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Airflow Dilemmas Solved With UFAD System

When planning for a new performing-arts center, an Atlanta university used a UFAD system to meet its uniform-airflow needs

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In 1995, after years of having its performing-arts facilities scattered across campus, Emory University in Atlanta began planning for a new performing-arts center.

Meeting the university's goals for such a diverse facility presented a challenge for the design team. First, the facility required office, classroom, and practice spaces. Second, support of the arts program dictated larger performance spaces with widely varying occupancy and loads. Third, the aesthetics of the facility, particularly the performance spaces, were a major concern. Acoustics—both ambient noise levels and isolation—were vital, as the building's final design also provided recording spaces for performers, as well as a black-box theater and dance studio. Finally, the centerpiece of the facility, an 825-seat concert hall, would be a challenge to condition properly.

To satisfy the facility's varying needs, the mechanical design team employed a variety of approaches. Office, classroom, and practice spaces were served by conventional variable-volume systems sized to minimize noise. The performance spaces were served by dedicated units—essentially, single-zone variable-volume units.

Besides being subject to large and rapid changes in occupancy and load, the concert hall's acoustical standards were higher. The design team chose a high-volume, low-pressure underfloor displacement-ventilation air-distribution system to satisfy the musicians' demands while controlling temperature and humidity. This article will describe the operation of this system and the commissioning process for Emory University's Donna and Marvin Schwartz Center for the Performing Arts.

Photo courtesy of J.J. Williams Architectural Photography

The Donna and Marvin Schwartz Center for the Performing Arts.

UNDERFLOOR DISPLACEMENT VENTILATION

From a mechanical standpoint, the concert hall was approached as a "building within a building." Although the main lobby leads di-

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rectly to the building's exterior, other areas of the facility enclose the remaining three sides of the concert hall, isolating it from exterior conditions. Achieving a large open space was one of the main goals.

The concert hall was designed with a 56-ft-high ceiling and mezzanine seating on three sides. Careful attention was paid to the acoustics and acoustical isolation. All mechanical systems serving this area were situated in their own remote mechanical room in the basement of the building.

Because of the sensitivity of musical instruments to temperature and humidity, the stability of the environment in the concert hall was a major concern. The design team chose to provide a system that met the space loads by circulating a constant large volume of air (36,000 cfm) at a minimal temperature difference. This approach helps to maintain stable conditions in the hall as supply air is introduced at close-to-ambient conditions. However, large volumes of air require large duct systems to keep velocity and air-distribution noise at acceptable levels. Large ductwork had significant architectural implications and was not desirable in the large open space of the concert hall. The ductwork was another reason the design team chose an underfloor displacement-ventilation delivery system, rather than a pressurized underfloor duct system or an open pressurized floor (as is commonly used in data centers with concentrated equipment loads).

DESIGN ISSUES

To provide the desired open space, maintain the desired acoustical properties, and achieve acoustical isolation from the remaining portion of the building, the concert hall was designed with a pre-cast concrete shell. The design team's concept for the concert-hall conditioning was to use a large chamber under the

Mysterious Clouds and Whistles

During the first six weeks of the Donna and Marvin Schwartz Center for the Performing Arts's operation, the humidification cycle for the theater lab ran wild one day, producing a roiling cloud in the space down to approximately 8 ft off the floor, so thick one could not see through it. The situation was traced to an incorrectly configured control loop that overran the humidity supply limit and was corrected. One performance had the lobby so warm that the exterior doors had to be opened on a 25-F winter evening to provide cooling. This eventually was traced to a stuck heating valve, but it did leave an impression on all concerned, leading to considerable review of the facility's performance. Data recorders were installed throughout the hall to monitor conditions, but the situation never recurred.

Another major challenge was maintaining the acoustical environment required by performers in the concert hall. Despite considerable design effort dedicated to these issues, the actual operation of the building found unexpected conditions.

The main stage area includes a stage lift used to raise pianos and other large instruments from a lower storage area. When lowered, the stage lift also provides a small orchestra pit. The mechanical design provided cooling to the area by providing a return path from the under-stage area through the pit. One of the earliest problems with the facility was from orchestra members on the stage complaining of an annoying whistle. Thinking it was a supply-air-related problem, the commissioning team expended considerable effort trying to locate the offending supply delivery point. Eventually, the problem was traced to an air noise at the fibrous "seal" at the edge of the stage lift. The volume of return air drawn from the pit area was reduced, and the noise problem across the seal was solved.

hall essentially as a slightly pressurized plenum to supply the space with conditioned air through floor-level diffusers in audience seating areas.

