Final Report

EMD Serono Research Center - existing | Billerica, MA



Prepared By: Shiyun Chen | mechanical | 4.3.2011

Prepared For:

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EMD Serono ResearchCenter -- existing | billerica, MA

Project Info

- Building Characteristics

size: 56,700 sf
story: 2 story+basement+penthouse
occupancy: pharmaceutical lab
cost: $15 million
delivery: fast-tract
duration: Nov,1999 - March 2002

- Project Team

owner: EMD Serono
architect: Ellenzweig Associate
landscape architect: John G. Crowe Associate
MEP engineer: Bard,Rao+Athanas Consulting Engineers
structural engineer: LeMessurier Consulting Engineers
contrator: Linbeck/Kennedy & Rossi

Architectural

- In 2002, the site accomodated both the EMD Serono Research Center existing lab building and a Biotech Center.
- Mechanical rooms are located on the basement and penthouse; animal facilities, research lab rooms,support rooms are located on the 1st and 2nd floor.
- The building facade is a combination of metal, brick, and glass. Aluminum sunshade is provided on north west cornor of the bldg.
- The builidng emphasis on the use of daylight for the labs and offices and maximize the views to the wooded countryside.

Construction

- The EMD Serono Research Center is a multi-phased pharmaceutical project, anticipated to total approximately 318,000sf.
- Phase 1 consists of the 56,700 sf Research Center existing lab building and a 17,000 sf Biotech Center.
- Subsequent phase will include 3 additional research and development building and an 80,000 sf processing facility.In addition, 600 parking spaces will be accommodated on site in a phased structure parking facility.
- The expansion of the exising lab building is currently under construction as of 2010.

Structural

- The main structure of the building consists of structural steel columns, beams, decks, and concrete slab.
- The lateral force resisting system is a combination of diagonally braced frames and moment resisting connections.
- Typical office floor beam size is W18x35 on the east and west bays and W18x65 on the center bay.
- Typical girder size is W16x26.
- Typical column size ranging from W8x28 to W8x67 and W10x60 to W10x6.

Mechanical

- The building has 3 air handling units (AHU).
- AHU-1 supplies conditioned air to the research and develpment portion of the bldg.
- AHU-2 supplies conditioned air to offices.
- AHU-3 supplies conditioned air to mechanical rooms in the basement and animal rooms.
- One 350 ton centrifugal chiller is located in the basement.
- Two steam boilers and boiler feed water pump in the penthouse.
- A 350 ton cooling tower and a 60 ton air cooled chiller are located on the roof adjacent to the penthouse.

ElectricalLighting

- Electrical

The primary electrical service is owned and maintained by Massachusetts Electric Co.
The primary transformer distributes 480/277 volt service to the building. The switchboard is 480/277V, 3phase, 4 wire, and 2400 amps.
The emergency electric power is provided by the indoor diesel driven engine generator.

- Lighting

The primary lighting system is recessed mounted fluorescent fixture with size of 1'x4' and 2'x2'.In the area where recessed fixtures are not used, pendant mounted fixtures are used.

Table of Contents

Acknowledgments

The Penn State University Architectural Engineering Faculty and Staff

Thesis Advisor: William Bahnfleth, Ph.D., P.E.

Dedicated Outdoor Air System Advisor: Stanley Mumma, Ph.D., P.E.

Control System Instructor: Stephen Treado, Ph.D., P.E.

Computational Fluid Dynamic Instructor: Jelena Srebric, Ph.D.

Project Sponsor: Bard, Rao + Athana Consulting Engineers

THANK YOU to all of my family and friends for their support!

Executive Summary

EMD Serono Research Center – existing lab building is a pharmaceutical research and development building. Majority of the building area are research laboratories and vivarium rooms. Large amount of ventilation are required for those types of rooms to maintain a safe and healthy indoor air environment. The primary goals for the project were to provide adequate air quality, thermal comfort, and consume energy efficiently. The long-term cost for operating the facility is also very importance.

The existing mechanical system has an electrical chilled water cooling plant and a gas fired central heating plant. Chilled water is generated by a water cooled chiller and an air cooled chiller to provide summer cooling. Steam is generated by two gas fired boilers and it is used for summer reheat, winter heating and humidification. Air is distributed throughout the building by variable and constant volume terminal boxes in each space. There are 3 air handling units in this building, one for office space, one for laboratory space, and one for vivarium space. Air handing units for laboratory and vivarium space provides 100% outside air to the space.

The proposed analysis of alternate systems involves the reduction of building load, improvement of thermal comfort and indoor air quality, as well as the reduction of energy consumption. Three analyses were performed to evaluate the possibility of system improvement by implementing Dedicated Outdoor Air System (DOAS) with Active Chilled Beam (ACB), applying heat recovery systems, and putting solar shading systems. Comparisons of the alternatives were based on the system's impact on energy consumption, thermal comfort, indoor air quality, space requirement, and cost.

To ensure the proposed systems function properly, an architectural study was conducted to determine the impact of solar shades on the building exterior views. An electrical study was also conducted to determine the adequacy of the existing mechanical switchboards to handle new mechanical loads.

DOAS/ACB with Runaround Coil and Solar Shading system was proven to be the most efficient and cost effective system for this building. Energy analyses showed that this system has the highest energy deduction of $81,023 per year. Cost analyses showed that this system has the highest first cost of $1,768,132 but a relatively low simple payback period of 7 years and 10 months. This system also has a relative low 30-year lifecycle cost when compare to other alternatives.

DOAS/ACB with Runaround Coil and Solar Shading system is able to provide significant energy saving, improves thermal comfort, lower background noise, improve indoor air quality for the occupants and also adds strong visual aspect to the building. Therefore, this system is chosen to be the best suitable system for design.

Building Overview

Building Summary

EMD Serono Research Center – existing lab building was constructed as the research and development building. This building has 2 stories, a basement, and a penthouse, with gross area of 56,700 square foot. The building program contains management office, research and development laboratories, and vivarium rooms. Mechanical rooms are located on the basement floor and in the penthouse. Vivarium facilities, research lab rooms, support rooms are located on both the 1st and 2nd floor.

Site

The site for the EMD Serono Research Center – existing lab building is located in Billerica, Massachusetts. This is a multi-phased pharmaceutical research and development project, anticipated to total approximately 318,000 sf. Phase 1 consisted of the 56,000 sf EMD Serono Research Center – existing building and a 17,000 sf pilot plant. Subsequent phases will include three additional research and development buildings and an 80,000 sf processing facility. As of 2010, the new EMD Serono building addition is under construction adjacent to the existing building.

Figure-1 Existing EMD Serono Research Center and Pilot Plant

Figure-2 New EMD Serono Research Center Addition Adjacent to Existing Building

Evaluation of Existing Mechanical System

Mechanical System Overview

There are a total for 3 air handling units in this building. AHU-1 provides 45,000 cfm air to all the research and development labs and AHU-2 provides 19,000 cfm air to all the administrative offices. Both units are located in the penthouse. AHU-3 is located in the basement and provides 5,000 cfm air to the vivarium rooms and the mechanical room in the basement. Since AHU-1 and AHU-3 serves laboratories and animal spaces, both air handling units provides 100% outside air to the space.

The mechanical system of the EMD Serono Research Center – existing lab building has a chilled water cooling plant and a gas fired central heating plant. The cooling plant consists of a 350 ton water cooled centrifugal chiller, a cooling tower, and a 60 ton air cooled chiller. The heating plant consists of two low pressure steam boilers (175hp and 50hp) and two heat exchangers. Air is distributed throughout the building by variable and constant volume terminal boxes in each space. There are three air handling units in this building. Inside each air handling units, there are low pressure steam pre-heat coils to precondition the outside air in the winter time, cooling coil are located downstream of the preheat coil to cool the air in the summer time. Conditioned air is then distributed into the spaces. In the winter season, pre-conditioned air from AHUs is conditioned again by the hot water heating coils in the terminal boxes prior to entering the space. Hot water inside the heating coils is coming from the heat exchangers.

Design Objective

EMD Serono intended for this research and development facility to contain the highest quality materials and systems practical for its designed uses. Getting the best value for dollars spent is essential, but cost must not take precedence over quality. The guiding principal governing selection of systems and design is to maximize comfort in a practical way for the scientists and staff to do their work. The main mechanical design objectives for the EMD Serono Research Center - existing lab building are environmental comfort, energy responsiveness, flexibility for future changes, durability, ease of maintenance, reliability, and modular approach.

Since laboratories and vivarium rooms are critical spaces that generate potential hazardous contaminants, air handling units need to provide 100% outside air into the spaces to ensure contaminated air does not circulate and transfer inside the building. High efficiency filters and 100% exhaust air rate are also required for those spaces.

Outdoor and Indoor Conditions

Climate Zone

The project is located at Billerica, Massachusetts. The climate zone of the project is Zone 5.

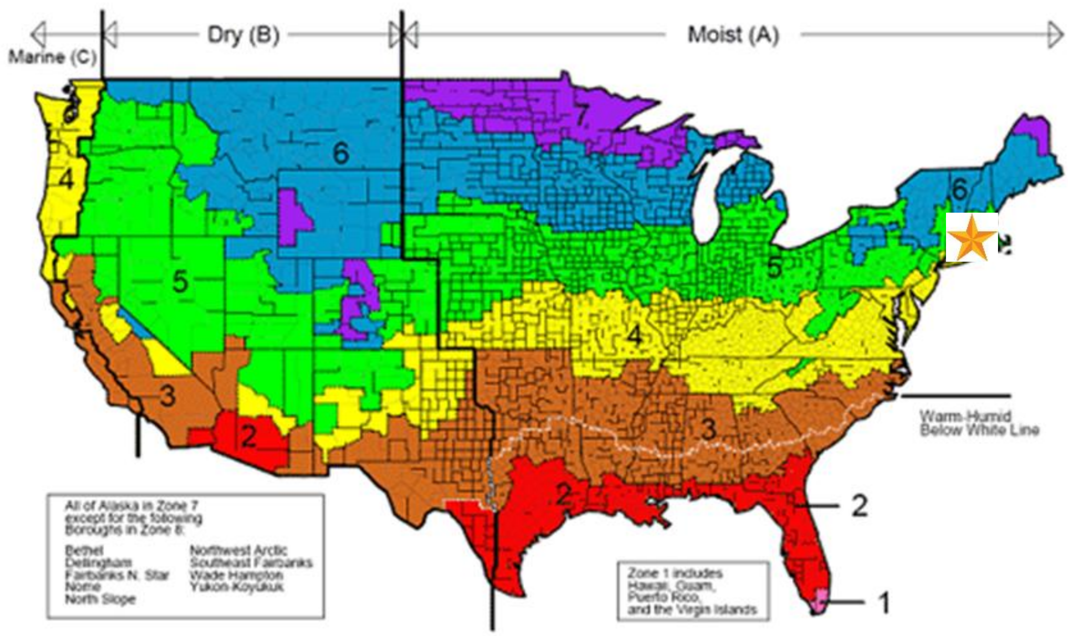


Figure-3 Climate Zone

Weather Data and Indoor Design Conditions

Outdoor weather design conditions were taken from the ASHRAE Handbook of Fundamentals 2009, and they represent the 0.4% summer cooling design and 99.6% winter heating design. Outdoor conditions for Boston, MA were selected.

Indoor design conditions were taken from the design documents. There are different design conditions for different type of spaces.

Weather Data		
	Dry Bulb (F)	**Wet Bulb (F)**
Summer Design Cooling	90.8	73.1
Winter Design Heating	7.7	N/A

Table-1 Weather Data

Indoor Design Conditions			
	Summer (F)	**Winter (F)**	**Relative Humidity (%)**
General Space	$75^o \pm 2^o$	$72^o \pm 2^o$	55 % Max
Animal Holding Room (Rodent, Nude Mice)	$64 - 79^o \pm 2^o$	$64 - 79^o \pm 2^o$	Summer: 35-58% ± 5% Winter: 40-70% ± 5%
Animal Holding Room (Rabbit)	$64 - 79^o \pm 2^o$	$61 - 70^o \pm 2^o$	Summer: 58-35% ± 5% Winter: 70-40% ± 5%
Animal Support Spaces	$70 - 75^o \pm 2^o$	$70 - 75^o \pm 2^o$	55 % Max
Mech./Elec. Spaces	10^o Above Ambient	65^o Min.	N/A
Transfer Room	10^o Above Ambient	65^o Min.	N/A

Table-2 Indoor Design Conditions

System Description and Schematics

Air Side System

There are a total for 3 air handling units in this building. AHU-1 that serves all the research and development labs and AHU-2 that serves all the administrative offices are located in the penthouse. AHU-3 that serves the vivarium rooms and the mechanical room in the basement is located in the basement. Since both AHU-1 and AHU-3 serves laboratories and animal spaces, both AHU-1 and AHU-3 provides 100% outside air to the space.

Since modern chemical and engineering sciences require daily use of toxic chemical and other potentially dangerous device, both laboratories and vivarium spaces are potentially dangerous places. AHU-1 and AHU-3 that serve those spaces provide 100% outside air into the spaces to ensure contaminated air does not circulate and transfer inside the building. AHU-2 that serves office space does have return air to recirculate back into the space to reduce energy consumption.

Automatic temperature control system is used to accomplish all sensing and control via electronics with pneumatic activation for large valves/dampers and electronic actuation for small terminal unit valves/dampers. All VAV/CAV devices have individual DDC (direct digital control) controllers.

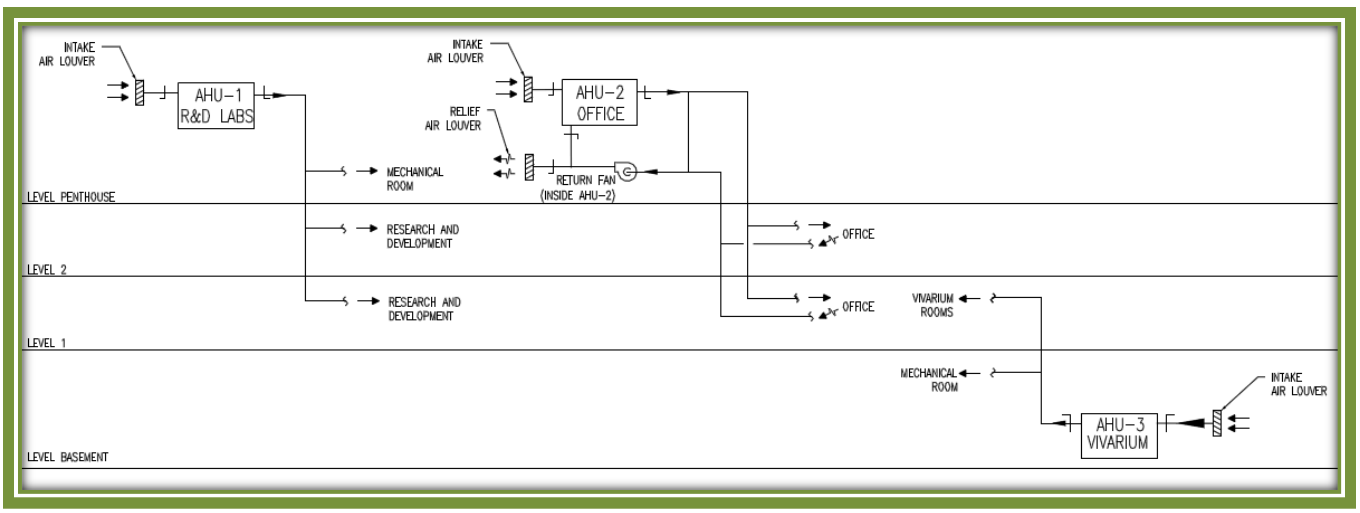


Figure-4 Air Side Riser Diagram

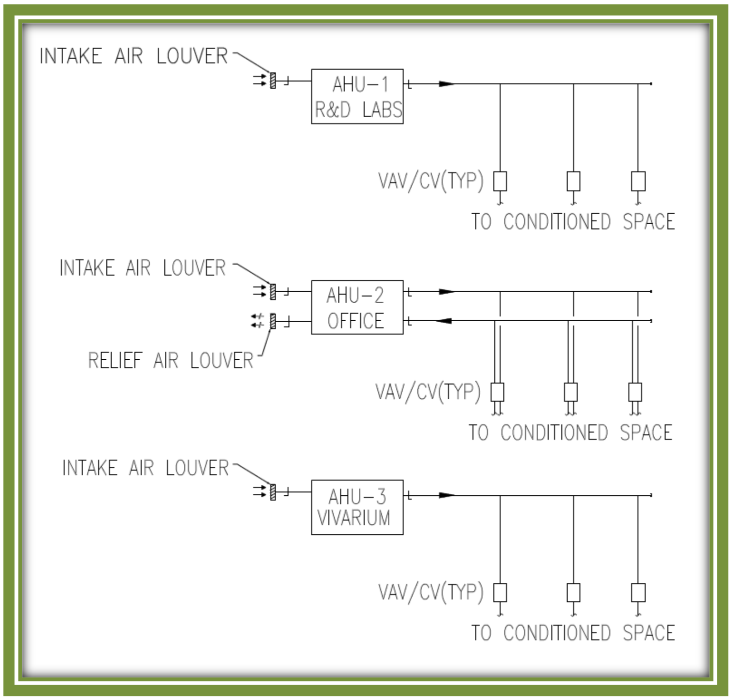


Figure-5 Air Side Schematic

Water Side Cooling System

The EMD Serono Research Center – existing lab building uses a chilled water system that utilizing a water cooled centrifugal chiller and an air cooled chiller. Direct Digital Control (DDC) with pneumatic actuators is used in this building. The chilled water system uses a primary centralized flow system.

At the design condition, AHU-1 requires 675 gpm of chilled water, AHU-2 requires 70 gpm, and AHU-3 requires 155 gpm. There is a water cooled chiller that provides 840 gpm of chilled water (350 tons) and an air cooled chiller work in parallel with it to provide an additional 135 gpm of chilled water (60tons). There are 2 equal capacity chilled water pumps on the return side of the air cooled chiller water loop; one of the two is for redundancy.

There is 1050 gpm of condenser water cycles between the cooling tower and the water cooled chiller condenser to reject system heat. On the water cooled chiller side, an 840 gpm chilled water pump is connected to the evaporator and a 1050 gpm condenser water pump is connected to the condenser. There is a standby pump sized for redundancy of the condenser water loop system. This standby pump is also in parallel with the chilled water loop system. It is piped and valved such that in the case of an emergency, it can be used for back up for either system.

The DDC control system sequences the chiller to maintain a supply water temperature of 45F. Whenever the leaving chilled water temperature is 5F below the desired chilled water set point, the compressor would automatically cycle off to minimize energy usage. During that period, chilled water pump would remain on. When the leaving chilled water temperature rises above the set point by a user-configured amount, the compressor will automatically be recycled back on.

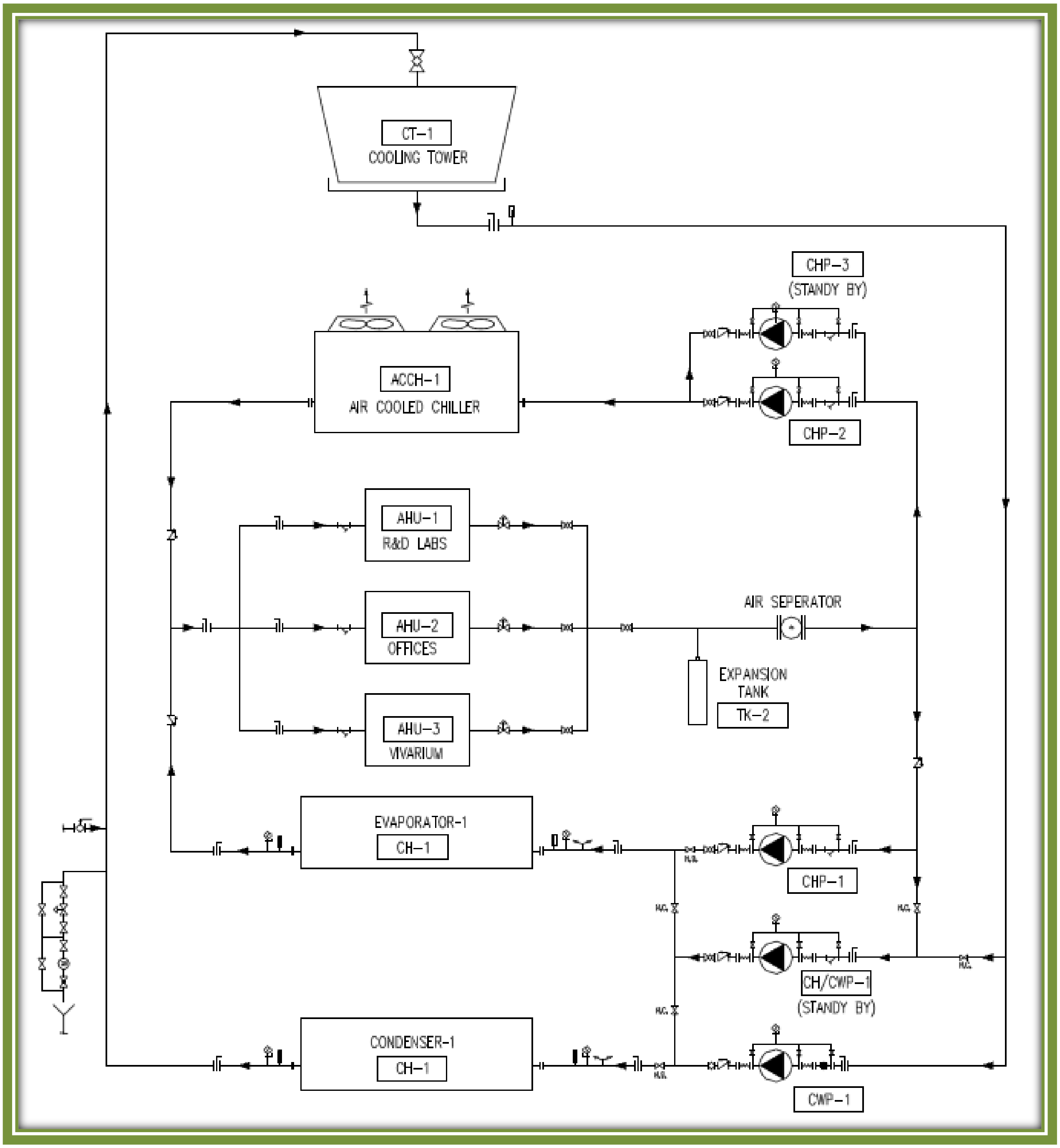


Figure-6 Water Side Cooling Schematic

Steam Heating System

The gas fired central heating plant operates year-round. Low pressure steam boilers were designed for 15 psig steam to provide winter heating, humidification, and summer reheat for temperature control. Only one boiler operates at any one time. The 175 hp boiler operates during the winter for heating and humidification purposes while the 50 hp boiler operates during the summer for reheat.

Water is treated by softener and brine before it goes to the boiler feed system. The boiler feed system has dual feed pumps to pump 10 gpm to feed water to the 50 hp boiler and pump 28 gpm of feed water for the 175 hp boiler at a 30 psig discharge pressure. A packaged chemical feed system provides an additional 100 gallons of chemically feed water to the boilers.

Low pressure steam generated by the boiler is distributed to the preheat coils and humidifiers inside the air handling units as well as to the two hot water heat exchangers. All the air handling units and heat exchangers work in parallel with each other. Two condensate pumps also works parallel, one pumps low pressure return from all the air handling units back to the boiler feed while the other pumps low pressure return from the two heat exchangers back to the boiler feed.

Inside the air handling units, the DDC control system modulate the 2-way preheat coil control valve to maintain a 55F leaving air temperature. If the discharge air temperature from the air handling units falls below 38F, the freeze protection thermostats locate downstream of the preheat coil would stop the supply fan.

Steam-to-hot water shell-and-tube heat exchangers supply hot water to the heating coils inside the terminal boxes throughout the building to provide winter heating. Hot water supply temperature is measured by a remote bulb transmitter with its sensing element downstream in the hot water supply. The remote bulb transmitter send signal to the DDC panel. The DDC panel will then modulate the hot water control valves to maintain a water discharge temperature set point. Air preheated by the air handling units is then passed through the heating coil at the terminal box into the space.

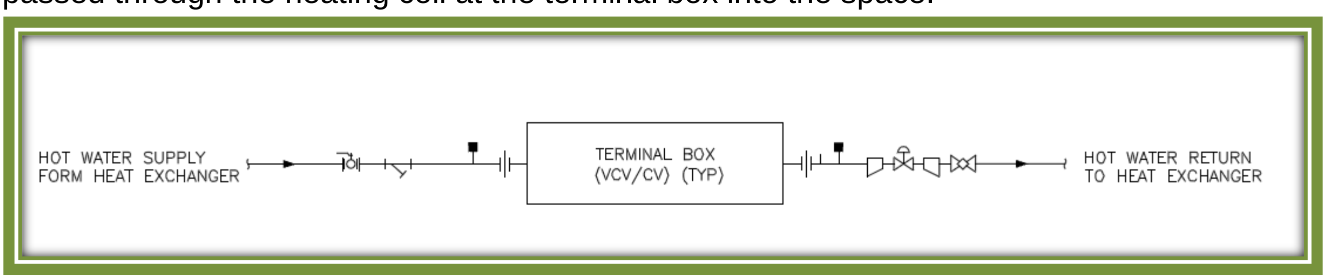


Figure-7 Water Side Hot Water Schematic

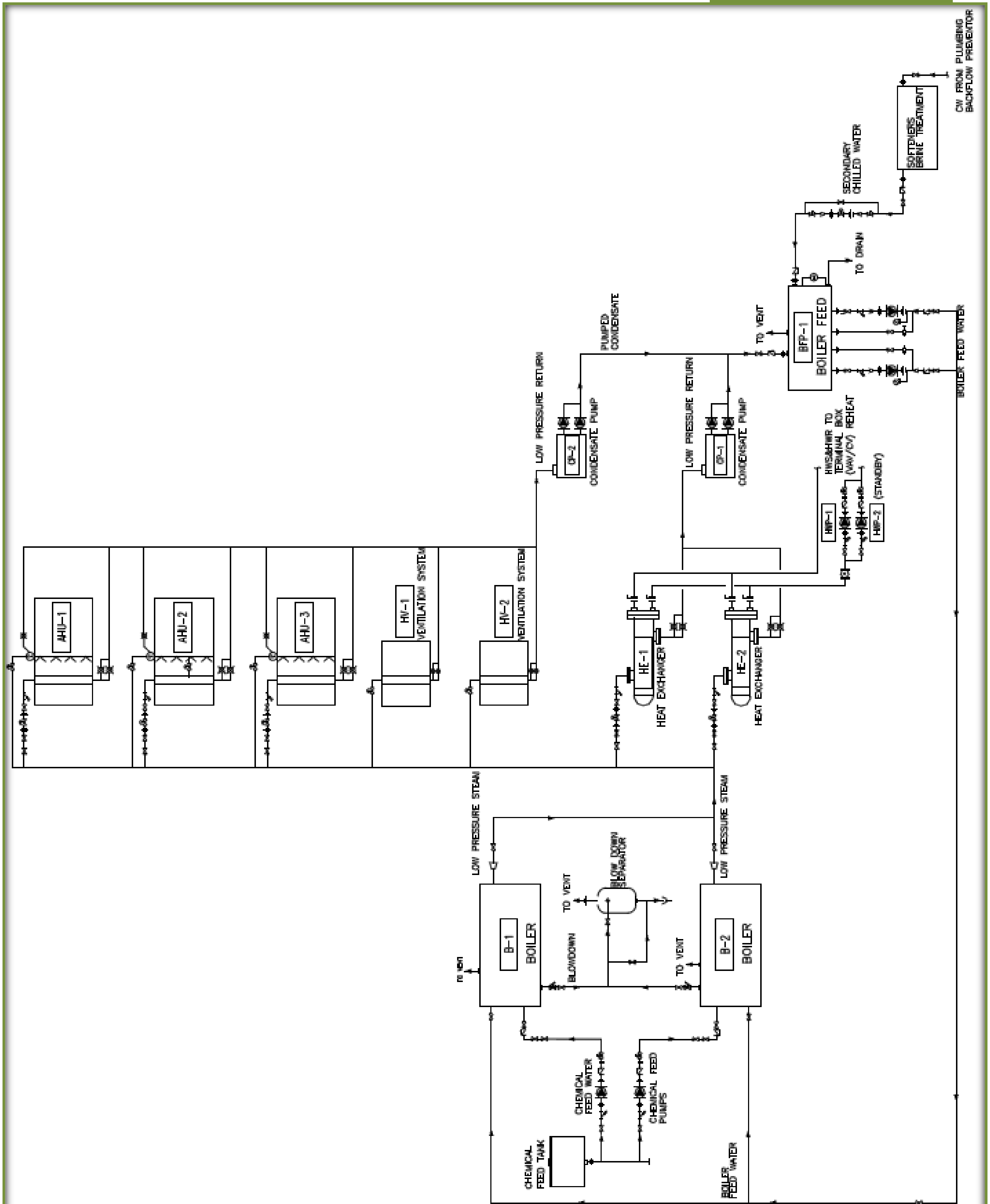


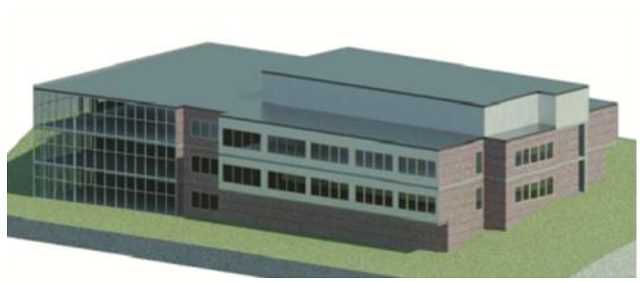
Figure-8 Steam Heating Schematic

Energy Analysis

Trane TRACE 700 Version 6.2 was used to determine the design load and energy consumption of the EMD Serono Research Center- existing lab building.

