Thesis Proposal

Lemma, Minnesota

the Auditorium

December 13 , 2013
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Introduction to Redesigned Alternatives for the Mechanical System in the Auditorium at Francis Michael Performing Arts Academy

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Executive Summary

This report is an investigation into alternative mechanical design characteristics, that aim to improve the Auditorium's energy consumption, and reduce the annual cost of operation. The Auditorium's current design meets all the requirements given by code in the state of Minnesota for occupancy comfort and energy efficiency of equipment. The current design even exceeds some of these standards. However, even though the goals have been met, there is always room for improvement and consideration of other ideas.

The current mechanical design of the Auditorium, a performing arts facility and office complex, utilizes both a campus steam heating plant and chilled water cooling plant. Steam is brought into the building and converted into hot water, which serves the building via fin-tube radiation units and heating coils in the air handling units. Chilled water is also distributed to the air handling units in addition to 16 active chilled beams to cool and dehumidify the spaces. Further information on the mechanical equipment can be found in the Equipment Summary section below.

When evaluating the options to improve the Auditoriums systems, several considerations came to mind:

- How could the building could benefit holistically from a change in design?
- What systems are affected by this change?
- What are the costs and benefits of the design change?

Some options included investigating the enclosure of the building, changing the airflow control system to a demand controlled ventilation system, expanding the use of chilled beams, and examining the potential for on-site renewable resources.

The proposed alternative that provides the best potential for educational value and overall building improvement is expanding the use of the chilled beam system to other areas of the building. This change impacts several systems including, acoustics, construction, electrical, and architecture. While investigating the mechanical sides of the expansion, there will also be checks to ensure that the change is not negatively affecting any of these systems. Furthermore a study into demand control ventilation will determine if energy savings can be achieved through monitoring the occupancy of the spaces.

The breadth topics to be investigated more fully than only a preliminary check include an acoustics analysis and a construction cost analysis. Implementing more chilled beams could affect how noise is perceived in spaces. Additionally, the size of duct work will change and how that affects construction cost and schedule will also be evaluated.

During the 14 weeks of the spring semester, milestones have been set to check progress throughout the analysis. Tools to run load simulations and analysis include IES Virtual Environment and Dynasonics AIM. More detailed information regarding the proposal ideas, tools to be used and schedule can be found in the following sections.

Building Overview

The Auditorium is a historic building located on the campus of the Francis Michael Performing Arts Academy (FMPAA). It was built in 1929, and has recently undergone a renovation to revitalize the performance space and allow for greater usage of the ancillary public spaces. After completion of construction the Academy Honors Program will permanently reside in the Auditorium

A pediment entrance way with ionic columns faces the prominent campus mall. The building facade is a 3 wyth historic brick construction with classical ornamentation. The building is approximately 172,000SF, five stories tall and located in the very cold climate of Lemma, Minnesota.

The plan below (Figure 1) shows the expanded performance space (green), audience chamber (maroon), and horseshoe of public spaces and office spaces (orange) surrounding.

