the AUDITORIUM

FRANCIS MICHAEL PERFORMING ARTS ACADEMY LEMMA, MN

APRIL
2014

Architectural Engineering Senior Thesis

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Mechanical Option
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B AE/M AE Integrated Program

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theAUDITORIUM

FRANCIS MICHAEL PERFORMING ARTS ACADEMY — LEMMA, MN

GENERAL PROJECT INFORMATION

Occupancy: Mixed Use Non-Separated - Theater
Size 172,000 GSF
Height: 5 Stories above grade
Project Team: *The project team is being withheld at the request of the building owner.*
Schedule: Feb 2011 (Demo Drawings Issued)
Feb 2014 (Substanital Completion)
Apr 2014 (Building Opening)
Cost: $75 Million (excluding soft cost)
Delivery Method: Design- Bid - Build
(GMP - design development)

HISTORICAL INFORMATION

Built: 1929
Constraints: Changes to building exterior need to comply with State Historical Preservation Office guidelines.

STRUCTURAL SYSTEM

Walls: Exterior is loadbearing 3-wythe brick. Interior structural steel and post tensioned concrete support 3 balconies and roof trusses.
Roof: Seven steel trusses span the audience chamber and stage. Beams and girders support the remaining composite metal deck roofs.

MECHANICAL SYSTEMS

Heating: Campus steam supplies a flooded high pressure heat exchanger which distributes hot water to fin tube radiaiton, radiant floor slabs, & 5 air handling units (AHU).
Cooling: Served through a 3000 ton campus chilled water plant located in the basement of the theater. Chilled water is distrbuted to the AHUs and active chilled beams.
Energy: A dual energy recovery wheel is located in a DOAS AHU which serves the active chilled beams.

ELECTRICAL SYSTEM

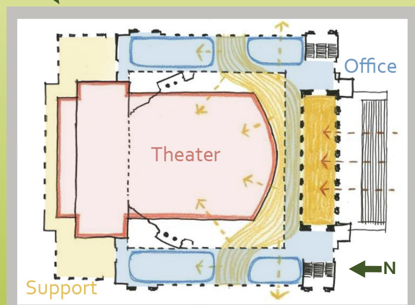
Service: 13.8kVA from campus
Main Distribution: Two 480/277V, 15,000kVA transformers distribute power to two 2500A switchboards. Other than the motors that require 480/277V, there are 7 transformers that supply 208/120V to the lighting, receptacles and controls systems.

LIGHTING DESIGN

Theater: An outside consultant was contracted to perform the theatrical lighting design. Light lofts were redesigned to accomodate the new stage dimensions.
Office Space: Occupancy sensors and time-of-day control sequences govern the lighting schemes of the office spaces.

NORTH EAST ELEVATION

NE ◁



NW ◁

PROGRAM SPACES

NORTH WEST ELEVATION

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AE Class of 2014
Family & Friends

Executive Summary

The Francis Michael Performing Arts Academy Auditorium renovation is the focus of research for this thesis report. The report seeks to investigate strategies that could benefit the building design in terms of energy conservation, first cost savings and renovation construction time. When evaluating the options to improve the Auditorium's systems, several considerations came to mind:

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

The owner's goal for the Auditorium is to revitalize the building and create to a world-class performing arts facility. While economic feasibility is a large constraint the owner also wanted innovative mechanical systems, that are conscious of energy consumption. Another goal is to correct the acoustics properties of the theater space within the Auditorium.

The depth of this report focuses on investigating alternative mechanical systems for the support spaces surrounding the theater. Active chilled beams and a demand based ventilation system were investigated for energy, cost and operational impact. Additionally, two breadth studies in construction and acoustics were explored. The construction study analyzed the first cost and schedule impacts of implementing a chilled beam system. The second breadth examines the acoustical properties of the support spaces and further studies the impact of the rooftop mechanical units on the theater audience.

Throughout a year of investigation into all of these areas of study the analysis yielded the following results:

Chilled Beam Analysis	[Mechanical Depth & Construction Breadth]
Option A - 42 added Active Chilled Beams	Option B - 98 added Active Chilled Beams
○ Annual Energy Savings: $15,348 (5%)	○ Annual Energy Savings: $18,805 (7%)
○ Added First Cost: $121,606 (10.5 yrs)	○ Added First Cost: $488,620 (N/A)
○ TCO Savings (20 yrs): $97,596	○ TCO Savings (20 yrs): - $214,529

Demand Controlled Ventilation Analysis	[Mechanical Depth]
Office Spaces	Performance Spaces
○ Potential Energy Savings: 45%	○ Potential Energy Savings: 20%

Acoustic Analysis	[Acoustic Breadth]
Room Acoustic Study (Original/Proposed)	Theater Acoustic Analysis
○ Open Office: NC - 29/NC - 24	○ Reverberation Time T(30): ~ 3.3 sec
○ Private Office : NC - 21/NC - 25	○ Background Noise Level: ~ NC - 35

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 wythe 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.

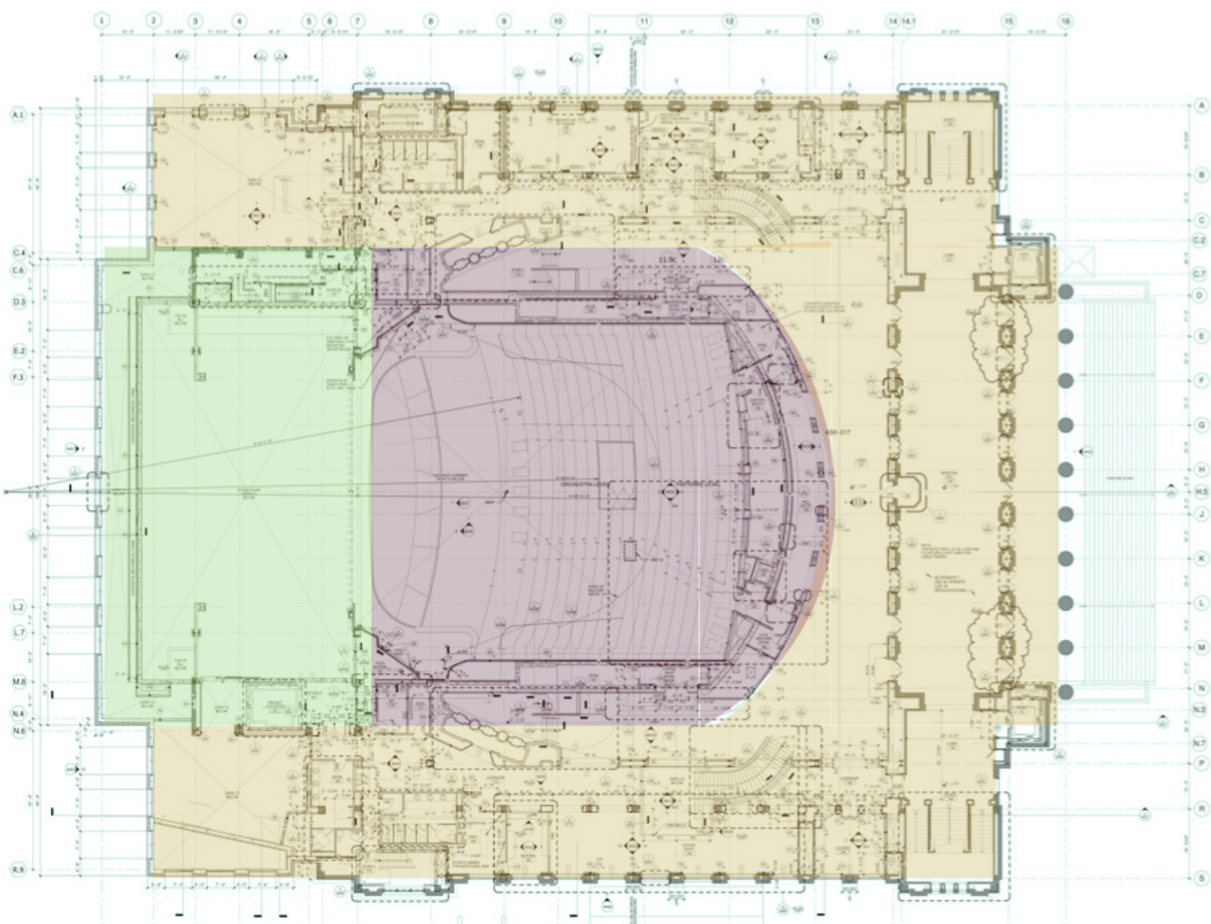


Figure 1 First Floor Level (Source: Architect of Record)

Part I: Existing Systems Evaluation

Existing Mechanical System

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, reheat coils 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 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 w/ Reheat
- AHU-2: Audience Chamber - Displacement Ventilation via Underfloor Air Distribution
- AHU-3: Performance Spaces - Variable Air Volume w/ Reheat
- 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*

Equipment

The following sections describe the equipment, system schematics and operation. Additionally, analysis on the space requirements, renovation first cost and LEED evaluation are included.

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.

Steam 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 .

Heating Equipment

Several types of fin tube radiation are used in the Auditorium based on their location and needed capacity. The number of rows range from three rows to a single row and the capacity also varies greatly. The basis for each fin tube design is on 180 °F entering water temperature (EWT), 150 °F leaving water temperature (LWT) and 65 °F entering air temperature (EAT). The system of fin tube radiators, in conjunction with hot water heating coils in 107 of the VAV boxes and a radiant floor slab above the load dock, keep the Auditorium warm during the heating season of Lemma, Minnesota.

Domestic Hot Water Heater

The domestic water is heated from the heating water from the flooded heat exchanger in a brazed plate heat exchanger. This water to water process uses the superheated steam condensate to raise the domestic water from 40 °F to 115 °F to supply the building. The brazed plate heat exchanger is rated at 150,000 BTUh output.

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.

Chilled Beams

Active chilled beams are supplied with the minimum amount of air required by code standards for adequate ventilation. They, in turn, cool the spaces by recirculating the room air and passing the warm return air over a series of cooling coils located in the unit via induction started by a pressurized supply plenum or ductwork. The inlet water temperature supplied to the cooling coil in the chilled beam is 57°F. Figure 2 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.

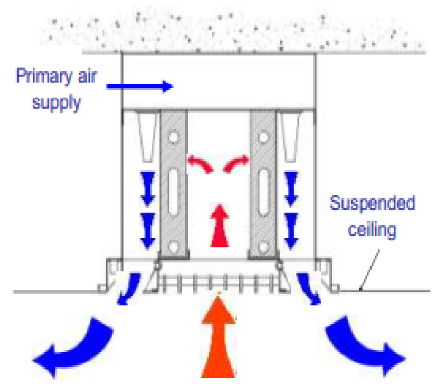


Figure 2 Chilled Beam Diagram (Source: Trox Chilled Beam Design Guide)

Air Terminal Units

The air handling units supply cooled air to the 130 VAV boxes that serve the public spaces. The boxes include a heating coil to reheat the air to the desired temperature based on space conditions. Of the 130 boxes, 23 serve spaces that cannot be accommodated with a water heating coil and therefore have electric reheat instead (i.e. electrical rooms). Air terminal unit supply temperature is controlled by thermostats located in the space served.

Pumps

Hot Water Pumps

Hot water is pumped to both the air handling units heating coils and distributed to the VAV boxes located throughout the building. There are two end suction pumps serving the building and have a flow rate of 740 gpm each. Additionally, the hot water pumps serving the AHUs are inline and range in flow rate from 132 gpm (AHU-1) to 18.8 gpm (AHU-5) to recirculate the water in the coils. See Table 1 for further properties of the hot water pumps.

PUMP NO.	LOCATION	SYSTEM	DESIGN PUMP DATA		
			CAPACITY [GPM]	HEAD [FT]	EFF. [%]
HWP - 1	B10 MECH	HWS	740	60	83.2
HWP - 2	B10 MECH	HWS	740	60	83.2
FPP - 1	AHU-1	HWS-COIL RECIRC	132	23	57.45
FPP - 2	AHU-2	HWS-COIL RECIRC	102	30	63.96
FPP - 3	AHU-3	HWS-COIL RECIRC	51.5	20	57.26
FPP - 4	AHU-5	HWS-COIL RECIRC	18.8	23	-
FPP - 5	AHU-5	HWS-COIL RECIRC	19.4	17	41.42

Table 1 Hot Water Pump Data (Source: Engineer of Record)

Chilled Water Pumps

From the chilled water plant, there are three double suction distribution pumps in parallel that serve the Auditorium and the rest of the campus. Additionally, there are four inline pumps that serve the active chilled beams in the performance support spaces. Each chilled beam pump (CBWP) supplies 21.4 gpm. On the return side, there are 3 double suction primary pumps that operate a constant volume to return water to the chillers. Further characteristics of the chilled water pumps can be seen on the next page in Table 2.

PUMP NO.	LOCATION	SYSTEM	DESIGN PUMP DATA		
			CAPACITY [GPM]	HEAD [FT]	EFF. [%]
CHWPP - 1	B10 MECH	CHWR	1600	50	-
CHWPP - 2	B10 MECH	CHWR	2000	50	-
CHWPP - 3	B10 MECH	CHWR	2800	108	82.21
CHWSP - 1	B10 MECH	CHWS	2000	95	79.72
CHWSP - 2	B10 MECH	CHWS	2000	95	79.72
CHWSP - 3	B10 MECH	CHWS	2000	95	79.72
CBWP - 1	AHU-1	CHILLED BEAM WATER	21.4	25	43.5
CBWP - 2	AHU-2	CHILLED BEAM WATER	21.4	25	43.5
CBWP - 3	AHU-3	CHILLED BEAM WATER	21.4	25	43.5
CBWP - 4	AHU-5	CHILLED BEAM WATER	21.4	25	43.5

Table 2 Chilled Water Pump Data (Source: Engineer of Record)

System Operation & Schematics

Campus Chilled Water Plant

The campus chilled water plant has a capacity of approximately 3000 tons. The chilled water is distributed to all campus buildings to serve cooling needs. The returned chilled water passes through one of three primary pumps operating in parallel sequence to provide constant volume through the three chillers. The condenser water is then sent to the packaged induced draft, cross flow cooling towers located on the roof to discharge the heat to the exterior of the building. After passing through the chillers, the chilled water passes through the variable speed distribution pumps to be sent to campus buildings. The supply pumps are controlled based on differential pressure of the system measured on the return and supply side at the plant. Flow meters are also placed on the chilled water supply and return to monitor flow rates. A schematic overview of the chilled water plant is shown in Figure 3.

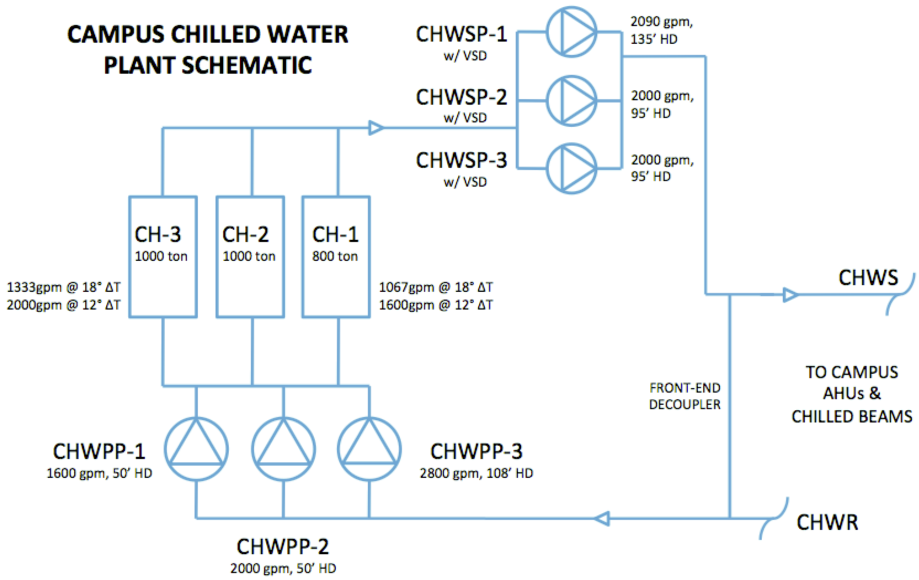


Figure 3 Campus Chilled Water Plant Schematic

Chilled Water - The Auditorium

Chilled water is distributed to the Auditorium and supplies the cooling coils in the air handling and fan coil units (45°F). The chilled water also serve the active chilled beam system. From the main supply line the chilled beam supply pipe branches off and serves four inline pumps (CBWP) as seen below in the system schematic in Figure 4. Depending on return water temperature from the chilled beams the chilled water is either recirculated back into the supply line (57°F) through a 3-way valve or set back to the plant through the chilled water return line. Both the chilled beam and cooling coil distribution are a direct return system. Capacity at the load is controlled by a thermostat in each space that the chilled beam or fan coil unit serves.

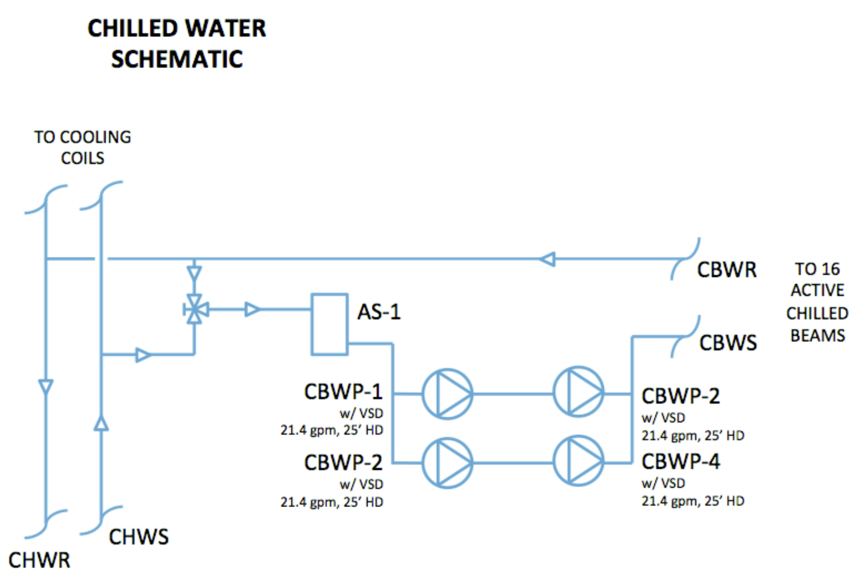


Figure 4 Building Chilled Water Schematic

Steam & Hot Water Schematic

High pressure steam is delivered to the Auditorium from a campus steam plant. The steam then enters a flooded heat exchanger (SHE-1) to heat up hot water for distribution to heating coils in the air handling and fan coil units. Furthermore, the steam condensate from the main supply line and flooded heat exchanger is then transferred to a flash tank to return condensate to the main plant. The designers included piping to accommodate a second heat exchanger if the capacity or flexibility is needed in the future.

After the flooded heat exchanger, the hot water supply then passes through two, end-suction pumps that serve the Auditorium, as seen on the next page in Figure 5. The hot water distribution is a direct return system, providing heating water to 107 VAV boxes, 4 air handling units, and several fan coil units throughout the Auditorium. Additionally, the hot water supply is also used to heat the domestic water in a brazed plate heat exchanger (HE-1).

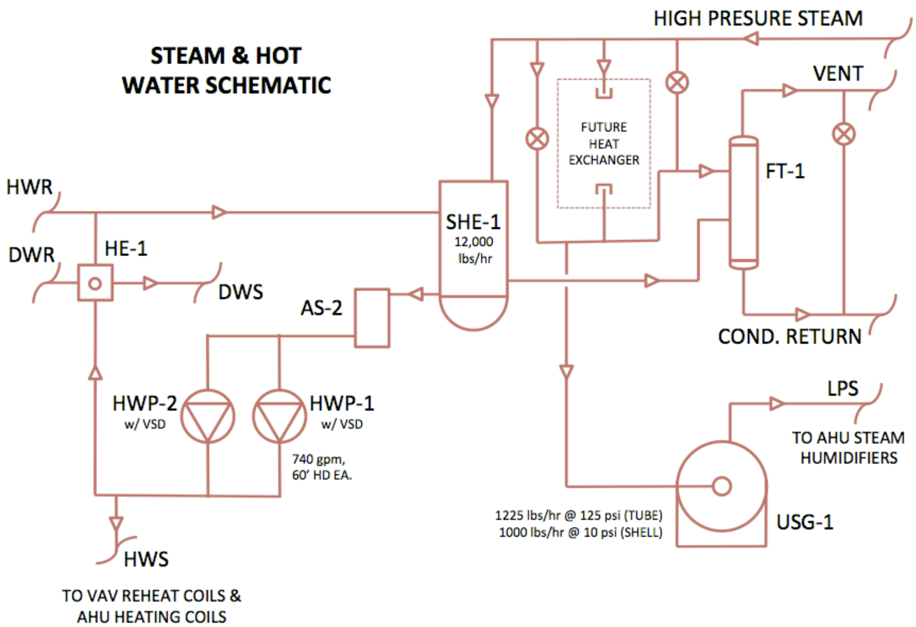


Figure 5 Building Steam & Hot Water Schematic

Airflow Schematic

To achieve required ventilation air flow rates in the Auditorium, there are 4 air handling units that take in outdoor air and condition it to supply spaces in the building. AHU-1 is a multi-zone variable volume and variable temperature packaged unit. AHU-2 is a single-zone variable volume and variable temperature packaged unit that serves the underfloor air distribution system in the audience chamber. AHU-3 serves the performance spaces with a multi-zone variable volume and variable temperature packaged unit with additional humidification and dehumidification capabilities. AHU-5 is variable volume, variable temperature and 100% outdoor air packaged unit that provides ventilation to the active chilled beam areas of the building.

All AHUs operate automatically on a direct digital control (DDC) system is PI and PID control methods. The supply air temperature for each unit is reset based on the temperature sensor located in the supply air plenum which transmits information to the economizer, heating and cooling coils. Additional pressure and temperature sensors are placed in the supply air plenums in each of the three balconies and main floor level in the audience chamber to control the air supplied from AHU-2. All units have an optimal start control sequence and air side economizers. See Figure 6 for a schematic of AHU-1, AHU-2, and AHU-3.

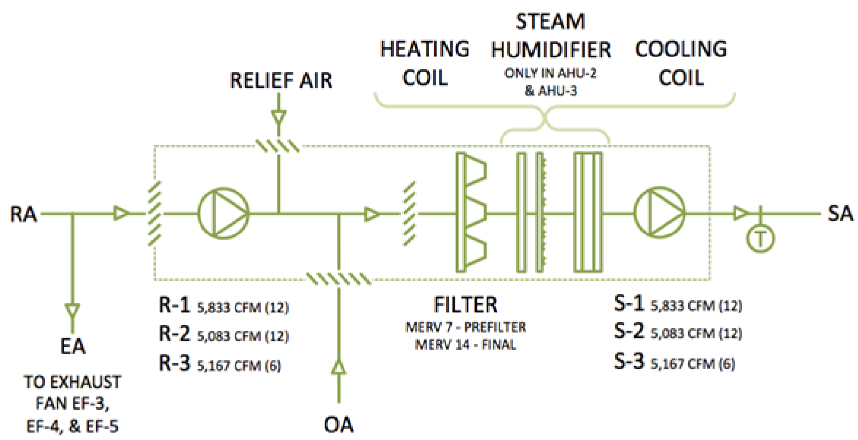


Figure 6
AHU-1, AHU-2, & AHU-3 Airflow Schematic

AHU-5 is a dedicated outdoor air system and supplies only the minimum required ventilation. It employs a dual energy recovery wheel; one wheel for passive dehumidification and another for energy recovery. Return air passes through one side of the unit and is then completely exhausted. While on the other side of the unit outdoor air enters and is pre heated or cooled down by the return air through the turning of the dual-energy wheels. Chilled water coils and hot water coils provide additional capacity for the outdoor air to be conditioned to the required supply air temperature. Figure 7 illustrates how the return air and outdoor air pass through the unit.

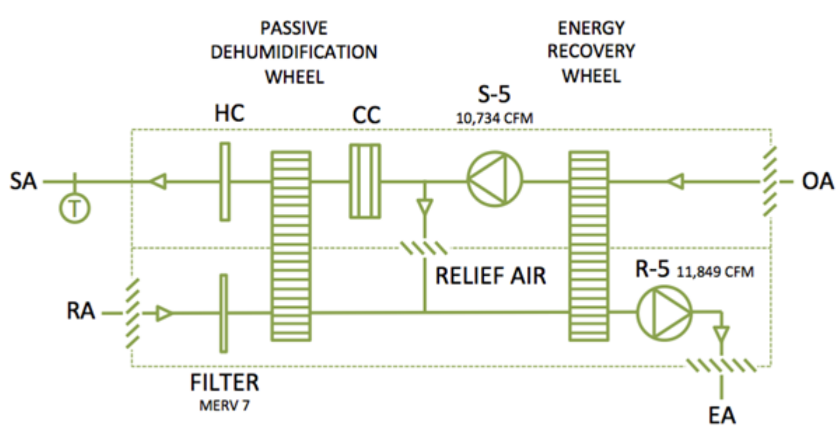


Figure 7
AHU-5 Airflow Schematic

Mechanical Space Requirements

There is a fairly large space allotted for mechanical equipment in the basement of the Auditorium apart from the central chilled water plant in the basement as well. It also should be noted that the shaft space requirement is also increased due to the several offset shaft openings and the very large ductwork needed to supply the underfloor air distribution system for the audience chamber. Below is a breakdown of each of the space types and their associated gross square floor areas (Table 3). The total lost usable space amounts to approximately 7,100 SF.

SPACE TYPE	AREA (SF)
Mechanical Room	2065
Steam Room	471
Chiller Room	2480
Shafts	2020
Total Lost Usable Space:	**7036**

Table 3 Mechanical Space Areas

System Renovation First Cost

The overall project construction cost is approximately $75 million dollars. The mechanical system material and labor costs total $8,472,706. Table 4 shows the cost breakdown by system type for the initial first cost of the renovated systems. Both ductwork and piping installation and materials contribute largely to the mechanical system cost.

	ITEM	LABOR	MATERIALS	TOTAL
WET SYSTEM	Demolition	$ 24,368	$ 6,092	$ 30,460
	Pumps & Accessories	$ -	$ 33,503	$ 33,503
	Piping	$ 1,711,305	$ 938,816	$ 2,650,121
	Heat Exchangers	$ -	$ 13,305	$ 13,305
	Heating Equipment	$ -	$ 142,572	$ 142,572
	Hydronic Equipment	$ -	$ 181,763	$ 181,763
DRY SYSTEM	Ducts & Accessories	$ 2,790,498	$ 1,187,949	$ 3,978,447
	Chilled Beam	$ 180,562	$ 157,013	$ 337,575
	HVAC Equipment	$ 94,243	$ 878,232	$ 972,475
	VAV Units	$ 15,300	$ 14,230	$ 29,530
	Exhaust Fans	$ 5,400	$ 73,129	$ 78,529
	Instruments & Controls	$ 359,342	$ 239,561	$ 598,903
	Test & Balance	$ 112,201	$ -	$ 112,201
ALT	Misc. Alternates & Contingency	$ (209,802)	$ (476,876)	$ (686,678)
TOTAL		**$ 5,083,417**	**$ 3,389,289**	**$ 8,472,706**

Table 4 Mechanical Cost Breakdown

Building Load Estimation

The original design team used Trane Trace software to calculate the design loads for the Auditorium. For this analysis, a model was developed using another load estimation software, IES Virtual Environment. The following sections detail the design conditions and load assumptions that the IES model followed to develop a representative energy model.

Design Conditions

Outdoor Design Conditions

The following table (Table 5) contains the outdoor design considerations for Lemma, Minnesota. The Auditorium is located in ASHRAE Zone 6A, which is characterized as cold and moist. Design conditions accommodate 99.6% of the days during the year.

COLDEST MONTH	HEATING DB (99.6%)	HUMIDIFICATION (99.6%)		
		DP	HR	MCWB
JANUARY	-14.9	-25.7	1.4	-14.0

WARMEST MONTH	COOLING (0.4%)		DEHUMIDIFICATION (0.4%)		
	DB	MCWB	DP	HR	MCWB
JULY	91.0 F	73.2	73.3	127.8	83.4

Table 5 Design Conditions (Source: ASHRAE 2005 Handbook of Fundamentals)

Indoor Design Conditions

The indoor design conditions were set to 75°F dry bulb for cooling and 70°F dry bulb for heating. The relative humidity was set for 50% for both heating and cooling. Additionally, thermostat locations were assumed to be in the room.

Building Construction

Table 6 lists the U-values and description of the how the exterior walls and windows were modeled using IES software. Being a historic building from the late 1920s, the envelope of the building is primarily brick construction with limited insulation. The infiltration of the building was modeled with average leakage and neutral pressurization (0.3 air changes/hour)

BUILDING CONSTRUCTION				
TYPE	DESCRIPTION	U-VALUE		SHADING COEFFICIENT
Wall	Face brick, 12" HW Conc, 1" Insul	0.168	btu/h-ft^2-F	- -
Below-Grade Wall	12" HW Conc 6" Insul	0.045	btu/h-ft^2-F	- -
Roof	Steel Sheet. 4" Insul	0.068	btu/h-ft^2-F	- -
Slab	4" LW Concrete	0.213	btu/h-ft^2-F	- -
Window	Double Clear 1/4"	0.600	btu/h-ft^2-F	0.82

Table 6 Building Construction U-Values

Load Assumptions

Occupancy and Schedules

The occupancy for the spaces was either determined from the architectural plans or the standardized SF/person values from Table 6-1 in ASHRAE 62.1-2010 were used. This table was also the basis for minimum outdoor airflow into the spaces to achieve proper ventilation.

See Appendix A for Table 6-1. Additionally, exhaust air requirements were also taken from Table 6-4 in ASHRAE 62.1-2010 (Appendix A) to incorporate accurate airflow into the model.

The typical office spaces' air distribution equipment is modeled with a standard office occupancy schedule shown in Table 7. Zones without regular occupancy are modeled with a worst case scenario of 100% available cooling. Rooms that follow under this category are the performance support spaces, stage, rehearsal spaces and the audience chamber.

START TIME	END TIME	PERCENTAGE [%]
SCHEDULE - OFFICE (WEEKDAY)		
12:00 AM	6:00 AM	0
6:00 AM	7:00 AM	10
7:00 AM	8:00 AM	30
8:00 AM	11:00 AM	100
11:00 AM	1:00 PM	80
1:00 PM	5:00 PM	100
5:00 PM	6:00 PM	10
6:00 PM	12:00 AM	0
SCHEDULE - OFFICE (WEEKEND)		
12:00 AM	12:00 AM	0

Table 7 Occupancy Schedule (Source: Trane Trace® Library)

Ventilation

Adequate ventilation air is supplied to all the space in the Auditorium through four air handling units (AHU). The Public Spaces, Audience Chamber and Performance Spaces are each served by a variable air volume AHU. The percentage of outdoor air for these units are 31%, 54% and 29% respectively. The Performance Support Spaces are supplied the minimum ventilation air required by ASHRAE 62.1-2010 and the loads are accommodated through and active chilled beam system. All ventilation air flows comply with ASHRAE 62.1-2010 and below is a summary of the airflows for each air handling unit (Table 8). For a more complete ventilation calculation procedure please see the ASHRAE Standard 62.1-2010 Compliance Evaluation section.

System Name [BASELINE]	Supply Area [SF]	Total Supply [CFM]	Total OA [CFM]	AHU Ventilation Efficiency	AHU OA Required [CFM]	Exhaust [CFM]	Total OA/Makeup Air Required	AHU OA %
AHU-1 : Public Spaces	91384	65,906	16,253	0.8	20,317	2,201	20,317	31%
AHU-2 : Audience Chamber	28807	49,725	24,267	0.9	26,963	0	26,963	54%
AHU-3 : Performance Spaces	11259	16,599	3,867	0.8	4,833	0	4,833	29%
AHU-5: Performance Support Spaces	38543	5,131	3,554	0.8	4,443	3,159	4,443	87%

Table 8 Baseline Design Airflow Calculations

Lighting and Miscellaneous Loads

Table 9.6.1 in ASHRAE 90.1-2010 defines the maximum lighting power density values and these were the basis of the heat gain and energy consumption due to lighting. For the miscellaneous loads, the original design team determined standard W/sf values for the standard spaces. Table 9 shows these assumptions.

Space Type	Code Lighting Power [W/sf]	Base Equipment/ Plug Load [W/sf]
Auditorium	2.60	0.50
Classroom	1.40	1.00
Conference Room	1.30	1.00
Corridor	0.50	0.20
Dining	0.90	0.20
Dressing Room	0.60	0.50
Enclosed Office	1.45	1.20
General Support Areas	1.30	1.00
Kitchen	1.20	10.0
Lecture Hall	1.40	1.00
Lobby	3.30	0.25
Mechanical/Electrical	1.50	0.20
Open Office	1.45	1.50
Restroom	0.90	0.10
Stage & Pit	2.60	0.10
Storage	0.80	0.20

Table 9
Lighting and Equipment Load Estimation (Source: Project Consultant)

Design Load Estimation Results

The baseline airflow load calculations were estimated using IES Virtual Environment Software for this report's analysis. The discrepancies in design heating and cooling loads listed in Table 10 are most likely due to the designer relying on his previous experience to determine more appropriate load values after using Trane Trace calculated airflows to determine a basis for the loads. The difference software calculation techniques also add discontinuities. See more information on annual energy consumption in sections below.

UPDATED 02/28/14	System Name	Supply Area [SF]	Total Supply [CFM]	AHU OA Required [CFM]	Exhaust [CFM]	HEATING [MBh]	COOLING [Ton]	FINAL SIZE [CFM]
MODEL	AHU-1 : Public Spaces	91384	65,906	20,317	2,201	1,495	275.8	- -
	AHU-2 : Audience Chamber	28807	49,725	26,963	0	2,445	250.7	- -
	AHU-3 : Performance Spaces	11259	16,599	4,833	0	443	82.6	- -
	AHU-5: Performance Support Spaces	38543	5,131	4,443	3,159	265	20.0	- -
TOTALS		**169,992**	**137,361**	**56,556**	**5,360**	**4,648**	**270**	**SF/Ton**
DESIGN	AHU-1 : Public Spaces	- -	69,909	18,455	11,341	2,964	195.3	70,000
	AHU-2 : Audience Chamber	- -	61,500	13,745	0	5,140	135.3	61,000
	AHU-3 : Performance Spaces	- -	28,655	6,957	0	2,744	36.7	31,000
	AHU-5: Performance Support Spaces	- -	7,990	3,763	5,509	803	99.4	10,000
TOTALS			**168,054**	**42,920**	**16,850**	**11,651**	**364**	**SF/Ton**

Table 10 Baseline Heating and Cooling Load Comparison

Energy Consumption and Operational Costs

The following sections describe the Auditorium's performance in terms of energy and water consumption. Based on the modeling information from the design team the energy sources and cost structures are also explained below. Images of the graphs presented can be found larger in Appendix A.

Energy Sources

Fuel Type

The Auditorium is feed by a steam plant and chilled water plant. The fuel sources that these plants use are electricity for the chilled water plant and a variety of heating fuel types including coal, oat hulls, fuel oil and natural gas. Depending on the economics of fuels, the central plant can operate to maximize efficiency and keep heating costs low.

Rates & Incentives

The Auditorium is supplied electricity from Xcel Energy Inc. The agreement that the FMPAA holds with Xcel Energy is summarized below in Table 11. Using a general time of day rate structure, The Auditorium is charged based on its consumption at different times of day and year.

Xcel Energy General Time of Day Rate Structure			
Fixed Monthly Charge	$ 25.00	per month	
Total Demand Charge - Summer	$ 10.71	per kW	June - September
Total Demand Charge - Winter	$ 7.37	per kW	October - May
Total On Peak Energy Charge	$ 0.064619	per kWh	9 am - 9 pm (weekdays)
Total Off Peak Energy Charge	$ 0.039929	per kWh	All other times

Table 11 Xcel Energy Rate Structure (Source: Xcel Energy)

The FMPAA estimates that its steam heating costs are $8.182/MMBTU. This figure takes into account fuel, operation, and maintenance costs for a given year. Additionally, using the electricity rate structures and the efficiency of the chilled water plant, FMPAA approximates that it costs $0.09/ton-hr for chilled water.

The Auditorium has a 6” water line connection and an 8” sanitary sewer line connection. Based on monthly meter readings the FMPAA is charged based on the following rate structure in Table 12.

Municipal Water Utility Rates			
Fixed Annual Charge	$ 100.00	per year	6" Water Line connection
Water Demand Charge	$ 3.29	per unit	1 water unit = 100 ft^3 (748 gal)
Fixed Annual Charge	$ 240.00	per year	8" Sanitary Sewer line connection
Sewer Demand Charge	$ 3.14	per unit	1 water unit = 100 ft^3 (748 gal)

Table 12 Water Utility Rates (Source: Municipal Water Utility)

The design team contracted an independent consultant to perform an energy study and life cycle cost analysis for different variations of the proposed mechanical system. Another task the consultant performed was an analysis on the estimated utility incentive the building could receive. Based on extensive computer modeling, the consultant approximated that the Auditorium could receive a rebate incentive of $13,000 - $14,000 to offset the first cost of the equipment.

Annual Energy Consumption

The monthly breakdown of electricity demand is shown in Figure 8. Additionally, each month broken down by system type. As expected the demand for electricity increases during the summer months due to the increased usage of the chilled water plant.

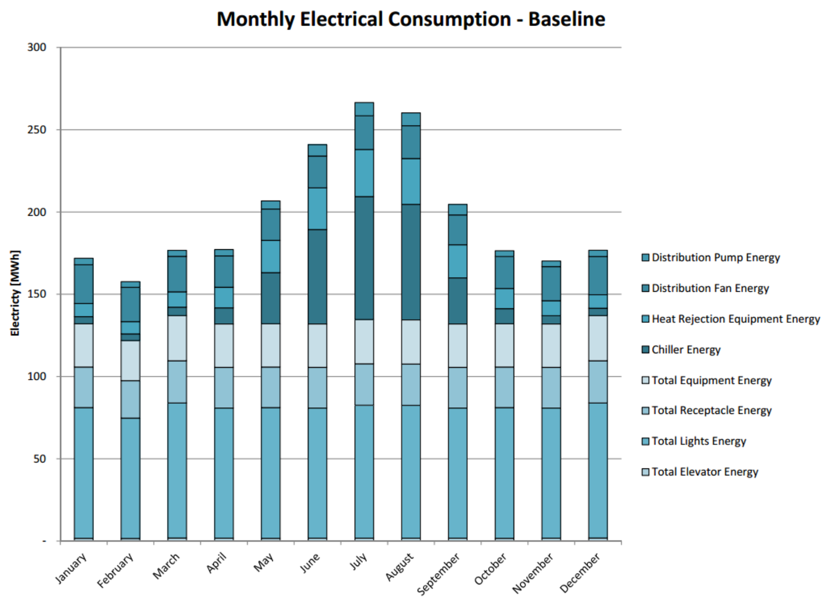


Figure 8
Baseline Monthly Electrical Consumption

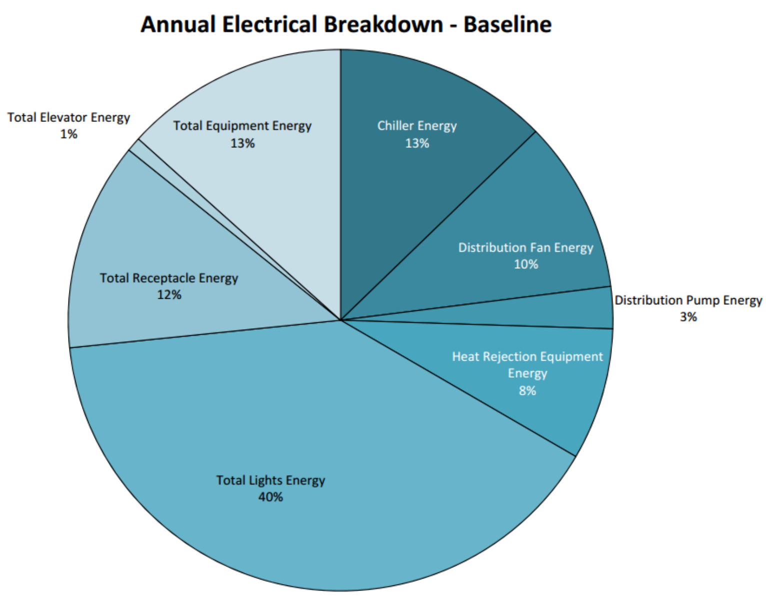


Figure 9 shows the percentage of electricity used by each system compared to the annual consumption. The annual demand for electricity is approximately 2,385 MWh. Note that a majority of electricity consumed is by the lights (40%) and chiller operation (13%)

Figure 9
Baseline Annual Electrical Consumption

Furthermore the demand for heating fuel shows the expected trend of a heating dominated climate from October through May (Figure 10). Additionally, in terms of water usage, the Auditorium requires approximately 2.8 million gallons of water annually for domestic use.

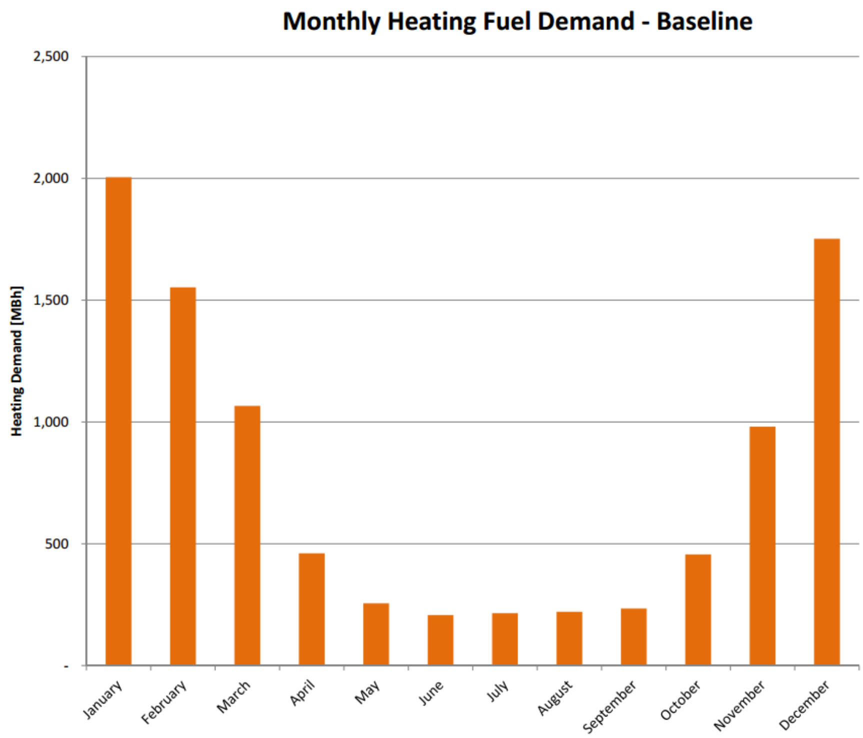


Figure 10 Baseline Monthly Heating Demand

System Emissions

The environmental impact of the building on its surroundings is due mainly to the consumption of electricity. Approximately 232,359 pounds of CO_2 are released per year to maintain occupant comfort and accommodate the electrical needs of the Auditorium. Figure 11 shows the approximate monthly emissions of CO_2 The impact of these greenhouse gas emission should be considered along with the type of refrigerant being used in the chilled water plant.

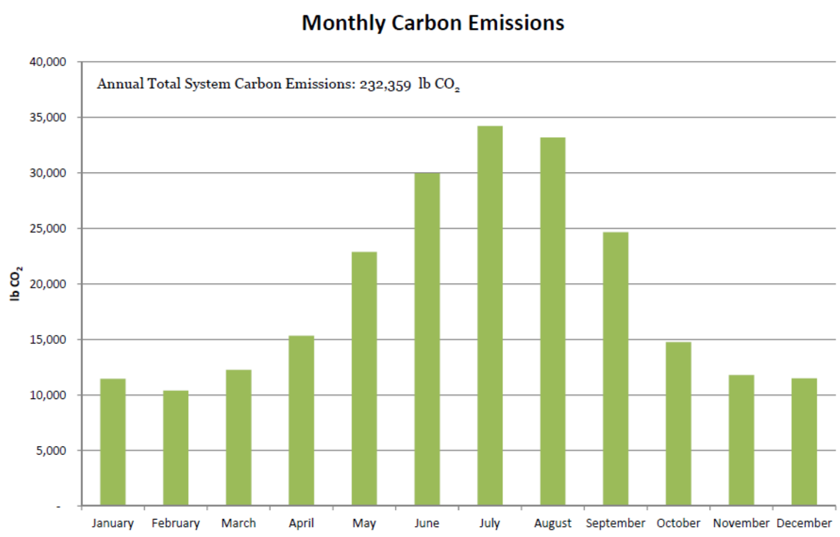


Figure 11 Monthly Carbon Emissions

Annual Operating Cost

The Auditorium's annual utility costs are approximately $328,617. This includes electricity based on the Xcel Energy Rate Structure shown in Table 11, heating fuel cost from the campus steam plant approximated at $8.182/MMBTU and water demand based on the utility rates shown in Table 12. It can be seen that electricity is a primary cost category at 74.3% of the total annual cost (Table 13).

BASELINE

ANNUAL UTILITY COST			
ELECTRICITY	**$**	**190,094.51**	**68.0%**
Chillers	$	29,940.09	*15.8%*
Distribution Fan Energy	$	19,056.38	*10.0%*
Distribution Pump Energy	$	5,322.76	*2.8%*
Heat Rejection Equipment	$	15,246.86	*8.0%*
Lights	$	71,281.30	*37.5%*
Equipment	$	24,473.55	*12.9%*
Receptacle	$	22,679.93	*11.9%*
Elevator	$	2,093.64	*1.1%*
HEATING FUEL	**$**	**76,975.81**	**27.5%**
WATER	**$**	**12,627.15**	**4.5%**
Total	**$**	**279,697.47**	**100.0%**

Table 13 Annual Utility Cost

The monthly utility cost distribution shown in Figure 12 is of particular interest. Over a typical year the utilities costs peak in January, July and December forming a tri-modal distribution. Milder months in the spring and fall greatly reduce heating and cooling costs for the Auditorium. Peak utility costs occur in January at approximately $32,043.

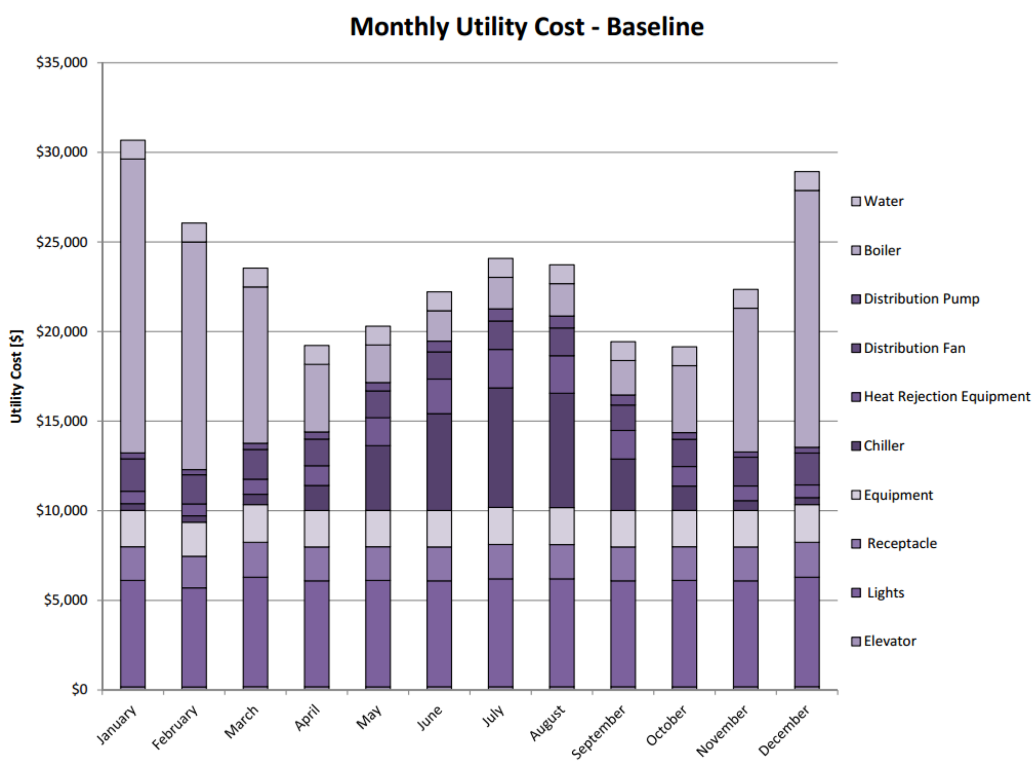


Figure 12 Monthly Utility Cost

LEED Analysis

The Auditorium renovation did not aim to achieve a LEED Certification. Below the breakdown of points for the mechanical system sections of the USGBC LEED 2009 for New Construction and Major Renovations are included below.

Energy & Atmosphere Credits

✓ EA Prerequisite 1: Fundamental Commissioning of Building Energy Systems

The purpose of this prerequisite is to verify that the mechanical system is installed and operates as the design intended. It is not known at this time if a commissioning professional was hired however it is required by 2006 Minnesota State Building Code. Therefore it is conservative to assume a professional was hired to verify the building energy systems.

✓ EA Prerequisite 2: Minimum Energy Performance

This prerequisite requires that the minimum level of improved energy efficiency is at least 5% over the baseline building performance rating for major renovations. The Auditorium would need to comply with Option 1: Whole Building Energy Simulation. A third-party consultant was contracted to perform the energy simulation. Their conclusions exceed the 5% improvement requirement. See EA Credit 1: Optimize Energy Performance for further results.

✓ EA Prerequisite 3: Fundamental Refrigerant Management

The use of chlorofluorocarbon (CFC) refrigerants are prohibited from use in the building. The Auditorium does not directly incorporate the use of refrigerant, however the campus chilled water plant utilizes R-123; a commonly used HCFC type of refrigerant.

✓ EA Credit 1: Optimize Energy Performance (3/19 pts)

This credit awards points based on the percentage improvement of the building performance rating when compared to a baseline building. The third-party consultant that performed an energy analysis concluded that the Auditorium improved 12% over the baseline building performance.

Existing Building Renovations	Points
8%	1
10%	2
12%	3
14%	4
16%	5
18%	6
20%	7
22%	8
24%	9
26%	10
28%	11
30%	12
32%	13
34%	14
36%	15
38%	16
40%	17
42%	18
44%	19

Table 14
EA Credit 1 (Source: LEED 2009 for New Construction & Major Renovations)

X EA Credit 2: On-site Renewable Energy (0/7 pts)

Based on the point scale, a building can receive up to 7 points for using on-site renewable energy (ie solar radiation and wind power). The Auditorium currently does not utilize any on-site renewable energy sources.

Percentage Renewable Energy	Points
1%	1
3%	2
5%	3
7%	4
9%	5
11%	6
13%	7

Table 15
EA Credit 2 (Source: LEED 2009 for New Construction & Major Renovations)

X EA Credit 3: Enhanced Commissioning (0/2 pts)

EA credit 3 requires that prior to the start of construction a commissioning authority is brought on to evaluate the design throughout the design and submittal process. The Auditorium did not implement this process during design and construction.

X EA Credit 4: Enhanced Refrigerant Management (0/2 pts)

As previously stated the Auditorium does not directly utilize any refrigerant, however indirectly the campus chilled water plan uses R-123 (HCFC-123). Using the given procedure and equations listed in Option 2, the HCFC-123 does not comply for the Enhanced Refrigerant Management credit. The calculations in Table 16 are based on the global warming potential and the ozone depletion potential; values determined by the U.S. Environmental Protection Agency (EPA) and Title 40 of the Code of Federal Regulations.

LCGWP+LCODPx10^5 ≤ 100

	GWP	ODP	LCODP	LCGWP	COMPLY?	VALUE
HCFC-123	93	0.02	0.0024	11.16	No	251.16

VARIABLES: *Worst Case & Default Values*

Lr	2%	Refrigerant Leakage Rate
Mr	10%	End-ofLife Refrigerant Loss
Rc	5	lbm/ton
Life	25	years

Table 16 LEED Refrigerant Management Calculations

Through further research, both the upstream and downstream building systems must comply with the EA Credit 4 requirements ("Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 – Design & Construction " 16). This therefore eliminates the Auditorium from receiving these credits.

X EA Credit 5: Measurement and Verification (0/3 pts)

This credit aims to ensure a continuing standard level of building performance after main construction or renovation is complete. Currently the Francis Michael Performing Arts

Academy has a commitment to sustainable building use and has plans in place to evaluate the performance of all its buildings through their lifetime. However this plan does not conform directly with either Option 1 or 2 outlined in EA Credit 5: Measurement & Verification.

✗ EA Credit 6: Green power (0/2 pts)

To receive credits, the building must engage in a least a 2 year contract with an electricity provider that supplies power generated from renewable resources. The percentage of the "green" power must be 35% of the buildings electricity consumption proven through either EA Credit 1: Optimized Energy Performance calculations or through the US Department of Energy's Commercial Building Consumption Survey database.

Since the Auditorium resides on a campus of buildings owned by the Francis Michael Performing Arts Academy, electricity is purchased at large from a provider for the entire academy. No points from this credit can be awarded.

Indoor Environmental Air Quality Credits

✓ IEQ Prerequisite 1: Minimum Indoor Air Quality Performance

This prerequisite is met by following sections 4 through 7 of ASHRAE Standard 62.1-2007 and complying with ASHRAE 62.1-2010 ventilation rate procedures for mechanically ventilated spaces. See ASHRAE Standard 62.1 - 2010 Compliance Evaluation section for a more in-depth evaluation of the Auditorium's compliance with ASHRAE 62.1-2010.

✓ IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

The Auditorium is a non-smoking facility and designated signage is in place to prohibit smoking within 25 feet of the building. This ensures the limited exposure of tobacco smoke to the building occupants, indoor surfaces and air distribution equipment.

✗ IEQ Credit 1: Outdoor Air Delivery Monitoring (0/1 pts)

Outdoor air is not monitored at the room level to ensure design ventilation airflow rates are being met.

✗ IEQ Credit 2: Increased Ventilation (0/1 pts)

The Auditorium was not designed to incorporate a 30% increase in outdoor ventilation airflow rates based on ASHRAE 62.1-2007 for mechanically vented spaces.

✗ IEQ Credit 3.1: Construction IAQ Management Plan—During Construction (0/1 pts)

✗ IEQ Credit 3.2: Construction IAQ Management Plan—Before Occupancy (0/1 pts)

An Indoor Air Quality (IAQ) plan was not developed in accordance with IEQ Credit 3.1 or 3.2 for during and before construction.

✗ IEQ Credit 4.1: Low-Emitting Materials—Adhesives and Sealants (0/1 pts)

✗IEQ Credit 4.2: Low-Emitting Materials—Paints and Coatings (0/1 pts)

✗IEQ Credit 4.3: Low-Emitting Materials—Flooring Systems (0/1 pts)

✗IEQ Credit 4.4: Low-Emitting Materials—Composite Wood and Agrifiber Products (0/1 pts)

After review of the drawings and specifications, low-emitting materials are recommended for use in some categories, however there is limited resources to determine if low VOC materials were used.

✗ IEQ Credit 5: Indoor Chemical and Pollutant Source Control (0/1 pts)
There is no dedicated strategy that complies with IEQ Credit 5 to contain and control chemical pollutants. The credit requires specific exhaust strategies to contain chemical contaminants, air filtration with a MERV of 13 or higher, and permanent entry ways fitted with 10ft of grated space to capture debris and particulates or regularly serviced mats.

✗ IEQ Credit 6.1: Controllability of Systems—Lighting (0/1 pts)
This credit is not satisfied because 90% of the lighting can not be individually controlled by the occupant.

✗ IEQ Credit 6.2: Controllability of Systems—Thermal Comfort (0/1 pts)
Thermal comfort is not controllable by 50% of the occupants and therefore does not meet the requirements for this credit

✓IEQ Credit 7.1: Thermal Comfort—Design (1/1 pts)
The basis of the design is derived from ASHRAE Standard 55-2004 and the design engineer was observant of Standard 55 in his design of the system. The requirement for achieving IEQ Credit 7.1 is compliance with ASHRAE 55-2004 and therefore has been met.

✗ IEQ Credit 7.2: Thermal Comfort—Verification (0/1 pts)
A thermal verification survey has not been planned for the permanent occupants of the Auditorium and therefore is not compliance with IEQ Credit 7.2.

✗ IEQ Credit 8.1: Daylight and Views—Daylight (0/1 pts)
To comply with this credit, 75% of the occupiable space must be lit with adequate daylight levels. One of four options for verification must be performed to prove the required light levels are met. They include simulation, prescriptive, measurement, and a combination. With a major historical renovation, changing the exterior of the building was not an option for the architects. Therefore a daylight analysis was not performed for the Auditorium and does not meet the requirements.

✗ IEQ Credit 8.2: Daylight and Views—Views (0/1 pts)
This credit requires a view to the exterior environment in at least 90% of the regularly occupiable spaces. This will not be achieved with the renovation design of the Auditorium and this credit can not be awarded points.

LEED Analysis Summary

The Auditorium would most likely only receive 3 of 35 Energy & Atmosphere points and 1 of 15 Indoor Environmental Air Quality points. Based on these results it is unlikely that the building will receive a LEED Certified rating. The priorities of the building owner seem to be directed toward restoring the Auditorium to a functional state rather than an extremely high performing building.

Further credits could be realized through evaluating the benefits and costs of refrigerant management and further energy saving measures to increase the building's performance over the baseline building. Additionally supplementary control systems at the occupant level would aid in achieving additional credits.

ASHRAE Standard 62.1 - 2010 Compliance Evaluation

This section evaluates at how the Auditorium complies with the ventilation standard, ASHRAE Standard 62.1-2010. Mechanical ventilation, exhaust methods and indoor air quality are the focus of this standard.

