC process in or outside of Texas.

COSTS

CC costs were recorded in the CxMatrix as stated in the reports along with the year the costs were incurred. The stated costs generally include consulting costs and implementation costs. The costs were adjusted to current dollars using the same methodology as that used for the savings data. All costs presented below are given in 2006 dollars ($2006).

Cost per Unit Area

Just as it is useful to analyze CC savings on a unit area basis, it is also useful to do the same with the CC costs. Across the entire data set, the cost per unit area has an average value of $0.4271/$ft^2$ ($4.57/$m^2$) and a median value of $0.4242/$ft^2$ ($4.57/$m^2$). The CC cost for the majority (94%) of the sites was less then $0.80/$ft^2$ ($8.61 m^2) with 3 sites having higher costs. The cost per unit area distribution is presented in Figure 4 below.

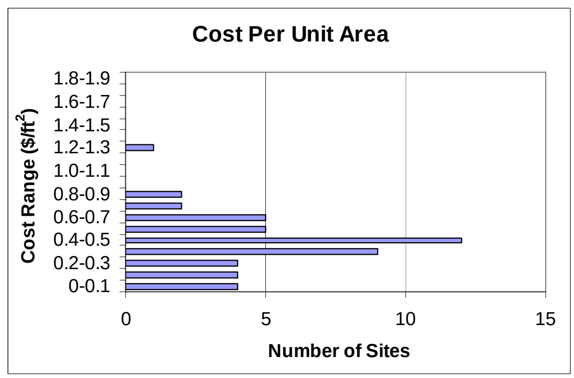

Figure 4. Cost per unit area distribution.

Cost by Building Type

In determining the projected CC cost for a project, knowing typical project costs for similar buildings can be very useful. The average cost per unit area and the number of buildings in each category are presented in Table 3 below.

Table 3. Cost per unit area for each building type

Building Type	Number of Type	$2006/sq.ft. (Avg)	$2006.sq.m. (Avg)
Education	14	$0.3339	$3.5939
Health Care	4	$0.4226	$4.5488
Laboratory	10	$0.6002	$6.4603
Lodging	1	$0.3712	$3.9951
Office	14	$0.4843	$5.2128
Public Assembly	4	$0.3300	$3.5521
Other	3	$0.1999	$2.1518

As shown in the table, analyzing the costs for each different type of building shows some clear differences between the various building types. The highest average cost is that of the laboratory type buildings. This average cost for laboratory facilities is 41% greater than that of the average site for the data set while the average cost for the health care facilities is approximately equal (1% less) to the overall average. Also worth noting are the CC costs for the two most common facility types by number of sites; office facilities are 6.7% greater than the average while education facilities are 29% less. Given the prevalence of these two facility sites in the U.S. building stock as a whole, education facilities seem to offer a large relatively lower cost opportunity for CC.

Simple Payback

Typical cost is only one half of the equation in determining if a building is a good candidate for CC; the other major component is savings potential. Numerous metrics exist for evaluating the relative effects of cost and savings on the economic feasibility of a project, (net present value, internal rate of return, and simple payback to name a few). Due to its intuitive nature and prevalence in the marketplace, the simple payback was chosen as the metric for this methodology. The savings utilized were typically measured for at least one year following the implementation of CC measures. The first year of savings and the stated cost are used to calculate the payback times discussed below. The overall average simple payback is 1.58 years (~19 months) and the median is 1.26 years. The maximum payback in the data set was 5 years and the minimum payback was just under 2 months. The distribution of payback times is shown in Figure 5. More than two thirds (71%) of the sites had payback times less than 2 years and 84% of the sites had payback times of less than 3 years.

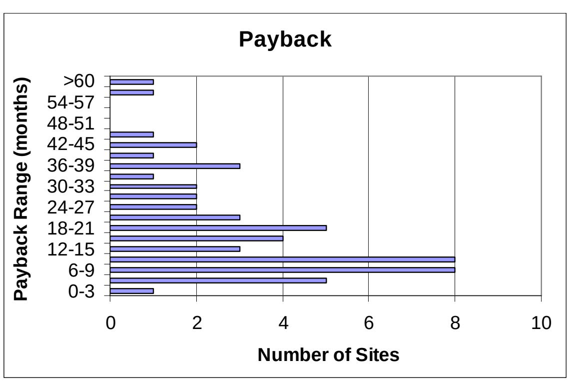

Figure 5. Payback time distribution

Also useful is the typical payback time for different types of buildings. The average payback time for each building type is presented below in Table 4.

