Existing Building Commissioning

A Case Study

By Ryan Lean and Molly Dee

The Brooklyn Museum—one of the oldest and largest in the United States—experienced the challenges associated with gallery climate control firsthand, following a phased renovation. Seeking to resolve unstable temperature and relative humidity in gallery spaces, the Museum underwent existing building commissioning.

As it relates to a building's heating, ventilation and air conditioning (HVAC) system, commissioning is a quality-assurance procedure confirming that the building is fully prepared to operate as intended. For an existing building, this systematic process verifies that existing building systems perform interactively according to the owner's operational needs and Current Facility Requirements (CFR). From visual checks to system-wide testing, existing building commissioning (EBCx) helps achieve operational objectives while optimizing performance and energy efficiency.

Nowhere is this more important than in a museum, where the robustness and reliability of HVAC systems are critical to providing stable environments for galleries and exhibition spaces.

BROOKLYN MUSEUM, 16.48_SL1.jpg

The Wilbour Plaque, ca. 1352–1336 B.C.E. or slightly later. Limestone, 6-3/16 x 8-11/16 x 1-5/8 in. (15.7 x 22.1 x 4.1 cm). Brooklyn Museum, Gift of Evangeline Wilbour Blashfield, Theodora Wilbour, and Victor Wilbour honoring the wishes of their mother, Charlotte Beebe Wilbour, as a memorial to their father, Charles Edwin Wilbour, 16.48. Creative Commons-BY.

KENNETH KURTZ, AIA, MUSEUM ARCHITECT

The Brooklyn Museum

Brooklyn Museum—Case Study Background

Founded in 1895, the Brooklyn Museum completed an eight-year renovation in 2016. The Museum added several new galleries to showcase collections ranging from Ancient Egyptian masterpieces to contemporary art. During its renovation, the Museum installed a state-of-the-art HVAC system with automated temperature controls for new and existing spaces. The renovation was completed in phases in order to spread costs across several years, and to ensure that the Museum remained open throughout the project.

Different teams of construction managers, contractors, and subcontractors completed the renovation across four distinct phases. Upon completion of all planned work, the African, Asian, Great Hall, and Blum galleries were built, and the following components of the new HVAC system were installed:

- Two custom-built headered variable-air-volume air-handling units (AHUs) equipped with preheat coils, chilled water cooling coils, hot-water-reheat coils, and atomizing steam humidifiers. The AHUs are served by two variable-air-volume (VAV) return fans.
- Thirty-one VAV terminal units with hot-water-reheat coils for additional temperature control.
- Three fan-powered boxes (FPBs) with interlocks to hot-water fin-tube radiation serving the perimeter of the building.
- Five supply-air distribution ducts tied to a dedicated header fed from the AHUs.
- Four return-air branch ducts tied to a common return-air plenum serving the return fans.

As each phase of the project was finished, new equipment from that phase was placed into operation. Bringing the various components of the system online in this staggered manner left room for error where one phase ended and another began. When the renovation was complete,

the Museum's Conservation and Facilities Departments observed issues that didn't manifest themselves until all system components had been enabled.

When the AHUs were only serving 10 VAVs in the expansion building at the end of the first phase, temperature and humidity remained stable, and trend logs did not indicate any trouble. However, when an additional 20 VAVs serving the galleries were installed and brought online in the second and third phases, building management systems (BMS) logs revealed that the temperature and humidity in the new galleries were frequently trending outside the acceptable ranges of 68–72°F (20–22°C) and 45–55% RH.

The Museum investigated, and found that certain VAVs located throughout all spaces were starving for air. To further complicate matters, many of the AHU parameters, such as discharge air temperature, drifted away from acceptable range because some sensors had fallen out of calibration.

To identify the cause of these issues, the Museum prescribed existing building commissioning of its air-distribution system.

Existing Building Commissioning Methodology

Phase 1: Visual Inspections

The EBCx team, in concert with the Museum's operations staff, began by visually inspecting every piece of equipment in the gallery air-distribution system. The team assessed each air-handling unit, inspected distribution ductwork, and verified that all individual system components were installed correctly.

