Implemented Continuous Commissioning® Measures for Schools, Hospitals, and Office Buildings in the U.S.

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ABSTRACT

This study presents an overview of 32 projects (i.e., 126 buildings) conducted in the U.S. regarding Continuous Commissioning[1]® (CC®) over the last 10 years. It includes the projects of 43 schools, 68 hospitals, 4 office, and 11 other buildings. In this study, we estimated the implemented CC® measures that were applied to the existing buildings of the projects in schools, hospitals, and office buildings (i.e., 115 buildings). We categorized the CC® measures by system and measure type using the standard annotation. The rankings of the measures were analyzed. This study shows that the five most frequent CC® opportunities through the projects are: Air Handling Unit (AHU) operation, AHU maintenance, AHU supply air temperature (SAT) cooling and heating setpoint adjustment, and Chilled Water (CHW) system operation.

INTRODUCTION

Saving building energy and improving occupant comfort is an important issue for today's building managers. One of the most effective methods is to tune and optimize HVAC systems for saving building energy as well as improving comfort. This method can be achieved by properly managing the existing HVAC systems or by controlling the operations of advanced HVAC systems such as variable air volume Air Handling Unit (AHU) systems, high efficiency chillers and boilers, and Building Automation Systems (BAS) (Liu et al. 2002).

The Energy Systems Laboratory (ESL), a division within the Texas A&M Engineering Experiment Station (TEES), has conducted CC® projects for existing buildings in various climates over 10 years in order to save building energy and improve occupant comfort. This paper describes the implemented CC® of 32 projects (i.e., 126 buildings) based on the final reports of the projects other than the reports of retrofit and ongoing projects. This paper provides the frequency of the implemented CC® measures by system and measure type, with the intention that if we know the frequency of the implemented CC® measures by specific type, we can more easily find where energy saving opportunities are obtained and better account for the opportunities in other buildings with similar situations. Specific examples of the most frequent CC® opportunities are also discussed in this study.

Table 1 shows the building type, number, conditioned square feet, savings per year, and savings per year by square feet of the 32 projects. The achieved savings[2] were calculated during the first year period after the CC® measures were implemented. The projects for school buildings accounted for approximately 40% of the total savings achieved through CC®. Table 2 shows the same categories above, however the projects were categorized by specific location and climate. The total conditioned area of 32 projects was 9,524, 849 ft^2, and the total savings per one year after the CC® measures were implemented was $ 2,740,563. The savings per year by square feet was $ 0.29. Overall, approximately 80% of the total achieved savings through CC® was obtained from the projects in Texas.

Table 1. Achieved Energy Savings by Building Type

Building Type	# of Buildings	Conditioned Square Feet	Savings $/ Year	Savings$/ Year,Sqft
Schools	43	4,526,962	1,112,604	0.25
Hospitals	68	3,554,897	960,863	0.27
Offices	4	187,506	143,465	0.77
Other (Courthouse, Research center, Cultural center, etc.)	11	1,255,484	523,631	0.42
Grand Total	**126**	**9,524,849**	**2,740,563**	**0.29**

[1] Continuous Commissioning® and CC® are Registered Trademarks of the Texas Engineering Experiment Station. Contact the Energy Systems Laboratory, Texas A&M University for further information.

[2] The achieved savings were calculated using the electricity and gas unit cost of the year when the projects were completed.

