Commissioning Through Digital Controls and an Advanced Monitoring System - *A Project Perspective*

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In recent years, commissioning of HVAC and electrical systems has been in the forefront of American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) initiatives to address a more efficient building turnover process. While the current practices followed by building owners and facilities engineers already include many of the elements of commissioning delineated in the ASHRAE guidelines, most do not, however, have a comprehensive approach to the commissioning challenge for their facilities. Ideally, such a comprehensive program would allow the building owners and facilities engineers to incorporate an integrated design process and commissioning under an overall quality assurance program for their facilities or projects. Furthermore, the use of on-site, project-specific data monitoring equipment and digital energy management control system during the commissioning process is critical to the successful system shakedown and performance verification effort.

The government of a Maryland county has applied the commissioning process in a mixed-use, multi-user government facility. A comprehensive array of monitoring equipment was installed with the assistance of the local utility for the specific purpose of facilitating the commissioning of the a state-of-the-art HVAC system and for real-time monitoring of its performance. The results of this monitoring effort have been data rich with solid lessons that can be shared with the ASH RAE community. Specific lessons include:

- Points to Monitor - How much is enough?
- Software vs Hardware - What to use and when?
- Reality Check - Who's interpreting the data?
- Cross Check - Is anybody watching?
- Air Balance - Helpful hints from Bill & Harvey.
- Commissioning Thermal Storage - Is there any ice left?
- Use of EMS in Trending System Performance.

Introduction

Owners and facility engineers engaged in the design and construction of buildings all have horror stories about buildings with serious flaws upon occupancy, such as HVAC systems not functioning correctly and temperature control systems with logic that would baffle the best of minds. Annoying problems such as unreliable temperature controls, overheating and overcooking of various zones, lack of credible air balancing, absence of building pressurization, and poor documentation continually to exasperate the facility engineers long after the building is occupied. Commissioning during the construction process can alleviate most of these headaches and facilitate the completion of building turnover to the owners, design engineers and building operators.

With increasing microprocessor capability in the direct digital control (DDC) technology that are available in the marketplace, opportunities are present for its use during the commissioning process. Because of the integration, flexibility and sophistication and monitoring capabilities inherent with the DDC controls, all major pieces of mechanical equipment can take advantages of its features. In fact, if applied properly, the monitoring capabilities should prove to be invaluable during the commissioning process. The building owners can be assured of properly functioning HVAC systems, the engineers and mechanical contractors can have confidence in the expected system performance of the installed equipment.

The county in Maryland completed a commissioning effort on a multi-user, mixed-use government center in 1991. With the assistance of the local electric power utility, other monitoring points were installed in addition to the standard HVAC control points for the expressed purpose of monitoring the system performance of the various state-of-the-art energy systems and components designed into this new facility. The intent was to use an array of monitoring equipment as the overarching arm for commissioning. Applying monitoring equipment and using the capability of DDC energy management control system have provided bountiful insights into the workings of the HVAC system. The results revealed numerous system problems that were not known before. Installation and design problems that normally would have gone unnoticed have been discovered as result of the commissioning effort.

Project Description

The facility is a three-story, L-shape county government building designed as a one-stop services center with several agencies as major tenants. These agencies include social services outreach, a community clinic, family counseling, school counselor offices, recreation offices, a day-care and a community library. The building is 94,000 square feet costing $8.23 million to build. The building cost was no higher than a conventional energy-inefficient building. The building was $2.0 million below budget or 20% lower than expected.

The building has numerous energy efficiency features in its design, including the following:

- **Window Optimization.** The fenestration areas were optimized through energy computer simulations. Low-emissivity exterior glazing was used throughout the building. Daylight transmittance and insulating values through the windows were also optimized in order to minimize annual lighting, heating and cooling loads.

- **Perimeter Daylighting.** A system of 350 fluorescent automatic dimming controls on all perimeter light fixtures reduces lighting energy in proportion to natural light available.

- **High Efficiency Lighting Design.** A lighting system was installed with the lowest life-cycle cost throughout. The installed lighting wattage meets ASHRAE standards (ASHRAE 90.1-1989). The entire lighting system is controlled through the energy management system (EMS).

- **High Performance Thermal Envelope.** The wall and roof are insulated with high-density, high-R-value rigid insulation throughout.

HVAC System Description

The facility is an energy showcase, with numerous state-of-the-art energy systems integrated into the design of the building. The advanced energy technologies incorporated into the building include the following:

- **Ice Harvesting Thermal Cool Storage System** - The system was installed for peak demand limiting using a weekly load shifting strategy. The ice storage system was selected over a hydronic heat pump and variable speed centrifugal chiller alternatives because of its lower life-cycle cost.

- **Low-Temperature Air Distribution System** - The system utilizes 32°F water temperature in the coils and 42°F primary air temperature in the main ductwork. The ventilation rates are designed to comply with ASHRAE ventilation standards (ASHRAE 1989). This system uses smaller air handlers, pumps and fan motors. Extra insulations were installed on the primary ducts to prevent condensation. Also the ductwork and mechanical room floor space were reduced.

- **Variable Air Volume Air Handlers** - The fan systems are driven by variable-frequency drives for maximum part-load energy savings.

- **Electric Heat Thermal Storage System** - The system was designed for winter peak load shifting by storing space heating thermal energy at 1.5 cents per KWH instead of the peak rate during the day.

