Case Studies of Commissioning HVAC Systems

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ABSTRACT

This paper discusses problems found during third party commissioning of projects where humidity control was an indicator of significant problems.

Project 1 was an 8000 square foot library. Problems found included air conditioning (A/C) and heating systems both running during the summer, A/C systems that ran most of the unoccupied period, and relative humidity that was over 90% every night.

Project 2 was a 1200 square foot meeting room. The outdoor air (OA) preconditioning system was found to operate in hot gas bypass mode with little humidity control capability.

Project 3 was the heating, ventilating, and air conditioning (HVAC) system on a 400 square foot library conference room with electric reheat for humidity control on a three-ton split system. The design was for a humidistat to call for cooling on high humidity. Reheat was energized as the space temperature dropped below the heating set point. The system functions with a wide space temperature swing as the control system oscillated through the heating/cooling deadband.

INTRODUCTION

Building commissioning has become an area of much interest. Building owners are finding that construction projects that do not include building commissioning frequently leave equipment and building systems with less than specified performance and even completely nonfunctional systems. The US Green Building Council LEED[1] (Leadership in Energy & Environmental Design) Program requires commissioning as a prerequisite to LEED rating. Owners who adopt building commissioning usually find that the cost of commissioning is recovered quickly through lower operating cost. Contractor's industry associations are urging contractors to adopt commissioning for the contractor's benefit[2].

A common finding of third party commissioning on projects in hot and humid climates is poor humidity control in conditioned spaces. Indications of poor humidity control can be the result of many problems and frequently indicates larger problems.

Buildings are systems. Within the building system are many subsystems that must operate as a synergist whole to achieve comfort and energy efficiency. The following case studies are indicative of interactions of systems that are frequently considered to be independent.

Project 1

Project 1 was an 8000 square foot library where third party commissioning was started when the general contractor declared bankruptcy after the building envelope was complete and the HVAC system installed. The HVAC system consisted of nine residential type gas furnaces with split direct exchange (DX) air conditioning systems. (The building owner has standardized on residential style split systems to control maintenance costs over the life of the building.) Five of the nine systems served one large open area that was half of the total floor area. Each system has its own temperature sensor (also known as a thermostat) controlling one zone of the building. All furnaces were installed on a common return plenum with OA supplied directly to the return plenum. Return air was from a common ceiling plenum above a suspended ceiling. The restroom exhaust was from a single exhaust fan that was scheduled to operate when one of the furnace blowers operated. A basic DDC control system scheduled occupied and unoccupied periods.

On A/C system startup, one zone would only run for a short time before switching to heating mode. The problem was found to be two zone temperatures sensors that were located in the other zone. The contractor 'corrected' the error but one temperature sensor could not longer be found.

Comfort control problems were reported shortly after the building was occupied and the weather turned humid in April. The operator reported hot complaints even when the zone set point temperature was 72^{o} F. Figure 1 shows the space temperature (Channel 1), supply temperature, (Channel 2), and relative humidity (Channel 3) for the zone where the complaints were occurring.

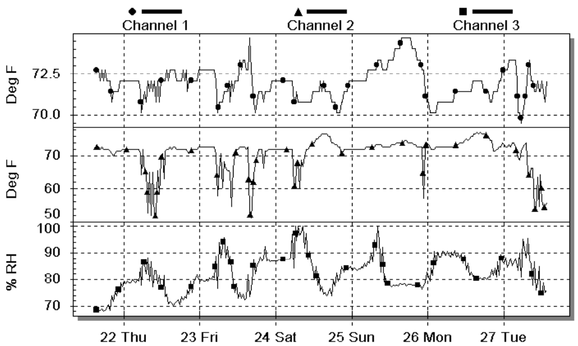

Figure 1 - Space temp (Ch 1), Supply temp (Ch 2), & RH for Zone 4 of Project 1

The relative humidity shown in Figure 1 was very high at all times but especially during the early morning hours. The supply temperature indicated the A/C would remove moisture from the air (supply temperature below 55^{o} F) when the A/C was running. The space temperature indicated there were significant interactions with other A/C in the large open area.