Table 2. Achieved Energy Savings by Location and Climate

State	City	ASHRAE Climate Zone	Building Type	# of Buildings	Conditioned Square Feet	Savings $/ Year	Savings $/ Year,Sqft
TX	Austin	2A (Hot & Humid)	School	15	1,765,264	265,703	0.15
			Office	3	106,550	72,119	0.68
			Other	7	604,020	375,301	0.62
TX	Brenham	2A (Hot & Humid)	Hospital	30	362,249	48,888	0.13
TX	College Station	2A (Hot & Humid)	School	1	61,658	61,828	1.00
TX	Corpus Christi	2A (Hot & Humid)	School	13	826,300	127,587	0.15
TX	Dallas	3A (Warm & Humid)	Office	1	80,956	71,346	0.88
TX	Kerrville	3B (Warm & Dry)	Hospital	18	316,700	179,600	0.57
TX	Laredo	2B (Hot & Dry)	School	3	408,000	276,434	0.68
TX	Lubbock	3B (Warm & Dry)	School	6	800,000	132,012	0.17
TX	Prairie View	2A (Hot & Humid)	School	3	278,291	112,464	0.40
TX	San Antonio	2A (Hot & Humid)	Hospital	5	1,468,592	329,437	0.22
TX	Terrell	3A (Warm & Humid)	Hospital	13	499,356	159,386	0.32
TX Subtotal				118	7,577,936	2,212,105	0.29
CA	Edwards	3B (Warm & Dry)	Other	3	281,464	41,500	0.15
GA	Fort Benning	3A (Warm & Humid)	Hospital	1	398,000	69,552	0.17
MN	Minneapolis	6A (Cold & Humid)	Hospital	1	510,000	174,000	0.34
PA	State College	5A (Cool & Humid)	School	1	37,449	86,000	2.30
UT	Salt Lake City	5B (Cool & Dry)	School	1	350,000	50,576	0.14
			Other	1	370,000	106,830	0.29
Other Subtotal				8	1,946,913	528,458	0.27
Grand Total				**126**	**9,524,849**	**2,740,563**	**0.29**

CC® MEASURE CATEGORY

Approximately 40 types of CC® measures were applied to the 32 projects (i.e., 126 buildings) as shown in Table 1 and 2 to save building energy and improve occupant comfort. In general, most commissioning measures are categorized by non-standard groups. However, a standard grouping is necessary to better understand and apply commissioning measures. Therefore, this paper presents standard annotations to categorize the implemented CC® measures.

First, the implemented CC® measures were categorized by two types: system and measure type. The system type consists of Air-Side HVAC System, Water-Side Central Plant, and other. Table 3 shows the sub-levels of the system types. The section called "other" mainly contains Fan Coil Unit and Heat Recovery Unit. The categorization of Table 3 was then applied to Figures 1, 3, and 5 for schools, hospitals, and office buildings.

Table 3. Categorization by System Type

1st Level System Type	2nd Level System Type	3rd Level System Type
Air-Side HVAC System	Single Zone (SZ) AHU	Constant Air Volume (CAV)/ Variable Air Volume (VAV)
	Multi Zone (MZ) AHU	Single Duct (SD) CAV/ SD VAV/ Dual Duct (DD) CAV/ DD VAV
	Terminal Box	CAV/VAV
Water-Side Central Plant	Chilled Water (CHW) System	N/A
	Heating Hot Water (HHW) System	N/A
	Steam HW System	N/A
	Domestic Hot Water (DHW)	N/A
Other	N/A	N/A

The other approach for categorizing the implemented CC® measures is by measure type that uses standard annotations. As the 1st level of measure type, the CC® measures were sorted by three categories: Operation, BAS Control/Optimization, and Maintenance. Table 4 describes each 1st level measure type. The standard annotation was used for the 2nd level measure type of BAS Control/Optimization. This BAS Control/Optimization section has many variables, so the standard annotation is helpful to understand the implemented CC® measures.

Table 4. Categorization by Measure Type

1st Level Measure Type	General Description for the 1st level	2nd Level Measure Type
Operation	Turn off system or reduce system quantity/volume or change operation	N/A
BAS Control/ Optimization	Optimize sequence of operation to take advantage of variable loads	**Standard Annotation**
Maintenance	Restore or repair components of systems to correct operation	N/A

In order to categorize the 2nd level measure type of BAS Control/Optimization with a standardized approach, additional process variables were used. Process variables consist of how to apply the CC® measures to control building systems to save energy and improve occupant comfort. Table 5 indicates the process variables of standard annotations. Table 6 shows the examples of the standard annotations used in Figures 2, 4, and 6. The standard annotations are created based on each process variable.

Figures 1 to 6 show the frequency of the implemented CC® measures of schools, hospitals, and offices[3] using the system (i.e., Table 3) and the measure (i.e., Table 4) type. Figures 1 and 2 show the frequency of the CC® measures implemented in 43 school buildings. CHW, SD VAV, and SD CAV systems, except "other", were the top three systems where CC® measures were implemented (see Figure 1). AHU operation, AHU maintenance, and AHU supply air temperature (SAT) cooling setpoint adjustment (i.e., indicator c) were the top three measures for the school buildings (see Figure 2). The fourth top measure was supply water flow cooling setpoint adjustment of CHW system (i.e., indicator t), and the fifth top measure was supply air pressure cooling &

[3] In this study, other type buildings were excluded for the categorizing analysis of the CC® measures.