- **Variable-Flow Hydronic Piping Systems** - Both the chilled water and hot water systems use pumps driven by variable frequency drive. The coil design utilized two-way valves.

- **Direct Digital Control System** - The system utilizes central DDC monitoring equipment with pneumatic actuators at valves and VAV boxes.

Energy Performance

The facility was assigned an energy performance budget of 57 KBtu/ft^2/yr. The historical energy performance index for similar building type in Montgomery County was 109 Kbtu/ft^2/yr. The assigned energy budget was a 48% reduction over the typical building of the same category. In the 2 1/2 years of operation, the actual recorded energy use has been 64 kbtu/ft^2/yr. This usage rate is 17% higher than the design energy budget. But the actual energy use is still 41% reduction over the historical data.

The projected cost avoidance due to energy use was to be $59,220 per year or $2,368,000 over 20 years of expected equipment life.

Control System Architecture

The control system utilized in the facility is a combination of direct digital control using central computer monitoring with pneumatic controllers and actuators for the dampers and valves. This combination of DDC and pneumatic control systems was made during the design, incorporating the concerns and input by the maintenance personnel who are more comfortable with the pneumatic devices. Pneumatic-type actuators were selected for their simplicity of maintenance, longevity, and low cost. The DDC controls were used for monitoring taking advantage of its flexibility, ease of diagnostics, and troubleshooting capabilities. The sensors used were all electronic due to their inherent accuracy. The sensors were installed on all major pieces of equipment. Signals were direct-wired back to the field panels in the mechanical room and also transmitted over the phone line to the central energy management computer console. Table 1 includes typical control points.

Levels of Monitoring

There were three levels of control points installed in the facility. Level one contains the standard HVAC control points. Figure 1 shows a typical set of monitoring points in an air handler unit. Level two provides monitoring points for the special energy-efficient technologies installed in the facility. Figure 2 shows the monitoring points for the electric hot water thermal storage system for winter peak demand shaving. Figure 3 shows the monitoring points for the ice harvester thermal cool storage system. Figure 4 shows the monitoring points for the cooling tower which operates in conjunction to the ice harvester.

Level three covers the energy metering points and contains the special set of monitoring points installed by the local utility for monitoring energy performance of the various systems and components. Examples of the metering points include:

- heat thermal storage BTU meter
- heat thermal storage KWH meter
- chilled water BTU meter
- building KWH meter
- lighting KWH meter
- chilled water GPM flow rate
- heating hot water GPM flow rate
- domestic hot water GPM flow rate
- ice harvesting thermal cool storage KWH meter
- air handler KWH meter
- hot water pump KWH meter
- condenser water pumps and cooling tower KWH meter
- chilled water pumps and recirculating pumps KWH meter

Lessons Learned

Lesson One: Points to Monitor - How Much Is Enough?

Commissioning begins with a proper set of monitoring points that are well defined in the construction documents and clearly delineated in the commissioning plan. Successful commissioning can only occur if the construction documents fully describe the points to be monitored and a well-defined commissioning plan is included in the specification. The question that should be asked prior to beginning the monitoring process and the design of the EMS control points should always be "What's in the (Commissioning) Plan?". If the points are vaguely defined in the construction documents, be it on the drawings or in the specifications, it is difficult for the contractor to install them, and the engineer certainly should not be addressing this issue during the controls equipment submittal stage. Unfortunately that frequently is the case on many projects. It is not unusual for the design engineer to be defining or clarifying for the controls subcontractor the intent of the control sequences. The owner often is forced to pay for added costs if critical monitoring points are missing from the bid documents.

How much is enough? How many points should be monitored? That should be decided by the design engineer in consultation with the owner's operating personnel during the design. As a practical matter, given the cost competitive nature of DDC systems, the cost differential between a bare-bones number of monitoring points and a fuller and more complete set is marginal. For example, a main cabinet from a manufacturer may be $8,000, each extra point may cost only $200 more. Every owner/operator to insist that the design engineer carefully define the scope of monitoring and control points. Actually, a full complement of points not only enables the owner's operating personnel to more efficiently maintain the system performance, it also save tremendous time for the design engineer during the building turnover phase of the construction.

Air Flow Monitors. A painful lesson was the omission of air flow monitoring stations on both the supply air and return air duct systems. In variable-air-volume (VAV) systems with variable speed drives (VSD), the lack of actual air flow data is a very serious operating handicap because, given the fluctuating system air flow rates, it is nearly impossible to obtain an "air balance" in the air distribution system, be it primary or secondary. Because

Table 1. Typical Monitoring Points in Main EMS Cabinet

28-JUL-93 MONTGOMERY COUNTY: UPCOUNTY
10:08 Cabinet Point Value Log
Network: UPCOUNTY Point: GCA1?? All Cabinets

