Introduction to Continuous Commissioning^{SM}

With the energy crisis of the early 1970s came the realization that buildings could be made more efficient without sacrificing comfort. Over the last 30 years, the building industry has made revolutionary changes: chiller systems have decreased their power requirements by a factor of two, from more than one kW/ton to less than 0.5 kW/ton; the use of variable air volume systems has become common practice; and the use of building automation systems has become the norm, with digital controls increasingly replacing pneumatics. Advances in HVAC technology have greatly improved building comfort and significantly decreased building energy consumption. The technological advances have increased the importance of proper operational practices in achieving the efficiency potential of the HVAC systems. While reducing energy use is a noble goal, it must not compromise comfort. Occupant comfort and productivity must be maintained or improved.

Building commissioning has emerged as the preferred method of ensuring that building systems are installed and operated to provide the performance envisioned by the designer. ASHRAE has detailed the commissioning process in Guideline 1-1996 [ASHRAE 1996]. A number of other building commissioning guidelines have been developed by different organizations, with the same basic objective as the ASHRAE guideline, i.e., to ensure proper operation of the building according to the design intent.

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In 1999, DOE developed a practical guide for commissioning existing buildings [Haasl and Sharp 1999]. Several building commissioning processes are discussed in this guide. These processes include: new building commissioning, existing building commissioning or retro-commissioning, Continuous Commissioning^{SM} and recommissioning. While most commissioning processes focus on bringing building operation to the original design intent, Continuous Commissioning^{SM} is different[1]. Continuous Commissioning^{SM} (CC^{SM}) focuses on optimizing HVAC system operation and control for the existing building conditions. This is an important distinction. Based on Continuous Commissioning^{SM} results from more than 130 buildings, the average measured utility savings are about 20%, with simple paybacks often in less than two years. These results are based on the experience of the Texas Engineering Experiment Station's Energy Systems Laboratory at Texas A&M University during the last 10 years [Liu et al. 1994, Claridge et al. 1994, Liu et al. 1999, Claridge et al. 2000]. Continuous Commissioning^{SM} maintains long-term savings by ongoing monitoring of energy savings with followup commissioning, as needed; improves the system reliability and building comfort by optimizing system operation and control schedules based on actual building conditions; upgrades the operating staff's skills by allowing direct participation of O&M staff; and reduces O&M costs.

[1] The terms Continuous Commissioning^{SM} and CC^{SM} have been service marked by the Texas Engineering Experiment Station Energy Systems Laboratory to ensure a consistent meaning for this terminology, as described in this guidebook.

This chapter defines CC℠ and provides an introduction to the CC℠ process. The detailed objectives, methods, and procedures are discussed for each step of the CC℠ process. This discussion includes the major goals of each step, the methods needed to achieve the specific goals and the procedures needed to conduct CC℠ wisely and efficiently.

1.1 Definition

Continuous Commissioning℠ (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 CC℠ team consists of a project manager, one or more CC℠ engineers and CC℠ technicians, and one or more designated members of the facility operating team.

CC℠ focuses on improving overall system control and operations for the building, as it is currently utilized, and on meeting existing facility needs. It goes beyond an operations and maintenance program. It does not ensure that the systems function as originally designed, but ensures that the building and systems operate optimally to meet the current requirements. During the CC℠ process, a comprehensive engineering evaluation is conducted for both building functionality and system functions. The optimal operational parameters and schedules are developed based on actual building conditions and current occupancy requirements. An integrated approach is used to implement these optimal schedules to ensure local and global system optimization and persistence of the improved operational schedules.

The CC℠ team consists of a project manager, one or more CC℠ engineers and CC℠ technicians[2], and one or more designated members of the facility operating team. The primary role of the project manager is to coordinate the activities of building personnel and the commissioning team and schedule project progress. The project manager can be an owner representative or a CC℠ contractor representative. The primary responsibilities of the CC℠ engineer are to:

- Develop metering and field measurement plans
- Develop improved operational and control schedules and set points
- Make necessary programming changes to the building automation system
- Supervise technicians implementing mechanical systems changes
- Estimate potential performance changes and energy savings
- Conduct an engineering analysis of the system changes
- Write a project report

The CC℠ engineer should have the qualifications to perform the work specified. The CC℠ technician will conduct field measurements and implement mechanical, electrical, and control system program modifications and changes, under the direction of the CC℠ engineer.