A simplified Revit model of this building was built based on the architectural drawing. Other design information such as building envelope, equipment load, outside air ventilation rate, and design criteria were input to the Trace model based on actual data taken from the design document.

East and South Sides



South and Ease Sides

Figure-9 Revit Model of EMD Serono – Existing Lab Building

This building was zoned into 5 types of spaces: lunch area, office area, mechanical room area, vivarium area, and research & development area. Each type of space has its unique design criteria. Spaces were assigned to 3 air handling units according to the actual design. In order for the model to have comparable result of the actual design, the model was then calibrated with the one-year electrical and natural gas usage data given by the building owner.

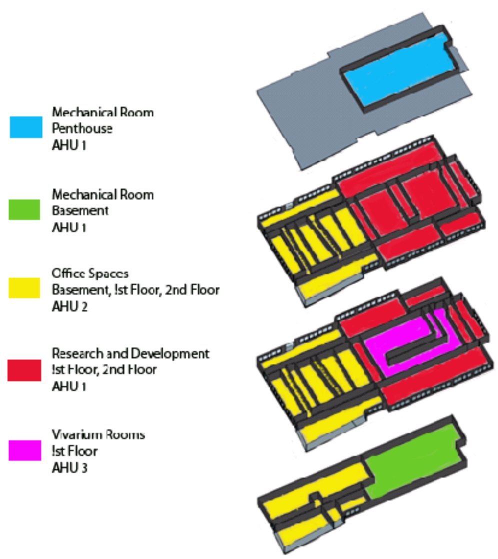


Figure-10 Building Division

Load Source and Modeling Information

Weather Data

Outdoor air conditions for heating and cooling for Boston, MA were used for this analysis. Weather conditions were taken from the ASHRAE Handbook of Fundamentals 2009, and they represent the 0.4% summer cooling design and 99.6% winter heating design.

Weather Data		
	Dry Bulb (F)	Wet Bulb (F)
Summer Design Cooling	90.8	73.1
Winter Design Heating	7.7	N/A

Table-3 Weather Data

Design Condition

Five types of blocks were selected because each block type has its unique design criteria from the design documents.

Design Criteria					
	Cooling DB (F)	Cooling Driftpoint (F)	Heating DB (F)	Heating Driftpoint (F)	Relative Humidity (%)
Office	75	77	72	70	50
Lunch	75	77	72	70	50
Mechanical	10^{o} above ambient	N/A	65 minimum	N/A	50
R&D	72	74	72	70	47
Vivarium	72	74	72	70	47

Table-4 Design Criteria

Building Envelope

Building envelope data were taken from the actual design documents and input into the Trace energy model to get comparable results.

Construction		
Location	Type	U-factor (Btu/h-ft^2-F)
Slab	6” HW Concrete	0.53
Roof	Steel Sheet, 3.33” Ins	0.08
Wall	Face Brick, 4” LW Conc. Blk, 6’ Ins	0.04

Table-5 Construction

Glass Type			
Location	Type	U-factor (Btu/h-ft^2-F)	Shading Coefficient
Window	Double Clear ¼”	0.6	0.82
Skylight	Double Clear ¼”	0.6	0.82

Table-6 Glass Type

Height	
Wall (ft.)	11.3
Floor to Floor (ft.)	14
Plenum (ft.)	2.7

Table-7 Height

Equipment Load and Lighting Load

The following equipment loads and lighting loads were taken from the design documents.

Load (Design Document)		
	Equipment Load (W/sf)	Lighting Load (W/sf)
Laboratories	10	2
Administration/Office	3.5	2
Lab Equipment Room	15	2
Animal Holding Room	N/A (15 AH/hr.)	N/A
Cage Washing	N/A (15 AH/hr.)	N/A
Corridor	2	1.5
Procedure Room	8	1.5

Table-8 Design Equipment and Lighting Loads

To reflect the actual building operation according to the utility data, adjustments were made for equipment and lighting loads to calibrate the model.

Load (Calibrated)		
	Equipment Load (W/sf)	Lighting Load (W/sf)
Office	1.5	1.5
Lunch	0.5	2
Mechanical	0	0.5
R&D	6	2
Vivarium	6	2

Table-9 Adjusted Equipment and Lighting Loads for Block Load Model

Outside Air Ventilation Rate

The table listed below shows the ventilation rate used in this energy analysis that was taken from the design document.

Outside Air Ventilation Rate	
	Outside Air Ventilation Rate (%)
Office	20 cfm/occupant minimum
Lunch	20 cfm/occupant minimum
Mechanical	100
R&D	100
Vivarium	100

Table-10 Outside Air Ventilation Rate

Schedule

Schedules were based on a typical office space provided by the Trace software.

Equipment Operation Schedule		
Start Time	End Time	Status
Midnight	5 a.m.	Storage
5 a.m.	6 a.m.	Off
6 a.m.	6 p.m.	Normal
6 p.m.	Midnight	Storage

Light Operation Schedule		
Start Time	End Time	Percentage
Midnight	6 a.m.	0
6 a.m.	7 a.m.	10
7 a.m.	8 a.m.	50
8 a.m.	5 p.m.	100
5 p.m.	6 p.m.	50
6 p.m.	7 p.m.	10
7 p.m.	Midnight	0

Occupancy Schedule		
Start Time	End Time	Percentage
Midnight	6 a.m.	0
6 a.m.	7 a.m.	10
7 a.m.	8 a.m.	30
8 a.m.	5 p.m.	100
5 p.m.	6 p.m.	30
6 p.m.	7 p.m.	10
7 p.m.	Midnight	0

Table-11 Equipment Operation, Lighting, and Occupancy Schedule

Energy Sources and Rates

Fuel Costs

The primary electrical service to the building is provided by the Massachusetts Electric Company. Since the building has a electrical demand of 1158kW, greater than 200kW, it is qualify for the Time-of-Use(G-3) electric rate.

$0.9108/therm was used as the natural gas rate. This gas rate was taken from the National Grid for Boston area with G-42-Low Load Factor General Service Rate-Medium building type.

Electricity Rate	
Customer Charge	$200.00/month
Distribution Demand Charge	$3.92/kW
Distribution Charge	
Peak Hours	1.1042¢/kWh
Off-Peak Hours	0.3512¢/kWh
Transmission Charge	1.328¢/kWh
Transition Energy Charge	0.030¢/kWh
Energy Efficiency Charge	0.433¢/kWh
Renewables Charge	0.050¢/kWh

Table-12 Electric Rate for Time-of-Use (G-3) Building

Design Load Estimate

Designed and modeled ventilation rate, heating loads and cooling loads were compared in Table-13, Table-14 and Table–15. Models were calibrated with the electrical and natural gas usages data given by the building owner. Results are within a reasonable range when compared to design values. One of the reasons that modeled values are different from design values is the use of simplified block load calculation method.

Both AHU-1 and AHU-3 provides 100% outside air to their conditioned spaces. AHU-3 utilizes return air to the system. Two ventilation rate comparisons were done: outside air ventilation rate and total supply air rate comparisons. There is a slight variation on modeled outside air ventilation rates and the actual design rates.

Total Ventilation (Cooling)							
	Type	Design OA	Design TA	Model OA	Model TA	Difference OA	Difference TA
		cfm	cfm	cfm	cfm	%	%
AHU-1	100%OA	45000	45000	29760	29760	-34%	-34%
AHU-2	With RA	6300	19000	13950	34876	121%	84%
AHU-3	100%OA	5000	5000	7374	7374	47	47%
Overall		**56300**	**69000**	**51084**	**72010**	**-9%**	**4%**

Table-13 Cooling Ventilation Rate Comparison

The modeled block heating load results in values smaller than the actual design values. AHU-3 has the largest variation among the 3 air handling units. AHU-3 serves the vivarium block on the first floor and the mechanical room in the basement. The vivarium block comprised of animal holding room, cold room, instrument room, preparation rooms and corridor. Various rooms has various loads, however, by simple grouping them into one block with one set of design criteria led to an underestimate value of heating load. The variation between the designed and modeled heating load seems significant. However, models were calibrated based on the one-year real gas consumption data. There is only 13.7% difference between the model and the real gas consumption data.

Heating Load			
	System Load		
	Design	Model	Difference
	Mbh	Mbh	%
AHU-1	2126	1118	-47%
AHU-2	920	569	-38%
AHU-3	320	152	-53%
Overall	3366	1837.7	-45%

Table-14 Heat Load Comparison

When comparing the design and modeled cooling loads, there was an average of 5.3% deviation. The main differences for this deviation are due to the different outside air conditions and the cooling coil selections. The actual design cooling load was not given from the design document. Calculations were done to find the sensible and latent loads of the air handling units from the given entering and leaving air temperature of the cooling coil. There were different entering and leaving air temperatures for design and modeled cooling coils in air handling units. 99.6% summer outdoor air conditions from the ASHRAE Handbook of Fundamentals 2009 was used to model the building. The design calculation used different outdoor air conditions, therefore different entering air temperature for the cooling coil. The modeled air handling units have higher humidity ratio difference than the design air handling units which causes higher latent loads. There was a 9.4% deviation compared to the electricity usage data during operation,

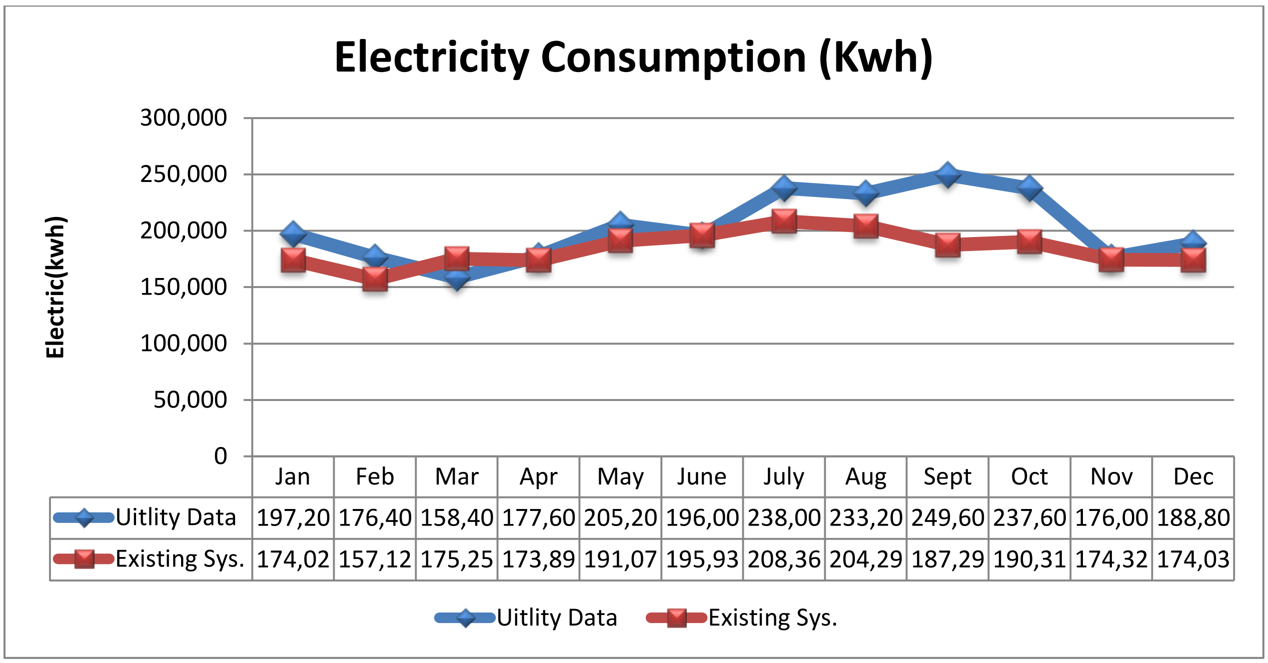
Cooling Load			
	System Load		
	Design	Model	Difference
	Mbh	Mbh	%
AHU-1	3245	2739	-18.5%
AHU-2	1039	1495	30.5%
AHU-3	307	615	50.1%
Overall	4592	4849.2	5.3%

Table-15 Cooling Load Comparison

Annual Energy Use

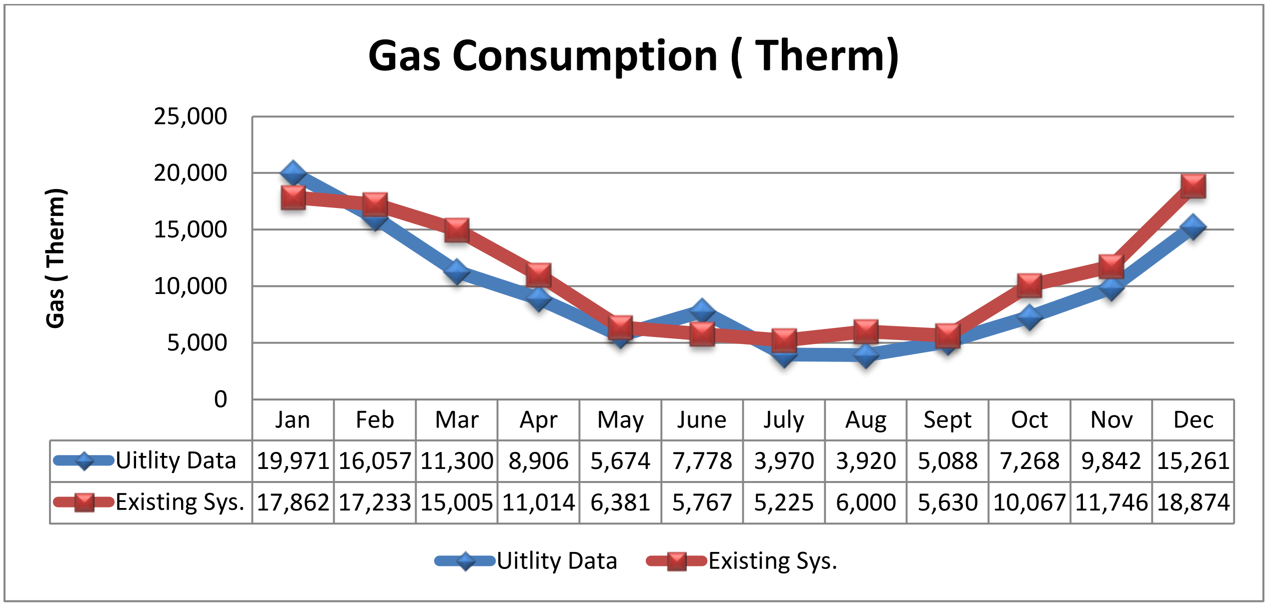
The annual energy simulation analysis was performed for EMD Serono Research Center –existing lab building using the Trace700 model. Cooling equipment uses electricity to operate. Water consumption is mainly come from the cooling tower operation. The gas fired central heating plant operates year-round. Low pressure steam boilers provide winter heating, humidification, and summer reheat for temperature control.

19 consecutive months (01/09-07/10) of electricity usage data and 14 consecutive months (07/09- 08/10) of gas usage data were given by the building owner. Those data were used to calibrate the trace model. Average values were used for months that overlap. High numbers and low numbers were ignored during this calibration. Comparison between utility values and model values were shown in Figure-11 and Figure-12.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Uitlity Data	197,20	176,40	158,40	177,60	205,20	196,00	238,00	233,20	249,60	237,60	176,00	188,80
Existing Sys.	174,02	157,12	175,25	173,89	191,07	195,93	208,36	204,29	187,29	190,31	174,32	174,03

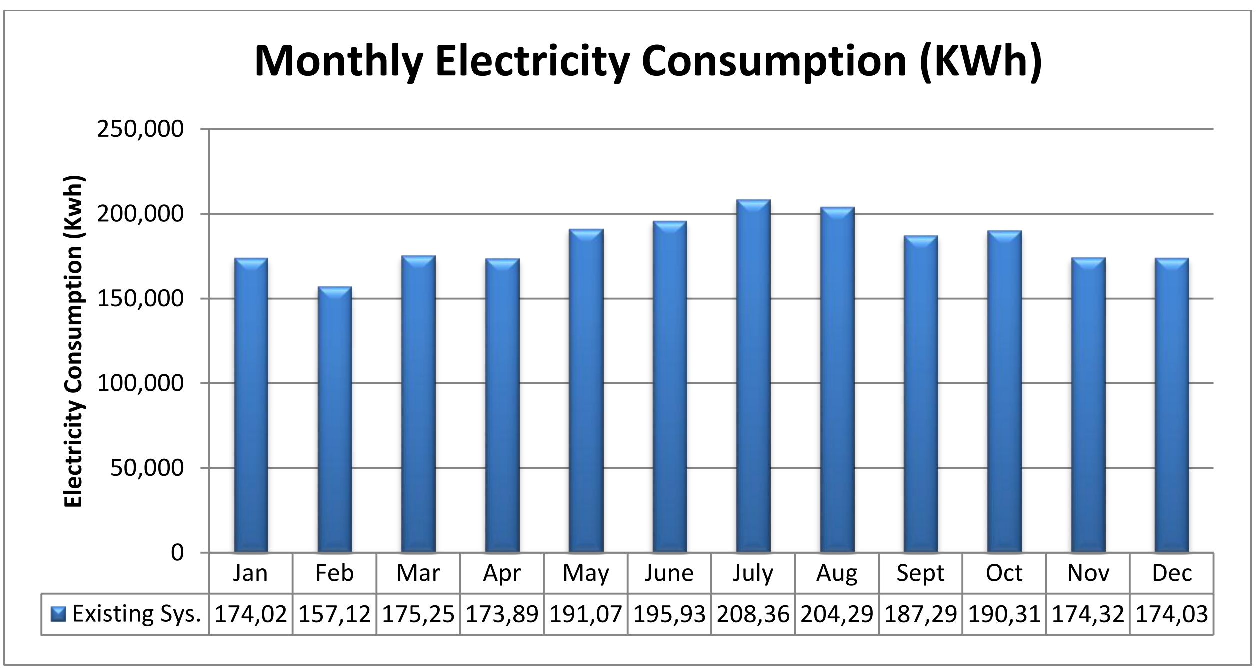
Figure-11 Electricity Consumption Comparison between Model and Utility Data



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Uitlity Data	19,971	16,057	11,300	8,906	5,674	7,778	3,970	3,920	5,088	7,268	9,842	15,261
Existing Sys.	17,862	17,233	15,005	11,014	6,381	5,767	5,225	6,000	5,630	10,067	11,746	18,874

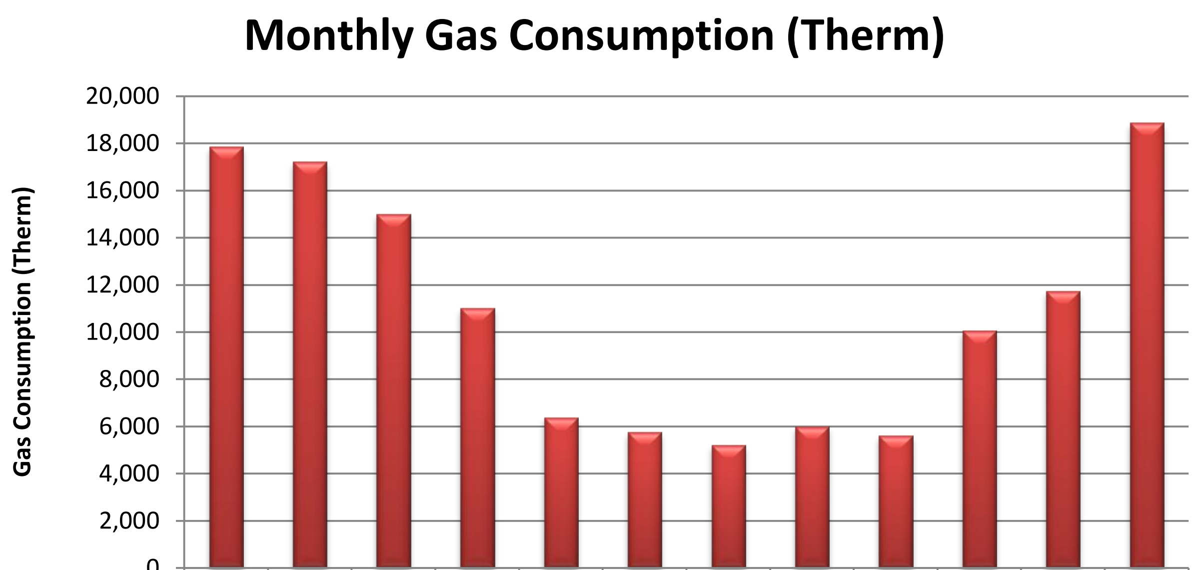
Figure-12 Gas Consumption Comparison between Model and Utility Data

The annual energy consumption for the EMD Serono Research Center-existing lab building is 2,205,940 Kwh of electricity and 130,803 Therm of natural gas. The annual water consumption for mechanical equipment of this building is 1,835,000 gallon. This building has a large equipment and lighting load since pharmaceutical research and development building has high electric demand of lab instruments and light.



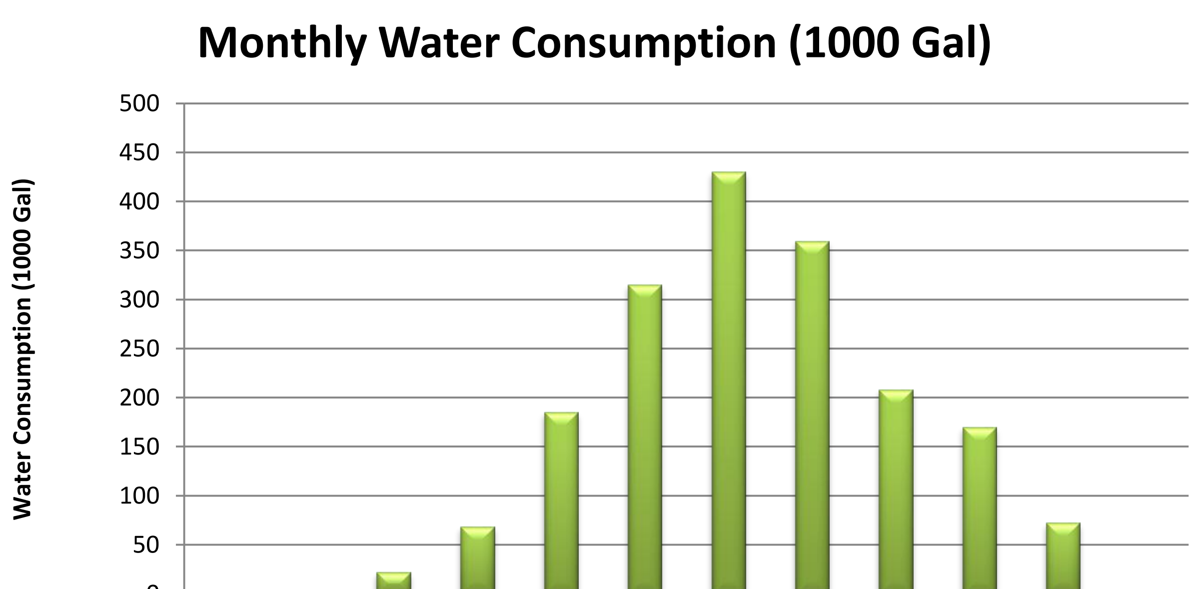
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Existing Sys.	174,02	157,12	175,25	173,89	191,07	195,93	208,36	204,29	187,29	190,31	174,32	174,03

Figure-13 Monthly Electricity Consumption



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Existing Sys.	17,862	17,233	15,005	11,014	6,381	5,767	5,225	6,000	5,630	10,067	11,746	18,874

Figure-14 Monthly Gas Consumption



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Existing Sys.	1	0	22	69	185	316	431	360	208	170	73	0

Figure-15 Monthly Water Consumption

Major Equipment Summary

The chiller plant of the EMD Serono Research Center – existing lab building consists of 2 chillers, a cooling tower, chilled water pumps, and condenser water pumps. The gas fire central heating plant consists of 2 boilers, steam-to-hot water shell-and-tube heat exchangers, boiler feed water pumps, and condensate pumps. The majority of the building's winter heating load is provided by the heating coils in the terminal boxes. There are a total of 207 terminal boxes throughout the building.