ASHRAE 62.1 Section 5: Systems & Equipment

5.1 Ventilation Air Distribution

The Auditorium is designed to comply with Section 5.1. The drawings indicate appropriate balancing information for compliant ventilation distribution in both ducted and plenum distribution. The drawings indicate requirements for sealing the underfloor supply plenum and reference SMACNA Class A Leakage seal requirements, along with additional leakage testing information.

5.2 Exhaust Duct Location

The exhaust duct locations in The Auditorium are negatively pressurized to mitigate the risk of harmful contaminants leaking into adjacent spaces or air supply or return ductwork. Two general exhaust fans are located on the east (EF-1) and west (EF-2) rooftops rated at an airflow of 4160 cfm and 4350 cfm respectively, to expel contaminants.

5.3 Ventilation System Controls

Francis Michael Performing Arts Academy requires all equipment control systems to interface with their Building Systems Automation Center (BSAC). All air terminal units are under the control of the BSAC and interface with occupancy sensors located in regularly occupied spaces to supply required ventilation.

5.4 Air Stream Surfaces

All air stream surfaces are constructed of sheet metal and connected using metal fasteners to comply with section 5.4.1 Resistance to Mold Growth and section 5.4.2 Resistance to Erosion.

5.5 Outdoor Air Intakes

All outdoor intakes are located on the north and west roofs. Each outdoor air inlet is located at least 10 feet from any exhaust or relief outlet, based on Class 2 exhaust air per Table 5-1 in Figure 13. All inlets exceed this minimum distance significantly. Additionally, each inlet is protected with a mesh screen and operable louvers that comply with sections 5.5.2 - 5.5.4, protecting the equipment from rain, snow and birds. Each outdoor air handling unit is also designed with access doors for periodic cleaning and maintenance.

TABLE 5-1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Class 2 air exhaust/relief outlet (Note 1)	10 (3)
Class 3 air exhaust/relief outlet (Note 1)	15 (5)
Class 4 air exhaust/relief outlet (Note 2)	30 (10)
Plumbing vents terminating less than 3 ft (1 m) above the level of the outdoor air intake	10 (3)
Plumbing vents terminating at least 3 ft (1 m) above the level of the outdoor air intake	3 (1)
Vents, chimneys, and flues from combustion appliances and equipment (Note 3)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 4)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 4)	25 (7.5)
Driveway, street, or parking place (Note 4)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 5 and 6)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: This requirements applies to the distance from the outdoor air intakes for one ventilation system to the exhaust/relief outlets for any other ventilation system.
Note 2: Minimum distance listed does not apply to laboratory fume hood exhaust air outlets. Separation criteria for fume hood exhaust shall be in compliance with NFPA 45[5] and ANSI/AIHA Z9.5.[6] Information on separation criteria for industrial environments can be found in the *ACGIH Industrial Ventilation Manual*[7] and in the *ASHRAE Handbook—HVAC Applications*.[8]
Note 3: Shorter separation distances shall be permitted when determined in accordance with (a) ANSI Z223.1/NFPA 54[9] for fuel gas burning appliances and equipment, (b) NFPA 31[10] for oil burning appliances and equipment, or (c) NFPA 211[11] for other combustion appliances and equipment.
Note 4: Distance measured to closest place that vehicle exhaust is likely to be located.
Note 5: Shorter separation distance shall be permitted where outdoor surfaces are sloped more than 45 degrees from horizontal or that are less than 1 in. (3 cm) wide.
Note 6: Where snow accumulation is expected, the surface of the snow at the expected average snow depth constitutes the "other surface directly below intake."

Figure 13 Table 5-1 (Source: ASHRAE Standard 62.1-2010)

5.6 Local Capture of Contaminants

Equipment generating contaminates is captured and directed outdoors away from any intake openings to be in compliance with section 5.6.

5.7 Combustion Air

The Auditorium does not utilize any combustion equipment therefore this section is not applicable. The heating system for this building is feed from the Academy's steam plant and converted to hot water through a flooded steam heat exchangers, as stated more thoroughly in the previous section, Mechanical Systems Overview.

5.8 Particulate Matter Removal

All filters specified are at minimum MERV 8 with additional filters rated at a minimum of MERV 11, therefore exceeding the MERV 6 requirement for section 5.8.

5.9 Dehumidification Systems

The outdoor air handling units were selected with a base relative humidity of 50%. This exceeds the 65% requirement. Also, in accordance with section 5.9.2 the total supply airflow far exceeds the exhausted air. Total maximum supply airflow from four outdoor air handling units accounts to 172,000 cfm compared to a total general exhaust airflow of 8,510 cfm.

5.10 Drain Pans

Specification section 233119 on condensate drain pans cites compliance with ASHRAE Standard 62.1-2010. The specification section also indicates that all drain pans shall extend a minimum of 12 inches past the cooling coil.

5.11 Finned-Tube Coils and Heat Exchangers

Drain pans are provided for all finned-tube coils and heat exchangers per section 5.10 to be in compliance with section 5.11. Finned tube coils are installed with 18 inches of access space for cleaning.

5.12 Humidifiers and Water-Spray Systems

The installation of the four types of humidifiers used in the Auditorium; steam injection, electric self-contained, heat exchangers, and electric steam, are specified to be in compliance with ASHRAE 62.1-2010. Each type uses potable water and a drain pan is installed underneath each humidifier.

5.13 Access for Inspection, Cleaning, and Maintenance

Sufficient access to HVAC equipment, ventilation equipment, and air distribution systems has been designed to comply with ASHRAE 62.1-2010 section 5.12. Access doors to clean and inspect air terminal units in ceilings have been included in addition to service spaces in the outdoor handling units. See Figure 14 for an example schematic of AHU-1 and the access spaces for routine maintenance.

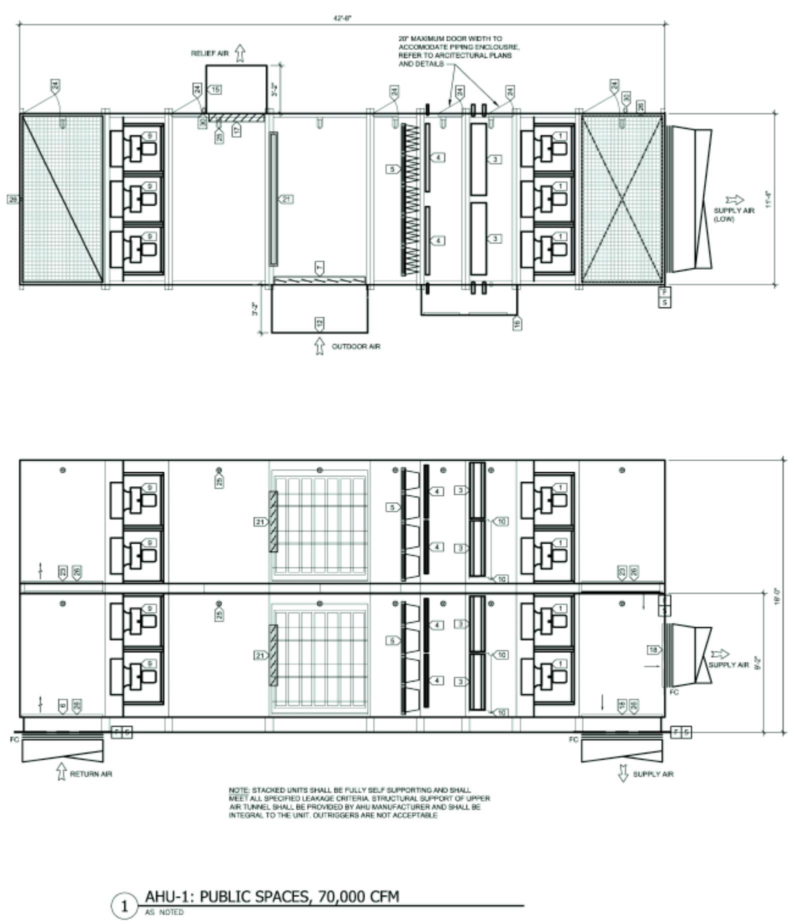


Figure 14
AHU-1 Diagram
(Source: Architect of Record)

5.14 Building Envelope and Interior Surfaces

The envelope of the Auditorium includes a moisture barrier as indicated in Figure 15 from architectural section detail on sheet A462. Additionally, specification section 230719 details what piping systems are to be insulated to prevent condensation.

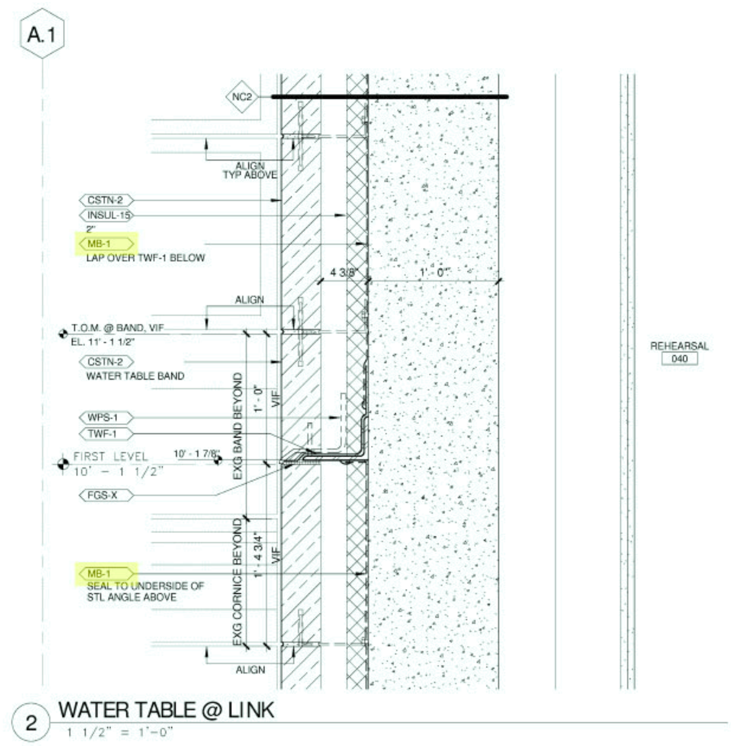


Figure 15 Facade Wall Section (Source: Architect of Record)

5.15 Buildings with Attached Parking Garages

The Auditorium is not attached to a parking garage, therefore this section does not apply.

5.16 Air Classification and Recirculation

The Auditorium spaces are classified as Class 1 or Class 2 as per Table 6-1 in ASHRAE 62.1-2010. However, most if not all air in the performance spaces, audience chamber, and public spaces is returned to AHU-1, AHU-2, and AHU-3. The performance support spaces, which are served by an active chilled beam system recirculates Class 1 air before being returned the DOAS AHU-5 for heat recovery.

5.17 ETS Air

The Auditorium is a non-smoking facility and all spaces can be classified as ETS-free spaces. Additionally, all inlets for air circulation are located on the roof of the building eliminating any exposure from smoking locations near to the building. Therefore this section's requirements are not applicable.

ASHRAE 62.1 Section 6: Procedures

6.1 General

The outdoor air is deemed acceptable for purposes of ventilation of the Auditorium. The airflow rates for achieving proper amounts of outdoor air follow the ventilation rate procedure and exhaust rate procedure. Natural ventilation strategies are not used in the building.

6.2 Ventilation Rate Procedure

Breathing zone air flows are calculated by using Equation 6-1 from ASHRAE 62.1-2010 for each space.

$$Vbz = Rp \times Pz + Ra \times Az \text{ (Eq. 6-1)}$$

Az: Occupiable area of the zone [ft²]
Pz: Population of the zone during typical usage [People]
Ra: Outdoor air rate per unit area [cfm/ft²]
Rp: Outdoor air rate per person in the zone [cfm/person]

Values for Ra and Rp, listed by space use, are located in ASHRAE 62.1-2010 Table 6-1 which is included in Appendix A for reference. The outdoor air requirement for the zone is then calculated based on the Zone Air Distribution Effectiveness (Ez). Values for Ez can be found in ASHRAE 62.1-2010 Table 6-2, included (Figure 16) and are based on how the air is supplied and returned to the zone

$$Voz = Vbz/Ez \text{ (Eq. 6-2)}$$

TABLE 6-2 Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air.	1.0
Ceiling supply of warm air and floor return.	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return.	0.8
Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level. ***Note:*** For lower velocity supply air, E_z = 0.8.	1.0
Floor supply of cool air and ceiling return provided that the 150 fpm (0.8 m/s) supply jet reaches 4.5 ft (1.4 m) or more above the floor. ***Note:*** Most underfloor air distribution systems comply with this proviso.	1.0
Floor supply of cool air and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification.	1.2
Floor supply of warm air and floor return.	1.0
Floor supply of warm air and ceiling return.	0.7
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return.	0.8
Makeup supply drawn in near to the exhaust and/or return location.	0.5

1. "Cool air" is air cooler than space temperature.
2. "Warm air" is air warmer than space temperature.
3. "Ceiling" includes any point above the *breathing zone*.
4. "Floor" includes any point below the *breathing zone*.
5. As an alternative to using the above values, E_z may be regarded as equal to air change effectiveness determined in accordance with ANSI/ASHRAE Standard 129[17] for all air distribution configurations except unidirectional flow.

Figure 16
Table 6-2
(Source: ASHRAE 62.1-2010)

These outdoor airflows are tabulated in Appendix A. The Auditorium's AHU-1, AHU-2 and AHU-3 fall under the classification of section 6.2.5 Multiple-zone Recirculating System and therefore additional calculations are required to determine the total outdoor air requirement for the building. To determine the effectiveness of the air handling units to recirculate outdoor air (Ev) the Primary Outdoor Air Fraction (Zp) must be determined from ASHRAE 62.1-2010 Equation 6-5 as follows:

$$Zp = Voz/Vpz \text{ (Eq. 6-5)}$$

Voz: the corrected outdoor air required as determined by Equation 6-2 [cfm]
Vpz: the total outdoor and recirculated air to the zone based on the design condition. [cfm]

Looking at all the zones in a given system, the maximum Zp is used to determine Ev from ASHRAE 62.1-2010 Table 6-3, included below (Figure 17).

Figure 17
Table 6-3
(Source: ASHRAE 62.1-2010)

TABLE 6-3 System Ventilation Efficiency

Max (Z_P)	E_v
≤0.15	1.0
≤0.25	0.9
≤0.35	0.8
≤0.45	0.7
≤0.55	0.6
>0.55	Use Appendix A

1. "Max (Z_{pz})" refers to the largest value of Z_{pz}, calculated using Equation 6-5, among all the *ventilation zones* served by the system.
2. For values of Max (Z_{pz}) between 0.15 and 0.55, the corresponding value of E_v may be determined by interpolating the values in the table.
3. The values of E_v in this table are based on a 0.15 average outdoor air fraction for the system (i.e., the ratio of the uncorrected outdoor air intake (V_{ou}) to the total zone primary airflow for all the zones served by the air handler). For systems with higher values of the average outdoor air fraction, this table may result in unrealistically low values of E_v and the use of Appendix A may yield more practical results.

Additionally, since the population of the Auditorium will fluctuate the population diversity is calculated for each AHU to determine an uncorrected outdoor air intake (Vou), which is calculated in accordance with ASHRAE 62.1-2010 Equation 6-6.

$$Vou = D \sum_{all\,zones}(Rp \; x \; Pz) + \sum_{all\,zones}(Ra \; x \; Az) \quad \text{(Eq. 6-6)}$$
$$\text{where, } D = Ps/\sum_{all\,zones} Pz \quad \text{(Eq. 6-7)}$$

Ps: maximum population served by the system at a given time [People]
$\sum_{all\,zones} Pz$*: summation of all the zone populations in the building* [People]

Lastly, the total outdoor air for each air handling unit is calculated by following ASHRAE 62.1-2010 Equation 6-8.

$$Vot = Vou/Ev \quad \text{(Eq. 6-8)}$$

The final outdoor air requirement is used to size AHU-1, AHU-2, AHU-3 and a summary of the results is tabulated below in Table 17.

AHU-5 is a 100% outdoor air system and therefore the outdoor air intake requirement is sized under section 6.2.4. The total outdoor air required is equal to the summation of the outdoor air required by each zone, in accordance with ASHRAE 61.1-2010 Equation 6-3

$$Vot = \sum_{all\,zones} Voz \quad \text{(Eq. 6-3)}$$

The final airflow requirements for AHU-5 are included in Table 17 below. AHU-5 is sized for the outdoor air requirement. Additional heating & cooling is supplied through the chilled beam system and finned-tube radiation.

System Name [BASELINE]	Supply Area [SF]	Total Supply [CFM]	Total OA [CFM]	AHU Ventilation Efficiency	AHU OA Required [CFM]	Exhaust [CFM]	Total OA/Makeup Air Required	AHU OA %
AHU-1 : Public Spaces	91384	65,906	16,253	0.8	20,317	2,201	20,317	31%
AHU-2 : Audience Chamber	28807	49,725	24,267	0.9	26,963	0	26,963	54%
AHU-3 : Performance Spaces	11259	16,599	3,867	0.8	4,833	0	4,833	29%
AHU-5: Performance Support Spaces	38543	5,131	3,554	0.8	4,443	3,159	4,443	87%

Table 17 System Calculations

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

6.5 Exhaust Ventilation

Exhaust airflows were taken into account based on ASHRAE 62.1-2010 Table 6-4, included in Appendix A and calculated to achieve proper ventilation requirements. Exhaust ventilation calculations can be seen in Appendix A.

ASHRAE 62.1 Evaluation Conclusions

As indicated previously, the Auditorium utilizes four outdoor air handling units. AHU-1 is sized to accommodate the public spaces, AHU-2 the audience chamber, AHU-3 the performance spaces, and AHU-5 the performance support spaces. Complete procedural verification calculations for each zone are tabulated in an Excel spreadsheet and summarized Appendix A.

The Auditorium is fully compliant with ASHRAE Standard 62.1-2010 and in many aspects far exceeds the standards set forth. The systems and design conditions all abide by the criteria required by Standard 62.1-2010 section 5 to prevent harmful contaminants, resist mold growth, and maintain a healthy system through routine maintenance and cleaning. The design team also followed proper prescriptive methods to calculate required outdoor air flows for ventilation purposes in designing ventilation equipment.

ASHRAE Standard 90.1 - 2010 Compliance Evaluation

This section evaluates at how the Auditorium's equipment and systems compare to ASHRAE Standard 90.1-2010. Efficiency, energy consumption and building construction are the focus of this standard.

ASHRAE 90.1 Section 5: Building Envelope

The Auditorium's location in Lemma, Minnesota falls under climate zone 6A. This zone is characterized as cold and moist. This area receives heavy snowfall throughout the winter months. Figure 18 below shows the climate zone breakdown by county. Individual county climate zones are also listed in ASHRAE 90.1-2010.

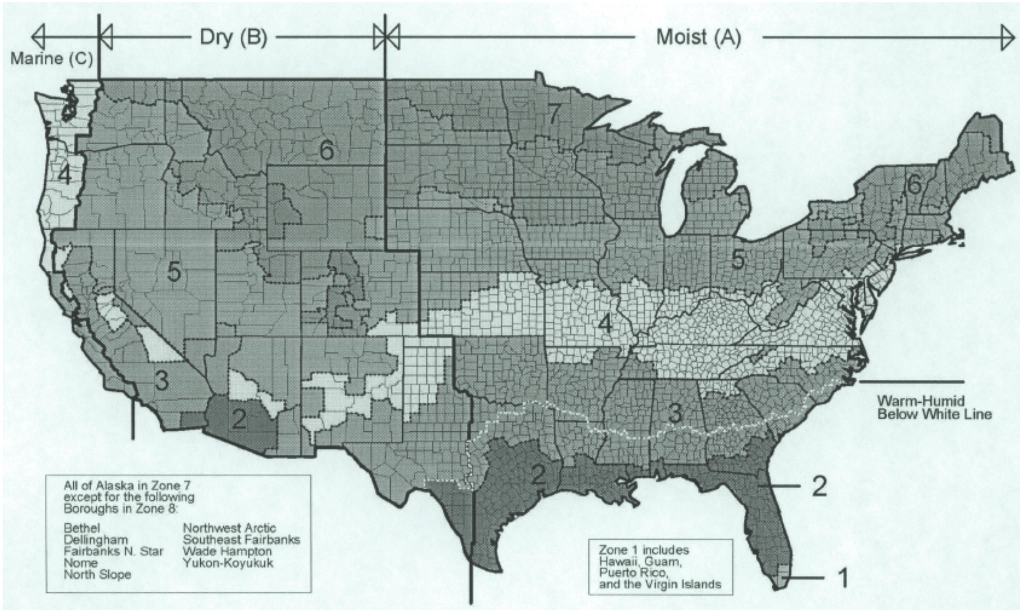


Figure 18 Climate Zones (Source: ASHRAE 90.1-2010)

5.2 Compliance Path

As illustrated in Table 18 below, the window to wall percentage is far below the 40% maximum allowable. Additionally the skylights located on the south roof account for far less than 5% of the building roof area.

	N	S	E	W	Roof
Wall Area	20224	20224	23750	23750	59400
Window/Skylight Area	0	1340	3360	3360	380
% Window Area	0.00%	6.63%	14.15%	14.15%	0.64%

Table 18 Window-Wall Ratio

5.4 Mandatory Provisions

The entrances to the Auditorium each have an enclosed vestibule space in accordance the the standard to separate the exterior environment with the interior conditioned spaces. Also, there is a continuous air barrier enclosing the building. Appropriate insulations and sealants have been utilized to insulated and seal the building against thermal and air leakage. Additionally all fenestration and door are in accordance with the leakage requirements set forth in ASHRAE 90.1-2010 Section 5.4.3.2.

5.5 Prescriptive Building Envelope

Table 19 details how the above and below grade walls, roof construction, and windows perform against Standard 90.1-2010 Section 5.5 minimum R-values and maximum U-values for climate zone 6A. Considering the building was originally constructed in 1929, the high U-values for the walls, roof and window are accepted, but noted.

Building Construction							
Type	Description	Actual U-Value		ASHRAE 90.1-2010 U-Value		Compliant [Yes/No]
Wall	Face brick, 12" HW Conc, 1" Insul	0.168	btu/h-ft^2-F	0.080	btu/h-ft^2-F	No
Below-Grade Wall	12" HW Conc 6" Insul	0.045	btu/h-ft^2-F	0.119	btu/h-ft^2-F	Yes
Roof	Steel Sheet. 4" Insul	0.068	btu/h-ft^2-F	0.048	btu/h-ft^2-F	No
Slab	4" LW Concrete	0.213	btu/h-ft^2-F	0.540	btu/h-ft^2-F	Yes
Window	Double Clear 1/4"	0.600	btu/h-ft^2-F	0.550	btu/h-ft^2-F	No

Table 19 Building Construction Thermal Resistance

ASHRAE 90.1 Section 6: Heating, Ventilation and Air Conditioning

6.4 Mandatory Provisions

All equipment selected in The Auditorium meets the minimum efficiency standards in accordance with ASHRAE 90.1-2010 Table 6.8.1A through Table 6.8.1H and Table 6.8.1K. The mechanical system does not use a variable refrigerant flow system, therefore those standards are not applicable. All load calculations followed prescriptive methods listed in ANSI/ASHRAE/ACCA Standard 183-2007 to size systems and equipment. Additionally, all zones are controlled individually by thermostat controls and all equipment is controlled in accordance with ASHRAE 90.1-2010 Section 6.4.3. Furthermore all equipment construction, installation and insulation follows the standard requirements listed in ASHRAE 90.1-2010 Section 6.4.4.

6.5 Prescriptive Path

The air handling equipment is equipped with economizers and control systems that are in accordance with ASHRAE 90.1-2010 Section 6.5.1. Additionally, the fan power levels comply with the requirements in ASHRAE 90.1-2010 Tables 6.5.3.1.1A/B.

Per Table 17 located in section 6.2 Ventilation Rate Procedure the percentage of outdoor air required at design condition for AHU-1 and AHU-3 are below the required amount to need an energy recovery system per ASHRAE 90.1-2010 Section 6.5.6 Table 6.5.6.1 (Figure 19). However each AHU uses an economizer system which accommodates AHU-2 because its percentage of outdoor air is above the allowable limit. AHU-5 is a dedicated outdoor air handling system and utilizes a dual wheel energy recovery system.

TABLE 6.5.6.1 Energy Recovery Requirement

Zone	% *Outdoor Air* at Full Design Airflow Rate					
	≥30% and < 40%	≥40% and < 50%	≥50% and < 60%	≥60% and < 70%	≥70% and < 80%	≥80%
	Design Supply Fan Airflow Rate (cfm)					
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR	≥5000	≥5000
1B, 2B,5C	NR	NR	≥26000	≥12000	≥5000	≥4000
6B	≥11000	≥5500	≥4500	≥3500	≥2500	≥1500
1A, 2A, 3A, 4A, 5A, 6A	≥5500	≥4500	≥3500	≥2000	≥1000	>0
7,8	≥2500	≥1000	>0	>0	>0	>0

NR—Not required

Figure 19 Table 6.5.6.1 (Source: ASHRAE 901.-2010)

ASHRAE 90.1 Section 7: Service Water Heating

The service water for heating purposes is supplied through a flood steam heat exchanger, from which the steam supplied comes from the campus steam generation plant at 12,000lbs/hr of steam. All equipment and piping located in the building is properly insulated in accordance with section 7.4.3. Additionally, the control system is controlled from a temperature sensor on the condensate supply side to regulate the amount of heat needed.

ASHRAE 90.1 Section 8: Power

The 2007 Minnesota Building adopted the 2008 National Electrical Code (NEC) which supersedes this section. The 2008 NEC specifies a 3% voltage drop on all feeders and 5% voltage drop on feeders and inclusive branch circuits. The Auditorium power requirements follow the NEC standard.

ASHRAE 90.1 Section 9: Lighting

The lighting controls for the Auditorium are broken down into different control zones:

- 24hr Egress Lighting
- Digital Time Control
- Occupancy Sensor
- Stand Alone Preset Dimming
- Time of Day with Maintenance/Security Override
- Time of Day without Override
- Time of Day with User Override

Figure 20, details an example break down of these zones for the second level lighting plan. These control are in compliance with ASHRAE 90.1 Section 9. The audience chamber and performance lighting are user controlled depending on the performance.

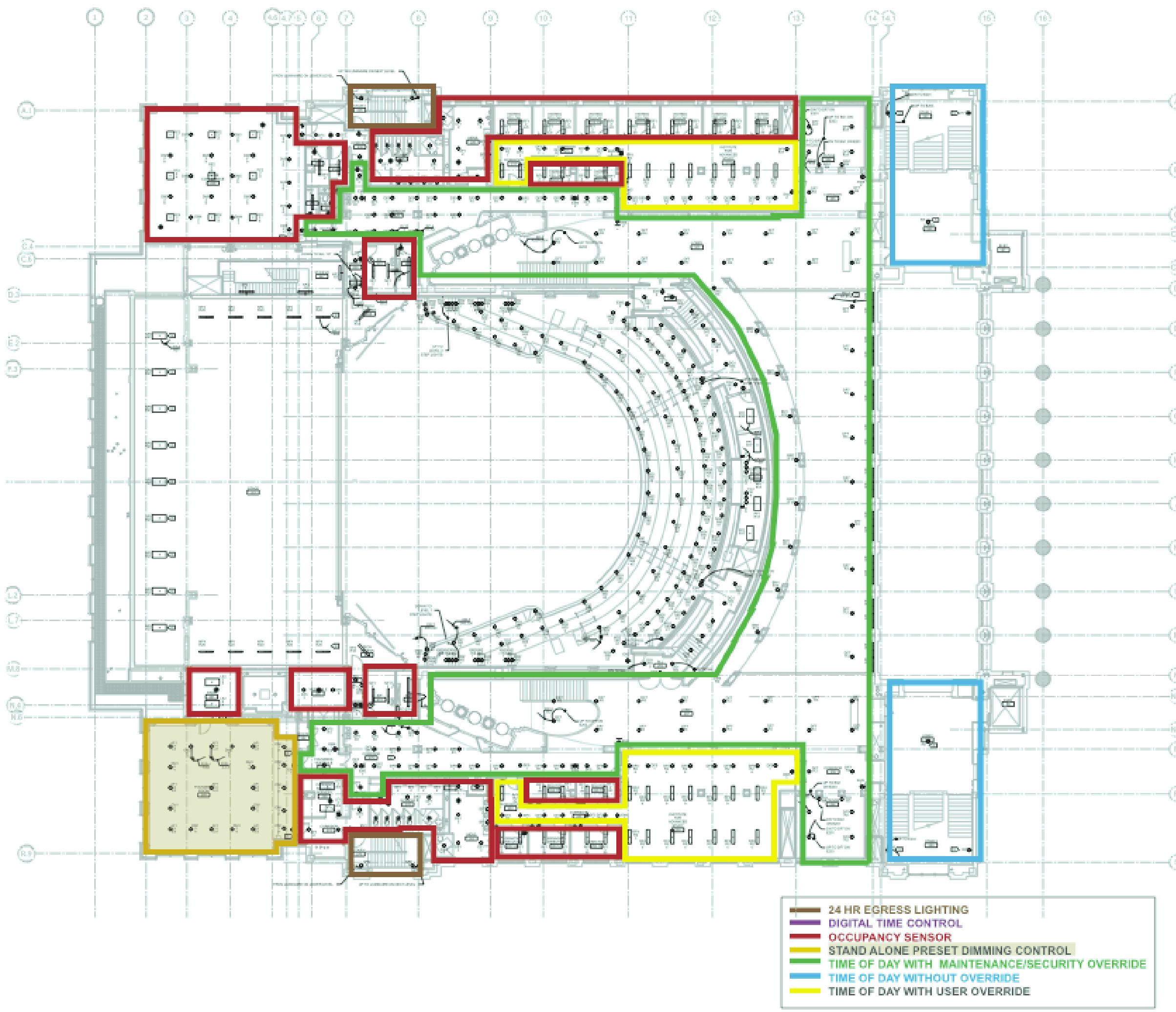


Figure 20 Lighting Control Zones (Source: Architect of Record)

The Space-by-Space method for determining the lighting power densities was used. All the spaces in the Auditorium comply with the standard limits.

ASHRAE 90.1 Section 10: Other Equipment

Per specification section 230513 Common Motor Requirements for HVAC Equipment, NEMA MG1 is cited as the requirements for all motors in the Auditorium. This meets the requirements set by ASHRAE 90.1-2010 section 10.

ASHRAE 90.1 Evaluation Conclusions

The systems used in the Auditorium are in general compliance with ASHRAE 90.1-2010 considering the historic nature of the building. All of the heating and cooling systems updated or replaced, comply, if not exceed, the standard efficiencies and power requirements set forth.

The area where the Auditorium lacks compliance is in the performance of the building envelope, which is to be expected. However, improving the quality of insulation and air tightness of the building could cause more thermal and moisture problems for the building later on.

Mechanical 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.

The overall renovation first cost for the project is approximately $8.5 million and results in an annual operation cost of approximately $279,697 ($1.65/SF). Considering that 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 LEED certification was not a priority on this project, the design team does incorporate energy saving measures to improve the state of the Auditorium. The overall building performance rating was improved by 12% through the use of economizers and replacing outdated equipment with new energy efficient systems.

Overall, the current renovation design achieves the design objectives and requirements set forth by the owner and local building codes. However, with further analysis other viable options could be presented to allow the Auditorium to exceed the minimum requirements. These design strategies mentioned and others deemed effective for the Auditorium's location and function will be discussed further in Part II: Proposed Redesign and Part III: Proposed Redesign Analysis.

Part II: Proposed Redesign

By proposing alternatives to the current design of the Auditorium, it in no way implies that the actual 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.

Alternatives Considered

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 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

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 and implementing a demand controlled ventilation system. These changes impact 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.

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. (Option A)
- Second, to compare if more support spaces could have benefited from a complete chilled beam system. (Option B)

Demand Control 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 CO_2 monitors that control the ventilation to a space. CO_2 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 a CO_2 monitored system to determine energy savings over traditional time-of-day automatic setbacks.

Impact

By implementing a chilled beam and DCV 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.

Constructability Check

To confirm that the workers are able to appropriately install the chilled beams and to ensure that adequate service space is available. Additionally, commissioning requirements will also be addressed.

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.

Breadth Analysis

Acoustics Breadth

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 Breadth

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.

Analysis 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 B is an overview for the work plan in Spring 2014. The four milestones are spaced to allow for adequate time and checks during the semester. See schedule for milestone details. The milestone deadlines are as follows:

- Milestone #1 (Jan. 26, 2014)
- Milestone #2 (Feb. 16, 2014)
- Milestone #3 (Mar. 9, 2014)
- Milestone #4 (Mar. 30, 2014)

Part III: Proposed Redesign Analysis

Depth Study 1: Chilled Beam Expansion

Overview Research

Active chilled beams (ACB) are not a new technology. However, there are many views on whether ACB should be adopted widely across the United States as an appropriate method for accommodating the heating and cooling loads in buildings. The American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) has published articles for and against the use of chilled beams in different applications. However, both sides agree that there are some common elements required for a well designed chilled beam systems. Some common benefits may include:

- *Higher Chilled Water Temperature* - A 57°F supply of chilled water to ACB units instead of 45°F chilled water to fan coil units or AHU cooling coils. (Brzezenski, 51) This has the possibility to reduce energy needed to reach the lower chilled water temperatures. (Price Industries Limited, 1058)
- *Reduced Mechanical Footprint* - Reducing mechanical ductwork to be sized only for ventilation airflow alone or using a pressurized plenum system to reduce the amount of space in the ceiling cavity can be a benefit in new construction and also renovations. The extra piping required will have cost implications, however piping is considerably smaller than an air duct to accommodate the same amount of heat transfer needed in a space. (Price Industries Limited, 1058)
- *Lower Annual Maintenance Costs* - Since the fins on the coils are spaced more generously, dust and other particles tend not to cling to the unit. (Alexander et al., 58) In an ASHRAE Journal article from September 2008, the author approximates that vacuuming once every 3 to 5 years and an occasional rubber nozzle replacement is all that is required.
- *Quiet Operation* - By removing noisy fan powered boxes adjacent to spaces, ACBs are an acoustic friendly option when dealing with sensitive spaces. (Price Industries Limited, 1058) The units themselves can produce some high frequency noise, but when the room attenuation is factored in, the sound dissipates quickly within the space. (Alexander et al., 53)

While ACB have many benefits, when applied in the wrong application or with incorrect control sequences, there can be unfavorable results in term of performance and energy consumption. Correct design procedures should be followed, along with a comprehensive control sequence to minimize the possibility of condensation and inadequate space conditioning. For instance, it is important to use ACBs in spaces that have a low air side load fraction (typically LF ≤ 0.33) (Price Industries Limited, 1064). This means the fraction of ventilation air should be as small as possible compared to the air required to condition the space. This will allow for reductions in AHU size and also ductwork. The remainder of the load for the space will be met through the hydronic coils in the active chilled beam unit. Both cooling and heating sensible loads can be met in the space by ACB, however it is important to consider the fraction of sensible to latent load. Chilled beams do not perform well in applications that have a high latent load. Spaces that should be avoided for chilled beam use are entry ways, atriums (areas with high infiltration), pools, kitchens, gymnasiums (spaces with high latent cooling requirements) and/or areas where recirculated air is not permitted. The sensible heat ratio should be checked for spaces under consideration for chilled beams (typically SHR ≥ 0.4). (Price Industries Limited, 1064)

Space Compatibility

The Auditorium currently has 15 rooms being served with active chilled beams in a select number of performance support spaces. This depth investigates expanding the use of chilled beams to other spaces and the impact that has on the building in terms of energy, emissions, construction and aesthetics. Based on modeling results the air side load fraction and sensible heat ratio were tabulated and are displayed Table 20 for the rooms currently designed with chilled beams. Table 21 shows spaces with chilled beams for Option A and Table 22 details the load fraction and sensible heat ratio for spaces with active chilled beams in Option B.

	Room	Air Side Load Fraction (LF ≤ 0.33 Desired)	Sensible Heat Ratio (SHR ≥ 0.4 Desired)
Baseline (Current Design)	020 OFFICE	0.22	0.78
	020.1 OFFICE	0.21	0.79
	020.2 OP OFFICE	0.13	0.85
	020.4 OFFICE	0.06	0.87
	020.6 OFFICE	0.07	0.88
	032 CORR	0.20	0.70
	035 CORR	0.28	0.78
	B43 LOCKER	0.65	0.00
	B49 BKRM	0.65	0.00
	B51 OFFICE	0.23	0.90
	B53 WKRM	0.70	0.10
	B57 WKRM	0.71	0.17
	B59 OFFICE	0.23	0.90
	B61 WKRM	0.70	0.11
	B63 WKRM	0.71	0.09

Table 20 Air Side Load Fraction & Sensible Heat Ratios - Baseline

	Room	Air Side Load Fraction (LF ≤ 0.33 Desired)	Sensible Heat Ratio (SHR ≥ 0.4 Desired)
Option A [Rooms added to Baseline]	017 OFFICE	0.21	0.81
	030 GREEN RM	0.46	0.24
	045 CORR	0.25	1.00
	065 CORR	0.28	0.65
	072 DRESS	0.65	0.00
	080 OP OFFICE	0.18	0.76
	080.02 OFFICE	0.08	0.88
	080.04 OFFICE	0.07	0.90
	080.06 WKRM	0.07	0.89
	082 OFFICE	0.20	0.81
	084 OFFICE	0.21	0.80
	087 OFFICE	0.21	0.79
	B25 CORR	0.27	0.92
	B32 CORR	0.25	1.00
	B35 CORR	0.41	0.50
	B37 CORR	0.35	1.00
	B45 CORR	0.35	0.77
	B65 CORR	0.35	0.75
	B82 AV	0.26	0.92
	B85 CORR	0.36	1.00
	B92 STOR	0.88	1.00

Table 21 Air Side Load Fraction & Sensible Heat Ratios - Option A (Rooms added to Baseline)

	Room	Air Side Load Fraction (LF ≤ 0.33 Desired)	Sensible Heat Ratio (SHR ≥ 0.4 Desired)
Option B [Rooms added to Baseline & Option A]	003 RSTRM	0.00	-
	003.1 TLT	0.00	-
	008 OFFICE	0.17	0.75
	011 STOR	0.52	1.00
	013 OP OFFICE	0.19	0.77
	029 TLT	0.00	-
	036 CORR	0.15	0.74
	055 CORR	0.10	0.94
	061 STOR	0.71	0.00
	064 JAN	0.35	1.00
	066 TLT	0.00	-
	070 DRESS	0.65	0.00
	070.1 TLT	0.00	-
	074 CORR	0.19	0.85
	089 OFFICE	0.21	0.81
	090 OP OFFICE	0.15	0.75
	090.2 OFFICE	0.06	0.89
	090.4 OFFICE/AV	0.06	0.92
	090.6 OFFICE	0.08	0.89
	091 STOR	0.58	1.00
	097 TLT	0.00	-
	098 RSTRM	0.00	-
	106 CONF	0.24	0.77
	110 CONF	0.24	0.77
	110.1 CONF	0.15	0.78
	210 OP OFFICE	0.17	0.75
	210.02 OFFICE	0.04	0.89
	210.04 OFFICE	0.04	0.89
	210.06 OFFICE	0.04	0.89
	210.08 OFFICE	0.04	0.89
	210.10 OFFICE	0.04	0.89
	210.11 OFFICE	0.20	0.82
	210.12 OFFICE	0.04	0.91
	210.13 OFFICE	0.21	0.73
	210.14 OFFICE	0.04	0.89
	215 CORR	0.11	0.79
	217 WKRM	0.20	0.73
	283 WKRM	0.17	0.80
	285 CORR	0.10	0.79
	290 OP OFFICE	0.10	0.87
	290.10 OFFICE	0.05	0.92
	290.11 OFFICE	0.17	0.75
	290.12 OFFICE	0.05	0.90
	290.13 OFFICE	0.19	0.82
	290.14 OFFICE	0.04	0.90
	310 OP OPEN	0.17	0.73
	310.02 OFFICE	0.04	0.90
	310.04 OFFICE	0.04	0.89
	310.06 OFFICE	0.04	0.89

	Room	Air Side Load Fraction (LF ≤ 0.33 Desired)	Sensible Heat Ratio (SHR ≥ 0.4 Desired)
Option B [Rooms added to Baseline & Option A]	310.08 OFFICE	0.04	0.90
	310.10 OFFICE	0.04	0.89
	310.11 OFFICE	0.19	0.75
	310.12 OFFICE	0.04	0.89
	310.13 OFFICE	0.20	0.73
	310.14 OFFICE	0.04	0.89
	310.15 OFFICE	0.20	0.75
	310.16 OFFICE	0.05	0.88
	315 CORR	0.11	0.70
	318 WKRM	0.18	0.69
	382 CONF	0.27	0.78
	385 CORR	0.10	0.74
	390 OP OFFICE	0.09	0.87
	390.1 OFFICE	0.16	0.83
	390.2 OFFICE	0.05	0.90
	390.3 OFFICE	0.17	0.73
	390.4 OFFICE	0.04	0.91
	390.5 WKRM	0.15	0.80
	B23 TLT	0.00	-
	B27 DRESS	0.65	0.00
	B30 UNCND	0.00	-
	B34 DRESS	0.65	0.00
	B36 TLT	0.00	-
	B40 DRESS	0.65	0.00
	B41 UNCND	0.00	-
	B42 TLT	0.00	-
	B44 DRESS	0.65	0.00
	B46 TLT	0.00	-
	B47 TLT	0.00	-
	B48 DRESS	0.65	0.00
	B50 TLT	0.00	-
	B52 DRESS	0.65	0.00
	B54 TLT	0.00	-
	B56 DRESS	0.65	0.00
	B58 TLT	0.00	-
	B60 DRESS	0.65	0.25
	B62 TLT	0.00	-
	B64 DRESS	0.65	0.00
	B66 TLT	0.00	-
	B67 CORR	0.35	0.50
	B72 STAIR	0.00	0.78
	B76 STAIR	0.00	0.75
	B80 JAN	0.59	1.00
	B83 MUSIC	0.79	0.00
	B84 CORR	0.24	1.00
	B86 CORR	0.37	0.75
	B88 TLT	0.00	-
	B90 LAUNDRY	0.71	0.20

Table 22 Air Side Load Fraction & Sensible Heat Ratios - Option B (Further rooms added to Baseline & Option A)

It is evident that some of the airside load factors and sensible heat ratio are not particularly conducive to active chilled beam design. Restrooms, denoted "TLT" or "RSTRM", will be assumed to be part of the chilled beam system for exhaust applications only and put no sensible or latent cooling load on the system. For the sake of further investigation, the rooms with high load factors and/or high sensible heat ratio will be assumed to be acceptable.

Sizing Procedure

The procedure for sizing active chilled beams is presented in this section based on information from the Price Engineer's HVAC Handbook (Price Industries Limited, 1115). Using an open office (Rm. 080) as an example space, the number of fixtures required and the adjusted airflow to the space can be determined for each of the spaces to be switched to ACB.

Step 1: Determined from load software (IES Virtual Environment or another load simulation program) the latent load, sensible load and total load in the room. This is based on the room's exterior wall areas, amount of windows, and number of occupants, lights, and equipment.

Room 080 has the following load quantities:

$$q_L = 1{,}089 \text{ Btu/hr}$$
$$q_s = 11{,}890 \text{ Btu/hr}$$
$$q_t = 10{,}952 \text{Btu/hr}$$

Step 2: Determine the required amount of outdoor air based on equation 1 from ASHRAE Standard 62.1-2010

$$Voz = Rp \times Pz + Ra \times Az \text{ (Eq. 1)}$$

Rm. 080 Open Office

Rp = 5 cfm/person	*Ra = 0.06 cfm/SF*
Pz = 6 people	*Az = 843 SF*

V_{oz} = (5 cfm/person)(6 people) + (0.06 cfm/SF)(843 SF) = 80.6 cfm

Step 3: Calculate the airflow required to accommodate the latent load (Eq. 2) which is dependent on the room setpoint and setpoint of the air coming from the air handling unit.

Room Setpoint: 75°F, 50% RH → $W_{Room} = 0.00925\ lb_w/lb_{DA}$
AHU Setpoint: 60°F, 46% RH→ W_{AHU} 0.00575 lb_w/lb_{DA} → Cooling Setpoint

$$q_L = 4840 \times V_L \times \Delta W \text{ (Eq. 2)}$$

(1,089 Btu/hr) = 4840(Q_L)(0.00925-0.00575 lb_w/lb_{DA})
V_L = 64.3 cfm

Step 4: Select the maximum airflow between required ventilation and airflow to accommodate the latent load.

$$V_s = \max[V_{oz}, V_L] \text{ (Eq. 3)}$$

V_s = max[80.6, 64.3]
V_s = 80.6 cfm

Step 5: Determine the amount of sensible load the primary air can accommodate using equation 4.

$$q_{S,air} = 1.08 \text{ x } V_S \text{ x } \Delta T \text{ (Eq. 4)}$$

$q_{S,air}$ = 1.08(80.6 cfm)(75°F - 60°F)
$q_{S,air}$ = 1,305 Btu/hr

Step 6: Calculate the amount of heat transfer that is required by the cooling coil in the beam from equation 5.

$$q_{S,hydronic} = q_t - q_{S,air} \text{ (Eq. 5)}$$

$q_{S,hydronic}$ = 10,952 - 1,305 Btu/hr
$q_{S,hydronic}$ = 9,647 Btu/hr

Step 7: Select beams that can accommodate the required airflow and heat transfer based on $q_{S,hydronic}$.

Based on $q_{S,hydronic}$ = 9,647Btu/hr for the entire space, the design uses 3 beams in the main work area spaced 9.5' from each other and 4.75' from the walls in the flow direction. A fourth beam is placed in the smaller side area to accommodate load there. This requires each beam to accommodate Q_{cw} = 2,412 Btu/hr and a minimum airflow of 25 cfm each. The four pipe condition was used to accommodate heating. The 4 ft active length sections was selected to fit into an already designed suspended ceiling grid. The selection values from the Trox Technik design guide are located in Table 23.

	Nozzle Type	V_{pr} CFM	Q_{tot} Btu/hr	Q_{cw} Btu/hr	Δp_w ft H_2O	Q_{tot} Btu/hr	Q_{cw} Btu/hr	Δp_w ft H_2O	Q_{net} Btu/hr	V_{hw} GPM	Δp_w ft H_2O	Throw ft 150	Throw ft 100	Throw ft 50	NC	Meet q_s?	Meet throw?	
4 ft Active Length	Z	20	2,685	2,250	2.1	2,504	2,068	3.1	3,083	0.4	0.2	3	4	6	18	-	OK	
		25	3,197	2,653		2,609	2,152		3,809	0.45	0.2	3	5	7	20	-	OK	
		30	3,621	2,968		3,392	2,739		4,611	0.55	0.3	4	5	8	23	OK	OK	(1)
	M	25	2,515	1,971		2,354	1,810		2,897	0.5	0.3	3	4	6	16	-	OK	
		35	3,398	2,636		3,191	2,429		4,104	0.6	0.4	3	5	7	21	OK	OK	(2)
		45	4,078	3,098		3,841	2,861		5,283	0.85	0.7	4	5	8	24	OK	OK	(3)
	J	35	2,828	2,066		2,660	1,898		3,303	0.75	0.6	3	4	6	17	-	OK	
		50	3,857	2,768		3,641	2,552		4,769	1.1	1.2	4	5	8	21	OK	OK	
		65	4,662	3,247		4,416	3,001		5,829	1.5	2.3	5	6	10	25	OK	-	
	G	45	3,249	2,270		3,067	2,087		3,817	1.15	1.4	3	4	6	18	-	OK	
		65	4,394	2,979		4,164	2,749		5,204	1.5	2.3	4	6	9	22	OK	-	
		85	5,307	3,457		5,049	3,198		5,999	1.5	2.3	5	7	12	27	OK	-	
	H	65	4022	2,606		3,816	2,401		4,354	1.5	2.3	4	5	7	19	-	OK	
		90	5093	3,134		4,854	2,895		5,154	1.5	2.3	5	6	10	23	OK	-	
		115	6011	3,508		5,750	3,246		5,628	1.5	2.3	6	8	14	26	OK	-	
	U	80	4,465	2,723		4,252	2,510		4,372	1.5	2.3	4	5	8	19	OK	OK	
		110	5,587	3,192		5,344	2,949		4,962	1.5	2.3	5	7	12	23	OK	-	
		140	6,576	3,528		6,313	3,265		5,267	1.5	2.3	6	8	15	30	OK	-	

Table 23 Active Chilled Beam Design Table (Source: Trox Technik)

Option (1) - Meets criteria for heat transfer, throw and airflow as well as a low NC value
Option (2) - Meets criteria for heat transfer, throw and airflow, however is a better fit for the given loads, dimensions and has lower NC value
Option (3) - Meets the criteria of heat transfer and airflow however has a less desirable throw condition

Step 8: Review that the beams are supplying the space with the correct amount of flow for ventilation and dehumidification.

$$V_s = \max[V_{oz}, V_L, V_{Beam}] \text{ (Eq. 6)}$$

V_{Beam} *= 35 cfm/beam x 4 beams = 140 cfm*
V_s *= max[80.6, 64.3, 140] = 140 cfm*

Step 9: Layout the beams in the space for best comfort using throw and throw velocity as parameters.

Active chilled beams (shown in yellow - Figure 21) were laid out to achieve adequate throw and comfort for the occupants. The overall dimensions of the room are 35.5' x 18.5'.

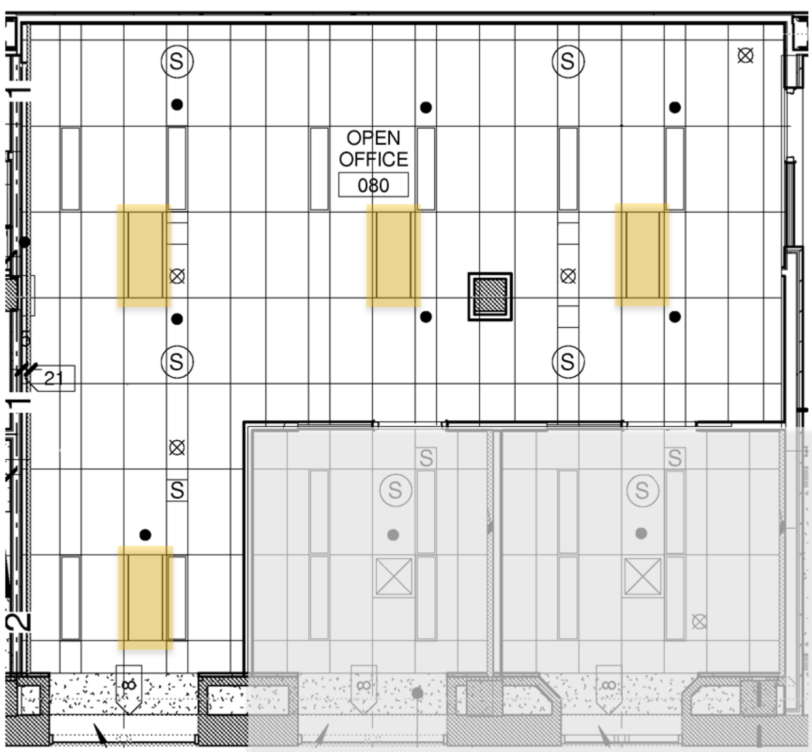


Figure 21 Ground Floor Reflected Ceiling Plan (Source: Architect of Record- Modified)

The ACB units for each room to be switched can be sized using this procedure. While each room was not fully designed, in terms of placement, the loads were used to calculate the number of ACB units required for each proposed design.

Option A: Chilled Beam Expansion

Option A switches 21 rooms from either a fan coil unit system or an induct reheat coil to an ACB system. These 21 rooms were originally designed to be served by ACB in an early phase of design, however were later changed in the final design. The purpose of this study is to investigate whether energy, emission and total life cycle cost savings can be achieved, therefore proving that the Auditorium would have benefited from the original design intent.

System Zoning & Operation

Figure 22 shows basement floor plan of the Auditorium. Spaces highlighted in orange are currently designed to be served by ACB. The areas highlighted in blue are added areas for investigation in Option A. Similarly, Figure 23 shows the proposed zone changes for the ground floor. The basement and ground floor have the best opportunity to receive a ACB system in terms of the type of spaces located there. Also localizing the system on two floors will assist with efficient ductwork layouts.

Baseline ACB (Orange), Option A ACB (Blue) - (Source: Architect of Record- Modified)

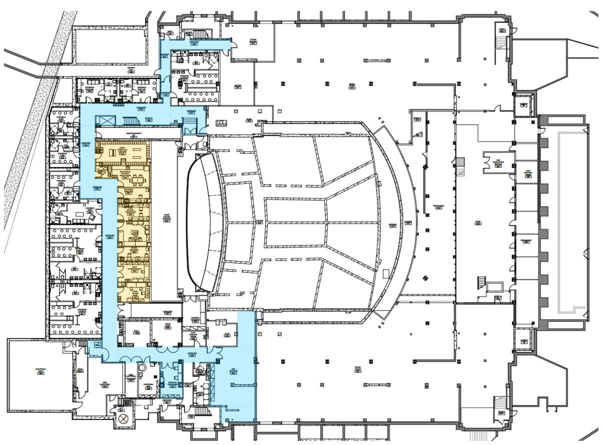


Figure 22 Basement Floor Plan

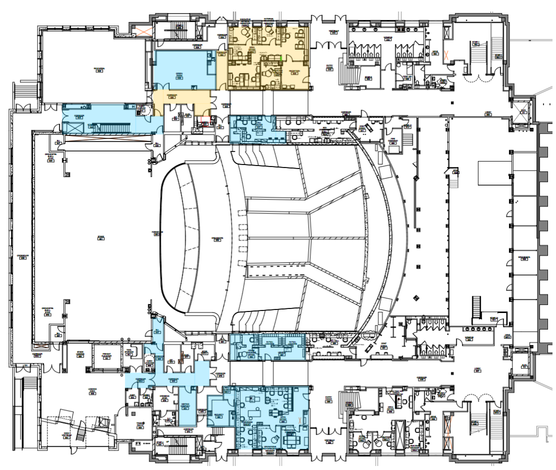


Figure 23 Ground Floor Plan

Energy & Emissions Evaluation

Changing 4.7% of the floor area (21 rooms) in the Auditorium results in a 9.3% decrease of yearly energy consumption for the Auditorium. The monthly electricity demand is still similar to the baseline in terms of distribution (Figure 24); however there is a decrease in kWh as seen in Figure 25. The annual reduction of electricity is approximately 1.8% The months of October and November show the greatest decrease in electricity use with 4.4% and 3.9% reductions respectively. However, the months of July and August show a slight increase.

Additionally, the heating demand also decreases regularly on a monthly basis as shown in Figure 26. Over the entire year the heat plant output can be reduced by 15% over the baseline model, with significant energy savings, up to 35%, in the summer months. Images of the graphs presented can be found larger in Appendix C.