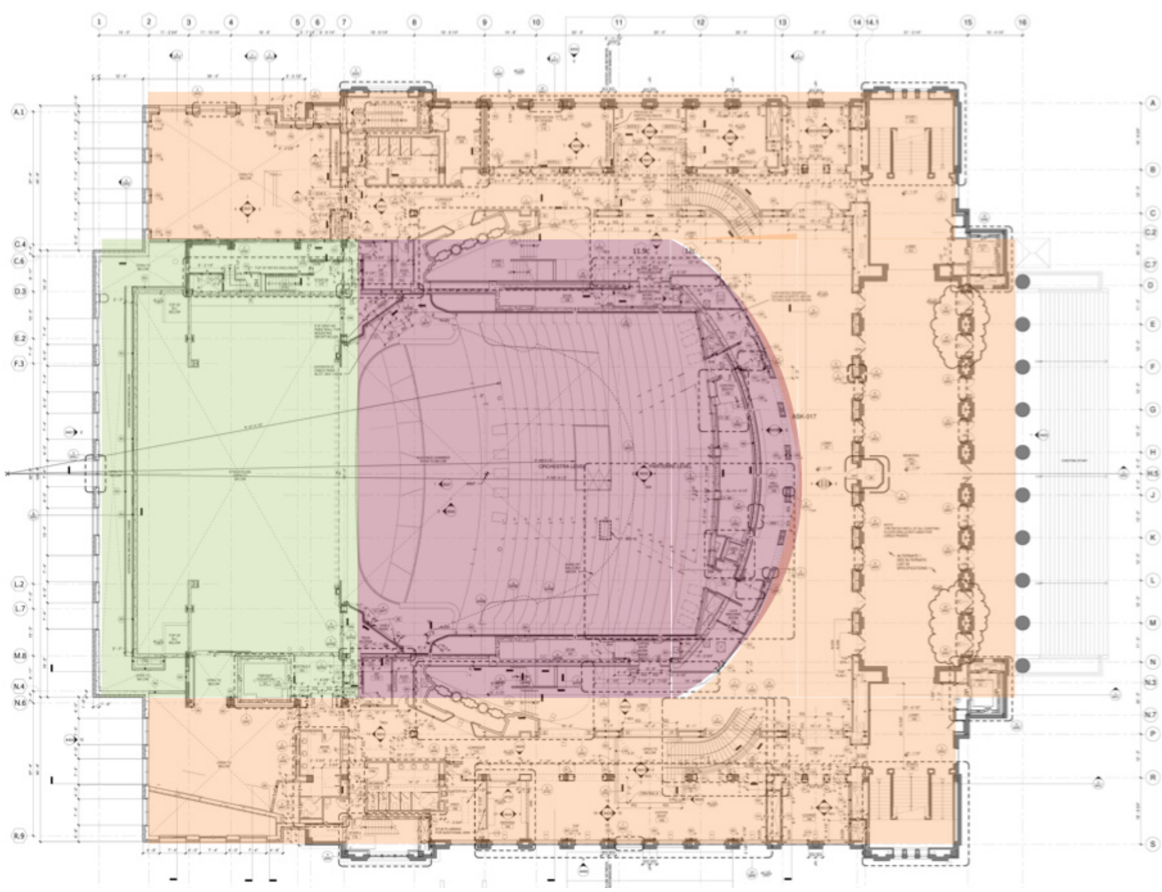

Figure 1 First Floor Level (Source: Architect of Record)

Mechanical Overview

The mechanical system of the auditorium employs several technologies to distribute heating and cooling to the building occupants. The primary heat source for the building is from a campus steam plant. The steam plant provides 150°F steam to a flooded high pressure heat exchanger to create hot water. The hot water is then distributed to fin tube radiation units, fan-powered boxes and four air handling units. Steam is also utilized in the air handling units humidification systems.

Located in the basement of the Auditorium is the campus cooling plant. It includes three -1000 ton centrifugal chillers, which accommodate the northwest corner of campus including the Auditorium. Chilled water is distributed to the air handling units, in addition to the active chilled beams which serve the performance support spaces.

Four air handling units serve the building. Each unit is sized to accommodate the following program spaces:

- AHU-1: Public Spaces - Variable Air Volume
- AHU-2: Audience Chamber - Displacement Ventilation via Underfloor Air Distribution
- AHU-3: Performance Spaces - Variable Air Volume
- AHU-5: Performance Support Spaces - DOAS with dual-energy recovery wheel - active chilled beams

Note: AHU-4 was not used and does not exist in the final construction documentation

Design Consideration

The objective of the renovation of the Auditorium was to restore the building to a functional state for the Academy's use. The performance and audience spaces needed to be redesigned to allow for better performance logistics and acoustical sound, while also providing more office space for the Academy Honors program to reside within the building. The role the mechanical system played in this renovation was to bring the existing system up to current day code regulations and provide a healthy and comfortable environment for the occupants. The major airside systems in the building were completely redesigned and previous systems were removed and replaced with up-to-date technologies. The building is served by campus steam and chilled water plants and their impact drove many design decisions. All standards enforced by the Minnesota State Building Code were complied with and in some cases were exceeded by the design team.

Equipment Summary

The equipment listed below is a sampling of the equipment included in the Auditorium's mechanical system. The major heating, cooling, and airside equipment is described below. A more comprehensive list of equipment is described in Technical Report 3.

Heating

Steam Plant

The campus steam plant includes 3 boilers; two natural gas and fuel oil boilers and a third circulating fluidized boiler. The circulating fluidized boiler burns coal, oat hulls and has the capacity to burn a blended version of fuel. Steam is produced and distributed to all campus buildings for heating and humidification purposes.

Heat Exchanger

When steam is delivered to the building, it enters at high pressure into a flooded heat exchanger (SHE-1). The heat exchanger is rated to accommodate 500 °F and 250 psi steam to heat water up to a maximum temperature of 200 °F. Valves control the amount of water held in the tank based on the load capacity needs. This heat exchanger has a capacity of 12,000 lbs/hr.