Name	Address	Descriptor	Value		Units	Condition	Priority
GCA1WU	#02800K99	AH1 WM UP FL	OFF			-N-	None
GCA1SP	#02900000	DISCH STATIC		1.471	IN H20	-N-	None
GCA1DA	#02900001	DISCH TEMP		41.625	DEG F	-N-	None
GCA1RH	#29000002	RETURN HUMID		42.250	PCT RH	-N-	None
GCA1RA	#02900003	RETURN TEMP		74.767	DEG F	-N-	None
GCA1ST	#02900004	1FL ADMIN TE		73.367	DEG F	-N-	None
GCA1ZS	#02900006	1 ZONE STAT		-0.033	IN WG	-N-	None
GCA1SS	#02900016	1ST FLO AHU	ON			-N-	None
GCA1WM	#02900017	WARMUP MAIN	OFF			-N-	None
GCA1VM	#02900018	VAV AIR MAIN	ON			-N-	None
GCA1NM	#02900019	NIGHT MAIN	OFF			-N-	None
GCA1RF	#02900025	RET FAN PRF	On			-N-	None
GCA1DM	#02900100	MIXING DMPRS		9.000	PSIG	-N-	None
GCA1CV	#02900101	CONTROL VLVS		11.351	PSIG	-N-	None
GCA1SV	#02900102	SFAN SPEED		11.902	PSIG	-N-	None
GCA1RV	#02900103	RFAN SPEED		9.902	PSIG	-N-	None
GCA1OC	#02900A01	OCCUPANCY FL	ON			-N-	None
GCA1NS	#02900A02	NITE SETBACK	OFF			-N-	None
GCA1CD	#02900A03	COOLDOWN FL	OFF			-N-	None
GCA1ES	#02900A04	ENTHALPY FL	ON			-N-	None
GCA1WN	#02900A05	WKDAY START		3.000	TIME	-N-	None
GCA1WF	#02900A06	WKDAY STOP		23.500	TIME	-N-	Operator
GCA1SN	#02900A07	SATDAY START		6.000	TIME	-N-	None
GCA1SF	#02900A08	SATDAY STOP		22.000	TIME	-N-	None
GCA1NT	#02900A09	SSTO START		3.000	TIME	-N-	None
GCA1FT	#02900A10	SSTO STOP		22.500	TIME	-N-	None
GCA1RE	#02900A11	RA ENTHALPY		26.387	BTU	-N-	None
GCA1PS	#02900A12	STATIC PR SP		1.500	IN WG	-N-	None
GCA1DS	#02900A13	DA SETPOINT		42.000	DEG F	-N-	None
GCA1DR	#02900A14	DA SETP RAMP		42.000	DEG F	-N-	None
GCA1UN	#02900A15	SUNDAY START		7.000	TIME	-N-	None
GCA1UF	#02900A16	SUNDAY STOP		18.000	TIME	-N-	None
GCA1VS	#02900U98	VIRT STATIC		0.000	IN WG	-N-	None
GCA1ZP	#02900U99	1 ZN ST SET		0.050	IN WG	-N-	None
GCA1DC	#02900Z01	CHANGEOVERPT	OFF			-N-	None

***End of Report+++

of the lack of air flow monitors, the outdoor air damper setpoint is difficult to ascertain at the outset and infiltrate rate is unknown. How much outdoor air is sufficient for a given air flow rate is not known during actual operation. The lack of sufficient outdoor ventilation is the cause of most indoor air quality complaints. Airflow monitors should be installed in every VAV system so that the building operator to ensure sufficient outdoor air is introduced into the building via the ventilation system (Figure 5).

CO2 Sensors. Another useful device that could have been useful had it been available is the CO2 monitors for use in the air handlers. At the time of the construction, available CO2 monitors were uncommon and of doubtful accuracy. The newer generation is much more reliable and is an effective monitoring point of adequate outdoor air ventilation. For future projects, CO2 monitors in the return air plenum are highly recommended.