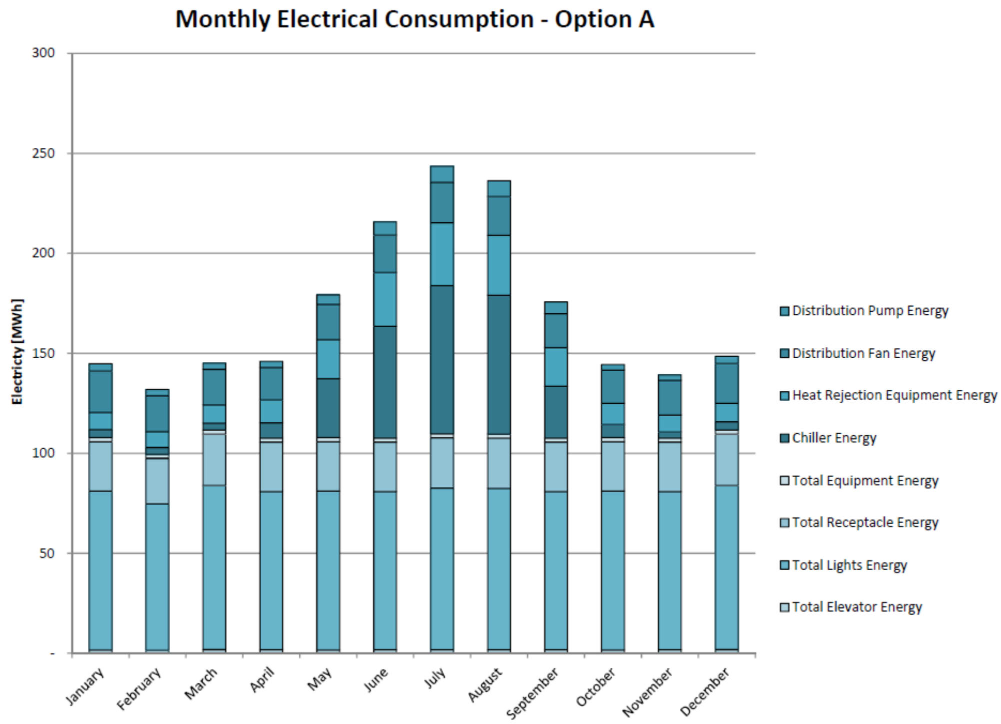


Figure 24 Modeled Monthly Electrical Consumption - Option A

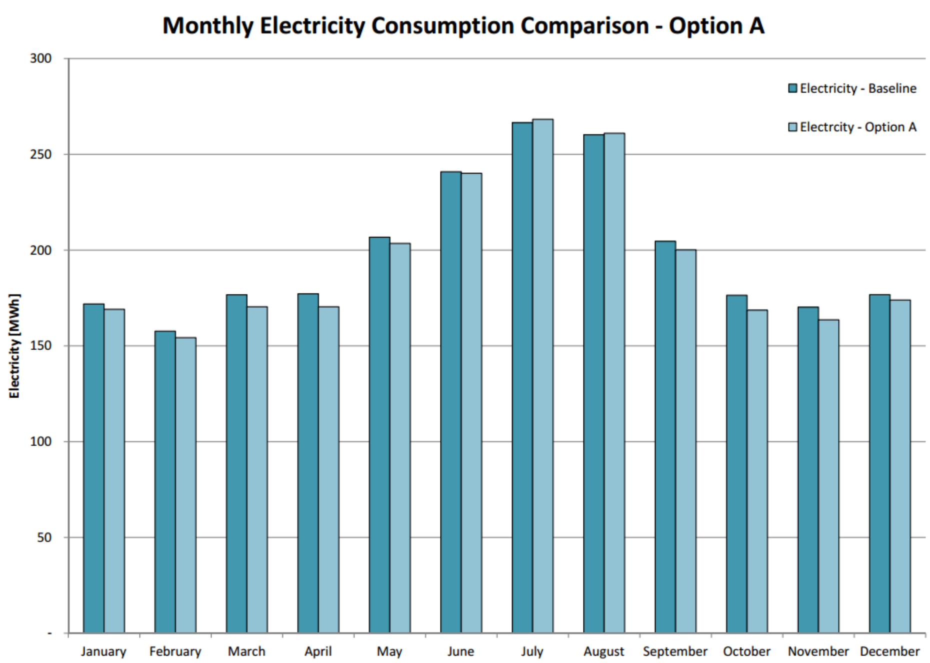


Figure 25 Modeled Monthly Electrical Consumption - Baseline vs. Option A

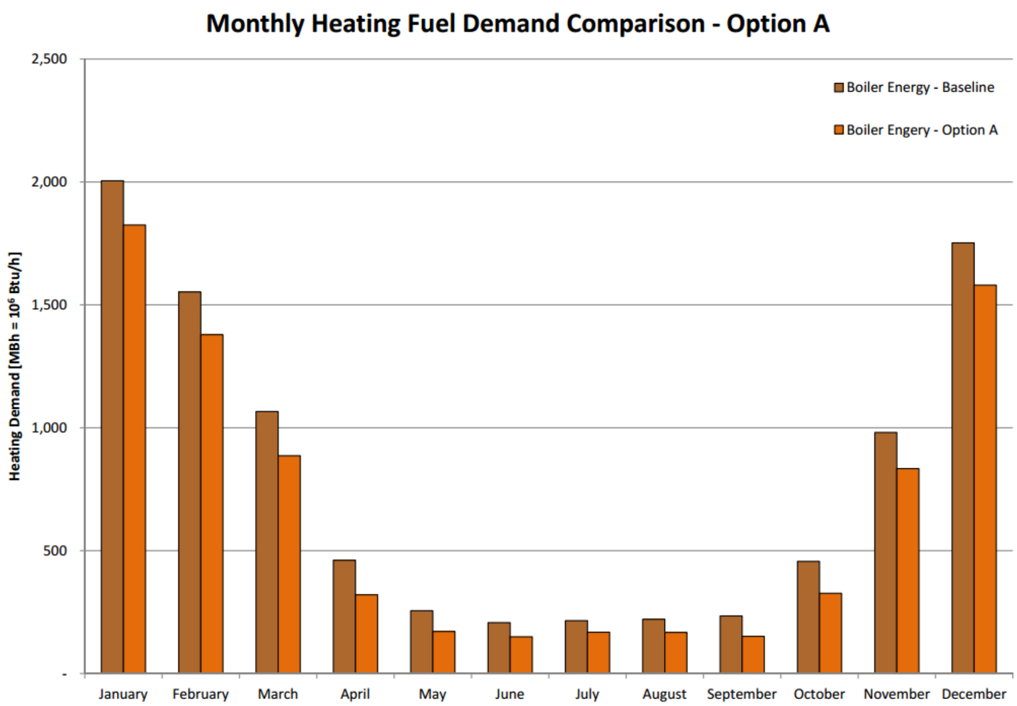


Figure 26 Modeled Monthly Heating Demand - Baseline vs. Option A

In terms of carbon emissions the amount of CO_2 produced is not significantly changed from the baseline productions.

Economic Evaluation

Using the same rate structures discussed in Part 1: Rates & Incentives for the utilities, Table 24 shows the annual utility cost for Option A. The right columns show the improvement over the baseline costs. The biggest change from switching 21 rooms over to ACB system can be seen in the 10% reduction in distribution fan energy. Overall the total annual cost is reduced by approximately 5% or $15,348 per year. This equates to a cost per square foot of $1.55 compared to $1.65/SF for the baseline system.

Table 24 Modeled Annual Utility Cost - Option A

PROPOSED #1 - OPTION A

ANNUAL UTILITY COST				Change from Baseline		
ELECTRICITY	**$**	**186,584.77**	**70.6%**	**$**	**(3,509.75)**	**-2%**
Chillers	$	28,508.28	*15.3%*	$	(1,431.80)	*-5%*
Distribution Fan Energy	$	17,070.25	*9.1%*	$	(1,986.13)	*-10%*
Distribution Pump Energy	$	5,023.62	*2.7%*	$	(299.14)	*-6%*
Heat Rejection Equipment	$	15,454.18	*8.3%*	$	207.33	*1%*
Lights	$	71,281.30	*38.2%*	$	-	*0%*
Equipment	$	24,473.55	*13.1%*	$	-	*0%*
Receptacle	$	22,679.93	*12.2%*	$	-	*0%*
Elevator	$	2,093.64	*1.1%*	$	-	*0%*
HEATING FUEL	**$**	**65,136.90**	**24.6%**	**$**	**(11,838.90)**	**-15%**
WATER	**$**	**12,627.15**	**4.8%**	**$**	**-**	**0%**
Total	**$**	**264,348.82**	**100.0%**	**$**	**(15,348.65)**	**-5%**

Option B: Further Expanded Chilled Beam Design

Option B adds 97 rooms to Option A , to bring the total number of rooms served by ACB to 133 rooms. This option expands the use of ACB to the first, second and third floors in office, open office and conference room spaces. While there are less spaces able to use an active chilled beam system on the first through third floors, the spaces are located so that ductwork can still be efficiently designed. The purpose of this option is to investigate if energy savings can be achieved with a majority of public and support rooms switched to a ACB system instead of served by VAV boxes, reheat coils in the ductwork, or fan coil units.

System Operation

Figure 27 shows basement floor plan of the Auditorium. Spaces highlighted in orange are currently designed to be served by ACB. The areas highlighted in blue are added areas for investigation in Option A, while green are to be added for investigation in Option B. Similarly, Figures 28 - 31 show the proposed zone changes for the ground floor, first floor, second floor and third floor respectively.

Baseline ACB (Orange), Option A ACB (Blue), Option B ACB (Green)
(Source: Architect of Record- Modified)

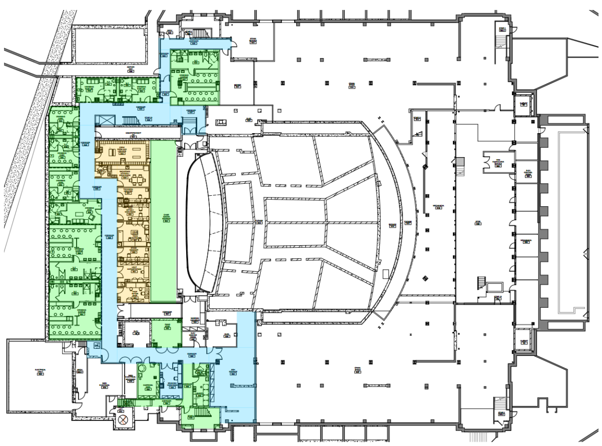


Figure 27 Basement Floor Plan

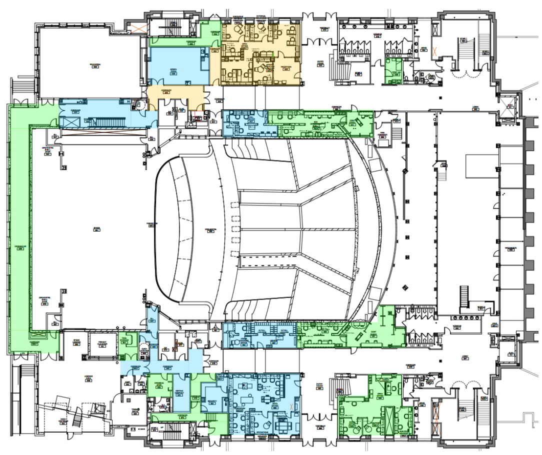


Figure 28 Ground Floor Plan

Baseline ACB (Orange), Option A ACB (Blue), Option B ACB (Green)
(Source: Architect of Record- Modified)

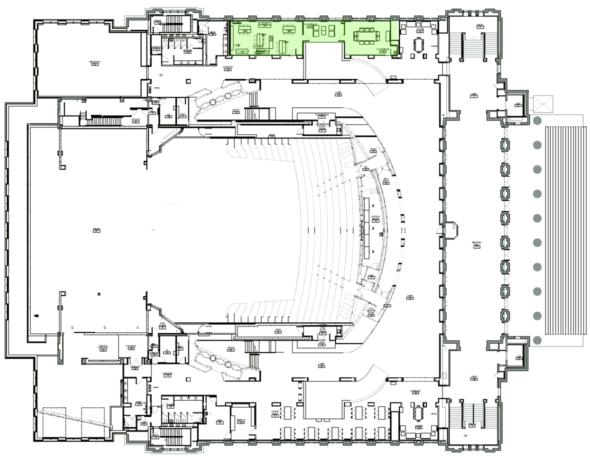


Figure 29 First Floor Plan

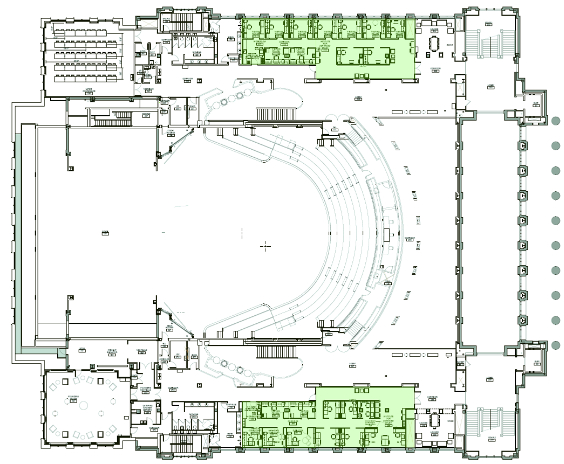


Figure 30 Second Floor Plan

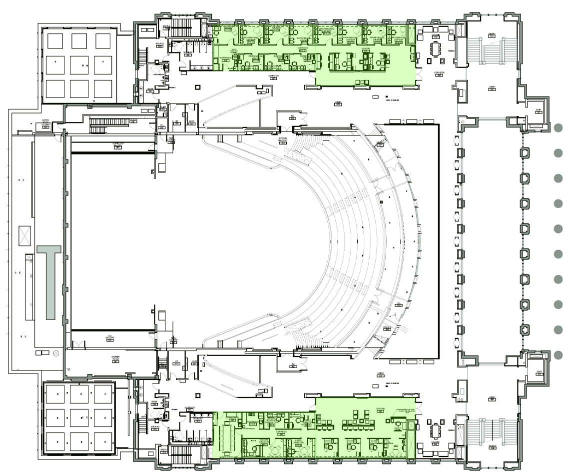


Figure 31 Third Floor Plan

Energy & Emissions Evaluation

Further energy reductions can be seen through adding more rooms to an active chilled beam system. For this study, 19% of the floor area of the Auditorium is served by ACB compared to only 2% floor area in the baseline design. This change equates to a modeled overall energy reduction of 11%. Electricity consumption is also reduced over the baseline model and Option A. The annual reduction is approximately 2.5%, with the months of March, April, October and November showing the greatest reduction in consumption; 3.8%, 3.7%, 4.5% and 4.3% respectively (Figure 32). However, the month of July still sees an increase in consumption, similar to Option A. In terms of heating energy consumption, the annual demand is decreased by 19%, again with significant decreases in the summer months, up to 39%, as seen in Figure 33. Furthermore, the emissions for Option B show a slight increase in lbs of CO_2 production.

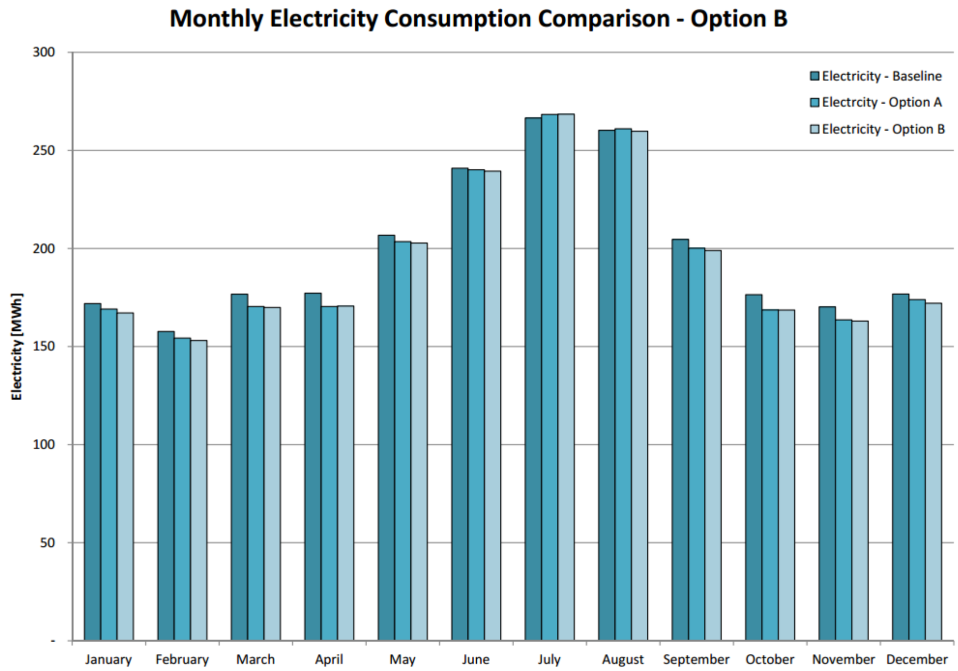


Figure 32
Modeled Monthly Electrical Consumption - Baseline vs. Option A & Option B

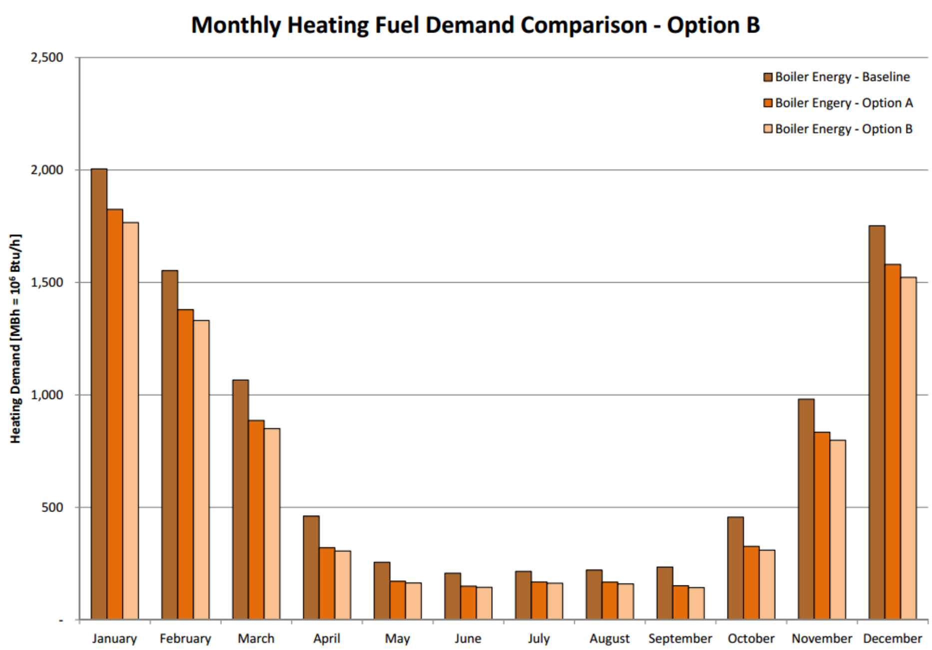


Figure 33
Modeled Monthly Heating Consumption - Baseline vs. Option A & Option B

The airflow capacity of the air handling units is also impacted by this design. AHU-1 sees the most significant reduction; 29% over the baseline model. Due to the rezoning, the airflow required for AHU-5 increases by 65% or 3,325 cfm. AHU-2 & AHU-3 are not significantly impacted. Table 25 shows the summary of airflow for Option B. Evaluating the actual loads on the building compared to the designed sizes of the air handling units, AHU-5 was significantly over-sized. AHU-5 was sized to accommodate 10,000 cfm design load and the design requirements for Option B do not exceed 9,000 cfm for AHU-5. In the case of AHU-1, the unit can be down-sized to meet a required design airflow of 50,000 cfm compared to the base design of 70,000 cfm.

System Name [OPTION B]	Supply Area [SF]	Total Supply [CFM]	Total OA [CFM]	AHU Ventilation Efficiency	AHU OA Required [CFM]	Exhaust [CFM]	Total OA/Makeup Air Required	AHU OA %
AHU-1 : Public Spaces	91384	46,964	14,514	0.8	18,143	2,201	18,143	39%
AHU-2 : Audience Chamber	28807	49,562	24,267	0.9	26,963	0	26,963	54%
AHU-3 : Performance Spaces	11259	16,216	3,867	0.8	4,833	0	4,833	30%
AHU-5: Performance Support Spaces	38543	8,456	5,293	0.8	6,617	3,159	6,617	78%

Table 25 Option B Design Airflow Calculations

Economic Evaluation

For Option B, Table 26 breaks down the annual utility costs by end-use based on the rate structures presented in an earlier section (Part 1: Rates & Incentives). Further reductions in all end-use areas with the exception of heat rejection equipment is possible. Overall there is a 7% reduction in annual cost (~$18,800). Similar to Option A, there is the most significant energy savings in distribution pumping and fan energy, 12% and 10% respectively. The cost per square foot to operate the Auditorium also decreases to $1.53/SF compared to $1.65/SF in the baseline design.

PROPOSED #2 - OPTION B

ANNUAL UTILITY COST				Change from Baseline		
ELECTRICITY	**$**	**185,610.60**	**71.1%**	**$**	**(4,483.91)**	**-2%**
Chillers	$	27,811.44	*15.0%*	$	(2,128.65)	*-7%*
Distribution Fan Energy	$	16,695.07	*9.0%*	$	(2,361.31)	*-12%*
Distribution Pump Energy	$	4,806.43	*2.6%*	$	(516.33)	*-10%*
Heat Rejection Equipment	$	15,769.24	*8.5%*	$	522.39	*3%*
Lights	$	71,281.30	*38.4%*	$	-	*0%*
Equipment	$	24,473.55	*13.2%*	$	-	*0%*
Receptacle	$	22,679.93	*12.2%*	$	-	*0%*
Elevator	$	2,093.64	*1.1%*	$	-	*0%*
HEATING FUEL	**$**	**62,654.73**	**24.0%**	**$**	**(14,321.08)**	**-19%**
WATER	**$**	**12,627.15**	**4.8%**	**$**	**-**	**0%**
Total	**$**	**260,892.49**	**100.0%**	**$**	**(18,804.99)**	**-7%**

Table 26 Modeled Annual Utility Cost - Option B

Impact

The active chilled beams (ACB) are based on design parameters from the Trox Technik DID632 unit. The product description and owners manual is attached in Appendix C and was used to evaluate the impact of implementing the active chilled beams.

Ceiling Coordination

Investigation into ceiling types for the spaces to be switched to active chilled beams was performed to ensure ease of installation and appropriate conditions for application. For the basement spaces, all the areas to be switched over to ACB are open to the decking above based on the reflected ceiling plan A300B. An open ceiling eliminates the coordination with a suspended ceiling grid and allows the flexibility to configure the units around lighting fixtures and other equipment. Conversely, the ground floor has a finished suspended ceiling grid. Most of the enclosed spaces have a suspended ceiling grid of either 2'x2' or 2'x4' tiles. The modular 2ft x 4ft and 2-way throw ACB will fit well into the grid based on the current spacing. An area that may require further coordination is the Crossover (Rm. 055). Since it's ceiling height is 26' the hanger coordination will need to take into account this height. Only two spaces (corridors 036 & 074) have gypsum board ceilings and the ACBs will need to be finished in place with an access panel to allow access to the piping shut off valves.

Lighting Layout

From a preliminary investigation into the reflected ceiling plans, the lighting layout should not be impacted. Most spaces either use linear light fixtures or 6" can light fixtures. The suspended ceiling grid on the ground floor should allow easy coordination of the lighting fixtures with the ACB units to keep the required lighting power density in the space.

Structural/ Connection Coordination

The weight of the ACB is significant compared to a standard diffuser. Each unit's weight can range from 33 lbs (2 ft length) to 160 lbs (10 ft length). Due to this added weight each unit will need to be tied into the structural decking above. It cannot be installed hanging on a suspended T-bar grid. The unit itself is provided with sliding hanging brackets on each side which allow for adjustment in hanging placement. It is recommended that a linear channel be provided for each unit and used to tie into the structural decking. Hanging can be accomplished with flexible wire or threaded rods. Furthermore, the manufacturer recommends the use of flexible ductwork and piping to allow for additional adjustments when tying into the air and water side systems. (Trox Technik)

The Auditorium floors are supported by a system of wide flange beams. The decking and concrete slab are sized for a mechanical equipment allowance. This allowance accommodates for the weight of each chilled beam. The ACB will be attached to the above decking and/or structural members.

Constructability & Commissioning

The chilled beams in each added space will be designed with adequate spacing to accommodate installation and air and water connections. The unit can be adjusted to receive the duct and pipe connections from a variety of positions. The duct connection can either be mounted on the side or the top of the unit. The water connections can either be on the left or right hand side of the unit as well. The maintenance associated with ACB is limited to vacuuming the fixture and coil every 3-5 years. The design placement will accommodate the needed accessibility to the unit. After installation it is important to ensure the units are working properly. The performance of the unit can be tested according to the system's owners manual for proper airflow. (Trox Technik)

Overall Evaluation - Depth Study 1

By implementing active chilled beams, there is the potential to save energy and money for the Francis Michael Performing Arts Academy. The Auditorium could see reduced energy consumption in a majority of the months for both heating, cooling and electrical consumption. Furthermore, the impact analysis can conclude that active chilled beams can be implemented and installed with little to no disruption to the current design of the building.

			BASELINE	OPTION A		OPTION B	
Annual Comparison			*Modeled*	*vs. Baseline*		*vs. Baseline*	
Energy		[MBH]	17,544	*(1,591)*	-9%	*(1,923)*	-11%
Electricity		[MWh]	2,386	*(42)*	-2%	*(58)*	-2%
Heating		[MBH]	9,408	*(1,447)*	-15%	*(1,750)*	-19%
Airflow	*AHU-1*	[CFM]	65,906	*(6,519)*	-10%	*(18,942)*	-29%
	AHU-2	[CFM]	49,725	*(163)*	0%	*163*	0%
	AHU-3	[CFM]	16,599	*(383)*	-2%	*(383)*	-2%
	AHU-5	[CFM]	5,131	*86*	2%	*3,325*	65%
Emissions		[lbsCO_2]	232,395	*(36.00)*	-0.02%	*2,720*	1.2%
Utility Cost		[$]	$ 279,697.47	*$ (15,348.65)*	-5%	*$ (18,804.99)*	-7%

Table 27 Option A & B Comparison Summary

Table 27, compares the two options considered for adding active chilled beams. Option A adds 42 chilled beams accounting for 4.7% of the total floor area of the Auditorium. Changing a small portion of the building results in a total energy savings of 9%, an electricity savings of 2% and a heating energy savings of 15% annually. Additionally, AHU-1 has the potential to be downsized by 10%, which could result in a first cost savings. Emissions produced in Option A are reduced, however only by a negligible margin. Finally, changes made in Option A can result in an annual utility cost savings of $15,348 or 5%. This annual savings will be used to compare the economic feasibility of the improved system.

For Option B, 98 additional chilled beams were added to the design. This results in 140 added active chilled beams to the Auditorium. Energy consumption savings only increased marginally above Option A with savings for energy, electricity and heating energy totaling to 11%, 2% and 19% respectively. The biggest savings is on the airflow capacity of AHU-1. The total capacity of the unit was reduced by 18,942 cfm or 29%. This is a significant reduction in required capacity for the unit and will result in a cost savings for the system. Furthermore, the capacity of AHU-5 will not need to be increased due to its original oversized capacity. The current design capacity of AHU-5 is 10,000 cfm which is a significant oversizing of its required capacity which is 5,131 cfm. Option B requires AHU-5 to be sized to 8,456 cfm which is well within the allowable capacity for the unit. In terms of emissions, Option B produces a 1.2% increase in lbs of CO_2 which can be considered negligible. Lastly, the annual utility costs for Option B decreased by $3,456 over Option A. Compared to the Baseline model, Option B decreases annual utility costs by $18,804 or 7%.

Option A, from several standpoints, can be viewed as a better option to implement due to the high energy savings per unit installed. Option B appears to be a less viable option to implement in terms of its energy savings and the large quantity of units needed. In conclusion, the potential for adding active chilled beams is present in terms of energy savings and annual utility costs. Furthermore, the applicability of these units fits well within the currently design system.

Depth Study 2: Demand Control Ventilation Study

Overview Research

The second area of study for the mechanical depth involves research into demand controlled ventilation and its application for spaces in the Auditorium. As desired energy efficiency increases, the level of technology controlling airflow, temperature and pressure must also increase as well. Demand controlled or demand-based ventilation is a strategy to tailor the amount of conditioned air supplied to a space to the actual amount of people occupying the space.

Widely accepted standard ASHRAE 62.1, outlines the minimum amount of outdoor air to be supplied to a space based on its occupants and floor area to ensure adequate air quality. However, even during occupied hours the number of people in a space is usually well below the designed occupancy. This creates a situation where the air handling system is over supplying conditioned outdoor air and therefore can be viewed as wasting energy. Occupancy sensors tied into a demand-based ventilation control sequence can better follow the actual occupancy patterns to potentially save energy by reducing fan power and required heating and cooling of outdoor air.

A standard method of control is to determine setback times during unoccupied hours to limit the over airing of spaces. For example, the building temperature would be “setback” and the airflow would be reduced to the ventilation required to accommodate building related contaminants from the hours of 10pm to 3am and/or all hours during the weekend which are categorized as “unoccupied”. During other hours, the system would supply conditioned air to accommodate the full load. The problem with setbacks are that they are static and cannot dynamically respond to changing occupancy loads.

The advantage that a demand based ventilation system has is the ability to automatically respond to occupancy load conditions irrespective of the time of day. This improved response can help save energy and also has the potential to increase the air quality which has been linked to increased productivity of the occupants. Additionally, with continual monitoring of the space the HVAC system can develop a more accurate start-up and turn-down time for morning and evening hours. A conservative start up time for a standard HVAC system could be 4:00 am, with occupants starting to arrive around 7:00 am. Even though it will not take 3 hours for the building to achieve the occupied comfort conditions, the system is only based on this structured time scale. Furthermore during occupied and/or unoccupied hours the demand based system could have the potential to detect excess moisture infiltration to spaces and correctly respond the to problem. (Dougan et al., 50) Excess moisture can lead to mold growth which reduces the “health” of the building for its occupants.

Depending on the type of monitor, occupancy sensor can either detect movement via infrared wavelengths or CO_2 concentration to determine the number of occupants in a space. Inherent to having sensors monitoring CO_2 levels is the challenge of keeping the sensors calibrated to respond appropriately. Initial calibration is very important to setting up the system correctly and continued calibration is required throughout the life of the system.

The initial design of the Auditorium has demand based controls specified for the audience chamber and lecture/recital spaces. These spaces have a high variability in terms of daily occupancy and it makes sense for the design engineers to place the sensors in these areas. However, other areas of the Auditorium could benefit from a demand based control using CO_2 sensors. Spaces like conference rooms, dressing rooms, open offices, student lounges and lobby spaces all see a highly variable occupancy on a daily basis. Furthermore, the Auditorium already has a direct digital control (DDC) system, which is the ideal system to integrate a series of demand based sensors. (Schell et al., 36)

It can appear simple to install a couple sensors and assume that the building will automatically see reductions in energy consumption. However the actual implementation is much more complicated that it appears.

System Implementation

It can be very difficult, if not impossible, to model a demand based ventilation system for a building. Computing the energy savings or even the standard building occupancy pattern requires previous experience with the building type, and even then, every building operates differently. The building itself accounts for a significant portion of the contaminants in the air and therefore there always must be a baseline amount of fresh air supplied. Also, there is the possibility that your system may call for more outdoor air than initially designed, causing an increase in energy usage instead of decreasing.

All of these unpredictable factors, have led design engineers to follow a methodology to implement a demand-based system. An article from the 2002 November issue of the ASHRAE Journal outlines the general process to evaluate the effectiveness of a demand-based system. This process take place during the design phase of the project and continues for 6-12 months after completion of the construction. The general analysis steps are summarized below (Schell et al., 36-37):

1. Compare the last 12 months of the buildings energy consumption to the operational data collected by the U.S. Department of Energy for the surround area.
2. Collect a representative sample of the quality of outdoor and indoor air at the site. This includes temperature, relative humidity and CO_2 concentration.
3. Review the existing building's HVAC operation schedules and set-points.
4. Evaluate the building HVAC system in terms of its compatibility to accept a demand based control sequence.
5. Based on the air quality data collected at the site, model the energy consumption of preconditioning the outdoor air for a given required ventilation rate to the occupancy patterns that would be processed by a CO_2 demand-based system. From this an economic feasibility study can be performed.
6. For 6-12 months after the building occupants have moved back into the space, evaluation of the system is performed to ensure it is operating as the design intended.

Model Assumptions

For this investigation, collecting data from the site was not possible. Therefore an abbreviated study into how an approximate occupancy schedule can affect the air distribution system was performed. Figure 34 & Figure 35 compare a typical setback schedule to dynamically responding demand-based schedule. Some assumptions were made in developing the demand based occupancy sensors for two types of spaces; typical office spaces and performance & performance support spaces. These assumptions include:

- Performance Spaces
    - No shows Monday - Thursday

- Friday performance at 7:00 pm
    - Saturday performances at 2:00 pm & 7:00 pm
    - Sunday performance at 2:00 pm
- Office Spaces
    - Design occupancy will not be achieved in all spaces at a given time
    - Design occupancy will slowly increase over the morning hours 5:00 - 8:00 am and decrease over the evening hours 5:00pm to 12:00am (midnight).

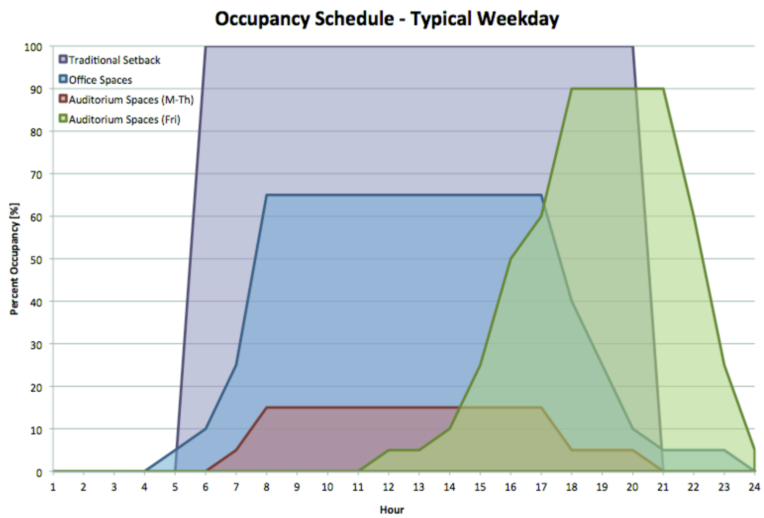


Figure 34 Modeled HVAC Occupancy Schedules - Typical Weekday

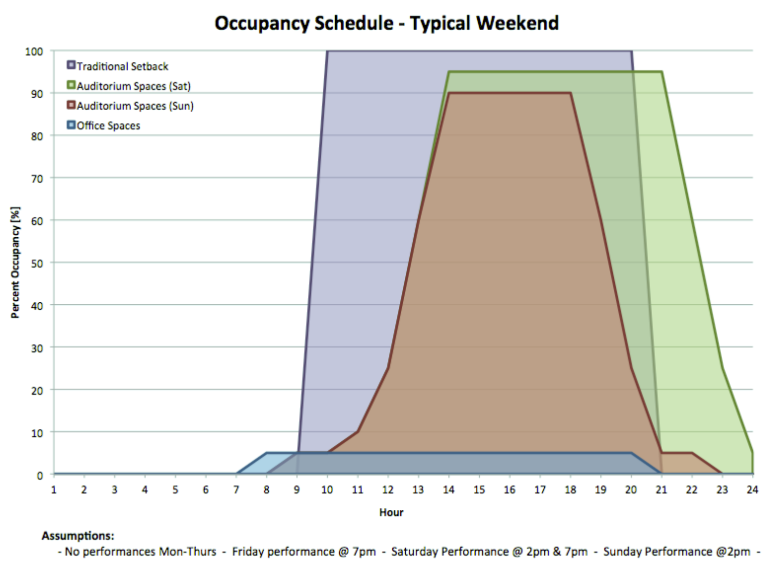


Figure 35 Modeled HVAC Occupancy Schedules - Typical Weekend

Modeling Procedure

These occupancy schedules were applied to a ventilation calculations procedure to evaluate the effectiveness of using demand based controls (Steps 1 - 4). Table 28 lists the rooms in the Auditorium that were selected to receive a CO_2 monitor to control the airflow.

Table 28

Rooms to Receive CO_2 Monitor Categorized by End-Use

AUDITORIUM SPACES	OFFICE SPACES
460 Lecture/Recital	240 Lg Conference Building
100.1 Audience Chamber	018 VEST
B27 DRESS	088 VEST
B34 DRESS	104 LNGE
B40 DRESS	106 CONF
B44 DRESS	110 CONF
B48 DRESS	110.1 CONF
B52 DRESS	125 LOBBY
B56 DRESS	196 LNGE
B60 DRESS	204 LNGE
B64 DRESS	210 OP OFFICE
013 OP OFFICE	260 FNDRS RM
087 OFFICE	290 OP OFFICE
089 OFFICE	296 LNGE
100 MEM HALL	304 LNGE
101 LOBBY	382 CONF
198 LOBBY	390 OP OFFICE
201 LOBBY	396 LNGE
203 LOBBY	
297 LOBBY	
298 LOBBY	
301 LOBBY	
303 LOBBY	
397 LOBBY	
398 LOBBY	

<u>Step 1</u>: Calculate the required ventilation airflow on an hourly basis over the course of a typical week using the equations from ASHRAE 62.1 Minimum Ventilation Procedure.

$$Voz = Rp \times Pz + Ra \times Az \text{ (Eq. 6-1)}$$

Each hour can be categorized as one of two options based on the modeled setback control sequence:

1. Unoccupied (Setback Control): Pz = 0; *Voz = Ra x Az*
2. Occupied (Setback Control): Pz ≠ 0; *Voz = Rp x Pz + Ra x Az*

<u>Step 2</u>: Calculate the required ventilation air flow on an hourly basis over the course of a typical week, modifying the ASHRAE 62.1 Minimum Ventilation Procedure to incorporate a demand based occupancy schedule.

$$Voz = Rp \times Pz \times (Occ.\ \%) + Ra \times Az \text{ (modified Eq. 6-1)}$$

Each hour can be categorized as one of two options based on the modeled demand based occupancy control:

1. Unoccupied (DCV): Occ. % = 0%; *Voz = Ra x Az*
2. Occupied (DCV): Occ. % ≠ 0%; *Voz = Rp x Pz x (Occ. %) + Ra x Az*

Step 3: Subtract the volume of airflow using demand based procedure (Step 2) from the volume of airflow using the setback procedure (Step 1) for each hour of the typical week.

$$\sum Voz = Voz_{setback} - Voz_{DCV} \text{ (Eq. 7)}$$

This represents the additional airflow that is over conditioning a space each hour.

Step 4: Using ∑Voz, the amount of energy can be calculated that is required to condition the additional outdoor air at design conditions.

$$q\ [BTU/hr] = 0.018 \times \sum Voz\ [CF/hr] \times (T_s - T_{OA}) \text{ (Eq. 8)}$$

T_{OA} = TMY hourly Dry Bulb [°F] for a typical week

Heating - January 1 - 7, 2004

Cooling - July 10 - 16, 2004

Model Results

Using the above procedure, it can be shown that there is the potential for significant energy savings using demand based control monitors in spaces. For spaces that are used during a performance or show, approximately 20% reduction in energy used to precondition ventilation air can be achieved. Office type spaces have the potential to decrease energy by 40%. Table 29 shows the summary of savings over at typical week in heating (January). Table 30 summarizes the the calculations for a typical week in cooling (July). A full summary of the energy calculations can be seen in Appendix C.

Boiler Effciency η_B = 85% REDUCTION

Heating Design Condition	Area	Su	Mo	Tu	We	Th	Fr	Sa	Demand Capacity	Capacity Required	Savings
	[SF]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[MBh]	[MBh]	[%]
AUDITORIUM SPACES	35,488	173,512	471,708	838,361	988,789	1,187,880	969,420	304,900	4,935	5,805	19%
OFFICE SPACES	19,432	87,287	59,889	106,721	125,380	150,717	123,408	128,567	782	920	45%
TOTAL	**54,920**	**260,799**	**531,597**	**945,082**	**1,114,169**	**1,338,597**	**1,092,829**	**433,468**	**5,717**	**6,725**	**24%**

Table 29 Modeled Demand Control Ventilation Summary - Heating Design Condition

Chiller Effciency COP = 6.62

** Converted from* $\eta_{Primary}$ *= 0.531 [kW/ton]* REDUCTION

Cooling Design Condition	Area	Su	Mo	Tu	We	Th	Fr	Sa	Demand Capacity	Capacity Required	Savings
	[SF]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[%]
AUDITORIUM SPACES	35,488	-8,862	-37,403	-32,019	-44,843	-44,213	-39,407	-23,332	-230,079	-34,737	22%
OFFICE SPACES	19,432	-5,200	-4,522	-3,923	-5,392	-5,432	-4,784	-8,806	-38,059	-5,746	45%
TOTAL	**54,920**	**-14,062**	**-41,925**	**-35,942**	**-50,235**	**-49,645**	**-44,191**	**-32,138**	**-268,137**	**-40,484**	**26%**

Table 30 Modeled Demand Control Ventilation Summary - Cooling Design Condition

Overall Evaluation - Depth Study 2

Demand based ventilation strategies has strong time and environment dependcies. For example, daily occupancy, outdoor air temperature and performance schedules will dictate the realistic energy savings possible for the Auditorium. Due to these factors, modeling the benefits of a demand control ventilation system pose a challenge in the design phase. Several ASHRAE Journal articles describe modeling demand controlled ventilation as a very approximate process. However, through making initial assumptions about a system, the benefits can be approximated through simple computational models. Also, differing the occupancy schedule for types of spaces throughout a typical week can provide an initial guess to how the system will perform.

The biggest benefit DCV has within buildings is the ability to allow the HVAC system to better follow the actual load pattern in terms of occupancy. Occupancy can be considered the most variable component of energy use on a daily and weekly basis. Following its pattern more closely could potentially save the building energy.

Furthermore, by providing the correct amount of "fresh" or outdoor air based on the CO_2 sensor readings the productivity of the workers inside the space will increase. Studies show that work productivity increases when the environment is managed to achieve desired comfort. This increase in productivity has a large impact of the bottom line of the product or service the organization is providing. In the case of the Auditorium, this means visiting fellows, honors advisors and students will have an environment that is conducive to learning, research and collaboration.

Breadth Analysis 1: Acoustics

Room acoustics is generally overlooked in building design, however it can have a large impact on occupant productivity and comfort. This analysis compares the original design of air terminal units (VAV boxes) with the proposed design using active chilled beams in terms of the sound transmission into office spaces. Also, in this breadth the impact of having large mechanical equipment on adjacent roofs to the performance space will be evaluated.

Existing Sound Power Level Conditions

Based on Chapter 48:Noise and Vibration Control from the ASHRAE Fundamentals Handbook, there are typical noise criteria (NC) and overall sound power levels that are acceptable in categorized spaces. The NC, dBA and dBC values are listed in Table 31 for a private office, open office and a performing arts theater.

The goal is to design spaces that will not receive excess noise from large mechanical equipment and smaller equipment located in the room, i.e. air terminal units and diffusers.

For this breadth two office spaces were evaluated to compare the original design to the proposed design. Room 310, an open office space, and room 310.13, a private office, were used to compare the two designs.

Table 31 Design Guidelines for HVAC-Related Background Sound in Rooms (Source: ASHRAE Fundamentals Handbook)

Room Types	Octave Band Analysis	Approximate Overall Sound Pressure Level	
	NC/RC	dBA	dBC
Private Offices	30	35	60
Open Offices	40	45	65
Theaters	20	25	50

To evaluate the background noise due to mechanical systems, the sound power data for the equipment is needed. Tables 32, 33, and 34 show the sound power for the air handling units, cooling towers and the air terminal units.

Air Handling Units		Sound Power Levels [dB re: 10^{-12} W]							
		63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
AHU-1	Supply Discharge Opening	85	80	88	85	81	80	78	73
	Return Air Inlet	91	88	83	87	82	81	80	71
	Casing Radiated	82	74	78	73	61	56	51	44
AHU-2	Supply Discharge Opening	81	77	85	79	77	76	73	67
	Return Air Inlet	95	91	87	81	80	79	75	69
	Casing Radiated	78	71	75	67	57	52	46	38
AHU-3	Supply Discharge Opening	78	74	82	76	74	73	70	64
	Return Air Inlet	88	84	80	81	77	76	75	67
	Casing Radiated	75	68	72	64	54	49	43	35
AHU-5	Supply Discharge Opening	80	32	28	21	76	70	65	59
	Return Air Inlet	74	85	89	73	65	61	54	51

Table 32 AHU-1 Sound Power Levels (Source: Engineer of Record)

Cooling Tower	Sound Power Levels [dB re: 10^{-12} W]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
One Cell (Spec Sheet)	*112*	*106*	*103*	*101*	*95*	*91*	*90*	*81*
Two Cells (Calculated)	115	109	106	104	98	94	93	84

Table 33 Cooling Tower Sound Power Levels (Source: Engineer of Record)

VAV BOXES	ROOM	UNIT	AIRFLOW [cfm]	Discharge Sound Power Levels [dB re: 10^{-12} W]					
				125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
BASELINE	310	ESV-8-2	500	55	53	46	44	40	36
	310.13	ESV-6-2	225	52	48	41	41	37	30
PROPOSED	310	ESV-6-2	150	47	43	36	37	34	27
	310.13	ESV-4-2	75	48	44	40	37	35	29

*Note: Each unit is selected for 0.5" w.g.

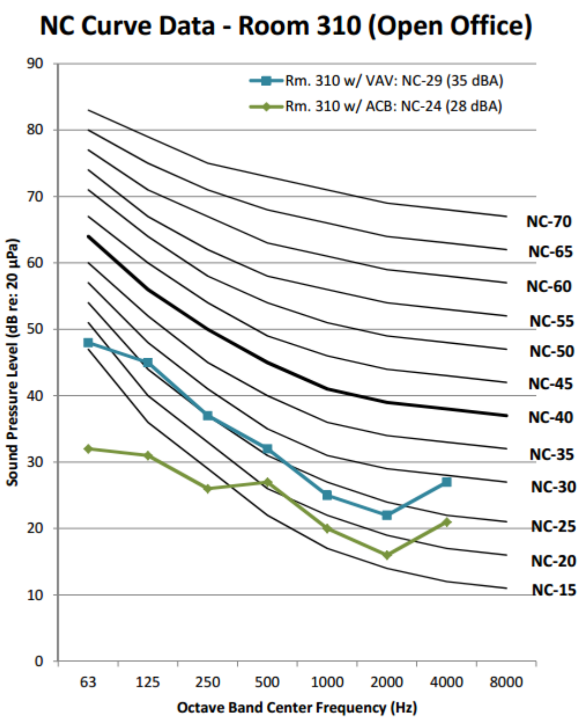
Table 34 Air Terminal Unit Sound Power Levels (Source: Price HVAC)

Chilled Beam Expansion Noise Impact

Dynasonics AIM software was used to determine the resulting background noise levels due to the HVAC equipment. The calculation sequence within Dynasonics is based directly from procedures and standards written in Chapter 48 of ASHRAE Fundamentals Handbook. The geometry of the duct work resulting in each room was used to create a sound path in Dynasonics. For the open plan office, room 310, four sound paths were modeled to the space to account for the 4 diffusers. Table 35 list the background sound level for room 310. On Figure 36 the sound levels are plotted at each octave band an overlaid on the NC curves to determine an overall NC value. The original design results in an NC-29. The proposed design reduces the size of the ductwork and the air terminal units (VAV boxes). Consequently, the NC value for the proposed design is NC-24. Both of these values are well below the required NC rating for an open office floor plan, NC-40, as described in Table 31.

	Whole-Octave Centre Band Frequencies (Hz)								
	63	125	250	500	1000	2000	4000	8000	NC
L_p Rm.310 w/ VAV (dB re: 20 μPa)	48	45	37	32	25	22	27	-	29
L_p Rm. 310 w/ ACB (dB re: 20 μPa)	32	31	26	27	20	16	21	-	24

Table 35 Background HVAC Sound Level - Room 310



The simulation was then performed on an example private office, room 310.13. Different from the open plan office study, the smaller air terminal size and decreased ductwork size adversely affected the background sound level slightly. The proposed design results in an NC-25 compared to NC-21 for the original design. Fortunately both designs are also well below the required sound level for the space which is NC-30. Table 36 and Figure 37 show the sound level results for the private office. A full space report from Dynasonics can be found in Appendix C for both the open plan office and private office.

Figure 36
Background HVAC Sound Level NC Plot - Room 310

	Whole-Octave Centre Band Frequencies (Hz)								
	63	125	250	500	1000	2000	4000	8000	NC
L_p Rm.310.13 w/ VAV (dB re: 20 µPa)	38	35	30	26	16	12	16	-	21
L_p Rm. 310.13 w/ ACB (dB re: 20 µPa)	34	32	30	30	20	15	20	-	25

Table 36 Background HVAC Sound Level - Room 310.13

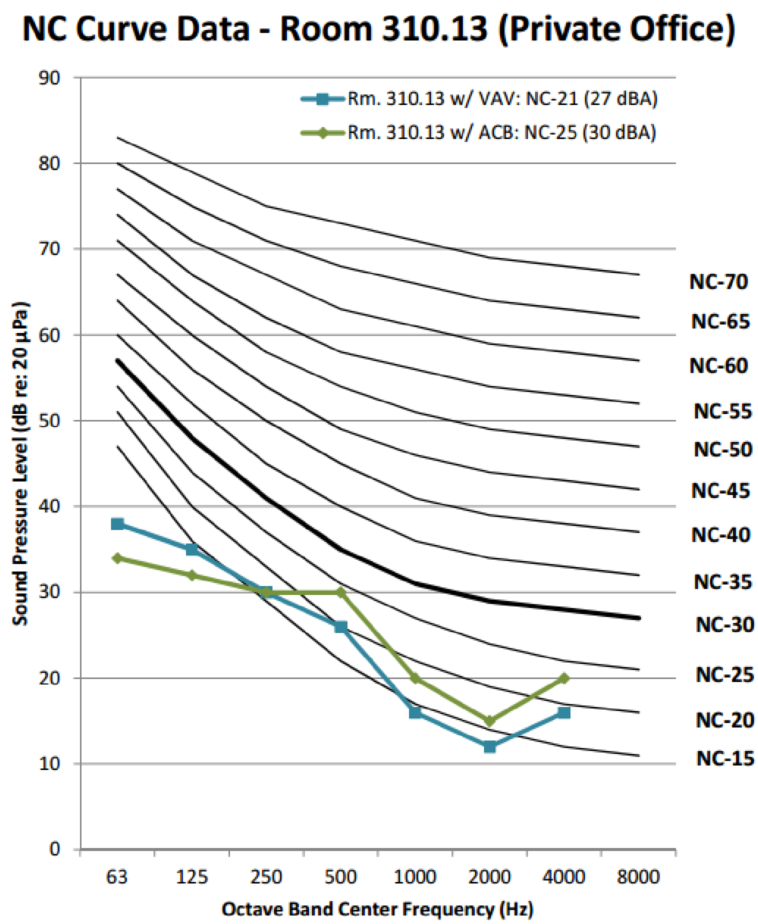


Figure 37 Background HVAC Sound Level NC Plot - Room 310.13

Roof-top Mechanical Equipment Impact

As for the performance space and audience chamber, the rooftop air handling units and cooling towers are adjacent to the exterior walls of the chamber. A more robust program was needed to evaluate the complex geometry and surfaces in the performance space for the possible transmission of sound. A Google Sketchup model of the interior surfaces was modeled to import into Odeon. Odeon is a room acoustic software that can handle more complex geometries and is used for a variety of room types including performance halls.

The exterior wall construction of the chamber is needed to determine the transmission loss through the walls. The north wall that separates AHU-3 and AHU-5 from the stage house has a mass construction of approximately 12 inches of brick/concrete. The mass law was used to determine the transmission values for the north wall with a surface density of 150 lbs/SF. Table 37 lists these values. The east and west walls that separate the cooling towers and AHU-1 and AHU-2 from the chamber respectfully, are a composite wall structure. The wall constructions are not precisely known due to the age of the building and lack of clear original construction documents. The best approximation of the wall layers include 12 inches of brick/concrete, 3 in air space, 3 inch batt insulation and 2 inch plaster finish. The transmission loss data for these two wall constructions was approximated from a typical exterior wall construction found in Architectural Acoustics (Mehta, et al.) and is listed in Table 37.

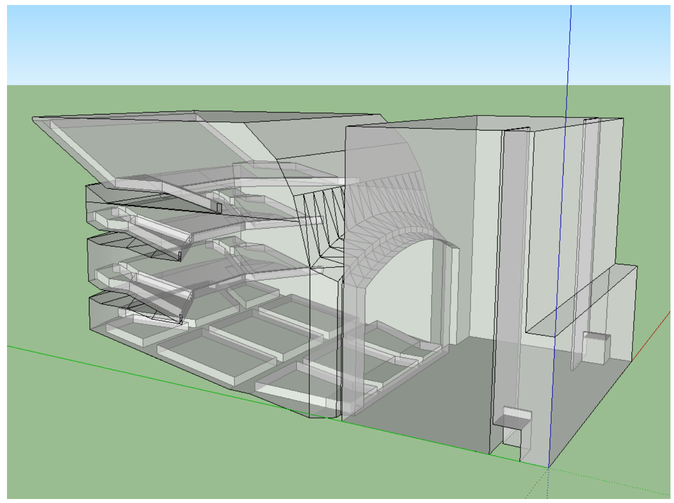


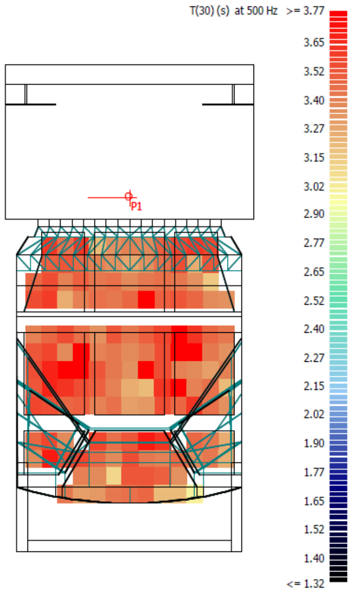
Figure 38 Google Sketch-up Model Performance Hall

TL (dB)	Frequency (Hz)																					
	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1500	2000	2500	3150	4000	5000	6300	8000
North Wall*	34	34	34	40	46	50	54	57	60	64	66	67	68	69	70	72	72	73	75	75	75	75
East/West Wall	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88

* Mass Law applies

Table 37 Exterior Wall Transmission Loss Data (Source: Mehta et al.)

The model geometry was then imported into Odeon where the material properties of each surface was assigned. A generic source was added to the stage to first calculate the reverberation time for each level of the theater. Figures 39 - 43 show the reverberation times across the audience surfaces. For a multi-purpose performance space, the prefered reverberation time should be between 1.6 - 2.4 seconds at 500 Hz. The times are higher than desired however, the exact material composition of the walls was not know. Also, the distribution is very uniform across each surface which is ideal for the seating consistency.



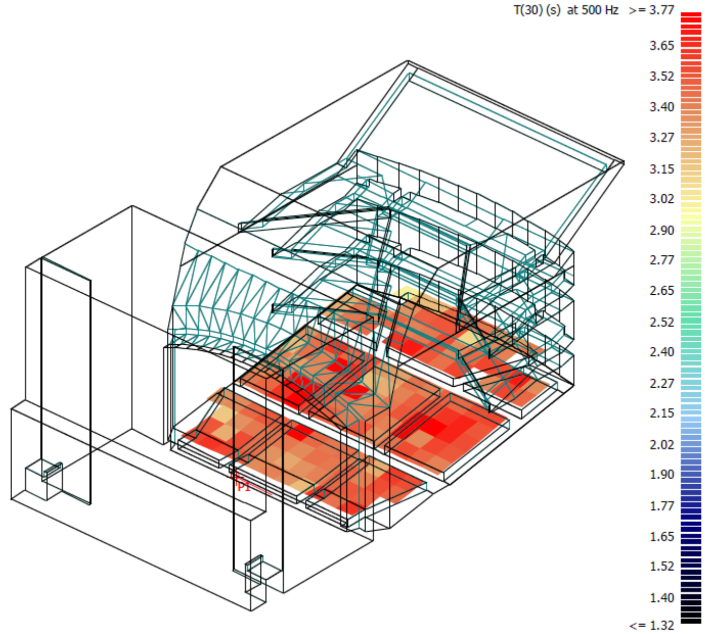
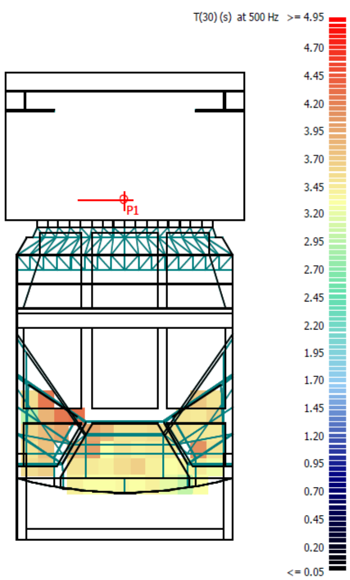
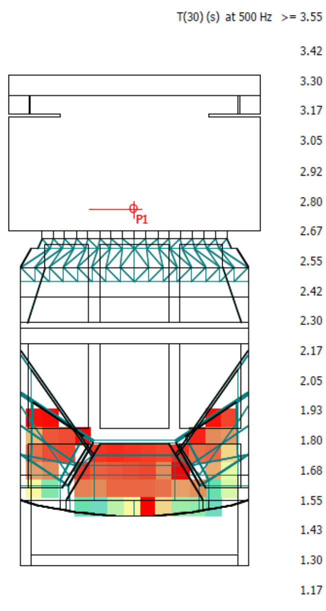


Figure 39 Orchestra Level T(30) at 500 Hz

Figure 40 Isometric Orchestra Level T(30) at 500 Hz





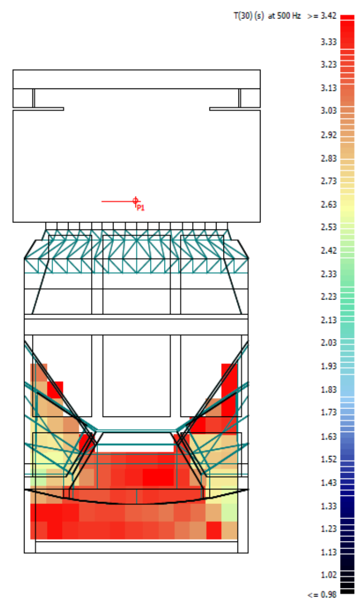


Figure 41 First Balcony T(30) at 500 Hz

Figure 42 Second Balcony T(30) at 500 Hz

Figure 43 Third Balcony T(30) at 500 Hz

After the reverberation time was calculated, the background noise level for each audience seating level could be computed. The mechanical equipment sources, AHU-1 (P4), AHU-2 (P5), AHU-3 (P2), AHU-5 (P2), CT-1 (P7) and CT-2 (P6) were added (Figure 44). Furthermore the transmission loss properties of the adjacent walls were applied. The grid simulation was then performed and the A-weighted sound pressure level SPL(A) was calculated. Figures 45-49 show SPL(A) for each seating level. As a rule of thumb the NC value for the space is generally 5 dB less than the SPL(A). For the orchestra level the background noise level is higher than the required NC-20 which is recommended for theaters. Values are on the order of 35 dBA (NC-30). Additionally, the first balcony and second balcony see lower levels than the orchestra level, about 30 dBA (NC-25). The second balcony has an area with high SPL(A), up to 50 dBA (NC-45). The results from the third balcony grid show very high levels; on the order of 45 dBA (NC-40). This is most likely due to the close proximity of the units to this level.

