

## **Success at Marlboro Memorial Middle School Makes Commissioning 'Business as Usual'**

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### **Synopsis**

The Marlboro Memorial Middle School is operated by the Marlboro Township Public Schools of Marlboro, New Jersey. The construction project was substantially complete in mid-2003, the physical structure was sound and the school looked great. But immediately prior to occupancy the school began experiencing complex, hidden problems with the HVAC systems. Complaints included discomfort issues, general poor indoor air quality and systems failing to operate. Needing an answer fast, the school district turned to the construction manager who recommended Dome-Tech for some fast commissioning. Dome-Tech was contacted in July, 2003 and completed a retro-commissioning survey of the school by the end of the summer.

The commissioning quality assurance process took the Marlboro school from being a giant headache to being an excellent example of a modern high-performance school. The components, architecture and engineering were very good from the start. But the complex and subtle interactions of the mechanical systems were not tested sufficiently at the end of construction. The school was initially operated with broken valves, inoperative motors, outdoor air dampers stuck in open and closed positions and air handling units (AHUs) that would not run.

Commissioning identified some 249 issues dealing with HVAC controls, reverse fan rotation, electrical shutdowns, air filtration, test, adjust and balance (TAB) and humidity control. At the time of this writing, some 244 of these issues have been corrected. School staff, officials and students were very pleased with the outcome of the commissioning process at Marlboro and the school is now operating correctly. But all concerned agree that it would have been much better if the commissioning process had started earlier, in the early stage of design. New building commissioning is going to be de rigueur, 'business as usual', for the district from now on.

### **About the Authors**

Cindy Barr-Rague is the Business Administrator and Board Secretary for the Marlboro School District. Holding this position for the past eight years, Cindy is responsible for all financial matters, payroll, purchasing, insurance, buildings and grounds, food service and transportation. Cindy began her School Board work as the Business Administrator of the Little Silver School District. Prior to this, she was the Accounting Manager and then the City Treasurer for the city of Harrisburg in Pennsylvania. She has a Bachelor of Science from Elizabethtown College in PA and was named the NJ Association of School Business Officials' School Business Administrator of the Year in 2004.

Ron Wilkinson, PE, LEED™ is Vice President of Operations for the Dome-Tech Commissioning Group. A nationally published author and speaker on commissioning, he is also an ASHRAE Distinguished Lecturer and an AIA Continuing Education Lecturer and author of the USGBC LEED commissioning training program. He is on the editorial board of Heating/ Piping/ Air Conditioning Engineering magazine and is published in the ASHRAE Journal, HPAC, Energy User News, Engineered Systems and Engineering News-Record magazines, among others. He is co-editor of the Commissioning Guideline Committee of the National Association of State Facilities Administrators which published its "Building Commissioning Recommended Guidelines" in April 2003, and had his "Best Practices in Commissioning" published by the Northwest Energy Efficiency Alliance in 2000. He earned his BSMAE from the Illinois Institute of Technology in 1971 and his master of Public Administration from the Evergreen State College in 1985.

## The Marlboro Memorial Middle School Overview

The Marlboro Memorial Middle School is a new facility of approximately 150,000 SF in floor area located in Marlboro Township in south-central New Jersey. The school is one story construction and includes classrooms, a media center and a cafeteria/ auditorium.

The heating, ventilating and air conditioning (HVAC) system consists of modular natural gas fired boilers and screw type electric chillers coupled with roof-top air conditioning / outside air units and interior air handling units. The classrooms are conditioned with unit ventilators that bring in outside air that is relieved through ducts and relief dampers to the outdoors. Science labs and office areas are served with dedicated air handling units (AHUs). Classroom unit ventilators and AHUs/RTUs are supplied with a four-pipe hydronic system of heating and chilled water.



### ***Issues Prior to Occupancy***

The school was constructed during 2002 and 2003, with official occupancy by staff only (no students) starting March 17, 2003. Incorrect system operation was first noted in the winter of 2003, but the project team was hopeful that corrections would be made. As construction proceeded, the school district officials relayed complaints to the Construction Manager (CM) and the CM brought in the design team for consultations. Still, the problems persisted. Because the CM had used commissioning on previous projects, they were familiar with the process. The specialized instruments and expertise of the Commissioning Authority (CxA) had helped the CxA root out problems in the past; as a result of this positive experience, the CM had added commissioning to their construction management “tool kit” and were well prepared to bring Dome-Tech to the site in July of 2003 to diagnose the problems.