One issue discovered during this phase was a set of fatigued backdraft dampers installed on the discharge side of the variable-air-volume return fans. With the fans in operation, these partially closed dampers were impeding the free flow of air back to the air-handling units, ultimately leading to a large deficit of air on the return side of the system. This problem was identified early in the process, but the full effect of the deficient backdraft dampers on the system was not realized until later, when the testing, adjusting and balancing contractor arrived onsite. This became a central focus of the balancing effort, and provided an excellent opportunity to improve the air-distribution system.

This simple first step of conducting visual inspections and promptly communicating any concerns also helped establish a strong working relationship among the EBCx team, the Museum's operations staff and the BMS service provider. Building a high level of trust with operations staff, which opened its doors and cooperated every step of the way, was critically important to the team's ability to successfully complete the EBCx process and resolve the Museum's climate challenges.

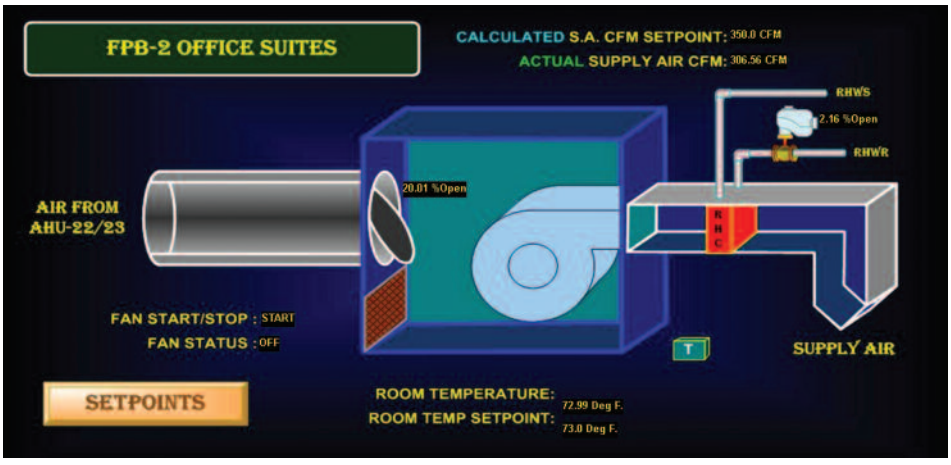
Phase 2: Verifying the Accuracy of Temperature and Humidity Sensors

The next task was to verify the accuracy of the gallery temperature and relative-humidity sensors. The accuracy of these sensors is critically important, because the HVAC system's ability to control climate is only as good as the input data it receives.

Temperature and relative humidity are sensed through wall-mounted thermostats and humidistats installed at multiple locations in each gallery. The team verified every thermostat and humidistat with a calibrated test gauge, and recorded local temperature and relative-humidity readings. These readings were then compared to the values recorded by the BMS. The team recalibrated or replaced any thermostat or humidistat with readings more than +/- 2% of the calibrated test-gauge value.

To improve the overall quality of the data monitored by the BMS, the team also verified the accuracy of monitoring sensors that are not used for direct control of equipment in the gallery HVAC system.

GRAPHIC BY LIBERTY CONTROLS



Building management system (BMS) graphic depicting operation of a fan-powered terminal unit serving Museum office suites.

Commissioning Engineer Philip Karnicki illustrating the change in airflow through a set of fatigued return air dampers when forced open.

Phase 3: Functional Testing of Individual Assets

The team needed to completely understand the original design intent of each phase, the installed condition of the system over the course of the eight-year project schedule, and the CFR. Therefore, prior to testing, the team compiled and reviewed the original design specifications, drawing sets, as-built documentation, and balancing reports from each phase. Functional performance testing began only after all team members clearly understood the expectations for every piece of equipment.

Each mode of operation was observed in the field, documented and compared to the original design documentation. The team then investigated any operational element that was not in agreement with the design documents.

Another aspect of the team's work was to gather information about the evolution of the control schemes for equipment in the air-distribution system. The team accomplished this through interviews with Museum operations staff, troubleshooting sessions with the BMS service provider, and review of raw data from trending operational parameters such as valve position, air temperature and static pressure.