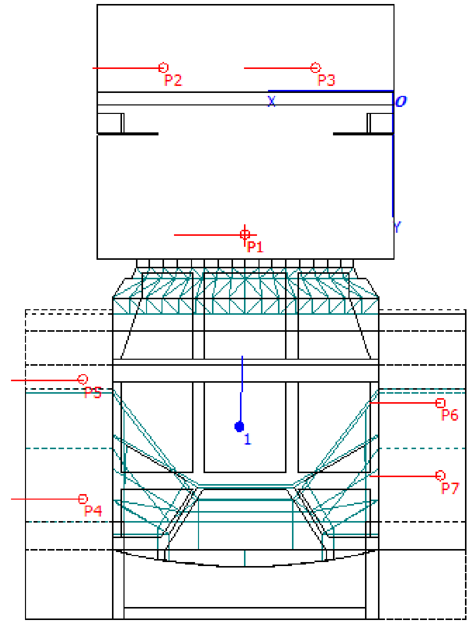


Figure 44
Position of Mechanical Equipment

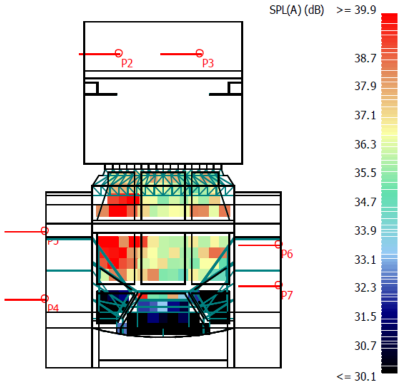


Figure 45 Orchestra Level SPL(A)

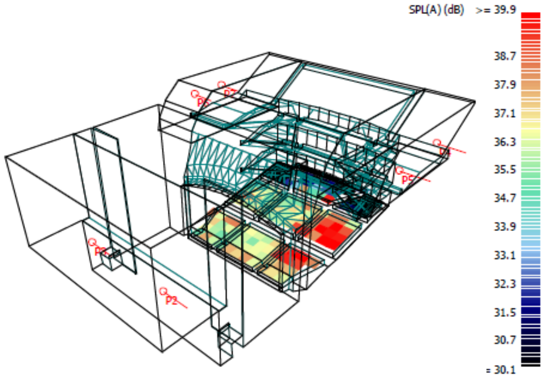


Figure 46 Isometric Orchestra Level SPL(A)

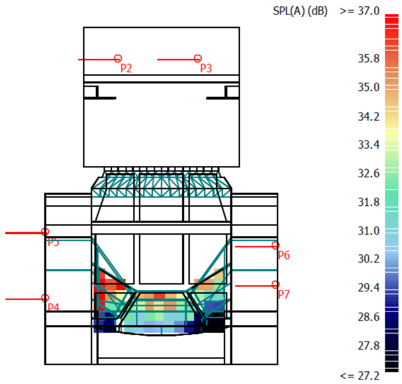


Figure 47 First Balcony SPL(A)

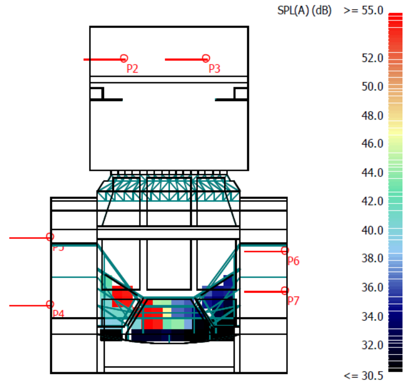


Figure 48 Second Balcony SPL(A)

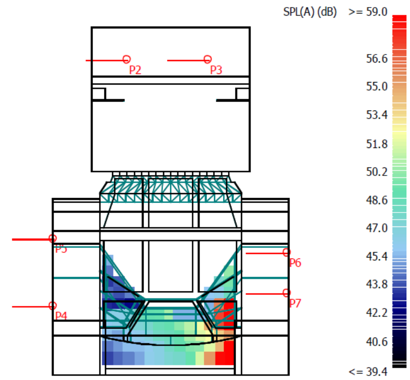


Figure 49 Third Balcony SPL(A)

While improvements could be made to the design of the materials to the theater, the current geometry is a vast improvement over the original design. Modeling the surface materials more precisely would have made the model more accurate, however time and information controlled the complexity of the analysis. If further improvements want to be made, the designers should look at the exterior wall materials, and the absorptivity of the wall surfaces in the stage house and the audience chamber.

Breadth Analysis 2: Construction

A cost and schedule analysis was performed to determine the construction impacts of implementing the active chilled beam expansion. Added labor and material costs were factored into a first cost analysis. Furthermore, schedule impacts were evaluated for the added elements to determine any time savings or whether extra time should be budgeted.

Assumptions

Existing System

When evaluating the cost and schedule implications, assumptions were made based on anticipated procedures for the construction of the Auditorium. The existing mechanical system for the rooms to be changed are either supplied with constant volume outdoor air or variable primary air. The constant volume system is either re-heated or cooled via hot water and chilled water fan coil units or is feed directly to the space at a constant rate. The existing variable primary air rooms use a VAV terminal unit to modulate the flow of air. These boxes also have a hot water reheat coil to heat the supply air to the room demand temperature.

Proposed ACB System

Portions of the existing mechanical systems are to be changed over to an active chilled beam system. The change will require the same zoning of VAV terminal units, without a hot water reheat coil, to modulate the airflow to the ACB units. Each installed unit will require a primary air connection and both hot water heating and chilled water cooling coil connections. Since more chilled water connections will need to be made, availability of existing or currently designed chilled water supply piping is a concern. Fortunately, all floors and areas that will be changed over to an active chilled beam system have the necessary piping capacity. Therefore cost information for the chilled water piping is assumed to be for sizes ranging for ½" - 1" diameters and also includes costs for hangers and standard transitions.

Air Handling Units

Additionally, by switching over a significant number of rooms to active chilled beams it decreases the capacity required for the large variable primary air handling unit (AHU-1). Based on data presented in section Option B: Further Expanded Chilled Beam Design AHU-1 can be downsized from 70,000 cfm to 55,000 cfm. Information from a large AHU manufacturer estimates that a $14,000 savings can be achieved on the first cost for Option B. It was conservatively assumed that Option A would not have a significant AHU-1 downsizing cost impact.

Schedule

In terms of assumptions that directly relate to the schedule impacts it was assumed that all primary air and piping connections are to be flexible. Also, some spaces are gridded ceiling and others are open ceilings. Mounting time for the active chilled beams will vary between these spaces. Moreover, consideration of the number of workers and crews was considered in installation and connection of the units. Mechanical pipe fitters will complete the entire scope of work pertaining to the installation and connection of the active chilled beams.

Maintenance

Furthermore, an average annual maintenance cost per SF was take from the ASHRAE Owning and Operating Cost Database (NAHB Research Center) to be factored into the life cycle cost analysis. The baseline cost can be approximated to be $0.091/SF and the proposed design maintenance is $0.063/SF. This difference in price to due to the different maintenance required for active chilled beams as opposed to variable air VAV terminal units. Also, these values are generally lower than a typical stand alone building due to the availability of a dedicated maintenance staff the the Francis Michael Performing Arts Academy.

Miscellaneous

Finally, there are additional costs that are not directly factored into the first cost and schedule analysis. These cost and time implications include additional engineering time to design the chilled beams, size piping and determine placement along with coordination time and costs.

Renovated First Cost Evaluation

A summary of the cost and time values used in the evaluation for materials, labor and schedule are listed in Table 38. As indicated, some values represent savings for switching the system, where others refer to an assumed general cost of materials and labor.

Materials		
Diffusers	$ 40.00	/unit
VAV w/o RH	$ 300.00	/unit
VAV w/ RH	$ 800.00	/unit
Active CB (4 pipe)	$ 1,200.00	/unit
FCU (4 pipe)	$ 500.00	/unit
Piping (1/2", 3/4", 1")	$ 11.80	/lf
Ductwork Savings	$ 0.41	/SF
Pipe insulation (incl. labor)	$ 4.50	/lf

Labor		
Number of Workers	6	workers
Worker	$ 70.00	/man-hr
VAV (setting)	4	hrs/unit
Active CB (4 pipe) - grid	8	hrs/unit
Active CB (4 pipe) - open	4	hrs/unit
VAV (2 pipe) - connection	4	hrs/unit
CB (4 pipe) - connection	8	hrs/unit
Ductwork Savings	$ 2.41	/SF
Piping	11	lf/man-day

Table 38 Material and Labor Assumptions (Source: Rhodes)

Material & Labor Costs

The results from evaluating the additional elements needed for the proposed design are summarized in Tables 39 and Table 40 For each option several areas were evaluated and included in the cost summary. These areas include:

- Determining the number of ACB units needed for each space
- Calculating the additional piping lengths required to serve each new unit
- Computing the number of man-hours needed to install and connect each unit
- If possible, comparing the cost of downsizing AHU-1 with manufacturers data
- Approximating the savings for downsizing the ductwork to only minimum ventilation requirements
- Counting and calculating the number of diffusers and fan coil unit that could be removed and the cost savings associated
- Evaluating the cost difference between using air terminal units (VAV boxes) with reheat coils and units without

SUMMARY ACB - Option A		
Additional Costs		
Material Cost - ACB Units	$	50,400.00
Material Cost - Piping	$	8,390.91
Labor Cost - ACB & Piping	$	90,886.98
Total	$	149,677.90
Adjustments		
AHU Downsizing	$	-
Ductwork Downsizing (Mat'l & Labor)	$	(22,771.67)
Miscellaneous (Diffusers, VAV, & FCU)	$	(5,300.00)
Total	$	(28,071.67)
Annual Savings		
Energy Saving Cost	$	15,348.65
Intial Total Costs	**$**	**121,606.23**
Simple Payback [Years]	**7.9**	

Table 39 Material & Labor Cost - Option A

SUMMARY ACB - Option B		
Additional Costs		
Material Cost - ACB Units	$	168,000.00
Material Cost - Piping	$	52,307.68
Labor Cost - ACB & Piping	$	388,490.33
Total	$	608,798.01
Adjustments		
AHU Downsizing	$	(14,000.00)
Ductwork Downsizing (Mat'l & Labor)	$	(81,497.85)
Miscellaneous (Diffusers, VAV, & FCU)	$	(24,680.00)
Total	$	(120,177.85)
Annual Savings		
Energy Saving Cost	$	18,804.99
Intial Total Costs	**$**	**488,620.15**
Simple Payback [Years]	**26.0**	

Table 40 Material & Labor Cost - Option B

Most of these studies resulting in added costs, however several provided savings. To implement Option A, it will require an additional $149,678 in material and labor costs. However, $28,071 can be saved on initial costs through ductwork downsizing and other miscellaneous costs. Furthermore, the annual energy cost savings is predicted to be $15,348. Taking into account these costs and adjustments, the total initial cost for Option A is $121,606 with a simple payback of 7.9 years.

As for Option B, the significant increase in rooms to be changed drastically changes the initial cost evaluation. For materials and labor, the total added costs is approximately $608,798. The adjustments for ductwork downsizing and miscellaneous items reduces the first cost to $502,620. With Option B, however, there can be an additional savings by downsizing AHU-1. This savings of $14,000 further lowers the initial first cost to $488,620. With this extremely high added cost and an annual energy savings of $18,804, the simple payback for this proposed option is 26 years. It is unlikely that any owner would agree to this option based on the economics. See the Life-Cycle Cost Analysis section for a more robust evaluation of the payback period for both options; including factors such as discount and escalation rates over a 20 year life-cycle.

Schedule

From initially looking at the parameters required to install an active chilled beam system versus standard diffusers and VAV boxes with reheat coils, it is apparent that there is going to be extra time required. Between extra piping required and a finer level of attention to detail required for each unit installed the construction schedule will surely be need to be lengthened.

The question is, how much more time is needed for each of the two options presented in the mechanical depth section 1.

Making the assumptions that it requires 8 hours to set a chilled beam unit and an additional 8 hours to make the 4 piping connections, plus the limiting factor that a single man can only hang 11 linear feet of piping per 8 hour day, the time required to install the system was evaluated for each option. A full set of assumptions can be seen in the prior section in Table 38. Table 41 separates the time required for the extra piping to the direct installation and connection of the units between Option A and Option B.

Table 41
Duration Time for Installation

Equipment Installation [Days]	Option A		Option B	
	Piping	Units & Connections	Piping	Units & Connections
Basement	0.8	13	3.1	23
Ground Floor	2.1	15.8	5.8	29.3
First Floor	-	-	1.1	6
Second Floor	-	-	4.4	22.5
Third Floor	-	-	3.7	22.5

It will take a significant time to install the added piping and equipment for both options. However, Option B is considerably longer duration for a 6 man crew to complete. Figure 50 and 51 shows the comparison in duration schedule impacts for both Option A and Option B, respectively. Option A can be expected to add 32 days to the project and Option B will add approximately 122 days (24.3 weeks).

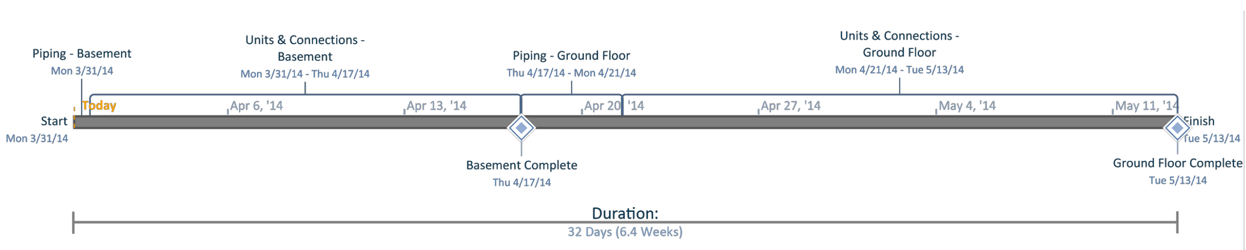


Figure 50 Option A Generic Timeline

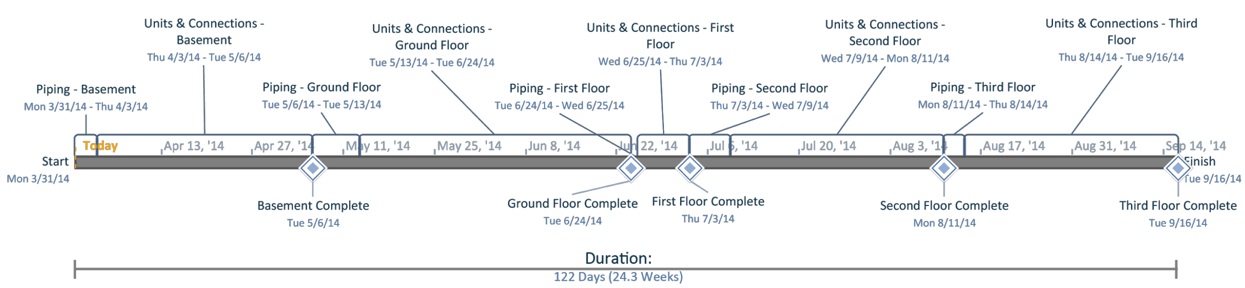


Figure 51 Option B Generic Timeline

In terms of workflow, installation on each floor will follow a systematic approach. For the Basement and Ground Floor the work will commence in a counter clockwise schedule starting on the eastern side of the building and continuing west. For the first through third floors it makes more sense to proceed in a clockwise rotation around the building and avoid the renovations in the theater area. Figures 52 and Figure 53 show a general progression of how the work will move forward. First, the sheet metal contractors will install the primary air duct runs to each space. Then, the mechanical pipe fitters will move through each space setting the ACB units in place. Next, the chilled water and hot water piping runs to the rooms will be installed and connected to each unit. and finally the primary air connections will be made. As stated previously, it is assumed that both flexible piping and duct connections are possible for installation.

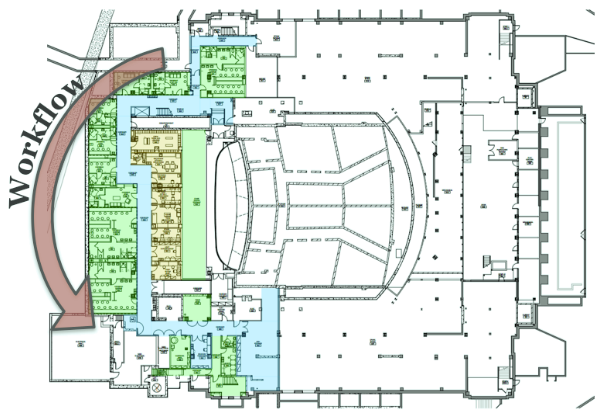


Figure 52 Workflow for Basement and Ground Floor

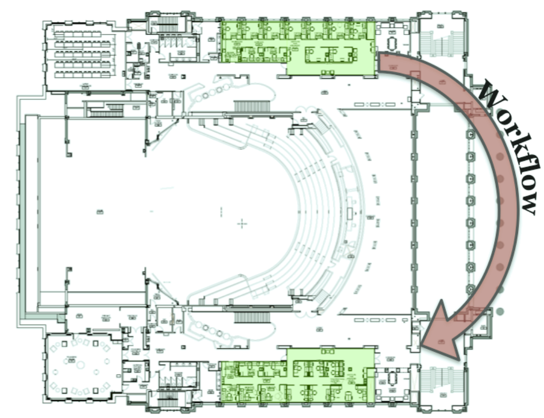


Figure 53 Workflow for First through Third Floors

Masters Coursework

Life-Cycle Cost Analysis

The assumption that adding chilled beams would add a significant cost to the project was evaluated through a life cycle cost (LCC) analysis. The analysis was performed on the added components of the building, including the active chilled beams and extra piping required. It was assumed all other components were equal in terms of cost and maintenance. The focus on this analysis was to determine how long it would take to payback the added cost while factoring in the energy savings available. Please see the Construction Breadth section for further assumptions made in terms of costs and labor for implementing the chilled beams.

The study period for the analysis is 20 years and all costs over the 20 year period were brought back to net present value using escalation and discount rates. Table 42 lists the assumptions made for these rates which were based on data from the National Institute of Standards and Technology.

Table 42
LCC Assumptions (Rushing, Kneifel, and Lippiatt)

Discount Rate	8.00%
Escalation Rates	
Electricity	3.75%
Natural Gas	5.00%
Materials	1.73%
Main. & Labor	1.73%
Study Period	20 years

Option A saved the Auditorium $15,349 per year in energy costs by implementing 42 chilled beams. To pay back this added expense it will take approximately 10.5 years. The simple payback is a smaller time frame, 7.9 years, however it is more realistic to assume a longer payback which accounts for the change in cost of primary energies and inflation. Figure 54 shows a 20 year analysis on the added components and the total cost of ownership (TCO) to run the building with more active chilled beams. The 20 year TCO savings compared to the baseline system is $97,596.

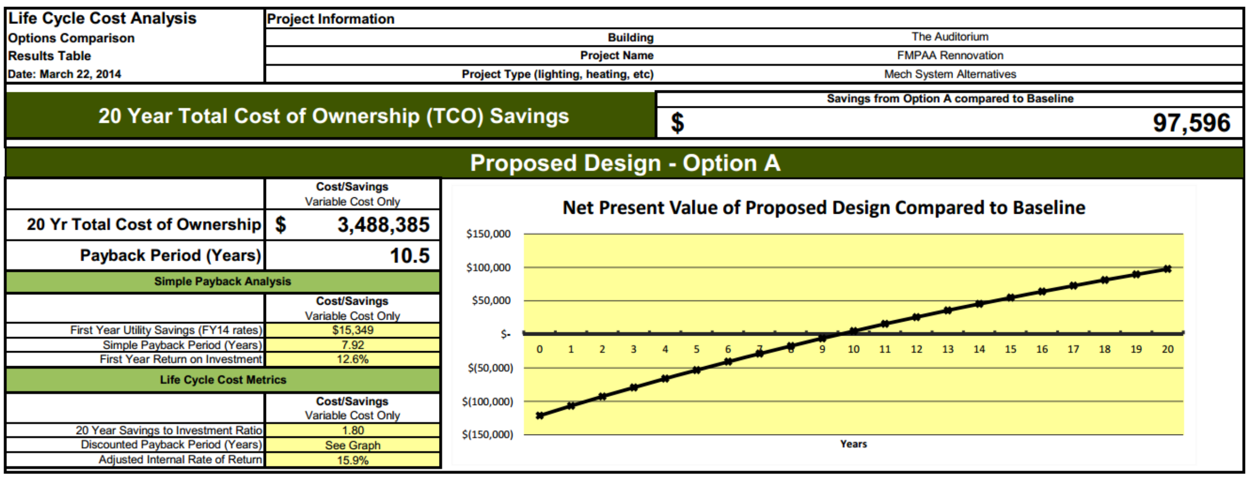


Figure 54 LCC - Option A

Using the same method, Option B will save the owner $18,805 per year in energy cost. This option implements 98 additional active chilled beams to spaces in the Auditorium and brings the total number of beams added to 140. The extra cost to add the beams is significant compared to their original system. The 20 year analysis shows that the system will most likely not payback and even the simple payback is estimated to be almost 26 years as seen in Figure 55. This option is not economically feasible when compared to the anticipated energy savings.

Life Cycle Cost Analysis Options Comparison Results Table Date: March 22, 2014	Project Information	
	Building	The Auditorium
	Project Name	FMPAA Rennovation
	Project Type (lighting, heating, etc)	Mech System Alternatives

20 Year Total Cost of Ownership (TCO) Costs/Savings	Savings from Option B compared to Baseline (NPV)
	$ (214,529)

Proposed Design - Option B

	Cost/Savings Variable Cost Only
20 Yr Total Cost of Ownership	$ 3,821,953
Payback Period (Years)	N/A
Simple Payback Analysis	
	Cost/Savings Variable Cost Only
First Year Utility Savings (FY14 rates)	$18,805
Simple Payback Period (Years)	25.98
First Year Return on Investment	3.8%
Life Cycle Cost Metrics	
	Cost/Savings Variable Cost Only
20 Year Savings to Investment Ratio	0.56
Discounted Payback Period (Years)	See Graph
Adjusted Internal Rate of Return	2.1%

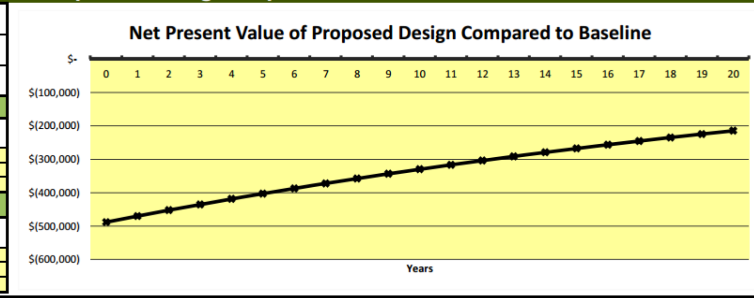


Figure 55 LCC - Option B

As mentioned previously, modeling the demand based ventilation system is approximate and difficult to determine designed savings. However, assuming that the demand based system will save the owner on equipment run-time, it can be asserted that the life-cycle cost for both options will improve as compared to the previously calculated analysis. The detailed inputs for the life cycle cost analysis can be found in Appendix C for both Option A and Option B.

This life cycle cost analysis method was derived from an approach studied in AE 558 - Centralized Heating Production and Distribution Systems.

Overall Proposed Alternative Evaluation

Through investigation into the design conditions of the Auditorium, recommendations can be made to FMPAA. Option A, evaluated in the Mechanical Depth, seems to be the most feasible energy saving option in conjunction with a demand based ventilation control sequence. Option B is an unrealistic design that would result in significant added cost and time to the project. Through evaluating these options from a constructability standpoint, the added first cost was evaluated and a life-cycle cost analysis show that Option A is the most worthwhile area for further examination.

Assessing the acoustics of the theater, more information is need to create a complete model. However, the initial results should that background noise level may prove to be a problem for some audience seating areas.

Great effort was taken to ensure the accuracy of information in this report. However, many assumptions and estimations were made in each analysis. Further investigation and confirmation of the assumptions should be made before progressing further into implementing any of these proposed changes. Finally, this report no way implies that there are any flaws with the original design of the Auditorium. The opinions expressed in the report are the sole interpretation of the writer.

References

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*.

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Appendix A

- *ASHRAE 62.1 Table 6-1 Minimum Ventilation Rates*
- *ASHRAE 62.1 Table 6-1 Minimum Exhaust Rates*
- *Monthly Electric Consumption (Figure 8)*
- *Annual Electrical Consumption (Figure 9)*
- *Monthly Heating Fuel Demand (Figure 10)*
- *Monthly Carbon Emissions (Figure 11)*
- *Monthly Utility Cost (Figure 12)*
- *Ventilation Calculations*

Appendix B

- *Proposed Work Plan*

Appendix C

- *Option A Basement Floor Plan - Enlarged (Figure 22)*
- *Option A Basement Floor Plan - Enlarged (Figure 23)*
- *Modeled Monthly Electrical Consumption - Option A (Figure 24)*
- *Modeled Monthly Electrical Consumption - Baseline vs. Option A (Figure 25)*
- *Modeled Monthly Heating Demand - Baseline vs. Option A (Figure 26)*
- *Option B Basement Floor Plan - Enlarged (Figure 27)*
- *Option B Ground Floor Plan - Enlarged (Figure 28)*
- *Option B First Floor Plan (Figure 29)*
- *Option B Second Floor Plan (Figure 30)*
- *Option B Third Floor Plan (Figure 31)*
- *Modeled Monthly Electrical Consumption - Baseline vs. Option A & Option B (Figure 32)*
- *Modeled Monthly Heating Consumption - Baseline vs. Option A & Option B (Figure 33)*
- *Trox Technik Active Chilled Beams - DID631 & DID632 Series Design Specifications*
- *Trox Technik Active Chilled Beams - Installation, Operation and Maintenance Manual*
- *Demand Based Ventilation Calculations - Heating*
- *Demand Based Ventilation Calculations - Cooling*
- *Dynasonics Space Report - Room 310*
- *Dynasonics Space Report - Room 310.13*
- *Life-Cycle Cost Analysis Input Data - Option A*
- *Life-Cycle Cost Analysis Input Data - Option B*

ASHRAE 62.1-2010 Table 6-1 - Minimum Ventilation Rates

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3		35	12	5.9	1
Multi-use assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
Kitchen (cooking)	7.5	3.8	0.12	0.6		20	14	7.0	2
General									
Break rooms	5	2.5	0.06	0.3		25	10	5.1	1
Coffee stations	5	2.5	0.06	0.3		20	11	5.5	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	–	–	0.06	0.3		–			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1

ASHRAE 62.1-2010 Table 6-1 - Minimum Ventilation Rates (con't)

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1
General manufacturing (excludes heavy industrial and processes using chemicals)	10	5.0	0.18	0.9		7	36	18	3
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5	2
Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
Shipping/receiving	10	5	0.12	0.6	B	2	70	35	2
Sorting, packing, light assembly	7.5	3.8	0.12	0.6		7	25	12.5	2
Telephone closets	–	–	0.00	0.0		–			1
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
Warehouses	10	5	0.06	0.3	B	–			2
Public Assembly Spaces									
Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
Libraries	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	–	–	0.06	0.3					1
Retail									
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2

ASHRAE 62.1-2010 Table 6-1 - Minimum Ventilation Rates (con't)

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
Coin-operated laundries	7.5	3.8	0.12	0.6		20	14	7.0	2
Sports and Entertainment									
Sports arena (play area)	–	–	0.30	1.5	E	–			1
Gym, stadium (play area)	–	–	0.30	1.5		30			2
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
Swimming (pool & deck)	–	–	0.48	2.4	C	–			2
Disco/dance floors	20	10	0.06	0.3		100	21	10.3	2
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
Stages, studios	10	5	0.06	0.3	D	70	11	5.4	1

GENERAL NOTES FOR TABLE 6-1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6-1

A For high school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

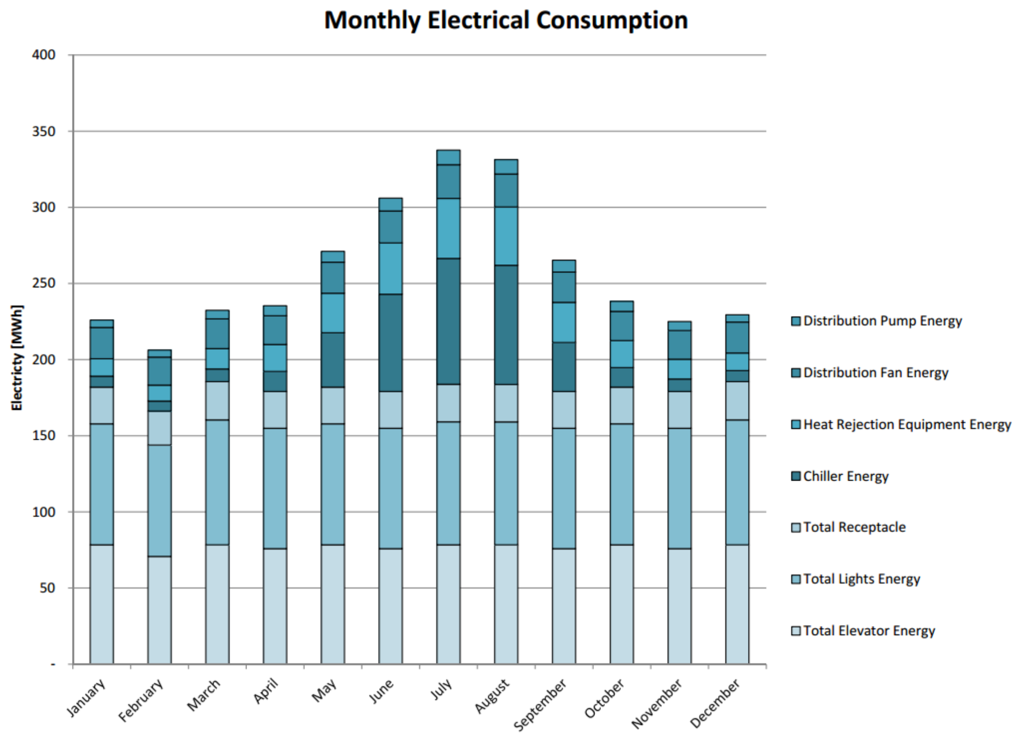
ASHRAE 62.1-2010 Table 6-4 - Minimum Exhaust Rates

TABLE 6-4 Minimum Exhaust Rates

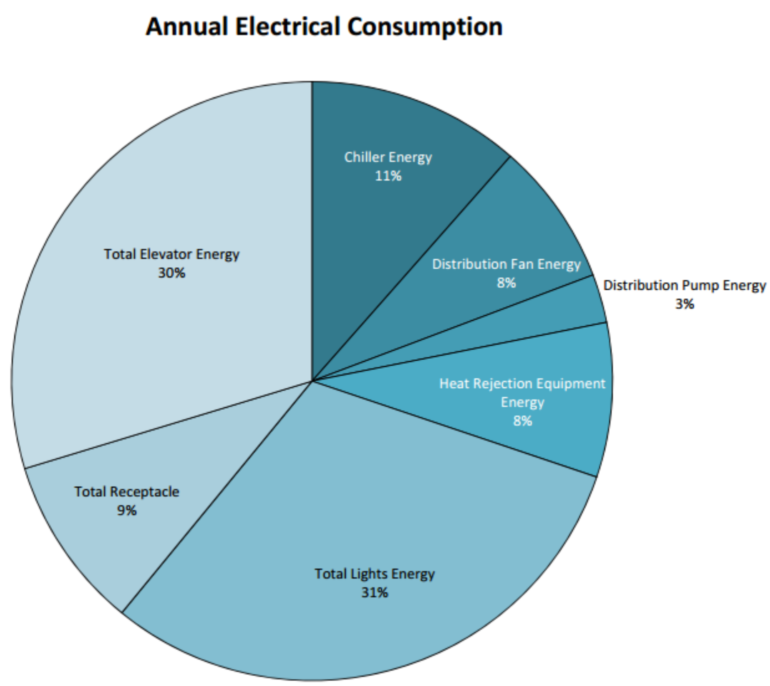
Occupancy Category	Exhaust Rate, cfm/unit	Exhaust Rate, cfm/ft^2	Notes	Exhaust Rate, L/s·unit	Exhaust Rate, $L/s \cdot m^2$	Air Class
Arenas	–	0.50	B	–	–	1
Art classrooms	–	0.70		–	3.5	2
Auto repair rooms	–	1.50	A	–	7.5	2
Barber shops	–	0.50		–	2.5	2
Beauty and nail salons	–	0.60		–	3.0	2
Cells with toilet	–	1.00		–	5.0	2
Copy, printing rooms	–	0.50		–	2.5	2
Darkrooms	–	1.00		–	5.0	2
Educational science laboratories	–	1.00		–	5.0	2
Janitor closets, trash rooms, recycling	–	1.00		–	5.0	3
Kitchenettes	–	0.30		–	1.5	2
Kitchens—commercial	–	0.70		–	3.5	2
Locker/dressing rooms	–	0.25		–	1.25	2
Locker rooms	–	0.50		–	2.5	2
Paint spray booths	–	–	F	–	–	4
Parking garages	–	0.75	C	–	3.7	2
Pet shops (animal areas)	–	0.90		–	4.5	2
Refrigerating machinery rooms	–	–	F	–	–	3
Residential kitchens	50/100	–	G	25/50	–	2
Soiled laundry storage rooms	–	1.00	F	–	5.0	3
Storage rooms, chemical	–	1.50	F	–	7.5	4
Toilets—private	25/50	–	E	12.5/25	–	2
Toilets—public	50/70	–	D	25/35	–	2
Woodwork shop/classrooms	–	0.50		–	2.5	2

A Stands where engines are run shall have exhaust systems that directly connect to the engine exhaust and prevent escape of fumes.
B When combustion equipment is intended to be used on the playing surface additional dilution ventilation and/or source control shall be provided.
C Exhaust not required if two or more sides comprise walls that are at least 50% open to the outside.
D Rate is per water closet and/or urinal. Provide the higher rate where periods of heavy use are expected to occur, e.g., toilets in theatres, schools, and sports facilities. The lower rate may be used otherwise.
E Rate is for a toilet room intended to be occupied by one person at a time. For continuous system operation during normal hours of use, the lower rate may be used. Otherwise use the higher rate.
F See other applicable standards for exhaust rate.
G For continuous system operation, the lower rate may be used. Otherwise use the higher rate.

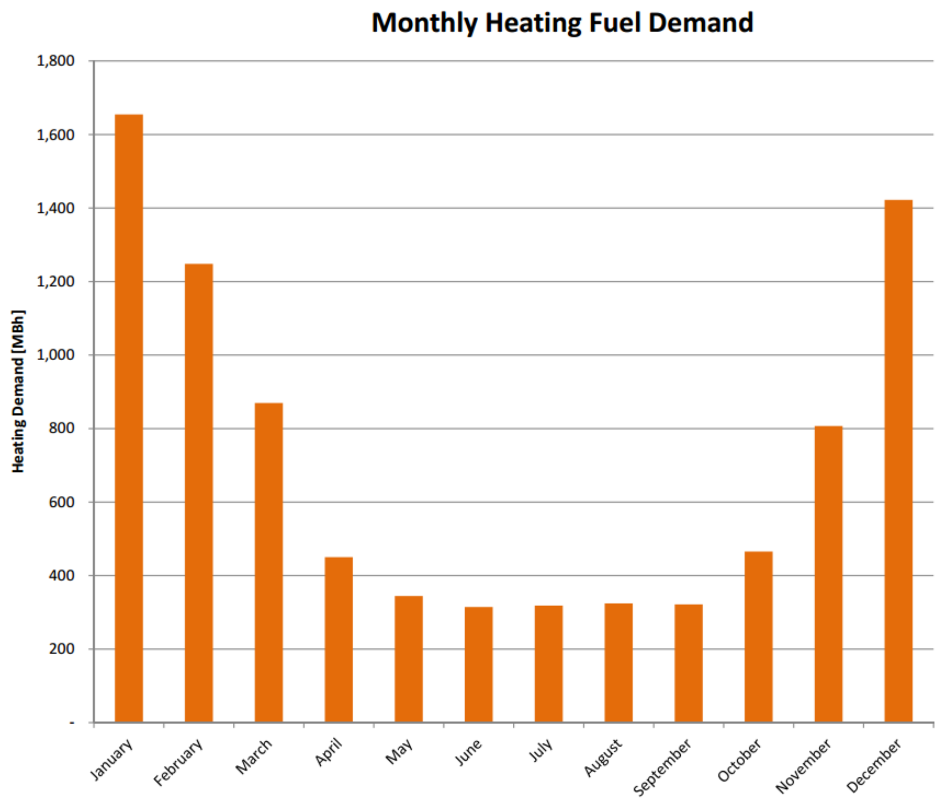
Monthly Electric Consumption (Figure 8)



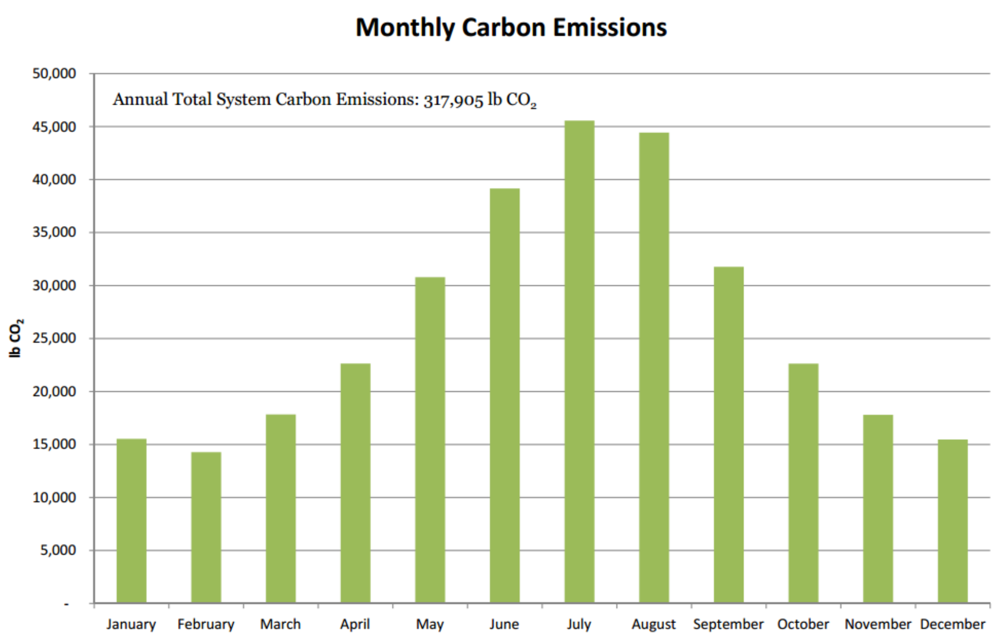
Annual Electrical Consumption (Figure 9)



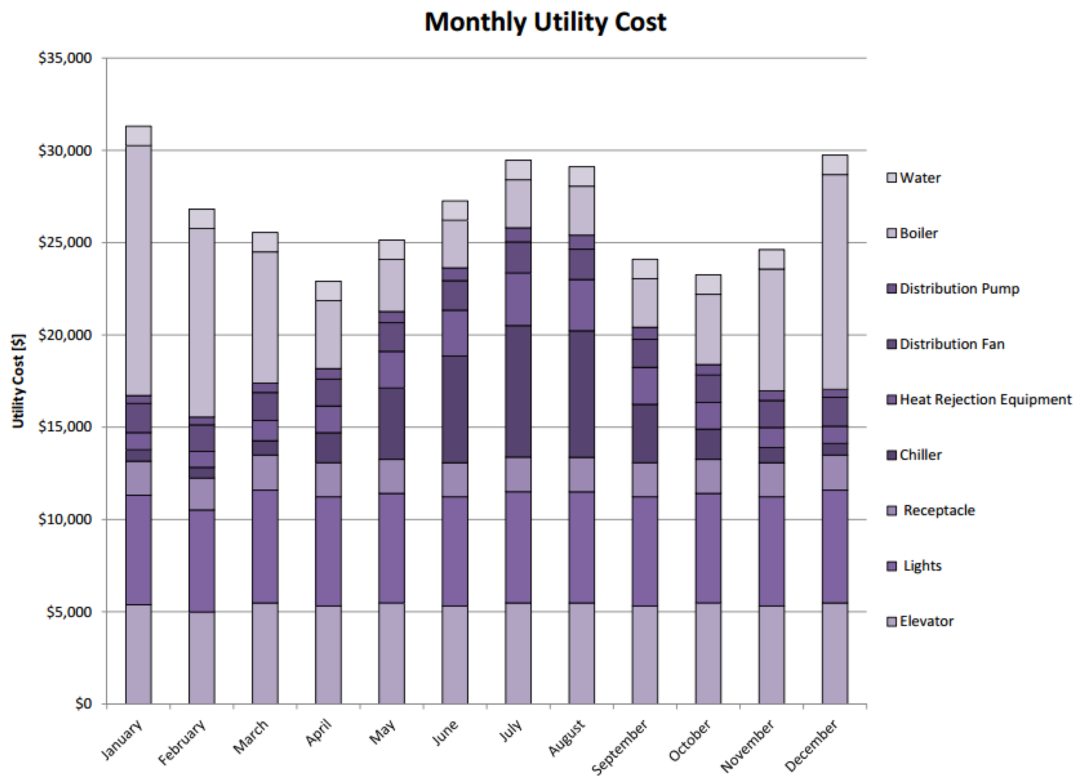
Monthly Heating Fuel Demand (Figure 10)



Monthly Carbon Emissions (Figure 11)



Monthly Utility Cost (Figure 12)



APPENDIX A

ASHRAE Standard 62.1-2010 Ventilation Rate Procedure: Zone Ventilation Calculations

ASHRAE 62.1-2010 Ventilation Rate Procedure: System Ventilation Calculations

ASHRAE 62.1-2010 Minimum Exhaust Air Requirements

		Room Input Conditions				Outdoor Air Rates		OA Required at Breathing Zone	Air Distribution Effectiveness		62.1 Min Room Supplied OA Rate	Design Case Room Supplied OA Rate	Primary Outdoor Air Fraction (Using Table 6-3 Method)								Uncorrected OA Rate			Zone Portion of Vot		Room Exhaust Air Requirements						90.1 Category
System	Room Name	Floor Area (ft2) = Az	Design Occupancy peak total per space = Pz	Room Type (Occupancy Category)	Default Occ (people/1000 ft2)	Rp (cfm/person)	Ra (cfm/ft2)	Vbz = (Rp*Pz) + (Ra*Az) (cfm)	Ez, Cooling	Ez, Heating	Voz = Vbz/Ez	Voz * Including "Increased Ventilation %"	Heating airflow Min Condition (min flow per heating load when SAT > RAT) (cfm), Vpz	Heating Zone Primary OA Fraction Zp = Voz/Vpz	Heating Adjusted Flow Rate	Heating Adjusted Zp	Cooling airflow Min Condition (min flow per cooling load and turndown when SAT < RAT) (cfm), Vpz	Cooling Zone Primary OA Fraction Zp = Voz/Vpz	Cooling Min Adjusted Flow Rate	Cooling Adjusted Zp	Vou, Occupant Portion (cfm)	Vou, Area Portion (cfm)	Vou, SUM of Occupant and Area Portions (cfm)	62.1 Min Vot	Design Case Vot *Including "Increased Ventilation %"	Room Type (Occupancy Category)	Exhaust Rate (cfm/ft2)	Exhaust Airflow Required (cfm)	Exhaust per Unit (e.g. Toilet, exh hood) (cfm)	# of Units (e.g. Toilet, exh hood)	Exhaust Airflow Required (cfm)	
AHU-1	System Totals	91,383.91	1,714.81					16,267.15			20,333.94	20,333.94	22,704.41		41,411.51	0.55	22,704.41		34,872.03	0.55	11,399.54	4,867.61	16,267.15	27,111.92	27,111.92			1,351.11	50.00	17.00	850.00	
Public Spaces																																
	008 OFFICE	115.986	0.58	Office Buildings - Office Space	5	5	0.06	9.9	1.0	0.8	12.32	12	20	0.62	22	0.55	20	0.50	20	0.50	2.9	7.0	9.9	16.4	16.4	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	009 MECH	155.343	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	9.3	1.0	0.8	11.65	12	33	0.36	33	0.36	33	0.29	33	0.29	0.0	9.3	9.3	15.5	15.5	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	010 RSTRM	833.078	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	011 STOR	183.076	0.00	General - Storage rooms	0	0	0.12	22.0	1.0	0.8	27.46	27	22	1.23	50	0.55	22	0.98	40	0.55	0.0	22.0	22.0	36.6	36.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
	013 OP OFFICE	522.762	2.61	Office Buildings - Office Space	5	5	0.06	44.4	1.0	0.8	55.54	56	89	0.63	101	0.55	89	0.50	89	0.50	13.1	31.4	44.4	74.1	74.1	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Open plan
	015 STAIR	578.238	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	87	0.00	87	0.00	87	0.00	87	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
	017 OFFICE	301.645	1.51	Office Buildings - Office Space	5	5	0.06	25.6	1.0	0.8	32.05	32	47	0.68	58	0.55	47	0.54	47	0.54	7.5	18.1	25.6	42.7	42.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	018 VEST	245.137	7.36	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	69.9	1.0	0.8	87.34	87	72	1.21	159	0.55	72	0.97	127	0.55	55.2	14.7	69.9	116.5	116.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	025 CORR	1655.551	0.00	General - Corridors	0	0	0.06	99.3	1.0	0.8	124.17	124	114	1.09	226	0.55	114	0.87	181	0.55	0.0	99.3	99.3	165.6	165.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	031 ELEC	91.253	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.5	1.0	0.8	6.84	7	10	0.71	12	0.55	10	0.57	10	0.55	0.0	5.5	5.5	9.1	9.1	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	033 IDF	115.332	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	6.9	1.0	0.8	8.65	9	12	0.73	16	0.55	12	0.59	13	0.55	0.0	6.9	6.9	11.5	11.5	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	038 STAIR	208.842	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	404	0.00	404	0.00	404	0.00	404	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
	041 DRESS	51.946	0.52	Sports and Entertainment - Health club/weight rooms	10	20	0.06	13.5	1.0	0.8	16.87	17	26	0.65	31	0.55	26	0.52	26	0.52	10.4	3.1	13.5	22.5	22.5	Locker rooms	0.50	26.0	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
	059 CORR	178.265	0.00	General - Corridors	0	0	0.06	10.7	1.0	0.8	13.37	13	21	0.64	24	0.55	21	0.51	21	0.51	0.0	10.7	10.7	17.8	17.8	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	060 UNCND	1530.499	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Void/Plenum
	063 DRESS	56.454	0.57	Sports and Entertainment - Health club/weight rooms	10	20	0.06	14.7	1.0	0.8	18.36	18	28	0.65	33	0.55	28	0.52	28	0.52	11.3	3.4	14.7	24.5	24.5	Locker rooms	0.50	28.2	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
	068 UNCND	339.671	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Void/Plenum
	073 IDF	119.586	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	7.2	1.0	0.8	8.97	9	15	0.61	16	0.55	15	0.49	15	0.49	0.0	7.2	7.2	12.0	12.0	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	074 CORR	454.687	0.00	General - Corridors	0	0	0.06	27.3	1.0	0.8	34.10	34	43	0.79	62	0.55	43	0.63	50	0.55	0.0	27.3	27.3	45.5	45.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	075 CORR	1631.685	0.00	General - Corridors	0	0	0.06	97.9	1.0	0.8	122.38	122	107	1.14	223	0.55	107	0.91	178	0.55	0.0	97.9	97.9	163.2	163.2	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	076 STAIR	226.639	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	413	0.00	413	0.00	413	0.00	413	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
	077 ELEC	92.969	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.6	1.0	0.8	6.97	7	10	0.68	13	0.55	10	0.54	10	0.54	0.0	5.6	5.6	9.3	9.3	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	077.1 STOR	81.444	0.00	General - Storage rooms	0	0	0.12	9.8	1.0	0.8	12.22	12	7	1.85	22	0.55	7	1.48	18	0.55	0.0	9.8	9.8	16.3	16.3	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
	084 OFFICE	181.225	0.91	Office Buildings - Office Space	5	5	0.06	15.4	1.0	0.8	19.25	19	30	0.64	35	0.55	30	0.51	30	0.51	4.5	10.9	15.4	25.7	25.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	086 STAIR	560.768	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	101	0.00	101	0.00	101	0.00	101	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
	088 VEST	215.095	6.45	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	61.3	1.0	0.8	76.63	77	61	1.26	139	0.55	61	1.00	111	0.55	48.4	12.9	61.3	102.2	102.2	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	089 OFFICE	314.876	1.57	Office Buildings - Office Space	5	5	0.06	26.8	1.0	0.8	33.45	33	53	0.63	61	0.55	53	0.51	53	0.51	7.9	18.9	26.8	44.6	44.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	090 OP OFFICE	503.403	2.52	Office Buildings - Office Space	5	5	0.06	42.8	1.0	0.8	53.49	53	94	0.57	97	0.55	94	0.46	94	0.46	12.6	30.2	42.8	71.3	71.3	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Open plan
	090.2 OFFICE	119.526	0.60	Office Buildings - Office Space	5	5	0.06	10.2	1.0	0.8	12.70	13	51	0.25	51	0.25	51	0.20	51	0.20	3.0	7.2	10.2	16.9	16.9	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	090.4 OFFICE/AV	105.749	0.53	Office Buildings - Office Space	5	5	0.06	9.0	1.0	0.8	11.24	11	48	0.23	48	0.23	48	0.19	48	0.19	2.6	6.3	9.0	15.0	15.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	090.6 OFFICE	193.872	0.97	Office Buildings - Office Space	5	5	0.06	16.5	1.0	0.8	20.60	21	62	0.33	62	0.33	62	0.26	62	0.26	4.8	11.6	16.5	27.5	27.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	091 STOR	394.898	0.00	General - Storage rooms	0	0	0.12	47.4	1.0	0.8	59.23	59	45	1.32	108	0.55	45	1.05	86	0.55	0.0	47.4	47.4	79.0	79.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
	100 MEM HALL	3542.313	106.28	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	1009.6	1.0	0.8	1262.04	1262	1893	0.67	2295	0.55	1893	0.53	1893	0.53	797.1	212.5	1009.6	1682.7	1682.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	101 LOBBY	717.668	21.53	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	204.6	1.0	0.8	255.69	256	176	1.46	465	0.55	176	1.17	372	0.55	161.5	43.1	204.6	340.9	340.9	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	104 LNGE	452.392	11.31	General - Break rooms	25	5	0.06	83.7	1.0	0.8	104.62	105	166	0.63	190	0.55	166	0.50	166	0.50	56.6	27.1	83.7	139.5	139.5	Kitchenettes	0.30	135.7	0.00	0.00	0.0	SPACE: Lounge/ Recreation
	106 CONF	526.134	35.08	General - Conference/meeting	50	5	0.06	207.0	1.0	0.8	258.69	259	273	0.95	470	0.55	273	0.76	376	0.55	175.4	31.6	207.0	344.9	344.9	None	0.00	0.0	0.00	0.00	0.0	SPACE: Conference/ Meeting/ Multipurpose
	109 STOR	248.678	0.00	General - Storage rooms	0	0	0.12	29.8	1.0	0.8	37.30	37	36	1.05	68	0.55	36	0.84	54	0.55	0.0	29.8	29.8	49.7	49.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
	110 CONF	687.492	45.83	General - Conference/meeting	50	5	0.06	270.4	1.0	0.8	338.02	338	364	0.93	615	0.55	364	0.74	492	0.55	229.2	41.2	270.4	450.7	450.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Conference/ Meeting/ Multipurpose
	110.1 CONF	203.47	13.57	General - Conference/meeting	50	5	0.06	80.0	1.0	0.8	100.04	100	161	0.62	182	0.55	161	0.50	161	0.50	67.8	12.2	80.0	133.4	133.4	None	0.00	0.0	0.00	0.00	0.0	SPACE: Conference/ Meeting/ Multipurpose
	113 STAIR	1239.481	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	137	0.00	137	0.00	137	0.00	137	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
	125 CORR	1175.666	0.00	General - Corridors	0	0	0.06	70.5	1.0	0.8	88.17	88	86	1.03	160	0.55	86	0.82	128	0.55	0.0	70.5	70.5	117.6	117.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	125 LOBBY	7593.649	227.83	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	2164.3	1.0	0.8	2705.42	2705	1841	1.47	4919	0.55	1841	1.18	3935	0.55	1708.7	455.6	2164.3	3607.2	3607.2	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	128 RSTRM	275.92	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	131 ELECL	88.355	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.3	1.0	0.8	6.63	7	11	0.62	12	0.55	11	0.50	11	0.50	0.0	5.3	5.3	8.8	8.8	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	133 IDF	110.248	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	6.6	1.0	0.8	8.27	8	12	0.69	15	0.55	12	0.55	12	0.55	0.0	6.6	6.6	11.0	11.0	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	134 RSTRM	335.995	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	136 CORR	59.5	0.00	General - Corridors	0	0	0.06	3.6	1.0	0.8	4.46	4	8	0.59	8	0.55	8	0.47	8	0.47	0.0	3.6	3.6	6.0	6.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	147 STAIR	594.149	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	346	0.00	346	0.00	346	0.00	346	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
	153 CTRL BTH	454.391	2.27	Office Buildings - Office Space	5	5	0.06	38.6	1.0	0.8	48.28	48	85	0.57	88	0.55	85	0.46	85	0.46	11.4	27.3	38.6	64.4	64.4	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	168 RSTRM	357.059	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	173 IDF	110.61	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	6.6	1.0	0.8	8.30	8	12	0.66	15	0.55	12	0.53	12	0.53	0.0	6.6	6.6	11.1	11.1	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	174 JAN	44.342	0.00	General - Storage rooms	0	0	0.12	5.3	1.0	0.8	6.65	7	8	0.87	12	0.55	8	0.70	10	0.55	0.0	5.3	5.3	8.9	8.9	None	0.00	0.0	0.00	0.00	0.0	SPACE: Active storage
	175 CORR	1476.32	0.00	General - Corridors	0	0	0.06	88.6	1.0	0.8	110.72	111	117	0.95	201	0.55	117	0.76	161	0.55	0.0	88.6	88.6	147.6	147.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	177 ELEC	84.194	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.1	1.0	0.8	6.31	6	10	0.61	11	0.55	10	0.48	10	0.48	0.0	5.1	5.1	8.4	8.4	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	178 RSTRM	324.793	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	182 PREP	299.686	20.97	Food and Beverage Service - Restaurant dining rooms	70	7.5	0.18	211.2	1.0	0.8	264.03	264	241	1.10	480	0.55	241	0.88	384	0.55	157.3	53.9	211.2	352.0	352.0	Kitchens - commercial	0.70	209.8	0.00	0.00	0.0	SPACE: Food preparation
	184 SERVING	229.937	16.09	Food and Beverage Service - Restaurant dining rooms	70	7.5	0.18	162.1	1.0	0.8	202.59	203	197	1.03	368	0.55	197	0.82	295	0.55	120.7	41.4	162.1	270.1	270.1	Kitchens - commercial	0.70	161.0	0.00	0.00	0.0	SPACE: Food preparation
	187 STAIR	1233.206	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	137	0.00	137	0.00	137	0.00	137	0.00	0.0	0.0	0.0	0.0	0.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
	190 COFFEE	1218.002	121.80	Food and Beverage Service - Bars, cocktail lounges	100	7.5	0.18	1132.8	1.0	0.8	1415.96	1416	618	2.29	2574	0.55	618	1.83	2060	0.55	913.5	219.2	1132.8	1888.0	1888.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Dining area - Bar lounge/ Leisure dining
	191 STOR	251.956	0.00	General - Storage rooms	0	0	0.12	30.2	1.0	0.8	37.79	38	35	1.08	69	0.55	35	0.87	55	0.55	0.0	30.2	30.2	50.4	50.4	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
	196 LNGE	448.317	11.21	General - Break rooms	25	5	0.06	82.9	1.0	0.8	103.67	104	184	0.56	188	0.55	184	0.45	184	0.45	56.0	26.9	82.9	138.2	138.2	Kitchenettes	0.30	134.5	0.00	0.00	0.0	SPACE: Lounge/ Recreation
	198 LOBBY	695.304	20.86	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	198.2	1.0	0.8	247.72	248	167	1.48	450	0.55	167	1.19	360	0.55	156.5	41.7	198.2	330.3	330.3	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	201 LOBBY	717.668	21.53	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	204.6	1.0	0.8	255.69	256	176	1.45	465	0.55	176	1.16	372	0.55	161.5	43.1	204.6	340.9	340.9	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	203 LOBBY	1955.152	58.66	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	557.3	1.0	0.8	696.57	697	456	1.53	1266	0.55	456	1.22	1013	0.55	440.0	117.3	557.3	928.8	928.8	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	204 LNGE	452.392	11.31	General - Break rooms	25	5	0.06	83.7	1.0	0.8	104.62	105	168	0.62	190	0.55	168	0.50	168	0.50	56.6	27.1	83.7	139.5	139.5	Kitchenettes	0.30	135.7	0.00	0.00	0.0	SPACE: Lounge/ Recreation
	210 OP OFFICE	917.551	4.59	Office Buildings - Office Space	5	5	0.06	78.0	1.0	0.8	97.49	97	160	0.61	177	0.55	160	0.49	160	0.49	22.9	55.1	78.0	130.0	130.0	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Open plan
	210.02 OFFICE	121.871	0.61	Office Buildings - Office Space	5	5	0.06	10.4	1.0	0.8	12.95	13	69	0.19	69	0.19	69	0.15	69	0.15	3.0	7.3	10.4	17.3	17.3	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	210.04 OFFICE	116.427	0.58	Office Buildings - Office Space	5	5	0.06	9.9	1.0	0.8	12.37	12	68	0.18	68	0.18	68	0.14	68	0.14	2.9	7.0	9.9	16.5	16.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	210.06 OFFICE	117.768	0.59	Office Buildings - Office Space	5	5	0.06	10.0	1.0	0.8	12.51	13	69	0.18	69	0.18	69	0.14	69	0.14	2.9	7.1	10.0	16.7	16.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	210.08 OFFICE	116.881	0.58	Office Buildings - Office Space	5	5	0.06	9.9	1.0	0.8	12.42	12	69	0.18	69	0.18	69	0.14	69	0.14	2.9	7.0	9.9	16.6	16.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	210.10 OFFICE	116.872	0.58	Office Buildings - Office Space	5	5	0.06	9.9	1.0	0.8	12.42	12	68	0.18	68	0.18	68	0.15	68	0.15	2.9	7.0	9.9	16.6	16.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	210.11 OFFICE	102.958	0.52	Office Buildings - Office Space	5	5	0.06	8.8	1.0	0.8	10.94	11	17	0.66	20	0.55	17	0.53	17	0.53	2.6	6.2	8.8	14.6	14.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	210.12 OFFICE	117.003	0.59	Office Buildings - Office Space	5	5	0.06	9.9	1.0	0.8	12.43	12	68	0.18	68	0.18	68	0.15	68	0.15	2.9	7.0	9.9	16.6	16.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	210.13 OFFICE	100.49	0.50	Office Buildings - Office Space	5	5	0.06	8.5	1.0	0.8	10.67	11	16	0.68	19	0.55	16	0.55	16	0.55	2.5	6.0	8.5	14.2	14.2	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	210.14 OFFICE	109.761	0.55	Office Buildings - Office Space	5	5	0.06	9.3	1.0	0.8	11.66	12	65	0.18	65	0.18	65	0.14	65	0.14	2.7	6.6	9.3	15.6	15.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	215 CORR	165.494	0.00	General - Corridors	0	0	0.06	9.9	1.0	0.8	12.41	12	23	0.54	23	0.54	23	0.43	23	0.43	0.0	9.9	9.9	16.5	16.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	217 WKRM	90.572	0.45	Office Buildings - Office Space	5	5	0.06	7.7	1.0	0.8	9.62	10	14	0.67	17	0.55	14	0.53	14	0.53	2.3	5.4	7.7	12.8	12.8	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	225 CORR	976.385	0.00	General - Corridors	0	0	0.06	58.6	1.0	0.8	73.23	73	70	1.04	133	0.55	70	0.83	107	0.55	0.0	58.6	58.6	97.6	97.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	228 RSTRM	300.383	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	231 ELEC	84.634	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.1	1.0	0.8	6.35	6	14	0.46	14	0.46	14	0.37	14	0.37	0.0	5.1	5.1	8.5	8.5	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	233 IDF	112.673	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	6.8	1.0	0.8	8.45	8	13	0.67	15	0.55	13	0.53	13	0.53	0.0	6.8	6.8	11.3	11.3	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	234 RSTRM	328.022	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	236 CORR	156.18	0.00	General - Corridors	0	0	0.06	9.4	1.0	0.8	11.71	12	19	0.61	21	0.55	19	0.49	19	0.49	0.0	9.4	9.4	15.6	15.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	241 TLT	61.535	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	242 JAN	59.544	0.00	General - Storage rooms	0	0	0.12	7.1	1.0	0.8	8.93	9	6	1.42	16	0.55	6	1.14	13	0.55	0.0	7.1	7.1	11.9	11.9	None	0.00	0.0	0.00	0.00	0.0	SPACE: Active storage
	243 AV	37.71	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	2.3	1.0	0.8	2.83	3	7	0.42	7	0.42	7	0.34	7	0.34	0.0	2.3	2.3	3.8	3.8	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	244 STOR	75.827	0.00	General - Storage rooms	0	0	0.12	9.1	1.0	0.8	11.37	11	8	1.40	21	0.55	8	1.12	17	0.55	0.0	9.1	9.1	15.2	15.2	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
	255 CORR	948.898	0.00	General - Corridors	0	0	0.06	56.9	1.0	0.8	71.17	71	117	0.61	129	0.55	117	0.49	117	0.49	0.0	56.9	56.9	94.9	94.9	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	261 STOR	217.917	0.00	General - Storage rooms	0	0	0.12	26.2	1.0	0.8	32.69	33	29	1.12	59	0.55	29	0.90	48	0.55	0.0	26.2	26.2	43.6	43.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
	266 CORR	405.273	0.00	General - Corridors	0	0	0.06	24.3	1.0	0.8	30.40	30	37	0.82	55	0.55	37	0.65	44	0.55	0.0	24.3	24.3	40.5	40.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	268 SERVING	160.036	11.20	Food and Beverage Service - Restaurant dining rooms	70	7.5	0.18	112.8	1.0	0.8	141.00	141	112	1.26	256	0.55	112	1.01	205	0.55	84.0	28.8	112.8	188.0	188.0	Kitchens - commercial	0.70	112.0	0.00	0.00	0.0	SPACE: Food preparation
	273 IDF	111.902	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	6.7	1.0	0.8	8.39	8	13	0.66	15	0.55	13	0.53	13	0.53	0.0	6.7	6.7	11.2	11.2	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	274 CORR	145.13	0.00	General - Corridors	0	0	0.06	8.7	1.0	0.8	10.88	11	20	0.54	20	0.54	20	0.43	20	0.43	0.0	8.7	8.7	14.5	14.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	275 CORR	886.411	0.00	General - Corridors	0	0	0.06	53.2	1.0	0.8	66.48	66	71	0.93	121	0.55	71	0.75	97	0.55	0.0	53.2	53.2	88.6	88.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	277 ELEC	84.26	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.1	1.0	0.8	6.32	6	14	0.46	14	0.46	14	0.37	14	0.37	0.0	5.1	5.1	8.4	8.4	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
	278 RSTRM	335.785	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	282 RSTRM	309.977	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0	1.0	0.8	0.00	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
	283 WKRM	82.376	0.41	Office Buildings - Office Space	5	5	0.06	7.0	1.0	0.8	8.75	9	16	0.56	16	0.55	16	0.45	16	0.45	2.1	4.9	7.0	11.7	11.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	285 CORR	155.18	0.00	General - Corridors	0	0	0.06	9.3	1.0	0.8	11.64	12	28	0.42	28	0.42	28	0.34	28	0.34	0.0	9.3	9.3	15.5	15.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
	290 OP OFFICE	1395.268	6.98	Office Buildings - Office Space	5	5	0.06	118.6	1.0	0.8	148.25	148	395	0.38	395	0.38	395	0.30	395	0.30	34.9	83.7	118.6	197.7	197.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Open plan
	290.10 OFFICE	144.622	0.72	Office Buildings - Office Space	5	5	0.06	12.3	1.0	0.8	15.37	15	70	0.22	70	0.22	70	0.18	70	0.18	3.6	8.7	12.3	20.5	20.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	290.11 OFFICE	103.676	0.52	Office Buildings - Office Space	5	5	0.06	8.8	1.0	0.8	11.01	11	19	0.57	20	0.55	19	0.46	19	0.46	2.6	6.2	8.8	14.7	14.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	290.12 OFFICE	122.076	0.61	Office Buildings - Office Space	5	5	0.06	10.4	1.0	0.8	12.97	13	67	0.19	67	0.19	67	0.16	67	0.16	3.1	7.3	10.4	17.3	17.3	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	290.13 OFFICE	108.726	0.54	Office Buildings - Office Space	5	5	0.06	9.2	1.0	0.8	11.55	12	19	0.62	21	0.55	19	0.50	19	0.50	2.7	6.5	9.2	15.4	15.4	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	290.14 OFFICE	103.434	0.52	Office Buildings - Office Space	5	5	0.06	8.8	1.0	0.8	10.99	11	63	0.17	63	0.17	63	0.14	63	0.14	2.6	6.2	8.8	14.7	14.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	296 LNGE	454.165	11.35	General - Break rooms	25	5	0.06	84.0	1.0	0.8	105.02	105	186	0.56	191	0.55	186	0.45	186	0.45	56.8	27.2	84.0	140.0	140.0	Kitchenettes	0.30	136.2	0.00	0.00	0.0	SPACE: Lounge/ Recreation
	297 LOBBY	1958.216	58.75	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	558.1	1.0	0.8	697.67	698	466	1.50	1268	0.55	466	1.20	1015	0.55	440.6	117.5	558.1	930.2	930.2	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	298 LOBBY	695.304	20.86	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	198.2	1.0	0.8	247.72	248	170	1.46	450	0.55	170	1.16	360	0.55	156.5	41.7	198.2	330.3	330.3	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	301 LOBBY	717.668	21.53	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	204.6	1.0	0.8	255.69	256	184	1.39	465	0.55	184	1.11	372	0.55	161.5	43.1	204.6	340.9	340.9	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	303 LOBBY	2304.055	69.13	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	656.7	1.0	0.8	820.88	821	553	1.48	1493	0.55	553	1.19	1194	0.55	518.5	138.2	656.7	1094.5	1094.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Lobby - Performing arts theater
	304 LNGE	452.392	11.31	General - Break rooms	25	5	0.06	83.7	1.0	0.8	104.62	105	185	0.56	190	0.55	185	0.45	185	0.45	56.6	27.1	83.7	139.5	139.5	Kitchenettes	0.30	135.7	0.00	0.00	0.0	SPACE: Lounge/ Recreation
	310 OP OPEN	885.199	4.43	Office Buildings - Office Space	5	5	0.06	75.2	1.0	0.8	94.05	94	176	0.53	176	0.53	176	0.43	176	0.43	22.1	53.1	75.2	125.4	125.4	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Open plan
	310.02 OFFICE	130.77	0.65	Office Buildings - Office Space	5	5	0.06	11.1	1.0	0.8	13.90	14	79	0.18	79	0.18	79	0.14	79	0.14	3.3	7.8	11.1	18.5	18.5	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	310.04 OFFICE	124.219	0.62	Office Buildings - Office Space	5	5	0.06	10.6	1.0	0.8	13.20	13	78	0.17	78	0.17	78	0.14	78	0.14	3.1	7.5	10.6	17.6	17.6	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	310.06 OFFICE	124.902	0.63	Office Buildings - Office Space	5	5	0.06	10.6	1.0	0.8	13.27	13	78	0.17	78	0.17	78	0.14	78	0.14	3.1	7.5	10.6	17.7	17.7	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
	310.08 OFFICE	125.568	0.63	Office Buildings - Office Space	5	5	0.06	10.7	1.0	0.8	13.34	13	78	0.17	78	0.17	78	0.14	78	0.14	3.1	7.5	10.7	17.8	17.8	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed