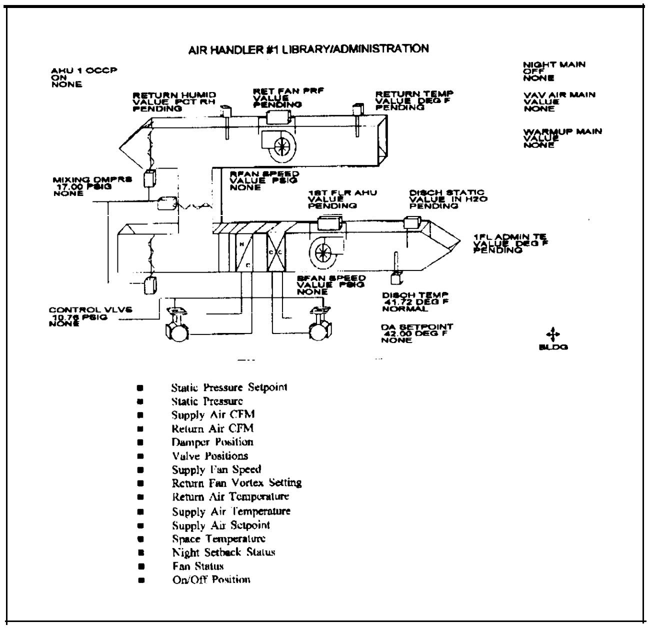

Figure 1. Typical Monitoring Points in Main EMS Cabinet

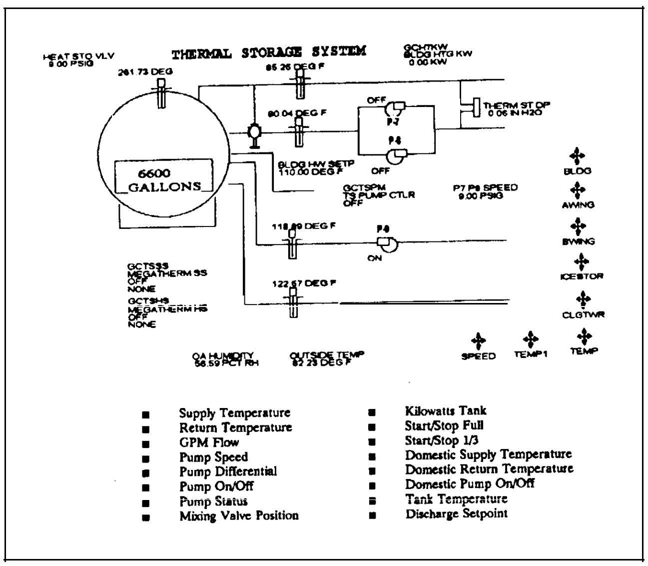

Figure 2. Monitoring Point for Electric Hot Water Storage

Multiple Thermistors. One space thermistor was installed for each air handler in the facility. However, experience has shown that there may be temperature swings within the same air-handler zone. One area in the zone may read 74°F while the another area may have 78°F. This temperature variation within the same zone is a source of numerous trouble calls by the occupants. It is recommended that more than one thermistor be installed for each thermal zone. If several thermistors are installed in a zone being served by the same VAV box, space temperature setpoint can easily be adjusted either using averaging of thermistor readings or modulating the VAV

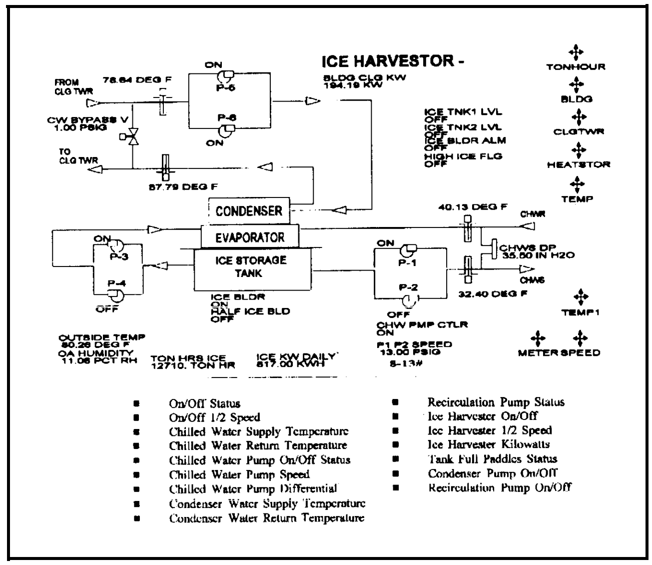

Figure 3. Monitoring Points for Ice Thermal Cool Storage System

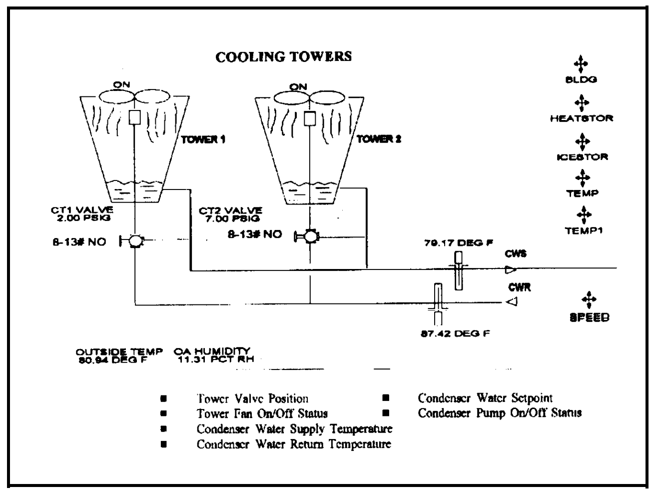

Figure 4. Monitoring Points for Cooling Tower

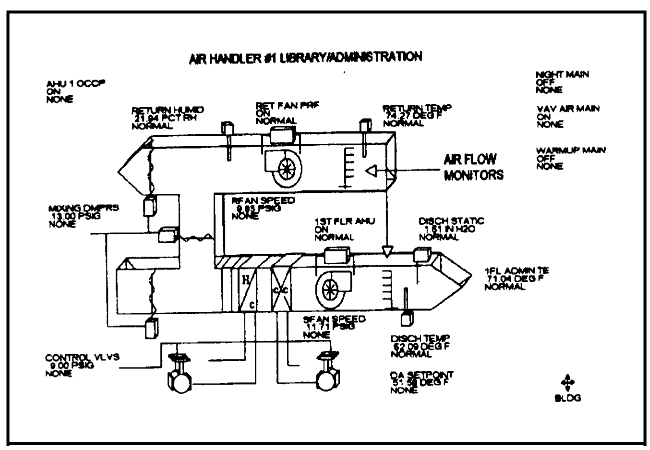

Figure 5. Air Flow Monitors for Supply/Return Fans

supply air to the zone. Another limitation of using one thermistor for each air handler is the inability to reset supply air temperature correctly. This shortcoming also affects the proper operation of the VAV boxes.

Return Fan Control. Another example is the omission of on/off control points on the return fans. The design engineer equipped the return air fans with vortex dampers instead of variable speed drives (VSD) in order to save money. However, the vortex damper allowed the return fans to modulate, only to a minimum position of 35%. They cannot turn the return fans off. Yet, the VSD-controlled supply fans can go down to 10%. Thus, the combination of VSD-controlled supply fans and vortex-damper-controlled return fans has proved to be less than ideal due to the inherent incompatibility of the two devices as a method of modulating airflows. It is recommended that if VSDs are applied, both the supply and return fans should have them. At a minimum, on-off controls on the return fans would have allowed for adequate control.