Cooling

Chilled Water Plant

The chilled water plant supplies chilled water to all campus buildings for space cooling purposes. The plant, located in the basement of the Auditorium, includes two 1000 ton centrifugal chillers and a third 800 centrifugal chiller, all manufactured by Trane. They use refrigerant R-123, a commonly used chlorofluorocarbon. The system is designed as primary/secondary with a front-end decoupling pipe with control valve. The pumping arrangement is centralized and includes a set of three primary pumps in parallel and three distribution pumps in parallel with variable speed drives.

Airside

Air Handling Units

There are four air handling units (AHU) serving the Auditorium. AHU-1, AHU-2, and AHU-3 are variable air volume units that serve the public spaces, auditorium chamber and performance spaces correspondingly. They all use a fan wall system and have rated filters of MERV 7 and MERV 14. AHU-1 is designed for 70,000 cfm and serves 130 VAV boxes. AHU-2 serves a 61,000 cfm underfloor air distribution systems located in the audience chamber. The performance spaces are served by AHU-3 directly, and it is designed for 31,000cfm.

AHU-5 uses a dual energy recovery wheel. One wheel is for heat recovery (HRW) to preheat the incoming outdoor air. The other is a passive dehumidification wheel (PDW) to control humidity. AHU-5 is a 10,000 cfm variable air volume unit that serves 16 active chilled beams in the performance support spaces. It also has filters rated at MERV 8 and MERV 14. Note, AHU-4 was not used and does not exist in the final construction documentation.

Chilled Beams

Active chilled beams are supplied with the minimum amount of air required by code for adequate ventilation. They, in turn, cool the spaces by recirculating the room air and passing the warm air over a series of cooling coils located in the unit. The inlet water temperature supplied to the cooling coil in the chilled beam is 60°F. Figure 2 to the right shows how the circulation process works. The cooling fluid is supplied by the chilled water plant and returned to the plant after it has cooled the air in the space. With these units, as stated before, only minimum outdoor airflow is needed which can significantly reduce energy costs.

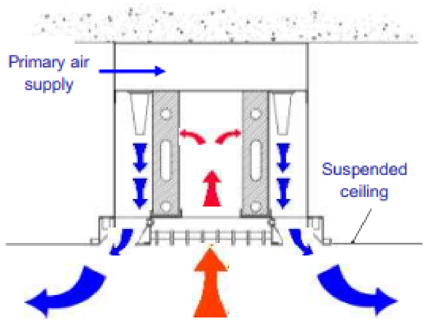

Figure 2 (Source: Trox Chilled Beam Design Guide)

System Evaluation

The goal for this renovation project was to recapture vital space on the campus of FMPAA and reengineer the performance space to create a world-class performing arts facility. The Auditorium's mechanical system adequately meets the requirements to properly heat and cool the building. Sufficient ventilation to achieve satisfactory indoor air quality, and comfort standards are also being met. Additionally, only 4% of the gross square footage of the project is devoted to mechanical space, the design team needed to use every square foot to achieve the proper ventilation and comfort standards. Tight floor to floor heights also restricted types of equipment that could be used.

While the mechanical system achieves the needs of the Auditorium in terms of comfort and safety, it is worthwhile to investigate whether additional energy savings or holistic improvements can be made to further revitalize the Auditorium.

Alternatives Considered

The following ideas were considered when developing areas of investigation for improving the Auditorium:

- Complete enclosure analysis evaluating:
    - Energy performance
    - Thermal properties
    - Moisture
    - Structural Impacts
    - Historic shell considerations
- Implementing demand control ventilation (DCV)
- Expanding the use of chilled beams and evaluating:
    - Energy performance
    - Cost savings

    - Humidity constraints
    - Acoustic problems
    - Space constraints
- Performing a chiller optimization study
- Investigating the potential for on-site renewable resources (ie solar, wind, etc)
- Evaluating the possibility of a ground source heat pumps

Due to time constraints and available information, not all of these alternatives can be investigated fully. For example, due to uncertainties regarding the historic brick enclosure, and availability of simulation software, a complete enclosure analysis is most likely not feasible. However, characteristics of the enclosure can be studied in relation to other design aspects investigated. Some of these considered alternatives will affect only parts of the Auditorium, while others greatly impact many systems. The options with the most potential for educational value and cross disciplinary research will be developed further.