To keep Museum staff fully informed, the team submitted biweekly reports documenting deficiencies. With approval from the Museum, the commissioning engineers worked directly with the BMS service provider to correct issues and optimize control schemes through reprogramming and control-loop tuning.

Functional testing of gallery air-handling units, along with a review of BMS trends for operational mode and humidifier-valve position, revealed that each unit was operating independently. This was contrary to the original design, which intended a parallel arrangement from a primary controller. Instead, one AHU was actively humidifying the supply air into the common headered ductwork, while the other AHU was actively dehumidifying the same air. This control scheme contributed to the swings in humidity observed throughout the gallery spaces.

To resolve this, the team worked with the BMS service provider to reprogram the units to operate in unison. This minor change in programming resulted in a major and immediate improvement to the air-distribution system.

The functional testing phase also identified an opportunity for improvement of the AHU humidification control program. When testing began, the AHUs were humidifying gallery supply air based on the relative humidity in the return-air plenum—an approach Museum staff deemed unsuccessful. The original design intent required the AHUs to humidify gallery supply air based on the lowest relative humidity reading across all galleries.

After returning the humidification program to its original design intent, the team closely monitored BMS temperature and RH trends for two to three days, in order to determine whether the change in programming had improved the climate in the galleries. It soon became clear that, due to the segmented layout of each gallery, controlling humidification to the lowest value was not the best approach, as it would cause some areas be to significantly over-humidified.

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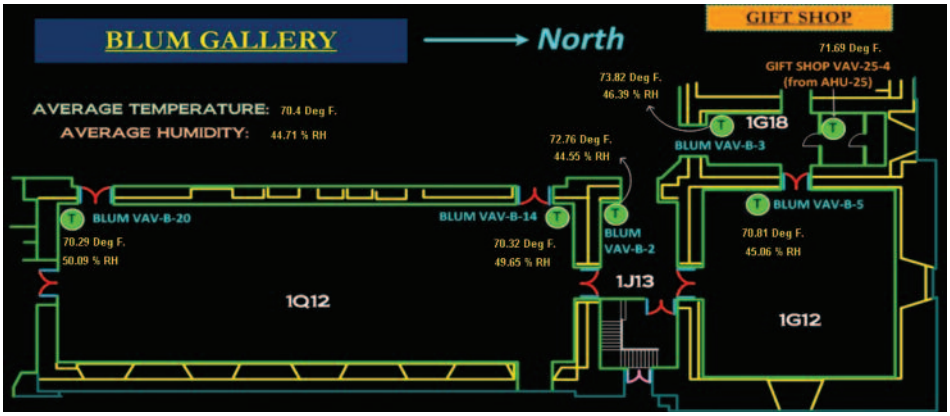

Building management system (BMS) graphic depicting the layout of the Museum's Blum Gallery with monitoring points for temperature and relative humidity.

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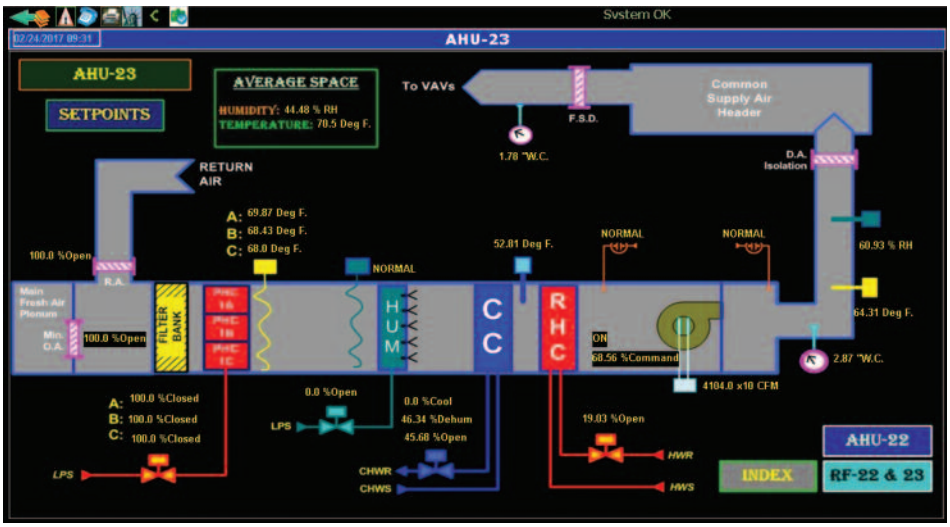


Building management system (BMS) graphic depicting operation of an air handling unit serving the various galleries at the Brooklyn Museum.