Air Handling Units								
	CFM	O.A.	Preheat Coil Steam	Cooling Coil		Humidifier	Filter	
				EDB	LDT		Pre-Filter	Final Filter
AHU-1	45,000	100%	10 psig	92	53	Yes	30%	65%
AHU-2	19,000	33%	10 psig	82	53	No	30%	65%
AHU-3	5,000	100%	10 psig	92	53	Yes	30%	65%

Table-16 Air Handling Unit Schedule

Heat Exchangers					
	Water Side (Tube)				**Steam Side (Shell)**
	EWT (F)	**LWT (F)**	**GPM**	**MBH**	
HE-1	170	190	225	2299	10 psig
HE-2	170	190	225	2299	10 psig

Table-17 Heat Exchanger Schedule

Water Pumps				
	GPM	**Total Head (ft. of H_2O)**	**Motor Data**	
			MHP	**RPM**
CHP-1	840	60	20	1750
CHP-2	135	50	3	1750
CHP-3	135	50	3	1750
CWP-1	1050	50	15	1750
CH/CWP-1	1050	50	15	1750
HWP-1	225	50	5	1750
HWP-2	225	50	5	1750

Table-18 Water Pump Schedule

Condensate Pumps				
	GPM	**Suction Temperature (F)**	**# of Pumps**	**MHP each**
CP-1	**4**	**220**	**2**	**1/3**
CP-2	**8**	**200**	**2**	**3/4**

Table- 19 Condensate Pump Schedule

Steam Boilers				
	Operating Pressure	HP	Lb/hr	Efficiency
B-1	15	175	6590	81%
B-2	15	50	2070	81%

Table- 20 Steam Boiler Schedule

Boiler Feed Water Pump					
	Service	GPM	Total Head (ft of H_2O)	Motor	
				HP	RPM
BFP-1	B-1,B-2	28/10	70	1 each	1750

Table-21 Boiler Feed Water Pump Schedule

Chillers									
	Type	Tons	Evaporator			Condenser			Compressor
			EWT	LWT	GPM	EWT	LWT	GPM	LW/TON
CH-1	Centrifugal	350	55	45	840	95	85	1050	0.56
ACCH-1	Air Cooled	60	55	45	150	NA			1.24

Table-22 Chiller Schedule

Cooling Tower					
	Tons	EWT	LWT	GPM	BHP
CT-1	350	95	85	1050	50

Table-23 Cooling Tower Schedule

Fans						
	CFM	S.P. (ft. of H_2O)	Fan RPM	Wheel Diameter (in)	MBHP	MHP
EX-1	20,000	2.5	1136	33	40	16.1
EX-2	20,000	2.5	1136	33	40	16.1
EX-3	7,000	3.0	1800	21	10	6.3
EX-3A	7,000	3.0	1800	21	10	6.3
EX-4	1,200	3.0	NA	NA	2	NA
EX-5	850	2.0	NA	NA	2	
EX-6	800	1.5	1750	12	½	0.33
EX-7	800	1.5	1750	12	½	0.33
EX-8	2,500	1.5	1725	NA	1 ½	NA

Table-24 Fan Schedule

Variable & Constant Volume Terminal Boxes								
	Design Range	Hot Water Coil					Air Side	
	CFM	MBH	EWT	LWT	GPM	MAX. ΔP (in H_2O)	EAT	LAT
VAV-5	65-250	12.2	180	140	0.6	0.5	55	100
VAV-6	75-400	19.4	180	140	1.0	0.5	55	100
VAV-8	150-700	34.0	180	140	1.7	0.5	55	100
VAV-10	250-1000	48.6	180	140	2.4	0.5	55	100
VAV-12	350-1500	72.9	180	140	3.7	0.5	55	100
VAV-14	475-1950	94.8	180	140	4.7	0.5	55	100
CV-5	65-250	12.2	180	140	0.6	0.5	55	100
CV-6	75-400	19.4	180	140	1.0	0.5	55	100
CV-8	150-700	34.0	180	140	1.7	0.5	55	100
CV-10	250-1000	48.6	180	140	2.4	0.5	55	100
CV-12	350-1500	72.9	180	140	3.7	0.5	55	100
CV-14	475-1950	94.8	180	140	4.7	0.5	55	100

Table-25 Variable & Constant Volume Terminal Box Schedule

Mechanical System First Cost

The approximate first costs for the mechanical, plumbing, and fire protection systems were listed in Table-26. The HVAC and controls systems total to $3,186,441, which equates to $54.4/sf and accounts for 20% of the total construction cost. Including plumbing and fire protection systems, the cost raises to $4,601,037, which equates to $78.58/sf and accounts for 29% of the total construction cost. The mechanical system cost is the most significant amount compared to other systems in the building.

Mechanical System Initial Cost			
	Total GMP ($)	$/sf	Percentage of Total Cost
Plumbing and Drainage	1,242,260	21.21	8%
Fire Protection	172,336	2.94	1%
HVAC	2,731,241	46.63	17%
Controls	455,200	7.77	3%
Total Mechanical Cost	4,601, 037	78.58	**29%**
Total Construction Cost	15,885,210	217.23	100%

Table-26 Mechanical System Initial Cost

Existing System Evaluation

The mechanical system for the EMD Serono Research Center – existing lab building was designed adequately for its purpose of reducing the spread of contaminates and maximizing comfort.

Air Distribution System Evaluation

The air distribution system designed in the way that contaminated air from the labs and the vivarium rooms does not circulate inside those spaces and transfer to other spaces in the building. Critical spaces such as laboratories and vivarium rooms were designed to maintain negative pressure relative to surrounding area. Conditioned air is distributed to space through variable volume or constant volume boxes. Terminal boxes in vivarium areas are constant volume boxes; boxes in laboratories and office areas are variable volume boxes. Since majority of the terminal boxes are variable volume boxes, it is difficult to maintain relative negative pressurization in critical spaces.

Heating System Evaluation

The steam and hot water system in this building is an effective system. The gas fired boilers generates low pressure steam to provide preheat and humidification inside each air handling units. Low pressure steam is also delivered to heat exchangers to generate hot water for summer reheat and winter heating. The 50 hp boiler operates during the summer while the 175 hp boiler operates during the winter.

By utilizing hot water heating as the primary heating method; large pump energy is consumed to deliver hot water throughout the building. Another potential concern of this system is the energy consumption for hot water reheat during the summer. Since the 50 hp boiler is dedicated for summer reheat, generating steam to transfer heat through heat exchanger to supply hot water for reheat might reduce the overall efficiency of the system.

Cooling System Evaluation

The chilled water system consists of a water cooled centrifugal chiller, an air cooled chiller, and a cooling tower. The cooling system is designed as a parallel chiller-primary constant flow system. Both the water cooled chiller and the air cooled chiller are designed to operate at the same time. In general, air cooled chiller has a higher kw/ton value than water cooled chiller. Using an air cooled chiller in parallel with the water cooled chiller might decrease the overall efficiency of the system.

A potential concern is the absence of the heat recovery or desiccant wheel for the 100% outside air AHUs. One of the issues found in the previous report is that there is a large latent load from the outside air. Since 2 out of the 3 systems utilize 100% outside air, large amount of energy is used to condition the outside air. This topic will be discussed in the Proposed System Alternatives section in this report.

Proposed System Alternatives

The mechanical system for the EMD Serono Research Center – existing lab building was well designed to meet the objectives of the building design. But as with any design, there can be alternative designs for improvement. The following is a list of alternatives that can be redesigned or investigated for potential system improvement in areas such as indoor air quality, energy consumption, carbon footprint, and construction cost.

- Investigate the pressure relationship between spaces to determine method to ensure contaminated air does not recirculate or transfer inside the building.
- Investigate heat recovery methods for the 100% outside air system by utilizing exhaust air stream.
- Investigate the dedicated outdoor air system with secondary cooling system
- Provide steam heating coil inside air handling units to eliminate heat exchangers and hot water distribution throughout the building to save hot water distribution pumping energy.
- Convert the 50hp steam boiler to high efficiency hot water boiler to provide summer reheat.
- Change the parallel water cooled chiller and air cooled chiller system to series water cooled chiller. Have the larger size chiller provide base load cooling and the smaller size chiller provide peak load cooling.
- Investigate changing the parallel chiller- primary constant flow system to primary/secondary or variable primary flow system.

The objective for alternative solution is to increase efficiency, provide thermal comfort and healthy indoor air quality as well as to reduce the operating cost and carbon footprint. Based on the objectives of this building design, two topics have been chosen from list above to be studied further: dedicated outdoor air system with active chilled beam and heat recovery systems.

Dedicated Outdoor Air System with Active Chilled Beam

The building utilizes 100% outside air system for the laboratory and vivarium area to ventilate and condition the space. Dedicated Outdoor Air System uses 100% outside air to ventilate the space. Since DOAS system only delivered ventilation air, the rest of the load is met by a parallel system such as fan coil units, chilled beams, radiant floor, etc. The latent load must be met at the air handler units while the sensible load can be picked up in the space.

By employing DOAS system in the EMD Serono Research Center – existing lab building, significant energy saving may be achieved. Air handing units and duct sizes can also be reduced due to the smaller volume of supply air to the space. On the other hand, DOAS system consumes more energy in a few areas such as pumping. Therefore, analysis will be done to calculate the total energy usage of the system when compared to the 100% outside air supply system.

Active chilled beam will be investigated as the parallel system for the DOAS system. In active chilled beam system, ventilation air from DOAS system is injected into the space through small air jets in the beam. Both induced air and ventilation air is conditioned by the cold water pipe inside the beam. Both summer cooling and winter heating can be achieved by either two-pipe or four-pipe chilled beams. A potential concern for the chilled system is the condensing water issue; therefore, humidity must be controlled in the space.

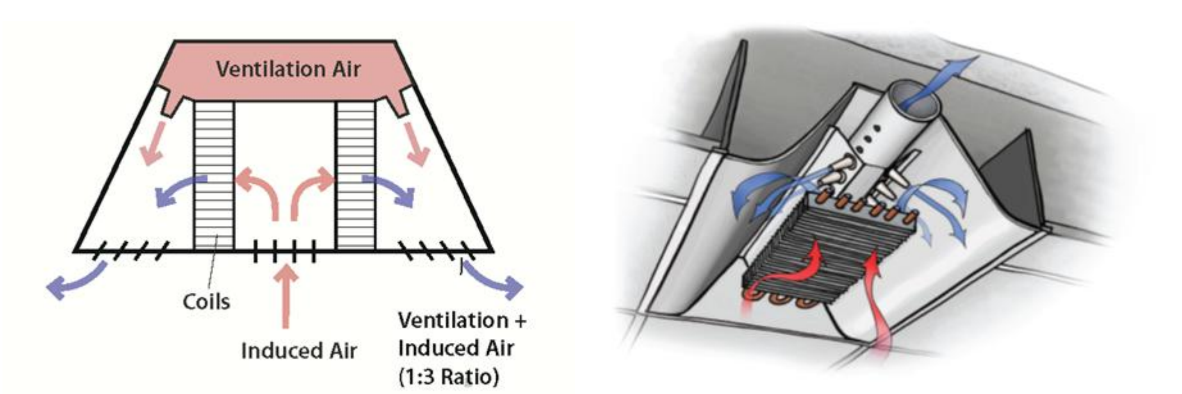


Figure-16 Active chilled beam systems use air supplied from an air handling unit

Heat Recovery System

The EMD Serono Research Center – existing lab building provides its occupants with excellent indoor air quality by utilizing 100% outdoor air system in critical spaces. AHU-1 and AHU-3 provides a total of 50,000 cfm 100% outside air to both the lab and vivarium areas which made up 89 % of the total supply air. This building also contains a total of 9 exhaust fans, exhausting a total of 61,150 cfm air out of the building. In harsh summer and winter condition, large amount of energy is needed to condition the outside air. By employing a heat recovery system to retrieving energy from the exhaust air stream, large amount of energy can be saved.

Ventilation System			
	System Type	CFM	% of CFM
AHU-1	100% OA	45000	80%
AHU-2	With RA	6300	11%
AHU-3	100% OA	5000	9%
AHU-1 + AHU-2	100% OA	50000	**89%**
Total		56300	100%

Table-27 Ventilation System

The proposed redesign is to utilize heat recovery system to recover heat from the exhaust air stream to precondition the outside air. This heat recovery process can be achieved by using different methods such as enthalpy wheel, plate heat exchangers, heat pipes, and runaround loops.

Enthalpy Wheel

Enthalpy wheel rotates between the supply air and exhaust air streams and picks up heat energy from the exhaust air stream and releases it into the supply air stream. Both sensible and latent energy are being transferred. The total cooling load of this building consists of 65% sensible load and 35% latent load. Therefore, system that can reduce latent load during the heat recovery process is very attractive. However, contaminated exhaust air might leak into the supply air stream causing cross contamination problem. As a result, other heat recovery system will also be investigated.

Sensible Load vs. Latent Load					
	Sensible Load (Mbh)	Latent Load (Mbh)	Total (Mbh)	% Sensible Load	% Latent Load
AHU-1	1895	1350	3245	58%	42%
AHU-2	800	239	1039	77%	23%
AHU-3	157	150	307	51%	49%
Total	2852	1739	4591	65%	38%

Table-28 Sensible Load vs. Latent Load

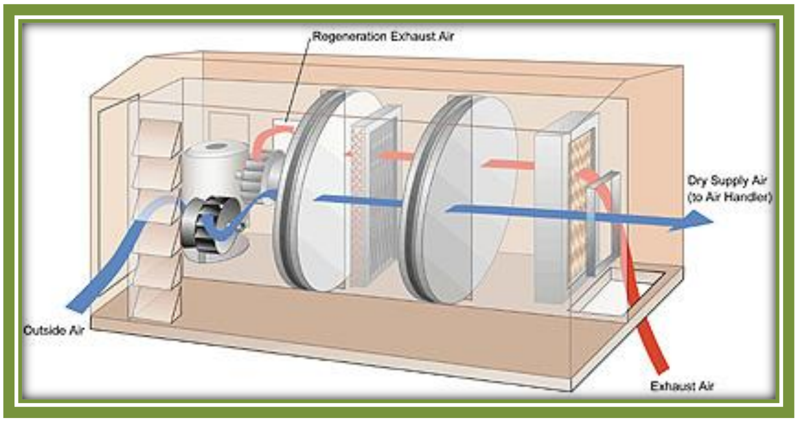


Figure-17 Heat Recovery System – Enthalpy Wheel

Fixed Plate

Plate heat exchanger consists of alternating layers of plates that are separated and sealed. Plates are arranged for cross flow or counter flow of supply and exhaust airstreams. Since plates are solid and non-permeable, only sensible energy is transferred, therefore, no cross contamination issue.

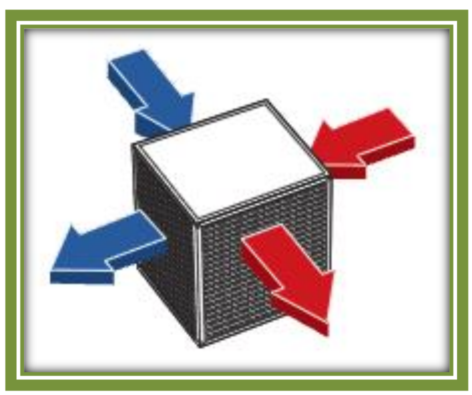


Figure-18 Heat Recovery System – Fixed Plate Heat Exchanger

Heat Pipe

Heat pipe heat exchanger is constructed of individual heat pipes. A partition divides the exchanger into 2 sections to ensure the separation of supply and exhaust air flows. Supply and exhaust air are ducted in counter flow direction across each other to transfer heat.

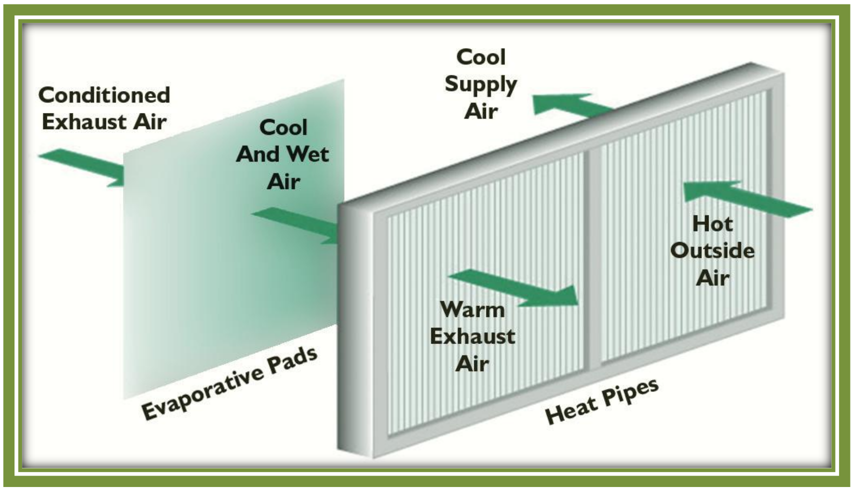


Figure-19 Heat Recovery System – Heat Pipe

Runaround Coil

Runaround loop system consists of finned tube water coils in the supply and exhaust air streams. The coils are connected in a closed loop via counter flow piping through which an intermediate heat transfer fluid is pumped.

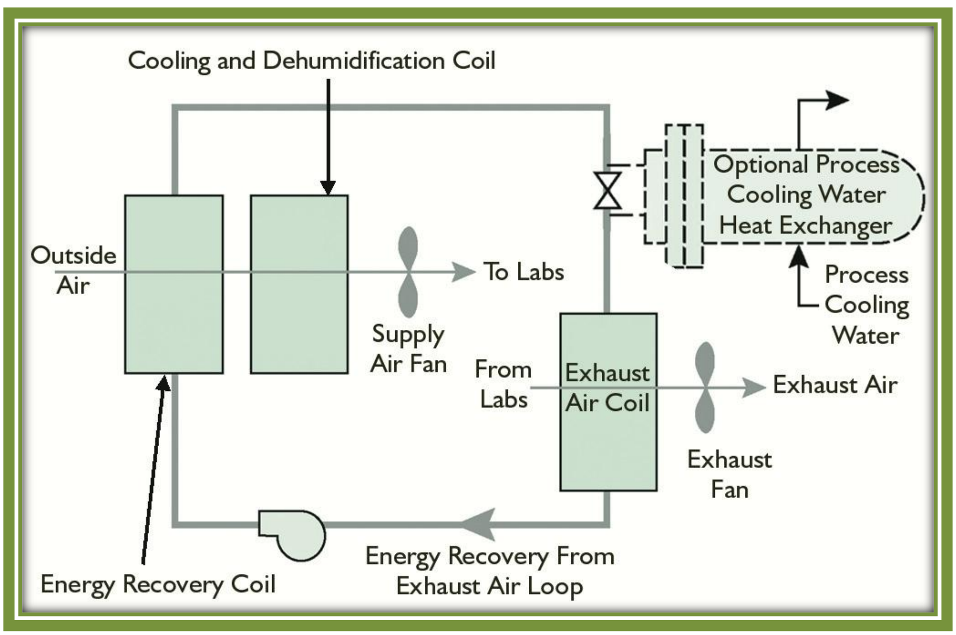


Figure-20 Heat Recovery System – Runaround Loop

Analysis will be done for all 4 heat recovery systems. Comparisons based on total effectiveness, energy saving, cross contamination issue, and maintenance can be made to decide which method is best suited for this building.

Mechanical System Redesign

Design Goals

The guiding principle for this project is to maximize comfort in a practical way for the scientists and staff to do their work. The main goals for the mechanical redesign are to provide healthy indoor environment, reduce building load, decrease energy consumption and be cost effective.

Dedicated Outdoor Air System with Active Chilled Beam Design

The dedicated outdoor air system in parallel with active chilled beam system offers many benefits compared to the existing constant-air-volume/variable-air-volume system with reheat scheme.

Majority of the building space have a fixed amount of ventilation air requirement. In the research and development spaces, ventilation air of 6 air change per hour is typically required. In the vivarium space, ventilation air of 8 air change per hour is typically required.

In the redesign system, DOAS system provides the required ventilation air conditioned by air handling units. That ventilation air is then supply through the active chilled beam system to the space. Water is circulated through the integral cooling/heating coils in the active chilled beam to condition the space air.

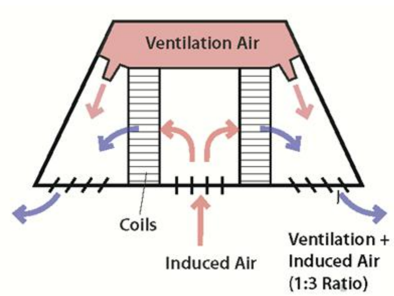


Figure-21 Active Chilled Beam Section

Since the chilled beam only provides sensible cooling and the air handling units provides latent cooling. Lower temperature chilled water (44F) is used in the air handling units while higher temperature chilled water (56F) is used in the chilled beam to avoid condensation problem.

There are many advantages for using DOAS/Active Chilled Beam system.

System Advantages:

1. DOAS system provides a fixed amount of ventilation air from the air handling units, and the rest of the sensible cooling is provided by the chilled beam. Therefore, outside air conditioning is minimized. Ducting and air handlers can also be downsized.

2. Cooling in the chilled beam is accomplished by adjusting the chilled water flow rather than the supply air flow. Water has a volumetric heat capacity 3,500 times that of air. Therefore, significant amount of fan energy can be reduced.

3. Since chilled beams control the individual space temperatures by adjusting the chilled water flow across the coils in the beams. Reheat energy can be eliminates and the hot water system can be downsized.

4. Since higher chilled water supply temperature is needed in the chilled beam, smaller and more efficient chilled water systems can be specified. Higher chilled water supply temperature will increase EER for the chiller. In order to take advantage of the higher chiller water supply temperature, a separate chiller is needed dedicated for the active chilled beam system.

5. Since there are no moving parts in the chilled beam and no filters to maintain, the DOAS/ACB system requires little maintenance.

Schematics Design

Figure-22 shows the schematic design for the chilled water system. Chiller 1 is a 350 ton screw chiller that provides 44F chilled water to the 3 air handlers. Chiller 2 is a 150 screw chiller that provides 56F chilled water to the active chilled beam system. Both chiller reject heat to the same cooling tower.

Figure-23 shows the air side schematic for the system and Figure-24 shows the steam heating schematic.

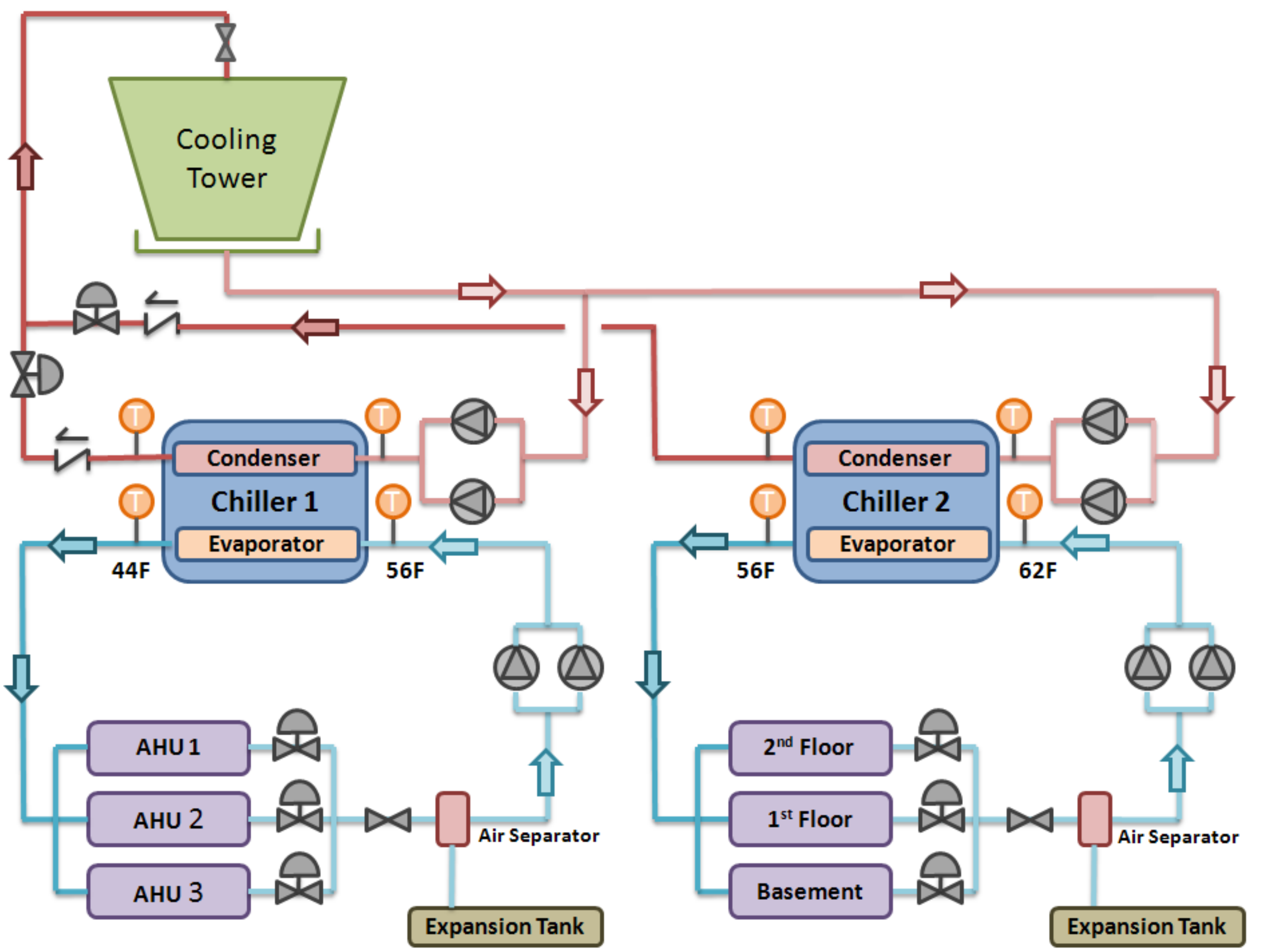


Figure-22 Active Chilled Beam Water Side Cooling Schematic

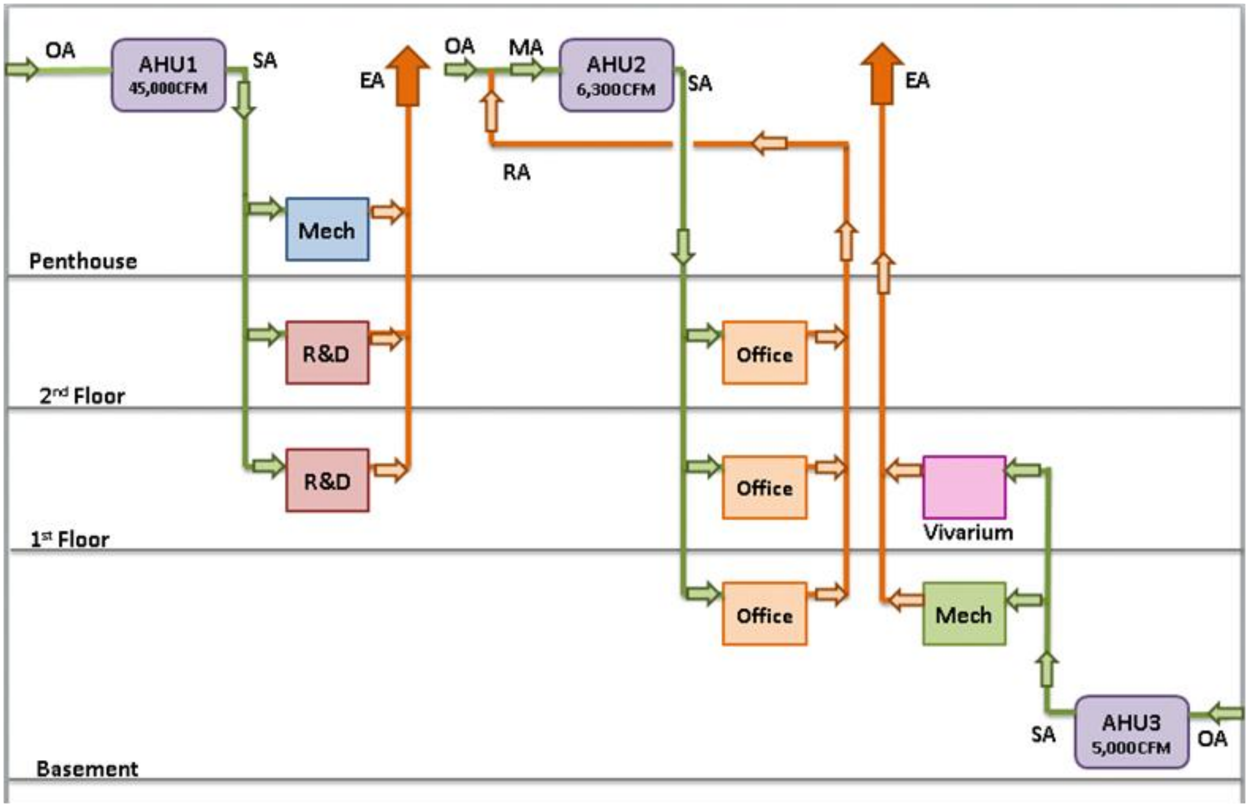


Figure-23 Active Chilled Beam Air Side Riser Diagram

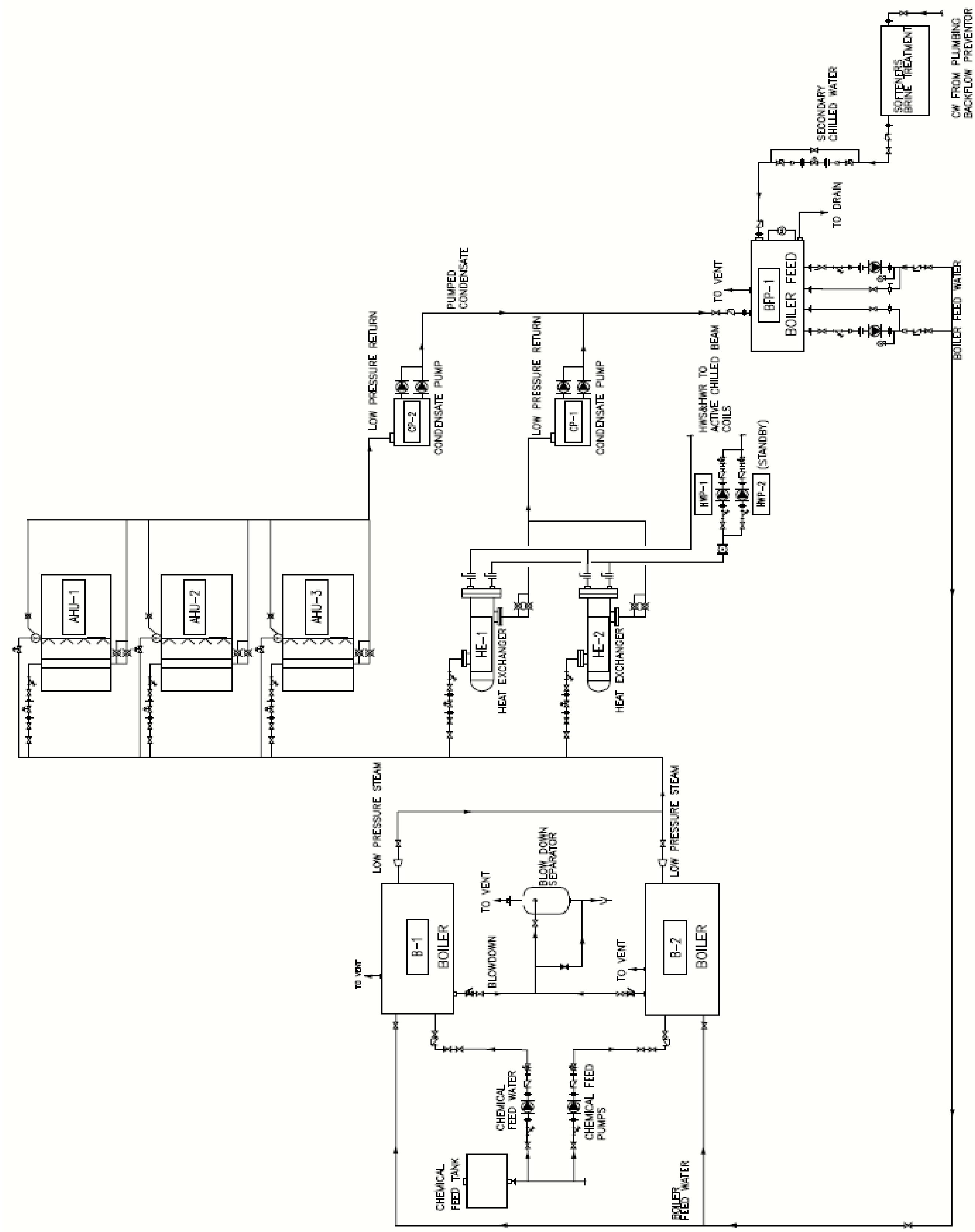


Figure-24 Active Chilled Beam Heating Schematic

Active Chilled Beam Selection

The active chilled beam system was selected based on the space load, air flow requirement and space availability. Room210 - Research and Development Room, the largest lab room in the building, was selected as a sample room to demonstrate chilled beam selection, layout, as well as to simulate Computational Fluid Model (CFD).

