Getting a Better Performing Building: Commissioning and Real Time Data Analysis

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Commissioning of new construction is becoming increasingly accepted as a quality assurance tool to deliver performance, reliability, and efficiency in building systems. But what about existing building stock? Does successful commissioning of the construction process ensure design performance throughout the life of building systems? If you believe that commissioning is the key to acquiring a system that performs as intended, what about building systems that were never commissioned? Short of a substantial system failure, can we assume optimal performance? The answer is no. Performance verification requires a method of measurement.

For those practitioners who have explored the commissioning of existing facilities, the consensus persists that existing buildings present energy saving opportunities upwards of 25%[1], while reconciling mechanical system performance shortfalls, occupant comfort issues, and potential Indoor Air Quality (IAQ) issues. The key to identifying these lost savings is a measurement plan based on real time system operational data.

Because of the dynamic nature and complexity of commercial building HVAC systems, they are the perfect target for periodic performance assessments, or recommissioning. Today's buildings are expected to supply designed conditioning and ventilation requirements as well as modulate to the loads and schedules of a variety of end use requirements throughout the building. Evaluating that the HVAC system is performing to load conditions is critical to the operating needs of the facility, and documenting that it meets the designed performance standards and the resulting energy use, *and no more*, ensures efficient system performance.

The key to documenting system performance is the ability to access and analyze reliable system performance data. This paper will utilize EH&E's commissioning experience and methods to explore the relationship between HVAC system performance verification and good Measurement and Verification practice in both the commissioning of new construction projects as well as trouble shooting existing building problems.

About the Author

Mike Della Barba is the Commissioning Program Manager for Environmental Health and Engineering (EH&E), Newton, MA. EH&E is an engineering firm specializing in commercial and institutional building sciences, including: Environmental Health and Safety, Indoor Air Quality, Indoor Environmental Quality, Engineering and Commissioning Services. EH&E has commissioned over 4 million square feet of space. Mike holds a B.S. in Economics and has extensive construction project management experience. While serving as a senior analyst at New England

[1] Energy Efficient Operations of Existing Buildings, P. Herzog, 1997

Power Service Company (a division of the NEES companies, now National Grid, USA) Mr. Della Barba designed, developed and managed their Building Commissioning program, which emphasized functional testing and performance data analysis as key tasks to ensure system performance.

ASSUMPTIONS AND IMPRESSSIONS

There's a terrific feeling I get when I enter a new building. Having spent most of my career in the commercial building construction business, the gleaming finish materials, the building cleanliness and crisp "feel" bring a proud feeling similar to that of a proud parent. I can envision the devotion, endless hours, and teamwork necessary to bring a building project from concept to fruition. There's a connotation associated with the "newness" of the building that implies a sort of perfection with all elements at their peak, complete and "full of life (capacity)", and absent of "wear and tear". When new, the building is perfect, or so it seems. What we know is what we can sense. We can see beauty and operation. We can also feel comfort. We know the building is operational.

If the HVAC systems in this building were commissioned by a third party engineer, I "*know*" a few more things (based on a building size of approximately 200,000 square feet)[2]:

- 150-200 components were reviewed, verified and documented to design.
- 200-300 deviations from the design were discovered (and possibly more!).
- 50% of the systems "failed" to reach acceptable design parameters when functionally tested.

And if the building was not commissioned, I "*know*" that:

- systems are under-performing
- operational problems are *lurking*
- energy is being wasted

Am I assuming poor design, manufacture, construction, or operation? No, and that's the point! Assume nothing. Operation can be physically verified, but performance needs to be measured. Operation does not necessarily equate to performance.

Our senses can fool us. Certain building equipment is intended to be supplemental and only operate during certain conditions. A visual inspection only confirms that a component appears to be installed to design and it is assumed that it *will* operate when the design operating conditions exist. Verification of nameplate data confirms that the designed component was actually installed, but without a functional performance test, operation to design is assumed. The commissioning of one school project found that the majority of unit heaters at entrances, corridors, and specialty areas were not functional. A physical verification of the component was not sufficient. A normal "punch list" review in this case would not have been able to verify operation since the units were not scheduled to be "on", but it was "*assumed*" that they would operate to design when the load required such. Wrong! This unit heater operation was a very simple temperature control sequence. Very often the application of commissioning is thought of in the context of complex and highly

[2] Based on EH&E commissioning experience.

intensive systems (i.e. hospitals, laboratories, manufacturing, etc.). However, whether the sequence of operation is simple or complex, complete system performance verification is a necessity.