Proposed Alternatives

By proposing alternatives to the current design of the Auditorium, it in no way implies that the design lacks in any particular detail. These proposed studies are meant to determine if the Auditorium could realize additional energy, cost or schedule savings through expending additional research time purely for educational value.

Depth

Chilled Beam Expansion

Comparing the final design documents to the design development drawings, the engineers initially designed more rooms in the Auditorium to utilize a chilled beam system. Through the "value engineering" phases of design however, the chilled beams were reduced from 33 chilled beams to 16. The proposed alternative research is two parts.

- First, to examine, the energy impact that could have taken place if the initial design intent was kept.
- Second to compare if all the support spaces could have benefited from a complete chilled beam system.

Impact

By implementing a chilled beam system many areas of the building are going to be impacted. From a mechanical stance, the zoning of spaces will need to be evaluated, the humidity levels in all spaces and especially in sensitive spaces need to be considered and the airflow rates to each space will need to be simulated for a chilled beam system. Other building systems and characteristics that will be impacted are the lighting design for spaces, the electrical input required to run a chilled beam as opposed to a fan-powered box, and the architectural aesthetics of the spaces. Furthermore, implementing a chilled beam system will affect initial cost and life-cycle costs for the project.

Additionally, by using chilled beams, which are significantly larger than standard diffusers, coordination of the ceiling plenum space will need to be re-evaluated. The following areas will be analyzed in relation to implementing a chilled beam system

Ceiling Layout Check
To confirm that the architectural intent of the ceiling design is being met

Lighting Check
To confirm that the lighting watts per square foot are available, if changes to fixtures are required.

Structural Check
To confirm that space is adequately provided in the ceiling plenum to accommodate a chilled beam fixture and supported structurally

Construction Check
To confirm that the workers are able to appropriately install the chilled beams and to ensure that adequate service space is available.

Demand Controlled Ventilation
Additional energy savings have the possibility to be realised through the control of the ventilation system based on actual occupancy. By providing only the required amount of conditioned outdoor air, energy can be saved, instead of pushing unneeded extra conditioned air into empty spaces. Demand controlled ventilation (DCV) is different than CO2 monitors that control the ventilation to a space. CO2 monitors check the concentration in a given room to determine the percent occupancy, while DCV can employ several different types of sensors to detect occupants including MOS or 'mixed gas' sensors (metal oxide semiconductors), and movement detectors (infrared or ultrasonic sensors). DCV can also monitor the occupancy on the room level or at a zone level by placing sensors in the return air plenums. DCV control systems can also be programed to adjust to the building conditions over time and 'learn' building patterns.
The proposed alternative is to investigate the effectiveness of a DCV and/or CO2 monitored system to determine energy savings over traditional time-of-day automatic setbacks.

Breadth

Acoustics
The changes from fan-powered boxes and or variable-air-volume dampers to chilled beams will have an impact on the sound in each of the spaces. Additionally, changes to the air handling units on the roof could impact sound levels transferred to the Auditorium.

An acoustical analysis will determine if the changes made to the air-distribution system negatively or positively impact the spaces that will be receiving the new chilled beam system.

Depending on the results, recommendations can be made to further decrease the noise transmitted to the spaces or confirm that a chilled beam system performs better acoustically.

Construction

Since chilled beams reduce the amount of airflow required by each space the ductwork sizes can be reduced while still achieving correct pressure drops and noise levels. An analysis of the amount of sheet metal required to be installed could lead to additional cost savings in labor and materials for the project.

The construction breadth analysis will also evaluate the overall cost implications of using additional chilled beams. Studies into schedule impacts and subsequent labor costs will be compared to the proposed and actual schedule of the project. Additionally, the cost impact of switch from traditional mixing boxes to chilled beam units will also be researched.

Masters Coursework

The expansion of the chilled beam system analysis will involve aspects from 500-level course work. Content from Centralized Cooling Production and Distribution Systems (A E 557) will aid in the evaluation of the chilled beam redesign. Additionally, from another 500-level course, Centralized Heating Production and Distribution Systems (AE 558), a life-cycle cost analysis will be performed.

Tools

Load Simulation

Software programs such as IES Virtual Environment, Trane Trace, and Engineering Equation Solver (EES) will be used to perform analysis in several different areas of the chilled beam expansion study and enclosure analysis. The Trane Trace Software has already been utilized in previous studies, however IES Virtual Environment will be used to analysis the systems and plants in more detail. Engineering economics will also be used in these programs to examine the initial and life cycle costs.

