Lessons Learned from Commissioning 15 Schools

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Synopsis

School building commissioning projects have challenges that differ from standard commercial commissioning projects. Schools are generally owner-occupied buildings with school district energy managers who are interested in saving energy in their facilities. However, these managers must give priority to teacher and student comfort. Sometimes the same school districts that emphasize energy efficiency and comfort are the ones that have an understaffed maintenance department running from school to school putting “band-aid” fixes on equipment just to get through the season. When commissioning or retro-commissioning a school project, the commissioning authority must meet several challenges: helping the district to minimize change orders, steering the design towards low maintenance and high efficiency systems, and working with the construction team to meet the fall class opening deadlines.

Because a child will spent close to 13,000 hours in the classroom from kindergarten through 12th grade, the air quality, lighting and daylighting systems, and comfort delivery systems need to operate at their maximum potential. Commissioning and retro-commissioning can optimize these systems' performance, thus producing the best possible learning environment with the least possible energy use.

This paper will discuss the issues to consider when commissioning a school facility, and present a guideline for school-related commissioning services, including new construction, retrofit (renovation) construction, retro-commissioning, and LEED™-related commissioning. General concepts are illustrated by specific project experiences.

About the Authors

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**School Commissioning Challenges and Goals**

**School Commissioning Goals**

Commissioning goals are generally the same whether one is commissioning a school facility, a commercial building, or any other facility. The main purpose and goal of commissioning is to verify that the installed systems meet the owner’s requirements and comply with design documents and design intent. School districts often have guide specifications that they have created over many years of construction, and the commissioning authority has the added responsibility of working with the design team to be sure the design meets the school district guide specification. Depending on how the design engineering company is selected and what the structure for communication protocol is, the commissioning authority may have a large role in helping the school district obtain the type of systems and design that meets all of their requirements.

By being heavily involved in the design process, the commissioning authority can also help the school district to minimize future change orders by providing thorough reviews of the design documents, and getting items corrected prior to bid day. The commissioning design review process is a critical element in the successful design and delivery of a project. The U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED™) program provides a common format used for sustainable building design and construction. This program requires that commissioning be included in the project, but only includes the design reviews in the commissioning scope if the design team has decided to include the "Best Practices Commissioning Credit.” Including this design review in the commissioning authority’s scope enables the entire design and construction team to minimize change orders and allows for tighter mechanical, electrical, and controls coordination.

To provide a learning environment suitable for young minds to thrive, some specific project goals for school buildings are as follows:

- Mechanical systems (including VAV systems) should provide the minimum fresh air required by ventilation standards.
- HVAC related noise should be kept to a minimum (refer to ANSI S12.60-2002).
- Products selected should contain low or no volatile organic compounds.
- Daylighting should be used to enhance the learning environment.
- Daylighting should be controlled to avoid direct beam sunlight on student desks and the teaching board.
- Daylighting design should include an analysis of the teaching board illumination such that the lighting levels do not interfere with Audio/Visual presentations.
- Electric lighting should compliment daylight with the proper lamp color, thus reducing eyestrain, and should not produce glare on computer screens.
- Electric light control in daylit rooms is dimming, not stepped, with manual override off.
School district requirements are driven by the need to reduce energy and maintenance costs. Some of these requirements are as follows:

- A mechanical system optimized for energy efficiency.
- A mechanical system with the lowest possible energy cost based on school scheduling.
- A mechanical system which can be properly operated and maintained.
- A control system that can be remotely monitored from a central computer.
- Proper lighting power density design such that the installed electric lighting design footcandles are between 30 to 45 fc at night.