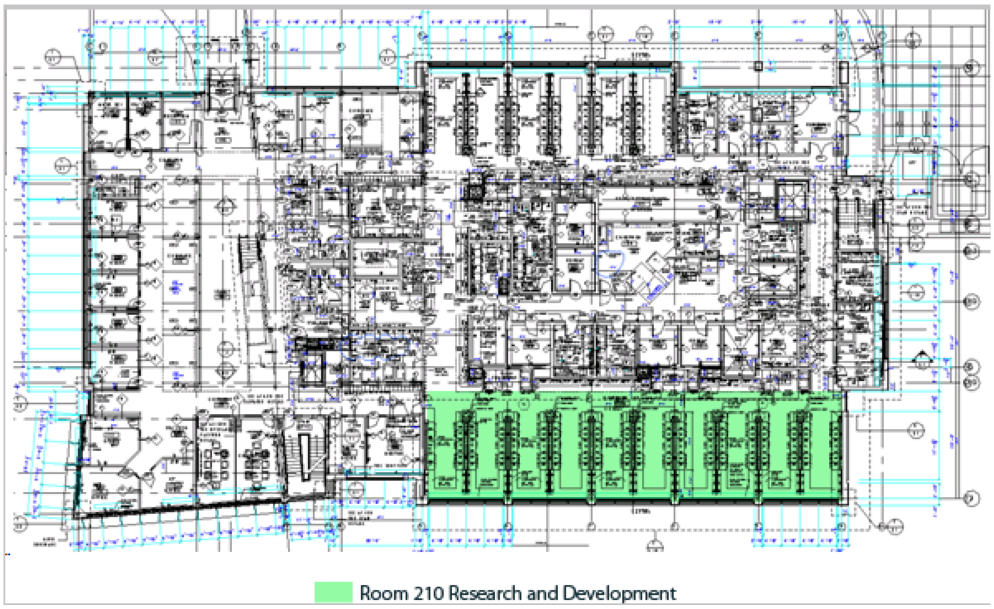


Figure-25 Room210 Research and Development Room

Room 210 has a width of 30 feet and a length of 98 feet. It has exterior walls on the south and west sides. Inside the room, there are eleven 20 feet long lab benches, 10 rows of active chilled beams can be placed on the ceiling between the benches. Therefore, space for 10 rows of 20 feet long active chilled beams is available.

In order to size the active chilled beam, information on primary air flow rate and secondary cooling load is needed. Air flow rate and cooling load information were taken from the trace model.

Active Chilled Beam Selection Calculation				
Primary Airflow (cfm)	**Secondary Cooling (Btuh)**	**Available Length (ft)**	**CFM/LF**	**BTUH/LF**
3,324	133,000	200	17	665

Table-29 Active Chilled Beam Selection Calculations

Active chilled beams were selected from TROX Technik. According to this calculation, 4 pipes chilled beam, model DID602, with type “C” nozzle was selected. This model has a NC rating of 25, which meets the noise requirement for lab space.

Active chilled beam come in modules of 4ft, 6ft, 8ft, and 10ft. Two 10 ft. chilled beam module was selected to place in each row, with a total of 20 chilled beams in the room.

Active Chilled Beam Sample Layout

The following figures show the actual picture of Room210 and the layout of the active chilled beam system in the room. The model was built in Phoenics, a CFD modeling software. The dimensions of the active chilled beams were taken from manufacture’s catalog. In order to demonstrate an accurate simulation with the available computing power and within a reasonable time frame, objects inside the room such as furniture, equipment, and mechanical system were modeled in a simplified version.

The existing VAV/CAV mechanical system was also modeled to do system comparison. The sizes and layout of the diffusers, exhaust grills, and fume hoods were taken from the mechanical drawings.

Figure-26 Room210 Picture

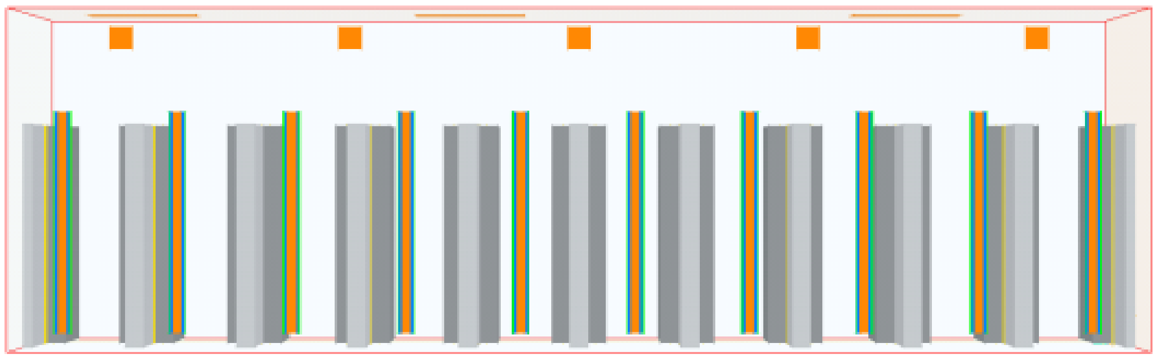


Figure-27 Active Chilled Beam Layout – Top View

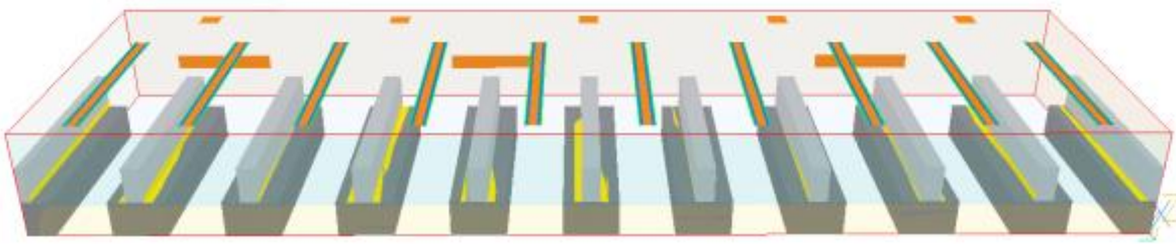


Figure-28 Active Chilled Beam Layout – Elevated View

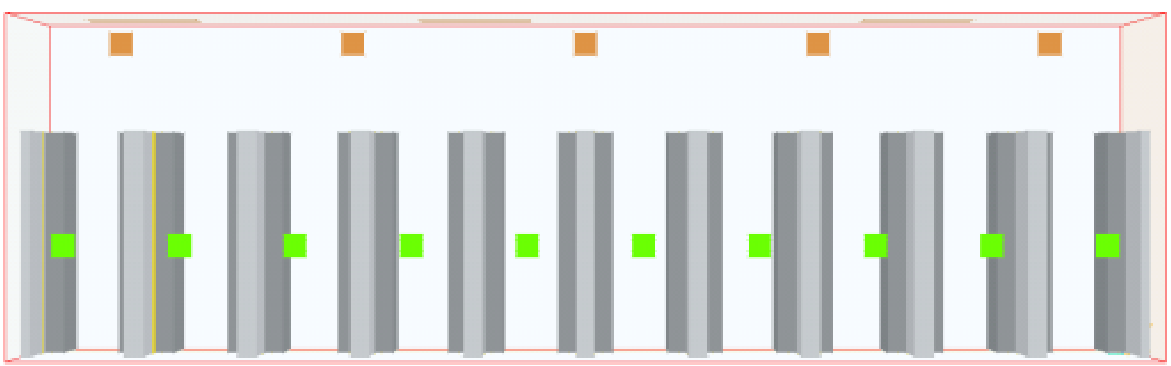


Figure-29 Existing Variable-Air-Volume Layout –Top View

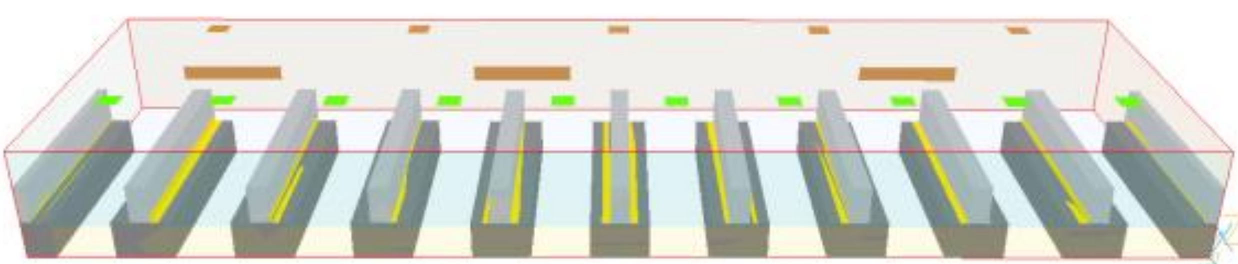


Figure-30 Existing Variable-Air-Volume Layout –Elevated View

CFD Model Comparison

Computational Fluid Models were built in Phoenics to analysis the effectiveness of the active chilled beam system in air flow distribution, temperature distribution and contaminant removal when compared to the existing VAV system.

To accurately represent the room, loads were taken from the Trace model. Exterior wall loads and glass load were taken from the trace model, and assigned as heat flux to the two exterior walls and the large window surfaces on the west wall. Lighting load was assigned to the ceiling surface as a heat flux as well. Interior walls and floor were assigned to an ambient temperature of 75.5F (24.180 C). Equipment load and occupant load were equally distributed on the top surfaces of the bottom lab benches and on the side surfaces of the top benches, where most equipment are placed and people occupied (as shown as the yellow strips on the benches in the figures).

Flow rates and supply air temperatures for the active chilled beam system were taken from the trace file. For the existing systems, data were taken from the design document.

In the research and development space, contaminants are generated in the space during research experiments. Since specific chemicals and the associate concentration level were not given, an arbitrary contaminant CO_2 with an arbitrary concentration, 200ppm, and a velocity of 0.2m/s is chosen to represent the contaminant generated inside the space by research experiments. Contaminant generations were assigned to the yellow strips on the benches where most of research work occurs. Simulations were done to evaluation the ability of mechanical ventilation systems to remove contaminant from the space which is very critical for indoor air quality and safety.

A mass residual less than 0.1% indicate the CFD models simulate by the Phoenics software have reached convergent state. However, a 0.1% mass residual is very difficult to achieve within a reasonable time frame for large space with complex system. Models with a mass residual less than 5% are within the acceptable range for accurate result. The active chilled beam model was able to achieve a mass residual of 0.54% while the existing VAV system has a mass residual of 1.30%. Both models have very good mass residual which indicates fairly accurate results.

General Information					
	Grid Size	Turbulence Model	Numerical Scheme	Number of Iterations	Mass Residual
Existing System	108x218x61	KE model	Upwind	7000	1.30%
Active Chilled Beam System	52x459x35	KE model	Hybrid	5000	0.54%

Table-31 CFD Models General Information

Air Flow Analysis

Air distribution in the y-direction for the VAV system was closely concentrated in the walk way between the benches while the distribution for the ACB system was more spread out in space between the benches.

Air flow in the x-direction for the VAV system was mostly concentration in the space directly beneath the square supply diffuser. On the other hand, the 20 ft long ACB diffuser was able to provide air flow along the diffuser to the area around the lab benches where people occupied.

As a result, the active chilled beam system provides a much better fresh air distribution throughout the space than the variable-air-volume system.

Air Flow Distribution Profile – VAV vs. ACB

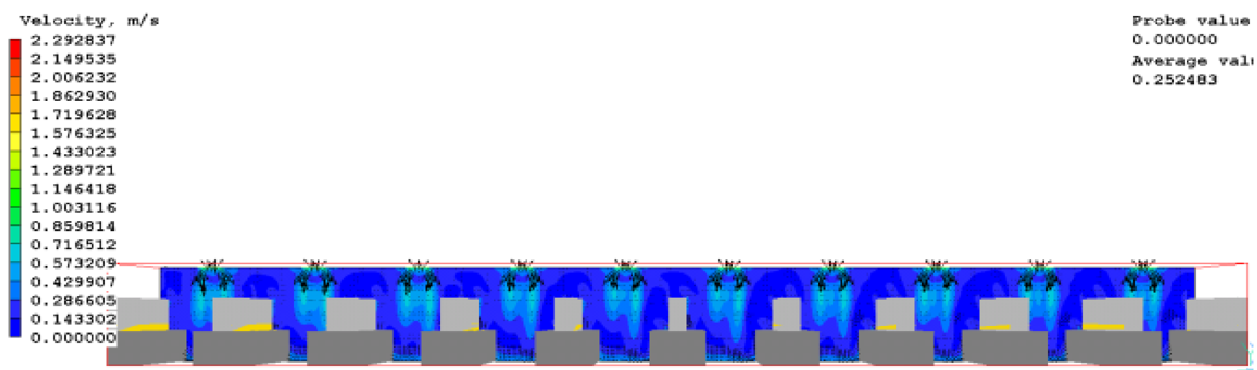


Figure-31 VAV System Velocity Profile Overview in Y-direction

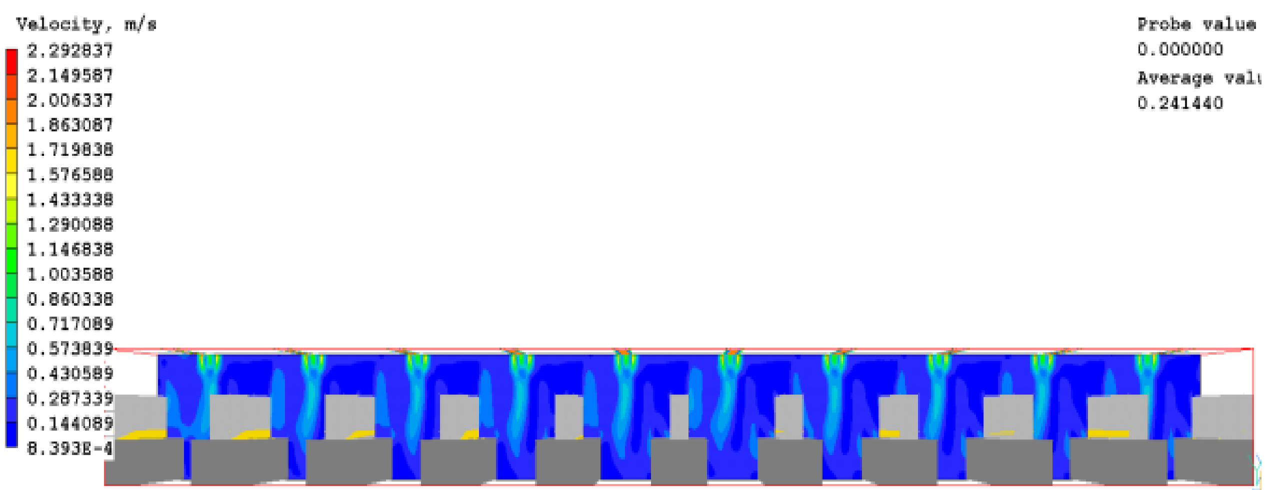


Figure-32 ACB System Velocity Profile Overview in Y-direction

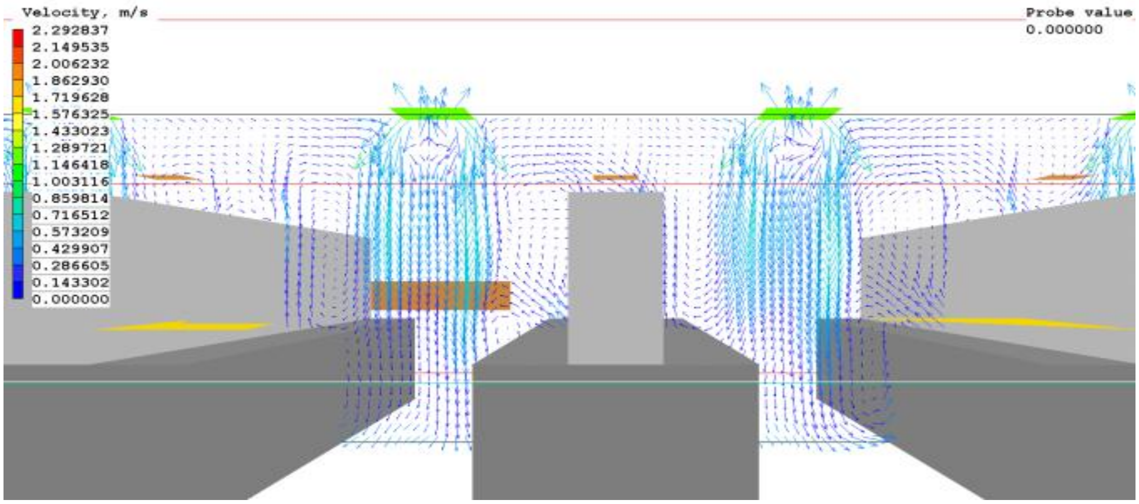


Figure-33 VAV System Velocity Profile Close View in Y-direction

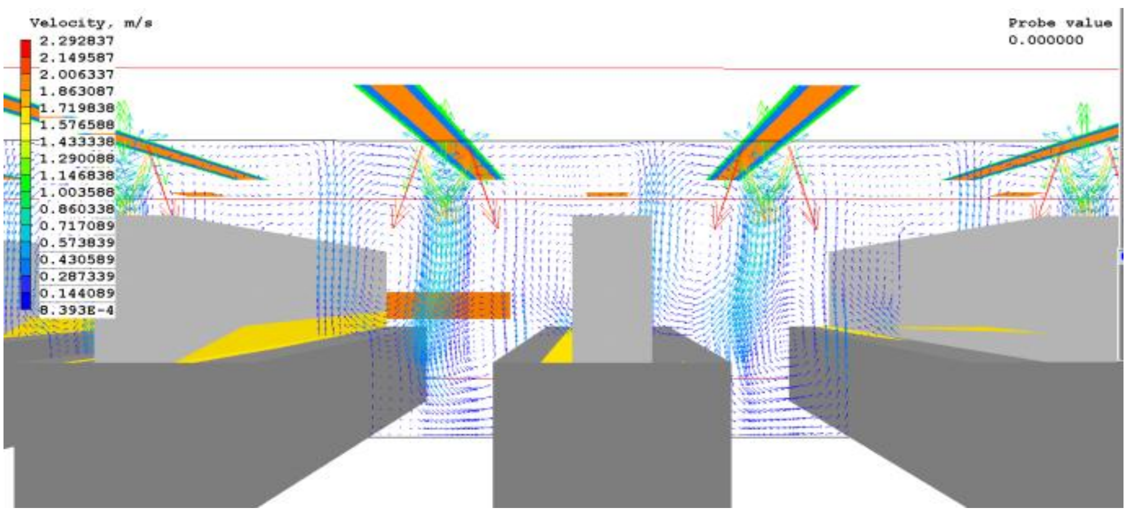


Figure-34 ACB System Velocity Profile Close View in Y-direction

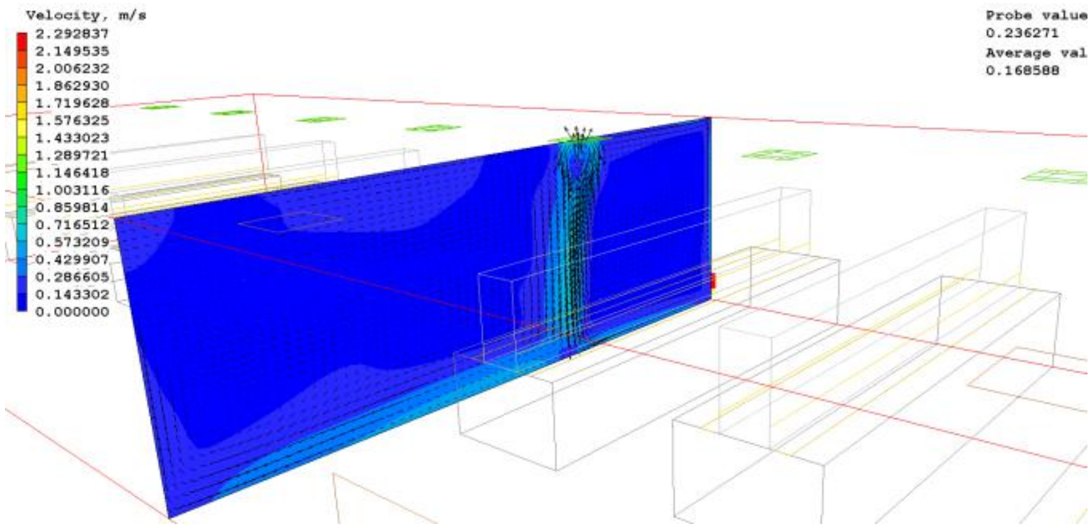


Figure-35 VAV System Velocity Profile Overview in X-direction

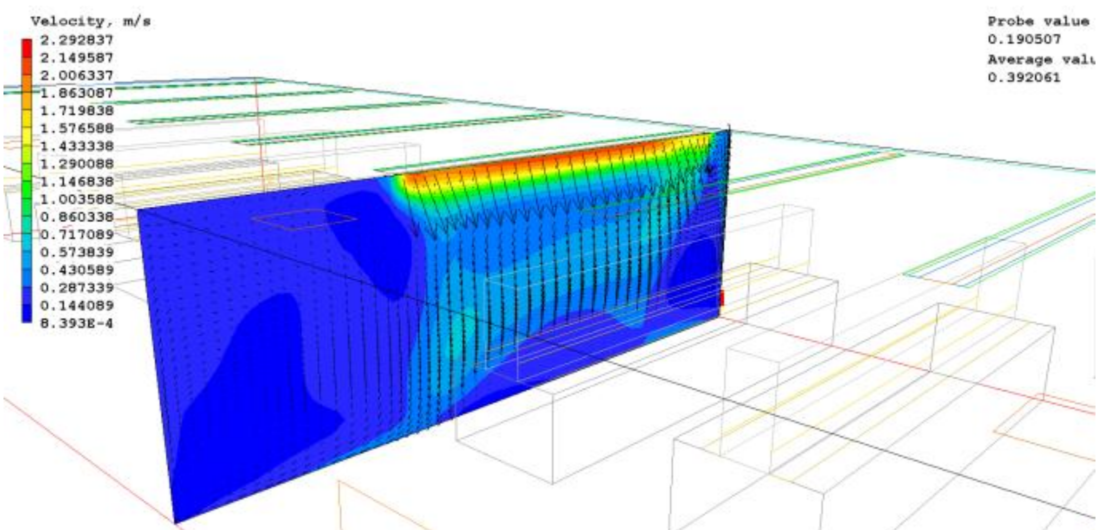


Figure-36 ACB System Velocity Profile Overview in X-direction

Temperature Distribution Analysis

According to ASHRAE Standard 55, a temperature difference of no more than 5F (2C) between the occupants head and feet is required to maintain thermal comfort. For the VAV system, air was supplying at 55F (13C). The room temperature had a gradient of 68F (20C) on the floor, 71F (22C) in the middle of the room, and 79F (26C) on the ceiling. A temperature difference of 3F (2C) was maintained by the VAV system which was within the limit of the ASHRAE standard.

The active chilled beam system has a very uniform temperature distribution though out the room. Air was supplying at an average of 67F (19.64C), temperatures on top of the lab bench and on the ceiling were around 73F (23), the rest of the room had a temperature of 71F (22C). With 0 to 2F (1C) temperature gradient between occupants head and feet, the active chilled beam system had met the requirement for thermal comfort.

With only 0-2F temperature gradient for the chilled beam system and 3F temperature gradient for the VAV system, the active chilled beam system provides a more uniform temperature distribution in the space than the VAV system.