Acoustic Analysis

To analysis the acoustic performance in spaces affected by the change of variable air to chilled beams, Dynasonics AIM, can be used. By inputting air-flow values, ductwork lengths and transitions, along with sound pressure levels at the air handling units the final room noise criteria values can be determined and compared to code recommended values.

Schedule

The attached schedule in Appendix A is a preliminary overview for the work plan in Spring 2014. The four milestones are spaced to allow for adequate time and checks during the semester. The milestone breakdown is as follows:

- Milestone #1 (Jan. 26, 2014) - Initial research - complete; CPEP Site up-to-date; IES Model developed for current system.
- Milestone #2 (Feb. 16, 2014) - IES Model Complete and running proposed alternative simulations; Enclosure Study in progress.
- Milestone #3 (Mar. 9, 2014) - Enclosure study - completed; Architectural Coordination breadth - complete
- Milestone #4 (Mar. 30, 2014) - Acoustics Breadth - complete; Only final revisions to report & presentation needed.

Research

Demand Controlled Ventilation

Demand controlled ventilation (DCV) is a control strategy to reduce energy consumption. By monitoring CO_2 levels at the zone level to determine the actual amount of outdoor air needed in a space, you are able to achieve proper indoor air quality levels while not over airing the space. Many factors play into proper indoor air quality including type of activity, the materials or furnishings in the space, and the occupancy associated with an activity. By monitoring quality of the air in the return system as opposed to only temperature or pressure as traditionally measured, the system can better accommodate the actual loads in a zone.

Dwyer, Tim. "CPD: September 09 - Sensing the need for demand controlled ventilation." *Chartered Institution of Building Services Engineers - CIBSE Journal*. Chartered Institution of Building Services Engineers, n.d. Web. 18 Nov 2013. <http://www.cibsejournal.com/cpd/2009-09/>.

The Chartered Institution of Building Services Engineers explains demand control ventilation systems, the methods for measuring the demand and system considerations in this article.

Energy Efficiency & Renewable Energy, U.S. DOE. "Demand Control Ventilation." *Building Technologies Program*. U.S. DOE Energy Efficiency & Renewable Energy, n.d. Web. 20 Nov 2013. <http://www.energycodes.gov/sites/default/files/documents/cn_demand_control_ventilation.pdf>.

The Energy Efficiency & Renewable Energy Information Center published an article that compares ASHRAE Standard 90.1-2010 and the International Energy Conservation Code in terms of incorporating demand controlled ventilation. It also lists the procedure for evaluating if a building can accommodate a DCV system.

Chilled Beams

Active chilled beams are supplied with the minimum amount of air required by code for adequate ventilation. They, in turn, cool the spaces by recirculating the room air and passing the warm air over a series of cooling coils located in the unit. The inlet water temperature supplied to the cooling coil in the chilled beam is typically 60°F.

"Chilled Beam Design Guide." *Trox Technik*. Trox USA, n.d. Web. 20 Nov 2013.
The Trox Design Guide is an overview of the chilled beam system and a resource for the type of chilled beams that Trox manufactures.

ASHRAE Wisconsin Chapter. "Chilled Beams: The new system of choice?" *Hammel Green and Abrahamson, Inc.* PowerPoint. 2010. 8 Dec 2013.<http://www.ashrae-wi.org/crc/CRC_files/ASHRAE%20CRC%20Presentation%20DOAS%20WITH%20CHILLED%20BEAM.pdf>.
This presentation discusses the advantages and disadvantages that are involved with using a chilled beam system. Areas of concern exist in humidity control, appearance and installation cost. Advantages are energy use reduction, occupant comfort, and ceiling plenum allowances.

References

ANSI/ASHRAE. (2010). *Standard 62.1-2010, Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.

ANSI/ASHRAE. (2010). *Standard 90.1-2010, Energy Standard for Buildings Except Low Rise Residential Buildings*.Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.

ASHRAE (2012). *2012 ASHRAE Handbook - Fundamentals*. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.

Note: *At the request of the owner, the identity of the project team is not to be published. For the sources related to the drawings or specifications referenced, please contact Erin Miller at erin.c.miller@psu.edu*.

Appendix A

Table 1 - Proposed Work Plan for Spring 2014 (page 13)

The Auditorium
Lemma, Minnesota
Francis Michael Performing Arts Academy

Appendix A: Firgure 1 - Work Plan for Spring 2014
THESIS SCHEDULE
Updated: 1/29/2014

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