**School Commissioning Challenges and Process**

The K-12 school construction schedule often requires extra attention. Timelines for designing and constructing schools are often tight because the fall start date for classes is a fixed milestone. The commissioning authority's challenge is to work with the design and construction teams to meet this deadline, and have the systems completely tested prior to the first day of classes. By being involved in the design and submittal review process, the commissioning authority can accelerate the construction schedule by catching any errors or problems while they are still on paper. An HVAC controls coordination meeting prior to submission of the controls submittal helps this process and is highly recommended. This meeting is attended by the commissioning authority, owner, general contractor, mechanical engineer, controls engineer, and mechanical equipment manufacturer. The purpose of this meeting is to go through the sequences of operation and systems requirements in great detail so that all wiring and system interface issues are openly discussed and addressed as early as possible. As a result, the controls contractor should not have to revise and resubmit their submittal because they will have a solid understanding of the design intent and project requirements. A similar meeting should also be held to address lighting control issues to ensure that the owner is satisfied with the lighting control scheme, and the contractor is clear with the requirements of the system and the commissioning process. By meeting with all of the appropriate parties and getting these coordination issues addressed prior to construction, the construction process will be smoother, and the lines of communication for quick resolution to problems will be opened.

**Lessons Learned**

When understood, the lessons learned with every commissioning project can enable the next project to go more smoothly and be better optimized for comfort, energy, and indoor air quality. When something is either overlooked, or value engineered to produce a less than satisfactory product, the owner may wind up living with the problem for years past the warranty period before it becomes a large enough issue to correct. When a commissioning authority is involved early in a project, these types of issues are more readily caught, brought to the attention of the owner or design team, and addressed in a timely fashion. The following are some lessons learned by AEC in its commissioning authority role.
Classroom Mechanical and Control Lessons

False money savings

During a value engineering session in the design phase, it was decided that it was not worth the cost to continue the DDC system into the classrooms. Instead of DDC system thermostats and controls, floating point hot water reheat valves were used with stand-alone thermostats with a range of 50-90 °F, and setpoint gradations of 5 °F. The problem with the proposed inexpensive thermostats was that when a teacher tried to change the temperature by a few degrees, the adjustment level would create dramatic changes in the setpoint. Night setback control became difficult to implement without a zone level DDC system, and the heating system had standby energy losses at night because the hot water flowed through open zone reheat valves with no airflow.

False comfort problems

False or misleading comfort problems can appear when an occupant has setpoint adjustment capability and can constantly look at an LED readout of the current temperature. Occupants are not aware of deadbands and zero energy bands associated with zone-level temperature control. If the sensor readout does not match the user-adjusted setpoint, the comfort complaint gets logged. We have found that it is much easier on the maintenance staff if the room thermostat is replaced with a plain sensor, and all setpoint changes only occur at the DDC interface with proper password protection.

Anticipation of scheduling needs

When maintenance is needed on a school classroom VAV box or reheat valve, it is often difficult to perform the required work if the class is in session and the devices are located in the ceiling above the class. To avoid schedule conflicts and education interruption, it is important that all zone control devices be located above hallways and corridors whenever possible. As a result, post occupancy commissioning efforts and maintenance checkout can be easily performed while class is in session.

Solving one problem while creating another

The design of an energy efficient mechanical system in a climate with favorable outdoor temperatures for space cooling included integration of the classroom VAV box airflow with the window position. This project had a minimum of three operable windows per classroom, each installed with a magnetic sash-mounted sensor switch to be monitored in series by the classroom DDC system. The theory was that if any window is open, the VAV box airflow can be closed off, and therefore reduced airflow can save energy at the air-handling unit from reduced airflow. The reality of the situation is that including all the window status contacts in the control wiring added a significant number of additional points of possible failure. After months of troubleshooting the window contacts, the concept was completely abandoned. Energy saving schemes need to address and consider persistent energy savings for the life of a project, and if it becomes too complicated or has too many potential points of failure, the scheme is not worth implementing. This is especially true in a school facility, where simple design rather than complicated interlocks will likely better achieve persistent energy savings.
Building Level Mechanical System Lessons