Table 5. Process Variables for Standard Annotations

System Type	Process Sensor Location	Process Sensor Medium	Process Sensor Type	Process Function	Modify the _____ Setpoint for the Process Variable	If Applicable, Add _____
AHU/ Terminal Unit/ CHW System/ HHW System/ DHW System/ Heat Pump/ Heat Recovery Unit	Outside/ Preheat Coil Leaving/ Supply/ Reheat Coil Leaving/ Space/ Return/ Exhaust	Air/ Water	Flow/ Temperature/ Pressure/ Humidity	Cooling/ Heating/ Cooling&Heating/ Preheat/ Reheat/ Bypass/ Economizer/ Dehumidification/ Ventilation	Min/ Operation/ Lockout	Setpoint Adjustment/ Control Sequence Optimization

Table 6. Examples of Standard Annotations

Indicator	System Type	Process Sensor Location	Process Sensor Medium	Process Sensor Type	Process Function	Modify the _____ Setpoint for the Process Variable	If Applicable, Add ____	Standard Annotation
c	AHU	Supply	Air	Temperature	Cooling	Operating	Setpoint Adjustment	AHU Supply Air Temperature Cooling Operating Setpoint Adjustment
i	AHU	Outside	Air	Flow	Ventilation	Operating	Setpoint Adjustment	AHU Outside Air Flow Ventilation Operating Setpoint Adjustment
p	Terminal Unit	Space	Air	Temperature	Cooling & Heating	Operating	Setpoint Adjustment	Terminal Unit Space Air Temperature Cooling & Heating Operating Setpoint Adjustment
r	Terminal Unit	Space	Air	Flow	Reheat	Lockout	N/A	Terminal Unit Space Air Flow Reheat Lockout
v	CHW System	Supply	Water	Flow	Cooling	Operating	Control Sequence Optimization	CHW System Supply Water Flow Cooling Operating Control Sequence Optimization

