

Case Study: Furman University Charles H. Townes Center for Science

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Synopsis

We present a case study that examines the commissioning of a phased university laboratory construction project with aggressive energy efficiency goals: The Furman University Charles H. Townes Center for Science. The building is named for Nobel Laureate Charles Townes, a 1935 graduate of Furman University. The project involved 85,000 square feet of new construction as well as renovation of the existing 120,000 square foot building. The building was designed for LEED® Gold certification, and included many innovative sustainable features such as chilled beams, energy recovery of fume hoods, radiant floor heating and cooling, and a solar aquatics water treatment system with graywater re-use. The project includes wet and dry laboratories for all university science departments, including biology, genetics, chemistry, physics, geology, and ecology. The building also includes a vivarium, herbarium, nuclear lab, planetarium and other specialty spaces. The project is designed to be highly energy-efficient using chilled beam technology, low-flow fume hoods, energy recovery, variable air volume with occupancy sensor controls, and other strategies. The building design has followed the guidelines of the Laboratories for the 21st Century program.

We, as the commissioning provider, were hired during early design of the project. Our expectations were to have several technical challenges in commissioning the project, due to the complexities of a laboratory building in general, and the innovative technologies being employed. And we did have technical challenges. However, the most challenging aspects of the project turned out to be non-technical; mainly the problems with the phased construction, and the failure by the construction team to correct numerous deficiencies related to installation of the building's systems and automated controls.

About the Authors

Michael K. Mantai, PE, CCP, CEM, LEED AP, is president of System WorCx, a building commissioning firm located in North and South Carolina. He has been performing building commissioning for 19 years. He graduated from Duke University with a degree in Mechanical Engineering and Materials Science. He spent seven years with Westinghouse performing various commissioning activities for mission critical nuclear facilities at the Savannah River Site. Since then he has worked in the roles of construction administrator for large hospital projects, project manager and mechanical design engineer for various projects, partner and principal for a

consulting engineering firm, and commissioning authority for more than 100 projects. He founded System WorCx in 2004 to focus on commissioning as a third-party consultant.

Michael has been a LEED-Accredited Professional since 2003 and started work on his first LEED project in 2002 as a commissioning authority. Since then he has been involved with more than 70 LEED projects in various stages of design of construction. Michael has recently taught Emerging Green Builders at various colleges and universities about the LEED Energy and Atmosphere section and Indoor Environmental Quality sections.

Michael is currently a board member and past president of the South Carolina chapter of the U.S. Green Building Council, and previously served as chairperson of the Marketing and External Relations Committee of the Building Commissioning Association.

Veronica Addison, PhD, LEED AP, is a commissioning technician at System WorCx in Columbia, South Carolina. She graduated from Georgia Tech with a Bachelors degree in Mechanical Engineering and attended graduate school at the University of South Carolina, earning a PhD in Mechanical Engineering with a focus on sustainable design. Veronica has been a LEED Accredited Professional since 2005 and worked on her first LEED project in 2006. She currently works as a commissioning technician, energy modeler, and LEED consultant on various projects throughout the southeast.

Contract Arrangements

The design team was an architectural/engineering firm that provided all design services.

The commissioning provider was hired as a third-party directly to the University.

The construction manager was selected through a qualifications-based process.

The major subcontractors were local and had worked on many previous projects for the University.

The test and balance contractor was hired as a third-party directly to the University.

Scope of Commissioning

Commissioning commenced during the design development stage of the project. The commissioning firm was hired as an independent third-party consultant directly to Furman University. The scope of commissioning included both Fundamental and Enhanced Commissioning for LEED® Certification under New Construction version 2.2. In addition to the systems required to be commissioned under LEED, the owner elected to include additional building systems in the commissioning process. The commissioned systems included HVAC, building automation, domestic hot water, fire protection, and emergency power.