False money savings

One way to reduce mechanical installation costs is to rely on barometric relief rather than provide for powered building exhaust. In many schools in the Denver area, barometric relief dampers installed in every classroom and other common areas has reduced installation costs. Barometric relief dampers work well for the first several years of their life, but tend to fail over the long term. The failure state of a barometric damper can be any position, thus resulting in either a permanent hole in the ceiling or a closed damper creating an over-pressurized space. Scheduled and frequent verification of barometric dampers (which are above classroom ceiling tiles, and therefore potentially difficult to access) is required to make sure the system is operating properly. Using plenum return transfer grills and a building pressure sensor controlling an exhaust fan is more reliable for proper building pressure control. This method also provides for considerably fewer roof penetrations and moving parts to maintain. A regular preventative maintenance schedule can reduce fan problems while current transducers can indicate whether the system is not operating properly by showing if a fan is in alarm state.

Solving one problem while creating another

In hopes of giving each classroom good temperature control, and to reduce the impact associated with a broken air handing system, one school district decided that each classroom should have its own small packaged rooftop unit. In a middle school, this resulted in over 50 small packaged rooftop units, each with factory-installed economizers, DX cooling, and hot water reheat. The result? Fifty roof penetrations to keep from leaking, 50 small (3-5 ton) DX systems to maintain, 50 airside economizers to maintain, and 50 filter sections to periodically replace. The statistics of this type of design almost ensure that there will always be something to fix and maintain, and at least one classroom suffering comfort problems when its system is down. Ceiling plenum heights were also a major factor in this design, as there appeared to be insufficient space to duct air through the building from a central air-handling unit. When the project was complete, the teachers were happy that their noisy old unit-ventilators were replaced with rooftop units, and so far the maintenance issues have been persistent but not overwhelming.

A loss of free-cooling

For maintenance convenience and to reduce the visual eyesores on the roof, all of the air-handling units were installed in a crawl space under the school. Because of this, the outside air was ducted from the roof of the building down to the crawl space and into each air-handling unit. This school is located in Denver, where airside economizers are a viable energy efficient component of the mechanical design. The problem with this approach is that when the outside air is ducted to the crawl space, it gains heat energy through the insulated duct walls, and the resulting outdoor air temperature measured at the air handling unit in the crawl space was often 5 to 10 degrees above the actual outdoor temperature (see Figure 1 below). The chiller plant therefore had to be enabled at a lower temperature than originally intended because the airside economizer system was not nearly as effective as the designer thought it would be.
Occupant problems

Students can find pleasure in hitting or kicking at thermostats in hallways, especially if they are mounted inside a large guard enclosure. At nearly every retro-commissioning school project, broken thermostats and missing thermostat guards have been found. We recommend that these installations use either a mechanical device with an integral thermostat that is completely concealed, or a stainless steel plate temperature sensor monitored by the DDC system. Hallways and stairways do not usually require perfect temperature control, and therefore a sensor that outlasts a child’s outburst will prove to be very effective for many years.

False economies

Twenty years ago unit-ventilators were the preferred solution to providing individualized comfort control in every classroom because of their individual fresh air intake capabilities. Today school districts are either adding DX cooling, or repairing / refurbishing the unit-ventilators, not realizing that teachers often prefer to keep them turned off because they are too noisy. It has proven difficult to meet current classroom noise standards with a unit-ventilator installation, and even the quietest unit-ventilators are often turned off by the teacher because of noise complaints. Fan speed control can help when the heating or cooling loads are not at design levels, but most of today’s unit-ventilator fan speed controls are hidden from normal occupant adjustment. Rather than spending money to refurbish bad and outdated technology, a better use of school district money would be to replace the unit-ventilator with a rooftop unit with VAV boxes.