Table 4. Payback for each building type

Building Type	Number of Type	Avg. Payback (years)
Education	17	2.39
Health Care	11	1.45
Laboratory	5	0.77
Lodging	1	0.26
Office	14	1.64
Public Assembly	3	0.51
Other	3	0.56

The shortest payback is for lodging facilities (~3 months) while the longest is for education facilities (~29 months). As previously mentioned, education facilities are on average among the lowest cost projects; however, they have the longest payback. This is most likely due to the fact that many education buildings have implemented some of the most basic cost effective CC measures including the classical most intuitive type measures such as the “shut it off if it isn’t needed” and “slow it down if you can” measures prior to the beginning of the CC process. For example, K-12 schools often have previously implemented basic shutdown schedules since they are not occupied for long periods of time in the summer and in the evenings during the school year. Further, in comparison to other building types, K-12 schools typically have a lower EUI to begin with (EIA 2003).

MEASURES

As part of the LBNL methodology, a measures matrix was created to categorize the many different measures that can be implemented during commissioning for the purposes of analysis. One modification to the original matrix was made to accommodate a number of sites in this data set which consist of many buildings. The purpose of the alteration was to allow for the counting of a type of measure once for each building without expanding the matrix to an unreasonably large size. This addition is denoted by the blue column near the center of the example matrix shown in Figure 6.

The matrix organizes interventions, or measures taken to remedy building performance deficiencies, based on the component affected and the action recommended. The component affected categories are intended to envelop all of the major components of a typical commercial building’s HVAC system. The recommended actions are first organized based on the general type of action and then by the specific action recommended. A unique code is then associated for each combination of component affected and intervention recommended. For a more detailed description of the matrix, please refer to the previous study conducted by Mills et al. (2004).

Frequency of Intervention Implementation

Intervention matrices are completed for a total of 53 sites. As previously mentioned, sites with multiple buildings have been condensed into a single matrix for ease of analysis. The overall total number of interventions implemented is 713. This total can be somewhat misleading due to the fact that interventions such as those pertaining to terminal units are simply counted as a single intervention even though they may apply to many terminal units. Similarly, interventions which apply to multiple air-handling-units are counted as a single intervention.

Approximately 68% of the interventions recommended deal with Operations & Controls items. Design, Installation, Retrofit, Replacement items and Maintenance items comprise 13% and 18% of the interventions, respectively.

Table 5: Interventions by component

Components	% of Total
HVAC (combined heating and cooling)	6.3%
Cooling plant	15.8%
Heating plant	12.9%
Air handling & distribution	55.5%
Terminal units	8.0%
Lighting	0.7%
Envelope	0.0%
Plug loads	0.0%
Facility-wide (e.g. EMCS or utility related)	0.7%
Other	0.0%

The detailed break down of interventions by recommended action is shown below in Table 6. As mentioned previously, over two thirds of the interventions are operations and controls items. Of these interventions more than half are advanced resets and modifications of the sequence of operations which make up 22% and 15% of the overall number of interventions, respectively. Of the design, installation, retrofit, and replacement interventions, only retrofit/equipment replacement tops 5% of the overall total. The low number of interventions of this type is partially due to the focus of CC. Since identifying retrofits is more of a side product of the CC process, not many of these actions are commonly recommended and implemented. One