To provide a return path from the concert hall without impacting the architectural and acoustical integrity of the space, return-air intakes located at the top of the concert hall, above the interior shell, were provided to collect warm air from the space. These intakes were connected to large ducts in the interstitial space between the concert-hall shell and the structure of the building. Return-air ducts were routed back to the remote mechanical room. This mechanical concept heavily influenced the structural design of the building and was cast in concrete with the underfloor supply plenum and return paths built into the hall's structure.

Minimum outside-air volume is controlled by modulating the primary return damper to maintain a constant mixed-air plenum static pressure with a fixed minimum outside-air-damper opening. This results in a fixed outside-air volume at the air-handling unit. This minimum quantity was configured to provide the desired pressurization of the concert hall and to provide a minimum ventilation quantity to the space. As concert-hall occupancy varies, the system responds to an increase in the return-air carbon-dioxide (CO_2) concentration by modulating open the maximum outside-air damper, resulting in a decrease in mixed-air static pressure. In response, the return-air damper is modulated closed to

Photos courtesy of Newcomb & Boyd Consultants and Engineers

Typical floor-level diffuser from floor level (left) and below (right).

maintain the desired mixed-air plenum static pressure, resulting in an increased flow of ventilation air. While retaining the ability to provide necessary ventilation rates when the facility is occupied, this approach allows a minimum flow of outside air during unoccupied periods.

Georgia weather provides a high-temperature/high-humidity ambient environment for most of the summer. The idea of maintaining tight temperature and humidity control by essentially blowing cold air at occupants' feet raised significant concerns.

Discussions with the design team and owner led to modifications of this supply ductwork to the underfloor plenum changing from a single discharge point into the underfloor plenum to a ductwork distribution system with six delivery points, each with dampers, to provide some balancing capability across the plenum space. Revisions were made to operating sequences to provide a "cascaded" control of supply-air temperature, maintaining a discharge supply temperature that was varied as necessary to satisfy concert-hall space conditions. Additionally, under-seat diffusers were changed from a front-and-back delivery arrangement to a left-and-right discharge arrangement.

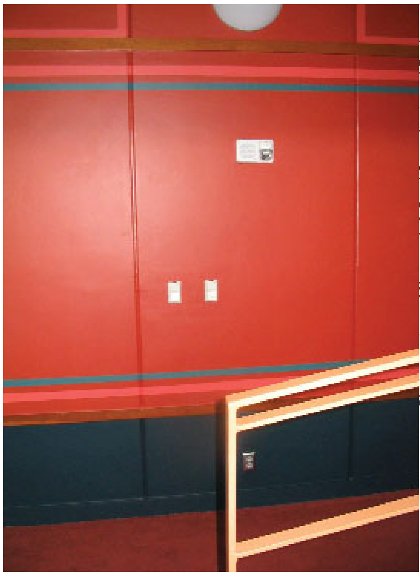

Photo courtesy of Newcomb & Boyd Consultants and Engineers

Concert-hall space-condition sensors.

COMMISSIONING CHALLENGES

The commissioning scope required complete functional testing of installed mechanical systems, including the underfloor displacement conditioning system for the main performance hall. The biggest challenges in accomplishing this task were setting up the controls and completing the final test and balance (TAB) and proper programming. The TAB contractor had difficulties properly configuring the air-handling units for minimum outside airflow. The mechanical contractor had deviated from the design documents by installing significantly oversized outside-air ducts, making regulation of outside-air quantities difficult. This issue was of particular concern for the concert-hall equipment, which was designed with a low minimum-outside-air requirement (enough to provide basic pressurization and ventilation) and provided with a demand-ventilation control sequence to account for the increased needs of the expected wide variation in occupancy. Control of the minimum outside airflow was vital for efficient operation of these systems. With the support of the mechanical design engineer and contractor, this issue eventually was resolved with some modifications to the outside-air connections. Oversized connections were reduced at the point of connection to the air-handling unit by blanking sufficient area to produce a measurable and repeatable pressure drop of approximately 0.25 in. wg. This pressure drop gave sufficient signal magnitude to allow accurate measurement and modulation of the return-air damper to maintain the required minimum outside-air volume.