Lesson Two: Software Versus Hardware - What to Use and When?

The control system described above was a combination of pneumatic controllers and actuators with a DDC central monitoring system. It was considered the ideal combination by many design engineers at the time in 1989-1990, when the building was designed. Our operational experience shows clearly the limitations of this combination of control technologies. The pneumatic actuators do not monitor. The pneumatic controller can only provide feedback as to the range of control pressures it operate. In fact, the pneumatic components of the installed control system seriously degrade the capability of the central DDC system.

A question that often confronts a design engineer is whether a control setpoint should be a hardware point or a software point. Generically speaking, a hardware point is a physical device or sensor installed on a piece of equipment or piping, whereas a software point is derived data resulting from the mathematical combination of several hardware inputs.

Hardware Points. Hardware points are a necessity. A good set of hardware points, carefully selected and properly located on the HVAC system by the design engineer, can perform tremendous functions during commissioning, debugging, and operation. Therefore, due to their nominal cost, extra sensors often more than pay for themselves in the first year of system shakedown. These monitoring sensors are well worth the investment by the owner and should be included in the design document by the design engineer. The key is specify enough hardware points to provide intelligent data for system diagnostics. It should not be left up to the control vendor or subcontractor to determine what and how many hardware points ought to be included in the bid documents. The design engineer's rationale of using a "performance-based" control system specification with vague control instructions is unsound and a disservice to the owner. For instance, discharge air temperature resets for the air handlers were left out of the project by the design engineer. This omission created unnecessary energy costs as well as nuisance maintenance calls for the contractor once the building occupied during the first year warranty period.

Software Points. The software points are derived from input data from a set of hardware points. The software points offer a multitude of monitoring possibilities. For instance, the project had seven space sensors installed—one for each of the air handlers throughout the building. By scanning the readings of the sensors, a software point showing average building temperature each month was derived. Another example is the determination of ice tank capacity, which can be calculated using readings from several hardware points. Another useful software point is the peak demand monitoring point for various equipment. With the software point, exact energy use and peak equipment load can be provided for either on-peak or off-peak periods. Software points can be easily added by the operating EMS technicians for data analysis, trending, and, with the use of spreadsheets, and predictions.

Lesson Three: Reality Check - Who Is Interpreting the Data?

When the DDC and monitoring are used for commissioning, it should be noted that one should not automatically believe all reading or data collected. What can be observed may not be what is actually happening. The information gathered by the DDC points needs to be sifted carefully for the following.

- Conflicting Energy Metering Data. The KWH and KW demand data were found to be conflicting. This discovery during commissioning indicated the need to do a reality check on the program to make appropriate changes to accurately measure electric demand.

- Software Errors. Bad programming by the controls contractor is a serious problem that, unless caught during commissioning, can easily remain invisible for a long time. On this project, the county's energy staff discovered and corrected over 100 software programming errors made by the contractor's controls technicians.

The discovery of multitude of programming errors by the controls subcontractor, who is a major controls manufacturer in the industry, demonstrates the need of oversight. This oversight function should be provided by the commissioning authority, with competent input and reviews by the design engineer. For an unsophisticated owner, the lack of careful checking of the controls programming will expose the building operation to mysterious failures and malfunctions.

Lesson Four: Cross Check - Is Anybody Watching?

The need for cross checks using the monitoring points during commissioning is not optional-it is a must! The verification phase of any commissioning effort would be ineffective without cross checks. The cross checking, be it by the owner's representative or the design engineer, cannot be cursory, such as is traditionally performed by the design engineer during the construction administration phase. Rather, the entire cross-checking effort needs to be a disciplined and structured one, as can be done if commissioning is included in the construction documents. If the design engineer has applied the recommended practices contained in ASHRAE (90.1-1989), much of the data on equipment and system performance can be easily compiled by the contractor and subcontractors. The commissioning requirements, as delineated in the specification, should be enforced by the commissioning agent for the owner.

Some pointers from this project include:

- **Changing Control Sequences.** Three versions of the control sequences for the thermal cool storage system were tried during commissioning. One by the design engineer was immediately proven to be unworkable. One version was suggested by the owner's project engineer, and a third version by owner's energy management technicians. The sequence of operations for the thermal cool storage system was not clear on the drawings, nor was it described by the design engineer in the specification. Control schematic diagrams were not properly depicted on the drawings. The design engineer should not just rely upon the controls manufacturer to decide on the control sequences. The point is that energy management system (EMS) was necessary to develop the sequence.

- **Checking Equipment.** Installed equipment verification is an important step in the cross check. In this project, the VAV manufacturer supplied improperly sized terminal boxes, and return air light fixtures were specified without return air slots installed, among others. The EMS made it possible to detect these defects.

- **Illogical Control Logic.** Some of the control sequences simply did not make sense. Ramping of the supply air temperature from 65°F to 42°F in 15 minutes, as stipulated in the control sequences, is simply unworkable. The monitoring of discharge air showed wild temperature swings as a result.

- **Static Pressure Ramping.** The specified ramp of duct static pressure setpoint from 0.1 in. w.g. and increased it incrementally 0.1 in. w. g. every 30 seconds is a scheme that needs careful planning to verify the actual performance of the supply air handlers. Static pressure sensor locations as installed must be carefully checked and verified during commissioning. Repositioning of the sensors may often be necessary, depending on the monitoring results.