Temperature Distribution Profile – VAV vs. ACB

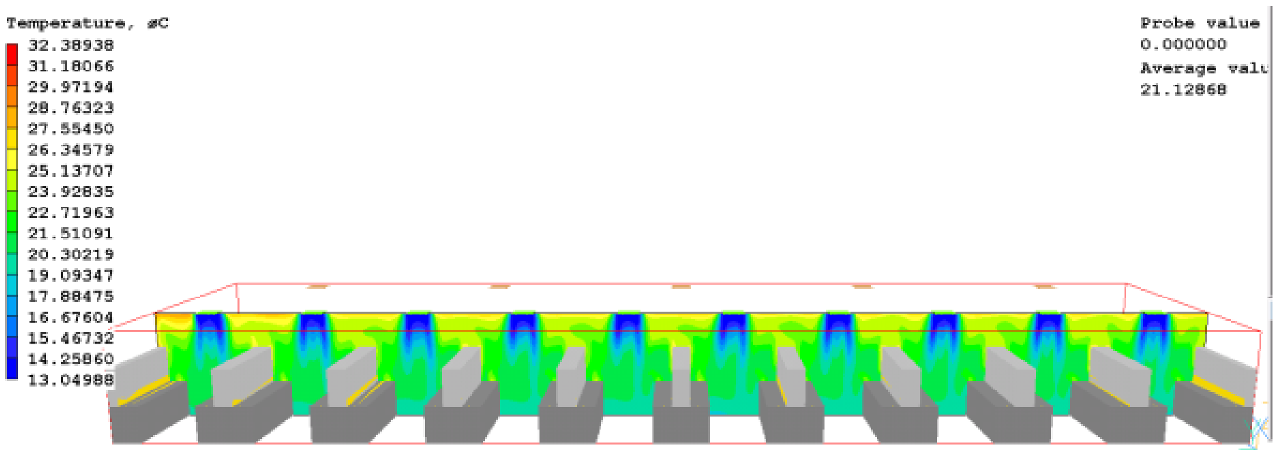


Figure-37 VAV System Temperature Profile Overview in Y-direction

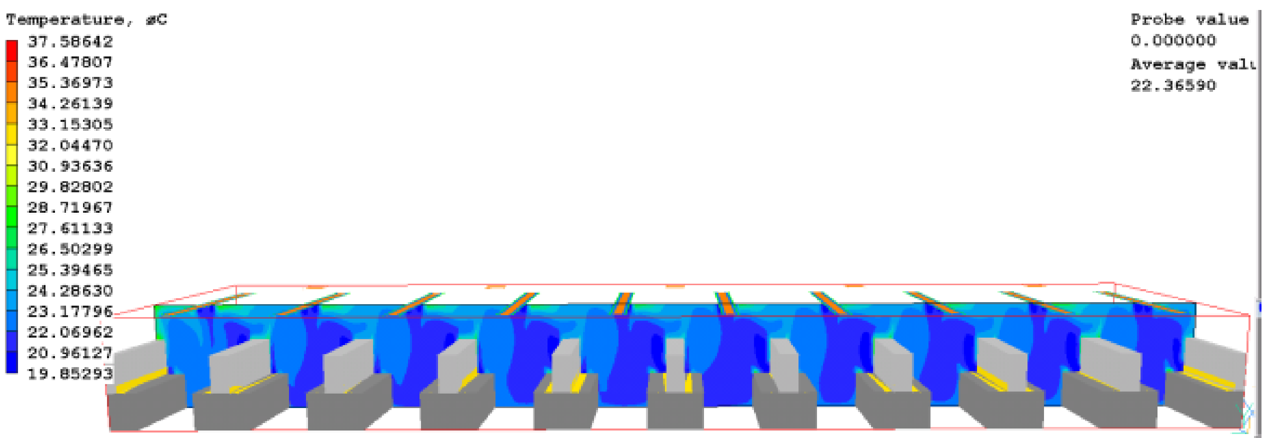


Figure-38 ACB System Temperature Profile Overview in Y-direction

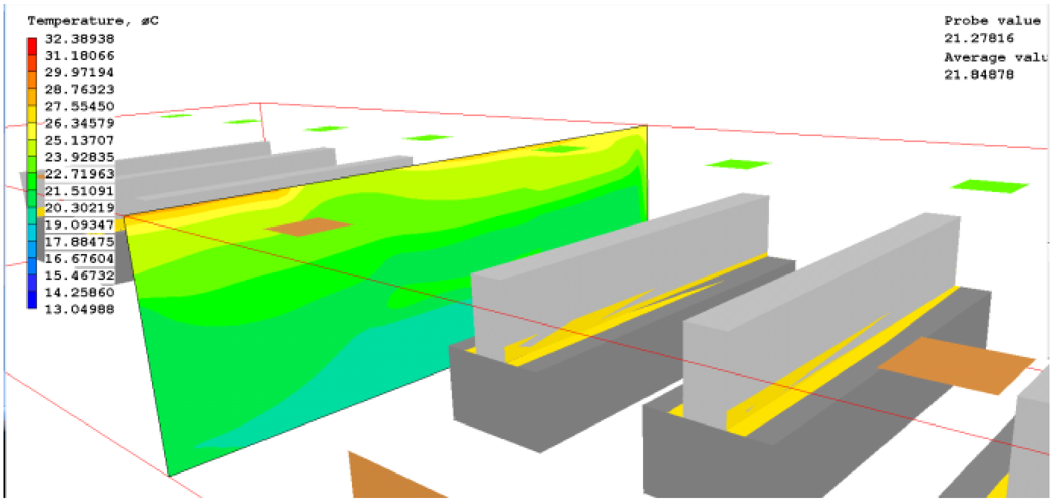


Figure-39 VAV System Temperature Profile Overview in X-direction

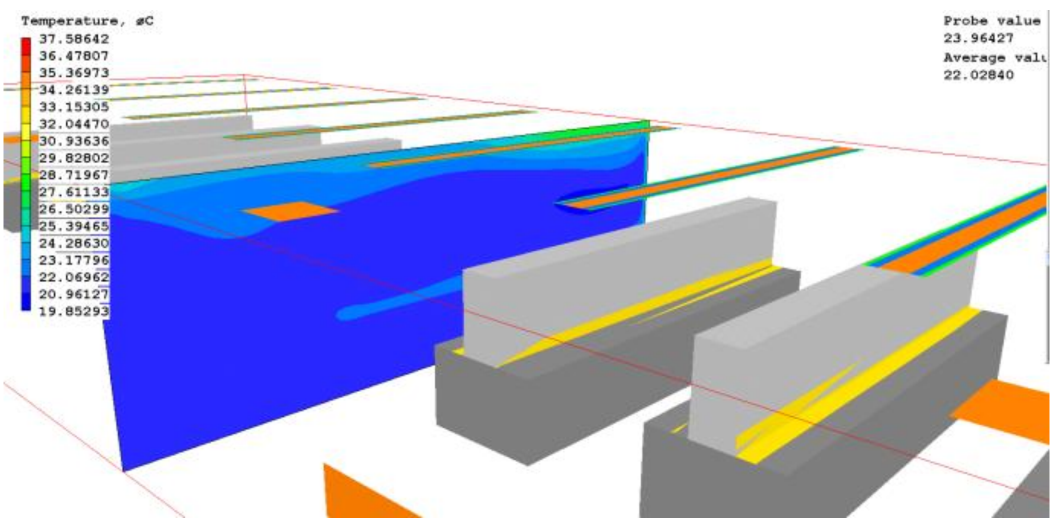


Figure-40 ACB System Temperature Profile Overview in X-direction

Contaminant Distribution Analysis

Airborne contaminant was generated on the top of the lab bench. At the source plane, the contaminant has a concentration of 200ppm in both models. For the VAV system, the contaminant concentration is still 200ppm. In the walkway between the benches, concentration has dropped to 150ppm which is a 25% decrease in concentration.

For the ACB system, concentration has dropped to 100-150ppm, which is a 25-50% decrease in concentration at the edge of the bench. In the walkway between the benches, concentration has dropped to 50ppm, which is a 75% decrease in concentration.

The results have clearly shown that the active chilled beam system provides a greater ability to remove airborne contaminant from the space.

Contaminant Distribution Profile – VAV vs. ACB

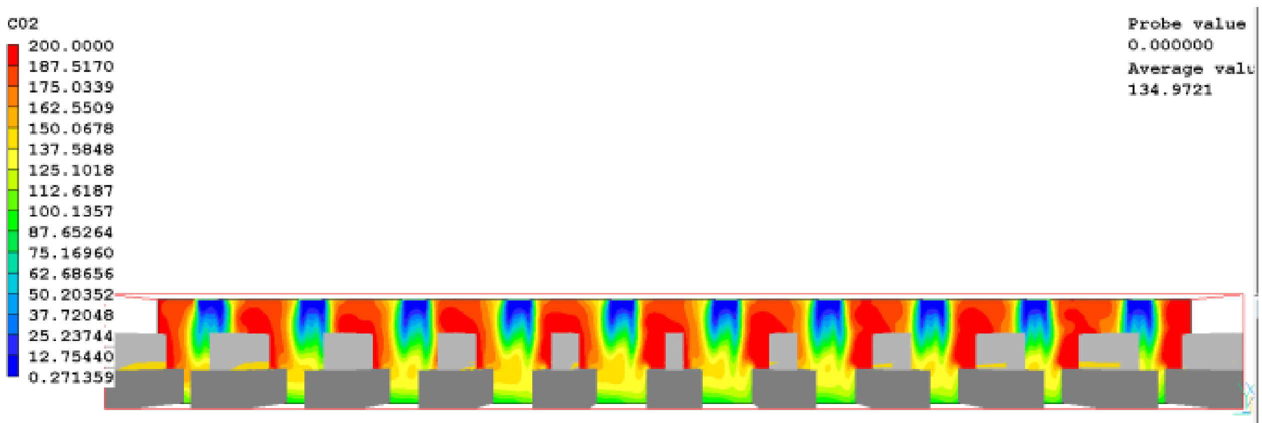


Figure-41 VAV System Contaminant Profile Overview in Y-direction

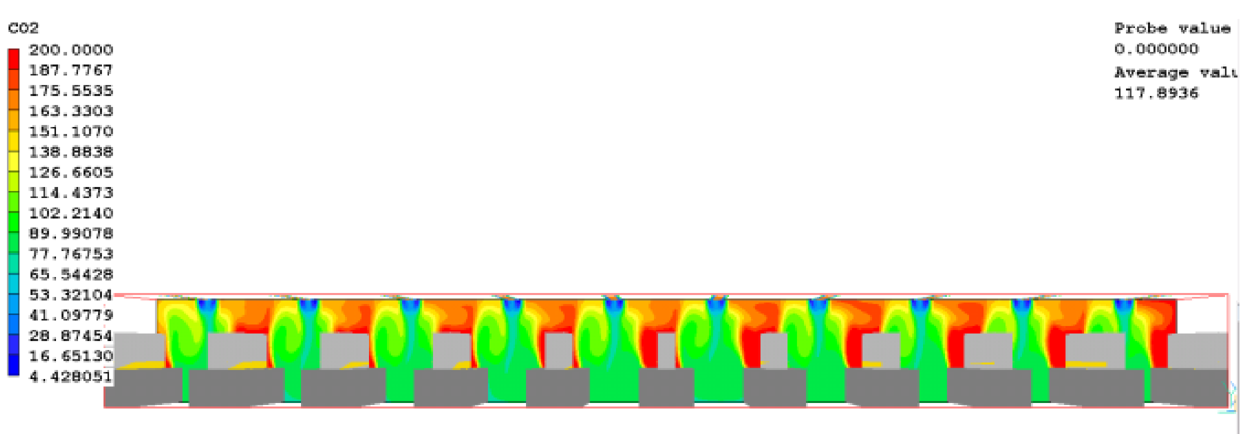


Figure-42 ACB System Contaminant Profile Overview in Y-direction

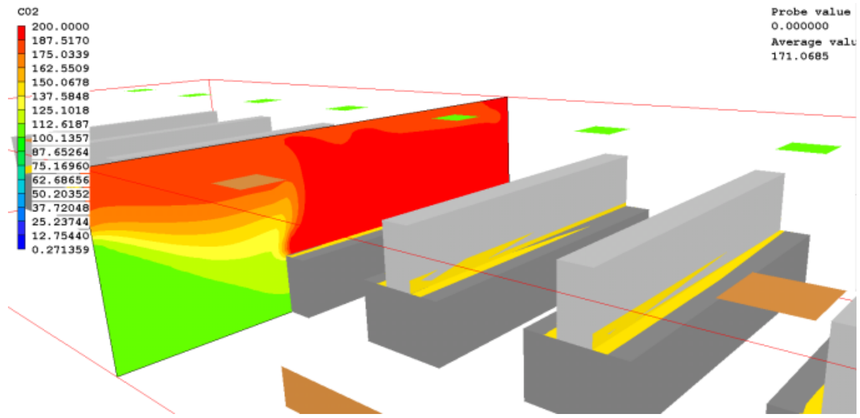


Figure-43 VAV System Contaminant Profile Overview in X-direction at the Source

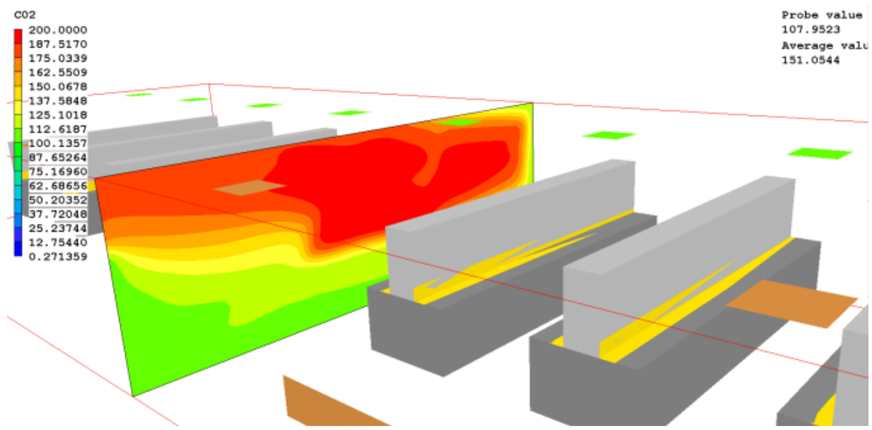


Figure-44 VAV System Contaminant Profile Overview in X-direction at the Edge of the Bench

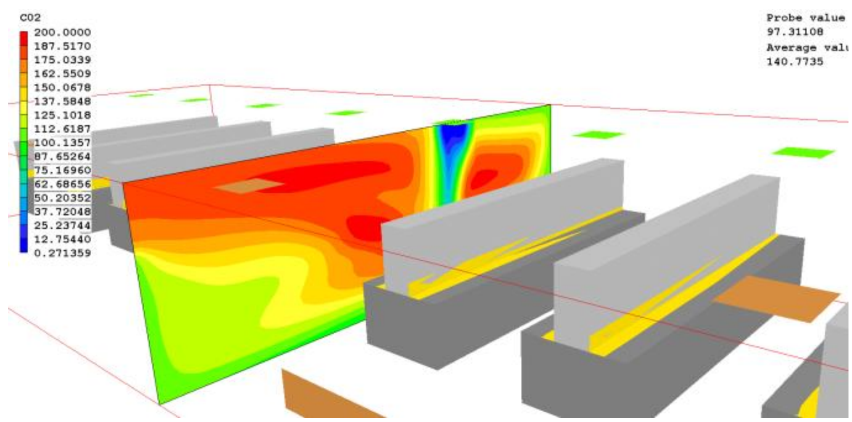


Figure-45 VAV System Contaminant Profile Overview in X-direction in the Walkway between Benches

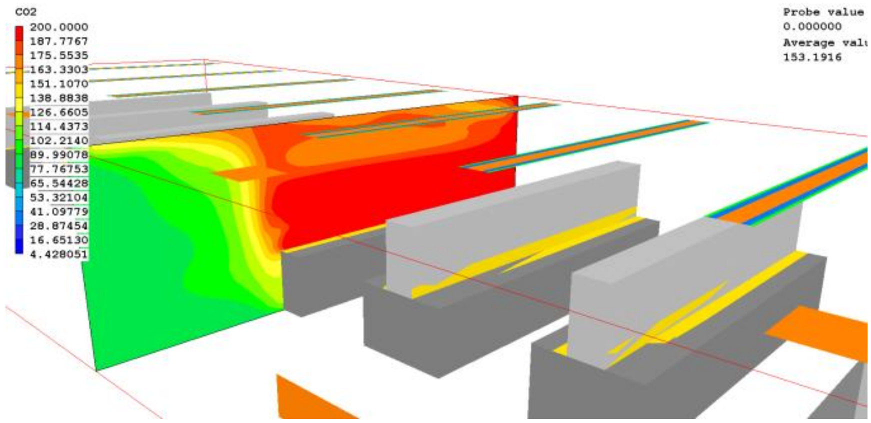


Figure-46 ACB System Contaminant Profile Overview in X-direction at the Source

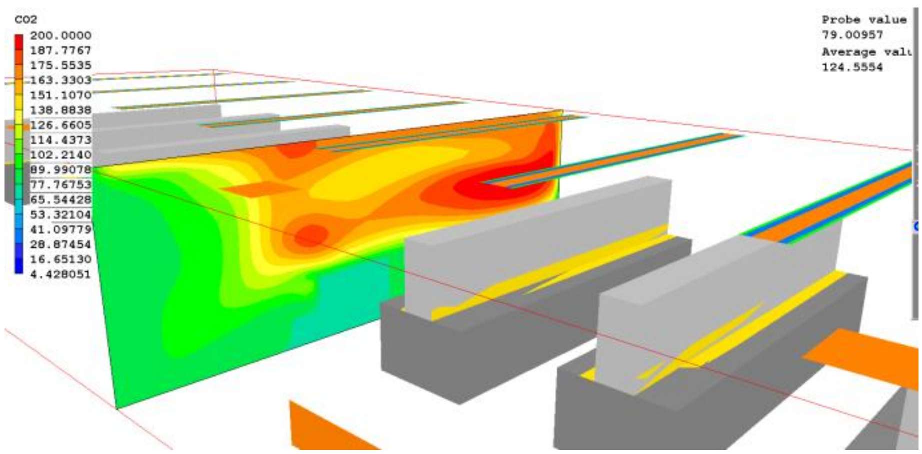


Figure-47 ACB System Contaminant Profile Overview in X-direction at the Edge of the Bench

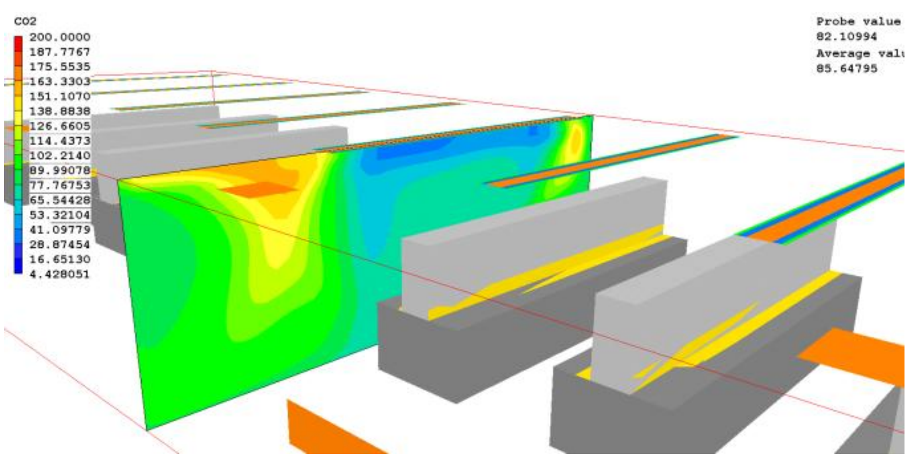
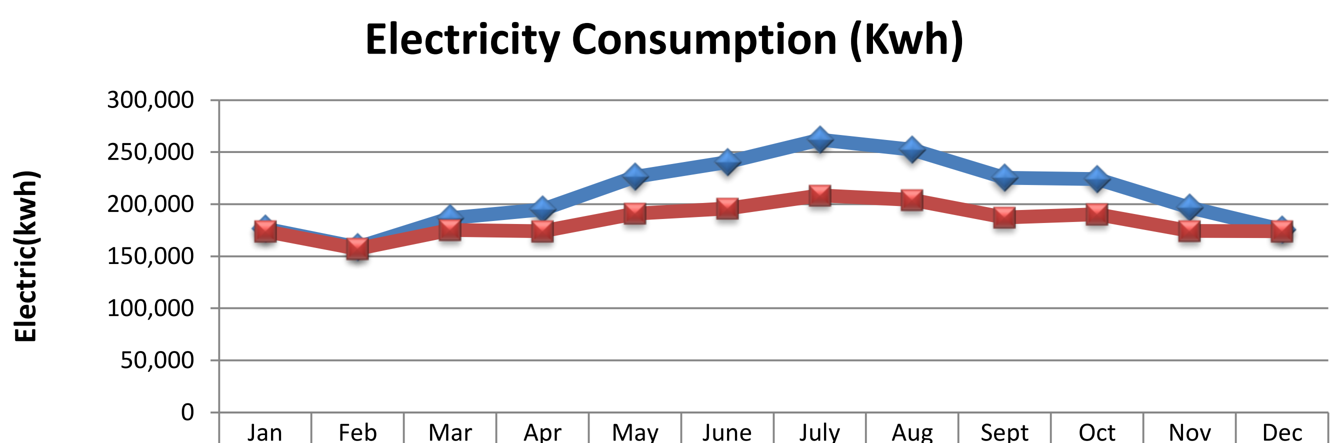


Figure-48 ACB System Contaminant Profile Overview in X-direction in the Walkway between Benches

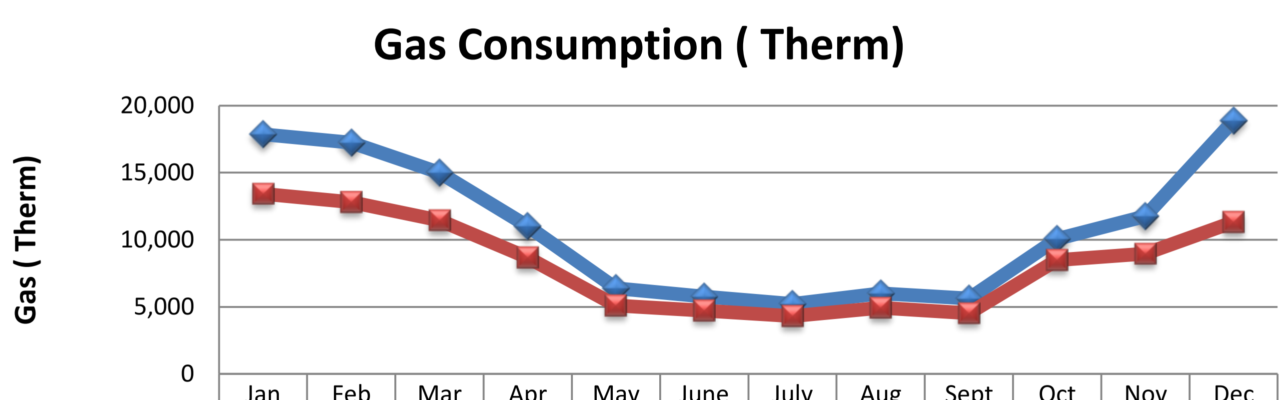
Energy Analysis

By implementing the DOAS and Active Chilled Beam system, the annual electricity consumption has a reduction of 313,789Kwh which is 12.5% of the total electricity consumption. Majority of the electricity savings occurs in the summer since the building has electric cooling system. The annual gas consumption has a reduction of 32,098 therm which is 24.5% of the total gas consumption. Majority of the gas saving occurs in the winter since the building has gas heating system. In the summer, there is some gas consumption reduction due to the elimination of reheat energy.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Existing Sys.	176,446	158,711	186,758	194,884	226,213	240,369	262,077	252,345	225,269	224,214	196,728	175,716
ACB	174,021	157,128	175,255	173,894	191,078	195,936	208,366	204,297	187,296	190,313	174,322	174,035

Figure-49 Electricity Consumption Comparison



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Existing Sys.	17,862	17,233	15,005	11,014	6,381	5,767	5,225	6,000	5,630	10,067	11,746	18,874
ACB	13,421	12,811	11,439	8,685	5,095	4,719	4,309	4,933	4,527	8,495	8,953	11,318

Figure-50 Gas Consumption Comparison

For the redesign system, air handling units cooled and dehumidified the outside air to meet the space latent load. The rest of the space sensible load is then provided by the chilled beams. By implementing this system, outside air conditioning is minimized. Supply air from the air handling units has reduced by 39% (27883 cfm). Additional 229,255 cfm of space air is conditioned by the coils in the chilled beam and circulated in the space.

Air Flow Comparison			
	Existing System	Active Chilled Beam System	
	Primary Airflow (cfm)	Primary Airflow (cfm)	Secondary Airflow (cfm)
AHU1	29,760	24,136	121,975
AHU2	34,876	12,679	70,411
AHU3	7,374	7,312	36,869
Total	72,010	44,127	229,255

Table-32 Air Flow Comparison

Cost Analysis

The DOAS with Active Chilled Beam system has an annual utility saving of $66,078 when compared to the existing system, which is 16% of the total utility cost.

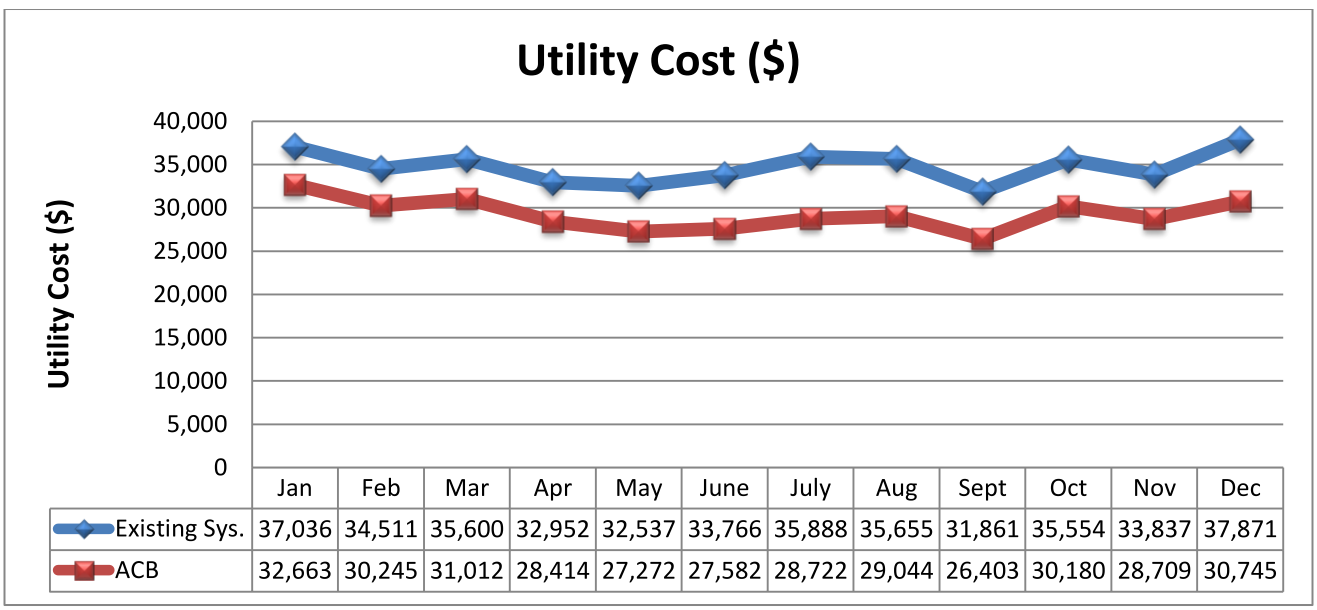


Figure-51 Utility Cost Comparison

A simple payback analysis was done for the DOAS/Active Chilled Beam system. The DOAS/ACB system requires additional cost for active chilled beams, additional piping, additional chilled water pumps, and two screw chillers. However, the redesign system is able to downsize many of the equipment by reducing energy consumption. The existing centrifugal chiller and air cooled chiller are removed from the system. Ductworks, air handling units, and boilers are downsized. Overall, the redesign DOAS/Active Chilled Beam system requires an additional $621,276 capital cost upfront. With an annual utility saving of $66,078, a simple payback period of 9 years and 5 months was calculated. Inflation did not take into account for this calculation. A 30-year life cycle analysis can be found at the Conclusion session at Page85.