[2]This guidebook will speak of a single CC engineer and a single CC technician for simplicity. However, there may be more than one CC engineer and more than one CC technician on large projects.

1.2 Process

The CC^{SM} process consists of two phases. The first phase is the project development phase, that identifies the buildings and facilities to be included in the project and develops the project scope. At the end of this phase, the CC^{SM} scope is clearly defined and a CC^{SM} contract is signed. The second phase implements CC^{SM} and verifies project performance.

This phase includes six steps:

- Develop the CC^{SM} plan and form the project team
- Develop performance baselines
- Conduct system measurements and develop CC^{SM} measures
- Implement CC^{SM} measures
- Document comfort improvements and energy savings
- Keep the commissioning continuous

Phase 1: Project Development

Step 1: Identify Buildings or Facilities

Objective:

Screen potential CC^{SM} targets with minimal effort to identify buildings or facilities that will receive a CC^{SM} audit. The CC^{SM} target can be a building, an entire facility, or a piece of equipment. If the building is part of a complex or campus, it is desirable to select the entire facility as the CC^{SM} target since one mechanical problem may be rooted in another part of the building or facility.

Method:

The initial CC^{SM} targets can be selected based on one or more of the following criteria:

- The target provides poor thermal comfort
- The target consumes excessive energy, and/or
- The design features of the facility HVAC systems are not fully used

If one or more of the above criteria fits the description of the facility, it is likely to be a good candidate for CC^{SM}. CC^{SM} can be effectively implemented in buildings that have received energy efficiency retrofits, in newer buildings, and in existing buildings that have not received energy efficiency upgrades. In other words, virtually any building can be a potential CC^{SM} candidate.

The CC^{SM} targets can be selected by the building owner or the CC^{SM} contractor. However, the building owner is usually in the best position to select the most promising targets because of his or her knowledge of the facility operation and costs. The CC^{SM} contractor should then perform a preliminary assessment to check the feasibility of using the CC^{SM} process on the target facilities before conducting a CC^{SM} audit.

Information needed for preliminary assessment:

- Actual monthly utility bills (both electricity and gas) for at least 12 months (preferable to just a table of historical energy and demand data because meter reading dates are needed)
- General building information: size, function, major equipment, and occupancy schedules
- O&M records, if available
- Description of any problem in the building, such as thermal comfort, indoor air quality, moisture, mildew

An experienced engineer should review this information and determine the potential of the CC^{SM} process to improve comfort and reduce energy cost. The CC^{SM} projects often improve building comfort and reduce building energy consumption at the same time. However, some of the CC^{SM} measures may increase building energy consumption in order to satisfy room comfort and indoor air quality requirements. For example, providing building minimum outside air will certainly increase the cooling energy consumption during summer and winter than providing no outside air to the building. If the potential justifies a CC^{SM} audit, a list of preliminary commissioning measures for evaluation in a CC^{SM} audit should also be developed. If the owner is interested in proceeding at this point, a CC^{SM} audit may be performed.

Step 2: Perform CC^{SM} *Audit and Develop Project Scope*

Objectives:

- Define owner's requirements
- Check the availability of in-house technical support such as CC^{SM} technicians
- Identify major CC^{SM} measures

Method:

The owner's representative, the CC^{SM} project manager and the CC^{SM} engineer will meet. The expectations and interest of the building owner in comfort improvements, utility cost reductions and maintenance cost reductions will be discussed and documented in detail. The availability and technical skills of in-house technicians will be discussed. After this discussion, a walkthrough must be conducted to identify the feasibility of the owner's expectations for comfort performance and improved energy performance. During the walkthrough, major CC^{SM} measures will be identified by the CC^{SM} engineer and project manager. An in-house technician should participate in the walkthrough. The CC^{SM} project manager will organize the audit and document the expectations of the building owner.