COMMISSIONING

Although individual definitions may vary slightly, commissioning is generally accepted as a quality assurance function to document that equipment and systems operate *as intended*. The "as intended" moniker implies a performance aspect. The system is expected to perform based on certain time based parameters, i.e. schedule or load demand, and in turn these parameters might dictate the level of operation, i.e. full, part, or none.

The system design intent (operation *as intended*) is developed based on three parameters:

- Building load (or need)
- Equipment and systems designed to meet the load.
- Mechanisms designed for the systems to respond to load (or lack thereof)

Commissioning is a methodical process of review, verification, and documentation of the ***design intent*** through the three phases of a project:

- Design
- Construction / Installation
- Operation

As noted above, numerous issues arise during the project relative to conformance to design intent. If these issues are not reconciled the building's expected performance will change, based on the amount of variation.

In my 1996 paper, "The Presumption of Persistence"[3], I discussed a performance equation. The system performance or Design Intent (P) is identified as the sum of Design (D), Installation (I), Operational (O) phases of a project. The equation assumed that all three phases of the project are effected by an implementation or Adherence (A) factor. Therefore the Persistence Equation becomes:

$$P = (D + I + O) \times A$$

with the Adherence factor becoming the biggest variable. However "A" can be weighted differently as it applies to individual phases, and therefore modifies the formula:

$$P = D(A^*) + I(A^*) + O(A^*)$$

with the asterisk signifying that "A" will vary by an unknown driven by project specific factors. Commissioning as a quality control function targets the Adherence factor and strives to decrease it's weight and therefore making the persistence formula more predictable and the product or "range of eventuality" more controllable. It's important to recognize the impact of a component or control change to the system dynamic. A change to an integral part of the formula Inputs (D, I, or A) inherently changes the Product or Output (P). Therefore, the number of possible outcomes can be significant without the systematic process of checks and testing Cx provides. The Cx process helps define the system design intent by identifying it as a tangible product

[3] "The Presumption of Persistence, Commissioning as a Customer Service", Della Barba, 1996 Proceedings from the National Building Commissioning Conference

through the documentation of actual testing and measurements.

PERFORMANCE

When identifying performance benchmarks, we move from observations to measurements. ***"You can't see performance."*** Operation is easy to identify: a comfortable building in the hot summer months is a good indication the air conditioning is operating. However, to say that the system is "working great" or "performing optimally as intended" would have no basis without knowing the system benchmark, "design intent," and having a means to measure. Positive performance without some means of measurement is not tangible. However, the inverse is true: system failure is, in most cases highly detectable. It's a safe assumption that in the example above, an uncomfortable building signifies an equipment or system shortfall. Tenant complaints will trigger corrective action. So, physical detection becomes a simple and easy method for identifying system performance shortfalls, but the same does not apply to optimal or specified performance. A system could be expending a lot more energy (and the associated run hours) than intended or specified to meet a target such as temperature. In this case, the lack of a physical or tangible signal could allow this performance shortcoming to go undetected indefinitely without a means of documentation or measurement. It also helps to have a tangible product of the measurement function such as a graphic that allows you to visualize system performance.

REAL TIME DATA TELLS A STORY (that might not otherwise be told)

Actual performance data collected on one project, upon completion of a chiller plant retrofit in an existing building, revealed that two 100 HP secondary chilled water pumps were ramping up in the middle of the night in December (Figure 1.). This occurred during unoccupied hours, unbeknownst to the facility staff. The culprit was later uncovered to be a hydraulic valve on the AHU cooling coils, operated by timer, that was apparently installed years prior (under different ownership and operation) to alleviate a coil freeze problem. Since no one knew this operational anomaly occurred, this "coil freeze protection" strategy operated all year including the cooling season when the entire chiller plant was impacted. Wasted energy and equipment life was the result of an undocumented condition, and a performance analysis of the entire system load curve uncovered the problem. The real time data collected documented this system anomaly that had gone undetected up to that point.