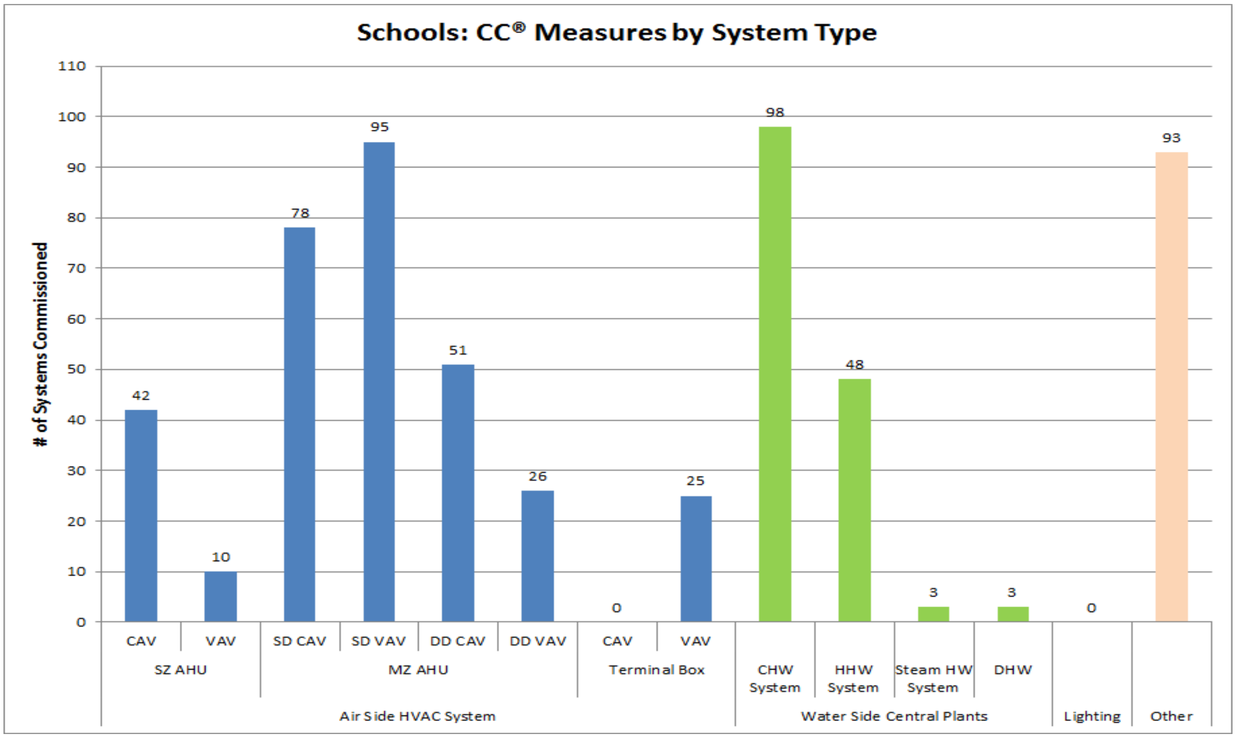

Figure 1. CC® measures by System Type in Schools

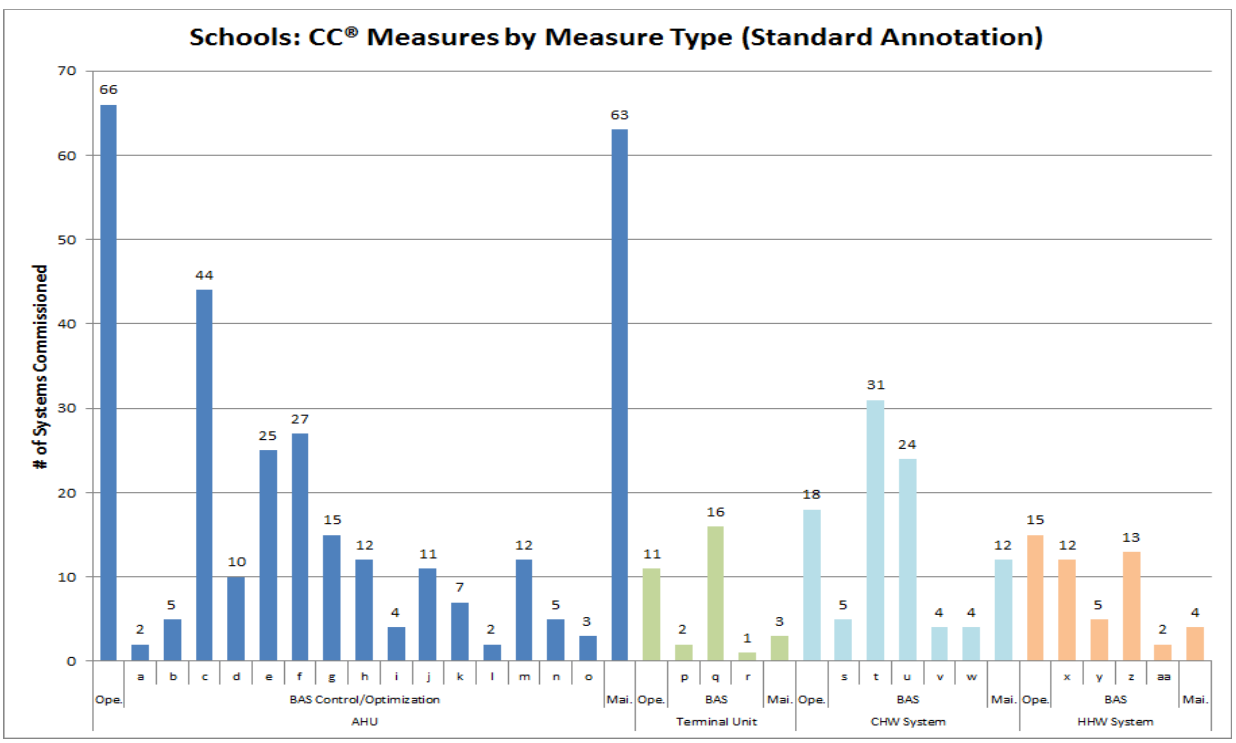

Figure 2. CC® measures by Measure Type in Schools

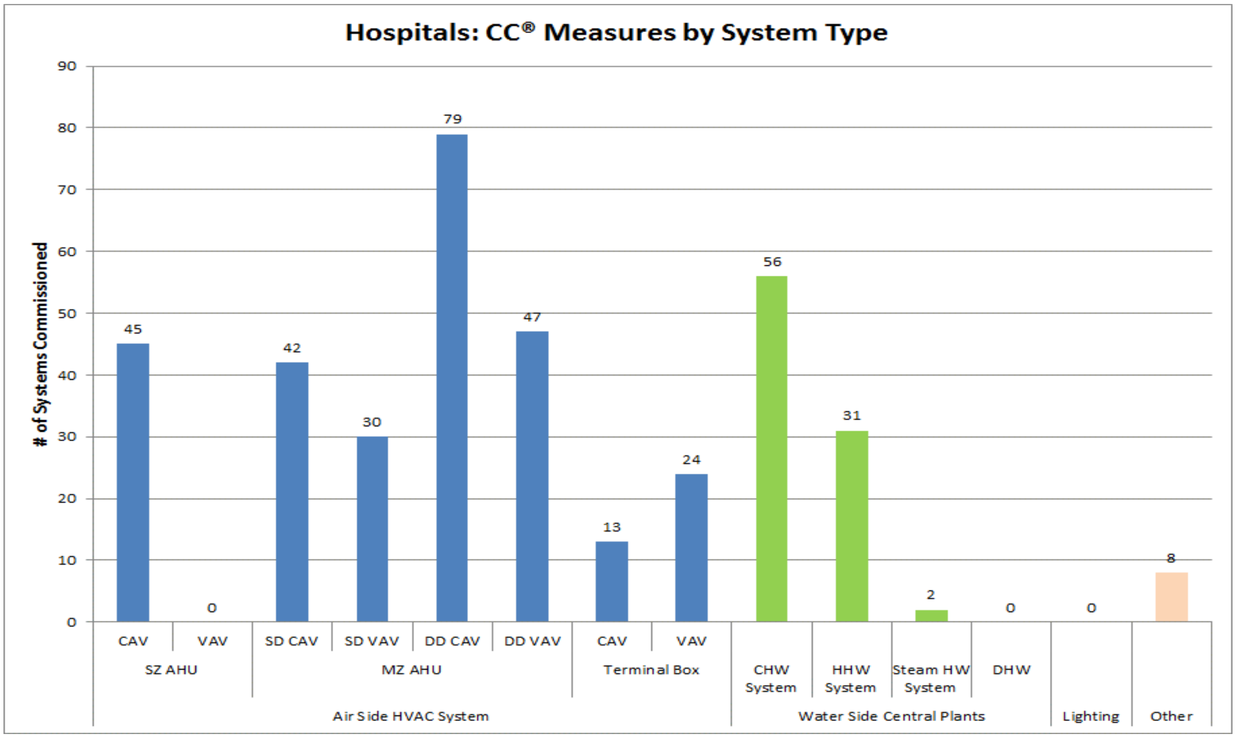

Figure 3. CC® measures by System Type in Hospitals

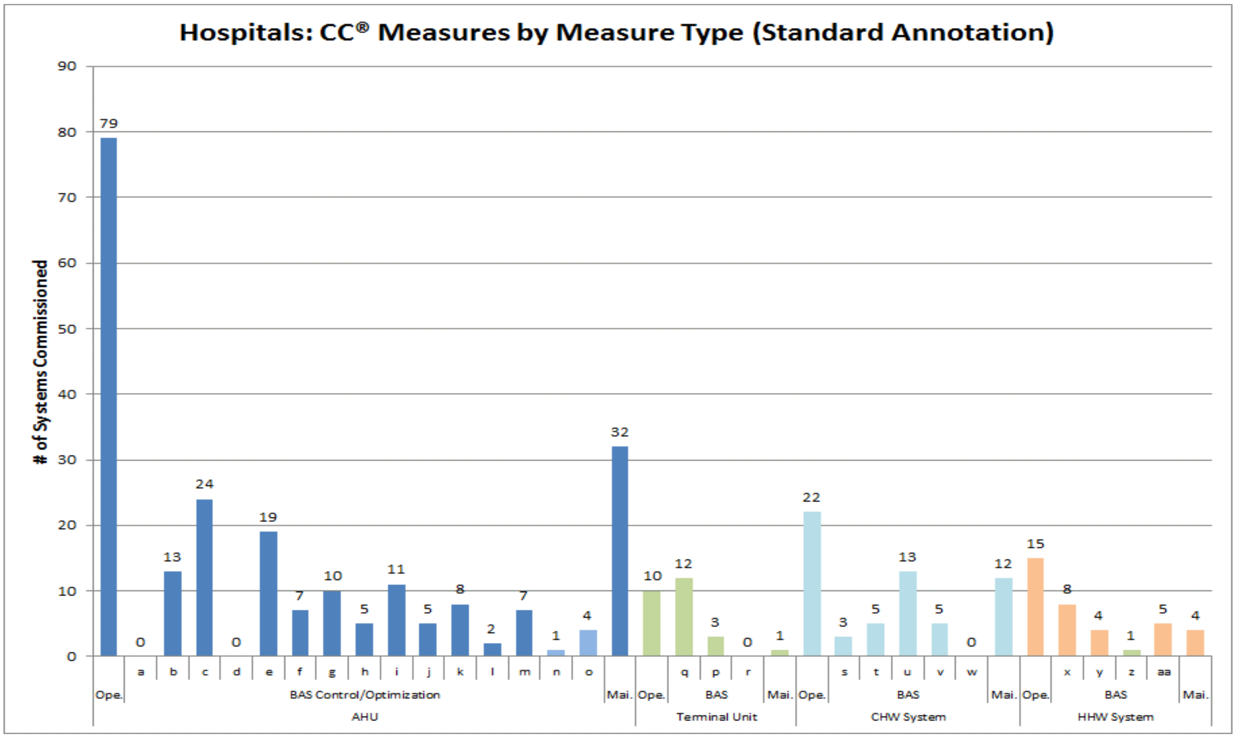