The second major challenge involved the control system. The setup and configuration data for the various terminal units were lost by the controls contractor multiple times, requiring the repetition of the TAB effort and significantly impacting the testing schedule. While the design engineer provided clear operating sequences, the controls contractor had difficulty converting these into correctly functioning programming and frequently installed alternative sequences that did not accomplish the design intent. We spent many hours assisting the programmers and installing technicians in producing correctly functioning programming of the direct-digital-control (DDC) system. Considerable effort was expended troubleshooting and calibrating sensor installations.

Some of the challenges with the sensor installations were related to the mechanical design of the systems. To provide the desired acoustical isolation of various performance spaces, particularly the concert hall, the mechanical systems were located some distance away from the areas served. From basement mechanical spaces, oversized ductwork with sound attenuators extended to the concert hall. The design provided space sensors to monitor temperature and humidity in the concert hall. Environmental controls respond to these sensors.

Based on recommendations from the design review, the design engineer incorporated a supply-air-temperature control loop, in which the operating set point is varied in response to space conditions, rather than directly controlled from space-condition measurements. This allows greater stability of the control system, as it is able to quickly sense and stabilize the supply-air temperature while the space conditions take significant time to respond to the change.

This cascade control is useful in applications in which either distance or a relatively large volume of space creates considerable lag between the mechanical system's action and the space experiencing the results of this action. In the case of the Schwartz Center, both conditions existed. This indirect-control concept proved to be a considerable challenge for the control-system programmer, who initially attempted to control space conditions directly from space-condition measurements, as typically would be done with a variable-volume terminal unit.

The delay between initial control action and space response was far longer than the standard software anticipated, resulting in oscillating control loops and unstable conditions. Implementing the design-required control sequences (with a supply temperature allowed to vary between 55 F and 90 F to satisfy space conditions and proper "tuning" of the control loops) produced stable supply-air temperatures and improved conditions in the concert hall.

The same concept was used in the building's other performance areas. The wide temperature range was established by the design engineer's sequence. Observation of the unit during testing found the supply temperature to be within 2 to 3 F of the space-temperature set point during conditions other than significant load, with minimal heating required. Even when fully occupied, the supply temperature does not fall significantly below the desired conditions. Likewise, return conditions have not been significantly different from the target values. This close agreement between desired conditions and measured air temperatures is attributed to the large volume of air being circulated by the mechanical system. Minimal temperature differences are required to satisfy the loads.

In a similar fashion, the humidity control loops suffered a considerable time lag from the detection of a lower-than-desired humidity condition to the actual delivery of additional moisture to a space. During this period, the control system tended to continue requesting additional humidity, frequently overrunning the supply-humidity high limit and saturating the ductwork and lining materials. The extra moisture resulted in significant swings in humidity conditions. Combined with cold winter evenings, there often was frost on the windows of the theater spaces and, sometimes, ice on the aluminum window mullions. The humidity swings also were problematic for the stringed instruments in the rehearsal hall and in the performance spaces. This problem was solved by revising the controlling sensor to monitor return-air conditions, rather than space, to increase the response time and by switching from a direct control loop to an indirect reset loop. While these revisions did not produce tight humidity control, they did limit the magnitude and frequency of the humidity swings.

Despite the anticipation of a time lag, the various spaces responded to the mechanical systems more rapidly than expected. Occupants noticed variations in comfort conditions significantly sooner than the control system measured a change. In the concert hall, a change in the supply-air temperature was noticeable to occupants and could be detected by test instrumentation in as little as 8 to 10 min, despite the fact that the space sensors required as much as 45 min to register