- **BTU Data.** The BTU data are derived from the temperature and pressure readings and the flow rates from the chilled-water and heating-water loops. Monitoring during commissioning revealed a $5,000 BTU meter installed by the local utility was defective. Coincidentally, the another BTU meter measuring the domestic hot water was also found to be incorrect. Had monitoring efforts not been made during commissioning, the defective meters would have become a warranty callback item. The faulty readings from these meters would have delayed the shakedown of the systems in the building.

Other non-monitoring related discoveries include the following:

- The discovery of several instances where the **combined air flow volume** of the constant volume diffisers **exceeded the maximum delivery** of the fan powered VAV boxes is a flag pointing to design error. For instance, a VAV box might have a specified maximum air delivery volume of 2,500 CFM, but the maximum capacity of the box produced by the manufacturer might be only 2,000 CFM.

- The **no-cost replacement** of new motors on the fan-powered VAV boxes by the mechanical contractor from 1/2 horsepower (Hp) to 3/4 Hp indicates a problem of the installation, the duct system, or the air handlers. In this project, the problem was all three.

- **Duplication of controls** was discovered. This error was costly to the owner and embarrassing to the design engineer, who specified two sets of controls that perform the same functions on the same piece of equipment. For example, in the electric heat storage unit installed, the manufacturer provided a complete set of control and monitoring points with the unit. However, the control subcontractor also provide a set of controls for the same control functions as specified by the design engineer. One set of controls and monitoring points was the disabled to keep the other set operational. In this specific incident the domestic hot water controller on the DDC system was disabled and disconnected in place.

Lesson Five: Air Balance - Helpful Hints

The issue of air balance is directly related to monitoring. It is addressed here as a lesson learned because the problem is a prevalent one. The lesson from this project is simply *"Watch them!"* This is particularly so during the air-balancing efforts by the testing and balancing (TAB) subcontractor. Owner and engineer should have knowledgeable representatives to monitor the TAB efforts. Attention should be paid to the sequencing of the balancing exercise. Did the TAB contractor balance the secondary system first or did he start from the primary distribution system?

When the TAB reports are submitted by the contractor, it is critical that the owner's representative (in this case, it may be the engineer) verify the measured flow rates by doing spot checks on both the primary and the secondary duct systems. Careful attention should be paid in the reviews of the TAB reports, particularly the notes made by the TAB technicians at the bottom of the report pages. These often include a wealth of information and indicate potential problems. For instance, odd size-balancing dampers were forced onto the ceiling diffusers by the sheetmetal subcontractor. In another instance, the county staff noticed too many notations of insufficient air flows at the fan powered VAV boxes. More curious is the fact that the mechanical contractor replaced the fan motors on many of the VAV boxes, 80%, from 1/2 Hp to the larger size at 3/4 Hp. That should be a flag for the owner's representative. Why would the mechanical contractor incur the expense of replacing new motors on the VAV boxes with the next larger size without extra cost to the owner? The county technician was able to determine that the VAV box manufacturer supplied units of the wrong size. For instance, instead of a 1,600 CFM unit, the manufacturer shipped a smaller 1,200 CFM unit. This discovery, by the county's technician, forced the mechanical contractor and the VAV box vendor to replace 80% of the 52 VAV boxes in the project at no additional cost, based on the documented evidence of units of the wrong size.

The second painful lesson was the absence of DDC controllers on the VAV boxes. This rendered the entire air balancing effort suspect. The EMS points were not present to measure the actual primary air flow rates delivered to any given VAV box by the pneumatic controllers. The constant volume fan-powered VAV boxes ensured the steady delivery of supply air via the secondary duct distribution system. These same VAV boxes, however, also masked the fluctuation of the primary air delivery. The lack of this primary air flow data was a serious problem in commissioning attempts. Given the prevalent application of VAV technology throughout the industry and the increasing reliability and versatility of the DDC controllers, it is highly recommended to incorporate DDC controllers on all VAV terminal units.

Lesson Six: Commissioning Thermal Storage - Is There Any Ice Left?

Monitoring of the ice thermal storage unit provided a wealth of information during commissioning. The initial building of the ice in the ice tank went surprisingly smoothly during commissioning. No obvious troubles were encountered. Soon after the initial run of the ice harvester, the problems began to appear. Some of the noteworthy incidents recorded from the monitoring effort include the following:

- **Ice Bridging.** The ice would continue to build up in the tank even when it reached capacity. This was due to faulty ice sensors which were mechanical paddle type wheels that rotate continuously until stopped by the increasing level of ice in the tank. The locations of these sensors did not provide a true reading of the ice level in the tank and resulted in numerous incidents of ice bridging over the top of the shield protecting the sensors. After noticing this problem, additional sensors were installed to prevent its occurrence.

- **Freeze Up.** The ice harvester would continually freeze-up over the plates (similar to the ice build-up in home freezer sections). The freeze-up would occur during the night ice-making mode and was not discovered until the next morning. The internal sensors of the ice harvester did not provide an alarm status to the EMS monitor console. This alarm status was later added during the commissioning. The freeze-up condition was attributable to the insufficient defrost cycle setting of the ice harvester. The splashes of water over the "spider type" tubing would initiate the freeze-up mode. Monitoring of the internal sensors of the ice harvester during commissioning facilitated the shake-down of the ice storage system.