Blower door and pressure measurements indicated the building was relatively tight for a small commercial building[3], with an air change per hour at 50 Pascal (ACH50) of 8.3. However, it was found that the air conditioners were introducing over 2600 CFM of outdoor air even when the OA intake was blocked. This indicated significant air leakage on the return side of the duct system. The source of the leakage was found to be installation details where the air barrier (sheathing) was cut out at structural elements. One example is shown in Figure 2 where the sheathing was cut out to clear structural members. Not only was the center of the channel left open, the sheathing was cut out several inches on each side of the channel. The result was roughly a square foot of open area to the outside every four feet along the perimeter of the building. This leakage path was a direct connection of the above ceiling return plenum to outdoors.

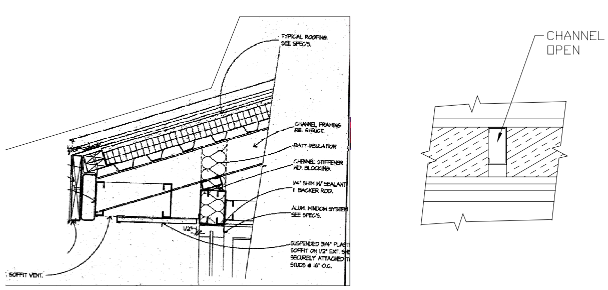

Figure 2 - Detail of Leakage Area Into Ceiling Plenum

Once the return plenum leakage was corrected, the humidity problem was reduced and changed in character, but not eliminated. As shown by Figure 3, the space relative humidity was still very high, but now the problem was primarily during unoccupied periods.

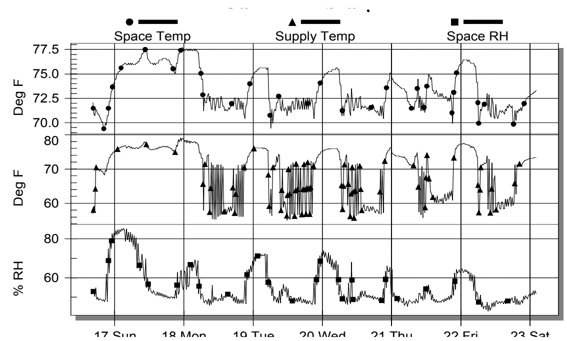

Figure 3 - Temperature & Relative Humidity After Return Plenum Corrections

The high humidity during unoccupied periods was traced to the restroom exhaust fan running 24 hours per day. The drawings indicated the exhaust fan was to be interlocked with one of the furnace blowers, but the interlock was never installed. Once the exhaust fan was interlocked with the HVAC control system the humidity during unoccupied hours improved significantly.

Figure 1 and Figure 3 both indicate poor temperature control. Overcooling of the space is indicated, frequently at times when the supply temperature shows that unit is not running.

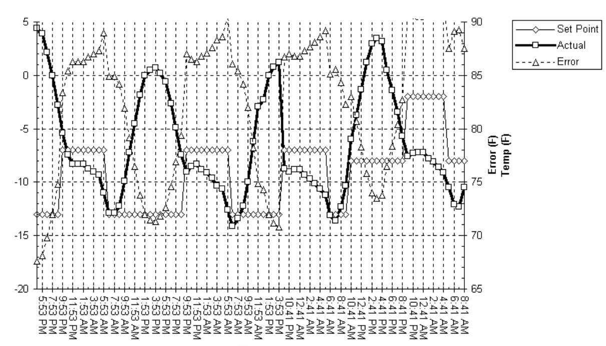

Figure 4 - Trend Log Temperature Data

Figure 4 is a trend log taken from the DDC control system. The heavy line is the actual temperature detected by the controls for the zone adjacent to the zone shown in Figure 1 and 3. The "square wave" line is the set point temperature for this zone. The control system was properly controlling the air conditioner based on its temperature readings.

Unfortunately, this temperature sensor (the one 'lost' after startup) had been relocated to halfway up a skylight well. The adjacent zone was cooling until the skylight reached the set point, frequently overcooling the adjacent zones. The sensor was reported to be mounted in the skylight well because that was the "only location in the zone that was accessible to the technician". Once the cause of the problem was identified, other locations in the zone became accessible.