During the winter of 2003, the installing technician for the building management system (BMS) contractor appeared to be “stretched thin” and was doing all of the field programming on his own. There were no records kept as he addressed issues on a day-by-day basis. Tragically, the control technician disappeared from the work site and, subsequently, his death was reported. Although this regrettable occurrence was unforeseen, the large control firm was expected to react by providing replacement staff. They did; but the complete lack of records and programming history made it all the harder for the replacement technician to recover in a timely manner. BMS related problems accounted for about 43% of the 249 issues found and corrected during the commissioning process.

Compounding controls issues was the fact that the power supplied by the local utility was of an incorrect voltage. The school is located in a residential area, making phase imbalances in the 3-phase power supply a significant issue. Furthermore, the supply voltage was found to be as much as 7% above normal which aggravated motor control coil failures. The unexpected power quality combined with the confused control programming made it difficult, at first, to diagnose frequent trips in the air handling equipment.

From the viewpoint of the school staff, they knew equipment was not operating consistently and they knew it was not controlling the indoor environment. Although voltage problems accounted for only 2% of the overall issues, the variable and random nature of their occurrence made their impact more severe than the percentage would suggest.

Also, the school thought they would get a greater degree of humidity control with the new systems than they had with the previous systems. Unfortunately, humidity control means different things to different people. While the new system condensed water from the outside air during cooling cycles, the system was not designed to do this continuously in such a way as to provide positive humidity control. Humidity control happened only partially and only in the right outdoor conditions. This is a design issue that would have been addressed in the Owner's Project Requirements if commissioning had been started during design. In this case, starting commissioning early would have paid big dividends in occupant comfort.

When the neighbors complained about the noise of the school's twin chillers, tests were performed to show that the chillers were within the code-required standards. This satisfied the letter of the law, but did not provide an improvement in public relations. But the neighbors would have been a lot happier if the chillers were placed differently or equipped with better sound attenuation from the beginning. A discussion of noise issues is a part of the Owner's Project Requirements (Design Intent) process at the beginning of commissioning.

### ***Issues Identified During Early Occupancy***

As staff moved into the new facility, work was still underway to sort out what was hoped to be the final problems with the school systems. In spite of moderate weather, staff complained of variable air quality with reports of the climate with in the building ranging from too hot to too cold to too humid. They also observed broken filter racks, noisy control valves, and missing parts on electrical switches and controls. Overall quality was unacceptably low and comfort was also unacceptable. Commissioning diagnosed the shutdowns as due to malfunctioning control panel communication boards and AHU motor starter failures due to supply over-voltage and incorrect control transformers (see above). Some days the units did not activate in the morning, with subsequent comfort complaints. When the units were not operating, humidity built up fast in the building.

The design team visited the site on several occasions and did their best to diagnose the problems with the equipment, but they lacked the instruments and the field diagnostic skills to understand why the high quality equipment specified was not working. The construction manager, who had

succeeded in building a first-class structure, needed specialized help and called Dome-Tech to the site in July of 2003. When the commissioning personnel arrived at the site and started speaking “contractors’ language,” things started to get done. In the two months after commissioning started, two hundred and forty-nine issues were identified at the school. They dealt with:

- HVAC Controls
- TAB (some fans were running backwards!)
- Power Quality
- Electrical shutdowns
- Broken and dirty air filter sections
- Damaged safety controls
- Leaking condensate pans
- Humidity control