Project ID Number: C35 TAMU - Harrington Tower Bldg #

	Components (locus of fault)										Interventions																		# of times intervention present	Interventions Code	Implemented [Y; Unknown]	Detail problems and remediation measures
											Design,				Operations & Control									Maintenance								
	HVAC (combined heating and cooling)	Cooling plant	Heating plant	Air handling & distribution	Terminal units	Lighting	Envelope	Plug loads	Facility-wide (e.g. EMCS or utility related)	Other	Design change	Installation modifications	Retrofit/equipment replacement	Other	Implement advanced reset	Start/Stop (environmentally determined)	Scheduling (occupancy determined)	Modify setpoint	Equipment staging	Modify sequence of operations	Loop tuning	Behavior modification/manual changes to operations	Other	Calibration	Mechanical fix	Heat transfer maintenance	Filtration maintenance	Other				
	V	C	H	A	T	L	E	P	F	O	D1	D2	D3	D4	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8	OC9	M1	M2	M3	M4	M5				
		x																					x						1	C-OC9	Y	turn on inline CHW pump serving computer server room
					x																			x					1	T-M1	Y	recalibrate VAV boxes
					x												x												1	T-OC3	Y	corrected day/night mode swith for VAV boxes
				x																					x				1	A-M2	Y	repaired all OA and RA dampers
		x																x											0	C-OC4	N	modify CHW DP pump setpoint
				x									x																0	A-D3	N	increase cold duct discharge temperature
							x							x															0	E-D4	N	add second static pressure sensor to cold duct
									x				x																0	F-D3	N	seal gaps allowing excessive infiltration
																													0	#N/A	N	install outside air pressure sensor
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Grand Totals:	4										4																					

Figure 6. Example interventions matrix

of the most common replacements recommended is that of control sensors. In a single project, multiple sensors may be recommended for replacement, but all of these actions count as a single measure in this matrix. This suggests that the number of replacement type interventions may be underestimated. Of the maintenance interventions nearly 90% are either calibration or mechanical fix recommendations. Many of these are related to terminal units which indicates that the number of maintenance items is also quite underestimated.

Table 6: Interventions by recommended action

Interventions	% of Total
Design change	1.3%
Installation modifications	3.4%
Retrofit/equipment replacement	7.0%
Other - Design, Installation, Retrofit, Replacement	1.5%
Implement advanced reset	22.0%
Start/Stop (environmentally determined)	4.1%
Scheduling (occupancy determined)	6.2%
Modify setpoint	8.4%
Equipment staging	0.8%
Modify sequence of operations	15.0%
Loop tuning	5.3%
Behavior modification/manual changes to operations	1.4%
Other - Operations & Control	5.2%
Calibration	9.1%
Mechanical fix	6.9%
Heat transfer maintenance	1.3%
Filtration maintenance	1.1%
Other - Maintenance	0.0%

Additional Notes on Specific Interventions

During the process of entering the interventions into the matrix, it was readily apparent that a small number of interventions were common to nearly every project. Particularly, resets of parameters related to AHU's and pumping systems were very common. These interventions along with other similar interventions make up 21% of the overall total (based on the sum of cooling plant, heating plant, and air-handling & distribution –advanced reset interventions). Approximately 13% of the overall total is from air-handling related resets alone. The most common resets are static pressure and discharge air temperature resets which may be based on outside air temperature or other controls parameters. In the cooling and heating plants, the most common reset was the differential pressure reset for the relevant pumping system.

CONCLUSIONS

Over the past ten years, the CC process has been widely implemented at sites throughout the nation with varying degrees of success. With an average payback of less than two years and an average savings of approximately 14% of annual energy costs, the CC work of the past 10 years reinforces the economic feasibility of the CC process and confirms the previously quoted CC savings performance values. For instance, 42% of the sites in this study had simple paybacks of less than 1 year and 71% had a simple payback less then 2 years. Another item not discussed here is the emissions reductions that resulted from the lowering of energy consumption at the sites. Although historically emissions reductions have not been one of the main drivers for CC, they are an important result and will likely only increase in importance in the future.

Another figure which demonstrates the success of the CC process is the aggregate cost savings for all of the projects. First year savings (in 2006 dollars) for all 60 sites totals \$5.284 million. The aggregate savings was calculated by considering the period since the first year of CC savings data to the present day assuming a typical degradation of 25% of savings every four years since CC was implemented (Toole and Claridge 2006). The results of a separate study for estimating persistence savings are used since no separate persistence study was done with this data set due to the lack of relevant data. It is also worth noting that a number of the buildings in the study cited above are included in this data set. That being said, the resulting aggregate savings (in 2006 dollars) is \$24.636 million for the data set.

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