Design Phase

The Design Phase of the project included all of the elements for which commissioning providers strive. The owner was committed to implementing energy conservation and sustainable strategies. The design team was forward-thinking, open-minded, and willing to research design alternatives. The commissioning firm was brought in during the early design process. The owner's project requirements and basis of design were well documented. And life cycle cost analysis was used to help make design choices. The owner and design team were very open to the integrated design process and worked and communicated well. There was very good interaction and discussion between the owner, design team, and the commissioning team. And finally, the construction documents were high quality, well-coordinated, and had detailed controls schematics and sequences of operations. All parties involved were enthusiastic and excited to be working on the project.

Design Phase Commissioning

Three formal commissioning design reviews were completed, at Design Development, 50% construction documents, and 100% construction documents. All comments were discussed with the team and responded to in writing by the design team. In addition, several team meetings were conducted to review design considerations, with one meeting dedicated to the controls

system design. Below is a table illustrating how the commissioning comments related to potential design issues.

Table 1: Commissioning Design Review Comments By Type

ISSUE	Quantity
Code compliance.	20
LEED compliance	12
National Consensus standard compliance	1
OPR compliance	17
Coordination/constructability problems	88
Operational problems	44
Maintenance/access problems	36
Indoor environmental problems	20
Energy efficiency	13
Commissioning scope of work	18
General comment	44
<i>Total</i>	<i>313</i>

HVAC System Design

The HVAC system design process involved extensive research and analysis to arrive at the basis of design for the project. The team used Labs 21 principles, case study data from other facilities, energy modeling, and life cycle cost analysis to make choices, most of which centered on achieving a high level of energy efficiency. The major system choices are described below.

Chilled Beams

We had seen many presentations and heard a lot of buzz about chilled beam technology, but had never seen this technology in practice. The expected high sensible loads of this laboratory led the design team to consider chilled beams. The decoupling of cooling and ventilation is not a new concept, but is also not typical in our experience. The high additional cost of the chilled beams themselves was offset by the reduced ductwork needed by an all-air system, and the analysis showed that implementing this technology would be cheaper in first-cost and in life-cycle cost.

Active chilled beams were selected, in which ventilation air is connected to the beams and delivered through nozzles in the beam. This type of chilled beam provides a built-in method for delivering ventilation air to the space, and also assists in effectiveness in inducing heat from the space through the chilled beam.

Furman University has a central chilled water plant. New chilled water pumps with variable frequency drives were implemented, creating separate chilled water loops for the chilled beams and the air handling units, since the chilled beams operate using higher temperature chilled water.

Being in the hot, humid climate of the Southeast (Greenville, SC) and having labs with exterior walls under negative pressure caused concerns over potential condensation on the chilled beam surfaces. This prompted implementation of moisture sensors on the chilled beam piping in each space to close the chilled beam control valves should condensation occur.

Ventilation

Room air change rates of six air changes/hour during occupied mode, and a reduction to four air changes/hour during unoccupied mode, was implemented as part of the owner's project requirements. Laboratory air terminal unit controls were connected to occupancy sensors used to control lighting in each space to setback ventilation rates.

Low-flow technology fume hoods reduced the necessary amount of fume hood exhaust. Hoods are constant volume designed to maintain 50 feet per minute face velocity.

All building exhaust, both fume hood exhaust and general exhaust, was routed through desiccant-type energy recovery wheels located in central air handling units that delivered 100% outside air to the building. All regularly occupied spaces in the building were served by these central air handling units. Air handling units were paired and connected to distribution ductwork in parallel for redundancy. Each air handling unit had two associated exhaust fans that were connected in parallel with each other and with the associated pair of fans for the other air handling unit. So most areas had two supply fans and four exhaust fans connected in parallel. The Owner and Design Team consulted several studies from Johns Hopkins University to gain a comfort level that cross-contamination from fume hood exhaust contaminants to the fresh air stream would not be an issue.

Heating

Heating hot water was provided through two gas-fired and one electric boiler, with distribution pumps on variable frequency drives. Perimeter space heating was by radiant panels installed just below ceiling-level. Central air handling units had hot water preheat coils. Air terminal units for ventilation air to spaces were equipped with hot water reheat coils.

Radiant Floor Heating and Cooling

Two spaces in the building were provided with a radiant floor heating and cooling system. These included a large concourse area and a large circular reading room. The systems had dedicated pumps with plate-frame heat exchangers, and automatic valves to allow for running either hot water or chilled water through the system.