Simple Payback Calculation		
Equipment	**Existing System**	**DOAS/ACB System**
Chiller	238,100	292,000
Cooling Tower	53,750	57,650
Chilled Water Pump **($25/gpm)**	987	1139
Ductwork **(4$/sf for VAV, 2.5$/sf for ACB)**	225,368	156,745
Active Chilled Beams **(260 beams for ACB system, $1000 each)**	-	260,000
AHU	143,450	93,650
Pipe Cost	425,948	851,895
Boiler	48,100	43,900
Total	1,135,702	1,756,978
Cost Difference	621,276	
Operating Saving	66,078	
Simple Payback	**9 years 5 months**	

Table-33 Simple Payback Calculation

Conclusion

Table-34 summarized the advantages and disadvantages of the DOAS/Active Chilled Beam system when compared to the existing VAV/CAV system. The DOAS/Active Chilled Beam system is able to downsize existing equipment, has low noise level and low level of maintenance, improve thermal comfort, and provide high indoor air quality. However, the DOAS/ACB system does have higher system complexity, higher first cost, and the risk of condensation. Overall, the DOAS/ACB system outperforms over the existing VAV/CAV system.

System Decision Matrix			
Item	**Existing VAV/CAV System**	**DOAS/ACB System**	**Net for DOAS/ACB System**
AHU	Large	Small	+
Ductwork	Large	Small	+
Riser	Large	Small	+
Ceiling Space	Large	Small	+
Pipework	Small	Large	-
Fan Energy	High	Low	+
Pump Energy	Low	High	-
Occupant Satisfaction	Low	High	+
Air Side System Cost	Low	High	+
Water Side System Cost	Low	High	-
Individual Control	Low	High	+
Thermal Comfort	Low	High	+
Noise Level	High	Low	+
Maintenance	High	Low	+
Risk of Condensation	Low	High	-
System Complexity	Low	High	+
Control System Complexity	High	Low	+
Overall			**+**

Table-34 System Decision Matrix

Heat Recovery Systems Design

Design Objective

The objectives of the heat recovery system design are to reduce energy consumption by reusing waste energy from the exhaust air stream to precondition the outside air. Four different types of heat recovery system were analyzed: enthalpy wheel, fixed plate heat exchanger, heat pipe, and run around loop. Analyses on energy saving, potential cross contaminant issue, maintenance, and cost were done to determine the best suitable system.

Energy Comparison Analysis

Air contains sensible and latent energy; both types of energy can be recovered. Among the four heat recovery systems, only enthalpy wheel is capable of recovering both types of energy. Being able to recover the latent energy in the summer when latent load is a big portion of the cooling load, can significantly reduce electricity consumption

In this analysis, heat recovery systems were added on AHU1 and AHU3 only. Due to its ability of recovering latent energy, enthalpy wheel has the largest electricity saving among systems. As shown in Figure-52, heat pipe, fixed plate, and runaround coil has average electricity saving of 6,000 Kwh, while the enthalpy wheel has electricity saving of 29,000 Kwh. Variation on system sensible effectiveness is the other cause for electricity saving differences. Heat pipe, fixed plate, and runaround coil have sensible effectiveness range from 48% to 67%, while the enthalpy wheel can have a sensible and latent effectiveness as high as 71-79%, which results in a total effectiveness of 71-79%.

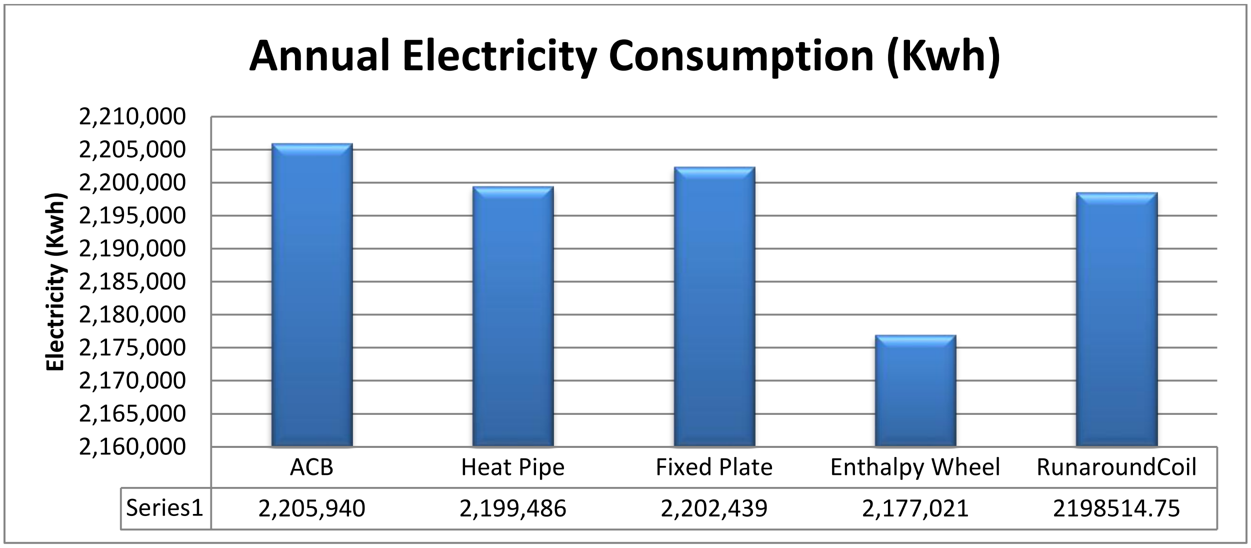


Figure-52 Heat Recovery Systems Annual Electricity Consumption Comparison

By recovering energy in the summer, heat pipe, fixed plate, and runaround coil systems result in an average of 50 ton cooling load reduction, which is 10% of the cooling load. The enthalpy wheel system results in 166 ton cooling load reduction, which is 35% of the cooling load.

DOAS/ACB + Heat Recovery Systems Cooling Load Comparison					
	DOAS + ACB Total Cooling Load (Ton)				
	No Heat Recovery	Heat Pipe	Fixed Plate	Enthalpy Wheel	Runaround Coil
AHU1+ACB	300	272	269	176	271
AHU2+ACB	87	87	87	87	87
AHU3+ACB	87	68	68	44	67
Total	474	427	424	308	426
Difference	-	47	50	166	48
Difference %	-	**9.9%**	**10.5%**	**35.0%**	**10.1%**

Table-35 Heat Recovery Systems Cooling Load Comparison

In the winter, the air is really dry and not much latent energy can be recovered. Variation in gas saving is reflected by the variation in system sensible effectiveness. The enthalpy wheel has the most saving: 14,477 therm; and the runaround coil has the least saving: 11,860 therm. Gas savings from heat recovery systems range from 12% to 15%.

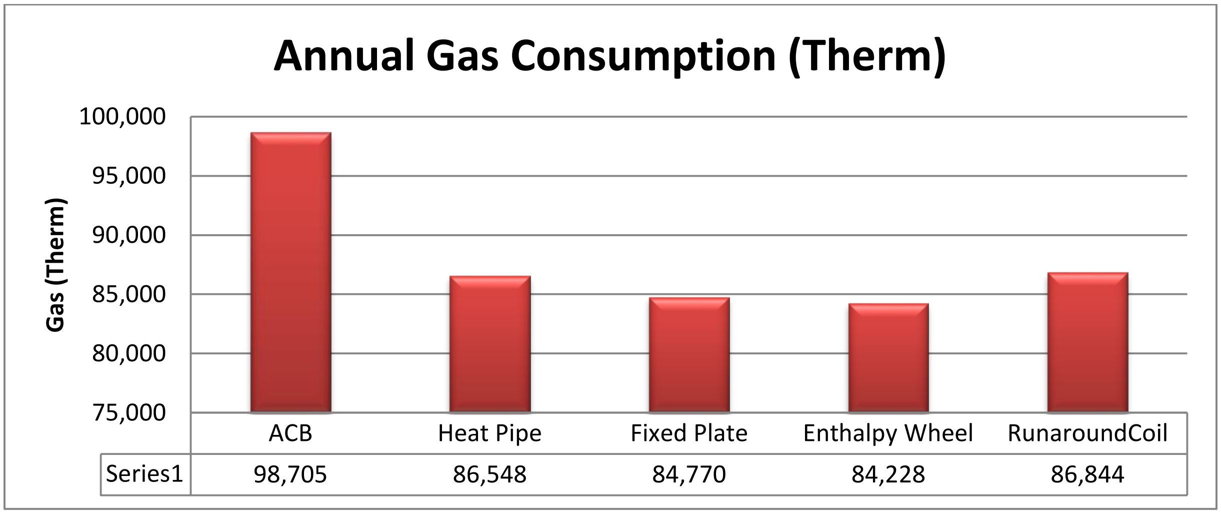


Figure-53 Heat Recovery Systems Annual Gas Consumption Comparison

By recovering energy in the winter, heat recovery systems result in an average of 1,100 Mbh heating load reduction, which is 30% of the heating load.

DOAS/ACB + Heat Recovery Systems Heating Load Comparison					
	DOAS + ACB Total Heating Load (Mbh)				
	No Heat Recovery	Heat Pipe	Fixed Plate	Enthalpy Wheel	Runaround Coil
AHU1+ACB	2221	1575	1425	1186	1603
AHU2+ACB	715	715	714	714	714
AHU3+ACB	640	349	316	258	353
Total	3576	2639	2454	2157	2669
Difference	-	937	1,122	1,419	907
Difference %	-	**26.2%**	**31.4%**	**39.7%**	**25.4%**

Table-36 Heat Recovery Systems Heating Load Comparison

Cost Comparison Analysis

The annual utility cost reflects savings in both electricity and gas consumptions. The enthalpy wheel system has the most saving: 4% ($14,212); while the runaround coil has the lease saving: 2 %($6188).

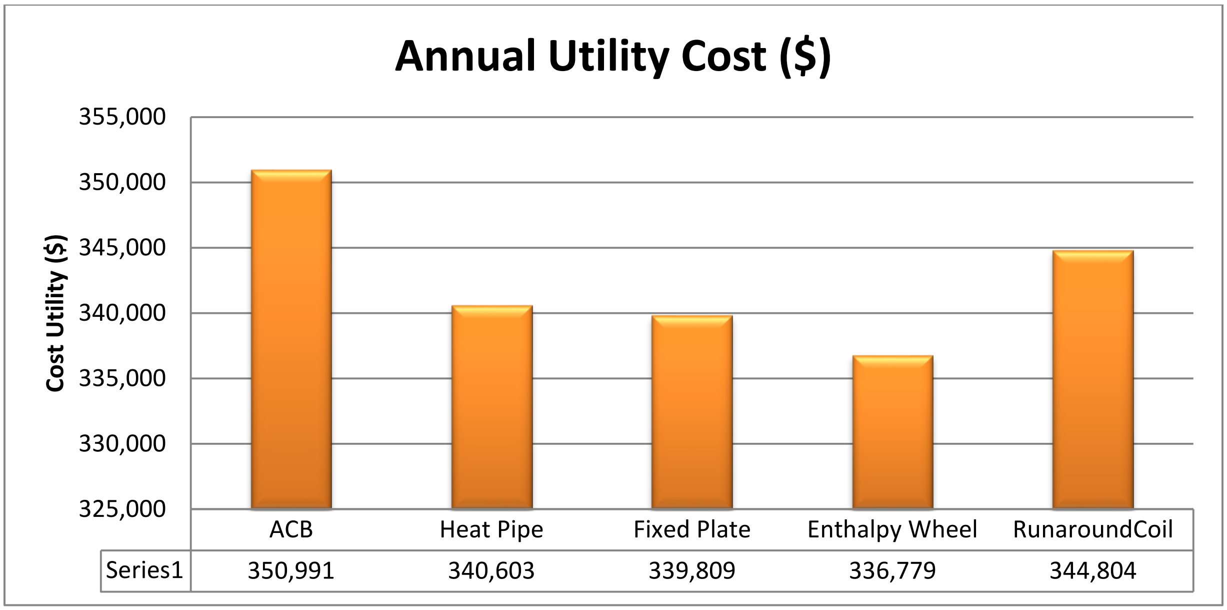


Figure-54 Heat Recovery Systems Annual Utility Cost Comparison

A simple payback analysis was done. Costs for heat recovery equipment such as heat pipe system, fixed plate air-to-air heat exchanger, enthalpy wheel, pumps and motors for runaround coil were taken from the RS Means Handbook and provided by manufactures' representatives. Chillers, AHUs and boilers are downsized due to the load reduction from heat recovery systems. Additional piping is needed to run between the outside air stream and the exhaust air steam for the runaround coil system.

With the additional first cost for heat recovery systems, reduction in first cost due to downsizing equipment, and reduction in utility cost; the heat pipe system has a simple payback period of 5 months. For the rest of the heat recovery system, the cost reduction in downsizing equipment is larger than the additional heat recovery system cost, which results in first cost saving upfront.

Simple Payback Calculation Comparison					
	DOAS + ACB + Heat Recovery System Cost ($)				
	No Heat Recovery	Heat Pipe	Fixed Plate	Enthalpy Wheel	Runaround Coil
Heat Recovery Equipment	-	66,650	51,277	45,400	9,140
Chiller	292,000	239,000	239,000	206,000	239,000
AHU	93,650	91,650	91,650	91,650	91,650
Additional Piping	-	-	-	-	4,158
Boiler	43,900	36,900	36,900	34,800	36,900
Total	429,550	434,200	418,827	377,850	379,574
Cost Difference	-	4,650	-10,723	-51,700	-49,976
Operating Saving	-	12,878	14,103	17,749	12,838
Simple Payback	-	**5 months**	**0**	**0**	**0**

Table-37 Heat Recovery Systems Simple Payback Comparison

Systems Decision Matrix

Among the four heat recovery systems, enthalpy wheel is the most efficiency system that can recover both sensible and latent energy from the exhaust air stream which saves the most energy. However, the enthalpy wheel system requires the supply and exhaust streams to be located next to each other, which is difficult to accomplish for AHU3. Enthalpy wheel system also has potential cross contaminant issue which is dangerous and risky in laboratory environment. Both the energy analysis and cost analysis have shown that the heat pipe, fixed plate and run around loop systems have similar energy saving and payback period. However, both heat pipe and fixed plate systems require the supply and exhaust stream to be adjacent to each other. Runaround coil system does not required air streams to be adjacent to each other, which provides the most flexibility in system design. As a result, runaround coil system is the best heat recovery option for this project due to its energy saving ability and system design flexibility. Therefore, it is chosen to further analyze for optimum design.

Systems Decision Matrix				
	Heat Pipe	Fixed Plate	Enthalpy Wheel	Runaround Coil
Efficiency	48-53	64-67	71-79	50
Energy Recovered	Sensible	Sensible	Sensible + Latent	Sensible
Cross Contamination Issue	No	No	Yes	No
Duct Adjacencies	Needed	Needed	Needed	Not Needed
Maintenance (1:lowest – 4:highest)	1	3	4	2

Table-38 Heat Recovery Systems Heating Load Comparison

Run Around Coil Loop Design

In the runaround coil system, supply and exhaust air streams does not need to be next to each other and there is not direct contact between the two air streams. The runaround coil system does not have cross-contamination issue and provides great flexibility in system design.

The runaround coil system has coil loop circulates a fluid between supply and exhaust air streams. To prevent freezing fluid in the coils, the system is filled with an ethylene glycol solution. As shown in Figure-55, the circulating pump is interlocked to run whenever the supply fan runs. The bypass valve and controller are used for low-limit control of the fluid temperature (35F) to prevent frost buildup on the exhaust coil.

Figure-56 shows the location of each supply and exhaust air streams as well as the runaround coil systems in the building.

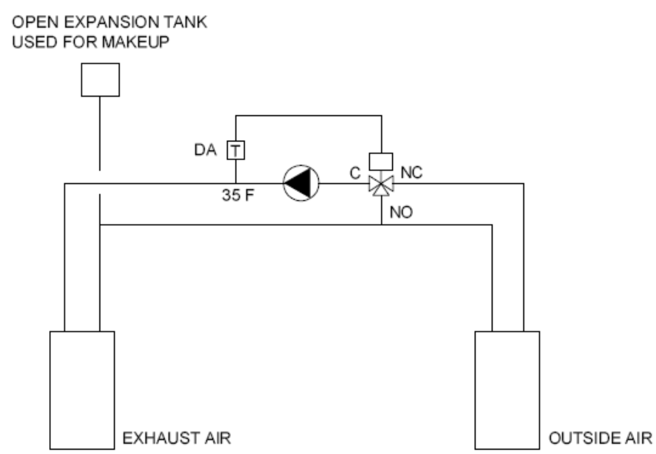


Figure-55 Runaround Coil System Control Schematic

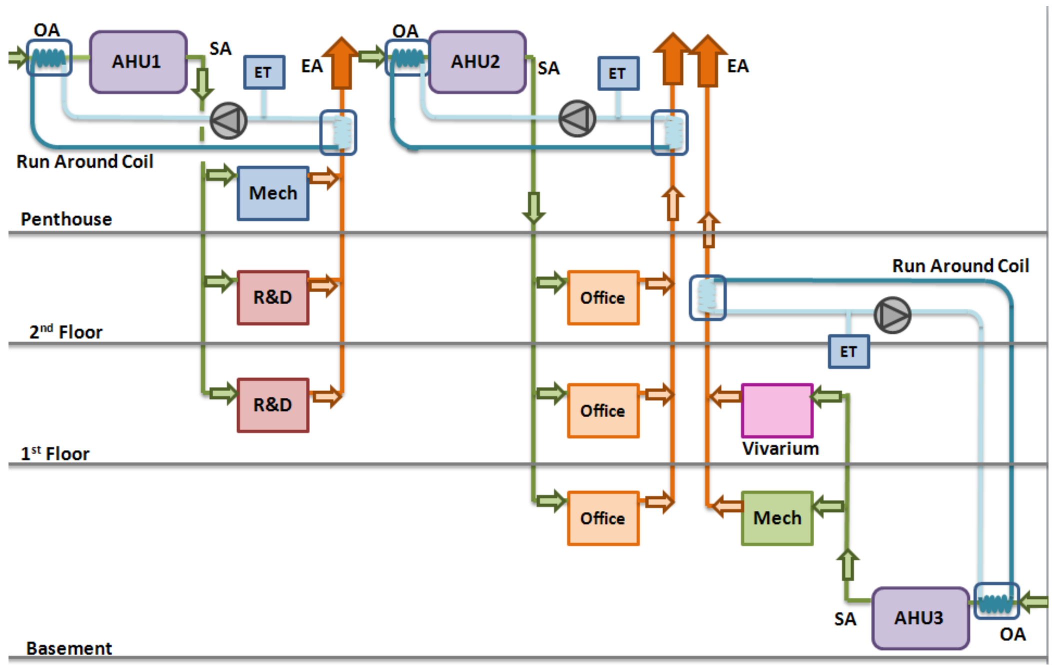


Figure-56 Runaround Coil System Schematic

Table -39 shows the recoverable energy for each air handlers. The exhaust air streams are assumed to have a room temperature of 73 in the summer and 72 in the winter. Outside air are assumed to be 88F in the summer and 34F in the winter. A total energy of 621 Mbh can be recovered in the summer and 980 Mbh can be recovered in the winter.

Recoverable Energy (Mbh)				
	AHU1	AHU2	AHU3	Total
Summer	347	38	235	621
Winter	618	74	287	980

Table-39 Runaround Coil System Recoverable Energy

By implementing the runaround coil system, the annual electricity consumption can be reduced from 6,394 Kwh to 10,340 Kwh while the gas consumption can be reduced from 3,121therm to 11,911 therm. Table-40 and Table-41 show the cooling load and heating load reduction comparisons by implementing the runaround coil system.

The annual utility cost has reduced from $3,743 for AHU1 to $12,524 for all three air handling units. The utility cost saving from runaround coil system at all air handling units is 3.6% of the total cost.

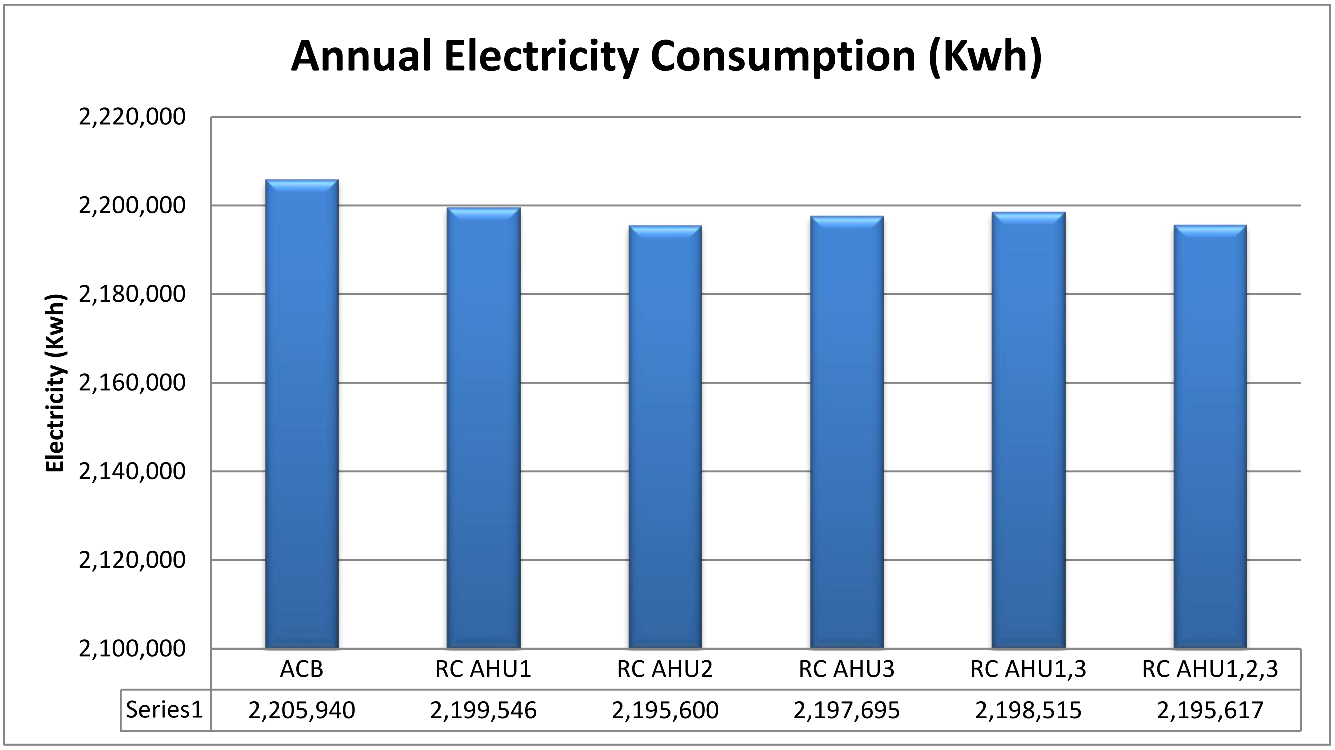


Figure-57 Runaround Coil System Annual Electricity Consumption Comparison

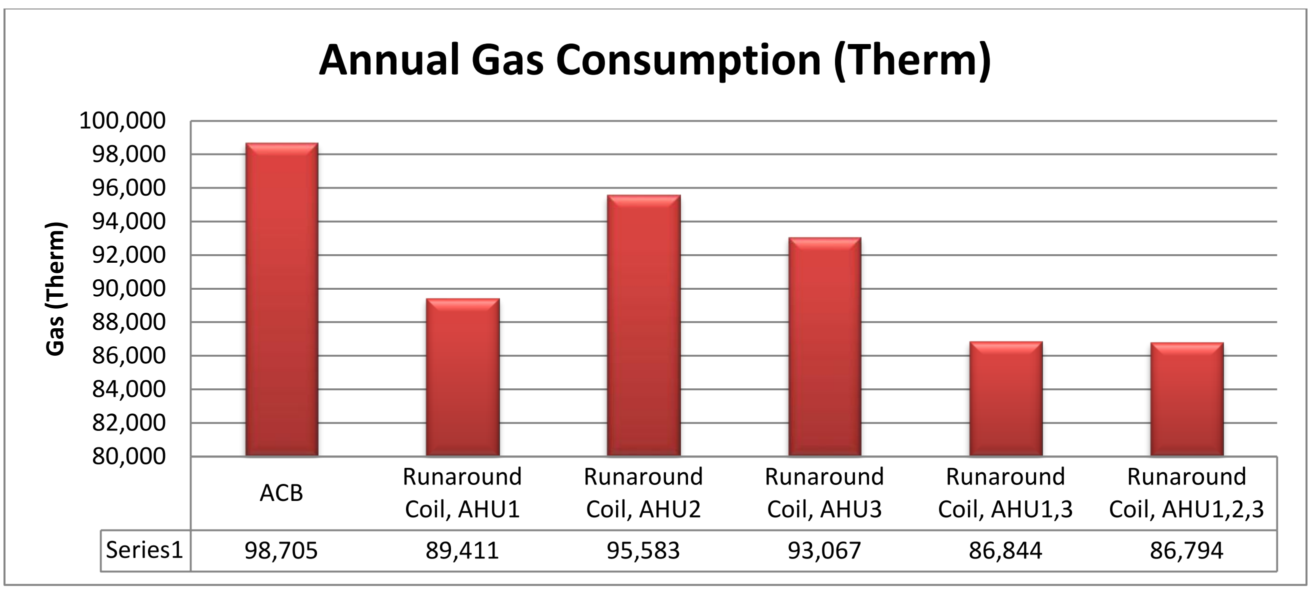


Figure-58 Runaround Coil System Annual Gas Consumption Comparison

DOAS/ACB + Runaround Coil System Cooling Load Comparison (Ton)						
	No Heat Recovery	With Run Around Coil Loop				
		AHU1	AHU2	AHU3	AHU1,2	AHU1,2,3
AHU1+ACBs	300	271	300	300	271	271
AHU2+ACBs	87	87	84	87	87	84
AHU3+ACBs	87	87	87	67	67	67
Total	474	446	471	455	426	423

Table-40 Runaround Coil System Cooling Load Comparison

DOAS /ACB + Runaround Coil System Heating Load Comparison (Mbh)						
	No Heat Recovery	With Run Around Coil Loop				
		AHU1	AHU2	AHU3	AHU1,2	AHU1,2,3
AHU1+ACBs	2,221	1,603	2,221	2,221	1,603	1,603
AHU2+ACBs	715	714	641	714	714	641
AHU3+ACBs	640	640	640	353	353	353
Total	3,576	2,957	3,502	3,288	2,669	2,597

Table-41 Runaround Coil System Heating Load Comparison

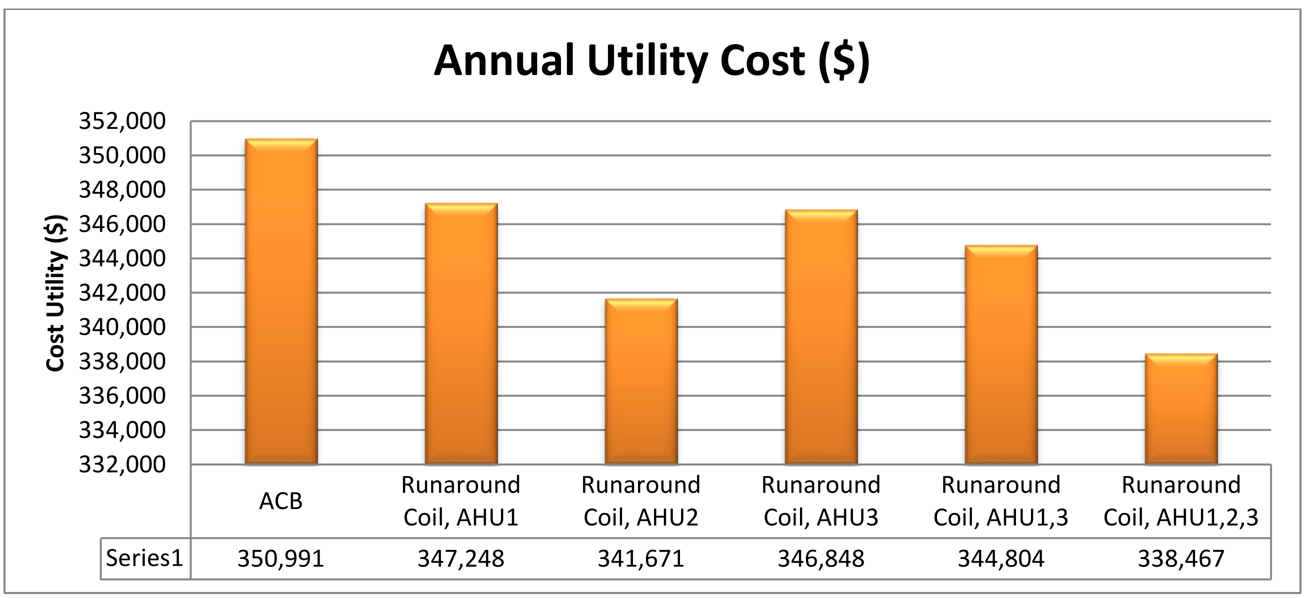


Figure-59 Runaround Coil System Annual Utility Cost Comparison

A simple payback analysis was done for the runaround coil system. Costs for runaround loop pipes and pumps were added to the first cost. Chillers, air handling units, and boilers are downsized to reduce their first cost. Overall, the runaround coil on AHU1, 3 and on AHU1, 2, 3 has 0 payback period, since their first costs are lower than the DOAS/ACB system without runaround coil. Putting runaround coil on all three air handling units results in the most utility saving and have 0 payback period, therefore, it is chosen to be the most cost effective system.