Maintenance Related Lessons

Small solutions leading to major problems – 1

When maintenance programs are poorly funded and understaffed, and the maintenance staff does not have time to properly repair equipment, a minor band-aid fix can make system problems exponentially worse. Providing a domestic water line plumbed into the hot water system, while initially appearing to be a reasonable design, opens the door to major problems because when the

Figure 1: Outside Air Temperature Differences
glycol tank runs dry (because there is a leak in the system that has not been repaired for months) it is too easy for a maintenance person to open the domestic valve and pressurize the system with tap water, thus temporarily solving the system flow and comfort problems. The glycol and rust inhibitor concentrations then become less than adequate and soon the school is plagued with freezing coils and clogged strainers and valves.

**Neglecting routine maintenance**

School maintenance departments are often understaffed and have difficulty executing a preventative maintenance program because they are too busy dealing with “today’s crisis.” When hot water system pressures are not routinely checked, a leak can go undetected for many months, resulting in a loss of fluid and pressure. Such was the case at a retro-commissioned two-story school. Because the system pressures had dropped far below design levels, the second floor classrooms’ reheat coils became starved for flow, and the rooms became very cold in the winter. Fixing the leaking air separator, and charging the system to design levels, returned the flow to the second floor, and restored comfort. A properly operating glycol fill tank with a monitored alarm would have allowed the maintenance staff to solve the problem long before it affected the occupants’ comfort.

**Small solutions leading to major problems – 2**

When a school maintenance program mainly handles crises, some of the solutions to comfort problems can fix the problem in the short term, but use excessive amounts of energy over time. This was the case at a retro-commissioned four-year-old middle school. The school had a DDC system with pneumatic actuators that were not functioning properly. We discovered that the transducers were not properly set up, and consequently when the maintenance staff investigated problems with the air handler controls, they found the hot water and chilled water valves operating inconsistently with the DDC system output signals. An immediate solution was to remove the control air to the valve actuator, and either leave the actuator in its fail position or put main air to it. In some instances, the butterfly valve linkages were completely taken apart and left hanging. These solutions appeared effective until the seasons changed and the opposite valve became needed. Eventually, the school district energy manager noticed excessive energy bills and comfort complaints and initiated a retro-commissioning project for the school. After correcting the actuator and transducer problems, as well as cleaning up some programming errors in the DDC system related to boiler controls, the comfort complaints ceased and the energy use dropped dramatically. The gas consumption savings were determined to be close to 46% (Figure 2), and electrical kWh savings were 22% (Figure 3) from the average of the previous two years.
Lighting Control Lessons

Daylighting is desirable in school settings, as studies have correlated it with better bone growth in children, faster learning rates, more attentive students, and a greater sense of harmony with the natural environment. Lighting controls are essential to obtain consistent and controlled lighting levels in the classrooms, regardless of the daily and seasonal fluctuations of daylight. However, a significant gap has routinely been observed between the lighting design and the finished product.
Specifications and coordination

In HVAC systems, CSI Specification 15990 exists to ensure that flow rates have been set according to design. There is, however, often no specification to ascertain that the installed lighting controls will be properly set for a particular illumination (footcandle) level. In fact, the desired levels often do not appear in the design documentation, which makes it particularly difficult to enforce a specification, and for the commissioning authority to verify proper settings.

Where the particulars of lighting controls are concerned, it is recommended to involve the electrical engineer, the lighting control manufacturer, the commissioning authority, and the owner in the design phase. Design charrettes can help to choose desired light levels on surfaces in offices, hallways, classrooms, and teaching boards as well as different audio and visual requirements or “scenes,” and dimming control parameters. From experience, we have determined that it is imperative that the design engineer indicate that the contractor is responsible to not only install the controls, but adjust and verify each setting and footcandle level per design. The installation can then be readily demonstrated by the installing contractor to the commissioning team according to functional performance tests created by the commissioning authority.