APPENDIX A

ASHRAE Standard 62.1-2010 Ventilation Rate Procedure: Zone Ventilation Calculations

System	Room Name	Room Input Conditions: Floor Area (ft2) = Az	Design Occupancy peak total per space = Pz	Room Type (Occupancy Category)	Default Occ (people/1000 ft2)	Outdoor Air Rates: Rp (cfm/person)	Ra (cfm/ft2)	OA Required at Breathing Zone: Vbz = (Rp*Pz) + (Ra*Az) (cfm)
	310.10 OFFICE	124.801	0.62	Office Buildings - Office Space	5	5	0.06	10.6
	310.11 OFFICE	105.848	0.53	Office Buildings - Office Space	5	5	0.06	9.0
	310.12 OFFICE	125.01	0.63	Office Buildings - Office Space	5	5	0.06	10.6
	310.13 OFFICE	94.502	0.47	Office Buildings - Office Space	5	5	0.06	8.0
	310.14 OFFICE	131.499	0.66	Office Buildings - Office Space	5	5	0.06	11.2
	310.15 OFFICE	99.407	0.50	Office Buildings - Office Space	5	5	0.06	8.4
	310.16 OFFICE	165.583	0.83	Office Buildings - Office Space	5	5	0.06	14.1
	315 CORR	199.704	0.00	General - Corridors	0	0	0.06	12.0
	318 WKRM	92.259	0.46	Office Buildings - Office Space	5	5	0.06	7.8
	325 CORR	893.961	0.00	General - Corridors	0	0	0.06	53.6
	331 ELEC	85.126	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.1
	333 IDF	110.113	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	6.6
	334 RSTRM	287.095	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	336 STAIR	208.623	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	341 RSTRM	175.104	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	351 FLY GAL	370.67	0.00	General - Corridors	0	0	0.06	22.2
	355 CORR	1038.853	0.00	General - Corridors	0	0	0.06	62.3
	361 DMR RM	637.337	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	38.2
	368 RSTRM	173.664	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	373 IDF	110.436	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	6.6
	374 STAIR	223.747	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	375 CORR	891.932	0.00	General - Corridors	0	0	0.06	53.5
	377 ELEC	84.814	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.1
	378 RSTRM	283.74	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	382 CONF	337.633	22.51	General - Conference/meeting	50	5	0.06	132.8
	385 CORR	160.12	0.00	General - Corridors	0	0	0.06	9.6
	390 OP OFFICE	1392.61	6.96	Office Buildings - Office Space	5	5	0.06	118.4
	390.1 OFFICE	96.728	0.48	Office Buildings - Office Space	5	5	0.06	8.2
	390.2 OFFICE	146.058	0.73	Office Buildings - Office Space	5	5	0.06	12.4
	390.3 OFFICE	91.737	0.46	Office Buildings - Office Space	5	5	0.06	7.8
	390.4 OFFICE	221.518	1.11	Office Buildings - Office Space	5	5	0.06	18.8
	390.5 WKRM	81.28	0.41	Office Buildings - Office Space	5	5	0.06	6.9
	396 LNGE	454.165	11.35	General - Break rooms	25	5	0.06	84.0
	397 LOBBY	2300.955	69.04	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	655.8
	398 LOBBY	695.304	20.86	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	198.2
	400 LEC GAL	1833.978	119.25	Educational Facilities - Lecture Classroom	65	7.5	0.06	1004.4
	401 STAIR	640.606	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	403 LOBBY	1542.294	46.27	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	439.6
	404 LOBBY	199.13	5.97	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	56.8
	407 CORR	206.284	0.00	General - Corridors	0	0	0.06	12.4
	410 MECH	272.816	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	16.4
	416 TLT	104.337	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	418 RSTRM	365.382	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	420 MECH	225.066	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	13.5
	423 STOR	115.491	0.00	General - Storage rooms	0	0	0.12	13.9
	425 CORR	1029.498	0.00	General - Corridors	0	0	0.06	61.8
	435 CORR	509.722	0.00	General - Corridors	0	0	0.06	30.6
	451 IDF	165.143	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	9.9
	460 RCTL	2327.296	348.90	Public Assembly Spaces - Auditorium seating area	150	5	0.06	1884.1
	462 STOR	542.896	0.00	General - Storage rooms	0	0	0.12	65.1
	468 STAIR	137.41	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	469 STAIR	137.759	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	470 ELEC	321.835	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	19.3
	473 JAN	158.683	0.00	General - Storage rooms	0	0	0.12	19.0
	475 CORR	477.142	0.00	General - Corridors	0	0	0.06	28.6
	476 STOR	116.644	0.00	General - Storage rooms	0	0	0.12	14.0
	479 STOR	80.031	0.00	General - Storage rooms	0	0	0.12	9.6
	485 CORR	928.887	0.00	General - Corridors	0	0	0.06	55.7
	485 STOR	109.362	0.00	General - Storage rooms	0	0	0.12	13.1
	486 RSTRM	586.797	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	493 CORR	205.668	0.00	General - Corridors	0	0	0.06	12.3
	496 LOBBY	161.495	4.85	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	46.0
	497 LOBBY	1553.742	46.62	Hotels, Motels, Resorts, Dormitories - Lobbies/prefunction	30	7.5	0.06	442.8
	498 STAIR	565.563	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	E1 ELEV	135.988	0.00	Miscellaneous Spaces - Elevator machine rooms	0	0	0.12	16.3
	E2 ELEV	146.95	0.00	Miscellaneous Spaces - Elevator machine rooms	0	0	0.12	17.6
	E3 ELEV	275.045	0.00	Miscellaneous Spaces - Elevator machine rooms	0	0	0.12	33.0
	M60 CRTL RM	321.835	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	19.3
	XXX PLNM	226.985	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	XXX PLNM	1521.331	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	XXX PLNM	384.618	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	XXX PLNM	299.363	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	XXX PLNM	230.631	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	XXX PLNM	87.454	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	XXX PLNM	307.835	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	XXX PLNM	389.096	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
AHU-2	System Totals	**28,806.74**	**3,949.21**					**21,570.39**
Audience Chamber								
	100.1 AUD	12995.863	1948.29	Public Assembly Spaces - Auditorium seating area	150	5	0.06	10521.2
	200.1 BAL 1	5315.047	796.81	Public Assembly Spaces - Auditorium seating area	150	5	0.06	4303.0
	300.1 BAL 2	4220.183	632.67	Public Assembly Spaces - Auditorium seating area	150	5	0.06	3416.6
	400.1 BAL 3	3811.691	571.43	Public Assembly Spaces - Auditorium seating area	150	5	0.06	3085.9
	436 PIPE E	287.627	0.00	General - Storage rooms	0	0	0.12	34.5
	472 PIPE W	253.243	0.00	General - Storage rooms	0	0	0.12	30.4
	474 ORGAN	218.352	0.00	General - Storage rooms	0	0	0.12	26.2
	M54 CHOIR	260.291	0.00	General - Storage rooms	0	0	0.12	31.2
	M55 CTWK	864.884	0.00	General - Corridors	0	0	0.06	51.9
	M56 CHMBR	101.859	0.00	General - Storage rooms	0	0	0.12	12.2
	M58 CHMBR	211.819	0.00	General - Storage rooms	0	0	0.12	25.4
	M59 SWELL	265.883	0.00	General - Storage rooms	0	0	0.12	31.9
AHU-3	System Totals	**11,258.58**	**590.10**					**3,866.73**
Performance Spaces								
	040 REHERSAL	2036.324	135.76	General - Conference/meeting	50	5	0.06	801.0
	051.1 STAGE	6018.169	240.72	Sports and Entertainment - Gym, stadium (play area)	30	0	0.3	1805.5
	240 CONF	1647.598	109.84	General - Conference/meeting	50	5	0.06	648.1
	260 FNDRS RM	1556.489	103.77	General - Conference/meeting	50	5	0.06	612.2
AHU-5	System Totals	**38,543.49**	**108.65**					**3,540.50**
Performance Support Spaces								
	003 RSTRM	385.24	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	003.1 TLT	68.786	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	029 TLT	74.532	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	030 GREEN RM	603.023	40.20	General - Conference/meeting	50	5	0.06	237.2
	045 CORR	667.49	0.00	General - Corridors	0	0	0.06	40.0
	055 CORR	1755.558	0.00	General - Corridors	0	0	0.06	105.3
	061 STOR	141.331	0.00	General - Storage rooms	0	0	0.12	17.0
	064 JAN	53.953	0.00	General - Storage rooms	0	0	0.12	6.5
	065 CORR	498.311	0.00	General - Corridors	0	0	0.06	29.9
	066 TLT	58.549	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	070 DRESS	152.024	1.52	Sports and Entertainment - Health club/weight rooms	10	20	0.06	39.5
	070.1 TLT	98.353	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	072 DRESS	170.056	1.70	Sports and Entertainment - Health club/weight rooms	10	20	0.06	44.2
	080 OP OFFICE	710.743	3.55	Office Buildings - Office Space	5	5	0.06	60.4
	080.02 OFFICE	172.415	0.86	Office Buildings - Office Space	5	5	0.06	14.7
	080.04 OFFICE	141.067	0.71	Office Buildings - Office Space	5	5	0.06	12.0

ASHRAE 62.1-2010 Ventilation Rate Procedure: System Ventilation Calculations

System	Room Name	Air Distribution Effectiveness: Ez, Cooling	Ez, Heating	62.1 Min Room Supplied OA Rate: Voz = Vbz/Ez	Design Case Room Supplied OA Rate: Voz * Including "Increased Ventilation %"	Primary Outdoor Air Fraction (Using Table 6-3 Method): Heating airflow Min Condition (min flow per heating load when SAT > RAT) (cfm), Vpz	Heating Zone Primary OA Fraction Zp = Voz/Vpz	Heating Adjusted Flow Rate	Heating Adjusted Zp	Cooling airflow Min Condition (min flow per cooling load and turndown when SAT < RAT) (cfm), Vpz	Cooling Zone Primary OA Fraction Zp = Voz/Vpz	Cooling Min Adjusted Flow Rate	Cooling Adjusted Zp	Uncorrected OA Rate: Vou, Occupant Portion (cfm)	Vou, Area Portion (cfm)	Vou, SUM of Occupant and Area Portions (cfm)	Zone Portion of Vot: 62.1 Min Vot	Design Case Vot *Including "Increased Ventilation %"
	310.10 OFFICE	1.0	0.8	13.26	**13**	77	0.17	77	0.17	77	0.14	77	0.14	3.1	7.5	10.6	17.7	17.7
	310.11 OFFICE	1.0	0.8	11.24	**11**	19	0.59	20	0.55	19	0.48	19	0.48	2.6	6.4	9.0	15.0	15.0
	310.12 OFFICE	1.0	0.8	13.28	**13**	77	0.17	77	0.17	77	0.14	77	0.14	3.1	7.5	10.6	17.7	17.7
	310.13 OFFICE	1.0	0.8	10.04	**10**	16	0.61	18	0.55	16	0.49	16	0.49	2.4	5.7	8.0	13.4	13.4
	310.14 OFFICE	1.0	0.8	13.97	**14**	78	0.18	78	0.18	78	0.14	78	0.14	3.3	7.9	11.2	18.6	18.6
	310.15 OFFICE	1.0	0.8	10.56	**11**	17	0.61	19	0.55	17	0.49	17	0.49	2.5	6.0	8.4	14.1	14.1
	310.16 OFFICE	1.0	0.8	17.59	**18**	85	0.21	85	0.21	85	0.17	85	0.17	4.1	9.9	14.1	23.5	23.5
	315 CORR	1.0	0.8	14.98	**15**	33	0.45	33	0.45	33	0.36	33	0.36	0.0	12.0	12.0	20.0	20.0
	318 WKRM	1.0	0.8	9.80	**10**	17	0.59	18	0.55	17	0.47	17	0.47	2.3	5.5	7.8	13.1	13.1
	325 CORR	1.0	0.8	67.05	**67**	76	0.88	122	0.55	76	0.70	98	0.55	0.0	53.6	53.6	89.4	89.4
	331 ELEC	1.0	0.8	6.38	**6**	12	0.53	12	0.53	12	0.42	12	0.42	0.0	5.1	5.1	8.5	8.5
	333 IDF	1.0	0.8	8.26	**8**	14	0.59	15	0.55	14	0.47	14	0.47	0.0	6.6	6.6	11.0	11.0
	334 RSTRM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	336 STAIR	1.0	0.8	0.00	**0**	48	0.00	48	0.00	48	0.00	48	0.00	0.0	0.0	0.0	0.0	0.0
	341 RSTRM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	351 FLY GAL	1.0	0.8	27.80	**28**	46	0.60	51	0.55	46	0.48	46	0.48	0.0	22.2	22.2	37.1	37.1
	355 CORR	1.0	0.8	77.91	**78**	142	0.55	142	0.55	142	0.44	142	0.44	0.0	62.3	62.3	103.9	103.9
	361 DMR RM	1.0	0.8	47.80	**48**	97	0.49	97	0.49	97	0.40	97	0.40	0.0	38.2	38.2	63.7	63.7
	368 RSTRM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	373 IDF	1.0	0.8	8.28	**8**	15	0.55	15	0.55	15	0.44	15	0.44	0.0	6.6	6.6	11.0	11.0
	374 STAIR	1.0	0.8	0.00	**0**	51	0.00	51	0.00	51	0.00	51	0.00	0.0	0.0	0.0	0.0	0.0
	375 CORR	1.0	0.8	66.89	**67**	84	0.80	122	0.55	84	0.64	97	0.55	0.0	53.5	53.5	89.2	89.2
	377 ELEC	1.0	0.8	6.36	**6**	13	0.51	13	0.51	13	0.41	13	0.41	0.0	5.1	5.1	8.5	8.5
	378 RSTRM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	382 CONF	1.0	0.8	166.01	**166**	178	0.93	302	0.55	178	0.75	241	0.55	112.6	20.3	132.8	221.3	221.3
	385 CORR	1.0	0.8	12.01	**12**	30	0.40	30	0.40	30	0.32	30	0.32	0.0	9.6	9.6	16.0	16.0
	390 OP OFFICE	1.0	0.8	147.96	**148**	476	0.31	476	0.31	476	0.25	476	0.25	34.8	83.6	118.4	197.3	197.3
	390.1 OFFICE	1.0	0.8	10.28	**10**	19	0.53	19	0.53	19	0.42	19	0.42	2.4	5.8	8.2	13.7	13.7
	390.2 OFFICE	1.0	0.8	15.52	**16**	82	0.19	82	0.19	82	0.15	82	0.15	3.7	8.8	12.4	20.7	20.7
	390.3 OFFICE	1.0	0.8	9.75	**10**	17	0.58	18	0.55	17	0.46	17	0.46	2.3	5.5	7.8	13.0	13.0
	390.4 OFFICE	1.0	0.8	23.54	**24**	146	0.16	146	0.16	146	0.13	146	0.13	5.5	13.3	18.8	31.4	31.4
	390.5 WKRM	1.0	0.8	8.63	**9**	16	0.53	16	0.53	16	0.42	16	0.42	2.0	4.9	6.9	11.5	11.5
	396 LNGE	1.0	0.8	105.02	**105**	216	0.49	216	0.49	216	0.39	216	0.39	56.8	27.2	84.0	140.0	140.0
	397 LOBBY	1.0	0.8	819.77	**820**	562	1.46	1490	0.55	562	1.17	1192	0.55	517.8	138.1	655.8	1093.0	1093.0
	398 LOBBY	1.0	0.8	247.72	**248**	178	1.39	450	0.55	178	1.11	360	0.55	156.5	41.7	198.2	330.3	330.3
	400 LEC GAL	1.0	0.8	1255.50	**1255**	1122	1.12	2283	0.55	1122	0.89	1826	0.55	894.4	110.0	1004.4	1674.0	1674.0
	401 STAIR	1.0	0.8	0.00	**0**	95	0.00	95	0.00	95	0.00	95	0.00	0.0	0.0	0.0	0.0	0.0
	403 LOBBY	1.0	0.8	549.48	**549**	412	1.33	999	0.55	412	1.07	799	0.55	347.0	92.5	439.6	732.6	732.6
	404 LOBBY	1.0	0.8	70.94	**71**	59	1.20	129	0.55	59	0.96	103	0.55	44.8	11.9	56.8	94.6	94.6
	407 CORR	1.0	0.8	15.47	**15**	24	0.64	28	0.55	24	0.51	24	0.51	0.0	12.4	12.4	20.6	20.6
	410 MECH	1.0	0.8	20.46	**20**	38	0.54	38	0.54	38	0.43	38	0.43	0.0	16.4	16.4	27.3	27.3
	416 TLT	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	418 RSTRM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	420 MECH	1.0	0.8	16.88	**17**	31	0.55	31	0.55	31	0.44	31	0.44	0.0	13.5	13.5	22.5	22.5
	423 STOR	1.0	0.8	17.32	**17**	16	1.10	31	0.55	16	0.88	25	0.55	0.0	13.9	13.9	23.1	23.1
	425 CORR	1.0	0.8	77.21	**77**	139	0.55	140	0.55	139	0.44	139	0.44	0.0	61.8	61.8	102.9	102.9
	435 CORR	1.0	0.8	38.23	**38**	111	0.34	111	0.34	111	0.27	111	0.27	0.0	30.6	30.6	51.0	51.0
	451 IDF	1.0	0.8	12.39	**12**	30	0.41	30	0.41	30	0.33	30	0.33	0.0	9.9	9.9	16.5	16.5
	460 RCTL	1.0	0.8	2355.17	**2355**	1192	1.98	4282	0.55	1192	1.58	3426	0.55	1744.5	139.6	1884.1	3140.2	3140.2
	462 STOR	1.0	0.8	81.43	**81**	66	1.24	148	0.55	66	0.99	118	0.55	0.0	65.1	65.1	108.6	108.6
	468 STAIR	1.0	0.8	0.00	**0**	33	0.00	33	0.00	33	0.00	33	0.00	0.0	0.0	0.0	0.0	0.0
	469 STAIR	1.0	0.8	0.00	**0**	32	0.00	32	0.00	32	0.00	32	0.00	0.0	0.0	0.0	0.0	0.0
	470 ELEC	1.0	0.8	24.14	**24**	45	0.54	45	0.54	45	0.43	45	0.43	0.0	19.3	19.3	32.2	32.2
	473 JAN	1.0	0.8	23.80	**24**	19	1.25	43	0.55	19	1.00	35	0.55	0.0	19.0	19.0	31.7	31.7
	475 CORR	1.0	0.8	35.79	**36**	122	0.29	122	0.29	122	0.24	122	0.24	0.0	28.6	28.6	47.7	47.7
	476 STOR	1.0	0.8	17.50	**17**	16	1.12	32	0.55	16	0.90	25	0.55	0.0	14.0	14.0	23.3	23.3
	479 STOR	1.0	0.8	12.00	**12**	13	0.96	22	0.55	13	0.77	17	0.55	0.0	9.6	9.6	16.0	16.0
	485 CORR	1.0	0.8	69.67	**70**	124	0.56	127	0.55	124	0.45	124	0.45	0.0	55.7	55.7	92.9	92.9
	485 STOR	1.0	0.8	16.40	**16**	15	1.09	30	0.55	15	0.87	24	0.55	0.0	13.1	13.1	21.9	21.9
	486 RSTRM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	493 CORR	1.0	0.8	15.43	**15**	24	0.63	28	0.55	24	0.51	24	0.51	0.0	12.3	12.3	20.6	20.6
	496 LOBBY	1.0	0.8	57.53	**58**	49	1.18	105	0.55	49	0.94	84	0.55	36.3	9.7	46.0	76.7	76.7
	497 LOBBY	1.0	0.8	553.56	**554**	414	1.34	1006	0.55	414	1.07	805	0.55	349.6	93.2	442.8	738.1	738.1
	498 STAIR	1.0	0.8	0.00	**0**	84	0.00	84	0.00	84	0.00	84	0.00	0.0	0.0	0.0	0.0	0.0
	E1 ELEV	1.0	0.8	20.40	**20**	282	0.07	282	0.07	282	0.06	282	0.06	0.0	16.3	16.3	27.2	27.2
	E2 ELEV	1.0	0.8	22.04	**22**	299	0.07	299	0.07	299	0.06	299	0.06	0.0	17.6	17.6	29.4	29.4
	E3 ELEV	1.0	0.8	41.26	**41**	410	0.10	410	0.10	410	0.08	410	0.08	0.0	33.0	33.0	55.0	55.0
	M60 CRTL RM	1.0	0.8	24.14	**24**	43	0.56	44	0.55	43	0.45	43	0.45	0.0	19.3	19.3	32.2	32.2
	XXX PLNM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	XXX PLNM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	XXX PLNM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	XXX PLNM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	XXX PLNM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	XXX PLNM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	XXX PLNM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	XXX PLNM	1.0	0.8	0.00	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
AHU-2	System Totals			**26,962.99**	**26,962.99**	**14,045.19**		**49,035.64**	**0.55**	**14,045.19**		**39,257.25**	**0.55**	**19,746.05**	**1,824.35**	**21,570.39**	**35,950.66**	**35,950.66**
Audience Chamber																		
	100.1 AUD	1.0	0.8	13151.50223	**13152**	6886	1.91	23912	0.55	6886	1.53	19129	0.55	9741.5	779.8	10521.2	17535.3	17535.3
	200.1 BAL 1	1.0	0.8	5378.697275	**5379**	2553	2.11	9779	0.55	2553	1.69	7824	0.55	3984.1	318.9	4303.0	7171.6	7171.6
	300.1 BAL 2	1.0	0.8	4270.726225	**4271**	2067	2.07	7765	0.55	2067	1.65	6212	0.55	3163.4	253.2	3416.6	5694.3	5694.3
	400.1 BAL 3	1.0	0.8	3857.339325	**3857**	2160	1.79	7013	0.55	2160	1.43	5611	0.55	2857.2	228.7	3085.9	5143.1	5143.1
	436 PIPE E	1.0	0.8	43.14405	**43**	31	1.37	78	0.55	31	1.10	63	0.55	0.0	34.5	34.5	57.5	57.5
	472 PIPE W	1.0	0.8	37.98645	**38**	29	1.33	69	0.55	29	1.06	55	0.55	0.0	30.4	30.4	50.6	50.6
	474 ORGAN	1.0	0.8	32.7528	**33**	25	1.31	60	0.55	25	1.05	48	0.55	0.0	26.2	26.2	43.7	43.7
	M54 CHOIR	1.0	0.8	39.04365	**39**	45	0.86	71	0.55	45	0.69	57	0.55	0.0	31.2	31.2	52.1	52.1
	M55 CTWK	1.0	0.8	64.8663	**65**	130	0.50	130	0.50	130	0.40	130	0.40	0.0	51.9	51.9	86.5	86.5
	M56 CHMBR	1.0	0.8	15.27885	**15**	20	0.78	28	0.55	20	0.62	22	0.55	0.0	12.2	12.2	20.4	20.4
	M58 CHMBR	1.0	0.8	31.77285	**32**	40	0.80	58	0.55	40	0.64	46	0.55	0.0	25.4	25.4	42.4	42.4
	M59 SWELL	1.0	0.8	39.88245	**40**	61	0.66	73	0.55	61	0.53	61	0.53	0.0	31.9	31.9	53.2	53.2
AHU-3	System Totals			**4,833.41**	**4,833.41**	**5,230.30**		**8,788.02**	**0.55**	**5,230.30**	**3.15**	**7,030.42**	**0.55**	**1,746.86**	**2,119.88**	**3,866.73**	**6,444.55**	**6,444.55**
Performance Spaces																		
	040 REHERSAL	1.0	0.8	1001.21805	**1001**	885	1.13	1820	0.55	885	0.91	1456	0.55	678.8	122.2	801.0	1335.0	1335.0
	051.1 STAGE	1.0	0.8	2256.813375	**2257**	2762	0.82	4103	0.55	2762	0.65	3283	0.55	0.0	1805.5	1805.5	3009.1	3009.1
	240 CONF	1.0	0.8	810.0886	**810**	773	1.05	1473	0.55	773	0.84	1178	0.55	549.2	98.9	648.1	1080.1	1080.1
	260 FNDRS RM	1.0	0.8	765.292925	**765**	811	0.94	1391	0.55	811	0.75	1113	0.55	518.8	93.4	612.2	1020.4	1020.4
AHU-5	System Totals			**4,425.63**	**4,425.63**	**11,364.15**		**11,906.52**	**1.00**	**11,364.15**	**58.71**	**11,906.52**	**0.80**	**1,167.60**	**2,372.91**	**3,540.50**	**4,425.63**	**4,425.63**
Performance Support Spaces																		
	003 RSTRM	1.0	0.8	0	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	003.1 TLT	1.0	0.8	0	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	029 TLT	1.0	0.8	0	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	030 GREEN RM	1.0	0.8	296.495475	**296**	189	1.57	296	1.00	189	1.25	296	0.80	201.0	36.2	237.2	296.5	296.5
	045 CORR	1.0	0.8	50.06175	**50**	57	0.88	57	0.88	57	0.70	57	0.70	0.0	40.0	40.0	50.1	50.1
	055 CORR	1.0	0.8	131.66685	**132**	720	0.18	720	0.18	720	0.15	720	0.15	0.0	105.3	105.3	131.7	131.7
	061 STOR	1.0	0.8	21.19965	**21**	12	1.71	21	1.00	12	1.36	21	0.80	0.0	17.0	17.0	21.2	21.2
	064 JAN	1.0	0.8	8.09295	**8**	7	1.13	8	1.00	7	0.91	8	0.80	0.0	6.5	6.5	8.1	8.1
	065 CORR	1.0	0.8	37.373325	**37**	41	0.91	41	0.91	41	0.73	41	0.73	0.0	29.9	29.9	37.4	37.4
	066 TLT	1.0	0.8	0	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	070 DRESS	1.0	0.8	49.4018	**49**	76	0.65	76	0.65	76	0.52	76	0.52	30.4	9.1	39.5	49.4	49.4
	070.1 TLT	1.0	0.8	0	**0**	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
	072 DRESS	1.0	0.8	55.2792	**55**	85	0.65	85	0.65	85	0.52	85	0.52	34.0	10.2	44.2	55.3	55.3
	080 OP OFFICE	1.0	0.8	75.518225	**76**	114	0.66	114	0.66	114	0.53	114	0.53	17.8	42.6	60.4	75.5	75.5
	080.02 OFFICE	1.0	0.8	18.318625	**18**	59	0.31	59	0.31	59	0.25	59	0.25	4.3	10.3	14.7	18.3	18.3
	080.04 OFFICE	1.0	0.8	14.986275	**15**	54	0.28	54	0.28	54	0.22	54	0.22	3.5	8.5	12.0	15.0	15.0

ASHRAE 62.1-2010 Minimum Exhaust Air Requirements

System	Room Name	Room Exhaust Air Requirements: Room Type (Occupancy Category)	Exhaust Rate (cfm/ft2)	Exhaust Airflow Required (cfm)	Exhaust per Unit (e.g. Toilet, exh hood) (cfm)	# of Units (e.g. Toilet, exh hood)	Exhaust Airflow Required (cfm)	90.1 Category
	310.10 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	310.11 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	310.12 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	310.13 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	310.14 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	310.15 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	310.16 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	315 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	318 WKRM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	325 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	331 ELEC	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	333 IDF	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	334 RSTRM	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	336 STAIR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Stairs - Active
	341 RSTRM	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	351 FLY GAL	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	355 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	361 DMR RM	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	368 RSTRM	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	373 IDF	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	374 STAIR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Stairs - Active
	375 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	377 ELEC	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	378 RSTRM	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	382 CONF	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Conference/ Meeting/ Multipurpose
	385 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	390 OP OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Open plan
	390.1 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	390.2 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	390.3 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	390.4 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	390.5 WKRM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	396 LNGE	Kitchenettes	0.30	**136.2**	0.00	0.00	**0.0**	SPACE: Lounge/ Recreation
	397 LOBBY	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Lobby - Performing arts theater
	398 LOBBY	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Lobby - Performing arts theater
	400 LEC GAL	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Classroom/ Lecture/ Training
	401 STAIR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Stairs - Active
	403 LOBBY	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Lobby - Performing arts theater
	404 LOBBY	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Lobby - Performing arts theater
	407 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	410 MECH	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	416 TLT	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	418 RSTRM	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	420 MECH	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	423 STOR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage
	425 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	435 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	451 IDF	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	460 RCTL	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Audience/ Seating area - Performing arts theater
	462 STOR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage
	468 STAIR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Stairs - Active
	469 STAIR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Stairs - Active
	470 ELEC	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	473 JAN	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Active storage
	475 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	476 STOR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage
	479 STOR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage
	485 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	485 STOR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage
	486 RSTRM	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	493 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	496 LOBBY	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Lobby - Performing arts theater
	497 LOBBY	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Lobby - Performing arts theater
	498 STAIR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Stairs - Active
	E1 ELEV	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Elevators - Equipment
	E2 ELEV	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Elevators - Equipment
	E3 ELEV	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Elevators - Equipment
	M60 CRTL RM	User Specified Exhaust Rate	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Electrical/ Mechanical
	XXX PLNM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Void/Plenum
	XXX PLNM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Void/Plenum
	XXX PLNM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Void/Plenum
	XXX PLNM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Void/Plenum
	XXX PLNM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Void/Plenum
	XXX PLNM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Void/Plenum
	XXX PLNM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Void/Plenum
	XXX PLNM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Void/Plenum
AHU-2	System Totals	**- -**	**-**	**-**	**50.00**	**38.00**	**1,900.00**	
Audience Chamber								
	100.1 AUD	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Audience/ Seating area - Performing arts theater
	200.1 BAL 1	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Audience/ Seating area - Performing arts theater
	300.1 BAL 2	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Audience/ Seating area - Performing arts theater
	400.1 BAL 3	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Audience/ Seating area - Performing arts theater
	436 PIPE E	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage - Museum
	472 PIPE W	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage - Museum
	474 ORGAN	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage - Museum
	M54 CHOIR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage - Museum
	M55 CTWK	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	M56 CHMBR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage - Museum
	M58 CHMBR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage - Museum
	M59 SWELL	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage - Museum
AHU-3	System Totals			**-**	**50.00**	**-**	**-**	
Performance Spaces								
	040 REHERSAL	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Conference/ Meeting/ Multipurpose
	051.1 STAGE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Gymnasium/ Exercise center - Playing area
	240 CONF	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Conference/ Meeting/ Multipurpose
	260 FNDRS RM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Conference/ Meeting/ Multipurpose
AHU-5	System Totals			**2,208.41**	**50.00**	**19.00**	**950.00**	
Performance Support Spaces								
	003 RSTRM	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	003.1 TLT	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	029 TLT	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	030 GREEN RM	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Conference/ Meeting/ Multipurpose
	045 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	055 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	061 STOR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Inactive storage
	064 JAN	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Active storage
	065 CORR	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Corridor/ Transition
	066 TLT	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	070 DRESS	Locker rooms	0.50	**76.0**	0.00	0.00	**0.0**	SPACE: Dressing/ Locker/ Fitting room
	070.1 TLT	Toilets - public	0.00	**0.0**	50.00	1.00	**50.0**	SPACE: Restrooms
	072 DRESS	Locker rooms	0.50	**85.0**	0.00	0.00	**0.0**	SPACE: Dressing/ Locker/ Fitting room
	080 OP OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Open plan
	080.02 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed
	080.04 OFFICE	None	0.00	**0.0**	0.00	0.00	**0.0**	SPACE: Office - Enclosed

APPENDIX A

ASHRAE Standard 62.1-2010 Ventilation Rate Procedure: Zone Ventilation Calculations

ASHRAE 62.1-2010 Ventilation Rate Procedure: System Ventilation Calculations

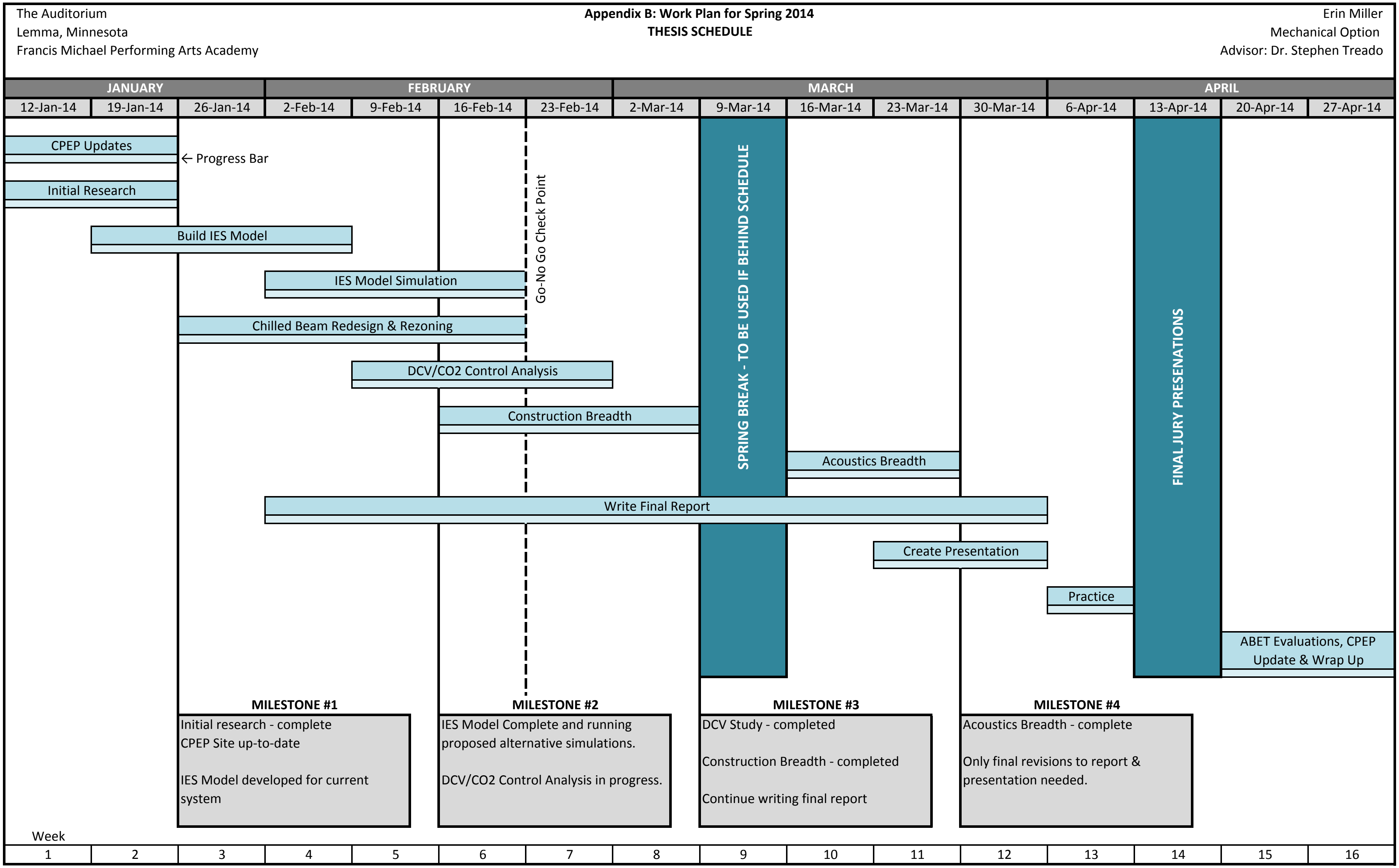
ASHRAE 62.1-2010 Minimum Exhaust Air Requirements

System	Room Name	Room Input Conditions: Floor Area (ft2) = Az	Design Occupancy peak total per space = Pz	Room Type (Occupancy Category)	Default Occ (people/1000 ft2)	Outdoor Air Rates: Rp (cfm/person)	Ra (cfm/ft2)	OA Required at Breathing Zone: Vbz = (Rp*Pz) + (Ra*Az) (cfm)
	080.06 WKRM	131.691	0.66	Office Buildings - Office Space	5	5	0.06	11.2
	082 OFFICE	238.213	1.19	Office Buildings - Office Space	5	5	0.06	20.2
	087 OFFICE	291.284	1.46	Office Buildings - Office Space	5	5	0.06	24.8
	093 RSTRM	612.314	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	097 TLT	60.07	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	098 RSTRM	404.348	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B02.1 STAIR	646.109	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B02.2 STAIR	830.282	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B05 ELEV RM	123.663	0.00	Miscellaneous Spaces - Elevator machine rooms	0	0	0.12	14.8
	B05 ELEV RM	3002.258	0.00	Miscellaneous Spaces - Elevator machine rooms	0	0	0.12	360.3
	B06 MECH	157.685	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	9.5
	B08.1 STOR	157.058	0.00	General - Storage rooms	0	0	0.12	18.8
	B08.2 STOR	195.595	0.00	General - Storage rooms	0	0	0.12	23.5
	B08.3 STOR	154.213	0.00	General - Storage rooms	0	0	0.12	18.5
	B08.4 STOR	157.627	0.00	General - Storage rooms	0	0	0.12	18.9
	B08.5 STOR	335.518	0.00	General - Storage rooms	0	0	0.12	40.3
	B09 MECH	185.328	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	11.1
	B10 MECH	1549.135	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	92.9
	B21 MDF	519.916	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	31.2
	B22 STOR	1472.367	0.00	General - Storage rooms	0	0	0.12	176.7
	B23 TLT	276.817	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B24 MECH	486.48	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	29.2
	B25 CORR	197.081	0.00	General - Corridors	0	0	0.06	11.8
	B26 MECH	82.016	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	4.9
	B27 DRESS	498.505	4.99	Sports and Entertainment - Health club/weight rooms	10	20	0.06	129.6
	B29 ELEC	500.216	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	30.0
	B30 UNCND	1229.858	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	B32 CORR	154.718	0.00	General - Corridors	0	0	0.06	9.3
	B34 DRESS	187.249	1.87	Sports and Entertainment - Health club/weight rooms	10	20	0.06	48.7
	B35 CORR	409.071	0.00	General - Corridors	0	0	0.06	24.5
	B36 TLT	99.014	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B37 CORR	351.201	0.00	General - Corridors	0	0	0.06	21.1
	B38 STAIR	162.81	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B40 DRESS	187.322	1.87	Sports and Entertainment - Health club/weight rooms	10	20	0.06	48.7
	B41 UNCND	423.293	0.00	Unoccupied thermal zone - e.g., wall void, service shaft, chilled slab, earth-tube,	0	0	0	0.0
	B42 TLT	94.899	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B44 DRESS	135.413	1.35	Sports and Entertainment - Health club/weight rooms	10	20	0.06	35.2
	B45 CORR	445.347	0.00	General - Corridors	0	0	0.06	26.7
	B46 TLT	130.331	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B47 TLT	60.583	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B48 DRESS	167.771	1.68	Sports and Entertainment - Health club/weight rooms	10	20	0.06	43.6
	B50 TLT	123.343	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B52 DRESS	161.187	1.61	Sports and Entertainment - Health club/weight rooms	10	20	0.06	41.9
	B54 TLT	144.14	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B56 DRESS	238.72	2.39	Sports and Entertainment - Health club/weight rooms	10	20	0.06	62.1
	B58 TLT	114.978	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B60 DRESS	562.519	5.63	Sports and Entertainment - Health club/weight rooms	10	20	0.06	146.3
	B62 TLT	312.642	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B64 DRESS	597.501	5.98	Sports and Entertainment - Health club/weight rooms	10	20	0.06	155.4
	B65 CORR	675.056	0.00	General - Corridors	0	0	0.06	40.5
	B66 TLT	302.9	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B67 CORR	275.493	0.00	General - Corridors	0	0	0.06	16.5
	B68.1 MECH	243.305	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	14.6
	B68.2 MECH	1186.331	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	71.2
	B69 MUSIC	226.833	0.00	General - Storage rooms	0	0	0.12	27.2
	B70 ELEC	565.211	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	33.9
	B72 STAIR	93.383	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B74 LIFT	109.167	0.00	Miscellaneous Spaces - Elevator machine rooms	0	0	0.12	13.1
	B76 STAIR	226.738	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B78 ELEC	120.671	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	7.2
	B80 JAN	220.377	0.00	General - Storage rooms	0	0	0.12	26.4
	B82 AV	236.626	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	14.2
	B83 MUSIC	238.931	0.00	General - Storage rooms	0	0	0.12	28.7
	B84 CORR	140.141	0.00	General - Corridors	0	0	0.06	8.4
	B84.1 MECH	88.601	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	5.3
	B85 CORR	587.002	0.00	General - Corridors	0	0	0.06	35.2
	B86 CORR	110.841	0.00	General - Corridors	0	0	0.06	6.7
	B87 ELEV RM	104.954	0.00	Miscellaneous Spaces - Elevator machine rooms	0	0	0.12	12.6
	B88 TLT	69.414	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B89 ELEC	223.728	0.00	Miscellaneous Spaces - Electrical Equipment rooms	0	0	0.06	13.4
	B90 LAUNDRY	145.023	0.00	General - Storage rooms	0	0	0.12	17.4
	B92 STOR	1145.445	0.00	General - Storage rooms	0	0	0.12	137.5
	B99.1 STAIR	880.053	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B99.2 STAIR	822.517	0.00	Unoccupied building zone - e.g. stairs, attic, restroom, garage	0	0	0	0.0
	B99.3 STOR	300.689	0.00	General - Storage rooms	0	0	0.12	36.1
	036 CORR	318.301	0.00	General - Corridors	0	0	0.06	19.1
	020 OFFICE	198.526	0.99	Office Buildings - Office Space	5	5	0.06	16.9
	020.1 OFFICE	143.709	0.72	Office Buildings - Office Space	5	5	0.06	12.2
	020.2 OP OFFICE	710.302	3.55	Office Buildings - Office Space	5	5	0.06	60.4
	020.4 OFFICE	143.283	0.72	Office Buildings - Office Space	5	5	0.06	12.2
	020.6 OFFICE	177.731	0.89	Office Buildings - Office Space	5	5	0.06	15.1
	035 CORR	263.048	0.00	General - Corridors	0	0	0.06	15.8
	B43 LOCKER	374.604	3.75	Sports and Entertainment - Health club/weight rooms	10	20	0.06	97.4
	B49 BKRM	220.833	2.21	Sports and Entertainment - Health club/weight rooms	10	20	0.06	57.4
	B51 OFFICE	138.903	0.70	Office Buildings - Office Space	5	5	0.06	11.8
	B53 WKRM	160.943	3.22	Educational Facilities - Wood/metal shop	20	10	0.18	61.2
	B57 WKRM	231.087	4.62	Educational Facilities - Wood/metal shop	20	10	0.18	87.8
	B59 OFFICE	131.104	0.66	Office Buildings - Office Space	5	5	0.06	11.1
	B61 WKRM	190.844	3.82	Educational Facilities - Wood/metal shop	20	10	0.18	72.5
	B63 WKRM	180.247	3.61	Educational Facilities - Wood/metal shop	20	10	0.18	68.5
	032 CORR	109.463	0.00	General - Corridors	0	0	0.06	6.6