To resolve this issue, the team recommended using the average RH as the humidification control point. The commissioning engineers and BMS provider made the programming change, monitored the trends of gallery temperature and humidity, and tuned the control loops until the gallery climate stabilized within the acceptable range.

Phase 4: Integrated Systems Testing

After determining that the operation of each individual asset was performing well, the team turned its attention to integrated systems testing. This phase began in the mechanical room, with confirmation that AHUs and components were operating in unison per the newly documented CFR. From there, attention moved downstream to the VAVs to confirm operation by zone.

The final phase of integrated systems testing (IST) required a different approach from that of previous phases, moving the process out of the mechanical room and into trend data. Over a span of three to four weeks, the team simulated conditions in the galleries and verified that the air-handling units and VAVs responded as expected. If the team didn't see the desired outcome from a simulated event, it would review the BMS trend data to pinpoint the issue and make incremental changes to the various equipment control programs until the desired outcome was achieved.

While the EBCx team identified and corrected many high-level issues with the gallery air-distribution system in the functional testing phase, it further improved the system by reviewing the interactions between the AHUs and VAVs. For example, the team discovered that the dehumidification mode setpoint at the VAVs was lower than the gallery humidity setpoint controlling the AHU humidification program. Thus, the VAVs were constantly dehumidifying the air in the galleries, even when the relative humidity in those areas was at setpoint and the supply air humidity was stable. This was corrected by resetting the VAV dehumidification setpoint.

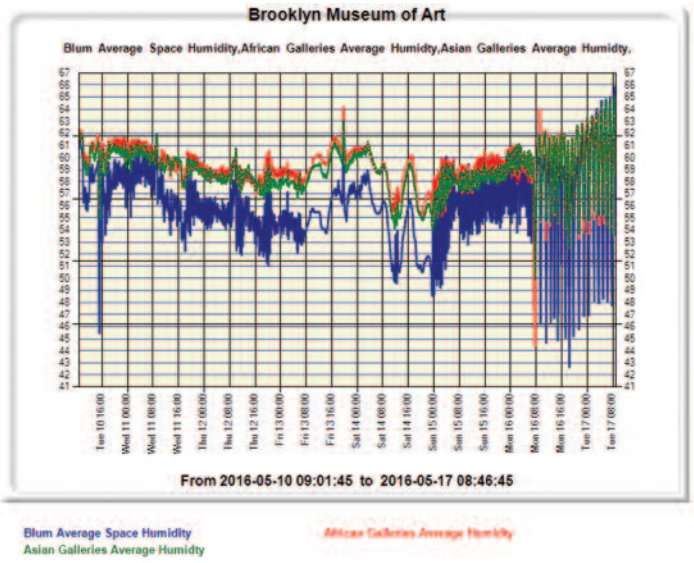
By the end of this multi-week process, the EBCx team was confident that each piece of equipment was accurately communicating with, and responding to, the other equipment in the system.

Phase 5: Balancing Verification

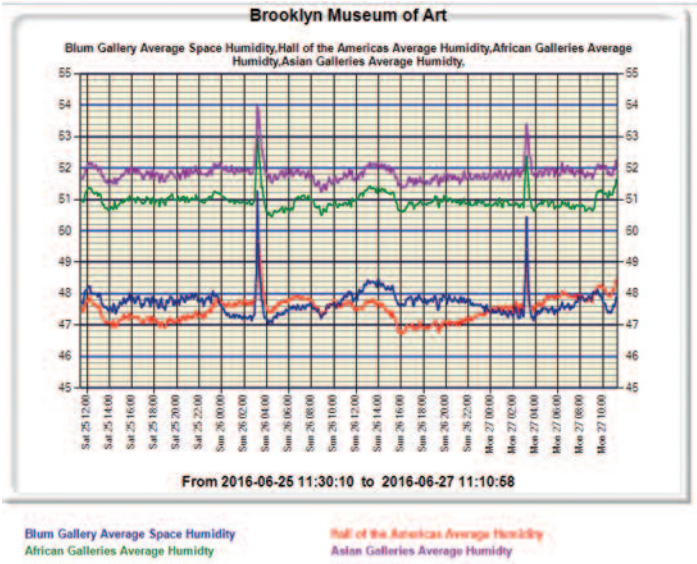
The final step in the Existing Building Commissioning process consisted of providing a balancer to verify airflow measurements and the accuracy of airflow sensors at the air-handling and terminal units.