Special Considerations:

- A complete set of mechanical and control system design documentation is needed

- The CC^{SM} engineer and technician will take preliminary measurements of equipment operating parameters
- Any available measured whole building level or sub-metered energy consumption data from stand-alone meters or the building automation system should be utilized

A CC^{SM} audit report must be completed that lists and describes preliminary CC^{SM} measures, the estimated energy savings from implementation and the cost of carrying out the CC^{SM} process on the building(s) evaluated in the CC^{SM} audit.

There may be more than one iteration or variation at each step described here, but once a contract is signed, the process moves to Phase 2 as detailed below.

Phase 2: CC^{SM} Implementation and Verification

Step 1: Develop CC^{SM} *plan and form the project team*

Objectives:
- Develop a detailed work plan
- Identify the entire project team
- Clarify the duties of each team member

Method:
The CC^{SM} project manager and CC^{SM} project engineer develop a detailed work plan for the project that includes major tasks, their sequence, time requirements and technical requirements. The work plan is then presented to the building owner or representative. During the meeting, the owner's representative and in-house technicians who will work on the project should be identified. If in-house technicians are going to conduct measurements and system adjustments, additional time should be included in the schedule unless they are to be dedicated full-time to the CC^{SM} project. Typically, in-house technicians must continue their existing duties and cannot devote full time to the CC^{SM} effort, which results in project delays. In-house staff may also require additional training. The work plan may need to be modified, depending on the availability and skill levels of in-house staff.

Special Issues:
- Availability of funding to replace/repair parts found broken
- Time commitment of in-house staff
- Training needs of in-house staff

Deliverable:

CC^{SM} report part 1: CC^{SM} plan that includes project scope and schedule, project team and task duties of each team member.

System problems should be documented based on interviews with occupants and technical staff, combined with field observations and measurements.

Step 2: Develop performance baselines

Objectives:

- Document existing comfort conditions
- Document existing system conditions
- Document existing energy performance

Method:

Precisely document all known comfort problems in individual rooms resulting from too much heating, cooling, noise, humidity, odors (especially from mold or mildew) or lack of outside air. Also, identify the following HVAC system problems:

- Valve and damper hunting
- Disabled systems or components
- Operational problems
- Frequently replaced parts

Utility bills may be used to develop the energy-use baseline if the CC process will result in energy savings that are a significant fraction of baseline use and if the building's functions and use patterns will remain the same throughout the project.

An interview and walk-through may be required, although most of this information is collected during the CC[SM] audit and step 1. Room comfort problems should be quantified using hand-held meters or portable data loggers. System problems should be documented based on interviews with occupants and technical staff and combined with field observations and measurements.

Baseline energy models of building performance are necessary if energy savings are to be documented after commissioning the building. The baseline energy models can be developed using one or more of the following types of data:

- Short-term measured data obtained from data loggers or the EMCS system
- Long-term hourly or 15-minute whole building energy data, such as whole building electricity, cooling and heating consumption, and/or
- Utility bills for electricity, gas and/or chilled or hot water

The whole building energy baseline models normally include whole building electricity, cooling energy and heating energy models. These models are generally expressed as functions of outside air temperature since both heating and cooling energy are normally weather dependent. Any component baseline models should be represented using the most relevant physical parameter(s) as the independent variable(s). For example, the fan motor power should be correlated with the fan airflow and the pump motor energy consumption should be correlated with water flow.

Short-term measured data are often the most cost-effective and accurate if the potential savings from CC[SM] measures are independent of the weather. For example, a single true power measurement can be used to develop the baseline fan energy consumption if the pulley were to be changed in a constant air volume system. Short-term data are useful to determine the baseline for specific pieces of equipment, but are not reliable for baselining overall building energy use.

Long-term measurements are normally required since potential savings of CC^{SM} measures are weather dependent. These measurements provide the most convincing evidence of the impact of CC^{SM} projects. Long-term data also help in continuing to detect/diagnose system faults during CC^{SM} follow-up. Although more costly than short-term measured data, long-term data often produce additional savings, making them the preferred data type. For example, unusual energy consumption patterns can be identified easily using long-term, short-interval measured data. "Fixing" these unusual patterns can result in significant energy savings. Generally speaking, long-term interval data for electricity, gas and thermal usage are preferred.