Controls

The building automation system was by Johnson Controls. Laboratory airflow was controlled by Phoenix venturi-type Valves, with room offsets used to control space pressurization. Control of the energy recovery wheels was packaged by the manufacturer (Semco) and interfaced with the BAS through open-protocol communications.

Emergency Power System Design

Two diesel emergency generators with paralleling gear and automatic transfer switches powered emergency lighting, limited ventilation and cooling, and emergency-power receptacles. The system included time delays and interlocks that would reduce the number of fan and pump motors that could operate simultaneously on emergency power, to reduce the size of the generators.

Construction Phase

Summary Results

The project was completed in two phases, with the first phase occupied in fall 2007 and the final phase completed in fall of 2008. Numerous significant issues have prevented the building from achieving all of the intended energy conservation features, as well as creating a lot of pain and frustration for the owner, design team, and commissioning provider.

Phase I Results

Coordination and Phasing

The first phase of construction went fairly smoothly for most of the project, from our perspective. Some relatively minor installation deficiencies and coordination issues were observed, as expected. The first major issue occurred as we started to discuss the functional testing schedule with the construction team.

The first phase included the two new wings added to the existing building, and approximately 1/3 of the renovated existing building.

It became apparent when we first met to discuss a detailed schedule for implementing functional testing that there were significant shortcomings in the coordination between the Construction Manager and the HVAC and electrical trades. Basic coordination items such as installing power to HVAC equipment were not being accomplished in a manner that would support the commissioning schedule. We implemented biweekly “commissioning” meetings that resulted in

mainly discussing coordination issues. While clearly this type of meeting is not typically within what we would classify as commissioning, we felt they were necessary and brought value to the owner, so made them part of the process.

Our approach to commissioning by phase was to functionally test all of the new systems that would serve Phase I as if it were a single-phase project. This approach was followed since the University would be occupying the first phase for approximately one year while the second phase was completed. All five of the building's air handling units were installed in Phase I, although not all ductwork and spaces would be connected to them. The central mechanical room that housed the chilled and hot water pumps and boilers was located in Phase II. So while the airside for the entire building was mostly installed in Phase I, the waterside would have to operate on the existing equipment until Phase II. Also, the new emergency generators and automatic transfer switches were installed in Phase I.

Unfortunately, the construction team did not really follow this same approach. Their approach was that the building was in a "temporary" state of operation that would be incomplete until Phase II was completed. This disconnect in approach resulted in numerous functionality issues that wreaked havoc on our attempt to implement functional testing in Phase I, and lots of complaints from the Owner as even basic temperature control could not be consistently maintained during the first months of occupancy. The heating system in particular was not reliable, and often it would be 95°F outside but only 65°F inside (more discussion on overcooling later).

Emergency Power

During one of our biweekly commissioning/coordination meetings, we discovered that the electrical contractor was not aware of the requirement for installing a large relay array to limit which HVAC fan and pump motors could run on emergency power. The relays' function was to only allow half of the fans and pumps to run to avoid overloading the emergency generators. Though there was a single electrical drawing that showed only this relay array, it still took several meetings, last minute coordination between the electrical and controls contractor, and a failed functional test to get the contractor to complete this work and get the system functioning. During the initial test, several other issues were found, including miswired automatic transfer switches, generator intake damper controls, generator exhaust stacks leaking into the attic mechanical room, and miswired receptacles were found. The case for including emergency power in the commissioning scope was definitely justified on this project.

Phase II Results

Once the second phase of construction was complete, we treated the project like every other construction project, and began functional testing of all systems, regardless of which installation phase.