Two important issues are highlighted by this case:

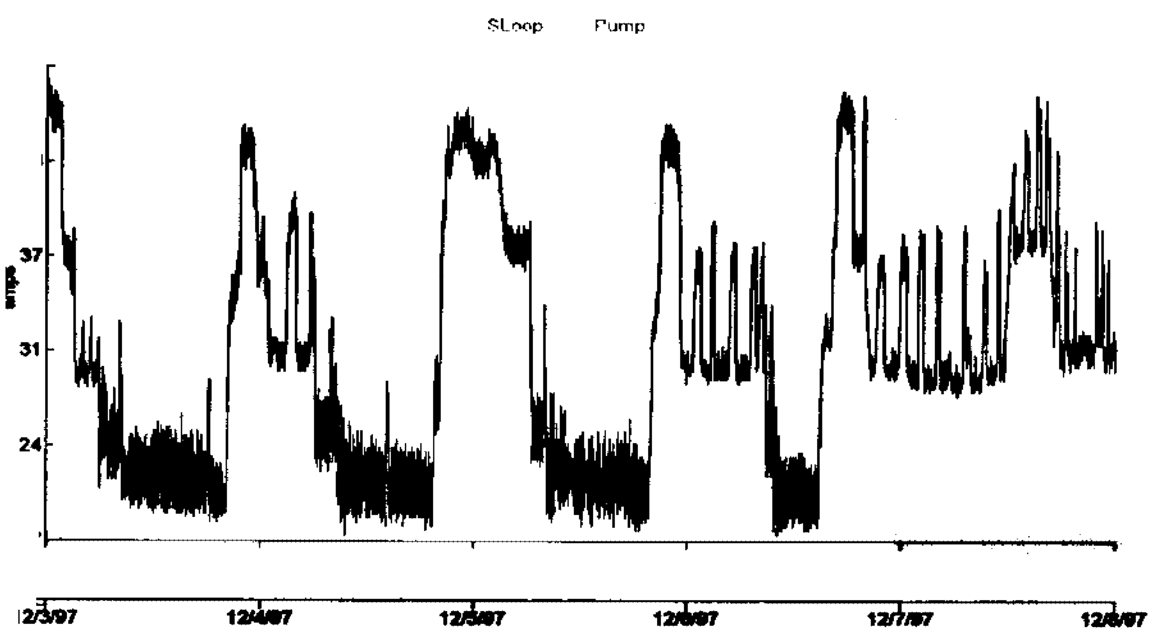
- The value of system measurement (metered data)
- Recognition that system performance can be invisible without a means to make it tangible

Adding "salt to the wound" in this example was the fact that there was another change during design that impacted the performance output, and in turn, effected the energy usage of the system. The original design called for two 80 HP pumps and the resulting calculated energy use was figured in constructing the "payback" formula for the project. However, the final design changed the pump sizing to 100 HP with the logic that the associated variable speed drives would control the necessary usage correctly. In fact the secondary pumping system ***was*** controlling to the system load. The differential pressure control ***was*** reacting properly to the signal from the chilled water loop. The activity in the loop was not in accordance with the design intent and therefore impacted the performance equation, *P* = ***D(A*)*** + *I(A*)* + *O(A*)*.

causing a change in the design adherence factor and therefore changing performance. ***An unintended change in input will cause an unexpected change in output.***

Data acquisition was the key to identifying this ***performance*** anomaly. The other point that this example demonstrates is the need to measure *actual performance* parameters when making decisions on existing systems. When integrating new and existing systems, ***do not rely on existing <u>design</u> data.*** Measure. Measure. Measure. It's all about the real time performance data!