Design discussions and planning

At one school, this gap was especially problematic due to the complexity of the system. Value engineering removed photocells from each room and placed one in each cardinal direction. This, as well as audio-visual scenes, had to be integrated into a smoothly operating, user-friendly lighting system. As a result of lack of detailed deliberations in the design phase, much effort and new funds were required to set up the system during construction. AEC (acting as the commissioning authority) organized charrettes with owner, contractor, and manufacturer; and then developed and implemented procedures so that the lighting could be set per the redefined design intent and owner comfort levels. It is important to remember that installing lighting systems does not imply that they will function according to design intent. The controls, once installed, must be tested and adjusted to meet design goals and satisfy the majority of the occupants. Detailing the expectations and goals of the lighting system in the design documentation is crucial to the success of the installed and operating system.

Appropriate use of personnel

Training the owner on the lighting system is also important. However, training the owner with the goal of having them commission the lighting controls is not advised. In the process of setting up the lighting system, the installing contractor weeds out unforeseen problems and provides solutions. To expect the owner to debug and set up a complex lighting system is not recommended as the repairs are not always simple. More often than not, the owner will become frustrated or overwhelmed with the magnitude of the effort and the quantity of deficiencies found. The specialist (lighting control manufacturer’s representative) has the expertise to set up the system completely and train the owner to make adjustments of a system that has successfully passed functional performance testing.
Appropriate sensor placement

One common component of a lighting control system is occupancy sensors. Sensors are frequently mounted in inappropriate locations, set for inappropriate delay times, or otherwise misused, which causes occupants to become frustrated and request that they be disabled. If sensors are disabled, the customer stops reaping the benefits of reduced lamp use or energy savings, and has bought useless equipment. Although the contractor is responsible for proper placement of the sensors, this is not always accomplished. On one project, the occupancy sensors were ultrasonic and were located near air diffusers. The air noise kept the lights on at all times and the contractor’s adjustments of sensitivity did not solve the problem. When the contractor moved the sensor, it was placed above a suspended light fixture. The result of this relocation was that the occupancy sensor would frequently turn lights off while students sat in the room because they were out of view of the sensor. A third location was then selected for the occupancy sensor, and the problems were finally remedied.

Appropriate training

Training the school maintenance staff, especially at a school where many people use the same equipment, is challenging. Instead of a typical training setting, we recommend an assembly of all staff who plan to use the rooms with automated lighting controls. This assembly should include 1) hands-on training, 2) a question-and-answer period, and 3) filming for future reference. If all staff are told that they must be trained before using the audio-visual and lighting controls, the quantity of complaints from otherwise frustrated teachers can be dramatically reduced.

Getting the right information to the right people

In a school environment, students are likely to be curious and will play with all of the available lighting controls. Sturdy controllers and informed students will prevent lighting system component casualties. At a college, a circular plastic dimming control was available for the users to dim the lights lower than what the photosensor determined the maximum value to be. Maximum lamp light levels were calibrated based on a design footcandle level on the desktop. As daylight entered the room, the lights were automatically dimmed. Thinking that the lights were too dim, and unaware of the function of each component, the occupants would twist the dimming control knobs up until they eventually broke. The manufacturer has since redesigned the dimming knob with a steel shaft, and has replaced all of the knobs in the project under warranty calls.

Occupants must clearly understand and accept dimming control where the lights are allowed to turn off when there is sufficient daylight harvesting. We have seen buildings where tape has been placed over photocells to increase light levels or keep lights on, which reduces the benefit of the installed control to zero. Typically, on/off only (no dimming) light control does not work well for daylighting and is not recommended. This provides too great of a disparity in light level at the time of switching. Stepped lighting controls can be appropriate in hallways and other common spaces. The seamlessness of daylighting control in a classroom will be less distracting to students and teachers if dimming controls and ballasts are utilized over on/off or stepped controls.
Summary

Because children spend a considerable number of their daytime hours in a school environment, it is imperative that architects and engineers provide the best possible learning environment. By being aware of the challenges that school districts face with understaffed maintenance programs and rising energy costs, commissioning providers can help to create a facility that will withstand the test of time, and achieve high levels of energy efficiency. Proper use of a commissioning authority for a school facility will result in a properly ventilated and healthy learning space that is designed and commissioned for learning and longevity.