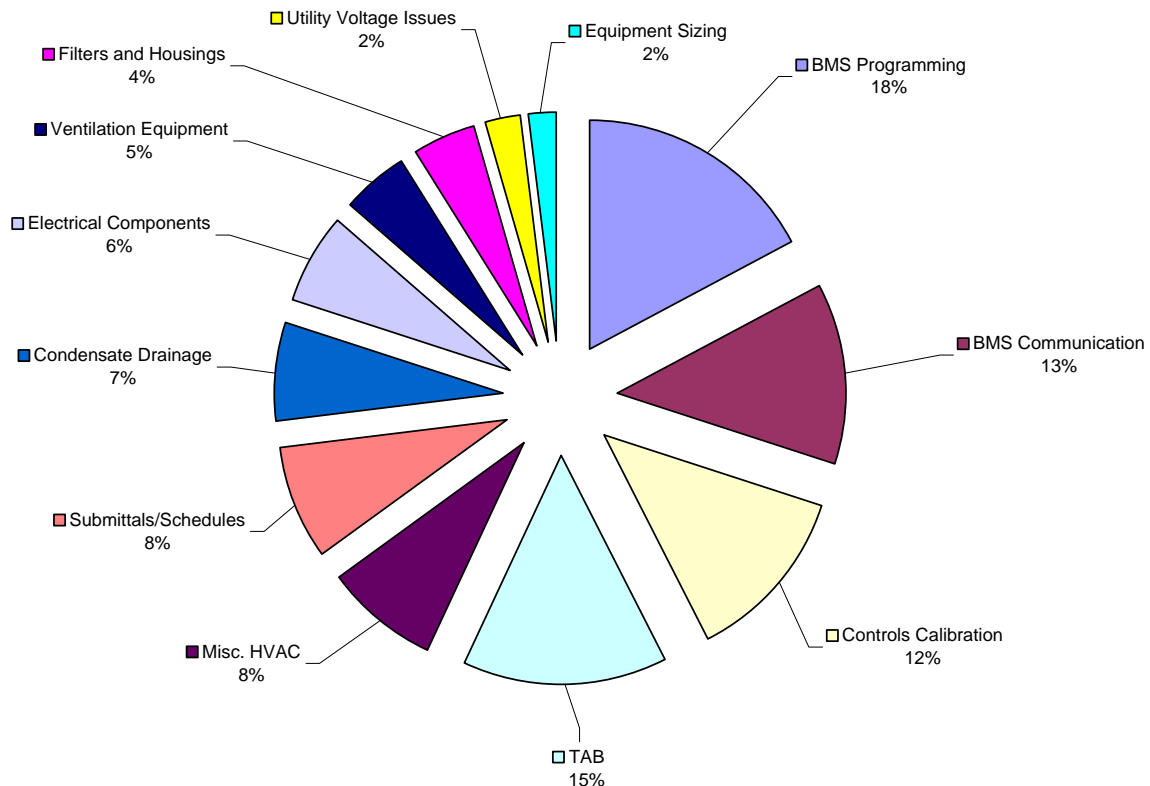
Table 1, below, shows the number and severity of the issues identified. Dome-Tech assigned an approximate level of importance to each deficiency. Level 1 deficiencies had the potential to stop entire systems from working and shut down the school. Level 2 deficiencies were less critical in the immediate, but would impact equipment life and reliability. Level 3 issues were comfort related, but posed no threats to safety or equipment life.

**Table 1: Breakdown of all commissioning issues**

| Issue                  | Quantity | Average Priority |
|------------------------|----------|------------------|
| BMS Programming        | 43       | 1.7              |
| BMS Communication      | 32       | 1.2              |
| Controls Calibration   | 31       | 2.1              |
| TAB                    | 36       | 1.9              |
| Misc. HVAC             | 20       | 1.8              |
| Submittals/Schedules   | 20       | 2.1              |
| Condensate Drainage    | 17       | 1.0              |
| Electrical Components  | 16       | 1.1              |
| Ventilation Equipment  | 12       | 1.1              |
| Filters and Housings   | 11       | 1.0              |
| Utility Voltage Issues | 6        | 1.2              |
| Equipment Sizing       | 5        | 1.0              |
| Total Issues           | 249      |                  |

Table 1 indicates that issues of filtration, condensate leakage, and equipment sizing were the first to be tackled. BMS issues were addressed at the same time. As CxA personnel patiently followed up on issues by personal, hands-on inspections, the contractors knew they were working with people who cared about quality and understood what had to be done. Eventually, all of the issues were corrected (see Conclusions).

Figure 1 below shows a breakdown of the issues identified by commissioning at the Marlboro Middle School by technical area.