Exhaust Fan Capacity

The first issue to emerge, during Test and Balance, was lack of exhaust fan capacity. The basis of design was a variable speed exhaust system which included capacity for future hoods. However, with fans running at 100% speed, design flow was not being achieved. The TAB firm reported that the fans were running at their maximum rated RPM. Investigative actions included taking duct static pressure measurements across all fittings in the exhaust duct runs to identify unexpected pressure drops, temporarily removing dampers and filters at the exhaust fans. Corrective actions included replacing some duct fittings, with marginal improvement. Below is a summary of the fan performance:

Table 2: Exhaust Fan Performance (Typical)

Criteria	Design	Actual
CFM	16,400	14,214
Static Pressure	6.0" w.g.	5.4" w.g.
Fan RPM	1824	1845

The fan performance was not consistent with the manufacturer's fan curves, and there was discussion about attributing this to a system effect caused by the configuration of the exhaust fans in parallel, with respect to proximity of the intakes of the fans (close-coupled installation-see figures below), and whether the fans should be rotating opposite to each other. These were more difficult to address and were not attempted to be corrected.

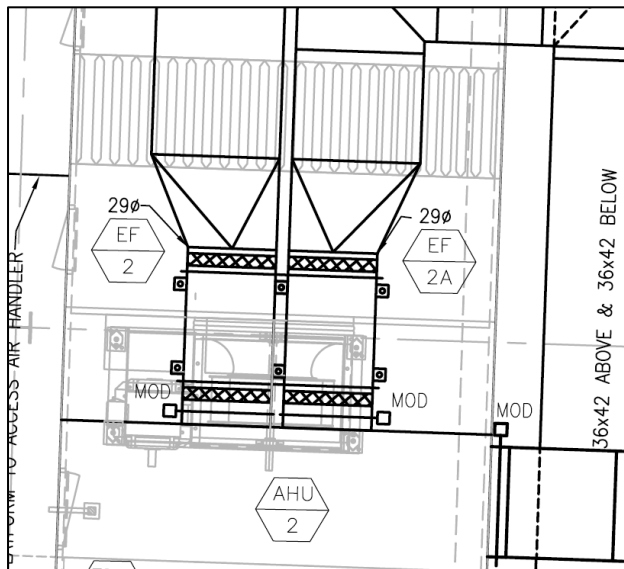


Figure A: Actual Fan Configuration

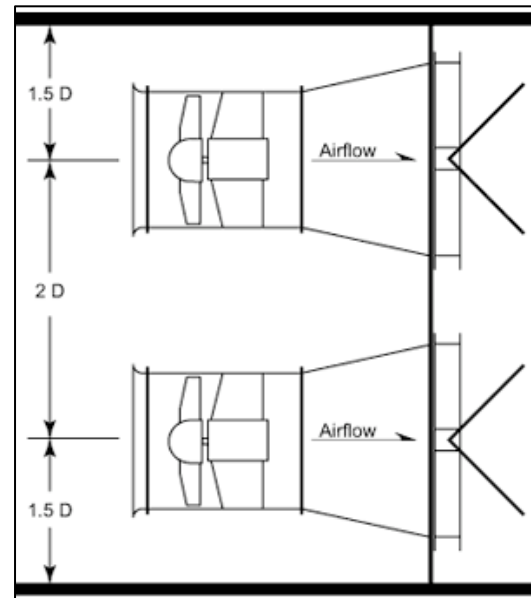


Figure B: Manufacturer Guidelines

Aggravating the fan performance problem was the issue of occupancy sensor interlocks with the building automation system (discussed further below). Because the building automation system was not interfaced with the occupancy sensors, the exhaust flow rates to the spaces in the

building were never setback, so no diversity could be attained. Correcting that issue helped the fan performance somewhat.

The end result was that the exhaust fan systems were able to achieve minimum flow at all fume hoods, but that energy savings from unoccupied setbacks will not be realized, and future capacity to add fume hoods to the system has been compromised.

Chilled Beam Condensate Sensors

During functional testing, it was quickly discovered that a large number of the spaces had the chilled beam cooling locked out (control valve closed) because the chilled beam condensate sensors were in alarm. Upon field observation, there was no condensation observed on the piping (the sensors are intended to sense condensation conditions prior to actual condensation occurring). Investigation into the mechanism that caused the sensors to alarm did not reveal any obvious solution to the issue, though it was observed that a number of the sensors had been painted along with the piping. The owner elected to remove all sensors in lieu of replacing sensors. During nearly two years of occupancy, condensation on the chilled beams has not been observed.