Room Name	Air Distribution Effectiveness: Ez, Cooling	Ez, Heating	62.1 Min Room Supplied OA Rate: Voz = Vbz/Ez	Design Case Room Supplied OA Rate: Voz * Including "Increased Ventilation %"	Primary Outdoor Air Fraction (Using Table 6-3 Method): Heating airflow Min Condition (min flow per heating load when SAT > RAT) (cfm), Vpz	Heating Zone Primary OA Fraction Zp = Voz/Vpz	Heating Adjusted Flow Rate	Heating Adjusted Zp	Cooling airflow Min Condition (min flow per cooling load and turndown when SAT < RAT) (cfm), Vpz	Cooling Zone Primary OA Fraction Zp = Voz/Vpz	Cooling Min Adjusted Flow Rate	Cooling Adjusted Zp	Uncorrected OA Rate: Vou, Occupant Portion (cfm)	Vou, Area Portion (cfm)	Vou, SUM of Occupant and Area Portions (cfm)	Zone Portion of Vot: 62.1 Min Vot	Design Case Vot *Including "Increased Ventilation %"
080.06 WKRM	1.0	0.8	13.989325	14	51	0.27	51	0.27	51	0.22	51	0.22	3.3	7.9	11.2	14.0	14.0
082 OFFICE	1.0	0.8	25.309725	25	36	0.71	36	0.71	36	0.57	36	0.57	6.0	14.3	20.2	25.3	25.3
087 OFFICE	1.0	0.8	30.9463	31	48	0.64	48	0.64	48	0.51	48	0.51	7.3	17.5	24.8	30.9	30.9
093 RSTRM	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
097 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
098 RSTRM	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B02.1 STAIR	1.0	0.8	0	0	109	0.00	109	0.00	109	0.00	109	0.00	0.0	0.0	0.0	0.0	0.0
B02.2 STAIR	1.0	0.8	0	0	657	0.00	657	0.00	657	0.00	657	0.00	0.0	0.0	0.0	0.0	0.0
B05 ELEV RM	1.0	0.8	18.54945	19	178	0.10	178	0.10	178	0.08	178	0.08	0.0	14.8	14.8	18.5	18.5
B05 ELEV RM	1.0	0.8	450.3387	450	3958	0.11	3958	0.11	3958	0.09	3958	0.09	0.0	360.3	360.3	450.3	450.3
B06 MECH	1.0	0.8	11.826375	12	35	0.34	35	0.34	35	0.27	35	0.27	0.0	9.5	9.5	11.8	11.8
B08.1 STOR	1.0	0.8	23.5587	24	33	0.72	33	0.72	33	0.57	33	0.57	0.0	18.8	18.8	23.6	23.6
B08.2 STOR	1.0	0.8	29.33925	29	41	0.72	41	0.72	41	0.57	41	0.57	0.0	23.5	23.5	29.3	29.3
B08.3 STOR	1.0	0.8	23.13195	23	33	0.71	33	0.71	33	0.56	33	0.56	0.0	18.5	18.5	23.1	23.1
B08.4 STOR	1.0	0.8	23.64405	24	34	0.69	34	0.69	34	0.55	34	0.55	0.0	18.9	18.9	23.6	23.6
B08.5 STOR	1.0	0.8	50.3277	50	81	0.62	81	0.62	81	0.50	81	0.50	0.0	40.3	40.3	50.3	50.3
B09 MECH	1.0	0.8	13.8996	14	59	0.23	59	0.23	59	0.19	59	0.19	0.0	11.1	11.1	13.9	13.9
B10 MECH	1.0	0.8	116.185125	116	253	0.46	253	0.46	253	0.37	253	0.37	0.0	92.9	92.9	116.2	116.2
B21 MDF	1.0	0.8	38.9937	39	35	1.10	39	1.00	35	0.88	39	0.80	0.0	31.2	31.2	39.0	39.0
B22 STOR	1.0	0.8	220.85505	221	71	3.09	221	1.00	71	2.48	221	0.80	0.0	176.7	176.7	220.9	220.9
B23 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B24 MECH	1.0	0.8	36.486	36	32	1.15	36	1.00	32	0.92	36	0.80	0.0	29.2	29.2	36.5	36.5
B25 CORR	1.0	0.8	14.781075	15	11	1.31	15	1.00	11	1.05	15	0.80	0.0	11.8	11.8	14.8	14.8
B26 MECH	1.0	0.8	6.1512	6	8	0.75	8	0.75	8	0.60	8	0.60	0.0	4.9	4.9	6.2	6.2
B27 DRESS	1.0	0.8	162.012875	162	249	0.65	249	0.65	249	0.52	249	0.52	99.7	29.9	129.6	162.0	162.0
B29 ELEC	1.0	0.8	37.5162	38	31	1.23	38	1.00	31	0.98	38	0.80	0.0	30.0	30.0	37.5	37.5
B30 UNCND	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B32 CORR	1.0	0.8	11.60385	12	11	1.07	12	1.00	11	0.85	12	0.80	0.0	9.3	9.3	11.6	11.6
B34 DRESS	1.0	0.8	60.843675	61	94	0.65	94	0.65	94	0.52	94	0.52	37.4	11.2	48.7	60.8	60.8
B35 CORR	1.0	0.8	30.680325	31	20	1.50	31	1.00	20	1.20	31	0.80	0.0	24.5	24.5	30.7	30.7
B36 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B37 CORR	1.0	0.8	26.340075	26	17	1.57	26	1.00	17	1.26	26	0.80	0.0	21.1	21.1	26.3	26.3
B38 STAIR	1.0	0.8	0	0	14	0.00	14	0.00	14	0.00	14	0.00	0.0	0.0	0.0	0.0	0.0
B40 DRESS	1.0	0.8	60.87415	61	94	0.65	94	0.65	94	0.52	94	0.52	37.5	11.2	48.7	60.9	60.9
B41 UNCND	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B42 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B44 DRESS	1.0	0.8	44.005975	44	68	0.65	68	0.65	68	0.52	68	0.52	27.1	8.1	35.2	44.0	44.0
B45 CORR	1.0	0.8	33.401025	33	24	1.40	33	1.00	24	1.12	33	0.80	0.0	26.7	26.7	33.4	33.4
B46 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B47 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B48 DRESS	1.0	0.8	54.532825	55	84	0.65	84	0.65	84	0.52	84	0.52	33.6	10.1	43.6	54.5	54.5
B50 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B52 DRESS	1.0	0.8	52.389025	52	81	0.65	81	0.65	81	0.52	81	0.52	32.2	9.7	41.9	52.4	52.4
B54 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B56 DRESS	1.0	0.8	77.579	78	119	0.65	119	0.65	119	0.52	119	0.52	47.7	14.3	62.1	77.6	77.6
B58 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B60 DRESS	1.0	0.8	182.813925	183	281	0.65	281	0.65	281	0.52	281	0.52	112.5	33.8	146.3	182.8	182.8
B62 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B64 DRESS	1.0	0.8	194.187575	194	299	0.65	299	0.65	299	0.52	299	0.52	119.5	35.9	155.4	194.2	194.2
B65 CORR	1.0	0.8	50.6292	51	42	1.22	51	1.00	42	0.97	51	0.80	0.0	40.5	40.5	50.6	50.6
B66 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B67 CORR	1.0	0.8	20.661975	21	20	1.06	21	1.00	20	0.85	21	0.80	0.0	16.5	16.5	20.7	20.7
B68.1 MECH	1.0	0.8	18.247875	18	25	0.74	25	0.74	25	0.59	25	0.59	0.0	14.6	14.6	18.2	18.2
B68.2 MECH	1.0	0.8	88.974825	89	117	0.76	117	0.76	117	0.61	117	0.61	0.0	71.2	71.2	89.0	89.0
B69 MUSIC	1.0	0.8	34.02495	34	16	2.19	34	1.00	16	1.75	34	0.80	0.0	27.2	27.2	34.0	34.0
B70 ELEC	1.0	0.8	42.390825	42	53	0.80	53	0.80	53	0.64	53	0.64	0.0	33.9	33.9	42.4	42.4
B72 STAIR	1.0	0.8	0	0	15	0.00	15	0.00	15	0.00	15	0.00	0.0	0.0	0.0	0.0	0.0
B74 LIFT	1.0	0.8	16.37505	16	141	0.12	141	0.12	141	0.09	141	0.09	0.0	13.1	13.1	16.4	16.4
B76 STAIR	1.0	0.8	0	0	17	0.00	17	0.00	17	0.00	17	0.00	0.0	0.0	0.0	0.0	0.0
B78 ELEC	1.0	0.8	9.050325	9	13	0.70	13	0.70	13	0.56	13	0.56	0.0	7.2	7.2	9.1	9.1
B80 JAN	1.0	0.8	33.05655	33	17	1.91	33	1.00	17	1.53	33	0.80	0.0	26.4	26.4	33.1	33.1
B82 AV	1.0	0.8	17.74695	18	19	0.95	19	0.95	19	0.76	19	0.76	0.0	14.2	14.2	17.7	17.7
B83 MUSIC	1.0	0.8	35.83965	36	17	2.06	36	1.00	17	1.65	36	0.80	0.0	28.7	28.7	35.8	35.8
B84 CORR	1.0	0.8	10.510575	11	12	0.88	12	0.88	12	0.70	12	0.70	0.0	8.4	8.4	10.5	10.5
B84.1 MECH	1.0	0.8	6.645075	7	7	0.89	7	0.89	7	0.71	7	0.71	0.0	5.3	5.3	6.6	6.6
B85 CORR	1.0	0.8	44.02515	44	40	1.11	44	1.00	40	0.89	44	0.80	0.0	35.2	35.2	44.0	44.0
B86 CORR	1.0	0.8	8.313075	8	5	1.55	8	1.00	5	1.24	8	0.80	0.0	6.7	6.7	8.3	8.3
B87 ELEV RM	1.0	0.8	15.7431	16	134	0.12	134	0.12	134	0.09	134	0.09	0.0	12.6	12.6	15.7	15.7
B88 TLT	1.0	0.8	0	0	0	0.00	0	0.00	0	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0
B89 ELEC	1.0	0.8	16.7796	17	17	0.96	17	0.96	17	0.77	17	0.77	0.0	13.4	13.4	16.8	16.8
B90 LAUNDRY	1.0	0.8	21.75345	22	7	3.15	22	1.00	7	2.52	22	0.80	0.0	17.4	17.4	21.8	21.8
B92 STOR	1.0	0.8	171.81675	172	55	3.15	172	1.00	55	2.52	172	0.80	0.0	137.5	137.5	171.8	171.8
B99.1 STAIR	1.0	0.8	0	0	114	0.00	114	0.00	114	0.00	114	0.00	0.0	0.0	0.0	0.0	0.0
B99.2 STAIR	1.0	0.8	0	0	679	0.00	679	0.00	679	0.00	679	0.00	0.0	0.0	0.0	0.0	0.0
B99.3 STOR	1.0	0.8	45.10335	45	21	2.18	45	1.00	21	1.74	45	0.80	0.0	36.1	36.1	45.1	45.1
036 CORR	1.0	0.8	23.872575	24	38	0.63	38	0.63	38	0.50	38	0.50	0.0	19.1	19.1	23.9	23.9
020 OFFICE	1.0	0.8	21.0957	21	28	0.76	28	0.76	28	0.61	28	0.61	5.0	11.9	16.9	21.1	21.1
020.1 OFFICE	1.0	0.8	15.271925	15	21	0.72	21	0.72	21	0.58	21	0.58	3.6	8.6	12.2	15.3	15.3
020.2 OP OFFICE	1.0	0.8	75.47265	75	146	0.52	146	0.52	146	0.41	146	0.41	17.8	42.6	60.4	75.5	75.5
020.4 OFFICE	1.0	0.8	15.221225	15	56	0.27	56	0.27	56	0.22	56	0.22	3.6	8.6	12.2	15.2	15.2
020.6 OFFICE	1.0	0.8	18.886075	19	61	0.31	61	0.31	61	0.25	61	0.25	4.4	10.7	15.1	18.9	18.9
035 CORR	1.0	0.8	19.7286	20	19	1.03	20	1.00	19	0.82	20	0.80	0.0	15.8	15.8	19.7	19.7
B43 LOCKER	1.0	0.8	121.7453	122	187	0.65	187	0.65	187	0.52	187	0.52	74.9	22.5	97.4	121.7	121.7
B49 BKRM	1.0	0.8	71.762475	72	110	0.65	110	0.65	110	0.52	110	0.52	44.2	13.2	57.4	71.8	71.8
B51 OFFICE	1.0	0.8	14.761475	15	19	0.76	19	0.76	19	0.61	19	0.61	3.5	8.3	11.8	14.8	14.8
B53 WKRM	1.0	0.8	76.449675	76	80	0.95	80	0.95	80	0.76	80	0.76	32.2	29.0	61.2	76.4	76.4
B57 WKRM	1.0	0.8	109.769575	110	116	0.95	116	0.95	116	0.76	116	0.76	46.2	41.6	87.8	109.8	109.8
B59 OFFICE	1.0	0.8	13.9328	14	19	0.74	19	0.74	19	0.59	19	0.59	3.3	7.9	11.1	13.9	13.9
B61 WKRM	1.0	0.8	90.6524	91	95	0.95	95	0.95	95	0.76	95	0.76	38.2	34.4	72.5	90.7	90.7
B63 WKRM	1.0	0.8	85.618075	86	90	0.95	90	0.95	90	0.76	90	0.76	36.1	32.4	68.5	85.6	85.6
032 CORR	1.0	0.8	8.209725	8	10	0.79	10	0.79	10	0.63	10	0.63	0.0	6.6	6.6	8.2	8.2

Room Name	Room Exhaust Air Requirements: Room Type (Occupancy Category)	Exhaust Rate (cfm/ft2)	Exhaust Airflow Required (cfm)	Exhaust per Unit (e.g. Toilet, exh hood) (cfm)	# of Units (e.g. Toilet, exh hood)	Exhaust Airflow Required (cfm)	90.1 Category
080.06 WKRM	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
082 OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
087 OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
093 RSTRM	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
097 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
098 RSTRM	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B02.1 STAIR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
B02.2 STAIR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
B05 ELEV RM	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Elevators - Equipment
B05 ELEV RM	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Elevators - Equipment
B06 MECH	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B08.1 STOR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
B08.2 STOR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
B08.3 STOR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
B08.4 STOR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
B08.5 STOR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
B09 MECH	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B10 MECH	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B21 MDF	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B22 STOR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
B23 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B24 MECH	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B25 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B26 MECH	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B27 DRESS	Locker rooms	0.50	249.3	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B29 ELEC	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B30 UNCND	None	0.00	0.0	0.00	0.00	0.0	SPACE: Void/Plenum
B32 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B34 DRESS	Locker rooms	0.50	93.6	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B35 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B36 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B37 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B38 STAIR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
B40 DRESS	Locker rooms	0.50	93.7	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B41 UNCND	None	0.00	0.0	0.00	0.00	0.0	SPACE: Void/Plenum
B42 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B44 DRESS	Locker rooms	0.50	67.7	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B45 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B46 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B47 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B48 DRESS	Locker rooms	0.50	83.9	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B50 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B52 DRESS	Locker rooms	0.50	80.6	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B54 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B56 DRESS	Locker rooms	0.50	119.4	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B58 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B60 DRESS	Locker rooms	0.50	281.3	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B62 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B64 DRESS	Locker rooms	0.50	298.8	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B65 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B66 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B67 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B68.1 MECH	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B68.2 MECH	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B69 MUSIC	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage - Museum
B70 ELEC	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B72 STAIR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
B74 LIFT	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Elevators - Equipment
B76 STAIR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
B78 ELEC	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B80 JAN	None	0.00	0.0	0.00	0.00	0.0	SPACE: Active storage
B82 AV	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B83 MUSIC	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage - Museum
B84 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B84.1 MECH	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B85 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B86 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B87 ELEV RM	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Elevators - Equipment
B88 TLT	Toilets - public	0.00	0.0	50.00	1.00	50.0	SPACE: Restrooms
B89 ELEC	User Specified Exhaust Rate	0.00	0.0	0.00	0.00	0.0	SPACE: Electrical/ Mechanical
B90 LAUNDRY	None	0.00	0.0	0.00	0.00	0.0	SPACE: Active storage
B92 STOR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
B99.1 STAIR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
B99.2 STAIR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Stairs - Active
B99.3 STOR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Inactive storage
036 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
020 OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
020.1 OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
020.2 OP OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Open plan
020.4 OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
020.6 OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
035 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition
B43 LOCKER	Locker rooms	0.50	187.3	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B49 BKRM	Locker rooms	0.50	110.4	0.00	0.00	0.0	SPACE: Dressing/ Locker/ Fitting room
B51 OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
B53 WKRM	Woodwork shop/classrooms	0.50	80.5	0.00	0.00	0.0	SPACE: Workshop
B57 WKRM	Woodwork shop/classrooms	0.50	115.5	0.00	0.00	0.0	SPACE: Workshop
B59 OFFICE	None	0.00	0.0	0.00	0.00	0.0	SPACE: Office - Enclosed
B61 WKRM	Woodwork shop/classrooms	0.50	95.4	0.00	0.00	0.0	SPACE: Workshop
B63 WKRM	Woodwork shop/classrooms	0.50	90.1	0.00	0.00	0.0	SPACE: Workshop
032 CORR	None	0.00	0.0	0.00	0.00	0.0	SPACE: Corridor/ Transition

Copy formulas down if additional rows are needed


The Auditorium
Lemma, Minnesota
Francis Michael Performing Arts Academy
Appendix B: Work Plan for Spring 2014
THESIS SCHEDULE
Erin Miller
Mechanical Option
Advisor: Dr. Stephen Treado
JANUARY
FEBRUARY
MARCH
APRIL
12-Jan-14
19-Jan-14
26-Jan-14
2-Feb-14
9-Feb-14
16-Feb-14
23-Feb-14
2-Mar-14
9-Mar-14
16-Mar-14
23-Mar-14
30-Mar-14
6-Apr-14
13-Apr-14
20-Apr-14
27-Apr-14
CPEP Updates
Progress Bar
Initial Research
Build IES Model
IES Model Simulation
Go-No Go Check Point
Chilled Beam Redesign & Rezoning
DCV/CO2 Control Analysis
Construction Breadth
SPRING BREAK - TO BE USED IF BEHIND SCHEDULE
Acoustics Breadth
Write Final Report
Create Presentation
Practice
FINAL JURY PRESENATIONS
ABET Evaluations, CPEP Update & Wrap Up
MILESTONE #1
Initial research - complete
CPEP Site up-to-date
IES Model developed for current system
MILESTONE #2
IES Model Complete and running proposed alternative simulations.
DCV/CO2 Control Analysis in progress.
MILESTONE #3
DCV Study - completed
Construction Breadth - completed
Continue writing final report
MILESTONE #4
Acoustics Breadth - complete
Only final revisions to report & presentation needed.
Week
1
2
3
4
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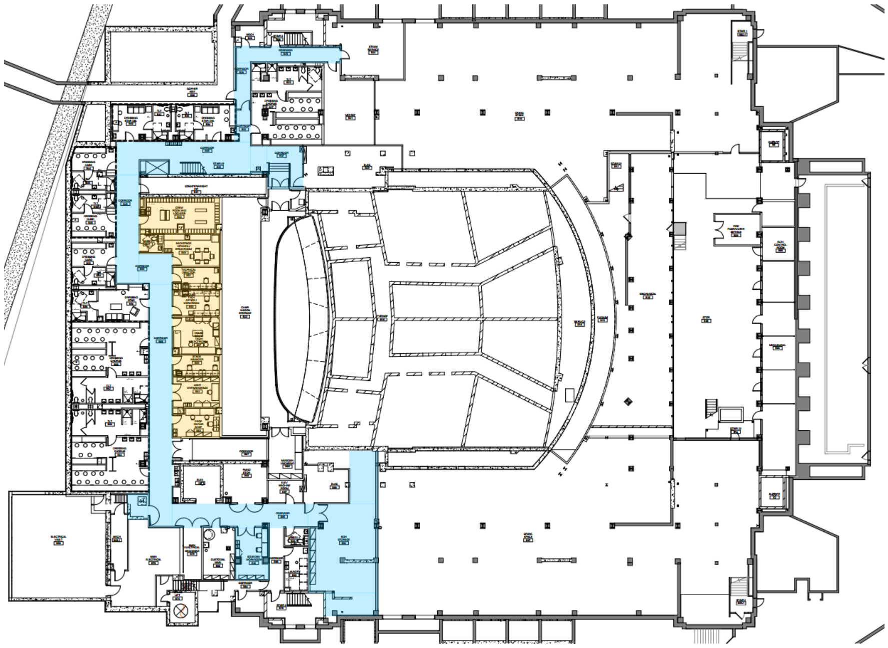
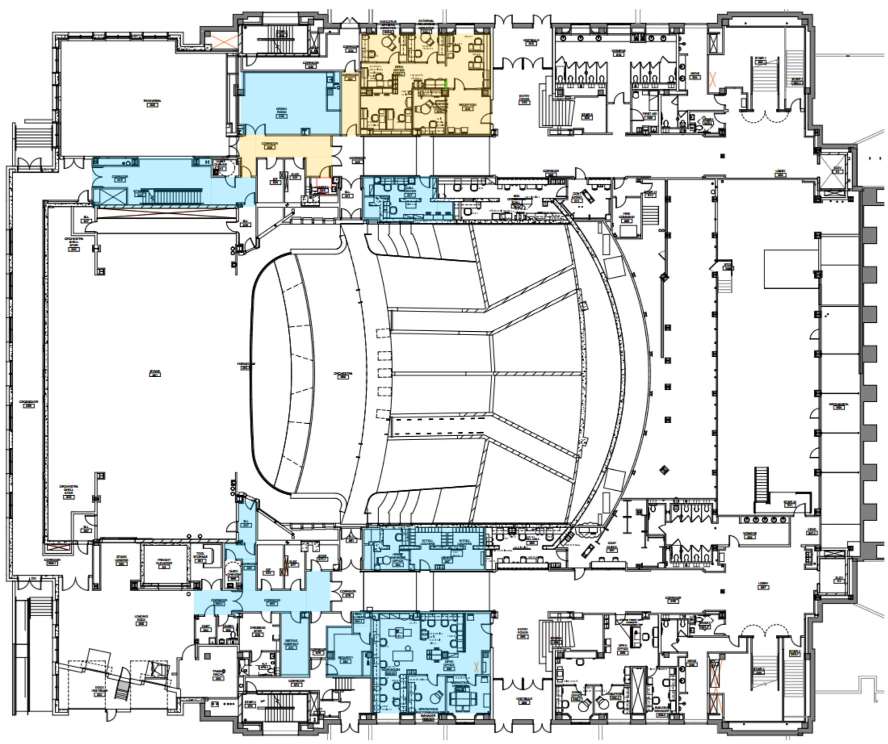
15
16

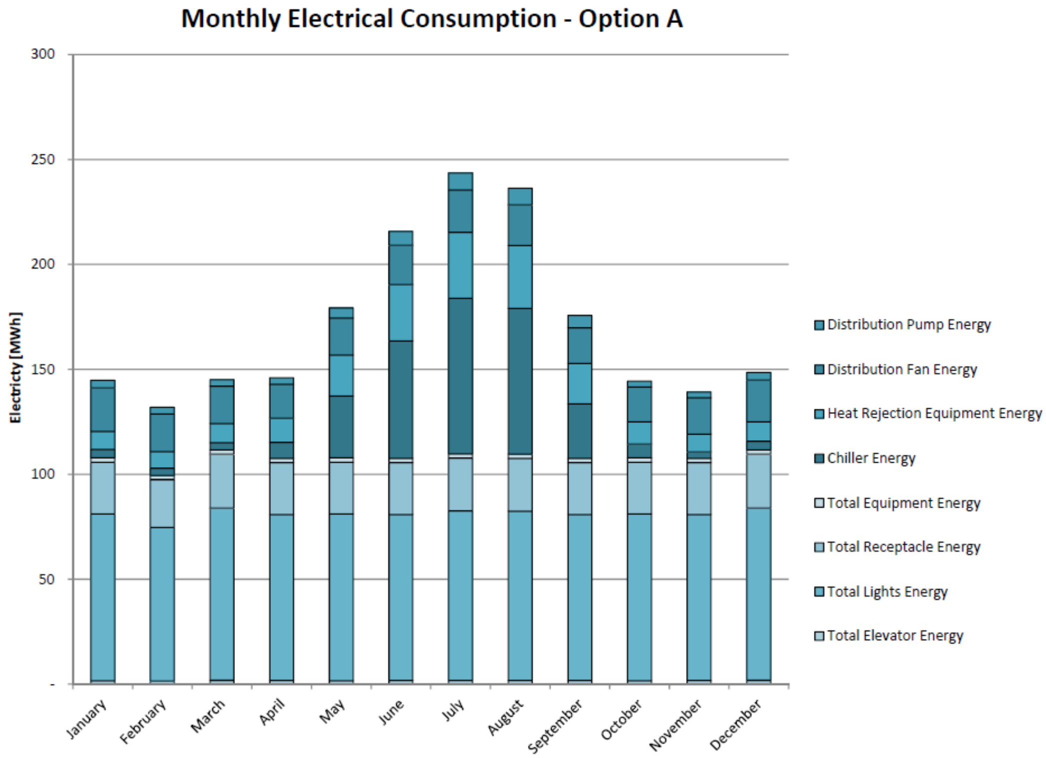
Option A Basement Floor Plan (Figure 22) Baseline ACB (Orange), Option A ACB (Blue)



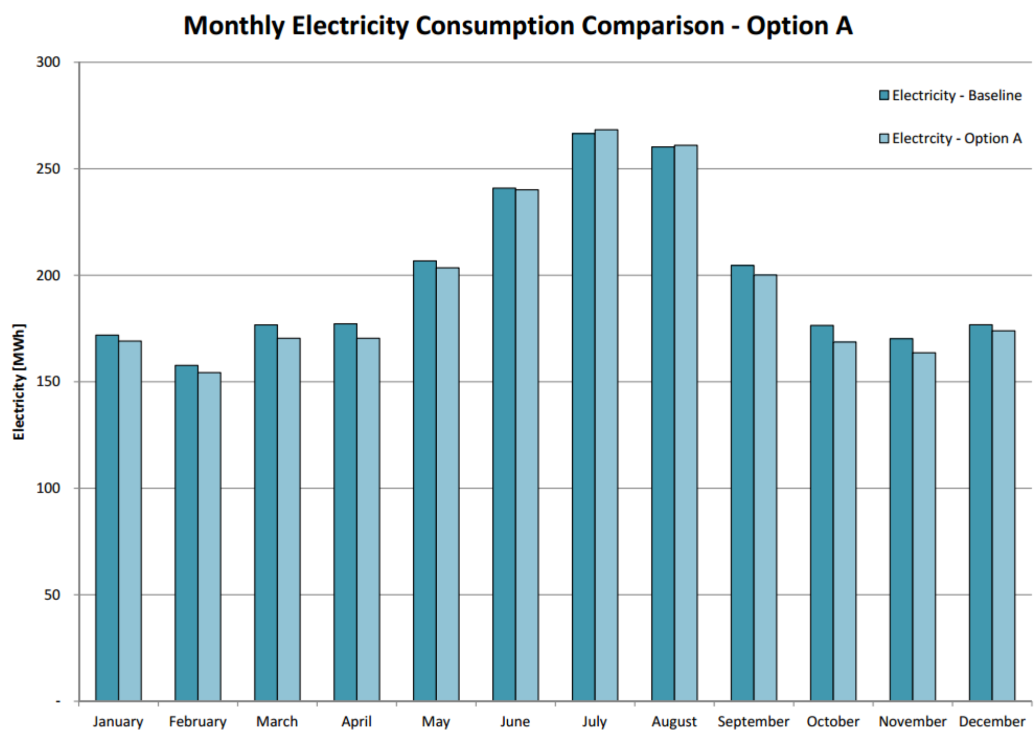
Option A Basement Floor Plan (Figure 23) Baseline ACB (Orange), Option A ACB (Blue)



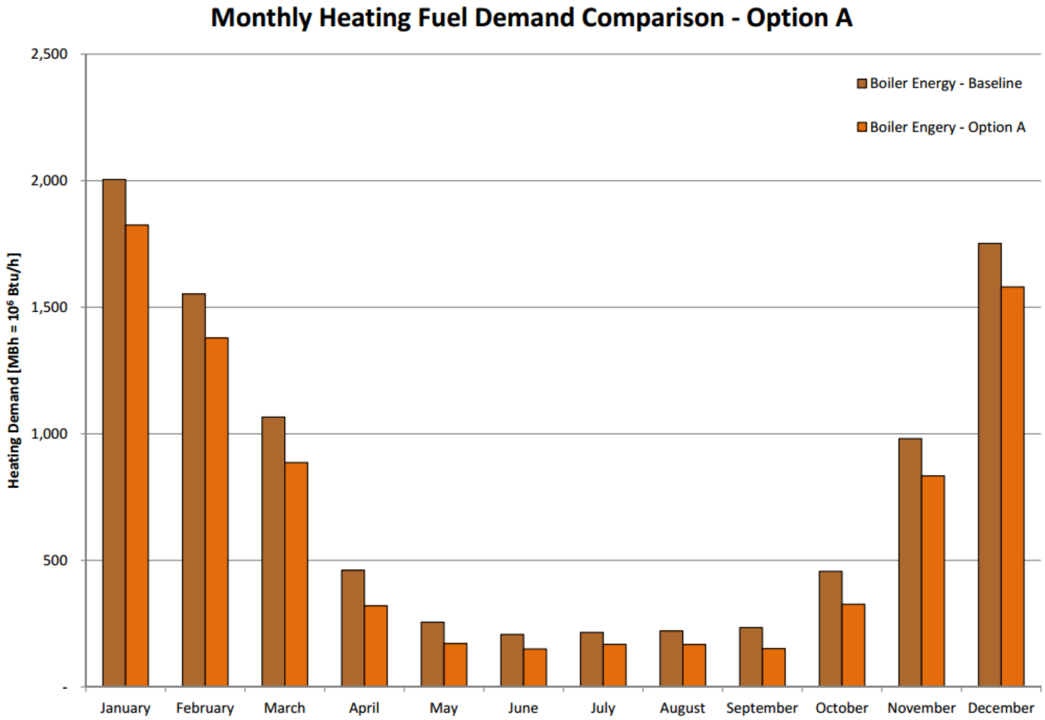
Modeled Monthly Electrical Consumption - Option A (Figure 24)



Modeled Monthly Electrical Consumption - Baseline vs. Option A (Figure 25)

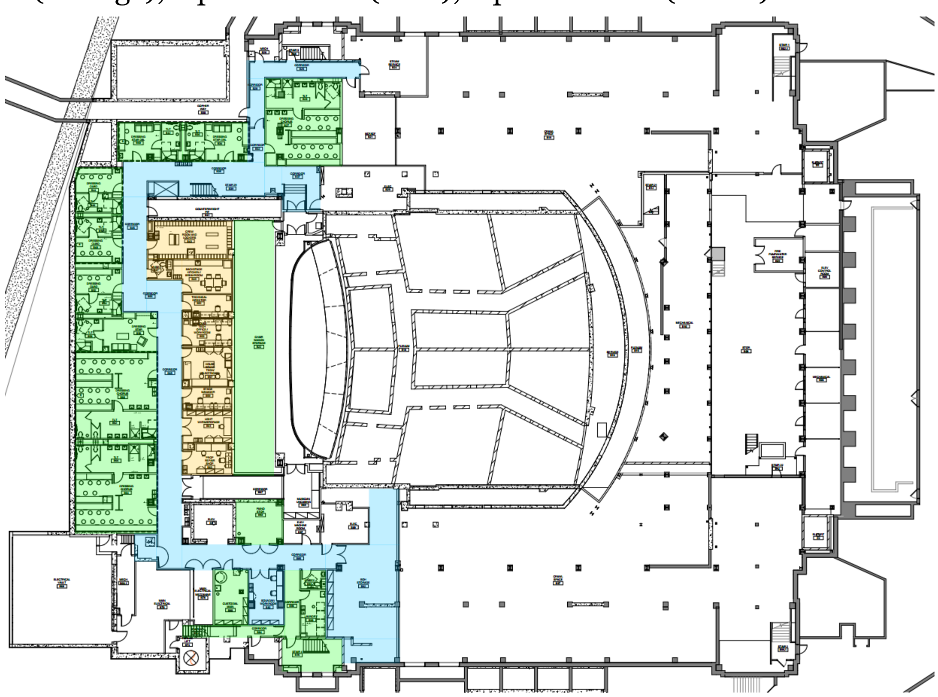


Modeled Monthly Heating Demand - Baseline vs. Option A (Figure 26)



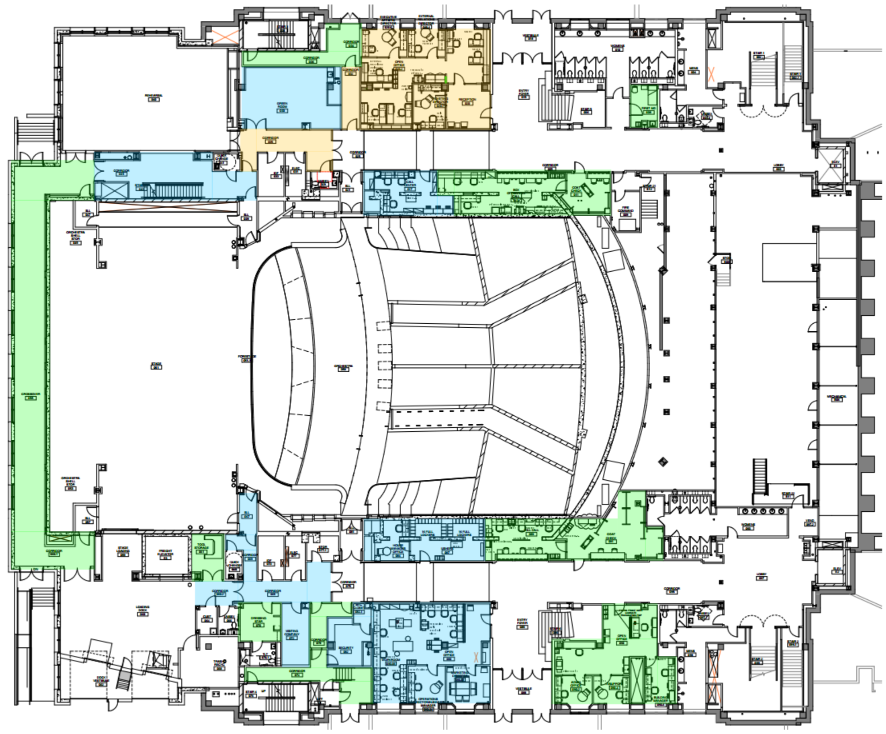
Option B Basement Floor Plan (Figure 27)

Baseline ACB (Orange), Option A ACB (Blue), Option B ACB (Green)



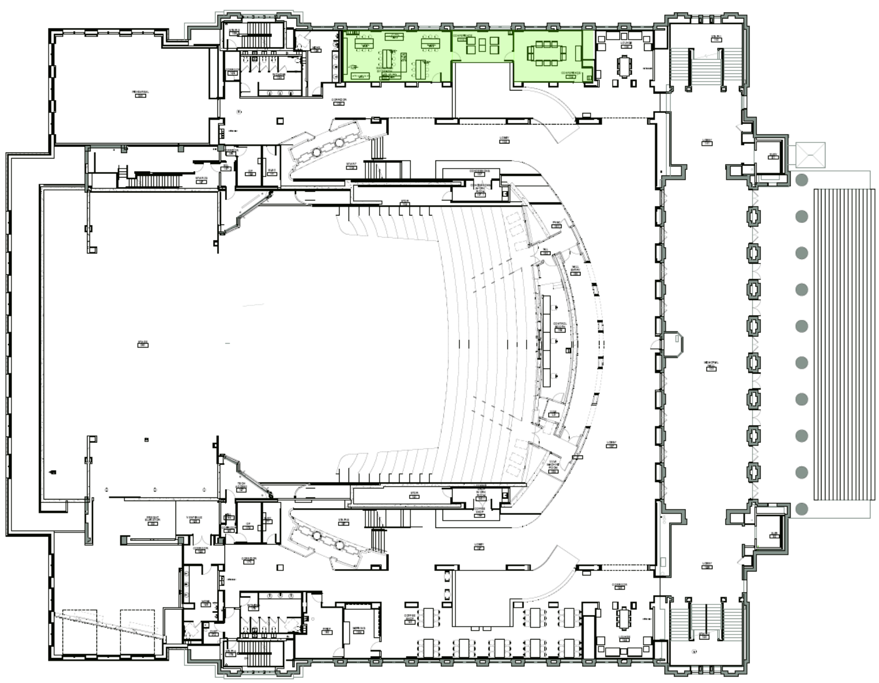
Option B Ground Floor Plan (Figure 28)

Baseline ACB (Orange), Option A ACB (Blue), Option B ACB (Green)



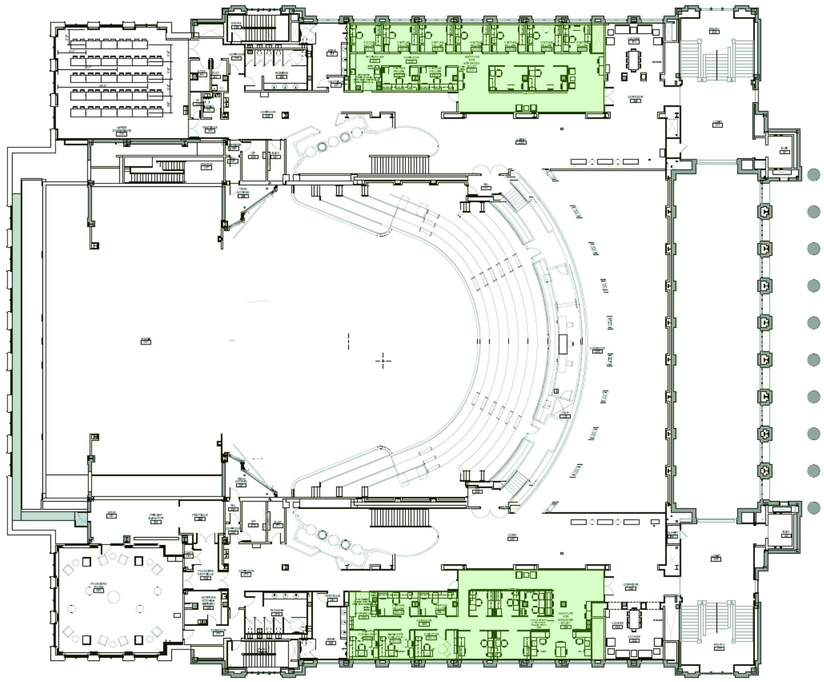
Option B First Floor Plan (Figure 29)

Baseline ACB (Orange), Option A ACB (Blue), Option B ACB (Green)



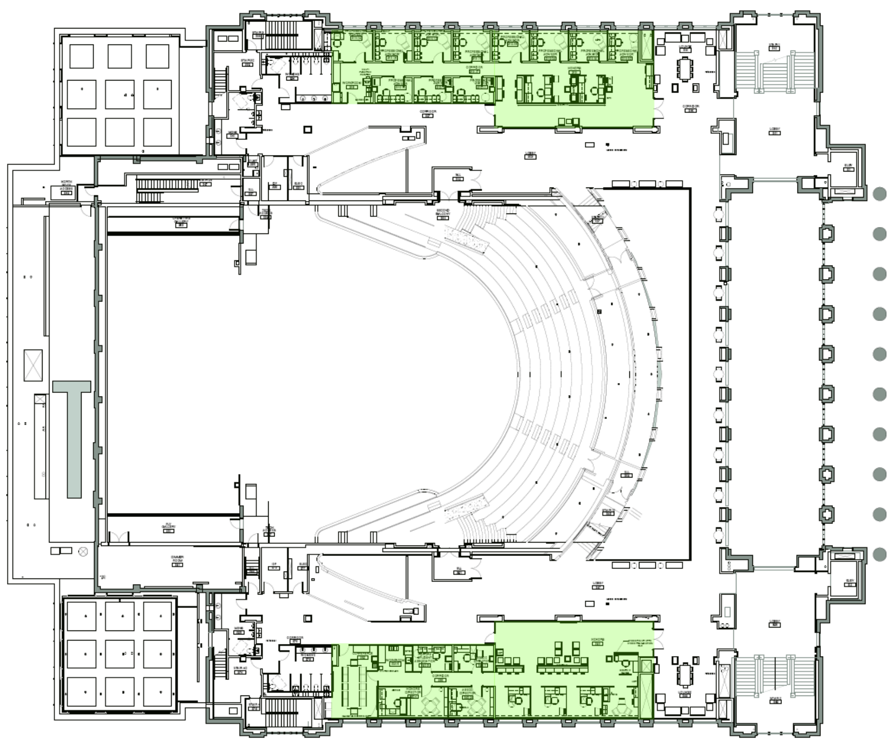
Option B Second Floor Plan (Figure 30)

Baseline ACB (Orange), Option A ACB (Blue), Option B ACB (Green)

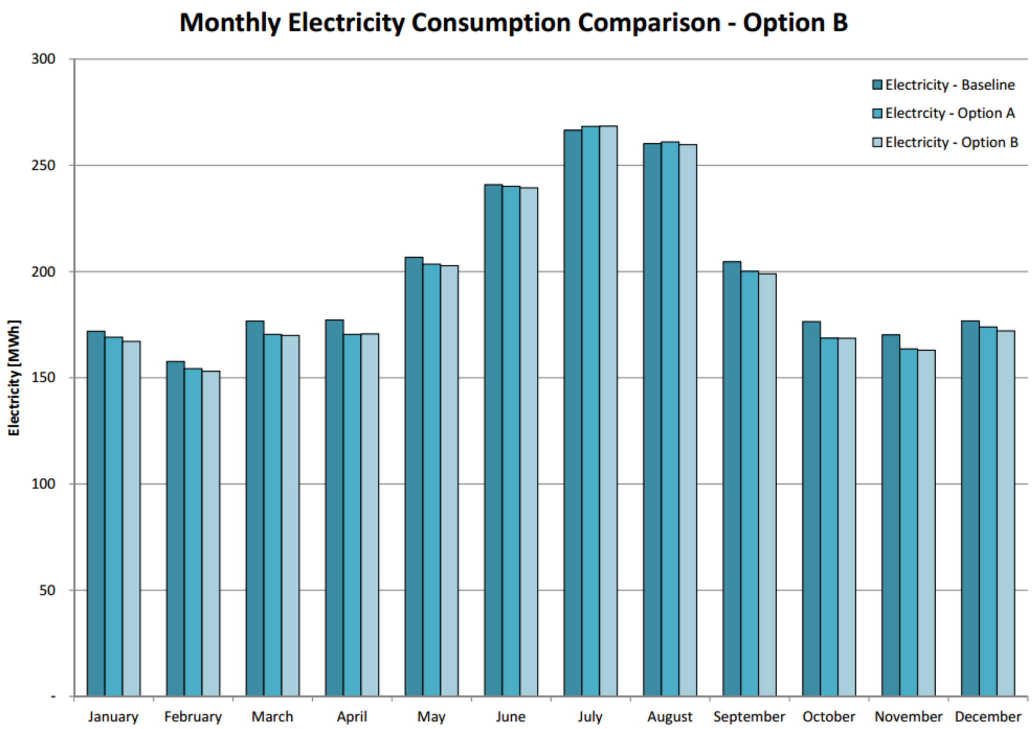


Option B Third Floor Plan (Figure 31)

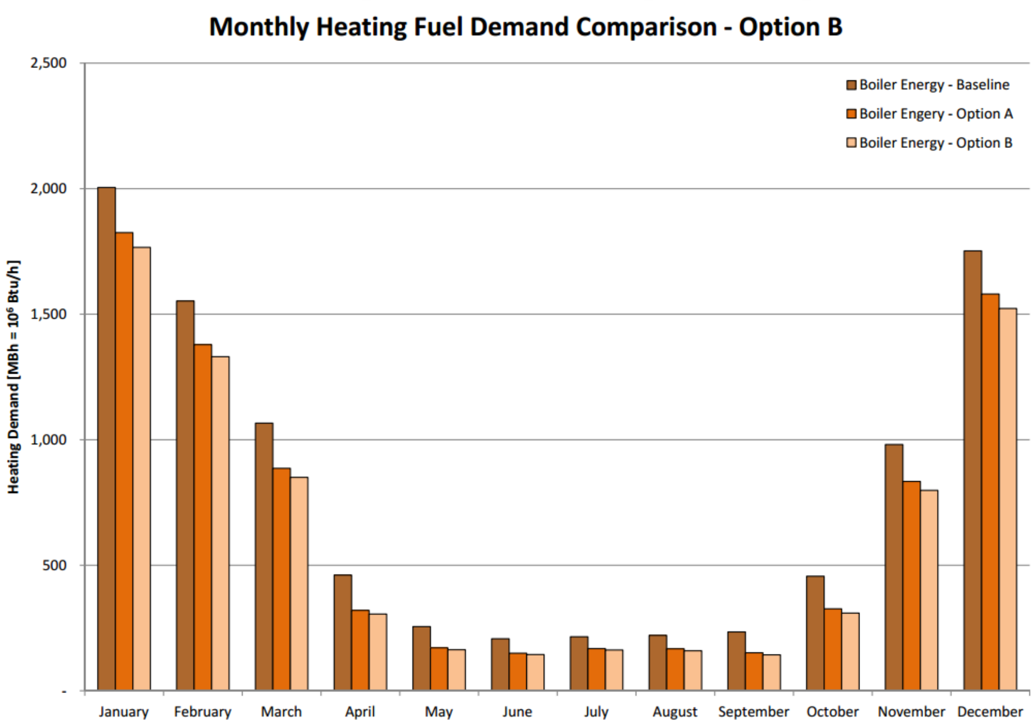
Baseline ACB (Orange), Option A ACB (Blue), Option B ACB (Green)



Modeled Monthly Electrical Consumption - Baseline vs. Option A & Option B (Figure 32)



Modeled Monthly Heating Consumption - Baseline vs. Option A & Option B (Figure 33)



T 2.4/12/US/7

APPENDIX C

Active Chilled Beams

DID631 and DID632 series

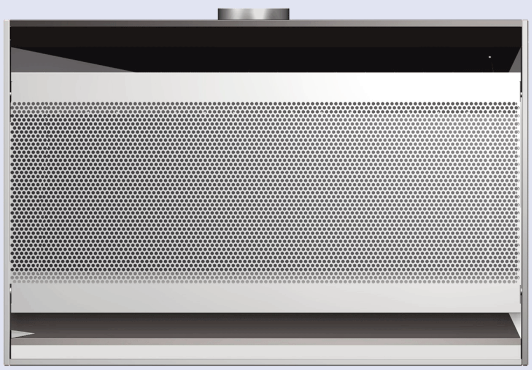
TROX® TECHNIK

TROX USA, Inc.
4305 Settingdown Circle
Cumming, GA 30028

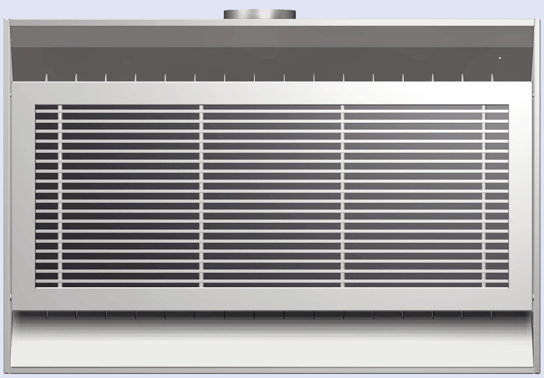
www.troxusa.com
e-mail trox@troxusa.com

Telephone 770.569.1433
Facsimile 770.569.1435

Contents · Description



DID631 & DID632...LR -
Perforated Grille
(standard)



DID631 & DID632...GL -
Linear Bar Grille
(cost option)

Active chilled beam systems provide comfortable air conditioning of rooms with a high cooling load. They combine the aerodynamic properties of ceiling diffusers with the energy benefits of heat transfer using water.

The design and positioning of the induction nozzles within the DID631 and DID632 active chilled beams enhance the amount of secondary room air drawn across the internal heat exchanger. This provides high cooling outputs with low amounts of primary air.

The beams discharge characteristics also allow for high levels of cooling without the penalty of high terminal velocities (normally associated with high induction chilled beams) into the occupied zone, making the DID631 and DID632 particularly well-suited for perimeter zones with high sensible loads where comfort must be maintained.

The high water-to-airside cooling ratio with primary air volume means the DID631 and DID632 are ideal for use with dedicated outdoor air system (DOAS) designs.

Special features

- High cooling capacity with low primary airflow rates
- Two induced air grille design options
- One-way (DID631) and two-way discharge (DID632) models available
- Heat exchangers for two or four pipe systems
- Cooling and/or heating is possible

The active chilled beams contain a primary air chamber with induction nozzles, horizontal heat exchanger and, as standard, a side inlet for the connection of the primary air.

Additional information can be found on our website, including the Chilled Beam Design Guide, selection programs, IOM's and Revit™ modules.

Active chilled beams supply conditioned fresh air (primary air) to the space from a central air handling unit (AHU). This air is required to maintain indoor air quality while providing additional cooling and/or heating using an integral heat exchanger.

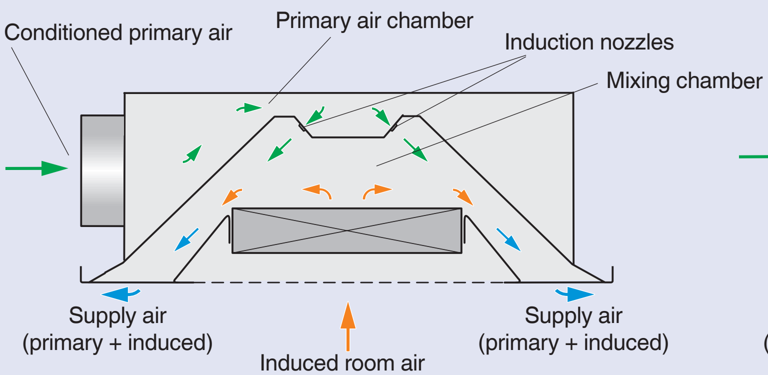
The primary air is discharged into the beam mixing chamber from the primary air chamber via induction nozzles. This causes room air to be induced through an induction grille before passing through a horizontally mounted heat exchanger and mixing with the primary air. This mixture is then discharged into the space through integral slot diffusers.

There are two types of heat exchange coils, a two-pipe system for cooling or heating (using a changeover mode) and a four-pipe system which enables any room to be cooled or heated independently.

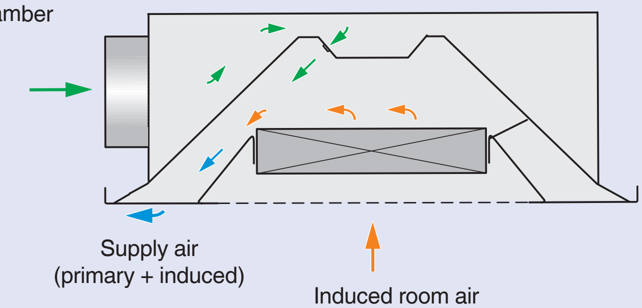
Caution!
The chilled water system must be designed to prevent the temperature of the water supplied to the heat exchanger from falling below the room dew point to ensure that the beam provides sensible cooling only. Chilled beam systems should not be designed to condense.

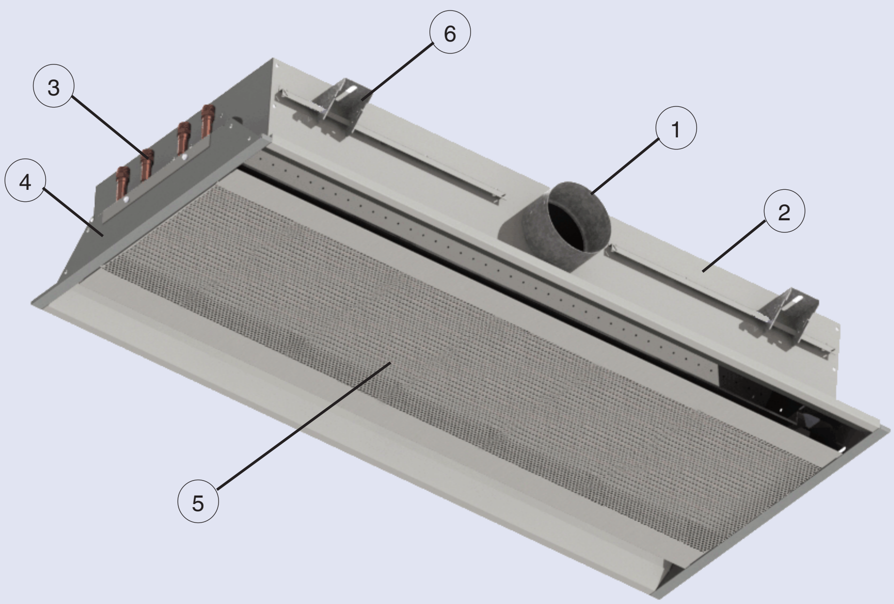
The primary air fed to the beams must be pretreated at the AHU to maintain the required ventilation and humidity control of the space.

Principle of operation DID632
2-way throw



Principle of operation DID631
1-way throw





1. Primary air connection
2. Primary air chamber
3. Water connections
4. Casing
5. Induction grille
6. Sliding hanging brackets

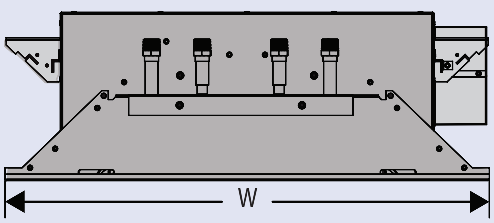
Dimensional data

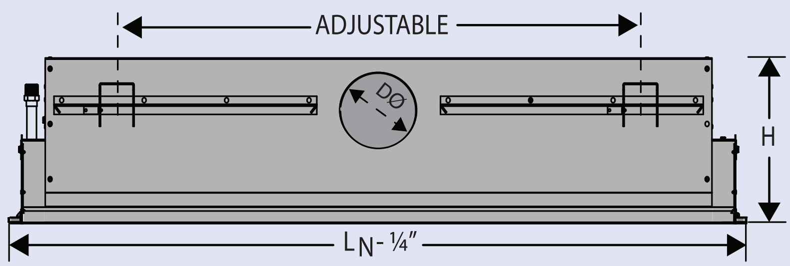
Characteristics
- Primary airflow range from 25 to 360 cfm
- For mounting heights of 8 to 15 ft
- Flush ceiling installation
- Side (standard) or top-entry primary air connection
- Lengths of 4, 5, 6, 7, 8, 9 and 10ft (other lengths on request)
- Integrates into most ceiling systems
- Nozzles in six sizes to optimize induction (see table below)
- Heat exchangers for two- or four-pipe systems
- Supply-return-air combination available (cost option)
- Maximum operating pressure: 250 psi
- Maximum operating temperature: 165˚F - 200˚F
  (other operating pressures and temperatures upon request)

Construction features
- Primary air connections suitable for circular connecting ducts
- 4 or 6 sliding hanging brackets (dependent on beam length) for on-site installation
- Water connections on the top near either end
- Induction grille can can be reversed in the field so that grille opens in the direction providing the easiest access to coil

Materials
- Casing, nozzle plate, hanging rails and primary air connection made of powder-coated steel
- Hanging brackets made of galvanized steel
- Perforated induction grille (option LR) made from powder-coated steel
- Linear bar induction grille (option GL) made from aluminum (cost option)
- Heat exchanger made of copper tubes and formed aluminum fins
- Heat exchanger natural finish (standard) or flat black (cost option)
- Visible surfaces powder-coated white (RAL 9010) as standard or alternative RAL color as cost option

Standard construction with 4-pipe heat exchanger
Side-entry, Type 0 Border





Standard border (Type 0) shown is designed for flush mounting in a 9/16” or 15/16” T-bar ceiling grid.

Optional border styles are shown below.

Available nominal lengths (L_N):
See chart at right

DID632
Height/Nozzle Type Table

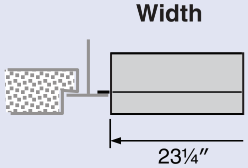
<table>
<tr><th rowspan="3">Beam Length L_N</th><th colspan="8">Nozzle Type</th></tr>
<tr><th colspan="2">Z</th><th colspan="2">M</th><th colspan="2">G/J</th><th colspan="2">H/U</th></tr>
<tr><th>H</th><th>DØ</th><th>H</th><th>DØ</th><th>H</th><th>DØ</th><th>H</th><th>DØ</th></tr>
<tr><td>4′</td><td rowspan="7">8½″</td><td rowspan="5">3⅞″</td><td rowspan="7">8½″</td><td rowspan="3">3⅞″</td><td rowspan="7">8½″</td><td rowspan="3">4⅞″</td><td>8½″</td><td>5⅞″</td></tr>
<tr><td>5′</td><td rowspan="6">11″</td><td rowspan="6">7⅞″</td></tr>
<tr><td>6′</td></tr>
<tr><td>7′</td><td rowspan="4">4⅞″</td><td rowspan="4">5⅞″</td></tr>
<tr><td>8′</td></tr>
<tr><td>9′</td><td rowspan="2">4⅞″</td></tr>
<tr><td>10′</td></tr>
</table>

T-BAR BORDER STYLE OPTIONS

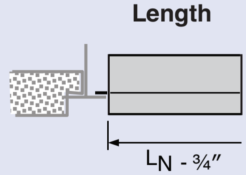
Type B1

Designed for flush mounting with tegular ceiling tiles for use in a 9⁄16˝ wide t-bar grid.

Width



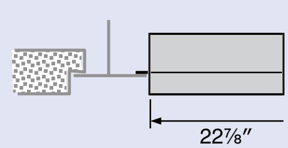
Length



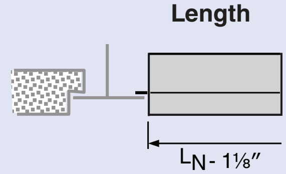
Type B2

Designed for flush mounting with tegular ceiling tiles for use in a 15⁄16˝ wide t-bar grid.

Width



Length



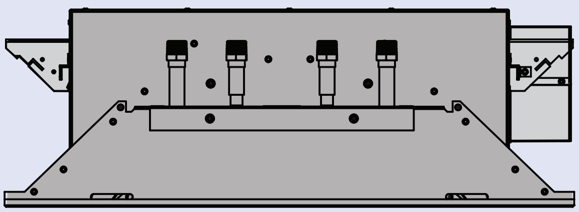
Coil and casing arrangements

Coil and casing options

DID631 and DID632 series beams are fitted with a 2-row coil, which can be supplied by a single set of water pipes (referred to as a 2 pipe coil) or connected to separate chilled and hot water piping circuits (hereby referred to as a 4 pipe coil). The primary (larger) circuit in 4 pipe coils commonly accepts chilled water while the smaller secondary circuit is connected to a hot water supply. All piping connections are ½″ straight copper pipe (⅝″ OD). As a cost option, ½″ NPT (male) fittings are available.

DID631 and DID632 series beams are also sub-classified as “-US” or “-HC” depending on the coil circuitry. The -US variants are single-circuit coils. The -HC variants feature a dual-circuit coil and allow water flow rates up to 2.4 GPM. The secondary piping circuit in four pipe versions in all variants is a single circuit.

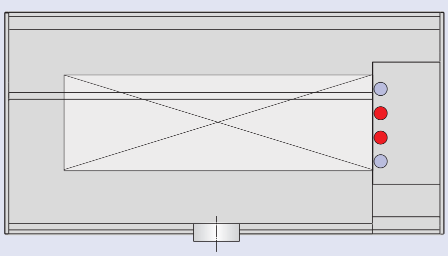
Side-entry (Standard)



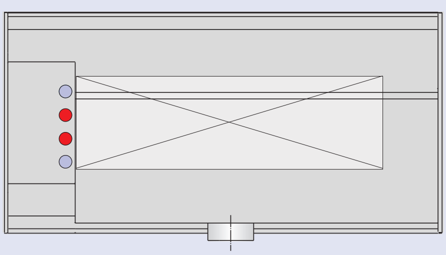
- All water connections are plain ends as standard
- Male NPT fittings are an available option (A2)

Chilled water

Warm water

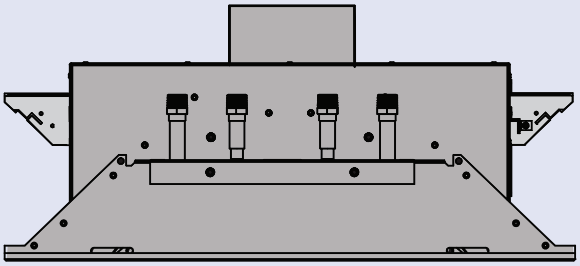


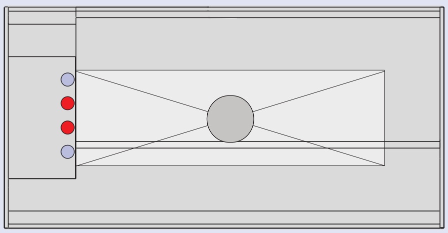
Right hand water connections
DID632-....MR



Left hand water connections
DID632-....ML

Top-entry





Coil handing can be left or right

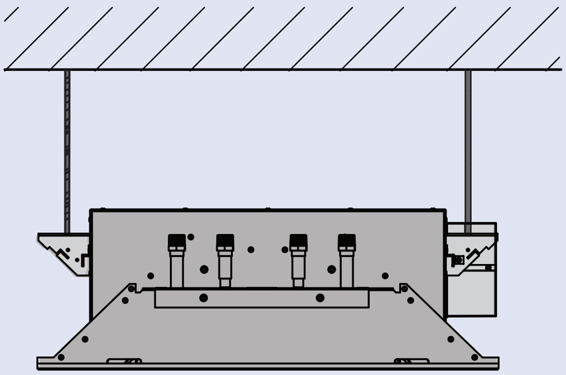
Installation

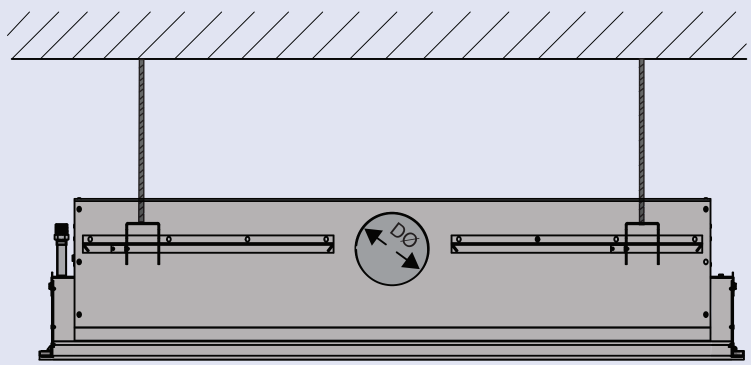
DID631 & DID632 active chilled beams are provided with at least two hanging brackets along each side of the beam's length. For lengths of 8 feet and greater, a third hanging bracket is added per side. These brackets slide on rails on the beam's housing, allowing some repositioning along the beam length and width.

The beam is installed on site using wire or metal hangers (provided by others) according to applicable building codes. The hangers should allow the beam to be vertically adjusted in order to position it with the ceiling grid.

The induction grille can be hinged down to access the heat exchanger. If preferred, for ease of access, the induction grille can be removed and rotated to hinge down in the opposite direction.

The coil connections can be plain-ended for soldered connections or provided with ½¨ male NPT fittings (cost option) for connection with flexible hoses (recommended option). Using NPT fittings and flexible hoses allows for adjustments of minor misalignment of the beam and supply/return ductwork and for movement of the beam to align with a modular ceiling. Each coil is factory tested for leakage and provided clean and capped off. TROX USA offers high quality stainless steel braided flexible hoses in 12", 18" or 24" lengths with NPT fixed and swivel joints.

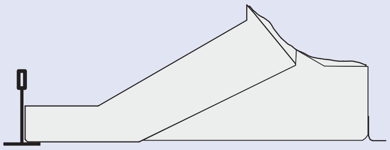




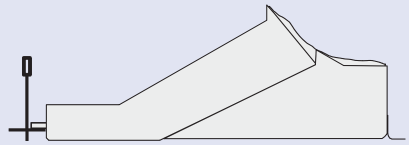
Caution - Weight must not be supported by ceiling grid!