**Figure 1: Marlboro Commissioning Issues**

### **Control Issues**

Operational issues caused by the malfunctioning Building Management System (BMS) at Marlboro fall into the following sub-categories:

- BMS Programming Documentation,
- BMS Communication and
- Controls Calibration

The low-bid control system was a standard, established offering of a reputable controls firm. But to paraphrase Dan McCormick, manager of the Marlboro Operations and Maintenance staff, there are several ways to program any one function into a BMS. If there is no record kept of the logic, this can make it difficult or impossible to make corrections without causing problems with

related parts of the programming. In the absence of records, diagnosing problems can be like looking for several needles in a haystack at the same time.

It appeared to all concerned that the original bid did not include a high enough labor cost to do the installation correctly. This is not unheard of, because the competitive marketplace does not always allow control contractors to make a profit on installation without change orders. This, coupled with the lack of complete controls understanding in the engineering design community, sets the stage for controls issues at the end of the job.

In addition to the lack of programming records, there were BMS communication problems due to hardware issues in control panel communications boards. As the communications circuits failed randomly at panels throughout the school, the resulting lack of communication between the Operators Work Station (OWS) and the field equipment prevented the equipment from starting on time. This factor combined with random motor starter failures often left the school without HVAC at morning start-up. The lack of communications also prevented the accurate reporting of alarms and trend logs.

Other programming errors of misaddressed rooms and equipment were also uncovered during the commissioning process, as well as about a dozen mis-calibrated or un-calibrated sensors and actuators.

### ***Power Supply Problems***

Power supply problems stemmed from the incorrect high supply voltage provided by the utility. These were compounded by phase imbalance and other phasing issues that resulted in equipment trips and damage due to single-phasing and phase-to-ground faults. The high supply voltage, in a scenario that was reminiscent of 'Murphy's Law', coupled with control transformers with windings and had exactly the opposite effect: low supply voltage. The transformer windings were about 10% below the nominal ratio which increased control voltage by 10% over-and-above the already high supply voltage. The result was a supply voltage to motor control coils that was up to 16% over nominal and led to frequent and random burn-outs of the AHU motor starters. Although the actual number of unit failures was small, they were repeated and frequently confused the diagnosis of the controls issues. As a result, the BMS was blamed for equipment failure that actually was due to the power supply problems coupled and incorrect control transformers.

For the Marlboro project, Dome-Tech sub-contracted with an electrical engineering firm (Winston Engineering) that specializes in field testing and diagnosis of power supply problems. Winston has since developed protective circuitry to protect the school against power instability and provide for the safe, automatic restart of equipment after recurring faults have cleared.

### ***Condensate Drainage***

While controls and power supply issues are complex, coil condensate drainage is simple. Unfortunately, even the simple systems had problems. Almost all of the AHU coil drain pans were initially installed sloping away from the drains, so that they overflowed during the cooling season. When this happened, the water ran through the HVAC unit, through the ceiling, to the floor below. A very simple item, the AHU drain pan overflows, was misunderstood to be the daunting complication of roof leaks, leading to further, inaccurate, “finger pointing” that caused delays in getting the repairs completed.

While comprising only 7% of total issues, condensate drainage had a composite priority ranking of 1.0, the highest possible, due to the potential for indoor air quality (IAQ) problems and interior finish damage. Again, it was the hands-on inspection by the CA during equipment operation in the “as installed” condition that revealed the problem. When this communicated by “speaking the same language” as the installing contractors, the required modifications were quickly made. Figure 2 below shows the standing water in the condensate pans beneath the cooling coil in the air handling unit.



*Figure 2—That reflection in the AHU basin is not shiny metal. It's standing water that won't drain if the pan is sloped away from the drain!*

### **Filters and Equipment Sizing**

Rounding out the group of 1.0 priority items were 16 items relating to damaged or missing air filtration and leaking control valves (equipment sizing - low shut-off ratings). These items, like the condensate issues, were ranked the highest priority because they have a direct impact on IAQ and can lead to rapid equipment degradation if uncorrected.

Equipment without filters not only degrades IAQ, it also clogs coils and becomes one of the “silent killers” that cause high energy bills by reducing the heat transfer between the coil and the building supply air. As heat transfer decreases, fans, boilers and chillers have to work harder to make the system's rated performance and control building temperature.