Figure 4. CC® measures by Measure Type in Hospitals

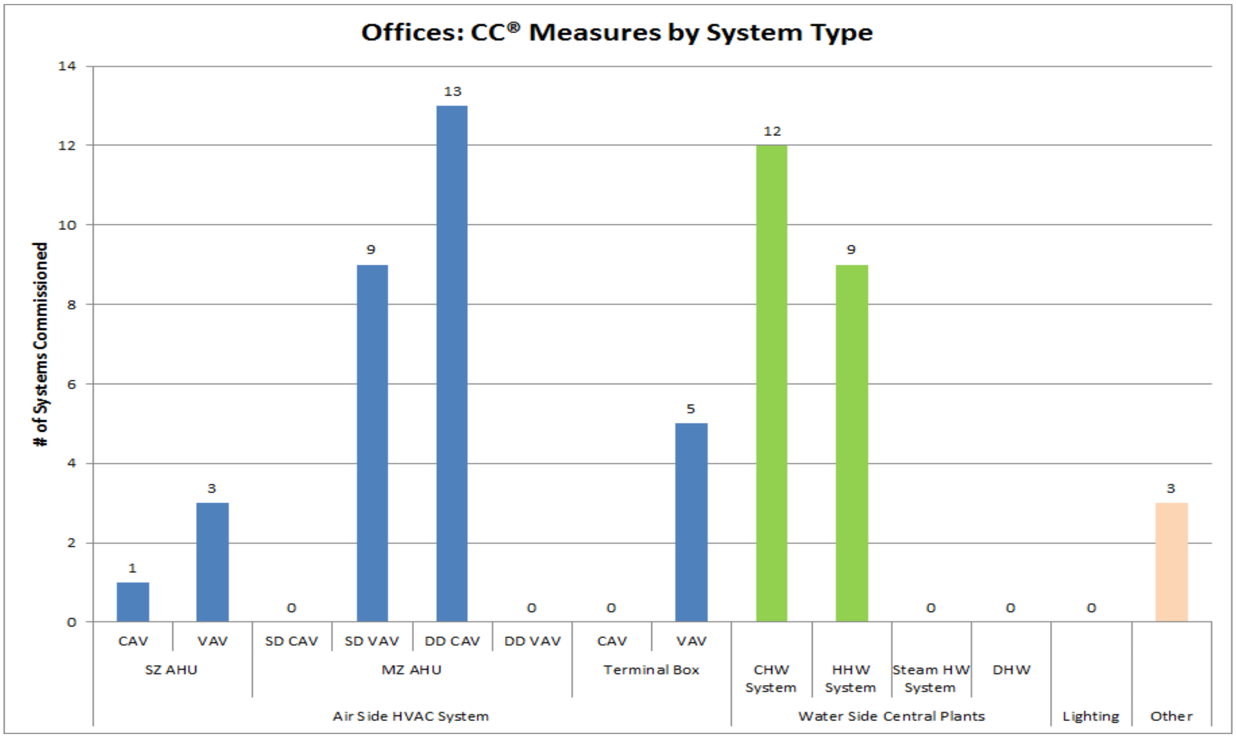

Figure 5. CC® measures by System Type in Offices

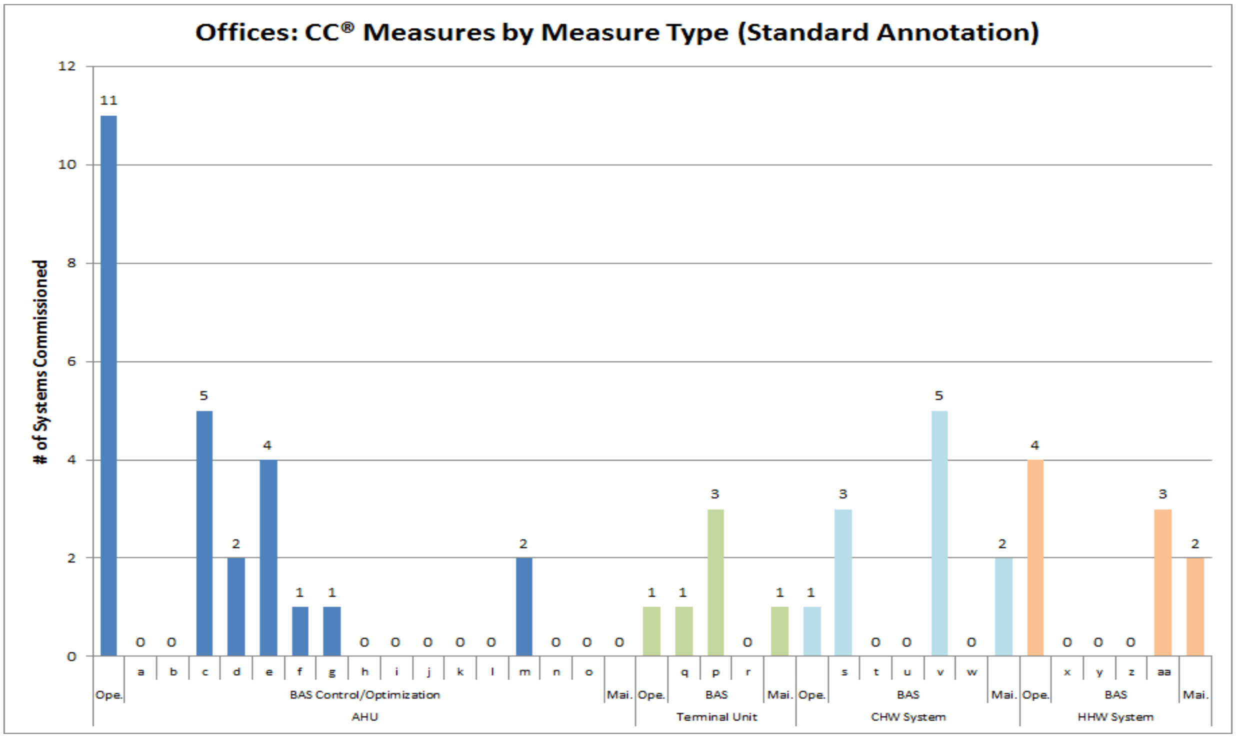

Figure 6. CC® measures by Measure Type in Offices

heating setpoint adjustment of AHU system (i.e., indicator f).

Figure 3 and 4 show the frequency of the CC® measures implemented in 68 hospital buildings. DD CAV, CHW, and DD VAV systems were the most frequent systems of CC® measures that were implemented (see Figure 3). AHU operation, AHU maintenance, and AHU supply air temperature cooling setpoint adjustment (i.e., indicator c) were the top three measures for the hospital buildings (see Figure 4), which is the same with the top three measures of the school buildings. The fourth measure was the operation of the CHW system, and the fifth was AHU supply air temperature heating setpoint adjustment (i.e., indicator e).