Utility bills may be used to develop the energy-use baseline if the CC^{SM} process will result in energy savings that are a significant fraction (>15%) of baseline use, and if the building functions and use patterns will remain the same throughout the project.

The CC^{SM} engineers should provide the metering option(s) that meet the project requirements to the building owner or representative. A metering method should be selected from the options presented by the CC^{SM} engineer and a detailed metering implementation plan developed. It may be necessary to hire a metering subcontractor if an energy information system is installed prior to implementing the CC^{SM} measures.

CC implementation should start by solving existing problems.

Special Considerations:

- Use the maintenance log to help identify major system problems
- Select a metering plan that suits the CC^{SM} goals and the facility needs
- Always consider and measure weather data as part of the metering plan
- Keep meters calibrated. When the EMCS system is used for metering, both sensors and transmitters should be calibrated using field measurements.

Deliverables:

CC^{SM} report part 2: Report on Current Building Performance, including current energy performance, current comfort and system problems, and metering plans if new meters are to be installed. Alternatively, if utility bills are used to develop the baseline models, the report should include baseline energy models.

Step 3: Conduct System Measurements and Develop Proposed CC^{SM} *Measures*

Objectives:

- Identify current operating schedules, set points, and problems
- Develop solutions to existing problems
- Develop improved operation and control schedules and set points
- Identify potential cost effective energy retrofit measures

Method:

The CC^{SM} engineer should develop a detailed measurement cut-sheet for each major system. The cut-sheet should list all parameters to be measured and all mechanical and electrical parts to be checked. The CC^{SM} engineer should also provide the technician with measurement training if a local technician is used to perform system measurements. The CC^{SM} technician should follow the procedures on the cut-sheets to obtain the specified measurements using appropriate equipment.

The CC^{SM} engineer conducts an engineering analysis to develop solutions for the existing problems; develops improved operation and control schedules and set points for terminal boxes, air handling units (AHUs), exhaust systems, water and steam distribution systems, heat exchangers, chillers, boilers and other components, as appropriate; and identifies potential cost effective energy retrofit measures.

Special Considerations:

- Trend main operational parameters using the EMCS and compare with the measurements from the hand meters
- Print EMCS control sequences
- Verify system operation in the building and compare to EMCS schedules

Deliverables:

CC^{SM} report part 3: Existing System Conditions. This report includes:

- Existing control sequences and set points for all major equipment, such as AHU supply air temperatures, AHU supply static pressures, terminal box minimum airflow and maximum airflow values, water loop differential pressure set points and equipment on/off schedules
- List of disabled control sequences
- List of malfunctioning equipment and control devices
- Engineering solutions to the existing problems and a list of repairs required
- Improved control and operation sequences

Step 4: Implement CC^{SM} *Measures*

Objectives:

- Obtain approval for each CC^{SM} measure from the building owner's representative prior to implementation
- Implement solutions to existing operational and comfort problems
- Implement and refine improved operation and control schedules

Method:

The CC^{SM} project manager and project engineer should present the engineering solutions to existing problems and the improved operational and control schedules to the building owner's representative in one or more meetings. The in-house operating staff should be invited to the meeting(s). All critical questions should be answered. It is important, at this point, to get "buy-in" and approval from both the building owner's representative and the operating staff. The meeting(s) will decide the following issues:

- Approval, modification or disapproval of each CC^{SM} measure
- Implementation sequence of CC^{SM} measures
- Implementation schedules

CC^{SM} implementation should start by solving existing problems. The existing comfort and difficult control problems are the first priority of the occupants, operating staff and facility owners. Solving these problems improves occupant comfort and increases productivity. The economic benefits from comfort improvements are sometimes higher than the energy cost savings, though less easily quantified. The successful resolution of the existing problems can also earn trust in the CC^{SM} engineer from the facility operating staff, facility management, and the occupants. This can lead to the team receiving support in a variety of unexpected ways.

The CC engineer should provide follow-up phone consultation to the operating staff as needed, supplemented by site visits.