Chilled Beam Performance/Excessive Reheat

During the first year of occupancy (Phase I) and during final functional testing of Phase II, we discovered that a large number of the chilled beam control valves were closed, and ventilation air terminal unit reheat control valves were open, even with outside air temperatures near summer design conditions. It was apparent that the nominal six air changes/hour provided through the chilled beam for ventilation, at 55°F, was more than enough air to offset the space cooling loads. The 55°F air delivered by the central air handling units was designed for constant temperature to provide dehumidification. Attempts to raise the discharge air temperature resulted in excessive space humidity during summer conditions. A discharge air temperature setback control strategy was implemented based on outside air conditions to reduce the amount of reheat needed during mild conditions. In hindsight, a second energy recovery wheel located downstream from the cooling coil would appear to have provided a more energy-efficient system, providing reheat from the exhaust air.

Radiant Floor Heating/Cooling

The system was initially installed incorrectly by the contractor, and by the time the corrections were made, the heating season had ended. The system was functionally tested, but performance during winter conditions has not yet been verified. The design includes a plate/frame heat exchanger intended to provide either heating or cooling to the spaces equipped with the system, but the owner has been hesitant to allow the system to operate in cooling mode, since much of the building is in reheat mode. We plan to further test the cooling mode during summer conditions.

Occupancy Sensors

The occupancy sensors supplied to control lighting in each space were designed to interface with the BAS so that the room ventilation could be set back to 4 ACH when the room was unoccupied. The electrical contractor provided incorrect sensors such that the relays could not operate correctly (277V relays provided, 120V relays needed). This issue was corrected but took a long duration before this feature of the system was operational.

Controls Issues

Our initial approach to commissioning individual space controls (air terminal units, chilled beams, heating coils) was to attempt a sampling strategy. As a firm, we generally do not employ sampling strategies, but in this case our fee arrangement was hourly, and due to the large number of spaces, we decided to try sampling as a means to keep our fee lower. Unfortunately, we quickly realized that a large number of rooms had issues, mainly related to controls. Examples included bad sensors, control valves operating backwards, improper setpoints, etc. These are not unusual findings in the commissioning process, but we were surprised by the volume of issues, and abandoned the sampling strategy in lieu of checking every space.

Summary

Overall Results

The selection of team members and the integrated design team seemed to establish a solid foundation for the project to succeed without major issues. However, this was not the case. The issues described above are just a small representation of the large number of issues encountered. Commissioning succeeded at identifying the system deficiencies, but was not nearly as successful at ensuring correction of deficiencies, as evidenced by the large number of outstanding issues. Of the over 400 deficiencies identified, nearly 300 remain to be corrected. Below is a chart of the deficiencies by system (note that some similar deficiencies were grouped in the Master Issues Log, such that the chart does not represent the total quantity of deficiencies).

In talking with building maintenance staff, we heard repeated comments to the effect that it was typical on their projects to have known issues that went uncorrected by the construction team. This has caused us to closely examine how we implemented the commissioning process on this project, and how we could have improved the results. Below are summary figures of the type and quantity of issues encountered.

Table 3: Issues Found During Construction Phase Commissioning Process

Note: Table does not indicate total quantity of issues, as some similar issues were grouped together.

ISSUE	Quantity
Potential code compliance	5
LEED compliance	2
University design standards compliance	2
Owner's project requirements compliance	1
Coordination or constructability problems	77
Operational problems	45
Maintenance/access problems	21
Indoor environmental problems	5
Energy efficiency	1
Commissioning scope of work	25
General comment	26
Other	41