Figure 1. Secondary Chilled Water Pump



Applying this example to the performance formula noted above, *P* = *D(A*)* + *I(A*)* + *O(A*)*, the design of the secondary pumping system was altered (albeit by an existing condition)

ELIMINATE ASSUMPTIONS

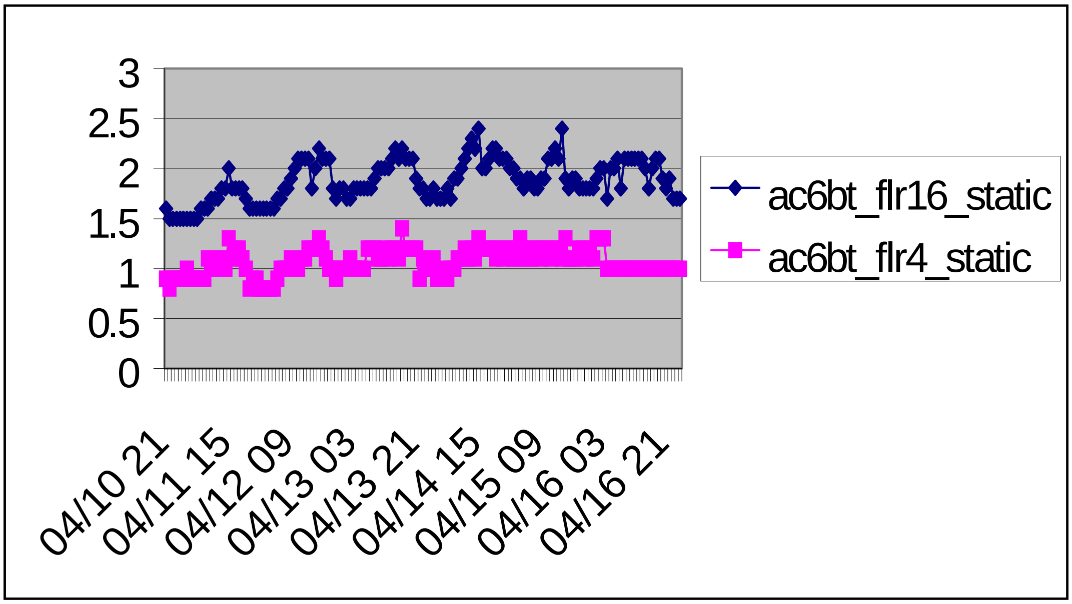
In most cases, building systems are assumed to be meeting design performance by occupants and facility staff when there is no tangible evidence to the contrary (i.e., complaints or equipment failure). However, true system performance needs to be measured. By documenting actual performance and, ultimately, reconciling such to the facility's operational intent, uncomfortable occupant conditions, substandard production conditions, premature equipment failure, and excessive energy costs can be avoided.

In assessing existing building performance, EH&E utilizes real time data to create a system performance profile. The intent of developing this profile is to create a 'tangible' picture of the building's design parameters, current use, and HVAC system performance. The initial task is to identify the system(s) to be commissioned, document all associated equipment, and review the system control sequences. This task creates the benchmark or operating intent to which all data collected and test results are compared. Data is then collected, analyzed against the benchmark, and any anomalies are documented.

In creating a performance profile on one hospital project in an inpatient building, data collected revealed that two 150 HP supply fans with Variable Speed Drives never modulated during the six day data period. They ran at full power (200 amps) and the supply air flow varied near capacity between 135,000 and 140,000 cubic feet per minute (cfm). These fans are under static pressure (SP) control from two points in the distribution run, fourth and sixteenth floors.

The written static pressure control strategy is: "The control system shall sense the static pressures in the supply air mains at floors four and sixteen and control the supply fans to maintain the static pressure (the static pressure set point to be determined during testing and balancing). The lesser of the two sensors shall determine the pressure control." Field verification showed that the static pressure set point was 1.2''. The fourth floor SP modulated but consistently stayed below or just at set point. Therefore, the supply fans continually ran at 100% power during the monitored time period. Figure 2 shows that the tracking of the two SP sensors during the monitored period. The SP at the sixteenth floor modulated from a low of 1.5 to a high of 2.4 and consistently floated to the higher range during late night and early morning hours. In contrast, the fourth floor sensor (denoted as fourth floor) modulated moderately and never exceeded the SP set point.