Runaround Coil System Simple Payback Calculation Comparison						
	No Heat Recovery	**With Run Around Coil Loop**				
		AHU1	**AHU2**	**AHU3**	**AHU1,3**	**AHU1,2, 3**
Heat Recovery Equipment($)	-	7,087	2,056	2,053	9,140	11,196
Chiller($)	292,000	292,000	292,000	292,00 0	239,000	239,000
AHU($)	93,650	93,650	93,650	91,650	91,650	91,650
Additional Piping($)	-	743	743	4,158	4,158	4,158
Boiler($)	43,900	40,100	43,900	43,900	36,900	36,900
Total($)	429,550	432,837	431,606	433,76 1	380,848	382,904
Cost Difference($)	-	4,030	2,798	4,211	-48,702	-46,646
Operating Saving($)	-	3,743	9,320	4,143	6,188	12,524
Simple Payback	-	**1year 2months**	**4months**	**1 year**	**0**	**0**

Table-42 Runaround Coil System Simple Payback Calculation Comparison

Conclusion

Four different types for heat recovery systems were analyzed: heat pipe, fixed plate, enthalpy wheel, and runaround coil. Runaround coil system was chosen to be the best suitable system among the four systems because it generates significant energy savings and provides the most flexibility in mechanical system design. A further analysis was done to determine the most cost effective way to design runaround coil system. It has been determine that putting runaround coil systems on all three air handling units provides the most energy saving and it’s most cost effective design.

Conclusion

When comparing the redesign DOAS/ACB system to the existing VAV/CAV system, it provides a significant energy saving as well as improves thermal comfort, lower background noise and improves indoor air quality for the occupants. By implementing runaround coil as the heat recovery system, more energy can be saved. The DOAS/ACB with runaround coil system reduces the building load and decreases energy consumption which downsizes most of the mechanical equipment. The redesign system has a higher first cost due to the additional chilled beams and runaround coils system. Overall, with a simple payback period of 9 years and 5 months for the DOAS/ACB and 7 years and 4 months for the DOAS/ACB with runaround coil system, the DOAS/ACB with runaround coil is the best system option.

Simple Payback Calculation			
	Existing System	DOAS/ACB	DOAS/ACB with Runaround Coil
Chiller	238100	292000	239,000
Cooling Tower	53750	57650	57650
Chilled Water Pump ($25/gpm)	987	1139	1139
Ductwork (4$/sf for VAV, 2.5$/sf for ACB)	225368	156744.5	156744.5
Active Chilled Beams (260 active chilled beams, $1000 each)	-	260000	260000
Run Around Coil Loop Equipment	-	-	11,196
AHU	143450	93650	91,650
Pipe Cost	425,948	851,895	856,053
Boiler	48100	43900	36,900
Total	1,135,702	1,756,978	1,710,333
Cost Difference		621,276	574,631
Operating Saving		66,078	78,602
Simple Payback		**9 years 5 months**	**7 years 4 months**

Table-43 Mechanical Redesign Systems Simple Payback Calculation

Architectural Breadth

Existing Condition

The EMD Serono Research Center-existing lab building heavily emphasizes on the use of daylight for the laboratories and offices. The existing building contains a total of 37% glass areas to maximize the use of daylight and views to the wooded countryside.

Fenestration Area			
Façade	Gross Wall (sf)	Glass (sf)	Fenestration %
East	6565	2542	38.7
South	10927	4082	37.4
West	4695	910	19.4
North	4274	2288	53.5
Total	26461	9822	37.1

Table-44 Building Fenestration Area

The building façade is a combination of metal, brick, and glass. The north and south façade is comprised of aluminum curtain wall, composition aluminum panel, and face brick. The east and west façade is comprised of insulated metal panel, face brick, aluminum curtain wall, composite aluminum panel, spandrel glass, and aluminum louver. Aluminum sunshade is provided on north west corner of the building.

Figure-60 Building Images

Proposal

The existing building contains a total of 37% glass areas. This high percentage of glass leads to a high solar load on the building. An analysis will be performed to see the load reduction possibilities for external solar shading. An energy model will be performed using Trane Trace to evaluate the solar shading effect on internal load.

External aluminum solar shading was constructed on the North West corner of the building. To evaluate the architectural impact of solar shading on the west and south sides of the building as well as on all four sides of the building. An architectural model will be constructed using Autodesk Revit and Adobe Photoshop. Solar shadings will be modeled in Revit to determine whether it is aesthetically pleasing. Research will be done on different solar shading products in the market today.

Solar Shading System Design

Solar Analysis

To evaluate solar shade placements and overhang lengths, the location of the EMD Serono Research Center –existing lab building needs to be shown in latitude and longitude.

Latitude	Longitude
42° 33' 29" N	71° 16' 9" W

Table-42 Building Location

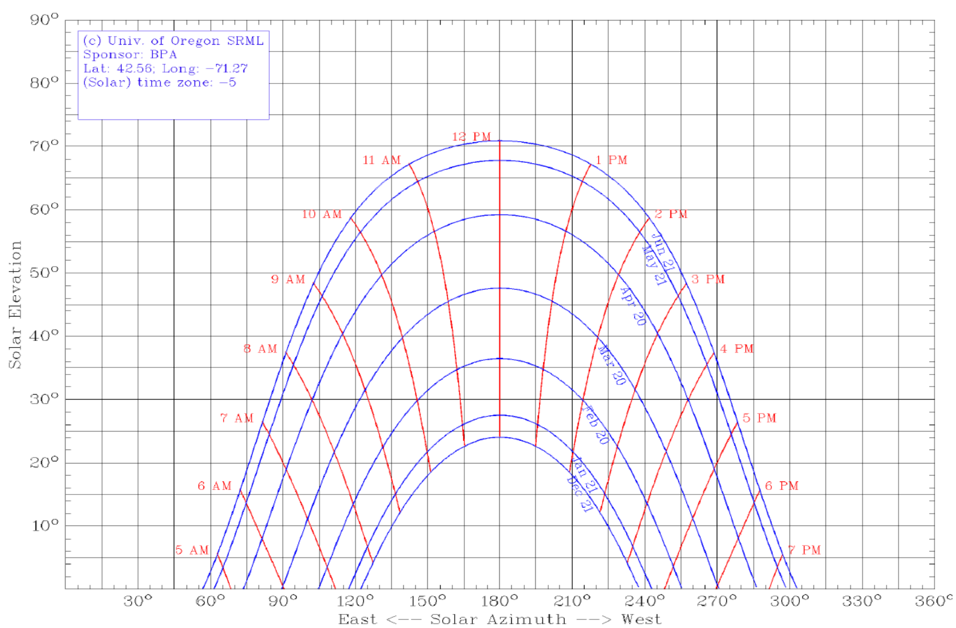


Figure-61 Sun Path

A Revit model was built to analysis the sun path on the site throughout the year. March 21st, July 21st, and November 21st were picked to reflect the sun path for spring, summer and winter. For each day, sun shadow at 9:00 am, 12:00pm, and 3:00pm were analyzed.

March 21st

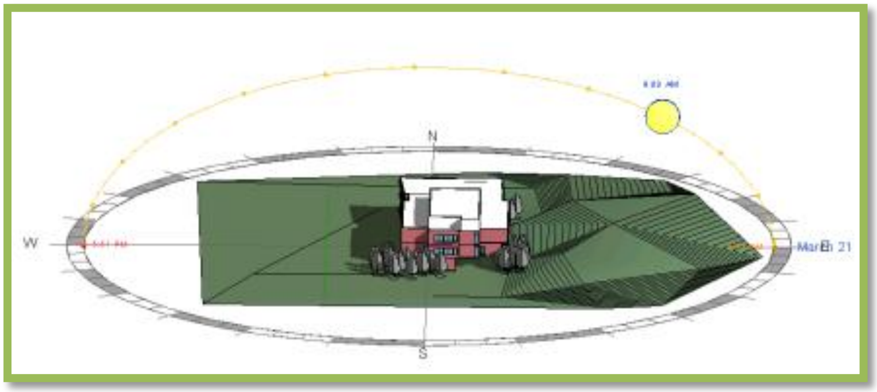


Figure-62 Sun Location on March 21st at 9 a.m.

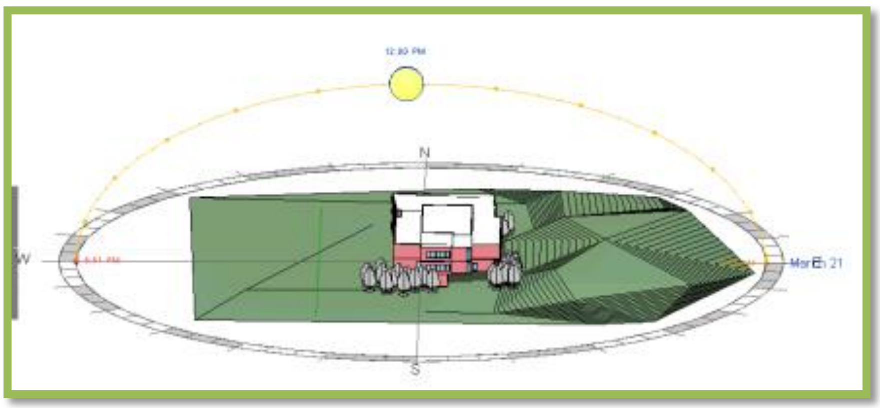


Figure-63 Sun Location on March 21st at 12 p.m.

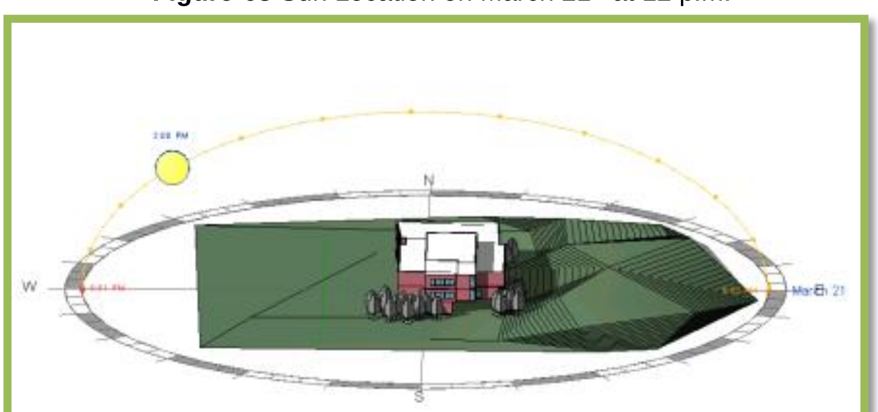


Figure-64 Sun Location on March 21st at 3 p.m.

July 21st

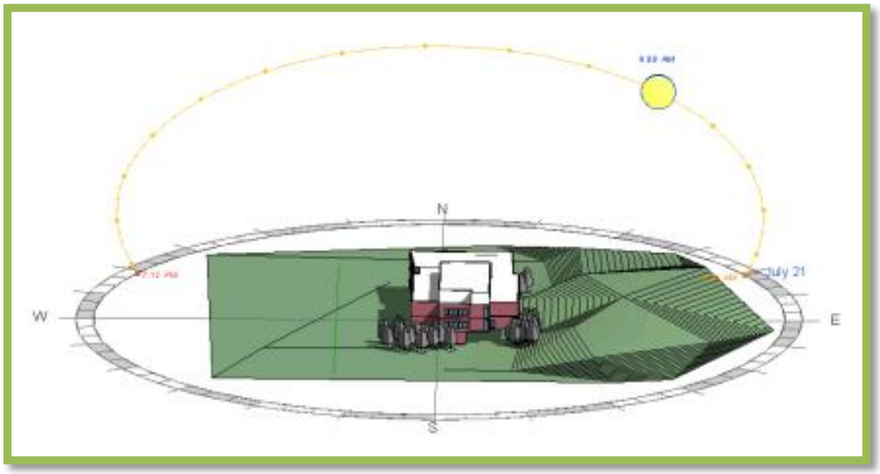


Figure-65 Sun Location on July 21st at 9 a.m.

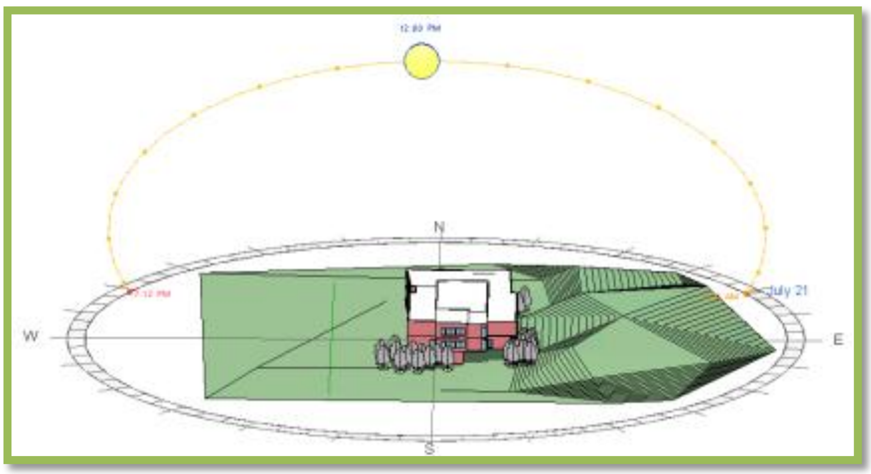


Figure-66 Sun Location on July 21st at 12 p.m.

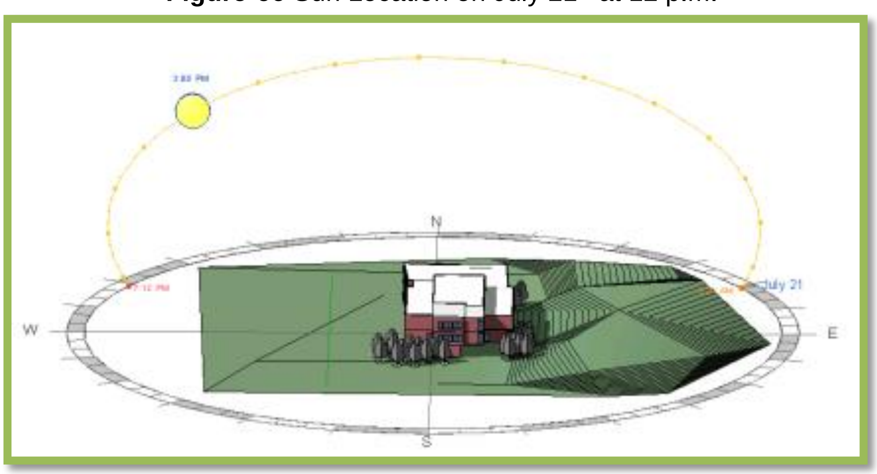


Figure-67 Sun Location on July 21st at 3 p.m.

November 21st

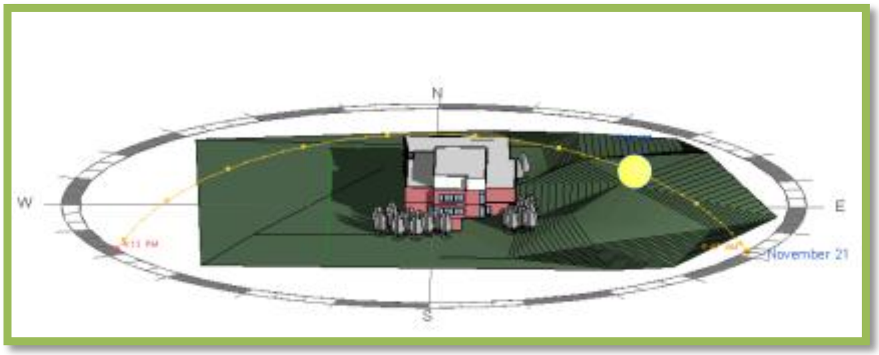


Figure-68 Sun Location on November 21st at 9 a.m.

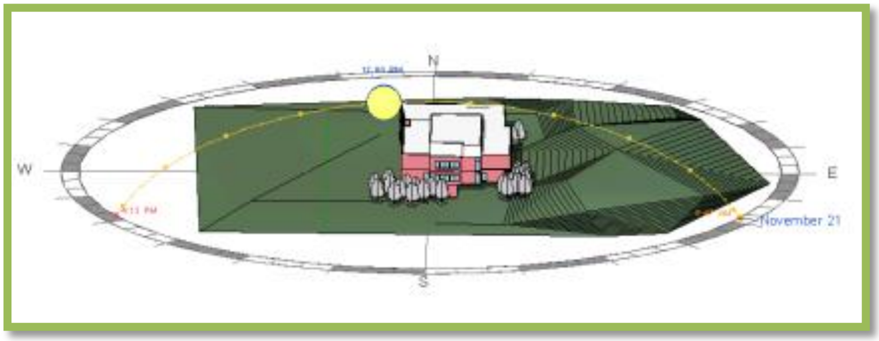


Figure-69 Sun Location on November 21st at 12 p.m.

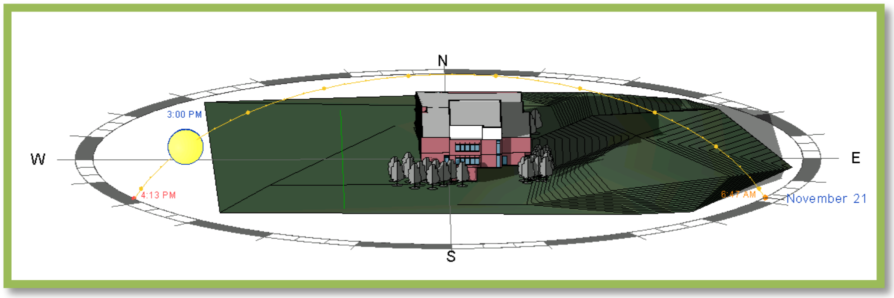


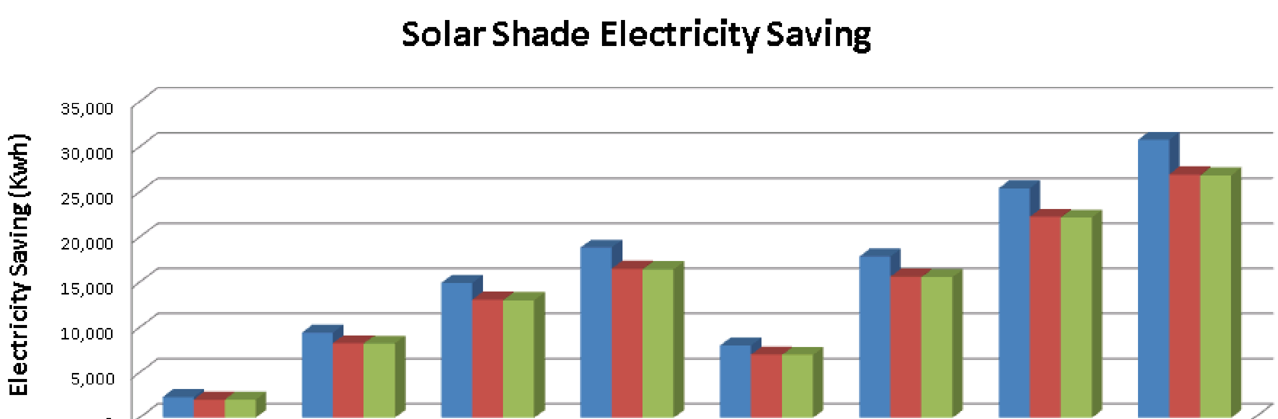
Figure-70 Sun Location on November 21st at 3 p.m.

Energy Analysis

The sun path analysis has demonstrated the necessarily for solar shading system for this building. Trance TRACE 700 was used to model the different types of solar shading system. Two cases of solar shade placement were analyzed. For the first case, solar shades were placed on the south and west side of the exterior walls. For the second case, solar shades were placed on all four sides of the building exterior walls. Each case was analyzed for shades at the lengths of 2ft, 3ft, 4ft, and 5ft.

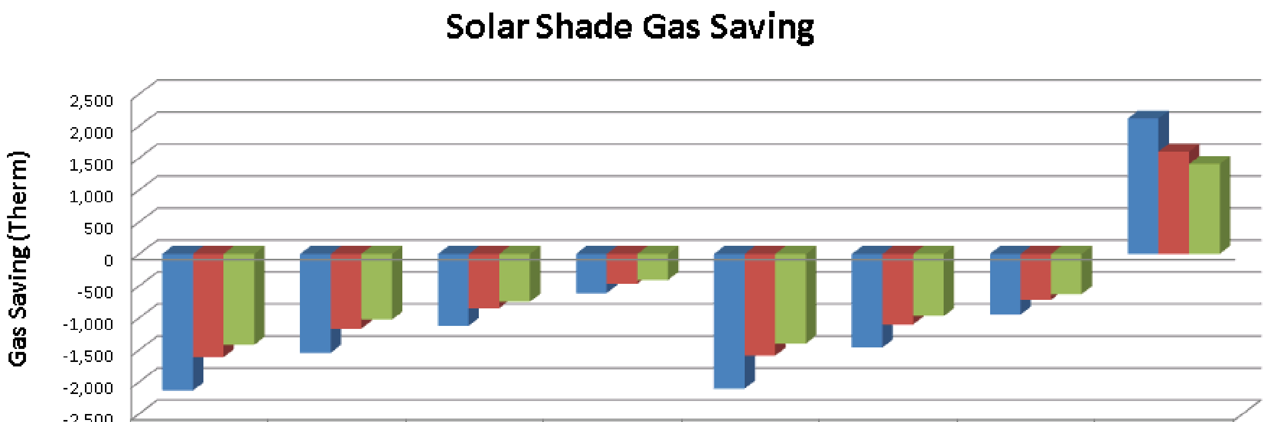
Solar shade system analyses were done for the existing system, DOAS/ Active Chilled Beam system, as well as the DOAS/Active Chilled Beam system with runaround coil. In following tables, DOAS/ACB + RC stands for Dedicated Outdoor Air System parallel with active chilled beam system and runaround coil system.

During the summer, when the sun is high, solar shading system will reduces the transmission from the sun which reduces the cooing load. However, in the winter, when the sun is low, the solar shading system actually brings in a small penalty in gas consumption due to the reduction in solar heating. As shown in Figure-71 and Figure-72, by placing solar shade systems on the building, electricity consumption reduced from 0.1 to 1.22% while gas consumption increased from 0.5 – 1.6%. The 5ft overhang system was the only exception with a 1.6% saving in gas consumption. The 5ft overhang system can actually reflects more of the low sun into the building, which increases the perimeter heating in the winter. The overall utility cost, which reflects both the electricity consumption saving and gas consumption increase, shows a cost saving of 0.1 to 1.8%.



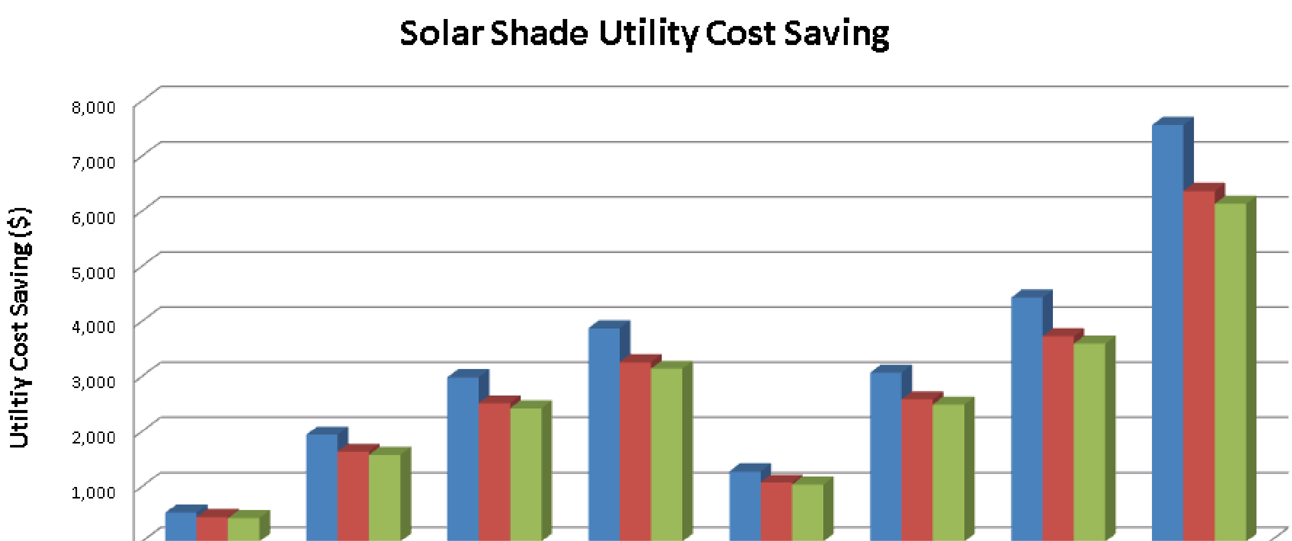
	2ft Overhang SW	3ft Overhang SW	4ft Overhang SW	5ft Overhang SW	2ft Overhang ALL	3ft Overhang ALL	4ft Overhang ALL	5ft Overhang ALL
Existing Sys.	2,295	9,425	14,927	18,845	8,000	17,863	25,414	30,777
ACB	2,009	8,251	13,068	16,499	7,004	15,638	22,249	26,944
ACB+RC	2,002	8,221	13,020	16,438	6,978	15,581	22,167	26,845

Figure-71 Solar Shading System Electricity Consumption Saving



	2ft Overhang SW	3ft Overhang SW	4ft Overhang SW	5ft Overhang SW	2ft Overhang ALL	3ft Overhang ALL	4ft Overhang ALL	5ft Overhang ALL
Existing Sys.	-2,137	-1,545	-1,122	-615	-2,105	-1,461	-947	2,117
ACB	-1,613	-1,166	-847	-464	-1,588	-1,103	-714	1,598
ACB+RC	-1,419	-1,026	-745	-408	-1,397	-970	-628	1,406

Figure-72 Solar Shading System Saving Consumption Saving



	2ft Overhang SW	3ft Overhang SW	4ft Overhang SW	5ft Overhang SW	2ft Overhang ALL	3ft Overhang ALL	4ft Overhang ALL	5ft Overhang ALL
Existing Sys.	528	1,942	2,983	3,872	1,274	3,068	4,430	7,564
ACB	444	1,634	2,510	3,258	1,073	2,582	3,728	6,366
ACB+RC	428	1,575	2,418	3,139	1,033	2,487	3,591	6,133

Figure-73 Solar Shading System Utility Cost Saving

Cost Analysis

This cost analysis calculated the simple payback periods for purchasing and installing solar shading systems. The cost for solar shading system was given by manufacture at $35/lf. Installation cost was calculated at 15% of the system cost.