Other quality-related problems were also found during commissioning of the ice thermal storage unit. These problems included the discovery of tiny pieces of metal shavings in the refrigerant dryers, indicating a manufacturing defect. The most serious quality problem was the multitude of refrigerant leaks-more than 60 of them—

found at solder joints. Refrigerant leak detecting fluids were introduced into the system. With the use of ultra-violet lights, a surprisingly large number of these leaks were observed at solder joints.

The sensors made the commissioning of the ice harvester unit feasible. The results of the monitoring provide many clues of equipment and operational problems. They also furnished capacity estimates of available ton-hours in the ice storage tank (Figure 6).

Lesson Seven: Use of EMS in Trending System Performance

An energy management system using DDC technology allows the commissioning authority to analyze trend data of various pieces of equipment. The memory requirements for trending points is quite large, but with the advent of higher capacity disk drives available in the central control microcomputers, it is now quite possible to trend a large number of points. At the facility, a total of 90 points were put in trend for one year using a 386-chip computer with an 80 megabyte hard drive. With the controls vendor software, this took 22 megabytes of memory. We also trend an additional 70 points in the 6 field panels in the building. These additional points are used only for short term records, typically a week, of equipment operation.

The ability to trend a large number of points at one time and to keep a record of them allows the building engineer to develop a pattern of equipment performance under varying operating conditions. This capability gives the commissioning authority and the building engineer the necessary documentary evidence of system performance for the mechanical equipment. The use of this trend data can be very effective in commissioning and critical to analyzing what went wrong with the system (Figure 7).

In this facility the use of trend data was helpful in solving and documenting a number of problems. The design engineer and the mechanical contractor found it very hard to argue with the data collected. It was a very powerful tool for the commissioning authority to obtain resolution of a number of problems. An example follows:

Names of Points Trended for the Problem

GCTSKW Heating KWH Thermal Storage Tank
GCTSWT Thermal Storage Tank Temperature
GCTSBU Thermal Storage BTU Used
GCTSSS Thermal Storage Stop/Start
GCTSHS Thermal Storage 1/3 Capacity
GCA/ST Space Temperatures
GCA/DA Air Handler Discharge Air Temperatures
GCA/RA Air Handler Return Air Temperatures