Figure 2 AHU, Static Pressure Sensors in Loop



System performance has a 'range of eventuality' (variations in performance) associated with it that contains numerous performance points. These points are dictated by the percentage of design adherence of each component and the interaction of all. In the case of the supply fans noted above, they were performing at or near their maximum value, with the size of its "range" dictated by the potential of the system to modulate to lesser values based upon getting the SP control to perform as intended. Over time, building changes will directly impact the performance of the building mechanical systems and the range of the resulting performance could be significant in terms of energy and equipment reliability. However, it is clear that data acquisition and analysis to a performance benchmark is the key to continuous optimal performance.

Energy use is a byproduct of performance. The acquisition of energy use (in the form of amps) on the fans noted above indicated that the system performance was falling short of the design intent. Energy can be a straight forward measurement and when transformed into a usage profile can be an important performance analysis tool. In this case the adherence factor of the operational component of the performance equation, $P = D(A^*) + I(A^*) + \boldsymbol{O(A^*)}$, was not in line with the performance profile anticipated with the intended design of the air handling unit (i.e., the actual data acquired displayed activity that was contrary to that expected). Again, an unintended change to a component of the system caused a significant change to the system output.

COMMISSIONING AND CONTINUOUS PERFORMANCE

Review, verify, document, and monitor. These four functions are the cornerstones for achieving optimum performance of building systems.

- Review the building or system's contract documents and interview facility staff to identify the Design Intent.
- Verify that all equipment and systems are installed in accordance with the building or system's Design Intent.
- Document system Performance through functional performance testing and performance data analysis.
- Monitor the continued operation of the building systems with real time performance data relative to the system Benchmark.

Functional performance testing is not complete without a performance trend over time. Likewise, data over time is incomplete without confirmation that the equipment and systems being monitored are capable of operating to the Design Intent.

EH&E is currently commissioning a project which is pursuing LEED[4] certification and is incorporating a Monitoring and Verification (M&V) Plan as a tool for the customer to continually monitor the facility's performance. The two performance verification tools are intended to work "hand in hand" to confirm and document performance into the life of the building as well as upon the completion of construction. The M&V Plan has two main components:

Energy and Water consumption at the whole building level (modified Option "C" of the International Performance Measurement and Verification Protocol, IPMVP)[5]

- Electricity, Steam & Water usage will be recorded for the monitoring period at the main building meter and reconciled with the utility billing information for the same time period.

End use performance data for the major building components will be collected, documented and benchmarked against the "building baseline" or "benchmark" for the appropriate seasonal time period (modified Option "B" of the International Performance Measurement and Verification Protocol, IPMVP).

The "Building Baseline" or "Benchmark", to which all subsequent measured data is compared, will be determined based on the following:

- Building Energy Model
- Building Design Intent and Basis of Design (system operational parameters)
- Commissioning of Monitored Systems
- First Year Seasonal Data

The intent of the M&V Plan is to collect building data periodically to verify continued performance to the Building Baseline.

Key criteria, which will impact the data output at any given time are:

- Weather
- Occupancy

[4] LEED, Leadership in Energy and Environmental Design, as sponsored by the U.S. Green Building Council

[5] International Performance Measurement and Verification Protocol (IPMVP), as sponsored by the Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

- Changes to system schedule, sequence of operation, equipment

This M&V plan is based on energy and water usage, not dollars (although the conversion would be simple). The intent of this plan is to monitor continued performance and the resulting energy consumption in the building and not have to account for utility price fluctuations. The analysis of the monitored data will be focused on:

- Usage
- Time
- Performance

A performance profile for each system will be established, which will track the output of system parameters against time. These profiles will be in the form of a system trend log generated by the Building Automation System.

The commissioning effort documents the ability of the system to perform as intended and the M&V plan acts as a tool to ensure that a “dynamic” system continues to meet the performance benchmarks throughout its life.

CONCLUSION

Real time data acquisition and analysis will take the assumption out of the performance equation and deliver persistence to your system design. Experience has proven that a methodical process of commissioning and time based data analysis is the best way to ensure conformance to contract and proof of performance of building systems.

If you can’t see it, measure and document it!