Implementation of the improved operation and control schedules should start at the end of the comfort delivery system, such as at the terminal boxes, and end with the central plant. This procedure provides benefits to the building occupants as quickly as possible. It also reduces the overall working load. If the process is reversed, the chiller plant is commissioned first. The chiller sequences are developed based on the current load. After building commissioning, the chiller load may be decreased by 30%. The chiller operating schedules are then likely to need revision.

The CC^{SM} engineer should develop a detailed implementation plan that lists each major activity. The CC^{SM} technician should follow this plan in implementing the measures.

The CC^{SM} engineer should closely supervise the implementation and refine the operational and control schedules as necessary. The CC^{SM} engineer should also be responsible for key software changes as necessary.

Special Considerations:

- Ensure that the owner's technical representative understands each major measure
- Encourage in-house technician involvement in implementation and/or have them implement as many measures as possible
- Document improvements in a timely manner

Deliverables:

CC^{SM} Report part 4: CC^{SM} Implementation. This report includes detailed documentation of implemented operation and control sequences, maintenance procedures for these measures, detailed O&M guidelines and additional measures recommended for implementation.

Step 5: Document comfort improvements and energy savings

Objectives:

- ➢ Document improved comfort conditions
- ➢ Document improved system conditions
- ➢ Document improved energy performance

Method:

The comfort measurements taken in step 2 (Phase 2) should be repeated at the same locations under comparable conditions to determine impact on room conditions. The measured parameters, such as temperature and humidity, should be compared with the measurements from step 2.

The measurements and methods adopted in step 4 should be used to determine post-CC^{SM} energy performance. Energy performance should be compared using appropriate occupancy and weather normalization. Typically, building energy consumption is regressed as a function of outside air temperature if annual projections are desired from short-term data. When hourly or daily models are used, separate models are generally developed for weekends and weekdays.

Special Considerations:

- ➢ Savings analyses should follow accepted measurement and verification protocols such as the International Performance Measurement and Verification Protocol [IPMVP 2001] or an agreed upon alternate method
- ➢ Comfort conditions should conform to appropriate guidelines/design documents such as ASHRAE standards

Deliverables:

CC^{SM} Report, Part 5: Measurement and Verification. This report includes results of detailed measurements of room conditions and energy consumption after CC^{SM} activities, and retrofit recommendations. The room conditions and energy consumption should be compared to those during the pre-CC^{SM} period. The annual energy savings are projected from the available measured data.

Step 6: Keep the Commissioning Continuous

Objectives:

- ➢ Maintain improved comfort and energy performance
- ➢ Provide measured annual energy savings

Method:

The CC^SM engineers should review the system operation periodically to identify any operating problems and develop improved operation and control schedules as described below.

The CC^SM engineer should provide follow-up phone consultation to the operating staff as needed, supplemented by site visits. This will allow the operating staff to make wise decisions and maintain the savings and comfort in years to come. If long term measured data are available, the CC^SM engineers should review the energy data quarterly to evaluate the need for a site visit. If the building energy consumption has increased, the CC^SM engineers determine possible reasons and verify with facility operating staff. Once the problem(s) is identified, the CC^SM engineer should visit the site, develop measures to restore the building performance, and supervise the facility staff in implementing the measures. If the CC^SM engineer can remotely log into the EMCS system, the CC^SM engineer can check the existing system operation quarterly using the EMCS system. When a large number of operation and control measures are disabled, a site visit is necessary. If the CC^SM engineer cannot evaluate the facility using long-term measured energy data and EMCS system information, the CC^SM engineer should visit the facility semi-annually.

One year after CC^SM implementation is complete, the CC^SM engineer should write a project follow-up report that documents the first-year savings, recommendations or changes resulting from any consultation or site visits provided, and any recommendations to further improve building operations.

Special Considerations:

- Operating personnel often have a high turnover rate. It is important to train new staff members in the CC^SM process and make sure they are aware of the reasons the CC^SM measures were implemented
- Ongoing follow-up is essential if the savings are to be maintained at high levels over time

Deliverables:

Special CC^SM Report, which documents measured first-year energy savings, results from first year follow-up, recommendations for ongoing staff training, and a schedule of follow-up CC^SM activities.

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