The balancer took airflow readings at each fan (AHU supply and return) and its associated supply and return branch ducts. This allowed the team to confirm design airflow at the source. This was a critically important step that alerted the EBCx team of the extent to which the fatigued backdraft dampers at the return fans were negatively affecting the performance of the system.

A close look at the return-branch duct airflow readings with the backdraft dampers partially closed, when compared with the readings taken at the fan discharges with the dampers forced fully open, revealed that nearly half of the air was being lost on the return side of the system. Additionally, the duct airflow readings drew the EBCx team's attention to a partially closed fire/smoke damper in a smaller return-air branch duct. By addressing these issues, the Museum could increase the airflow in the system and further



Building management system (BMS) trend of average gallery relative humidities in May of 2016 at the start of the Existing Building Commissioning (EBCx) process. Trend data revealed poorly controlled humidities well outside of the acceptable range.



Building management system (BMS) trend of average gallery relative humidities in June of 2016 after implementation of corrective actions identified during EBCx. Trend data revealed improved control and conditions within the 45–55% RH range.

improve temperature and humidity control in the galleries.

The balancer also reviewed the calibration of the VAV terminal-unit airflow sensors from each phase of the project. This revealed that a handful of airflow sensors set in the earliest phases of the project were no longer accurate. By recalibrating these sensors, the EBCx team recovered an additional 2,500 cubic feet per minute (CFM) (1.18 m^3/s) of air on the supply side of the system.

Conclusion

By applying the EBCx process at the Brooklyn Museum through systematic investigation, analysis and optimization of the performance of the gallery air-distribution system, the commissioning engineers, BMS service provider and Museum staff solved the issue of unstable gallery climate control, and provided operations staff with the tools for continuous improvement of the air-distribution system's performance.

The work did not end when the EBCx process was complete. According to Ann Kaufman Webster, the Museum's Vice-Director for Planning and Architecture, "While this commissioning effort was essential to get the multiple-phased HVAC infrastructure back to the original design intent, the Museum learned that maintenance of a perfectly calibrated museum standard environment requires constant and ongoing diligence." 🏛

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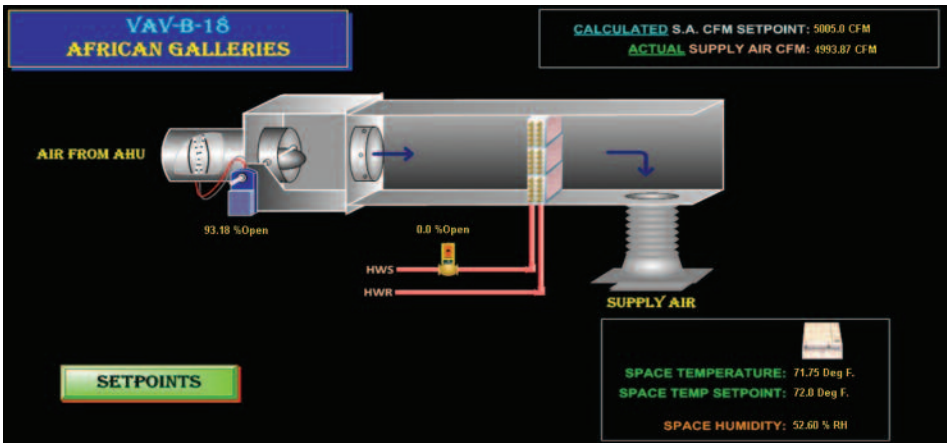

Building management system (BMS) graphic depicting operation of a variable-air-volume terminal unit serving the African Gallery.

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