### **Test, Adjust and Balance (TAB)**

Like many projects, the Marlboro school had balancing issues. Probably the most dramatic issue arose from the fact that the installed equipment differed from the equipment on the original design schedules. When design engineers make drawing and specifications they frequently use a particular line of equipment as the design model, but allow other makes of equipment to get cost control through competitive bidding. On this project the contractor submitted an equal make of unit ventilator and the engineer accepted the substitution. That is fine. Unfortunately, the TAB contractor did not check the balance requirements of the *actual installed equipment* as compared to the requirements shown in the schedules in the original bid drawings. The TAB technician balanced the new equipment to old flows that were much too high. This resulted in a 28 psig drop across the pressure regulating bypass valve instead of the final, correct, 7 psig drop. (*Figure 2* shows the bypass valve below that was stretched to its limits by the greatly increased flow).

The system was designed so that the valve would close its bypass loop to increase the pressure and flow to the coils in the unit ventilators, depending on the number of units calling for flow. The valve was pinched nearly shut in an attempt to regulate at the required excessive pressure drop and the squealing from the turbulent/cavitating flow through the valve could be heard three rooms away. The seats would have been destroyed in quick order operating at such extreme, mis-matched conditions.

At first, the TAB contractor was defensive about being called on the carpet, but when they saw the facts and figures proving the simple mistake that had been made they quickly, and voluntarily, corrected all the flows. The result was a 7 psig drop across the control valve, accurate, stable, and quiet operation and anticipated long valve seat life.



*Figure 2—Due to extreme hydronic balance mis-matches this valve could be heard screeching three rooms away!*

### **Ceiling Insulation, Electrical Components and Ventilation Equipment**

The group of items comprising the remainder of the identified commissioning issues includes: missing attic insulation, electrical components missing buttons, arms and a variety of parts, and minor items from binding unit ventilator dampers to submittal inaccuracies. The missing ceiling/roof insulation was actually correctly installed and verified by the construction manager on the job prior to occupancy. But in the course of repairing other “above ceiling” problems, contractors removed the insulation batts for access and never put them back. The result—office spaces below the suspended ceiling that were impossible to heat.

The amazing thing about these minor items is that, although minor in and of themselves, they combine to make major holes in the modern building operating system and undermined the foundation on which building IAQ and energy efficiency rest. At the time of this writing these items have been corrected.

### **Conclusions**

At Marlboro Memorial Middle School, the commissioning process identified some two hundred and forty nine issues dealing with HVAC controls, TAB, power quality, condensate drainage and missing or broken parts

At the time of this writing, all but five of the two hundred and forty nine separate issues have been corrected and the last five are expected to have been corrected by the time this paper is submitted.

As Dan McCormick, the head of the facilities staff, pointed out, the old paradigm of building schools to 85% completion and then relying on maintenance contracts and/or O&M staff to finish construction is no longer viable. Projects must be finished and operating by the first day of occupancy for the health and welfare of staff, students, and the public. Although Cindy pointed out that commissioning is a relatively unknown tool among most school business administrators in the mid-Atlantic region, it is quickly gaining mind-share. Construction Managers and New Jersey school project management firms (PMFs) are uniting to bring more projects into the commissioning fold.

In fact, the New Jersey Association of School Business Officials decided that commissioning is an important enough tool for new school construction to include it in the April, 2005 “Facilities Cracker-Barrel” session in Atlantic City. This program to share ideas among school business administrators will be focusing on commissioning as a method of providing better schools.

In the case of Marlboro Memorial Middle School, the HVAC system accounted for about \$4 million of the \$16 million general construction budget. This is a huge investment and must be protected. Both Cindy and Dan feel it is extremely important that the CA be an independent firm that can act without any bias and operate strictly an advocate for the school board. It is imperative that the CA answer directly to the board and be contracted directly to the board. Throughout the corrective process, the board relied on direct communication with Dome-Tech to give them direct visibility into the school project.

In conclusion, the results of the commissioning could have been obtained with less work, less expense, and better benefits if commissioning had been started early on this project. The Marlboro board of education, O&M staff, contractors and the construction management firm would have been better off if these issues had been identified and corrected during design (as many would have been). Cindy and Dan have joined the Marlboro District School Board in making new building commissioning *de rigueur* or, as they call it, “business as usual” for the district from now on. Commissioning will be a line item in all future new school budgets and will be a part of future levies. This will ensure that there are funds for its inclusion in the project from the start. Just as commissioning established quality for the new middle school, it will ensure healthy and productive indoor environments for all future projects as well.