Installation into T-bar ceilings

(see page 4 for border styles & dimensions)



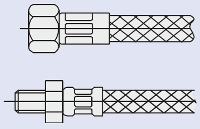
Installation into T-bar ceilings with 9/16" or 15/16" flat T on 24" centers, border type - O



Installation into T-bar ceilings with 9/16" and 15/16" T-bar with tegular tile on 24" centers, border type - B1 & B2

Flexible hose (cost option)

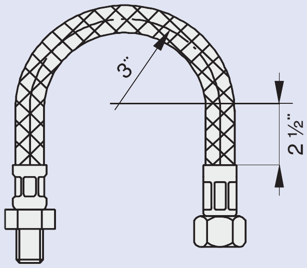
For water connection ½˝ NPT



Female swivel thread for connection to beam

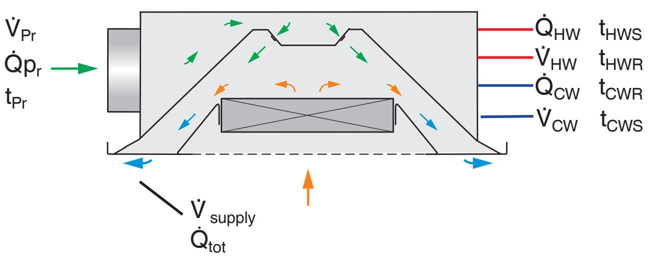
Male fixed thread for connection pipe header

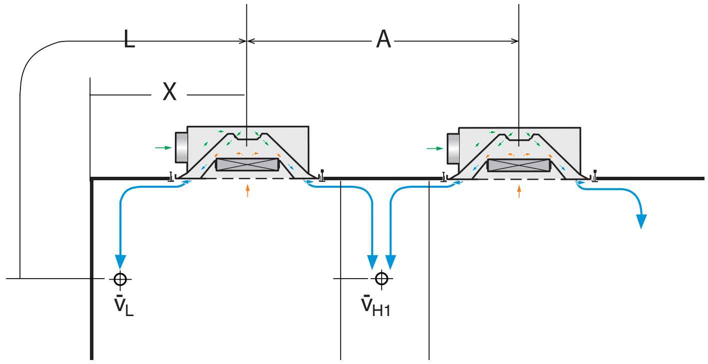
L = 12", 18", 24"



Min. bending radius

Nomenclature · Performance notes





$\dot{Q}_{SEN}$	in	Btu/h:	Space sensible load
$\dot{Q}_{LAT}$	in	Btu/h:	Space latent load
$\dot{V}_{Pr}$	in	cfm:	Primary airflow rate to offset space latent gains
$\dot{V}_{HW}$	in	gpm:	Water volume flow rate, heating
$\dot{V}_{CW}$	in	gpm:	Water volume flow rate, cooling
$\dot{V}_{supply}$	in	cfm:	Discharge flow rate
$\dot{Q}_{Pr}$	in	Btu/h:	Primary air cooling capacity
$\dot{Q}_{HW}$	in	Btu/h:	Water heating capacity
$\dot{Q}_{CW}$	in	Btu/h:	Water cooling capacity
$\dot{Q}_{tot}$	in	Btu/h:	Net beam thermal capacity
W_{ROOM}	in	gr:	Room humidity ratio
W_{Pr}	in	gr:	Primary air humidity ratio
ΔW	in	gr:	Difference between room and primary air humidity ratio
Δt_{Pr}	in	°F:	Difference between room air and primary air temperature
Δt_W	in	°F:	Supply to return water temperature difference
Δt_{RW}	in	°F:	Difference between room air and water supply temperature
Δp_t	in	in. $H_2$0:	Air pressure drop
Δp_W	in	ft. $H_2$0:	Water pressure drop
t_R	in	°F:	Room temperature
t_{HWS}	in	°F:	Water supply temperature, heating
t_{HWR}	in	°F:	Water return temperature, heating
t_{CWS}	in	°F:	Water supply temperature, cooling
t_{CWR}	in	°F:	Water return temperature, cooling
t_{Pr}	in	°F:	Primary air temperature
$\bar{v}_L$	in	fpm:	Air velocity distance L
$\bar{v}_{H1}$	in	fpm:	Air velocity distance H_1
A	in	ft:	Spacing between two diffusers with opposing blow patterns
L	in	ft:	Horizontal and vertical distance $(x+H_1)$ discharge to the wall
H_1	in	ft:	Distance from ceiling to top of occupied zone (5´ 6˝ above the floor)

	Coil Water Flow Rate, GPM					
	0.50	0.75	1.00	1.25	1.50	2.00
Multiply Q_{CW} or Q_{HW} by:	29	0.93	1.00	1.00	1.03	1.07
Multiply Δp_w in table by:	0.7	1.3	2.3	1.0	1.4	2.4

Table 1: Corrections for other water flow rates

Useful equations:

$$\dot{Q}_{Pr} = 1.09 \times \dot{V}_{Pr} \times (t_R - t_{Pr})$$
$$\Delta t_W = \dot{Q}_W / (500 \times \dot{V}_W)$$

	t_R - t_{CWS}					
	10	12	14	16	18	20
Multiply Q_{CW} by:	0.56	0.67	0.78	0.89	1.00	1.11

Table 2a: Corrections for other chilled water supply temperatures

	t_{HWS} - t_R					
	20	30	40	50	60	70
Multiply Q_{HW} by:	0.40	0.60	0.80	1.00	1.20	1.40

Table 2b: Corrections for other hot water supply temperatures

Quick selection table

Reference Values - Cooling

t_R 75 °F t_{CWS} 57 °F
t_{Pr} 55 °F $\dot{V}_{CW}$ 1.0 GPM

Reference Values - Heating

t_R 70 °F t_{HWS} 120 °F
t_{Pr} 55 °F

Active Length	Nozzle Type	Primary Air		Cooling Two-pipe system			Cooling Four-pipe system			Heating Four-pipe system			Isothermal Throw[6]	NC[7]
		$\dot{V}_{Pr}$	Δp_t	$\dot{Q}_{tot}$[1]	$\dot{Q}_{CW}$[2]	Δp_w[3]	$\dot{Q}_{tot}$[1]	$\dot{Q}_{CW}$[2]	Δp_w[3]	$\dot{Q}_{NET}$[4]	$\dot{V}_{HW}$[5]	Δp_w[3]		
ft		CFM	in. H_2O	Btu/h	Btu/h	ft. H_2O	Btu/h	Btu/h	ft. H_2O	Btu/h	GPM	ft. H_2O	ft.	
4	Z	20	0.36	2,685	2,250	2.1	2,504	2,068	3.1	3,083	0.40	0.2	3-4-6	18
		25	0.56	3,197	2,653		2,609	2,152		3,809	0.45	0.2	3-5-7	20
		30	0.81	3,621	2,968		3,392	2,739		4,611	0.55	0.3	4-5-8	23
	M	25	0.25	2,515	1,971		2,354	1,810		2,897	0.50	0.3	3-4-6	16
		35	0.48	3,398	2,636		3,191	2,429		4,104	0.60	0.4	3-5-7	21
		45	0.80	4,078	3,098		3,841	2,861		5,283	0.85	0.7	4-5-8	24
	J	35	0.23	2,828	2,066		2,660	1,898		3,303	0.75	0.6	3-4-6	17
		50	0.46	3,857	2,768		3,641	2,552		4,769	1.10	1.2	4-5-8	21
		65	0.78	4,662	3,247		4,416	3,001		5,829	1.50	2.3	5-6-10	25
	G	45	0.22	3,249	2,270		3,067	2,087		3,817	1.15	1.4	3-4-6	18
		65	0.46	4,394	2,979		4,164	2,749		5,204	1.50	2.3	4-6-9	22
		85	0.79	5,307	3,457		5,049	3,198		5,999	1.50	2.3	5-7-12	27
	H	65	0.23	4022	2,606		3,816	2,401		4,354	1.50	2.3	4-5-7	19
		90	0.45	5093	3,134		4,854	2,895		5,154	1.50	2.3	5-6-10	23
		115	0.73	6011	3,508		5,750	3,246		5,628	1.50	2.3	6-8-14	26
	U	80	0.22	4,465	2,723		4,252	2,510		4,372	1.50	2.3	4-5-8	19
		110	0.42	5,587	3,192		5,344	2,949		4,962	1.50	2.3	5-7-12	23
		140	0.68	6,576	3,528		6,313	3,265		5,267	1.50	2.3	6-8-15	30
6	Z	25	0.24	3,257	2,712	3.0	3,044	2,500	4.4	3,899	0.45	0.3	3-4-5	16
		35	0.48	4,339	3,547		4,045	3,283		5,495	0.55	0.4	3-4-6	21
		45	0.79	5,093	4,113		4,798	3,818		7,081	0.75	0.8	4-5-8	24
	M	45	0.35	4,274	3,294		4,025	3,045		5,245	0.65	0.6	3-4-6	21
		60	0.63	5,313	4,007		5,024	3,718		6,997	0.90	1.2	4-5-7	27
		75	0.98	6,147	4,515		5,833	4,200		8,778	1.50	3.2	4-6-9	34
	J	55	0.25	4,256	3,058		4,021	2,824		5,221	1.00	1.4	3-4-6	19
		75	0.46	5,489	3,856		5,208	3,575		7,129	1.50	3.2	4-5-8	23
		95	0.74	6,478	4,410		6,168	4,100		8,183	1.50	3.2	4-6-10	29
	G	85	0.36	5,647	3,796		5,369	3,518		6,817	1.50	3.2	4-5-8	24
		105	0.55	6,585	4,300		6,281	3,995		7,739	1.50	3.2	4-6-10	30
		125	0.78	7,410	4,689		7,087	4,366		8,408	1.50	3.2	5-7-11	35
	H	100	0.23	5,878	3,701		5,606	3,429		6,340	1.50	3.2	4-5-8	19
		140	0.45	7,445	4,397		7,135	4,088		7,411	1.50	3.2	5-7-11	24
		180	0.75	8,792	4,874		8,461	4,542		7,988	1.50	3.2	6-8-14	27
	U	130	0.24	6,784	3,954		6,497	3,667		6,465	1.50	3.2	4-6-9	21
		180	0.47	8,472	4,554		8,156	4,237		7,156	1.50	3.2	5-7-13	25
		230	0.76	9,980	4,973		9,644	4,637		7,430	1.50	3.2	7-9-17	31
8	Z	35	0.27	4,359	3,597	3.8	4,092	3,330	5.8	5,337	0.50	0.5	3-4-5	18
		50	0.55	5,714	4,626		5,394	4,305		7,803	0.70	0.9	3-5-7	23
		65	0.93	6,708	5,293		6,359	4,944		10,129	1.05	2.1	4-5-8	30
	M	60	0.34	5,446	4,140		5,150	3,844		7,032	0.80	1.2	3-4-6	21
		75	0.53	6,429	4,796		6,101	4,468		8,806	1.05	2.1	4-5-7	23
		90	0.76	7,247	5,288		6,898	4,939		10,569	1.50	4.3	4-6-8	28
	J	80	0.29	5,878	4,137		5,582	3,841		7,653	1.40	3.7	3-4-6	20
		105	0.49	7,222	4,936		6,888	4,602		9,383	1.50	4.3	4-5-8	24
		130	0.76	8,333	5,503		7,975	5,145		10,499	1.50	4.3	5-6-10	29
	G	110	0.33	7,038	4,643		6,717	4,322		8,535	1.50	4.3	4-5-7	23
		140	0.53	8,359	5,311		8,009	4,961		9,810	1.50	4.3	4-6-10	29
		170	0.78	9,503	5,802		9,134	5,433		10,673	1.50	4.3	5-7-12	35
	H	140	0.26	7,790	4,742		7,464	4,416		8,299	1.50	4.3	4-5-8	21
		190	0.47	9,598	5,461		9,242	5,105		9,400	1.50	4.3	5-7-11	25
		240	0.76	11,186	5,961		10,812	5,587		9,975	1.50	4.3	6-8-14	31
	U	150	0.20	7,847	4,582		7,529	4,264		7,721	1.50	4.3	4-5-8	20
		220	0.42	10,350	5,424		9,859	5,069		8,805	1.50	4.3	5-7-12	27
		290	0.73	12,213	5,968		11,907	5,594		9,174	1.50	4.3	7-9-16	38

Refer to table continued on page 9 for performance notes...

Quick selection table continued... (10ft DID632)

Active Length	Nozzle Type	Primary Air		Cooling Two-pipe system			Cooling Four-pipe system			Heating Four-pipe system			Isothermal Throw⁶	NC⁷
		$\dot{V}_{Pr}$	Δp_t	$\dot{Q}_{tot}$[1]	$\dot{Q}_{CW}$[2]	Δp_w[3]	$\dot{Q}_{tot}$[1]	$\dot{Q}_{CW}$[2]	Δp_w[3]	$\dot{Q}_{NET}$[4]	$\dot{V}_{HW}$[5]	Δp_w[3]		
ft		CFM	in. H_20	Btu/h	Btu/h	ft. H_20	Btu/h	Btu/h	ft. H_20	Btu/h	GPM	ft. H_20	ft.	
10	Z	40	0.22	4,831	3,960	4.6	4,544	3,673	7.4	6,097	0.55	0.7	2-3-5	17
		60	0.49	6,618	5,312		6,268	4,962		9,414	0.80	1.5	3-4-6	22
		80	0.87	7,865	6,123		7,486	5,744		12,492	1.25	3.8	4-5-8	26
	M	70	0.30	6,175	4,651		5,854	4,330		8,203	0.90	2.0	3-4-6	21
		90	0.50	7,454	5,494		7,096	5,137		10,458	1.15	3.2	4-5-7	26
		110	0.75	8,489	6,095		8,111	5,716		12,489	1.50	5.4	4-5-8	32
	J	100	0.29	6,887	4,710		6,735	4,558		9,344	1.50	5.4	3-4-6	22
		130	0.49	8,377	5,547		8,210	5,380		11,174	1.50	5.4	4-5-8	27
		160	0.75	9,622	6,139		9,445	5,962		12,403	1.50	5.4	5-6-10	33
	G	120	0.26	7,612	4,999		7,275	4,662		9,304	1.50	5.4	3-5-7	24
		150	0.41	8,992	5,727		8,626	5,361		10,790	1.50	5.4	4-5-8	30
		180	0.59	10,182	6,263		9,798	5,879		11,826	1.50	5.4	5-6-10	35
	H	170	0.25	8,989	5,288		8,826	5,125		9,784	1.50	5.4	4-5-8	22
		230	0.46	11,067	6,060		10,892	5,884		11,021	1.50	5.4	5-7-11	28
		230	0.72	12,905	6,592		12,722	6,409		11,636	1.50	5.4	6-8-14	35
	U	180	0.20	9,197	5,279		8,849	4,930		9,067	1.50	5.4	4-5-7	22
		250	0.38	11,532	6,089		11,153	5,711		10,176	1.50	5.4	5-6-10	31
		320	0.63	13,600	6,634		13,206	6,239		10,620	1.50	5.4	6-8-14	40

PERFORMANCE NOTES:

[1]$\dot{Q}_{tot}$ includes $\dot{Q}_{CW}$ plus sensible cooling provided by primary air 20°F below room temperature at the flow rate indicated.
[2]$\dot{Q}_{CW}$ is coil sensible cooling using 1.0 GPM of chilled water supplied 18°F below the room temperature.
[3]Δp_W is the water head loss at the referenced water supply flow rate.
[4]$\dot{Q}_{NET}$ is coil heating using referenced hot water flow rate supplied 50°F above the room temperature.
[5]$\dot{V}_{HW}$ is hot water flow rate limited to the lesser of 1.5 GPM or that which results in a supply to room air temperature differential not exceeding 20°F.
[6]Isothermal throw values presented to 150, 100 and 50 FPM, indicated as VH_1 in selection program.
[7]NC values are based on a room absorption of 10 dB (per octve band) re 10^{-12} watts. (-) indicates NC value less than 15.

Selection Software
For detailed selections, designers may download DID631 and DID632 selection software at www.troxusa.com. This software (see sample right) affords easy access to the beams' performance data against user defined parameters.

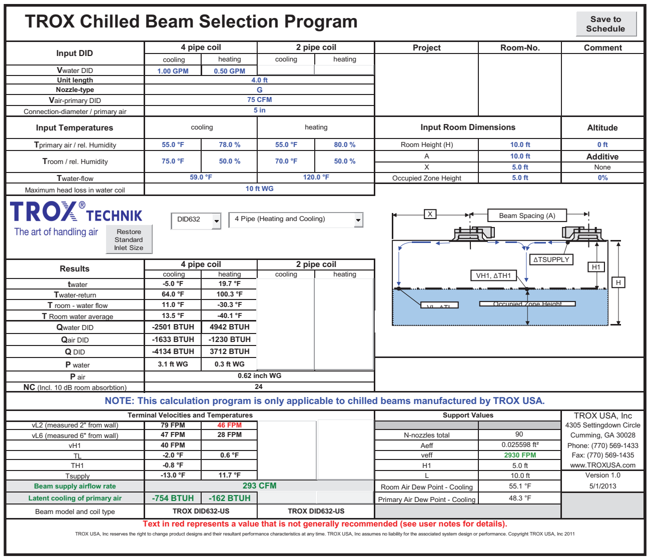
User defined input parameters include:
- Beam length and nozzle type
- Water flow rates and supply temperatures
- Primary airflow rate, temperature and RH
- Room temperature and RH
- Room height, beam spacing, distance to walls and occupied zone height

Upon entry of these parameters, the software returns values for:
- Air and water pressure requirements
- Sensible and latent cooling and/or heating capacity
- Return water temperature
- Waterside pressure loss
- Resultant noise (NC) levels
- Local velocities and temperatures in the occupied zone

NOTE: Macros must be enabled for the spreadsheet to function.

Revit™ blocks for DID631 & DID632 series beams can be found at www.troxusa.com.

Selection Software Example



Room air distribution with active chilled beams

Active chilled beams distribute air within the room in a manner consistent with that of linear slot diffusers. As such, the relationship between air stream terminal velocities and thermal decay of the supply air stream that applies to linear slot diffusers also applies to active chilled beams. Upon discharge to the open space, velocity and temperature differentials between the supply air mixture and the room begin to diminish due to room air entrainment. As with linear slots, chilled beams exhibit relatively long throw characteristics and their velocity and temperature differentials diminish at a rate that is directly proportional to the distance the air has traveled within the space.

Most manufacturers present throw data using isothermal air for terminal velocities of 150, 100 and 50 FPM. This data can be used to map the airstream and predict the local velocity at the point where it enters the occupied zone. As the room to supply air differential decays at a similar rate, its temperature can also be predicted at the entry point based on the initial temperature difference (Δt_o) between the beam discharge temperature and that of the room into which it is introduced.

TROX USA selection software can be used to predict the value of local velocities and temperatures at critical locations where the air stream enters the occupied zone.

As the region near outside walls is not defined as part of the occupied zone, local velocities and temperatures do not generally affect occupant thermal comfort. Care should still be taken that velocities down walls are not so high they affect processes (e.g. fume hoods) on outer walls and that they are sufficient to provide adequate heating where applicable.

The area of greatest draft risk usually occurs directly below the point where two opposing airstreams collide. Figure 1 indicates that at a temperature difference of 1.25°F (i.e. air is 1.25°F cooler than the occupied space temperature measuring point), the velocity ($\overline{v}_{H1}$) entering the occupied zone below the collision point should be 50 FPM or less to prevent draft complaints by more than 20% of the occupants. Throw mapping techniques can be used to determine the minimum centerline spacing of those beams that will limit the velocity ($\overline{v}_{H1}$) entering the occupied zone to 50 FPM or less. The selection example that follows illustrates the use of mapping to determine the minimum beam spacing. Other temperature differences can also be used to vary the air velocity to keep draft complaints under the 20% criteria.

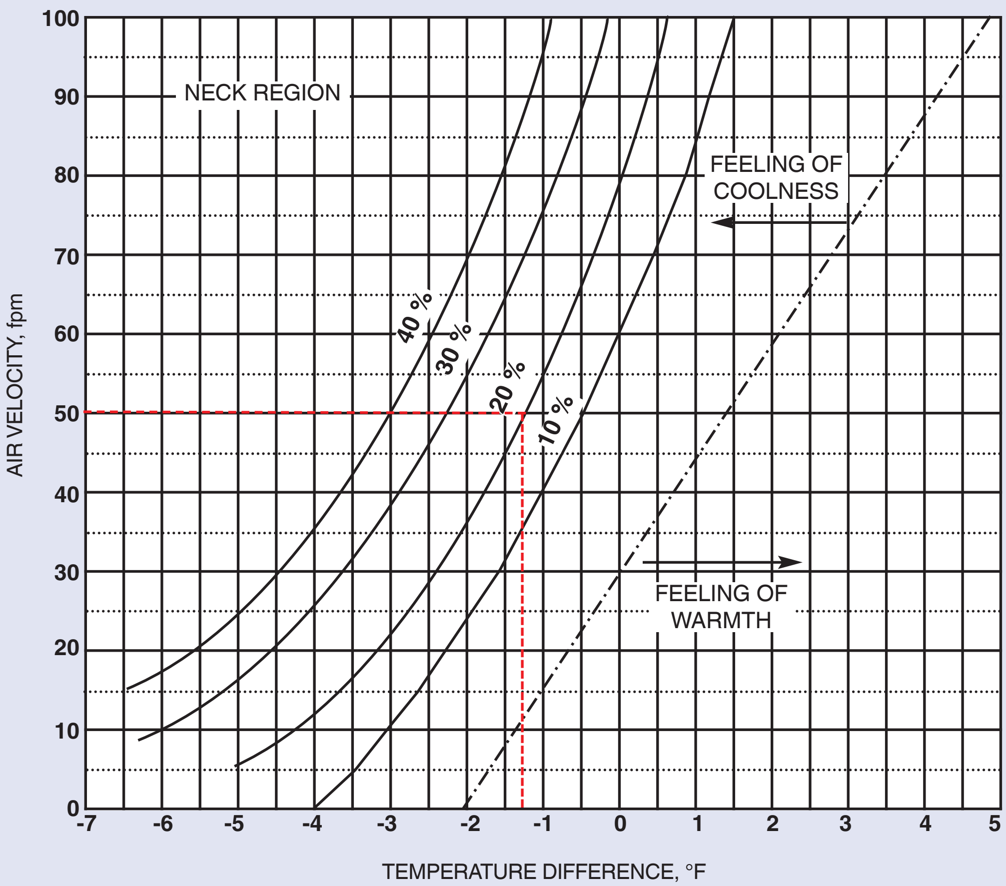


Figure 1: Percentage of Occupants Objecting to Drafts

(Source: 2009 ASHRAE Handbook - Fundamentals)

Selection Example:

The 630 ft^2 laboratory space shown in figure 2 has a sensible cooling load of 62 Btu/h-ft^2 (39,000 Btu/h) and a latent gain of 4,350 Btu/h. DID632 beams will be used to serve the space. A space ventilation airflow rate (100% outdoor air) of 6 ACH^{-1} (630 cfm) minimum is to be maintained.

The room will be controlled at 75°F and 50% RH (65 grains) allowing the supply of chilled water at 57°F. Primary air is delivered at 55°F with a humidity ratio of 54 grains (approximately 50°F dew point temperature). The beams will be mounted flush in a 10 foot high ceiling and the occupied zone is considered to be the lower six (6) feet of the space.

Determine the required space primary airflow rate and select/locate the beams such that no velocities exceeding 50 fpm will enter the defined occupied zone.

Solution:

The primary airflow rate must be sufficient to cool and ventilate the space while providing sufficient latent heat removal to maintain the required space dew point temperature (55°F).

The primary airflow rate required to maintain the design space dew point is calculated as:

$$\dot{V}_{LAT} = \dot{Q}_{LAT} / (.68 \times \Delta W)$$
$$= 4{,}350 / [(0.68 \times (65 - 54)] = 582 \text{ cfm}$$

Therefore the airflow needed to meet the latent requirements is 582 cfm (less than the space ventilation rate) and 630 cfm becomes the predominant minimum primary airflow rate needed under these design conditions.

If we consider 6 beams (2 pipe coils) for this space, by referring to the table on page 8, six (6) six foot beams with "G" nozzles, delivering 105 cfm each and a water flow rate of 1.0 GPM (model DID632-US) will provide a total sensible cooling of:

6,585 Btu/h each ($\dot{Q}_{Pr} + \dot{Q}_{CW}$)
six beams = 39,510 Btu/h and 630 cfm
Sensible cooling and latent air volume is achieved.

As this airflow requirement exceeds the space sensible and latent cooling requirements at the minimum ventilation airflow rate, the selection is confirmed.

The individual acoustical level of each beam is NC30.

The beams' throw (at 105 cfm) to a terminal velocity of 50 fpm is 10 feet. The throw to 50 fpm should not exceed half of the beam's (center line) spacing, plus the distance from the ceiling to the top of the occupied zone. In this case, the vertical distance is five (5) feet, so the beams should be spaced at least ten (10) feet apart.

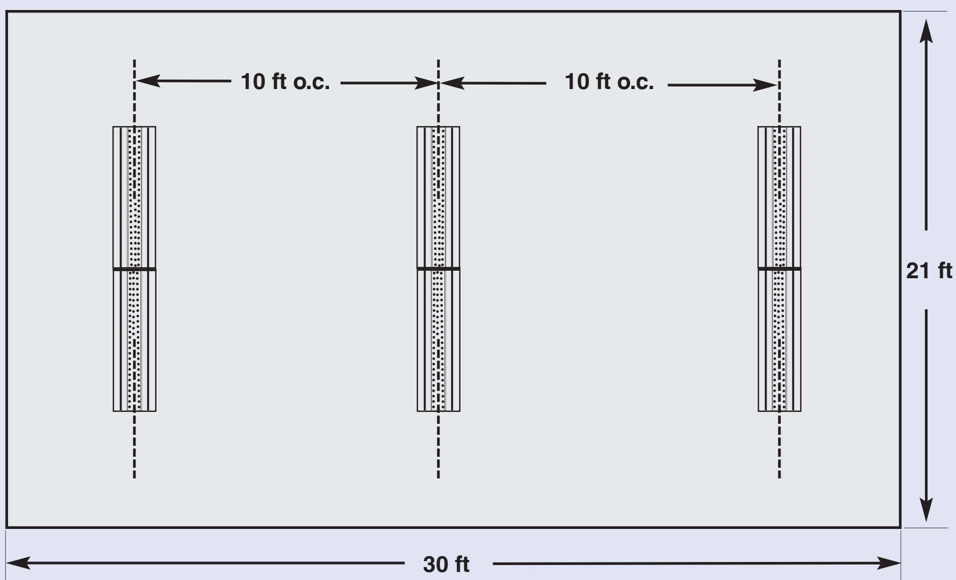


Figure 2: Chilled beam locations for selection example

$\dot{Q}_{SEN}$ = 62 Btu/h - ft^2

$\dot{Q}_{LAT}$ = 7.25 Btu/h - ft^2

$\dot{V}_{Pr}$ = 630 cfm

Specification · Order details

Specification text
Furnish and install TROX DID631 and DID632 series active chilled beams in the quantities, sizes and configurations shown on the project plans and schedules. The assembly shall consist of a primary air inlet and upper chamber, a series of high induction nozzles and lower chamber housing with hydronic heat exchanger coil, with intake grille and discharge slots.

Primary air is supplied through the integral nozzles, creating induction of room air through the induction grille and heat transfer coil, where it is reconditioned and then mixed with the primary air before being discharged through linear slots located along the sides of the assembly.

The diffuser face shall consist of an induction grille with a free area not less than fifty (50) percent. The face shall hinge down, without tools, to allow access to heat transfer coil and nozzles.

Water entering the heat exchange coil shall be maintained at or above the dew point temperature of the space. Heat transfer coil shall be (two-pipe or four-pipe) configuration for cooling only or heating and cooling operation.

Materials
Diffuser casing and face components shall be constructed of powder coated steel (white RAL 9010 or a standard color from the RAL range).

Integral heat transfer coil shall be finned tube type with fin spacing not greater than 8 fins per inch. Water connections shall be plain-ended or ½″ male NPT. Fin thickness shall be at least 0.0055 inches. Coils shall be factory leak tested at 360 psi and rated according to AHRI Standard 410 and delivered clean, flushed and capped to prevent ingress of dirt. The water pipes shall be factory fitted with one water drain valve per circuit.

Installation
Diffuser shall be constructed for mounting in the application (surface mount or t-bar) specified. Mounting brackets shall be furnished which allow support of the diffuser assembly from the structure above. Mounting brackets shall be attached to the casing by means of a rail system to allow linear movement of the chilled beam; brackets can be locked in position. To install, connect a circular duct to the unit primary air inlet and chilled and/or hot water to the appropriate supply and return water connections.

Submittals
Contractor shall submit dimensional information and a schedule of performance data for all models and sizes to be furnished. Performance data submitted shall include the following:

- Primary airflow rate (CFM), temperature (°F) and air side pressure loss (in. w.g)
- NC level (based on attenuation specified)
- Chilled (and where applicable hot) water supply temperature (°F)
- Chilled (and where applicable hot) water flow rate (GPM) and head loss (ft. H_20)
- Cooling (and where applicable heating) capacity (BTU/H) and room temperature (°F)
- Discharge air throw values to terminal velocities of 150, 100 and 50 FPM
- Beam mounting height, mounting centers and distance to walls (ft)

Connection (optional)
Terminals shall be provided with factory furnished flexible hoses (12", 18" or 24"long) for connection of the assembly to the supply and return water circuits.

Insulation (optional)
Insulation is not required in most applications and should only be used when the primary air temperature is below the room dew point. If required, ⅛″ Armaflex insulation shall be attached to the interior of the primary air plenum.

Order Code

DID632-US - LR - 2 - G - ML - A2 - B1 / **6 x 6 x 5** / **0** / **RAL 9010** / **G1** / **I**

1 (DID632-US), 2 (LR), 3 (2), 4 (G), 5 (ML), 6 (A2), 7 (B1), 8 (6 x 6 x 5), 9 (0), 10 (RAL 9010), 11 (G1), 12 (I)

1 **Type**
DID631 - US
DID632 - US
DID631 - HC
DID632 - HC

2 **Face options**
Perforated - LR
Linear Bar - GL

3 **Coil circuitry**
Two-pipe - 2
Four-pipe - 4

4 **Nozzle options**
Small ↓ Large
- Z
- M
- J
- G
- H
- U

5 **Casing/piping handing**
(See page 5)

6 **Coil Connections**
Plain (standard) - 0
Male NPT - A2

7 **Border type**
T-Bar (flush) - 0
Tegular 9/16" T-Bar - B1
Tegular 15/16" T-Bar - B2

8 **Nominal length x active length x inlet size**
L_N x L_{ACTIVE} x inlet size

9 **Face finish**
0 - Standard finish
Powder-coated to RAL 9010
P1 - Powder-coated to RAL...

10 **Face color**

11 **Coil finish**
0 - Standard self finish
G1 - Flat black

12 **Insulation**
0 - Standard no insulation
I - Internal insulation

Special Note:
Selection of air discharge location (DOS or DSS) is required for the DID631. See submittal for details.

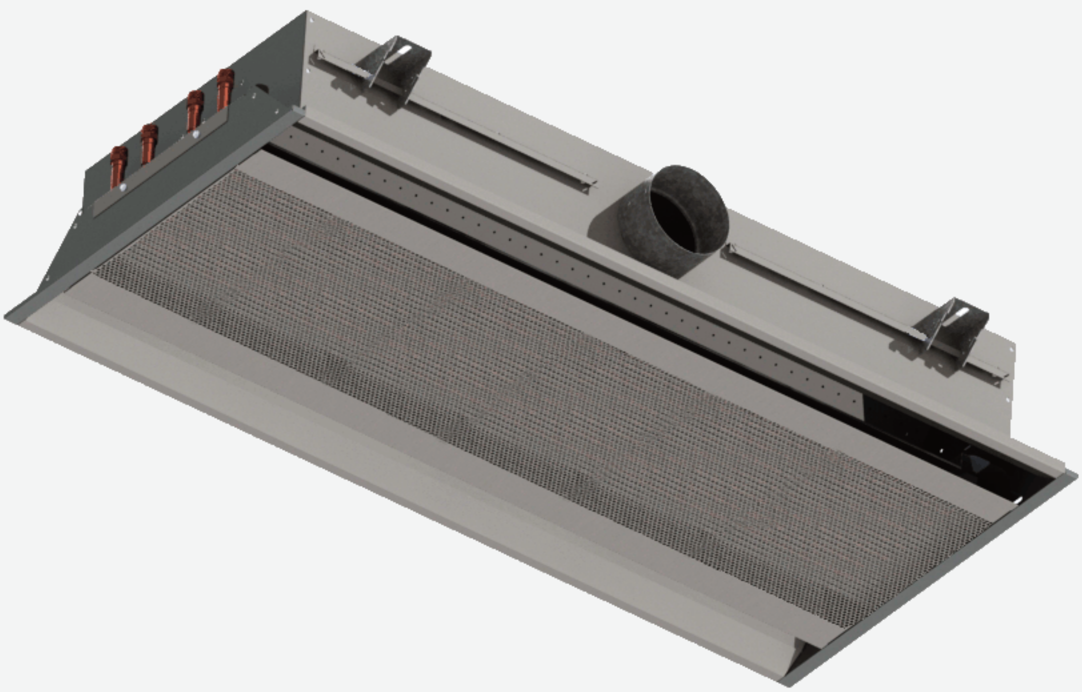
Order example:
Make: TROX
Type: DID632-US-LR-2-G-ML-A2-B1 / 6 x 6 x 5 / 0 / RAL 9010 / G1 / I

OM/US/DID631-632/5

APPENDIX C

Installation, Operation and Maintenance Manual

Active Chilled Beams Type DID631 and DID632



TROX® TECHNIK

The art of handling air

Contents

TROX® TECHNIK

TROX USA, Inc.

4305 Settingdown Circle
Cumming, Georgia 30028

Phone: 770.569.1433
Fax: 770.569.1435

E-Mail: trox@troxusa.com
www.troxusa.com

1 - General Information

1.1 Introduction

This installation, operation and maintenance manual is intended for active chilled beam Type DID631 and DID632.

You must read all instructions prior to the installation, operation or maintenance of this product. Take special note of the information that is accompanied by the symbols described in section 1.3 below.

The DID631 and DID632 active chilled beams are designed for dealing with high internal thermal loads using a combination of air and water. This is achieved by using primary air delivered via ductwork and chilled water delivered via pipe work from the central plant, directly to the beam. Primary air is ducted to the upper air chamber via a side or top inlet. The primary air is then discharged through nozzles to a lower section containing a 2- or 4-pipe heat exchanger coil. This causes room air to be induced via the perforated face panel, up and through the heat exchanger coil. The cooled (or heated) room air is then mixed with the primary air before being delivered back to the space through the beam's discharge slot(s).

The beam uses the primary air energy to induce air through the coil; it does not contain any moving parts, fans or motors.

1.2 Safety

The customer must use qualified personnel and follow all applicable building codes and safety regulations when installing, commissioning and performing maintenance of this product. Eye protection, gloves and hard hat should be worn at all times when handling the product.

Consult all local building, occupational safety and other codes applicable to the installation.

Please pay particular attention to the symbols used throughout the manual that indicate safety related issues, warnings and important notices or information; read the complete manual before installation and be familiar with the meaning of the safety symbols in the next section 1.3.

1.3 Symbols used in this manual

When reading this manual, particular attention must be given to the parts marked with the following symbols:

Warning!
Indicates a potentially dangerous situation for the product and the environment

Important!
Designation of a danger that can cause personal injury or damage to property.

Note
Indicates important notices or information

Fragile
Handle with care. The chilled beam should not be handled using the water pipes or damage to the coil assembly may result!

1.4 Receiving, Inspection and Storage

All TROX products are inspected and tested prior to shipment to ensure the highest quality. Chilled beams are packed individually in cardboard cartons.

Upon receipt of the chilled beam shipment, conduct a thorough inspection of the outer packaging and pallets for possible damage. If damage has occured during shipping, indicate the damaged items on the delivery papers immediately and inspect the chilled beams contained in those containers for damage.

If damage has occurred during shipping, immediately file a claim with the carrier.

Refer to the ***Manufacturer's Representations and Warranties*** (included in each carton and on page 11 of this manual) for detailed handling instructions and damage reporting procedures.

Note
Chilled beam should not be removed from its individual carton for storage. Beams should not be unpacked until they have been moved to the installation location and just before installation is to begin (see details on pages 4-5).

Beams should be stored in a clean and dry location. If beams remain packaged as delivered (strapped and wrapped on pallet), they can be stored as delivered (do not stack pallets). If packaged beams are removed from pallet, they should not be stacked more than four high. Packaging is not suitable for outside storage.

2 - Product Description/Installation Preparation

2.1 Product overview

Chilled beams are ceiling mounted heat exchangers. Primary air is introduced into the active chilled beam through induction nozzles. This series of nozzles induces room air into the chilled beam and across its water coil where the room air is either cooled or heated. The now cooled or heated room air is mixed with the primary air and discharged back into the space to control the room temperature. TROX DID631 and DID632 active chilled beams should be installed in the quantities, sizes and configurations shown on the project plans and schedules.

2.2 Construction description

The assembly (figure 1) of the DID631 and DID632 consists of:

(1) primary air connection
(2) primary air chamber
(3) induction nozzles
(4) one (DID631) or two (DID632) discharge slots on front face assembly
(5) the outer borders
(6) heat exchanger coil
(7) removable inner border assembly with induction grille

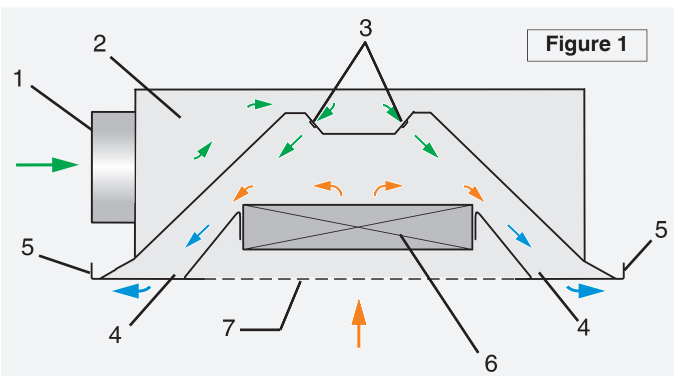


Figure 1

Construction Description
DID632 Active Chilled Beam

2.3 Application precautions

Note
DID631 and DID632 active chilled beams provide sensible cooling only and cannot be used to do latent cooling. Condensate trays or the option to retrofit one is not available.

The primary air delivered to the space must be of sufficient quantity, temperature and dryness to ensure the room dew point temperature is maintained below the temperature of the chilled water supplied to the beam. The chilled water supply temperature should be maintained above the dew point temperature of the room.

2.4 Preparation for installation

Important!
Installation is to be performed by properly trained and authorized personnel only! Read all instructions before beginning installation.

1.) Chilled beam unit (figure 2) delivered by TROX USA with:

1 Round primary air connection
2 Primary air chamber
3 Water connections
4 Casing
5 Induction grille
6 4 to 6 sliding hanging brackets

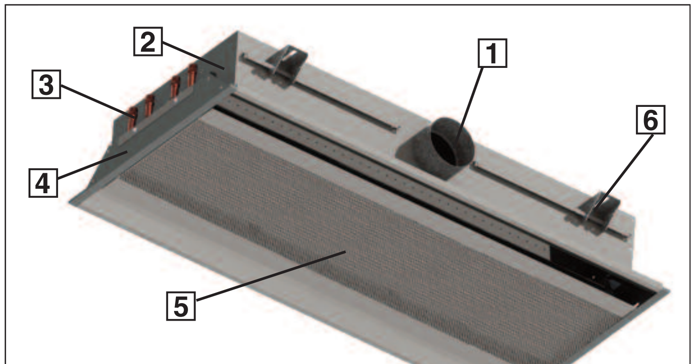


Figure 2

2.) Installer to provide (according to all applicable building codes):

- A suspension system (including all hardware) for mounting the chilled beam
- Flexible duct (recommended) or sheet metal duct for air connection
- Primary air volume control damper (can be provided by TROX)
- Flexible hoses (recommended) for water connections from assembly to the supply and return water circuits (unless factory furnished flexible hoses are included with product order) or hard connections.

3.) Precautions:

Important!
Wear eye protection and gloves during installation. Product includes sharp edges and burrs.

Product is heavy!
Machinery recommended for movement and installation of beams. Refer to table below for unit weights and use caution when removing from packaging.

Chilled beam should be placed on the ground with perforated induction grille (see figure 2) facing up!

Chilled Beam Length	Chilled Beam Weight	Chilled Beam weight w/ fully charged coil
2' Unit	30 lbs	33 lbs
4' Unit	60 lbs	64 lbs
6' Unit	90 lbs	96 lbs
8' Unit	120 lbs	128 lbs
10' Unit	150 lbs	160 lbs

3 - Installation

3.1 General procedure

Chilled beams should be mounted and connected prior to installing the suspended ceiling or drywall. The unit should be installed in the location shown on the design drawings. Deviation from the designed mounting position should be avoided as the chilled beam location in relation to the room walls and other chilled beams is critical to the comfort of the conditioned space.

The chilled beam leaves the factory with low tack film applied to the face (see photo) to protect the painted surface. Film should remain on beam during installation.

Warning!
Care should be taken to avoid any water or condensation buildup between the blue film and the beam face during handling and waterside commissioning. Remove film BEFORE the air system is started.

3.2 Installation considerations

Note
It is recommended that chilled beams be installed using flexible hoses.

If hard connections are used, the connections should be made after the chilled beam is lowered into the ceiling grid and is in its final position.

3.3 Hanging the chilled beam (by Mechanical Contractor)

STEP ONE —

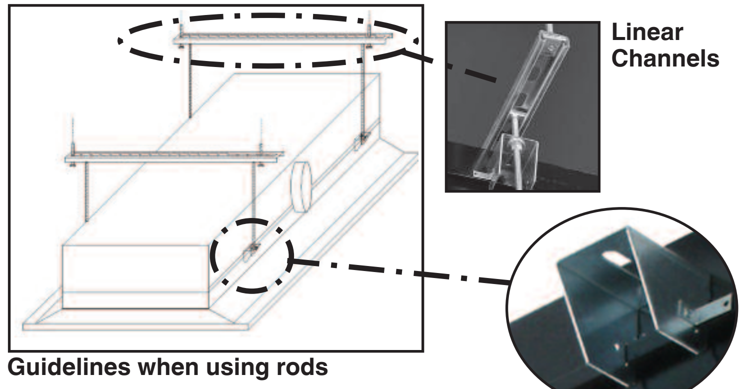
- Determine beam locations according to design drawings.
- Fix anchors (type dependant on building design and determined by others) into the structure above the chilled beam mounting location.

STEP TWO —

The beam should be suspended 3" above the finished ceiling elevation using building code approved threaded rods (recommended) or wires. The rod or wire (both provided by others) allow the beam's vertical height to be adjusted so that the beam can be lowered into the ceiling grid with which it is to be integrated.

It is recommended that the unit be suspended from **linear channels** to provide adjustability in every direction.

The unit is provided with **sliding hanging brackets** that allow for adjustment along the length and width of the beam (both shown here):



Guidelines when using rods

1. Install Unistrut with appropriate support to carry the beam
2. Fasten studs to Unistrut with Unistrut nut in proper location above the beam's hanging brackets
3. Adjust beam as needed to final hanging location

Guidelines when using Wire/Cable

1. Distribute sliding brackets evenly spaced along the sliding rail on the plenum box of the beam
2. Wire/cable should be looped through and around the *inside* of the bracket
3. Wire/cable should run from the bracket straight up or slightly away from the beam to the anchor location.

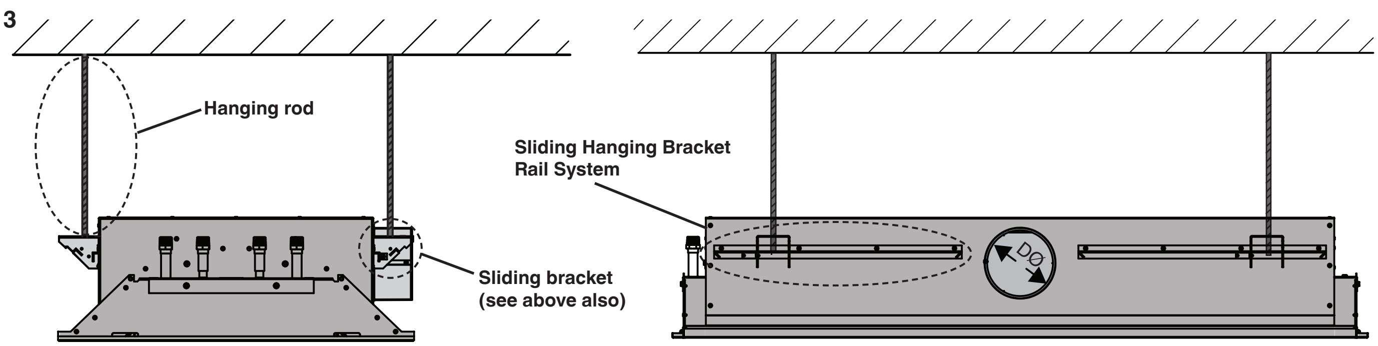
Warning!
The hanging wire should NEVER angle across the beam as it will put undue stress on the sliding bracket and rail.

Suspension device requirements

Chilled beams up to 6 ft in length should be supported by a minimum of four (4) suspension devices. Chilled beams above 6 ft in length must be supported by a minimum of six (6) suspension devices.

Warning!
Each unit must be supported independently from the suspended ceiling. The fixing points should only carry the weight of the chilled beam. Separate supports should be provided for adjacent systems components.

Figure 3



3 - Installation

Once the chilled beam is lowered into the ceiling grid and is in its final position, the air and water connections can be made.

3.4 Air connections

STEP ONE —

Make the air connection with either sheet metal or flexible duct.

> **Note**
> Flexible duct, when using in conjunction with flexible hose for water connections, enables easier alignment of the beam with the ceiling grid!

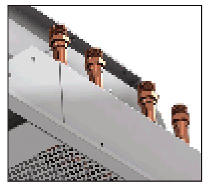
Flexible duct should be limited to a maximum length of 5ft.

The air connections should include a minimum of one duct diameter length of straight ductwork upstream of the beam connection to prevent excessive turbulence and noise generation.

> **Note**
> Active chilled beam systems operate at higher terminal pressures than diffusers in standard VAV systems therefore the ductwork and connections feeding the beam must be thoroughly sealed to prevent excessive leakage.

3.5 Water connections

The chilled beam is fitted with two or four water pipes (see image below for pipe configuration) which terminate in either NPT threaded male connections or straight pipe ends for field soldering. Each coil is factory tested for leakage and provided clean and capped.



STEP ONE —

Identify the warm and/or chilled water **supply connections** on the beam — noted by labels on the casing.

STEP TWO —

Remove the plastic cap before making the final water connections.

STEP THREE —

Make water connections. If NPT connections apply, do NOT over-tighten — applying excessive force on the water pipes may damage the heat exchange coil.

NOTE: See section 3.8 (page 7) for typical installation photographs.

Active Chilled Beam Pipe Configurations

DID632 4-pipe connnection

DID632 2-pipe connnection (can be cold or hot)

Note: Air duct connection location does not affect coil connection configuration

3 - Installation

3.6 Flushing the water piping system

Before flushing the water system, close all valves that isolate the beams and flush the main piping system first.

3.7 Filling and venting the water system

To ensure easy venting, the main pipes should be installed at a higher level than the beams. The horizontal pipes should be installed rising slightly towards the venting points.

Note
There should be no high points to create "air pockets" within the sytem.

Warning!
The hanging wire should NEVER angle across the beam as it will put undue stress on the sliding bracket and rail.

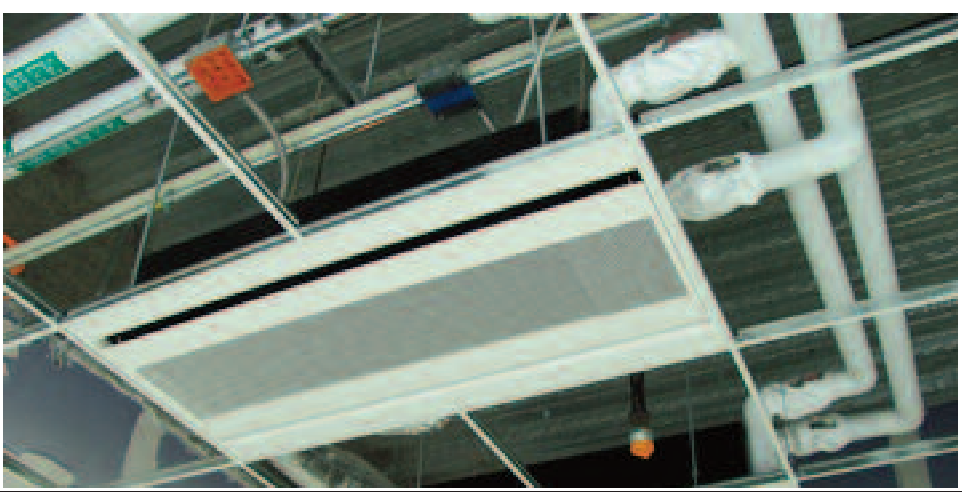
Before filling, all shut-off and control valves must be in the fully open position. The pumps should not be running during the filling-up (static filling). Continuous venting is necessary. The installation of both manual and automatic venting systems is recommended. The pump should only be started when filling is complete.

To remove all air from the system, the majority (>75%) of the system should be closed so that the water can circulate fast enough. When each section is full, it should be closed and the procedure repeated throughout the system.

Note
Use non-chilled water when filling up the system! Cold water can cause immediate condensation on the pipes. Warm water contains less oxygen which can limit venting to some extent.

3.8 Typical active chilled beam installation photos

Active chilled beams with 1-way flow installed for lab application



Active chilled beams installed for office application

4 - Commissioning

Important!
Commissioning is to be performed by properly trained and authorized personnel only!

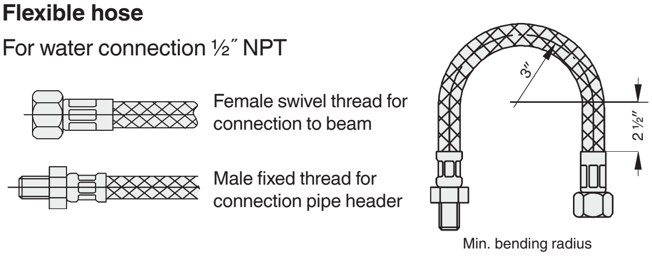
Important!
Wear eye protection and gloves.
Product includes sharp edges and burrs.

4.1 Waterside commissioning

1. Fully purge the complete hydronic system of air prior to commissioning.
2. Carefully inspect the system for leaks, paying particular attention to the connections.
3. Carefully inspect flexible hose, if applicable, for leaks. *Factory-provided* flexible hose shown (not provided on all orders).

Flexible hose

For water connection ½″ NPT



Note
The chilled beam is not provided with any water flow control or measuring devices, therefore the pipe work system should be fitted with sufficient balancing aids to enable adjustment of the flow rate.

4.2 Airside commissioning

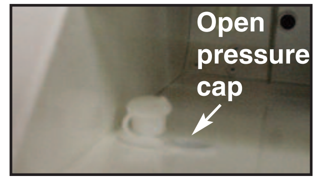
Note
Do not attempt to read the total discharge airflow rate using a hood or any other device that adds down-stream pressure to the beam, as it will reduce the amount of induction and give false readings.

The total air flow (primary + induced) cannot be measured.

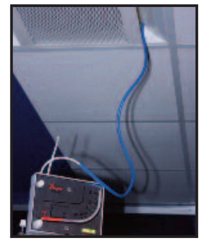
The primary air flow rate is determined by measuring the static pressure in the primary air chamber and referring to the calibration chart label provided on each beam or by calculating the volume by using the formula and tables in section 4.3.

To measure static pressure:

1. Locate the pressure tap fitted in the nozzle plate at the pipe connection end of the beam (see image). To reach the tap, it is not necessary to lower induction grille, but it can be lowered if preferred. Remove cap.



2. Attach a measuring gauge (as shown here):



4.3 Airside commissioning tables

Note
The constraints detailed in the tables below are for standard TROX chilled beams. For chilled beams with non-standard nozzle configurations, contact Trox USA.

The primary air volume in CFM can be calculated with this formula:

$$CFM = K \times \sqrt{\Delta P}$$

CFM	=	primary airflow (CFM)
K	=	constant - read from tables below
ΔP	=	static pressure measured in primary air chamber (in. W.G.)

Table 1:
Commissioning constraints for DID632

	K					
Beam Length	Nozzle Type					
	Z	M	J	G	H	U
2′	16	24	35	45	64	82
3′	25	37	54	71	100	127
4′	33	50	73	95	135	170
5′	42	63	92	119	173	220
6′	51	76	110	141	208	263
7′	59	90	131	169	242	306
8′	67	103	149	192	276	338
9′	77	115	167	214	309	368
10′	86	127	185	235	341	404

4/5 - Commissioning/Maintenance

4.3 Airside commissioning tables, continued..

Table 2:
Commissioning constraints for DID631

Beam Length	K					
	Nozzle Type					
	Z	M	J	G	H	U
4′	17	26	37	49	68	87
5′	21	32	47	61	87	110
6′	26	39	57	74	104	132
7′	30	46	67	87	122	154
8′	34	53	76	100	139	171
9′	39	59	86	112	156	187
10′	43	66	96	125	172	205

Example: DID632; 8ft; M-nozzle, measured static pressure of 0.33 in. W.G.

K = 103 (from table 1)

CFM = $103 \times \sqrt{0.33}$

= 60.0 CFM

5.1 Cleaning instructions

The chilled beam unit contains no moving or consumable parts, therefore the maintenance requirements are limited to periodic inspection for leakage and occasional cleaning of the heat exchanger coil and induction grille.

The accumulation of dust on the heat exchanger coil will eventually restrict the airflow through the coil, reducing cooling and heating performance.

The inspection frequency is subject to the environmental conditions and occupancy levels, for example, environments where bed linen is in use will require more frequent cleaning than office environments.

It is recommended that the beams be inspected on an annual basis until a pattern is established.

Important!
Maintenance is to be performed by properly trained and authorized personnel only!

Important!
Wear eye protection and gloves.
Product includes sharp edges and burrs.

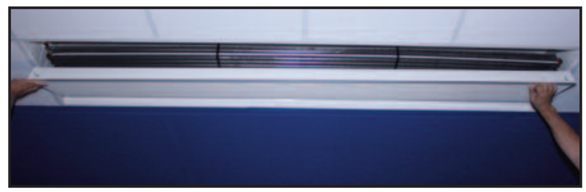
5.1 Cleaning instructions

To clean the heat exchanger coil:

1. To access the coil, release the unit's two (2) visible locking devices with spring mechanism (shown here) located on opposite sides of the beam's length. Lower the grille gently until it is hanging vertical to the ceiling.

Induction grille locking devices

Important!
For beams longer than 4' in length, it is recommended that 2 people lower the induction grille for cleaning and maintenance.



Release the locking devices and lower the grill gently.

2. Using a soft nozzle brush attached to vacuum cleaner (similar to image shown), gently vacuum back and forth in the direction of the coil to remove any accumulated dust.

3. After cleaning the coils, the induction grille should be carefully pushed back up into place and locking devices should be inserted back into their holes and locked into place.

4. If necessary, the face of the beam and visible painted surfaces can be cleaned using a *mild detergent diluted with warm water*, applied with a soft cloth, rinsed and wiped off.

Note
Strong or abrasive chemical detergents should not be used as they may cause damage to the paint finish. Only stubborn stains, if not removed by washing, can be wiped off with white spirit, but care is necessary to avoid affecting the gloss level of the surface by harsh rubbing.

5.2 Replacement parts

DID631 and DID632 chilled beams contain no serviceable or consumable parts.

6 - Troubleshooting

6.0 Troubleshooting

Symptom	Probable Cause	Solution
Loss of airflow	Obstruction on induction grille or heat exchanger coil	Remove induction grille and inspect/clean grille and heat exchanger as necessary
	Air connection detached from beam	Inspect attachment hardware and reconnect ductwork
	Obstruction in primary air plenum	Remove primary air connection and check for debris
	Air dampers incorrectly set	Inspect and adjust air dampers as necessary.
	Faulty or incorrectly set air handling unit	Inspect and re-comission air handling unit (by certified contractor)
Reduced Cooling	Obstruction on induction grille or heat exchanger coil	Remove induction grille and inspect/clean grille and heat exchanger as necessary
	Loss of water circulation through heat exchanger coil	Inspect control valves and check flow using system check points
Condensation on pipe-work or heat exchanger	Chilled water temperature too low	Measure chilled water temperature and reset to design value
	Incorrect primary air temperature or condition	Measure room humidity level. If humidity is higher than design condition, the primary air is failing to control room humidity. The air handling unit must be set so the primary air is dry enough to offset the latent gains.
	Primary air volume too low	Measure primary air volume using procedure described in section 4.3. Increase air volume design figure.

7 - Representations and Warranties

7 Warranties

7.1 Manufacturer's Representations & Warranties

MANUFACTURER'S REPRESENTATIONS AND WARRANTIES

TROX USA, INC.
4305 Settingdown Circle
Cumming, GA 30028

Phone: +1 (770) 569 1433
Fax: +1(770) 569 1435

These Representations and Warranties are applicable to all customers (the "Customers" and each, individually, a "Customer") purchasing products (the "Products") manufactured by TROX USA, Inc. (the "Company").

1. Warranty and Limitations:

1.1. Company warrants solely to the original purchaser of the Products that for the Warranty Period (as defined below), the Products will be free from defects in materials and workmanship under normal use, and will conform to Company's published specifications of the Products. Notwithstanding the foregoing, Company retains its right to deviate from its published specifications due to the latest innovations and improvements in function and design of the Products. The foregoing warranty is subject to the proper storage, transportation, installation, use and maintenance of the Products and does not include defects due to normal wear and tear or deterioration, improper modifications of the Products, improper construction of the surrounding facilities and unsuitable static, chemical, electrochemical or electrical conditions.