In testing it is desired that all data indicate the same problem with little ambiguity. The data shown herein does not show a clear and unambiguous picture of the problems discussed. As with most projects, many variables were changing at the time tests were made - not the least of which was the weather. Data have been selected that were the first found that indicated the problems discussed. Proof that the problems were the result of the causes identified was not available until all the corrections were made and summer weather conditions returned.

Lessons Learned

Lessons learned include the building acts as a system where ALL of the parts are interconnected. First indications of problems data may not indicate clear solutions because of interactions with other systems. Correction of one problem exposed other problems that were not evident before the first problem was corrected. Some of the problems could have been caught by site visits and inspections during construction, but many would not have been found until testing was performed.

Project 2

Project 2 was a 1200 square foot meeting room that was part of an 8000 square foot library. Commissioning was started during conceptual design. Two, two and a half-ton split systems with gas furnaces and an OA preconditioning unit served the room. The A/C systems were paralleled and set for first stage / second stage operation. The meeting room maximum occupancy was 60 people, but was empty most of the time. The highly variable occupancy caused the design engineer to schedule an outdoor air pre-conditioning unit to be used when a large number of occupants require significant ventilation air.

The OA preconditioning unit was scheduled around a major manufacturer's guideline, which consisted of a three-ton condenser with a one and a half-ton DX coil. The difference in sizing was to ensure the DX coil was capable of removing moisture under the high latent load conditions of 100% outside air. A hot gas bypass system was scheduled for this system to allow for capacity control at lower load conditions. The contract documents specified the size of the condenser, evaporator, and blower, control and safety devices, and that the hot gas was to bypass to the evaporator distributor. The contractor was allowed all other design decisions. Figure 5 shows a schematic of the OA preconditioning unit refrigeration circuit as installed.

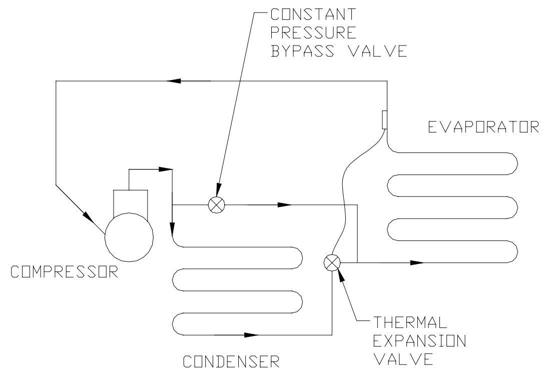

Figure 5 - OA Preconditioning System Refrigerant Circuit

The project was turned over to the owner as complete with the OA preconditioning unit locked out and tagged as do not operate. The contractor had locked out the unit because there was no information in the contract documents on proper refrigerant charging and operation. Normally, there is no need for such information since standard split system installations can follow the standard installation instructions. However, the installer did not believe the standard instructions applied to a unit with such a size difference between the coil & condenser. He felt it was wise to check before starting the system.

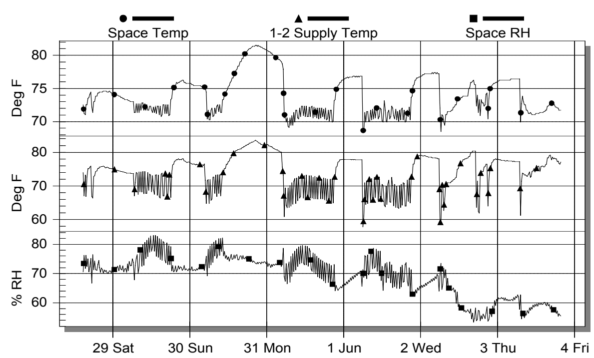

Figure 6 - Space Temp, Supply Temp, & Relative Humidity in Meeting Room

Figure 6 shows the temperature and relative humidity in the space after the unit was started and reported to be operating properly. At the end of May, the latent load was clearly out of control.