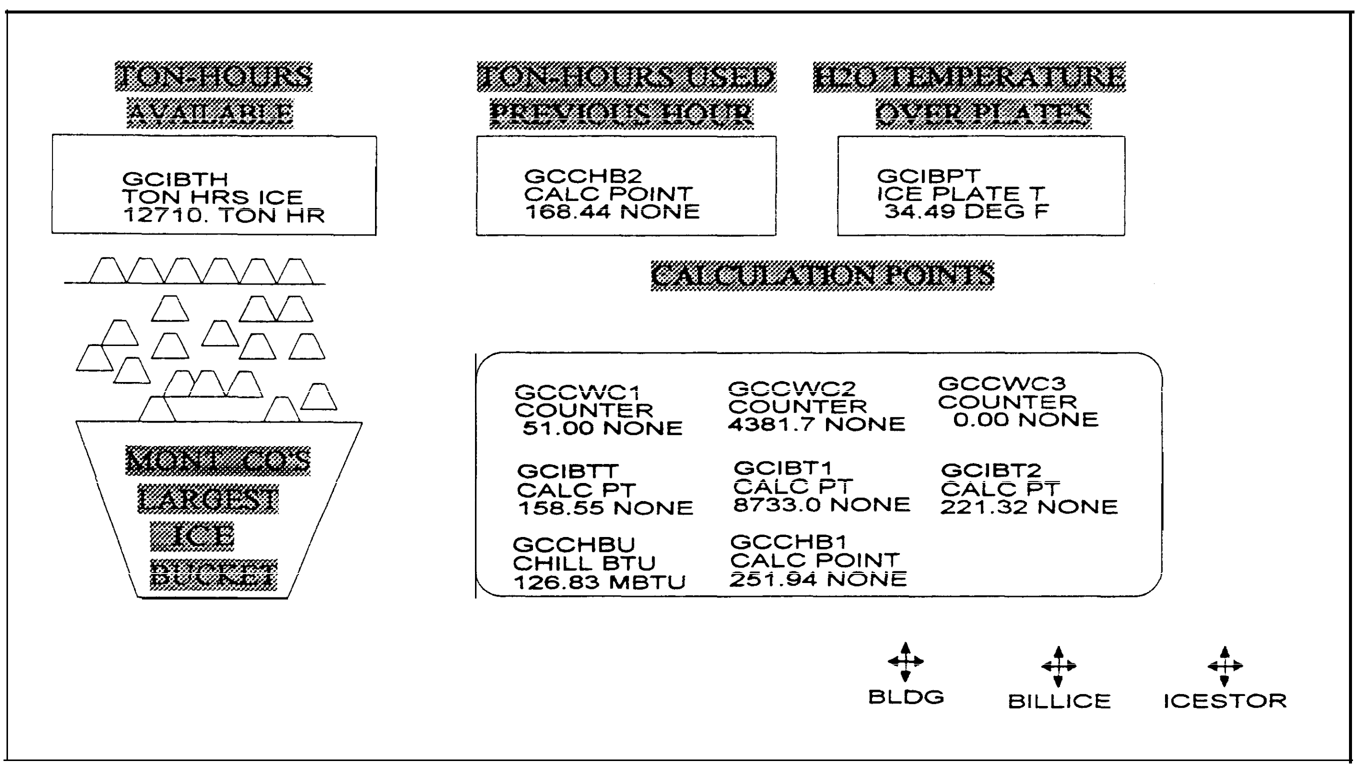

Figure 6. Ice Storage Ton-Hours

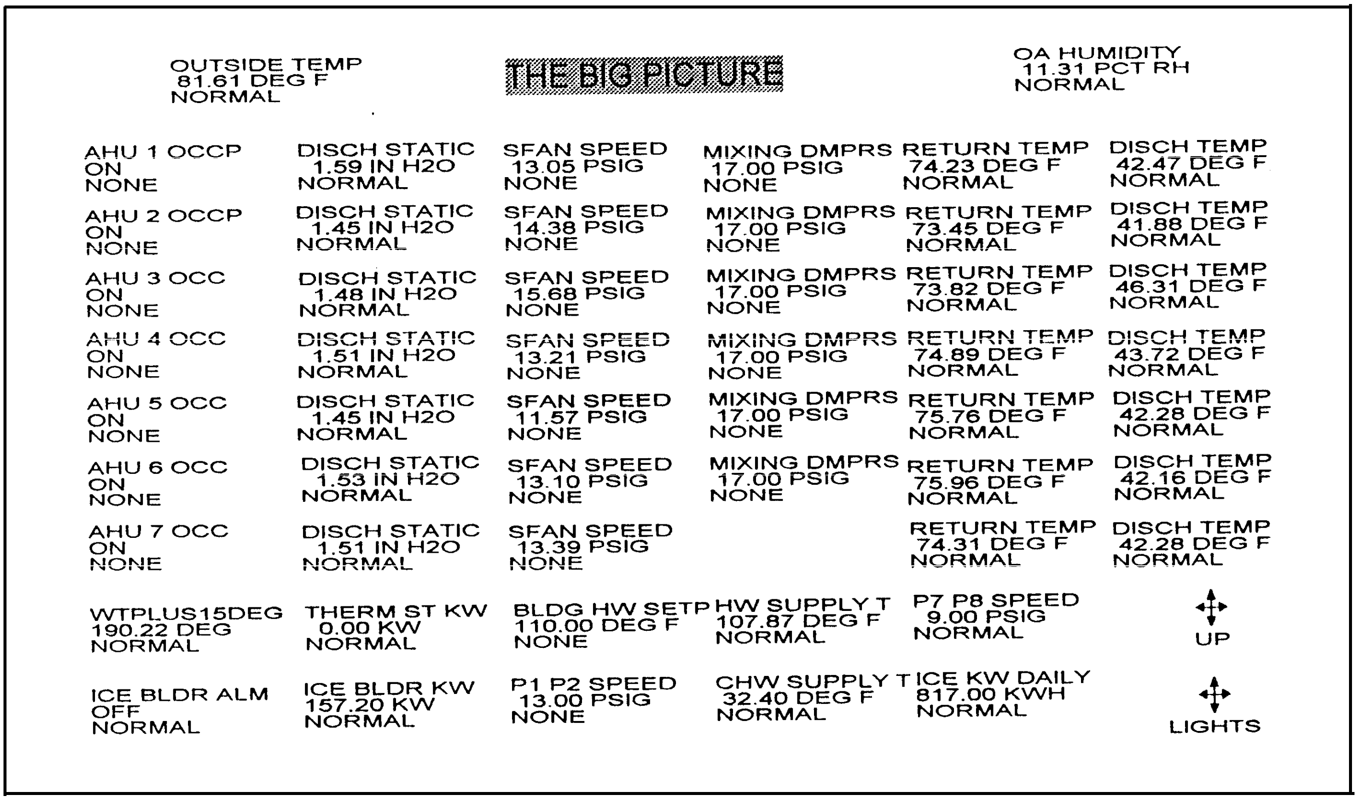

Figure 7. Use of Energy Management System in Trending System Performance

The building was designed with an electric hot water storage tank that was to heat 6,600 gallons of water to 270°F during the off-peak night hours in the winter months. The tank was to be drawn down to 150°F during the day and then, during the hours between 10 P.M. to 7 A.M., be recharged at the rate of 15 degrees an hour.

Using the trend data, it was possible to verify the operation of the thermal storage tank and that it was recharged at the specified rate. It was also possible (using the thermal storage BTU-used point) to determine that the building heat load calculations were too small. On a 30°F day outside, we were using almost twice as many BTU's as we suppose to use on the design winter day. We also used the data from the air handlers to determine if we were overheating the spaces, which we were not. The conclusion of the monitoring effort was that the thermal storage tank was undersized. It was simply impossible to make up the 15°F per hour rate of recovery on cold nights because of the heaters in the stairwells and because of the spaces coming on heat during night setback mode. The undersized storage tank made use of the design night setback mode impossible.

Conclusion

The use of monitoring in commissioning and building turnover is not an option but an essential equipment. Experiences from this project perspective have amply demonstrated the critical role of monitoring in the commissioning of mechanical systems. The capability and the flexibility of the DDC technology should be fully exploited by the design engineer as well as the contractors. Owner oversight, preferably using a commissioning agent, is mandatory to successful building turnover. The monitoring protocol during commissioning should be well thought out prior to the start of the effort and not during the course of commissioning.

The final point on the use monitoring for commissioning is that the data gathered from the monitoring points provided a second level of understanding for the design engineer, contractor and owner as well. Hidden problems can be uncovered, equipment defects can be detected, design errors can be demonstrated and performance of the systems can be documented.

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