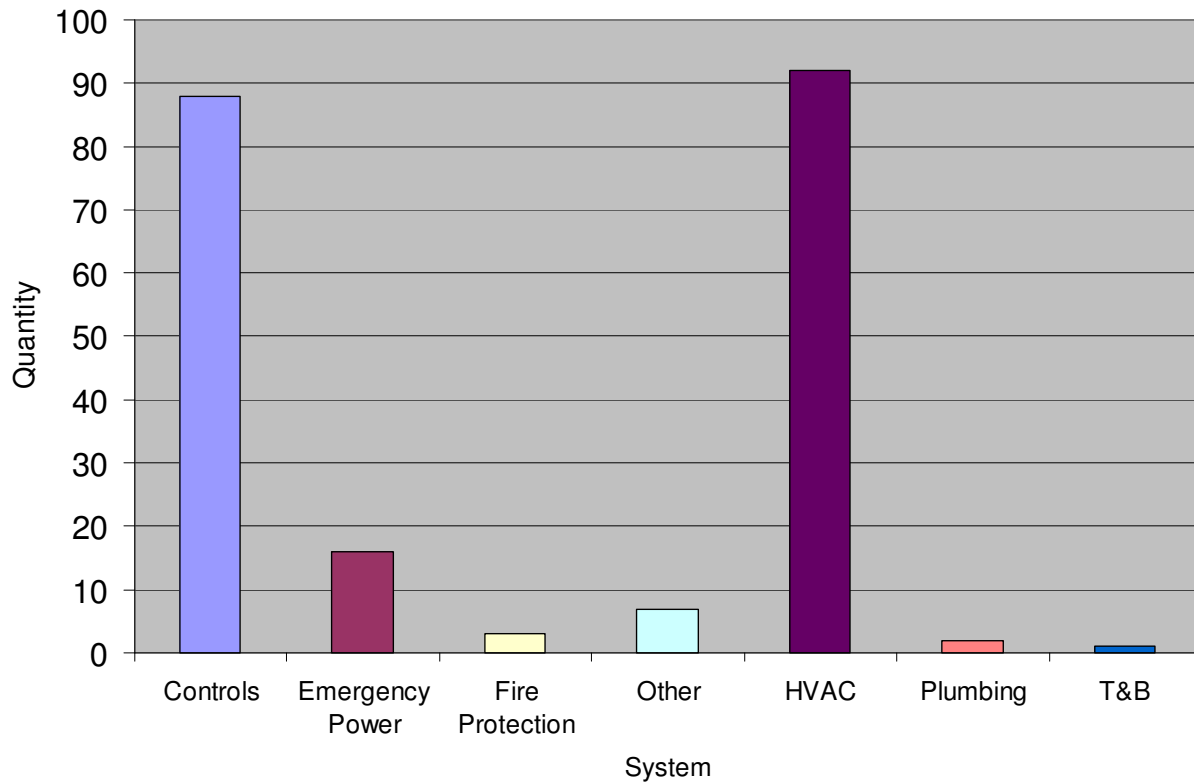


Figure C: Issues found by System

Room for Improvement?

What Went Wrong

The fundamental lack of coordination between the construction manager and mechanical and electrical subcontractors and their approach toward phasing of the project were major contributing factors to the issues. We attempted to address this deficiency through regular commissioning meetings, but this was only marginally successful. Some of the significant issues were more technical in nature, and though everything appeared to be done properly through the integrated design process and interactive discussions during design, somehow our commissioning process still failed to avoid some fundamental systems issues that relate to the design of the building's HVAC systems. Also, some less obvious issues (e.g. incorrect relays in occupancy sensors) were not part of our checklist process intended to catch issues early.

Issues Resolution

Frustrations were often expressed by the owner, engineer, and the commissioning firm as to the lack of the subcontractors' timeliness in correcting identified deficiencies, yet the team did not seem to be able to implement any actions to get the deficiencies corrected. It's not easy to identify the specific causes of this, but again the commissioning process failed to establish a solid means to ensure issues were not only identified, but corrected quickly. At this point in the project, at least some of the building is still under its one-year warranty, and our major goal during this phase is to determine how to get the construction team to address outstanding deficiencies.

Hourly Contractual Arrangement

Most of our firm's projects are through a lump sum fee arrangement. For this project, the owner elected to contract with us on an hourly basis for construction site visits. Because of this arrangement and our consciousness that each trip we made would cost the owner money, we believe we made fewer visits to the site than we would have otherwise, which may have contributed to some of the shortcomings of the commissioning process. We don't feel that additional site visits would have dramatically improved the outcome of the project, but wonder whether this type of fee arrangement can be detrimental to the process.