On June 2, the contractor was met on site to identify the source of the humidity control problem. The OA preconditioning unit was found to have a leaving dry bulb temperature of 64° F. Since the leaving dew point temperature could be no lower than the leaving dry bulb temperature, the OA preconditioning unit was not able to remove enough moisture from the outdoor air to maintain the space humidity. (Note - the leaving dew point temperature will be the lowest possible space dew point in moisture generating spaces located in humid climates. Moisture generating spaces includes latent load from occupants.)

The high leaving temperature was initially thought to be an undercharge of refrigerant because the condenser sub-cooling was only 3° F. When the charge was increased, the bypass regulator would open and actually increase the leaving temperature to the high 60s. The hot gas bypass regulator was reset to remain closed under design conditions and only open when the system was unloaded.

Note that the hot gas was bypassed to the evaporator inlet near the distributor. This configuration is shown in the 1998 ASHRAE Refrigeration Handbook as "the most satisfactory hot-gas bypass arrangement" with respect to full (100%) unloading. However, this installation was using the hot gas bypass for partial unloading under conditions where the evaporator should be kept cold. When this configuration is installed on an OA preconditioning unit, the moisture removal capacity is greatly reduced anytime the bypass regulator opens. The hot gas warms the evaporator and greatly reduces the latent (and sensible) capacity of the system.

After the hot gas bypass was set to open only under extreme conditions, the relative humidity was maintained below 60% during occupied periods.

Lessons Learned

The lesson learned was the contract documents need to specify ALL information required for system installation and operation of 'unusual systems'. Hot gas bypass systems are not standard installations for most contractors. The technician in the field needs enough information to install and setup the installation. Manufacturer's design guidelines are not generally available to the installer and rarely include detailed installation and setup information. Additionally, a detailed functional check should be made to verify the design guideline matches the design intent. Handbook references to "most satisfactory" arrangement need to be carefully reviewed for the particular design.

Project 3

Project 3 was a 400 square foot conference room on an 8400 square foot library. A single three-ton residential style split system and gas furnace with a 6 kW electric duct heater (reheat) for moisture control served the space. The control was a low-end direct digital control (DDC) system with additional hardwired logic for the electric reheats. The control system set points were 74° F cooling and 70° F heating. Commissioning was started during the schematic design phase.

At the control submittal, the decision was made to drive the air conditioner (not reheat) on when the humidistat indicated high humidity. On high humidity, the duct heater would be switched in as a replacement for gas furnace. The plan was that if the air conditioner stayed on long enough to overcool the space, the control system would sense low space temperature and switch to heat. The call for heat would be used to bring on the electric reheat and bring the space temperature back up. The gas furnace would be switched back into the circuit (and duct heater out) when the humidity was back under the setpoint.

Figure 7 shows the space temperature, supply temperature, dew point, and duct heater current for the space collected during cooling conditions for one day in October 2000. The space temperature indicates the space is being overcooled in an attempt to control the humidity. The relative humidity varies from 50% to near 100%. The reheat is coming on to control the overcooling. However, the gas furnace is also coming on as indicated by the supply temperature over 100° F.

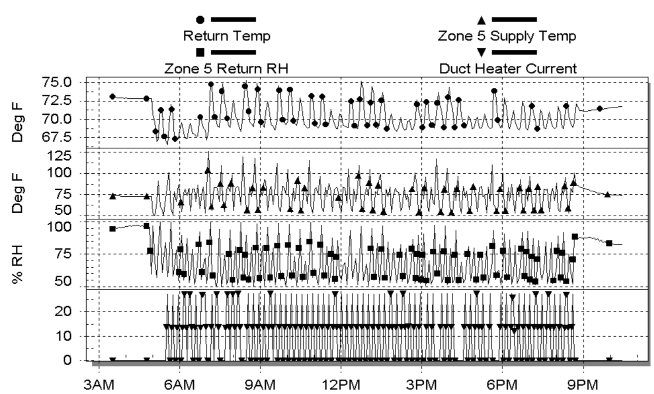

Figure 7 - Return Temp, Supply Temp, Return RH, & Duct Heater Current

Note that the space temperature and relative humidity are represented by the return temperature and relative humidity. The sensor had to be located in the return duct near the duct heater in order for the duct heater current to be monitored by the same data logger. Comparison of these data with data from a logger located in the space indicated the return duct location was very similar to space conditions EXCEPT when the blower was off during unoccupied periods. The relative humidity near 100% before 6:00AM and after 9:00PM should be disregarded as a measurement anomaly.