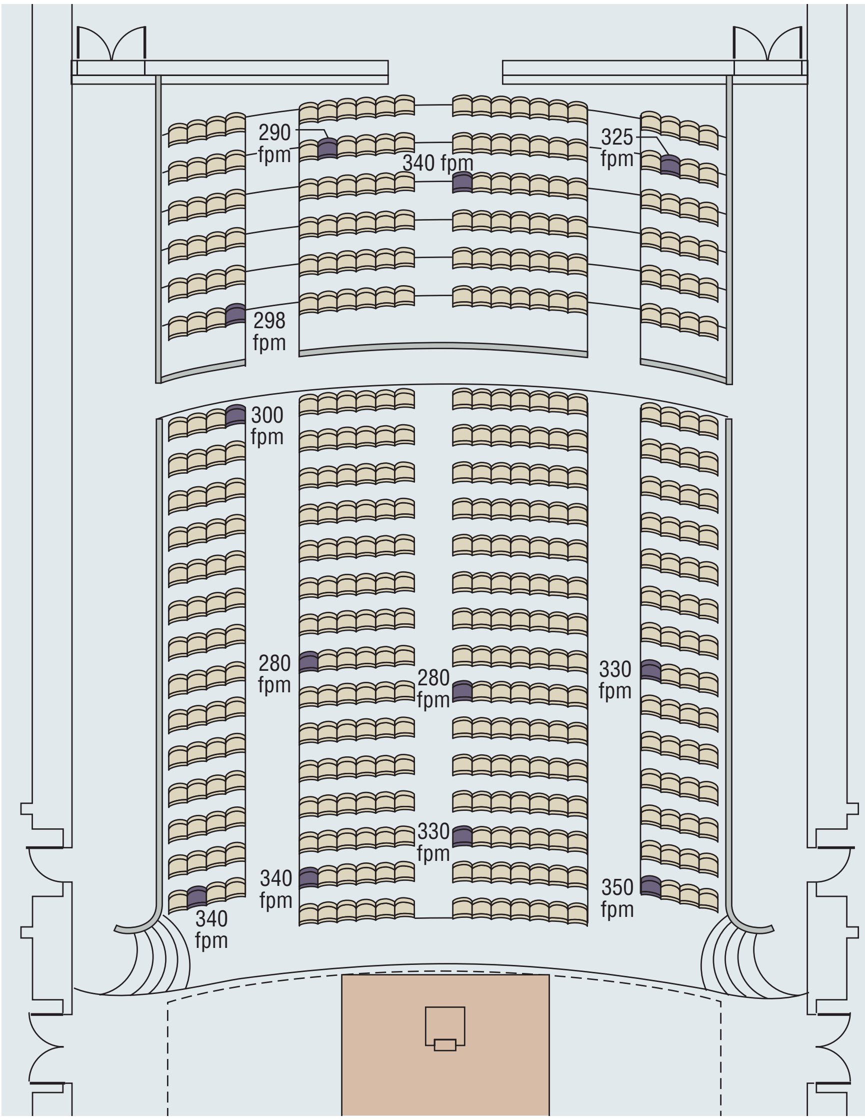

FIGURE 1. Typical floor diffuser measurements.

the change. This large temporal decoupling of the observed space conditions from the feedback measurement presented quite a problem in maintaining the steady conditions required by the instruments. To resolve this situation, the controls contractor included return-air-temperature measurement in the control algorithm. This provided a more rapid indication of the effect of the mechanical system and, with sufficient tuning, allowed the system to satisfy the space loads with minimal variation in conditions. Monitoring return-air humidity also allowed the incorporation of a "high-humidity override" into the control strategy. Whenever return humidity rises more than 5 percent above the target value, the cooling-coil control is overridden to increase the flow of chilled water to the cooling coil. The unit-mounted reheat coil then is modulated to maintain the required supply-air-temperature set point. Since the implementation of these feedback loops, space conditions in the concert hall have been stable.

The commissioning of the major feature of the building, the underfloor displacement-ventilation air-distribution system, proved to be relatively anticlimactic. The air-handling unit delivered conditioned supply air to the plenum space. Achieving the design flow, even through the extended ductwork and sound attenuators needed to meet the acoustical standards, required a relatively low supply static pressure of approximately 1.8 in. wg at the air-handling unit. The underfloor supply distribution was adjusted to provide equal flows at each of the six delivery points in the underfloor plenum, and supply air was allowed to escape through the floor-level openings in the plenum and then through the under-seat diffusers throughout the audience area. The pressure differential proved to be quite consistent across the seating area: approximately 0.005 to 0.007 in. wg across the underfloor plenum. Supply airflows, although not identical, were both low and reasonably consistent across the floor. Figure 1 shows supply velocity measurements taken across the audience area, measured using a rotating vane anemometer at the discharge side of the plenum opening before the diffusers and seating were installed. Because the seating and diffuser configuration prevented final volume measurements and because no quantifiable criteria other than total volume had been required by the design documents, this “uniform” distribution was accepted as meeting the design team’s expectations and intent.

CONCLUSION

Once past the initial problems, the occupants have been satisfied with the building and its performance. With the initial operational problems addressed, there have been no significant complaints from audiences during performances. In addition, the past performance of the space and the mechanical systems gives everyone confidence in the ability of the systems to meet the challenge. Receiving great reviews from both patrons and performers, the Schwartz Center has become another crown jewel in the world of performance halls.