Figure 5 and 6 show the frequency of the CC® measures implemented in four office buildings. DD CAV, CHW, SD VAV, and HHW systems were the top three systems where CC® measures were implemented. SD VAV and HHW systems had the same frequency of occurrence (see Figure 5). AHU operation, AHU supply air temperature cooling setpoint adjustment (i.e., indicator c), and supply water flow cooling control sequence optimization for CHW system (i.e., indicator v) were the top three measures for the office buildings (see Figure 6). AHU supply air temperature heating setpoint adjustment (i.e., indicator e) and HHW system operation shared the fourth position.

THE MOST FREQUENT CC® MEASURES

The total of the CC® measures implemented in all the school buildings in this study was 491, the total in hospital buildings was 346, and the total of the office buildings was 50. Among the overall CC® measures (i.e., 887), AHU operation, AHU maintenance, and AHU supply air temperature cooling setpoint adjustment (i.e., indicator c) were the top three measures. The fourth was supply air temperature heating setpoint adjustment (i.e., indicator e), the fifth was CHW operation. Figure 7 shows the percentage of top five CC® measures implemented in the schools, hospitals, and office buildings.

The top five measures account for 47% of the total implemented measures. The examples of the most frequent CC® measures are included in the following sections.

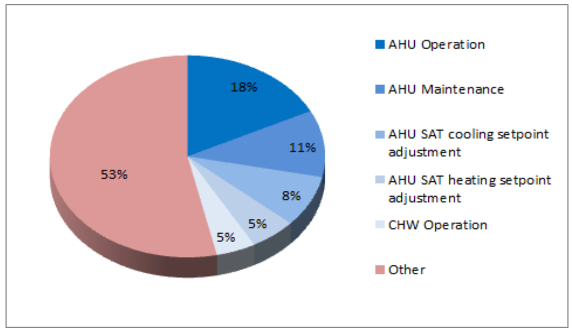

Figure 7. Top Five Implemented CC® measures

AHU Operation

In many projects, AHUs operated during unoccupied periods. This caused an unnecessary increase of overall energy use. Therefore, AHUs were turned off or AHU schedules were changed based on operation schedules. For example, an occupied/unoccupied schedule was obtained from a site visit. After that, the schedule was modified based on the survey, and it was then implemented in the control program of BAS. During an unoccupied period, the fans and cooling and heating coil valves were shut down.

AHU Maintenance

The major CC® measures that were conducted usually identified and repaired AHU malfunctions. Examples include wrong temperature, humidity, and static pressure sensors, which were calibrated or replaced for proper AHU operation without erroneous readings. In some cases, fan pulleys and belts were replaced to increase air flow and improve static pressure.

AHU SAT cooling and heating setpoint adjustment

The 3rd and 4th most frequent CC® measures were to adjust AHU SAT cooling and heating setpoints. In such cases, there were existing DDC controllers that maintained cooling and heating temperature. However, resetting cooling and heating coil temperature based on outside air temp (OAT) was a more efficient measure to maintain room comfort and reduce waste of cooling and heating energy. For example, a cooling coil temperature was reset according to a room temperature when OAT is below 60°F, and it was maintained at 55°F when OAT is above 60°F. Therefore, these strategies were applied to many projects to save cooling and heating energy for AHUs.

CHW Operation

The 5th most frequent CC® measure was to turn on and off a chiller using an occupancy schedule. This approach was explained at the above section of AHU operation. In the same way, a chiller was turned off based on an occupied/unoccupied schedule. For example, a new control program was written in the BAS language to turn a chiller off when all the AHUs were off (i.e., an unoccupied period).

SUMMARY

Over the last 10 years, the ESL has conducted CC® projects for hundreds of existing buildings in the U.S in order to save energy and improve occupant comfort. This paper describes the implementation of CC® measures in 115 buildings based on the final reports of the projects on file at the ESL. A standard grouping was applied to better understand and make use of commissioning measures. The implemented CC® measures for schools, hospitals, and office buildings were categorized using the standard annotation (i.e., grouping).

The five most frequent CC® opportunities used in schools, hospitals, and office buildings were: Air Handling Unit (AHU) operation, AHU maintenance, AHU supply air temperature cooling and heating setpoint adjustment, and Chilled Water (CHW) system operation. These measures account for 47% of the total implemented measures.

FUTURE WORK

Additional analysis is required to better represent implemented CC® measures in order to allow building operators to use the CC® opportunities in other buildings with similar conditions. Additional standard annotations, histograms by ambient temperature and energy use, and cost analysis by measure will be needed to expand this study into more buildings.

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