Clearly there is a problem from a large source of moisture driven into the space. Initial indications were that the moisture was due to space depressurization and/or envelope problems. After those problems were corrected, the temperature and humidity variations were still very similar to Figure 7. This moisture was due to ventilation air brought into the space through the air conditioner. When the space temperature cools to the thermostat set point, the air conditioner cycle off and the OA is brought into the space unconditioned. The zone was scheduled for a constant 130 cfm of OA on a 1300 cfm air flow. Other zones of this project are not experiencing the humidity problem because all other zones have two-stage air conditioners. With two-stage air conditioning, at least one of the units is removing moisture from the space a larger portion of the occupied hours. Doty[4] and Henderson[5], et al, discuss evaluation of such problems when using DX systems on mechanically ventilated spaces.

Other problems indicated by Figure 7 include the large temperature swings as the system cycles into and out of the dehumidification operation. The space temperature is shown in Figure 7 varying from approximately 67° F to 75° F. The supply temperature indicates the HVAC controls are operating and trying to maintain the space within the normal comfort range. The air conditioner supply temperature is low enough to dehumidify the air while the air is cooled. The duct heater is operating providing reheat for additional moisture control.

Figure 8 is an expanded time scale during the morning shown in Figure 7. Note that before 9:00, the air conditioner was on in response to high humidity. The air conditioner supply temperature is in the 50s and the space is drying out. When the space temperature reached roughly 70° F, the duct heater came on as indicated by the duct heater current and the increase in supply temperature. At about 9:10, the humidistat was satisfied and the system came out of humidity control mode. Once

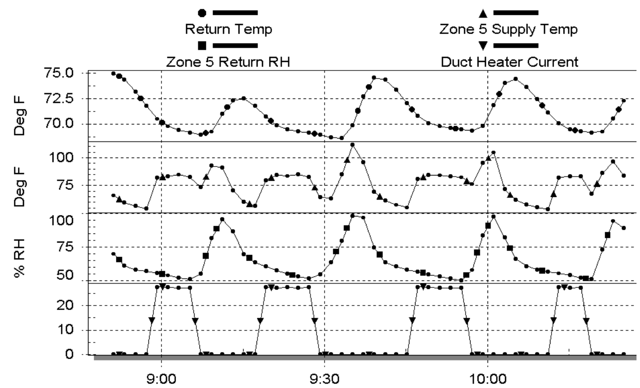

Figure 8 - Expanded Time Scale of Figure 7

back in 'normal' mode (not humidity control mode), the controls sensed the space was below the heating set point and turned on the gas furnace. The furnace quickly brought the space temperature above the 70° F heating setpoint. However, by the time the space temperature was up to 72° F, the relative humidity was high again and the system went back into humidity control mode with the air conditioner locked on.

The cycle repeated again with a peak space temperature of 75° F at 9:40. At some point during a summer day, the sensible load should become high enough the space temperature would exceed the cooling setpoint before the humidity exceeds the humidity set point. When this occurs, the control system heating-to-cooling switchover will happen before the cooling would come on in response to high relative humidity. The switchover has a deadband (temperature or time) to prevent the system from quickly switching from heating to cooling or cooling to heating. It appears this cycle has the larger temperature swing characteristic of passing through the deadband. A close inspection of the data log indicates that no cooling or heating was on between roughly 9:35 and 9:39. At around 9:39 AM the system had gone back into humidity control mode.

Instrumentations and data interpretation are areas that need very careful review. Figure 8 shows the duct heater increased the supply temperature to a little over 75° F. At the same time, the duct heater is operating; space temperature is shown to drop below 70° F. It would seem that a source of heat removal other than the supply air would be required for this to occur. However, a check of the average temperature of a three-ton air supply (1200 cfm) at 55° F reheated by a 5.6kW (27A at 208V) duct heater would be 70° F. By this calculation the space temperature is verified and the supply temperature needs to be investigated. The supply temperature sensor location was found to be near a wall of the supply duct in an area that was warmer than the average temperature of the entire supply airflow.