1.2. In the event of any shipping and freight damages of the Product, Customer shall refer any claims to the shipping company.

1.3. Upon delivery, Customer shall immediately and within seven (7) working days inspect the Products for conformity and visible defects (other than the shipping and freight damages described above in Section 1.2). Customer shall give Company immediate written notice of any non-conformities or visible defects regarding the Products, including photographs of the same, and contact Company in writing concerning return or repair, as the case may be. In order to make a determination regarding the existence of the alleged defect or non-conformity and the proper remedy thereof, the Company shall have the right to inspect the Products at Customer's premises . In the event that the Customer refuses to give Company access to its premises in order to inspect the Products, Customer shall lose all warranty claims related to the Products to be inspected.

1.4. Any defect or non-conforming Product discovered upon delivery should immediately be stored in a safe place and not be installed. If the defective or non-conforming Product is installed, TROX USA shall not be liable for any labor or charges associated with installation or labor costs, unless specific prior authorization is issued in writing by an officer of the Company.

1.5. Customer shall notify Company in writing of any defects of the Products immediately upon discovery. Any defect or non-compliant Product or part thereof should be put aside for inspection by the Company and should not be installed. Company's sole obligation under the foregoing warranty is, at Company's option, to repair or correct any such covered defect or to replace or exchange the Product. Customer shall bear all shipping and handling expenses related to the return of the Products. Any repaired, corrected, replaced or exchanged Products shall be subject to the warranty set forth in 1.1., following their repair, correction, replacement or exchange. If Company has received notification from Customer, and no defects of the Product could be discovered, Customer shall bear the costs that Company incurred as a result of the notice.

1.6. With respect to orders made to custom, any defects of the Products caused by Customer's specifications are excluded from the warranty set forth in 1.1.

1.7. Company also makes no warranty that the Products manufactured under an order made to custom do not infringe the intellectual property or other proprietary rights of any third party and Customer is solely responsible for assuring that such Products do not so infringe.

1.8. The "Warranty Period" begins on the invoice date, and continues to be in effect for twelve (12) months.

1.9. Company does not authorize any person or party to assume or create for it any other obligation or liability in connection with the Products except as set forth herein.

1.10. All requests and notices under this Warranty shall be directed to:

TROX USA, Inc.
Attn. Thomas J. Bosko, Production Manager
4305 Settingdown Circle
Cumming, GA 30028

Fax: +1(770) 569 1435
E-Mail: tjb@troxusa.com

1.11. THE WARRANTY SET FORTH IN SECTION 1.1 IS MADE IN LIEU OF ALL OTHER WARRANTIES (WHETHER EXPRESS OR IMPLIED), RIGHTS OR CONDITIONS, AND CUSTOMER ACKNOWLEDGES THAT EXCEPT FOR SUCH LIMITED WARRANTY, THE PRODUCTS ARE PROVIDED "AS IS." COMPANY SPECIFICALLY DISCLAIMS, WITHOUT LIMITATION, ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, OF ANY KIND, INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, NON-INFRINGEMENT, AND THOSE WARRANTIES ARISING FROM A COURSE OF PERFORMANCE, A COURSE OF DEALING OR TRADE USAGE.

2. Limitation of Liability:

2.1. IN NO EVENT SHALL COMPANY BE LIABLE FOR ANY INDIRECT, INCIDENTAL, PUNITIVE, SPECIAL OR CONSEQUENTIAL DAMAGES, INCLUDING BUT NOT LIMITED TO, DAMAGES FOR LOSS OF PROFITS, REVENUE, GOODWILL OR USE, INCURRED BY CUSTOMER OR ANY THIRD PARTY, WHETHER IN AN ACTION IN CONTRACT, TORT, STRICT LIABILITY, OR IMPOSED BY STATUTE, OR OTHERWISE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. COMPANY'S LIABILITY FOR DAMAGES ARISING OUT OF OR IN CONNECTION WITH THIS AGREEMENT SHALL IN NO EVENT EXCEED THE PURCHASE PRICE OF THE PRODUCTS. IT IS AGREED AND ACKNOWLEDGED THAT THE PROVISIONS OF THIS AGREEMENT ALLOCATE THE RISKS BETWEEN COMPANY AND CUSTOMER, THAT COMPANY'S PRICING REFLECTS THIS ALLOCATION OF RISK, AND BUT FOR THIS ALLOCATION AND LIMITATION OF LIABILITY, COMPANY WOULD NOT HAVE ENTERED INTO THIS AGREEMENT.

2.2. IN JURISDICTIONS THAT LIMIT THE SCOPE OF OR PRECLUDE LIMITATIONS OR EXCLUSION OF REMEDIES OR DAMAGES, OR OF LIABILITY, SUCH AS LIABILITY FOR GROSS NEGLIGENCE OR WILLFUL MISCONDUCT OR DO NOT ALLOW IMPLIED WARRANTIES TO BE EXCLUDED, THE LIMITATION OR EXCLUSION OF WARRANTIES, REMEDIES, DAMAGES OR LIABILITY SET FORTH ABOVE ARE INTENDED TO APPLY TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW. CUSTOMER MAY ALSO HAVE OTHER RIGHTS THAT VARY BY STATE, COUNTRY OR OTHER JURISDICTION.

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APPENDIX C

Heating Design Condition Boiler Effciency η_B 85%

Room	AHU	Area	Occ. Density	Su	Mo	Tu	We	Th	Fr	Sa	REDUCTION Demand Capacity	Capacity Required	Savings
AUDITORIUM SPACES		[SF]	[#ppl/1000 SF]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[MBh]	[MBh]	
460 Lecture/Recital (1)	AHU-1	2,327	150.0	21,476	58,383	103,764	122,382	147,024	119,985	37,737	611	719	19%
100.1 Audience Chamber (1)	AHU-2	12,996	150.0	119,922	326,018	579,428	683,395	820,995	670,009	210,730	3,410	4,012	19%
B27 DRESS (3)	AHU-5	499	10.0	307	834	1,482	1,748	2,099	1,713	539	9	10	20%
B34 DRESS (3)	AHU-5	187	10.0	115	313	557	656	789	644	202	3	4	20%
B40 DRESS (3)	AHU-5	187	10.0	115	313	557	657	789	644	202	3	4	20%
B44 DRESS (3)	AHU-5	135	10.0	83	226	402	475	570	465	146	2	3	20%
B48 DRESS (3)	AHU-5	168	10.0	103	281	499	588	707	577	181	3	3	20%
B52 DRESS (3)	AHU-5	161	10.0	99	270	479	565	679	554	174	3	3	20%
B56 DRESS (3)	AHU-5	239	10.0	147	399	710	837	1,005	820	258	4	5	20%
B60 DRESS (3)	AHU-5	563	10.0	346	941	1,672	1,972	2,369	1,933	608	10	12	20%
B64 DRESS (3)	AHU-5	598	10.0	368	999	1,776	2,095	2,516	2,054	646	10	12	20%
013 OP OFFICE (1)	AHU-1	523	5.0	161	437	777	916	1,101	898	283	5	5	22%
087 OFFICE (1)	AHU-5	291	5.0	90	244	433	511	613	501	157	3	3	22%
089 OFFICE (1)	AHU-1	315	5.0	97	263	468	552	663	541	170	3	3	22%
100 MEM HALL (2)	AHU-1	3,542	30.0	6,538	17,774	31,590	37,258	44,760	36,528	11,489	186	219	19%
101 LOBBY (2)	AHU-1	718	30.0	1,325	3,601	6,400	7,548	9,068	7,401	2,328	38	44	19%
198 LOBBY (2)	AHU-1	695	30.0	1,283	3,489	6,201	7,313	8,786	7,170	2,255	36	43	19%
201 LOBBY (2)	AHU-1	718	30.0	1,325	3,601	6,400	7,548	9,068	7,401	2,328	38	44	19%
203 LOBBY (2)	AHU-1	1,955	30.0	3,609	9,810	17,436	20,564	24,705	20,162	6,341	103	121	19%
297 LOBBY (2)	AHU-1	1,958	30.0	3,614	9,826	17,463	20,597	24,744	20,193	6,351	103	121	19%
298 LOBBY (2)	AHU-1	695	30.0	1,283	3,489	6,201	7,313	8,786	7,170	2,255	36	43	19%
301 LOBBY (2)	AHU-1	718	30.0	1,325	3,601	6,400	7,548	9,068	7,401	2,328	38	44	19%
303 LOBBY (2)	AHU-1	2,304	30.0	4,253	11,561	20,547	24,234	29,114	23,760	7,473	121	142	19%
397 LOBBY (2)	AHU-1	2,301	30.0	4,247	11,546	20,520	24,202	29,075	23,728	7,463	121	142	19%
398 LOBBY (2)	AHU-1	695	30.0	1,283	3,489	6,201	7,313	8,786	7,170	2,255	36	43	19%
		35,488		173,512	471,708	838,361	988,789	1,187,880	969,420	304,900	4,935	5,805	19%
OFFICE SPACES				[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[kBtu/h]	[MBh]	[MBh]	
240 Lg Conference Building (1)	AHU-3	1,648	66.7	14,564	9,992	17,806	20,919	25,146	20,590	21,451	130	153	45%
018 VEST (2)	AHU-1	245	30.0	975	669	1,192	1,400	1,683	1,378	1,436	9	10	45%
088 VEST (2)	AHU-1	215	30.0	855	587	1,046	1,228	1,477	1,209	1,260	8	9	45%
104 LNGE (1)	AHU-1	452	25.0	1,499	1,028	1,833	2,153	2,588	2,119	2,208	13	16	45%
106 CONF (1)	AHU-1	526	66.7	4,648	3,189	5,683	6,677	8,026	6,572	6,847	42	49	45%
110 CONF (1)	AHU-1	687	66.7	6,074	4,167	7,426	8,725	10,488	8,588	8,947	54	64	45%
110.1 CONF (1)	AHU-1	203	66.7	1,798	1,233	2,198	2,582	3,104	2,542	2,648	16	19	45%
125 LOBBY (2)	AHU-1	7,594	30.0	30,192	20,716	36,915	43,369	52,133	42,687	44,471	270	318	45%
196 LNGE (1)	AHU-1	448	25.0	1,485	1,019	1,816	2,134	2,565	2,100	2,188	13	16	45%
204 LNGE (1)	AHU-1	452	25.0	1,499	1,028	1,833	2,153	2,588	2,119	2,208	13	16	45%
210 OP OFFICE (1)	AHU-1	918	5.0	608	417	743	873	1,050	860	896	5	6	47%
260 FNDRS RM (1)	AHU-3	1,556	66.7	13,752	9,435	16,813	19,753	23,745	19,442	20,255	123	145	45%
290 OP OFFICE (1)	AHU-1	1,395	5.0	924	634	1,130	1,328	1,596	1,307	1,362	8	10	47%
296 LNGE (1)	AHU-1	454	25.0	1,505	1,032	1,840	2,161	2,598	2,127	2,216	13	16	45%
304 LNGE (1)	AHU-1	452	25.0	1,499	1,028	1,833	2,153	2,588	2,119	2,208	13	16	45%
382 CONF (1)	AHU-1	338	66.7	2,983	2,047	3,647	4,285	5,151	4,218	4,394	27	31	45%
390 OP OFFICE (1)	AHU-1	1,393	5.0	923	633	1,128	1,325	1,593	1,305	1,359	8	10	47%
396 LNGE (1)	AHU-1	454	25.0	1,505	1,032	1,840	2,161	2,598	2,127	2,216	13	16	45%
		19431.95		87,287	59,889	106,721	125,380	150,717	123,408	128,567	782	920	45%
Totals	-	**54,920**	-	**260,799**	**531,597**	**945,082**	**1,114,169**	**1,338,597**	**1,092,829**	**433,468**	**5,717**	**6,725**	**24%**

APPENDIX C

Cooling Design Condition Chiller Effciency COP 6.62

** Converted from $\eta_{Primary}$ = 0.531 [kW/ton]*

Room	AHU	Area	Occ. Density	Su	Mo	Tu	We	Th	Fr	Sa	REDUCTION Demand Capacity	Capacity Required	Savings
AUDITORIUM SPACES		[SF]	[#ppl/1000 SF]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	
460 Lecture/Recital (1)	AHU-1	2,327	150.0	-1,097	-4,629	-3,963	-5,550	-5,472	-4,877	-2,888	-28,477	-4,299	21%
100.1 Audience Chamber (1)	AHU-2	12,996	150.0	-6,125	-25,851	-22,130	-30,993	-30,558	-27,236	-16,126	-159,017	-24,009	21%
B27 DRESS (3)	AHU-5	499	10.0	-16	-66	-57	-79	-78	-70	-41	-407	-61	23%
B34 DRESS (3)	AHU-5	187	10.0	-6	-25	-21	-30	-29	-26	-15	-153	-23	23%
B40 DRESS (3)	AHU-5	187	10.0	-6	-25	-21	-30	-29	-26	-15	-153	-23	23%
B44 DRESS (3)	AHU-5	135	10.0	-4	-18	-15	-22	-21	-19	-11	-110	-17	23%
B48 DRESS (3)	AHU-5	168	10.0	-5	-22	-19	-27	-26	-23	-14	-137	-21	23%
B52 DRESS (3)	AHU-5	161	10.0	-5	-21	-18	-26	-25	-23	-13	-131	-20	23%
B56 DRESS (3)	AHU-5	239	10.0	-8	-32	-27	-38	-37	-33	-20	-195	-29	23%
B60 DRESS (3)	AHU-5	563	10.0	-18	-75	-64	-89	-88	-79	-47	-459	-69	23%
B64 DRESS (3)	AHU-5	598	10.0	-19	-79	-68	-95	-94	-83	-49	-487	-74	23%
013 OP OFFICE (1)	AHU-1	523	5.0	-8	-35	-30	-42	-41	-37	-22	-213	-32	24%
087 OFFICE (1)	AHU-5	291	5.0	-5	-19	-17	-23	-23	-20	-12	-119	-18	24%
089 OFFICE (1)	AHU-1	315	5.0	-5	-21	-18	-25	-25	-22	-13	-128	-19	24%
100 MEM HALL (2)	AHU-1	3,542	30.0	-334	-1,409	-1,206	-1,690	-1,666	-1,485	-879	-8,670	-1,309	22%
101 LOBBY (2)	AHU-1	718	30.0	-68	-286	-244	-342	-338	-301	-178	-1,756	-265	22%
198 LOBBY (2)	AHU-1	695	30.0	-66	-277	-237	-332	-327	-291	-173	-1,702	-257	22%
201 LOBBY (2)	AHU-1	718	30.0	-68	-286	-244	-342	-338	-301	-178	-1,756	-265	22%
203 LOBBY (2)	AHU-1	1,955	30.0	-184	-778	-666	-933	-920	-820	-485	-4,785	-722	22%
297 LOBBY (2)	AHU-1	1,958	30.0	-185	-779	-667	-934	-921	-821	-486	-4,793	-724	22%
298 LOBBY (2)	AHU-1	695	30.0	-66	-277	-237	-332	-327	-291	-173	-1,702	-257	22%
301 LOBBY (2)	AHU-1	718	30.0	-68	-286	-244	-342	-338	-301	-178	-1,756	-265	22%
303 LOBBY (2)	AHU-1	2,304	30.0	-217	-917	-785	-1,099	-1,084	-966	-572	-5,639	-851	22%
397 LOBBY (2)	AHU-1	2,301	30.0	-217	-915	-784	-1,098	-1,082	-965	-571	-5,631	-850	22%
398 LOBBY (2)	AHU-1	695	30.0	-66	-277	-237	-332	-327	-291	-173	-1,702	-257	22%
		35487.875		-8,862	-37,403	-32,019	-44,843	-44,213	-39,407	-23,332	-230,079	-34,737	22%
OFFICE SPACES		[SF]	[#ppl/1000 SF]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	[ton]	
240 Lg Conference Building (1)	AHU-3	1,648	66.7	-868	-754	-654	-900	-906	-798	-1,469	-6,350	-959	44%
018 VEST (2)	AHU-1	245	30.0	-58	-50	-44	-60	-61	-53	-98	-425	-64	45%
088 VEST (2)	AHU-1	215	30.0	-51	-44	-38	-53	-53	-47	-86	-373	-56	45%
104 LNGE (1)	AHU-1	452	25.0	-89	-78	-67	-93	-93	-82	-151	-654	-99	45%
106 CONF (1)	AHU-1	526	66.7	-277	-241	-209	-287	-289	-255	-469	-2,027	-306	44%
110 CONF (1)	AHU-1	687	66.7	-362	-315	-273	-375	-378	-333	-613	-2,648	-400	44%
110.1 CONF (1)	AHU-1	203	66.7	-107	-93	-81	-111	-112	-99	-181	-784	-118	44%
125 LOBBY (2)	AHU-1	7,594	30.0	-1,799	-1,564	-1,357	-1,865	-1,879	-1,655	-3,046	-13,164	-1,988	45%
196 LNGE (1)	AHU-1	448	25.0	-88	-77	-67	-92	-92	-81	-150	-648	-98	45%
204 LNGE (1)	AHU-1	452	25.0	-89	-78	-67	-93	-93	-82	-151	-654	-99	45%
210 OP OFFICE (1)	AHU-1	918	5.0	-36	-31	-27	-38	-38	-33	-61	-265	-40	46%
260 FNDRS RM (1)	AHU-3	1,556	66.7	-819	-712	-618	-850	-856	-754	-1,387	-5,996	-905	44%
290 OP OFFICE (1)	AHU-1	1,395	5.0	-55	-48	-42	-57	-58	-51	-93	-403	-61	46%
296 LNGE (1)	AHU-1	454	25.0	-90	-78	-68	-93	-94	-82	-152	-656	-99	45%
304 LNGE (1)	AHU-1	452	25.0	-89	-78	-67	-93	-93	-82	-151	-654	-99	45%
382 CONF (1)	AHU-1	338	66.7	-178	-155	-134	-184	-186	-163	-301	-1,301	-196	44%
390 OP OFFICE (1)	AHU-1	1,393	5.0	-55	-48	-41	-57	-57	-51	-93	-402	-61	46%
396 LNGE (1)	AHU-1	454	25.0	-90	-78	-68	-93	-94	-82	-152	-656	-99	45%
		19,432		-5,200	-4,522	-3,923	-5,392	-5,432	-4,784	-8,806	-38,059	-5,746	45%
Totals	-	**54,920**	-	**-14,062**	**-41,925**	**-35,942**	**-50,235**	**-49,645**	**-44,191**	**-32,138**	**-268,137**	**-40,484**	**26%**

Life Cycle Cost Analysis

Options Comparison
Input Table
Date: March 22, 2014

Project Information

Building	The Auditorium
Project Name	FMPAA Rennovation
Project Type (lighting, heating, etc)	Mech System Alternatives

Costs

Initial Costs - FY14

	Baseline	Option A
Total Cost	$ -	$ 149,678
Adjustments	$ -	$ (28,072)
Net Costs	**$ -**	**$ 121,606**

Replacement Costs

	Baseline	Option A
Expected Life (Years)	20	20
Replacement Cost	$ -	$ 149,678

One Time Operating Costs

		Baseline Materials	Baseline Main./Labor	Baseline Total		Option A Materials	Option A Main./Labor	Option A Total
FY15	Year 1	$ -	$ 1,044	$ 1,044	Year 1	$ -	$ 722	$ 722
FY16	Year 2	$ -	$ 1,044	$ 1,044	Year 2	$ -	$ 722	$ 722
FY17	Year 3	$ -	$ 1,044	$ 1,044	Year 3	$ -	$ 722	$ 722
FY18	Year 4	$ -	$ 1,044	$ 1,044	Year 4	$ -	$ 722	$ 722
FY19	Year 5	$ -	$ 1,044	$ 1,044	Year 5	$ -	$ 722	$ 722
FY20	Year 6	$ -	$ 1,044	$ 1,044	Year 6	$ -	$ 722	$ 722
FY21	Year 7	$ -	$ 1,044	$ 1,044	Year 7	$ -	$ 722	$ 722
FY22	Year 8	$ -	$ 1,044	$ 1,044	Year 8	$ -	$ 722	$ 722
FY23	Year 9	$ -	$ 1,044	$ 1,044	Year 9	$ -	$ 722	$ 722
FY24	Year 10	$ -	$ 1,044	$ 1,044	Year 10	$ -	$ 722	$ 722
FY25	Year 11	$ -	$ 1,044	$ 1,044	Year 11	$ -	$ 722	$ 722
FY26	Year 12	$ -	$ 1,044	$ 1,044	Year 12	$ -	$ 722	$ 722
FY27	Year 13	$ -	$ 1,044	$ 1,044	Year 13	$ -	$ 722	$ 722
FY28	Year 14	$ -	$ 1,044	$ 1,044	Year 14	$ -	$ 722	$ 722
FY29	Year 15	$ -	$ 1,044	$ 1,044	Year 15	$ -	$ 722	$ 722
FY30	Year 16	$ -	$ 1,044	$ 1,044	Year 16	$ -	$ 722	$ 722
FY31	Year 17	$ -	$ 1,044	$ 1,044	Year 17	$ -	$ 722	$ 722
FY32	Year 18	$ -	$ 1,044	$ 1,044	Year 18	$ -	$ 722	$ 722
FY33	Year 19	$ -	$ 1,044	$ 1,044	Year 19	$ -	$ 722	$ 722
FY34	Year 20	$ -	$ 1,044	$ 1,044	Year 20	$ -	$ 722	$ 722
	Totals	**$ -**	**$ 20,872**	**$ 20,872**	**Totals**	**$ -**	**$ 14,450**	**$ 14,450**
	Yr 20 Remaining Equip. Value			**$ -**	**Yr 20 Remaining Equip. Value**			**$ -**

Annual Consumption

	Baseline Annual Consumption	Baseline Cost ($)	Option A Annual Consumption	Option A Cost ($)
Electricity		$ 190,095		$ 186,585
Natural Gas		$ 76,976		$ 65,137
	TOTALS	**$ 267,070**	**TOTALS**	**$ 251,722**

Assumptions

Discount Rate	Escalation Rates: Electricity	Natural Gas	Materials	Maint. and Labor	Study Period
8.00%	3.75%	5.00%	**1.73%**	**1.73%**	**20**

APPENDIX C

Life Cycle Cost Analysis	Project Information	
Options Comparison	Building	The Auditorium
Input Table	Project Name	FMPAA Rennovation
Date: March 22, 2014	Project Type (lighting, heating, etc)	Mech System Alternatives

Costs

	Baseline		Option B	
Initial Costs - FY14				
Total Cost	$ -		Total Cost	$ 608,798
Adjustments	$ -		Adjustments	$ (120,178)
Net Costs	**$ -**		**Net Costs**	**$ 488,620**
Replacement Costs				
Expected Life (Years)	20		Expected Life (Years)	20
Replacement Cost	$ -		Replacement Cost	$ 608,798

One Time Operating Costs

		Baseline Materials	Baseline Main./Labor	Baseline Total		Option B Materials	Option B Main./Labor	Option B Total
FY15	Year 1	$ -	$ 2,938	$ 2,938	Year 1	$ -	$ 2,034	$ 2,034
FY16	Year 2	$ -	$ 2,938	$ 2,938	Year 2	$ -	$ 2,034	$ 2,034
FY17	Year 3	$ -	$ 2,938	$ 2,938	Year 3	$ -	$ 2,034	$ 2,034
FY18	Year 4	$ -	$ 2,938	$ 2,938	Year 4	$ -	$ 2,034	$ 2,034
FY19	Year 5	$ -	$ 2,938	$ 2,938	Year 5	$ -	$ 2,034	$ 2,034
FY20	Year 6	$ -	$ 2,938	$ 2,938	Year 6	$ -	$ 2,034	$ 2,034
FY21	Year 7	$ -	$ 2,938	$ 2,938	Year 7	$ -	$ 2,034	$ 2,034
FY22	Year 8	$ -	$ 2,938	$ 2,938	Year 8	$ -	$ 2,034	$ 2,034
FY23	Year 9	$ -	$ 2,938	$ 2,938	Year 9	$ -	$ 2,034	$ 2,034
FY24	Year 10	$ -	$ 2,938	$ 2,938	Year 10	$ -	$ 2,034	$ 2,034
FY25	Year 11	$ -	$ 2,938	$ 2,938	Year 11	$ -	$ 2,034	$ 2,034
FY26	Year 12	$ -	$ 2,938	$ 2,938	Year 12	$ -	$ 2,034	$ 2,034
FY27	Year 13	$ -	$ 2,938	$ 2,938	Year 13	$ -	$ 2,034	$ 2,034
FY28	Year 14	$ -	$ 2,938	$ 2,938	Year 14	$ -	$ 2,034	$ 2,034
FY29	Year 15	$ -	$ 2,938	$ 2,938	Year 15	$ -	$ 2,034	$ 2,034
FY30	Year 16	$ -	$ 2,938	$ 2,938	Year 16	$ -	$ 2,034	$ 2,034
FY31	Year 17	$ -	$ 2,938	$ 2,938	Year 17	$ -	$ 2,034	$ 2,034
FY32	Year 18	$ -	$ 2,938	$ 2,938	Year 18	$ -	$ 2,034	$ 2,034
FY33	Year 19	$ -	$ 2,938	$ 2,938	Year 19	$ -	$ 2,034	$ 2,034
FY34	Year 20	$ -	$ 2,938	$ 2,938	Year 20	$ -	$ 2,034	$ 2,034
	Totals	**$ -**	**$ 58,759**	**$ 58,759**	**Totals**	**$ -**	**$ 40,679**	**$ 40,679**
	Yr 20 Remaining Equip. Value			**$ -**	**Yr 20 Remaining Equip. Value**			**$ -**

Annual Consumption

	Baseline Annual Consumption	Baseline Cost ($)	Option B Annual Consumption	Option B Cost ($)
Electricity		$ 190,095		$ 185,611
Natural Gas		$ 76,976		$ 62,655
	TOTALS	**$ 267,070**	**TOTALS**	**$ 248,265**

Assumptions

Discount Rate	Escalation Rates				Study Period
	Electricity	Natural Gas	Materials	Maint. and Labor	
8.00%	3.75%	5.00%	**1.73%**	**1.73%**	**20**

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APPENDIX C

Project Name:	The Auditorium	**Project/Reference Number:**	
Location:	Lemma, MN	**Engineered By:**	Erin Miller
Architect:		**Company:**	Penn State
Mechanical Engineer:		**Run Date:**	3/28/2014
Contractor:		**Notes:**	

Room 310 - VAV

Calculation Summary

				Octave Midband Frequency, Hz							
Element		**Properties**	**NC**	**63**	**125**	**250**	**500**	**1K**	**2K**	**4K**	**dB(A)**
1	**Room 310 - VAV**	**Criteria: NC-40**	**29**	**48**	**45**	**37**	**32**	**25**	**22**	**27**	**35**
2	**Supply Path (1)**	**Criteria: NC-40**									
3	AHU-1			85	80	88	85	81	80	78	
4	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
5	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
6	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
7	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
8	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
9	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
10	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
11	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
12	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
13	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
14	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				17	10	1	0	0	0	0	
15	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
16	Rectangular Duct	32"x20"x10' (0")		-2	-2	-1	0	0	0	0	
17	Takeoff (Branch Power Split)	32"x20" / 32"x20"		-1	-1	-1	-1	-1	-1	-1	
				51	46	39	32	24	15	6	
18	Rectangular Duct	32"x20"x9'0.84" (0")		-2	-1	-1	0	0	0	0	
19	Rectangular Elbow Radius	32"x20" (0")		0	-1	-2	-3	-3	-3	-3	
				13	9	4	0	0	0	0	
20	Rectangular Duct	32"x20"x6'2.4" (0")		-1	-1	-1	0	0	0	0	
21	Rectangular Duct	22"x20"x5' (0")		-1	-1	-1	0	0	0	0	
22	Takeoff (Branch Power Split)	22"x20" / 22"x20"		0	0	0	0	0	0	0	
				72	67	61	54	45	36	26	
23	Rectangular Duct	22"x20"x12' (0")		-3	-2	-1	0	0	0	0	
24	Takeoff (Branch Power Split)	22"x20" / 12"		-5	-5	-5	-5	-5	-5	-5	
				34	28	21	13	4	0	0	
25	Circular Duct	12"x5'1.08" (0")		0	0	0	0	0	0	0	
26	Circular Elbow Radius	12" (0")		0	0	-1	-2	-3	-3	-3	
				13	9	5	0	0	0	0	
27	Circular Duct	12"x4'8.4" (0")		0	0	0	0	0	0	0	
28	Circular Duct	8"x3'7.08" (0")		0	0	0	0	0	0	0	
29	VAV 3-8 (1)			55	55	53	46	44	40	36	
30	Rectangular Duct	12"x10"x7' (0")		-2	-1	-1	0	0	0	0	
31	Tee (Branch Power Split)	12"x10" / 8"x8"		-5	-5	-5	-5	-5	-5	-5	
				27	22	16	10	3	2	2	

32	Rectangular Duct	8"x8"x9'7.8" (0")		-3	-2	-1	-1	-1	-1	-1	
33	Takeoff (Branch Power Split)	8"x8" / 8"		-3	-3	-3	-3	-3	-3	-3	
				17	13	8	1	0	0	0	
34	Circular Duct	8"x1'6" (0")		0	0	0	0	0	0	0	
35	Flexible Duct	8"x3'		-2	-5	-7	-14	-15	-16	-8	
36	Room Correction (Normally Furnished)	19'1.2"x47'1.2"x10'		-7	-8	-9	-10	-11	-12	-13	
37	**SUM**		**24**	**40**	**37**	**30**	**25**	**20**	**16**	**21**	**29**
38	**Supply Path (2)**	**Criteria: NC-40**									
39	AHU-1			85	80	88	85	81	80	78	
40	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
41	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
42	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
43	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
44	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
45	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
46	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
47	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
48	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
49	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
50	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				17	10	1	0	0	0	0	
51	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
52	Rectangular Duct	32"x20"x10' (0")		-2	-2	-1	0	0	0	0	
53	Takeoff (Branch Power Split)	32"x20" / 32"x20"		-1	-1	-1	-1	-1	-1	-1	
				51	46	39	32	24	15	6	
54	Rectangular Duct	32"x20"x9'0.84" (0")		-2	-1	-1	0	0	0	0	
55	Rectangular Elbow Radius	32"x20" (0")		0	-1	-2	-3	-3	-3	-3	
				13	9	4	0	0	0	0	
56	Rectangular Duct	32"x20"x6'2.4" (0")		-1	-1	-1	0	0	0	0	
57	Rectangular Duct	22"x20"x5' (0")		-1	-1	-1	0	0	0	0	
58	Takeoff (Branch Power Split)	22"x20" / 22"x20"		0	0	0	0	0	0	0	
				72	67	61	54	45	36	26	
59	Rectangular Duct	22"x20"x12' (0")		-3	-2	-1	0	0	0	0	
60	Takeoff (Branch Power Split)	22"x20" / 12"		-5	-5	-5	-5	-5	-5	-5	
				34	28	21	13	4	0	0	
61	Circular Duct	12"x5'1.08" (0")		0	0	0	0	0	0	0	
62	Circular Elbow Radius	12" (0")		0	0	-1	-2	-3	-3	-3	
				13	9	5	0	0	0	0	
63	Circular Duct	12"x4'8.4" (0")		0	0	0	0	0	0	0	
64	Circular Duct	8"x3'7.08" (0")		0	0	0	0	0	0	0	
65	VAV 3-8 (1)			55	55	53	46	44	40	36	
66	Rectangular Duct	12"x10"x7' (0")		-2	-1	-1	0	0	0	0	
67	Tee (Branch Power Split)	12"x10" / 8"x8"		-5	-5	-5	-5	-5	-5	-5	
				27	22	16	10	3	2	2	
68	Rectangular Duct	8"x8"x9'7.8" (0")		-3	-2	-1	-1	-1	-1	-1	
69	Takeoff (Branch Power Split)	8"x8" / 8"		-3	-3	-3	-3	-3	-3	-3	
				17	13	8	1	0	0	0	
70	Circular Duct	8"x9'5.4" (0")		0	0	0	0	-1	-1	-1	
71	Circular Elbow Radius	8" (0")		0	0	-1	-2	-3	-3	-3	
				0	0	0	0	0	0	0	
72	Circular Duct	8"x1'6" (0")		0	0	0	0	0	0	0	

73	Flexible Duct	8"x3'		-2	-5	-7	-14	-15	-16	-8	
74	Room Correction (Normally Furnished)	19'1.2"x47'1.2"x10'		-7	-8	-9	-10	-11	-12	-13	
75	**SUM**		**21**	**40**	**37**	**29**	**23**	**16**	**13**	**17**	**27**
76	**Supply Path (3)**	**Criteria: NC-40**									
77	AHU-1			85	80	88	85	81	80	78	
78	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
79	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
80	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
81	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
82	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
83	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
84	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
85	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
86	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
87	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
88	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				17	10	1	0	0	0	0	
89	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
90	Rectangular Duct	32"x20"x10' (0")		-2	-2	-1	0	0	0	0	
91	Takeoff (Branch Power Split)	32"x20" / 32"x20"		-1	-1	-1	-1	-1	-1	-1	
				51	46	39	32	24	15	6	
92	Rectangular Duct	32"x20"x9'0.84" (0")		-2	-1	-1	0	0	0	0	
93	Rectangular Elbow Radius	32"x20" (0")		0	-1	-2	-3	-3	-3	-3	
				13	9	4	0	0	0	0	
94	Rectangular Duct	32"x20"x6'2.4" (0")		-1	-1	-1	0	0	0	0	
95	Rectangular Duct	22"x20"x5' (0")		-1	-1	-1	0	0	0	0	
96	Takeoff (Branch Power Split)	22"x20" / 22"x20"		0	0	0	0	0	0	0	
				72	67	61	54	45	36	26	
97	Rectangular Duct	22"x20"x12' (0")		-3	-2	-1	0	0	0	0	
98	Takeoff (Branch Power Split)	22"x20" / 12"		-5	-5	-5	-5	-5	-5	-5	
				34	28	21	13	4	0	0	
99	Circular Duct	12"x5'1.08" (0")		0	0	0	0	0	0	0	
100	Circular Elbow Radius	12" (0")		0	0	-1	-2	-3	-3	-3	
				13	9	5	0	0	0	0	
101	Circular Duct	12"x4'8.4" (0")		0	0	0	0	0	0	0	
102	Circular Duct	8"x3'7.08" (0")		0	0	0	0	0	0	0	
103	VAV 3-8 (1)			55	55	53	46	44	40	36	
104	Rectangular Duct	12"x10"x7' (0")		-2	-1	-1	0	0	0	0	
105	Tee (Branch Power Split)	12"x10" / 12"x10"		-2	-2	-2	-2	-2	-2	-2	
				30	25	19	12	6	5	5	
106	Rectangular Duct	12"x10"x3'11.16" (0")		-1	-1	0	0	0	0	0	
107	Takeoff (Branch Power Split)	12"x10" / 12"x10"		-2	-2	-2	-2	-2	-2	-2	
				12	6	4	4	4	4	4	
108	Rectangular Duct	12"x10"x3'7.68" (0")		-1	-1	0	0	0	0	0	
109	Circular Duct	8"x6'6" (0")		0	0	0	0	0	0	0	
110	Circular Elbow Radius	8" (0")		0	0	-1	-2	-3	-3	-3	
				0	0	0	0	0	0	0	
111	Circular Duct	8"x3' (0")		0	0	0	0	0	0	0	
112	Flexible Duct	8"x3'		-2	-5	-7	-14	-15	-16	-8	
113	Room Correction (Normally Furnished)	19'1.2"x47'1.2"x10'		-7	-8	-9	-10	-11	-12	-13	

114	**SUM**		**25**	**45**	**41**	**33**	**27**	**20**	**17**	**22**	**31**
115	**Supply Path (4)**	**Criteria: NC-40**									
116	AHU-1			85	80	88	85	81	80	78	
117	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
118	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
119	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
120	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
121	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
122	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
123	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
124	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
125	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
126	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
127	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				17	10	1	0	0	0	0	
128	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
129	Rectangular Duct	32"x20"x10' (0")		-2	-2	-1	0	0	0	0	
130	Takeoff (Branch Power Split)	32"x20" / 32"x20"		-1	-1	-1	-1	-1	-1	-1	
				51	46	39	32	24	15	6	
131	Rectangular Duct	32"x20"x9'0.84" (0")		-2	-1	-1	0	0	0	0	
132	Rectangular Elbow Radius	32"x20" (0")		0	-1	-2	-3	-3	-3	-3	
				13	9	4	0	0	0	0	
133	Rectangular Duct	32"x20"x6'2.4" (0")		-1	-1	-1	0	0	0	0	
134	Rectangular Duct	22"x20"x5' (0")		-1	-1	-1	0	0	0	0	
135	Takeoff (Branch Power Split)	22"x20" / 22"x20"		0	0	0	0	0	0	0	
				72	67	61	54	45	36	26	
136	Rectangular Duct	22"x20"x12' (0")		-3	-2	-1	0	0	0	0	
137	Takeoff (Branch Power Split)	22"x20" / 12"		-5	-5	-5	-5	-5	-5	-5	
				34	28	21	13	4	0	0	
138	Circular Duct	12"x5'1.08" (0")		0	0	0	0	0	0	0	
139	Circular Elbow Radius	12" (0")		0	0	-1	-2	-3	-3	-3	
				13	9	5	0	0	0	0	
140	Circular Duct	12"x4'8.4" (0")		0	0	0	0	0	0	0	
141	Circular Duct	8"x3'7.08" (0")		0	0	0	0	0	0	0	
142	VAV 3-8 (1)			55	55	53	46	44	40	36	
143	Rectangular Duct	12"x10"x7' (0")		-2	-1	-1	0	0	0	0	
144	Tee (Branch Power Split)	12"x10" / 12"x10"		-2	-2	-2	-2	-2	-2	-2	
				30	25	19	12	6	5	5	
145	Rectangular Duct	12"x10"x3'11.16" (0")		-1	-1	0	0	0	0	0	
146	Takeoff (Branch Power Split)	12"x10" / 8"		-5	-5	-5	-5	-5	-5	-5	
				9	3	0	0	0	0	0	
147	Circular Duct	8"x2' (0")		0	0	0	0	0	0	0	
148	Flexible Duct	8"x3'		-2	-5	-7	-14	-15	-16	-8	
149	Room Correction (Normally Furnished)	19'1.2"x47'1.2"x10'		-7	-8	-9	-10	-11	-12	-13	
150	**SUM**		**25**	**43**	**38**	**31**	**26**	**20**	**17**	**22**	**30**

Dynasonics

Dynasonics AIM Software
HVAC Noise Prediction Tool

APPENDIX C

Project Name:	The Auditorium	**Project/Reference Number:**	
Location:	Lemma, MN	**Engineered By:**	Erin Miller
Architect:		**Company:**	Penn State
Mechanical Engineer:		**Run Date:**	3/28/2014
Contractor:		**Notes:**	

Room 310 - ACB

Calculation Summary

				Octave Midband Frequency, Hz							
	Element	**Properties**	**NC**	**63**	**125**	**250**	**500**	**1K**	**2K**	**4K**	**dB(A)**
1	**Room 310 - ACB**	**Criteria: NC-40**	**24**	**32**	**31**	**26**	**27**	**20**	**16**	**21**	**28**
2	**Supply Path (1)**	**Criteria: NC-40**									
3	AHU-1			85	80	88	85	81	80	78	
4	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
5	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
6	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
7	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
8	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
9	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
10	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
11	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
12	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
13	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
14	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				0	0	0	0	0	0	0	
15	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
16	Rectangular Duct	20"x14"x10' (0")		-3	-2	-1	0	0	0	0	
17	Takeoff (Branch Power Split)	20"x14" / 20"x14"		-1	-1	-1	-1	-1	-1	-1	
				45	41	36	30	24	16	8	
18	Rectangular Duct	20"x14"x9'0.84" (0")		-3	-2	-1	0	0	0	0	
19	Rectangular Elbow Radius	20"x14" (0")		0	-1	-2	-3	-3	-3	-3	
				23	20	15	10	4	0	0	
20	Rectangular Duct	20"x14"x6'2.4" (0")		-2	-1	-1	0	0	0	0	
21	Rectangular Duct	20"x14"x5' (0")		-2	-1	-1	0	0	0	0	
22	Takeoff (Branch Power Split)	20"x14" / 20"x14"		0	0	0	0	0	0	0	
				39	35	31	26	19	13	10	
23	Rectangular Duct	20"x14"x12' (0")		-4	-3	-2	-1	-1	-1	-1	
24	Takeoff (Branch Power Split)	20"x14" / 6"		-10	-10	-10	-10	-10	-10	-10	
				31	25	19	12	3	0	0	
25	Circular Duct	6"x5'1.08" (0")		0	0	0	0	-1	-1	-1	
26	Circular Elbow Radius	6" (0")		0	0	0	-1	-2	-3	-3	
				3	0	0	0	0	0	0	
27	Circular Duct	6"x4'8.4" (0")		0	0	0	0	0	0	0	
28	Circular Duct	6"x3'7.08" (0")		0	0	0	0	0	0	0	
29	VAV 3-8 (2)			47	47	43	36	37	34	27	
30	Rectangular Duct	6"x6"x7' (0")		-2	-1	-1	-1	-1	-1	-1	
31	Tee (Branch Power Split)	6"x6" / 6"x6"		-4	-4	-4	-4	-4	-3	-3	
				5	3	3	3	3	3	3	

32	Rectangular Duct	6"x6"x9'7.8" (0")		-3	-2	-1	-1	-1	-1	-1	
33	Takeoff (Branch Power Split)	6"x6" / 6"		-3	-3	-3	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
34	Circular Duct	6"x1'6" (0")		0	0	0	0	0	0	0	
35	Flexible Duct	8"x3'		-2	-5	-7	-14	-15	-16	-8	
36	Room Correction (Normally Furnished)	19'1.2"x47'1.2"x10'		-7	-8	-9	-10	-11	-12	-13	
37	**SUM**		**19**	**26**	**25**	**20**	**21**	**15**	**11**	**16**	**23**
38	**Supply Path (2)**	**Criteria: NC-40**									
39	AHU-1			85	80	88	85	81	80	78	
40	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
41	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
42	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
43	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
44	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
45	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
46	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
47	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
48	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
49	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
50	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				0	0	0	0	0	0	0	
51	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
52	Rectangular Duct	20"x14"x10' (0")		-3	-2	-1	0	0	0	0	
53	Takeoff (Branch Power Split)	20"x14" / 20"x14"		-1	-1	-1	-1	-1	-1	-1	
				45	41	36	30	24	16	8	
54	Rectangular Duct	20"x14"x9'0.84" (0")		-3	-2	-1	0	0	0	0	
55	Rectangular Elbow Radius	20"x14" (0")		0	-1	-2	-3	-3	-3	-3	
				23	20	15	10	4	0	0	
56	Rectangular Duct	20"x14"x6'2.4" (0")		-2	-1	-1	0	0	0	0	
57	Rectangular Duct	20"x14"x5' (0")		-2	-1	-1	0	0	0	0	
58	Takeoff (Branch Power Split)	20"x14" / 20"x14"		0	0	0	0	0	0	0	
				39	35	31	26	19	13	10	
59	Rectangular Duct	20"x14"x12' (0")		-4	-3	-2	-1	-1	-1	-1	
60	Takeoff (Branch Power Split)	20"x14" / 6"		-10	-10	-10	-10	-10	-10	-10	
				31	25	19	12	3	0	0	
61	Circular Duct	6"x5'1.08" (0")		0	0	0	0	-1	-1	-1	
62	Circular Elbow Radius	6" (0")		0	0	0	-1	-2	-3	-3	
				3	0	0	0	0	0	0	
63	Circular Duct	6"x4'8.4" (0")		0	0	0	0	0	0	0	
64	Circular Duct	6"x3'7.08" (0")		0	0	0	0	0	0	0	
65	VAV 3-8 (2)			47	47	43	36	37	34	27	
66	Rectangular Duct	6"x6"x7' (0")		-2	-1	-1	-1	-1	-1	-1	
67	Tee (Branch Power Split)	6"x6" / 6"x6"		-4	-4	-4	-4	-4	-3	-3	
				5	3	3	3	3	3	3	
68	Rectangular Duct	6"x6"x9'7.8" (0")		-3	-2	-1	-1	-1	-1	-1	
69	Takeoff (Branch Power Split)	6"x6" / 6"		-3	-3	-3	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
70	Circular Duct	6"x9'5.4" (0")		0	0	0	0	-1	-1	-1	
71	Circular Elbow Radius	6" (0")		0	0	0	-1	-2	-3	-3	
				0	0	0	0	0	0	0	
72	Circular Duct	6"x1'6" (0")		0	0	0	0	0	0	0	

73	Flexible Duct	8"x3'		-2	-5	-7	-14	-15	-16	-8	
74	Room Correction (Normally Furnished)	19'1.2"x47'1.2"x10'		-7	-8	-9	-10	-11	-12	-13	
75	**SUM**		**16**	**25**	**25**	**20**	**20**	**12**	**7**	**12**	**20**
76	**Supply Path (3)**	**Criteria: NC-40**									
77	AHU-1			85	80	88	85	81	80	78	
78	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
79	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
80	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
81	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
82	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
83	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
84	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
85	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
86	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
87	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
88	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				0	0	0	0	0	0	0	
89	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
90	Rectangular Duct	20"x14"x10' (0")		-3	-2	-1	0	0	0	0	
91	Takeoff (Branch Power Split)	20"x14" / 20"x14"		-1	-1	-1	-1	-1	-1	-1	
				45	41	36	30	24	16	8	
92	Rectangular Duct	20"x14"x9'0.84" (0")		-3	-2	-1	0	0	0	0	
93	Rectangular Elbow Radius	20"x14" (0")		0	-1	-2	-3	-3	-3	-3	
				23	20	15	10	4	0	0	
94	Rectangular Duct	20"x14"x6'2.4" (0")		-2	-1	-1	0	0	0	0	
95	Rectangular Duct	20"x14"x5' (0")		-2	-1	-1	0	0	0	0	
96	Takeoff (Branch Power Split)	20"x14" / 20"x14"		0	0	0	0	0	0	0	
				39	35	31	26	19	13	10	
97	Rectangular Duct	20"x14"x12' (0")		-4	-3	-2	-1	-1	-1	-1	
98	Takeoff (Branch Power Split)	20"x14" / 6"		-10	-10	-10	-10	-10	-10	-10	
				31	25	19	12	3	0	0	
99	Circular Duct	6"x5'1.08" (0")		0	0	0	0	-1	-1	-1	
100	Circular Elbow Radius	6" (0")		0	0	0	-1	-2	-3	-3	
				3	0	0	0	0	0	0	
101	Circular Duct	6"x4'8.4" (0")		0	0	0	0	0	0	0	
102	Circular Duct	6"x3'7.08" (0")		0	0	0	0	0	0	0	
103	VAV 3-8 (2)			47	47	43	36	37	34	27	
104	Rectangular Duct	6"x6"x7' (0")		-2	-1	-1	-1	-1	-1	-1	
105	Tee (Branch Power Split)	6"x6" / 6"x6"		-4	-4	-4	-4	-4	-3	-3	
				5	3	3	3	3	3	3	
106	Rectangular Duct	6"x6"x3'11.16" (0")		-1	-1	0	0	0	0	0	
107	Takeoff (Branch Power Split)	6"x6" / 6"		-4	-4	-4	-4	-4	-4	-4	
				0	0	0	0	0	0	0	
108	Circular Duct	6"x1'6" (0")		0	0	0	0	0	0	0	
109	Flexible Duct	8"x3'		-2	-5	-7	-14	-15	-16	-8	
110	Room Correction (Normally Furnished)	19'1.2"x47'1.2"x10'		-7	-8	-9	-10	-11	-12	-13	
111	**SUM**		**20**	**27**	**25**	**20**	**21**	**15**	**11**	**16**	**23**
112	**Supply Path (4)**	**Criteria: NC-40**									
113	AHU-1			85	80	88	85	81	80	78	
114	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	

115	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
116	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
117	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
118	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
119	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
120	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
121	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
122	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
123	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
124	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				0	0	0	0	0	0	0	
125	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
126	Rectangular Duct	20"x14"x10' (0")		-3	-2	-1	0	0	0	0	
127	Takeoff (Branch Power Split)	20"x14" / 20"x14"		-1	-1	-1	-1	-1	-1	-1	
				45	41	36	30	24	16	8	
128	Rectangular Duct	20"x14"x9'0.84" (0")		-3	-2	-1	0	0	0	0	
129	Rectangular Elbow Radius	20"x14" (0")		0	-1	-2	-3	-3	-3	-3	
				23	20	15	10	4	0	0	
130	Rectangular Duct	20"x14"x6'2.4" (0")		-2	-1	-1	0	0	0	0	
131	Rectangular Duct	20"x14"x5' (0")		-2	-1	-1	0	0	0	0	
132	Takeoff (Branch Power Split)	20"x14" / 20"x14"		0	0	0	0	0	0	0	
				39	35	31	26	19	13	10	
133	Rectangular Duct	20"x14"x12' (0")		-4	-3	-2	-1	-1	-1	-1	
134	Takeoff (Branch Power Split)	20"x14" / 6"		-10	-10	-10	-10	-10	-10	-10	
				31	25	19	12	3	0	0	
135	Circular Duct	6"x5'1.08" (0")		0	0	0	0	-1	-1	-1	
136	Circular Elbow Radius	6" (0")		0	0	0	-1	-2	-3	-3	
				3	0	0	0	0	0	0	
137	Circular Duct	6"x4'8.4" (0")		0	0	0	0	0	0	0	
138	Circular Duct	6"x3'7.08" (0")		0	0	0	0	0	0	0	
139	VAV 3-8 (2)			47	47	43	36	37	34	27	
140	Rectangular Duct	6"x6"x7' (0")		-2	-1	-1	-1	-1	-1	-1	
141	Tee (Branch Power Split)	6"x6" / 6"x6"		-4	-4	-4	-4	-4	-3	-3	
				5	3	3	3	3	3	3	
142	Rectangular Duct	6"x6"x3'11.16" (0")		-1	-1	0	0	0	0	0	
143	Takeoff (Branch Power Split)	6"x6" / 6"x6"		-3	-3	-3	-3	-3	-3	-3	
				1	1	1	1	1	1	1	
144	Rectangular Duct	6"x6"x3'7.68" (0")		-1	-1	0	0	0	0	0	
145	Circular Duct	6"x6'6" (0")		0	0	0	0	-1	-1	-1	
146	Circular Elbow Radius	6" (0")		0	0	0	-1	-2	-3	-3	
				0	0	0	0	0	0	0	
147	Circular Duct	6"x2' (0")		0	0	0	0	0	0	0	
148	Flexible Duct	8"x3'		-2	-5	-7	-14	-15	-16	-8	
149	Room Correction (Normally Furnished)	19'1.2"x47'1.2"x10'		-7	-8	-9	-10	-11	-12	-13	
150	**SUM**		**16**	**27**	**25**	**20**	**20**	**13**	**8**	**13**	**21**

APPENDIX C

Project Name: The Auditorium
Location: Lemma, MN
Architect:
Mechanical Engineer:
Contractor:

Project/Reference Number:
Engineered By: Erin Miller
Company: Penn State
Run Date: 3/28/2014
Notes:

Room 310.13 - VAV

Calculation Summary

	Element	Properties	NC	63	125	250	500	1K	2K	4K	dB(A)
				Octave Midband Frequency, Hz							
1	**Room 310.13 - VAV**	**Criteria: NC-30**	**21**	**38**	**35**	**30**	**26**	**16**	**12**	**16**	**27**
2	**Supply Path (1)**	**Criteria: NC-30**									
3	AHU-1			85	80	88	85	81	80	78	
4	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
5	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
6	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
7	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
8	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
9	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
10	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
11	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
12	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
13	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
14	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				17	10	1	0	0	0	0	
15	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
16	Rectangular Duct	32"x20"x9'5.04" (0")		-2	-2	-1	0	0	0	0	
17	Takeoff (Branch Power Split)	32"x20" / 18"x12"		-6	-6	-6	-6	-6	-6	-6	
				46	41	35	28	20	11	1	
18	Rectangular Duct	18"x12"x6'3.6" (0")		-2	-1	-1	0	0	0	0	
19	Takeoff (Branch Power Split)	18"x12" / 6"		-9	-9	-9	-9	-9	-9	-9	
				46	43	38	32	25	18	9	
20	Circular Duct	6"x2'4.56" (0")		0	0	0	0	0	0	0	
21	VAV 3-5 (1)			52	52	48	41	41	37	30	
22	Rectangular Duct	12"x8"x9" (0")		0	0	0	0	0	0	0	
23	Rectangular Elbow Radius	12"x8" (0")		0	0	-1	-2	-3	-3	-3	
				0	0	0	0	0	0	0	
24	Rectangular Duct	12"x8"x2'9.72" (0")		-1	-1	0	0	0	0	0	
25	Takeoff (Branch Power Split)	12"x8" / 12"x8"		-1	-1	-1	-1	-1	-1	-1	
				16	11	5	5	5	5	5	
26	Rectangular Duct	12"x8"x4'5.52" (0")		-1	-1	0	0	0	0	0	
27	Takeoff (Branch Power Split)	12"x8" / 6"		-7	-7	-7	-7	-6	-6	-6	
				6	0	0	0	0	0	0	
28	Circular Duct	6"x3' (0")		0	0	0	0	0	0	0	
29	Circular Elbow Radius	6" (0")		0	0	0	-1	-2	-3	-3	
				0	0	0	0	0	0	0	
30	Circular Duct	6"x1' (0")		0	0	0	0	0	0	0	
31	Flexible Duct	6"x3'		-3	-5	-6	-13	-17	-19	-11	

32	Room Correction (Normally Furnished)	11'2.64"x7'8.04"x10'		-2	-3	-4	-5	-6	-7	-7	
33	**SUM**		**21**	**38**	**35**	**30**	**26**	**16**	**12**	**16**	**27**

Project Name:	The Auditorium	**Project/Reference Number:**	
Location:	Lemma, MN	**Engineered By:**	Erin Miller
Architect:		**Company:**	Penn State
Mechanical Engineer:		**Run Date:**	3/28/2014
Contractor:		**Notes:**	

Room 310.13 - ACB

Calculation Summary

	Element	Properties	NC	63	125	250	500	1K	2K	4K	dB(A)
				Octave Midband Frequency, Hz							
1	**Room 310.13 - ACB**	**Criteria: NC-30**	**25**	**34**	**32**	**30**	**30**	**20**	**15**	**20**	**30**
2	**Supply Path (1)**	**Criteria: NC-30**									
3	AHU-1			85	80	88	85	81	80	78	
4	Rectangular Duct	116"x48"x3'3.96" (0")		0	0	0	0	0	0	0	
5	Rectangular Duct	128"x48"x9'6.36" (0")		-1	-1	0	0	0	0	0	
6	End Reflection Loss	128"x48" (Flush)		-1	0	0	0	0	0	0	
7	Rectangular Duct	108"x52"x27' (0")		-3	-2	-1	0	0	0	0	
8	Rectangular Elbow Miter	108"x52" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
9	Rectangular Duct	86"x48"x111' (0")		-14	-9	-6	-2	-2	-2	-2	
10	Rectangular Elbow Miter	86"x48" (0")		-5	-8	-4	-3	-3	-3	-3	
				0	0	0	0	0	0	0	
11	Rectangular Duct	86"x48"x19' (0")		-2	-2	-1	0	0	0	0	
12	Plenum	15'6"x6'2"x18'5"		0	0	0	0	0	0	0	
13	Rectangular Duct	36"x40"x15'6" (0")		-3	-2	-1	0	0	0	0	
14	Rectangular Elbow Miter	36"x40" (0")		-1	-5	-8	-4	-3	-3	-3	
				0	0	0	0	0	0	0	
15	Rectangular Duct	40"x36"x10' (0")		-2	-1	-1	0	0	0	0	
16	Rectangular Duct	20"x14"x9'5.04" (0")		-3	-2	-1	0	0	0	0	
17	Takeoff (Branch Power Split)	20"x14" / 10"x10"		-6	-6	-6	-6	-6	-6	-6	
				41	37	32	26	19	12	4	
18	Rectangular Duct	10"x10"x6'3.6" (0")		-2	-1	-1	0	0	0	0	
19	Takeoff (Branch Power Split)	10"x10" / 6"		-7	-7	-7	-7	-7	-7	-7	
				21	18	13	8	2	0	0	
20	Circular Duct	6"x2'4.56" (0")		0	0	0	0	0	0	0	
21	VAV 3-5 (2)			48	48	44	40	37	35	29	
22	Rectangular Duct	6"x6"x9" (0")		0	0	0	0	0	0	0	
23	Rectangular Elbow Radius	6"x6" (0")		0	0	0	-1	-2	-3	-3	
				0	0	0	0	0	0	0	
24	Rectangular Duct	6"x6"x2'9.72" (0")		-1	0	0	0	0	0	0	
25	Takeoff (Branch Power Split)	6"x6" / 6"x6"		-3	-3	-3	-3	-3	-3	-3	
				1	1	1	1	1	1	1	
26	Rectangular Duct	6"x6"x4'5.52" (0")		-1	-1	0	0	0	0	0	
27	Takeoff (Branch Power Split)	6"x6" / 6"		-4	-4	-4	-4	-4	-4	-4	
				0	0	0	0	0	0	0	
28	Circular Duct	6"x3' (0")		0	0	0	0	0	0	0	
29	Circular Elbow Radius	6" (0")		0	0	0	-1	-2	-3	-3	
				0	0	0	0	0	0	0	
30	Circular Duct	6"x1' (0")		0	0	0	0	0	0	0	
31	Flexible Duct	6"x3'		-3	-5	-6	-13	-17	-19	-11	

APPENDIX

32	Room Correction (Normally Furnished)	11'2.64"x7'8.04"x10'		-2	-3	-4	-5	-6	-7	-7	
33	**SUM**		**25**	**34**	**32**	**30**	**30**	**20**	**15**	**20**	**30**