A legitimate argument can be made that the duct heater is undersized since it is not capable of reheating the supply air to the cooling set point temperature. If the duct heater were this large, the system would be capable of masking the moisture problem from occupants of the space by running the air conditioner and the reheat concurrently. For many designs, this would be a desirable situation. For buildings with very limited operating budgets, it is more desirable to keep operating cost lower by ensuring problems cannot be hidden by overcooling and reheating.

It is a common finding that if electric reheat is installed; it will find a way to come on. If the cooling and reheat are balanced, it is likely that both will run for long periods consuming lots of energy. For this reason, the author and others prefer to not to use reheat. However, small spaces such as this with a highly variable occupancy make moisture control a design challenge. The design compromise in this case was to ‘unbalance’ the cooling and reheat so a problem would become apparent.

The instrumentation shown here was mounted in the return duct in the mechanical room well removed from the space (approximately 80 foot duct runs). This location was used because it allowed the duct heater current to be measured. The location does bring into question how well the return duct represents the space conditions. A data logger in the space showed good correlation of temperature and moisture, but indicated a transport time delay between space conditions and the data log.

Lessons Learned

Building pressurization IS NOT a simple matter of more air in that air out of the building to keep the entire building under positive pressure. Individual rooms such as this can be depressurized with the rest of the building under positive pressure.

The choice of driving on the air conditioner instead of the reheat for humidity control is a design selection. Each has advantages and disadvantages. As discussed, engaging the cooling on high humidity causes the system to cycle through the heating/cooling deadband that increases the temperature swing. Engaging the reheat on high humidity can cause the air conditioning to cycle too quickly to maintain a cold DX coil long enough to remove enough moisture. Operating details of a system are frequently not known during design because the competitive bid and submittal processes allow for changes of equipment and other important details. It is not unusual for the contractor submitting the bid and making the installation to not know such critical details.

The design process is a series of compromises and trade offs. In this case, a design that can maintain space design conditions can also hide a latent defect, but at increased operating cost. The trade off was made to provide a limited reheat for moisture control, but not enough to counter very high latent load conditions. Most designs assume that defects, such as air leaks from outside or unconditioned ventilation air, will not exist in a new building.

Even proven methods of humidity control (electric reheat) can be overwhelmed if there is enough moisture driven into the space. If the moisture load had been somewhat smaller, the system installed probably would have hidden the underlying problem. The only visible indication would have been a somewhat higher electric bill. However, since this was a new building that did not have a ‘typical electric bill’ for comparison, the problem is not likely to have been noticed.

Instrumentation and measurement errors should be suspected in all cases. Even when the instrumentation itself is calibrated and proven, the location of sensors and other factors can introduce errors. Errors can make the data interpretation task even more challenging than it already is due to system interactions and multiple problems.

CONCLUSIONS

Temperature and humidity control can be indications of underlying problems. Reported comfort problems caused maybe the first indicators of larger underlying problems. In all three projects discussed here, the first indication was complaints that the space was ‘hot’ even with the setpoint lowered to 72^{o} F.

Visual inspections, especially if only performed at the end of construction, are not likely to catch all problems. It is recommended that installation tests be performed as early as possible and be required of the contractor to prove substantial completion. Problems indicated by test results after building occupancy will be more difficult to correct and more disruptive to the occupants.

Measurement and test data require careful review and interpretation. Between instrumentation and measurement errors, interactions between systems, constantly changing outdoor conditions, and multiple concurrent problems, data interpretation can be very challenging. However, even confusing test data is a better indicator of actual operation than no test data.

Building design is a series of compromises that attempt to tailor the project to the needs and budget of the owner. Some of the compromises are clear and unambiguous selection of the best solution. Some compromises are the selection of the lesser of two undesirable solutions. And some compromises are the selection of a design the details of which will not truly be known until the project is bid and possibly the installation complete. Continuity of the design team through construction administration can be critical in these cases. Building commissioning and design documentation can be critically important if the design team does not have continuity from design through project closeout.

REFERENCES

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