As shown in Table-44, it is more economical to place solar shade on the south and west sides of the building than to place them on all four sides of the building. For systems on the south and west walls, 3ft solar shade and 4ft solar shade have the same payback period. Since 4ft solar shading system reduces a larger amount of cooling load, saves more energy and utility cost, it is chosen to be the optimum system for this building.

Solar Shade System Cost Analysis								
	South & West Solar Shade				All Sides Solar Shade			
	2ft	3ft	4ft	5ft	2ft	3ft	4ft	5ft
Total Length (ft)	1,012	1,518	2,024	2,530	1,973	2,960	3,946	4,933
Solar Shade Cost	14,840	32,550	50,260	67,970	40,390	74,918	109,445	143,973
Installation Cost	2,226	4,883	7,539	10,196	6,059	11,238	16,417	21,596
Total Cost ($)	17,066	37,433	57,799	78,166	46,449	86,155	125,862	165,568

Table-43 Solar Shading Systems Cost Analysis

Solar Shade System Simple Payback Period (Years)								
	Solar Shade on South & West Walls				Solar Shade on All Walls			
	2ft	3ft	4ft	5ft	2ft	3ft	4ft	5ft
Existing System	32	19	19	20	36	28	28	22
DOAS/ACB	38	23	23	24	43	33	34	26
DOAS/ACB + RC	40	24	24	25	45	35	35	27

Table-44 Solar Shading Systems Simple Payback Period

Architectural Model

Revit models were built to see the impact of solar shades on the building exterior views. According to the energy analysis and cost analysis, solar shade should be placed on the south and west sides of the building. In order for the building to look smooth and consistent, existing aluminum shades on the north-west building corner were chosen for the rest of the solar shading system. Comparisons between the existing design and the design with solar shade were shown in the following figures.

Figure-74 Building Top View

Figure-75 Existing Building –West View

Figure-76 Building with Solar Shade –West View

Figure-77 Existing Building –South View

Figure-78 Building with Solar Shade –South View

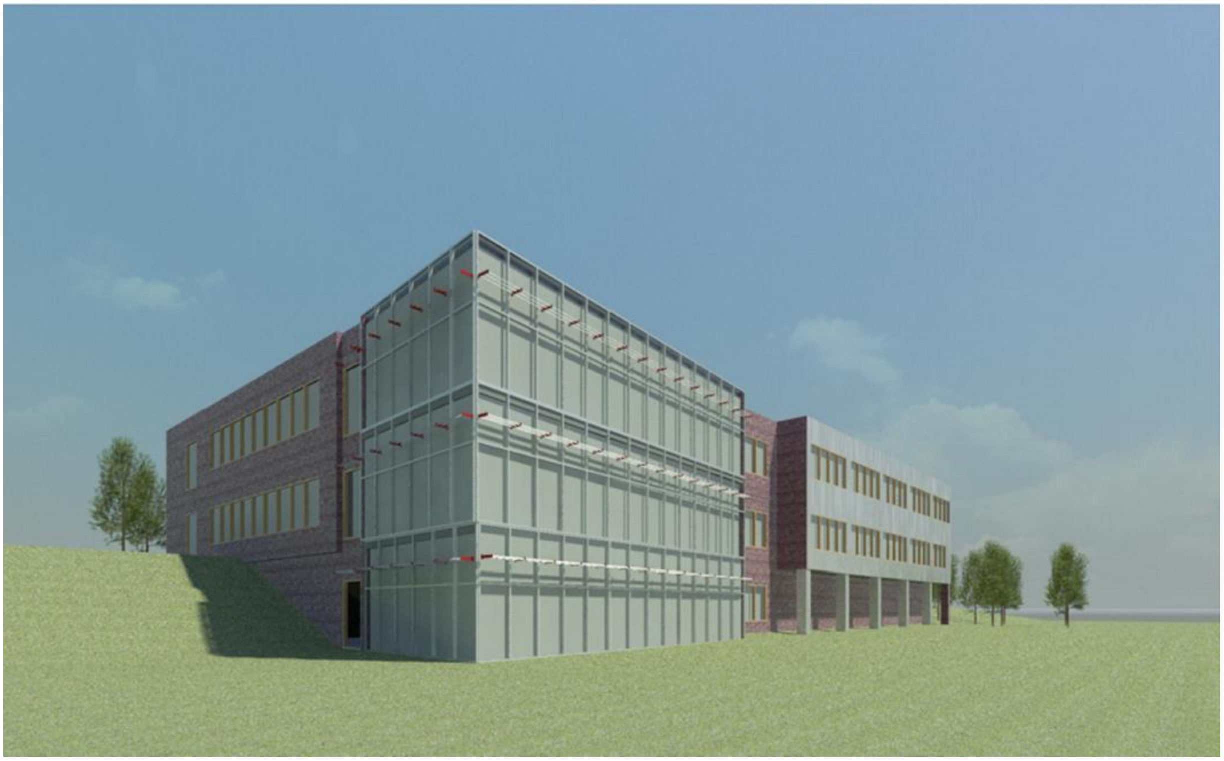


Figure-79 Existing Building –North West View

Figure-80 Building with Solar Shade –North West View

Figure-4 Existing Building –East View

Conclusion

In conclusion, by placing solar shading system on the exterior wall of the building, summer cooling load and the winter solar heating will both be reduced. Reduction in electricity consumption and a small penalty in gas consumption can be seen in analyses. The reduction in utility cost shows the overall utility saving by implementing solar shading system. According to the energy and cost analyses, putting 4ft solar shading system on the south and west sides of the building is the optimum design. This system can achieve a simple payback period of 19 year for the existing mechanical system, 23 years for the DOAS/Active Chilled Beam system, and 24 years for the DOAS/Active Chilled Beam system with Runaround Coil system.

Not only does the solar shading system provides energy and cost savings for the building, it also adds a strong visual aspect to the building. By choosing overhang that are similar to the existing aluminum overhang on the north-west corner of the building, the redesign system provides a smooth and consistency appearance for the building.

Electrical Breadth

Electrical System Overview

The primary electrical service to the building is owned and maintained by Massachusetts Electric Co. (MECo.)The primary service is provided to the pad mounted transformer which distributes 480/277 volt service to the building. The secondary service feeder is provided from the utility company transformer to the interior switchboard. The switchboard is 480/277V, 3 phase, 4 wire, and 2400amps. From the switchboard, electricity goes to lighting and receptacle loads, as well as specialty loads including HVAC, plumbing equipment and laboratory equipment.

There is also an indoor diesel driven engine emergency generator and a diesel fuel tank located in the penthouse. The emergency electric power is used to support life safety, auxiliary and animal facility loads.

Proposal

The changing of the building mechanical system will have an impact on the design of the electrical system. Implementing the dedicated outdoor air system with chilled beam will possibly reduce the size of the chillers and air handling units, since less amount of air will need to be conditioned. The other design alternative is to implement heat recovery systems to reduce the energy needed to condition the outside air. However, additional energy is needed to power the heat recovery systems. Therefore, an electrical analysis will be done to determine the power distribution requirements for the facility as compared to the existing design.

Electrical Analysis

Redesign Goals

The new mechanical design, Dedicated Outdoor Air System with Active Chilled Beam in addition with Runaround Coil as heat recovery system, has replaced the existing air cooled chiller and the centrifugal chiller with two screw chillers. Sizes of the AHU1, AHU2, and AHU3 have been reduced. However, additional pumps for the heat recovery system must be added to the panels. The goal for this electrical analysis is to determine the new load connected to the mechanical switchboards with sizing of new feeders to each panel and sizing of new breakers.

Equipment Added/Removed

Table-45 shows the equipment that was removed from each panel as well as equipment that was added to each panel. Breaker and wire sizes are also given in those tables. To calculate the electricity consumption of chiller, 0.5Kw/Ton was used. The existing panel schedules are available in Appendix C with new panel schedule in Appendix D.

Equipment Removed					
	KVA	**A**	**480 Volt Over current**	**Conductors (3 phase, 4 wire) with Ground**	**Conduit Size**
AHU1	114.1	172	200A, 3P	4#2/0 & 1#6G	2”
AHU3	25.6	39	60A, 3P	4#4 & 1#10G	1 ¼”
AHU2 Supply (30 HP)	51	60	90A,3P	4#4 & 1#10G	1 ¼”
AHU2 Return (15HP)	25.6	39	50A,3P	4#4 & 1#10G	1 ¼”
ACCH-2	10	45	80A, 3P	4#4 & 1#10G	1 ¼”
Chiller CH-1	58.3	263	400A, 3P	4#350 KCMIL & 1#4G	3”

Table-45 Equipment Removed

Equipment Added					
	KVA	**A**	**480 Volt Over current**	**Conductors (3 phase, 4 wire) with Ground**	**Conduit Size**
AHU1	97.8	147	300A, 3P	4#1/0 & 1#6G	2”
AHU2	21	25	30A, 3P	4#4 & 1#10G	1 ¼”
AHU3	23.8	36	60A, 3P	4#4 & 1#10G	1 ¼”
Chiller 1	49.2	222	400A, 3P	4#4/0 & 1#4G	2” ½’
Chiller 2	23	104	200A, 3P	4#1/0 & 1#6G	2”
Pump 1	15	23	60A, 3P	4#4 & 1#10G	1 ¼”
Pump 2	2.2	3	20A, 3P	4#4 & 1#10G	1 ¼”
Pump 3	2.2	3	20A, 3P	4#4 & 1#10G	1 ¼”

Table-46 Equipment Added

Conclusion

By redesigning the mechanical system, some existing loads need to remove from the electrical panel while new loads need to add to the panel. Existing chillers were replaced by two screw chiller, air handling units were downsized, and pumps for runaround coils were added to the panel. Overall, the existing panel was able to handle the changes from mechanical redesign with loads removed and added to the panel,

Conclusion

After completing multiple analyses, the best system choice for this application is combination of utilize solar shading system to first reduce building load, use Dedicated Outdoor Air System parallel with Active Chilled Beam as the main mechanical system with Runaround Coil as heat recovery system. When presenting potential savings to an owner, both first cost and lifecycle cost for the system alternatives must be presented.

First cost analysis was done to compare the initial cost difference between each alternative. To calculate the 30-year lifecycle cost analysis, the Uniform Present Value (UPV) discount factors adjusted for fuel price escalation for Massachusetts State were used. Factors are based on OMB discount rate with 1.9% discount rate from year 1 to 10 and 2.7% discount rate from year 11 to 30. The commercial building discount factor for electricity price is 20.56 and 23.32 for natural gas price.

As shown in Table-48, the maintenance cost for DOAS/ACB system is significantly lower than that for the existing VAV/CAV system. Since there are no moving parts in the system and no filters to maintain, the DOAS/ACB system requires little maintenance. The only maintenance cost calculated in the analysis was the system cleaning process every 5 year, with an approximate cost of $56,235/5years. Maintenance cost for the existing VAV/CAV system is $198,450/year.

Table-47 summarized the simple payback period for different systems. Table-48 summarized the system first cost as well as the annual maintenance and utility cost for each system, discount factors and fuel price escalation factors were not included. Table-49 summarized the lifecycle cost for different systems.

Overall Simple Payback Calculation				
	Existing System	DOAS/ACB	DOAS/ACB +Runaround Coil	DOAS/ACB + Runaround Coil + Solar Shade
Chiller	238,100	292,000	239,000	239,000
Cooling Tower	53,750	57,650	57,650	57,650
Chilled Water Pump ($25/gpm)	987	1,139	1,139	1,139
Ductwork (4$/sf for VAV, 2.5$/sf for ACB)	225,368	156,745	156,745	156,745
Active Chilled Beams (260 active chilled beams, $1000 each)	-	260,000	260,000	260,000
Runaround Coil System Equipment	-	-	11,196	11,196
Solar Shading System	-	-	-	57,799
AHU	143,450	93,650	91,650	91,650
Pipe Cost	425,948	851,895	856,053	856,053
Boiler	48,100	43,900	36,900	36,900
Total	1,135,702	1,756,978	1,710,333	1,768,132
Cost Difference		621,276	574,631	632,430
Operating Saving		66,078	78,602	81,023
Simple Payback		**9 years 5 months**	**7 years 4 months**	**7 years 10 months**

Table-47 System Simple Payback Calculation Comparison

Annual System Cost Analysis				
	Existing System	DOAS/ACB	DOAS/ACB + Runaround Coil	DOAS/ACB + Runaround Coil + Solar Shade
First cost ($)	1,135,702	1,756,978	1,710,333	1,768,132
Maintenance Cost ($/yr. for existing system; $/5years for redesign systems)	198,450	14,560	15,000	15,000
Annual Natural Gas Cost($)	296,098	252,449	252,088	250,323
Annual Electricity Cost($)	119,135	102,074	94,016	93,358

Table-48 System Annual Cost Comparison

30-Year Life Cycle Cost Analysis				
	Existing System	DOAS/ACB	DOAS/ACB + Runaround Coil	DOAS/ACB + Runaround Coil + Solar Shade
First cost ($)	1,135,702	1,756,978	1,710,333	1,768,132
Maintenance Cost($)	4,044,980	56,235	57,935	57,935
Annual Natural Gas Cost($)	6,905,005	5,887,111	5,878,692	5,837,532
Annual Electricity Cost($)	2,449,416	2,098,641	1,932,969	1,919,440
Total	**14,535,103**	**9,798,965**	**9,579,929**	**9,583,039**

Table-49 System 30-Year Life Cycle Cost Comparison

As shown in the above tables, the DOAS/ACB with Runaround coil and Solar Shading system has highest initial cost. However, it has low maintenance cost and has the highest energy saving which results in a comparatively low lifecycle cost. With the advantages of reducing building load, improving indoor air quality, lower noise level, lower energy consumption, as well as providing a strong visual aspect to the building, the DOAS/Active Chilled Beam with Runaround coil and Solar Shading system is the recommended system for design.

Related M.A.E Work

As part of the MAE requirement for the senior thesis, Master level courses were incorporated within the project. The Master courses that have been included in this report are as follow:

AE557 Centralized Heating Production and Distribution Systems

The material learned in this class was used to understand the existing heating system in the building. Judgments were made in the heating system redesign based on the material covered in the class. Within AE 558 was a section on lifecycle cost analysis. This was utilized within the report to generate the 30-year lifecycle cost calculation to compare different design alternatives.

AE 558 Centralized Cooling Production and Distribution System

The material covered in these courses was directly applicable to the depth study of this project as it largely focuses on the cooling analysis for mechanical redesign. For example, within the AE558 was a section on chiller. This was utilized to select the most appreciate chiller type for my project.

AE552 Air Quality in Buildings

Material covered in this course was heavily used in this project. One of main objective for the redesign was to provide a healthy indoor environment for the occupants. Since majority of the building space is laboratory and vivarium rooms, mechanical system needs to ensure that airborne contaminant does not circulate and transfer inside the building. Computational Fluid Dynamic models were built to analysis the indoor air quality within a lab space.

AE559 Computational Fluid Dynamics in Building Design

This course involved learning and developing reliable simulations using CFD program such as Phoenics. In this project, CFD models were built to analysis the air flow, temperature, and contaminant distribution for the existing system and for the redesign active chilled beam system. The CFD analysis plays a very important role in determining the effectiveness of the active chilled beam system on fresh air flow, thermal comfort, and its ability to remove contaminant from the space.

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Appendix A – Utility Data

EMD Serono Research Center Utility Data					
Billing Month	**Service**	**kWh**	**MWh**	**Service**	**MMBTU**
Jan-09	Electric	197200	197.2	-	-
Feb-09	Electric	176400	176.4	-	-
Mar-09	Electric	158400	158.4	-	-
Apr-09	Electric	177600	177.6	-	-
May-09	Electric	205200	205.2	-	-
Jun-09	Electric	196000	196	-	-
Jul-09	Electric	238000	238	Gas	511.46
Aug-09	Electric	233200	233.2	Gas	467.65
Sep-09	Electric	249600	249.6	Gas	508.83
Oct-09	Electric	237600	237.6	Gas	726.81
Nov-09	Electric	176000	176	Gas	984.16
Dec-09	Electric	188800	188.8	Gas	1526.13
Jan-10	Electric	188400	188.4	Gas	1997.08
Feb-10	Electric	172800	172.8	Gas	1605.65
Mar-10	Electric	194000	194	Gas	1130.04
Apr-10	Electric	185200	185.2	Gas	890.56
May-10	Electric	189200	189.2	Gas	567.36
Jun-10	Electric	250800	250.8	Gas	777.82
Jul-10	Electric	239600	239.6	Gas	282.24
Aug-10	-	-	-	Gas	316.47

Table-50 EMD Serono Research Center Utility Data

Appendix B – Equipment Cost

Chiller Cost					
	Chiller Type		Chiller Price		
	Chiller 1	Chiller 2	Chiller 1 Price	Chiller 2 Price	Total Price
Existing System	350 Ton Centrifugal	60 Ton Air Cooled	182,000	56,100	238,100
DOAS/ACB	350 Ton Screw	150 Ton Screw	195,500	96,500	292,000
DOAS/ACB + Heat Pipe	300 Ton Screw	150 Ton Screw	142,500	96,500	239,000
DOAS/ACB + Fixed Plate	300 Ton Screw	150 Ton Screw	142,500	96,500	239,000
DOAS/ACB +Enthalpy Wheel	200 Ton Screw	150 Ton Screw	109,500	96,500	206,000
DOAS/ACB + Runaround Coil	300 Ton Screw	150 Ton Screw	142,500	96,500	239,000

Table-51 Chiller Cost

Ductwork Cost			
Existing System		DOAS/ACB	
Unit Price	Total Price	Unit Price	Total Price
$4/sf	225,368	$2.5/sf	156,745

Table-52 Ductwork Cost

Piping Cost					
Existing System			DOAS/ACB		
length (lf)	Unit Cost ($/lf)	Total Cost	length (lf)	Unit Cost ($/lf)	Total Cost
8,605	49.5	425,948	17,210	49.5	851,895

Table-53 Piping Cost

Boiler Cost			
	Heating (MBh)	Gas Fired Boiler Size	Boiler Price
Existing System	3,937	4,488Mbh	48,100
DOAS/ACB	3,628	3,808Mbh	43,900
DOAS/ACB+ Heat Pipe	2,690	2,856Mbh	36,900
DOAS/ACB+ Fixed Plate	2,505	2,856Mbh	36,900
DOAS/ACB+ Enthalpy Wheel	2,209	2,312Mbh	34,800
DOAS/ACB+ Runaround Coil	2,721	2,856Mbh	36,900

Table-54 Boiler Cost

Air Handling Unit Cost									
	AHU1			AHU2			AHU3		
	CFM	Size	Price	CFM	Size	Price	CFM	Size	Price
Existing System	29,760	34,000 cfm VAV	56,000	34,876	40,000 cfm VAV	62,500	7,374	7500 cfm CAV	15,700
DOAS/ACB	24,136	27000 cfm CAV	44,600	12,679	13200 cfm CAV	24,100	7,312	7500 cfm CAV	15,700
DOAS/ACB+ Heat Pipe	24,136	27000 cfm CAV	44,600	12,679	13200 cfm CAV	24,100	7,312	7500 cfm CAV	15,700
DOAS/ACB+ Fixed Plate	24,136	27000 cfm CAV	44,600	12,679	13200 cfm CAV	24,100	7,312	7500 cfm CAV	15,700
DOAS/ACB+ Enthalpy Wheel	24,136	27000 cfm CAV	44,600	12,679	13200 cfm CAV	24,100	7,312	7500 cfm CAV	15,700
DOAS/ACB+ Runaround Coil	24,136	27000 cfm CAV	44,600	12,679	13200 cfm CAV	24,100	7,312	7500 cfm CAV	15,700

Table-55 Air Handling Unit Cost

Heat Recovery System Equipment Cost			
	$/cfm	Main cfm	Total cost
Heat Pipe	2.34	28,483	66,650
Fixed Plate Heat Exchanger	1.8	28,487	51,277
	Model cfm	Main cfm	Total Cost
Enthalpy Wheel	25,000 max CFM + 6,000 max CFM	28,517	45,400

Table-56 Heat Recovery System Equipment Cost

Runaround Coil System Cost						
	Ton of cooling	$/ton for Motor	$/ton for Equipment	Price for Motor	Price for Equipment	Price for Total Equipment
DOAS/ACB Runaround Coil, AHU1	300.3	4.8	18.8	1,441	5,646	7,087
DOAS/ACB Runaround Coil, AHU2	87.1	4.8	18.8	418	1,637	2,056
DOAS/ACB Runaround Coil, AHU1,3	87	4.8	18.8	418	1,636	2,053
DOAS/ACB Runaround Coil, AHU1,3	387.3	4.8	18.8	1,859	7,281	9,140
DOAS/ACB Runaround Coil, AHU1,2,3	474.4	4.8	18.8	2,277	8,919	11,196

Table-57 Runaround Coil System Cost

Additional Piping Cost for Runaround Coil System			
	length (lf)	Unit Cost ($/lf)	Total Cost
DOAS/ACB Runaround Coil, AHU1	15	49.5	743
DOAS/ACB Runaround Coil, AHU2	15	49.5	743
DOAS/ACB Runaround Coil, AHU1,3	84	49.5	4,158
DOAS/ACB Runaround Coil, AHU1,3	84	49.5	4,158
DOAS/ACB Runaround Coil, AHU1,2,3	84	49.5	4,158

Table-58 Additional Piping Cost for Runaround Coil System

Appendix C – Existing Panel Schedule

DISTRIBUTION PANEL "D4P" SCHEDULE

277/480 VOLTS 3 PHASE 4 WIRE AIC: SEE SPECS

MAIN BUS SIZE: 600 AMPS NEUTRAL: 100% GROUND BUS: FULL

MAIN DEVICE: 600 AMPS MOUNTING: SURFACE

CIRCUIT NUMBER	LOAD ITEM	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	AHU-2 SUPPLY (30HP)	100	90	3	SEE MOTOR WIRING SCHEDULE	
2	AHU-2 RETURN (15HP)	100	50	3	SEE MOTOR WIRING SCHEDULE	
3	AHU-1 (75HP)	250	200	3	SEE MOTOR WIRING SCHEDULE	
4	SPARE	100	70	3		
5	ATS-LS	150	150	3	SEE RISER DIAGRAM	
6	PANEL R2P VIA TRANSFORMER	100	60	3	SEE RISER DIAGRAM	
7	EX-1 (40HP) VIA VFD	150	125	3	SEE MOTOR WIRING SCHEDULE	
8	EX-2 (40HP) VIA VFD	150	125	3	SEE MOTOR WIRING SCHEDULE	
9	CT-1 (25HP) VIA VFD	100	70	3	SEE MOTOR WIRING SCHEDULE	
10	SPACE					
11	SPACE					
12	SPACE					

DISTRIBUTION PANEL "EQD4G" SCHEDULE

277/480 VOLTS 3 PHASE 4 WIRE AIC: SEE SPECS

MAIN BUS SIZE: 225 AMPS NEUTRAL: 100% GROUND BUS: FULL

MLO: 225 AMPS MOUNTING: SURFACE

CIRCUIT NUMBER	LOAD ITEM	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	PANEL EQ2G VIA TRANSFORMER	100	60	3	SEE RISER DIAGRAM	
2	CHP-2&3 (2@3HP)	20	20	3	3#12 & 1#12G – 3/4"C	
3	DUPLEX SEWAGE EJECTOR (2@1-1/2HP)	20	20	3	3#12 & 1#12G – 3/4"C	
4	DISTRIBUTION PUMP (3HP)	20	20	3	SEE MOTOR WIRING SCHEDULE	
5	DUPLEX TLW EJECTOR (2@3HP)	20	20	3	3#12 & 1#12G – 3/4"C	
6	AHU-3 (10HP) VIA VFD	30	30	3	SEE MOTOR WIRING SCHEDULE	
7	CP-1 (1/2HP)	20	20	3	SEE MOTOR WIRING SCHEDULE	
8	PANEL EQ2GA VIA TRANSFORMER	100	60	3	SEE RISER DIAGRAM	
9	AHU-3 (10HP) VIA VFD	30	30	3	SEE MOTOR WIRING SCHEDULE	
10	SPARE	20	20	3		
11	SPACE	20	20	3		
12	SPACE	30	30	3		

DISTRIBUTION PANEL "EQD4P" SCHEDULE

277/480 VOLTS | 3 PHASE | 4 WIRE | AIC: SEE SPECS

MAIN BUS SIZE: 400 AMPS | NEUTRAL: 100% | GROUND BUS: FULL

MAIN DEVICE: 400 AMPS | MOUNTING: SURFACE

CIRCUIT NUMBER	LOAD ITEM	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	ACCH-1	200	150	3	4#1/0 & 1#6G – 2"C	
2	EX-3A (7-1/2HP)	50	30	3	SEE MOTOR WIRING SCHEDULE	
3	EX-3 (7-1/2HP)	50	30	3	SEE MOTOR WIRING SCHEDULE	
4	B-2 (3/4HP)	50	20	3	SEE MOTOR WIRING SCHEDULE	
5	PANEL EQD4G	225	150	3	SEE RISER DIAGRAM	
6	PANEL EQD2P VIA TRANSFORMER	225	200	3	SEE RISER DIAGRAM	
7	SPACE					
8	SPACE					
9	SPACE					
10	SPACE					
11	SPACE					
12	SPACE					

MAIN DISTRIBUTION PANEL "MSB" SCHEDULE

277/480 VOLTS | 3 PHASE | 4 WIRE | AIC: SEE SPECS

MAIN BUS SIZE: 2000 AMPS | NEUTRAL: 100% | GROUND BUS: FULL

MAIN DEVICE: 2000 AMPS | MOUNTING: SURFACE

CIRCUIT NUMBER	LOAD ITEM (4)	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	ELEVATOR (75HP)	250	200	3	SEE MOTOR WIRING SCHEDULE	GROUND FAULT
2	D4G	800	800	3	SEE RISER DIAGRAM	GROUND FAULT
3	ATS-EQ	800	400	3	SEE RISER DIAGRAM	GROUND FAULT
4	MCCP	800	600	3	SEE RISER DIAGRAM	GROUND FAULT
5	D4P	800	600	3	SEE RISER DIAGRAM	GROUND FAULT
6	D42	800	600	3	SEE RISER DIAGRAM	GROUND FAULT
7	D41	800	600	3	SEE RISER DIAGRAM	GROUND FAULT
8	CHILLER CH-1	800	600	3	4#600 KCMIL & 1#3G. – 4" C.	GROUND FAULT
9	SPACE					
10	SPACE					
11	SPACE					
12	SPACE					

MOTOR CONTROL CENTER "MCCG" SCHEDULE

(FOR ADDITIONAL INFORMATION REFER TO ELECTRICAL SPECIFICATIONS)

277/480 VOLTS | 3 PHASE | 3 WIRE | AIC: SEE SPECS

MAIN BUS SIZE: 225 AMPS | NEUTRAL: --- | GROUND BUS: FULL

ITEM	NAMEPLATE	HP	KW	FLA	PHASE	VOLTS	BRANCH CIRCUIT OVERCURRENT DEVICE		MOTOR CONTROLLER TYPE	BRANCH CIRCUIT WIRING	NOTES
							MCP	FEEDER C.B.			
1	CHP-1	20		27	3	480	50		FVNR	SEE MOTOR WIRING SCHEDULE	
2	CWP-1	15		21	3	480	30		FVNR	SEE MOTOR WIRING SCHEDULE	
3	EX-8	1½		3	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
4	HV-1	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
5	CH/CW-P1	15		21	3	480	30		FVNR	SEE MOTOR WIRING SCHEDULE	
6	SPARE										
7	SPARE										
8	SPACE										

MOTOR CONTROL "MCCP" CENTER SCHEDULE

(FOR ADDITIONAL INFORMATION REFER TO ELECTRICAL SPECIFICATIONS)

277/480 VOLTS | 3 PHASE | 3 WIRE | AIC: SEE SPECS

MAIN BUS SIZE: 600 AMPS | NEUTRAL: --- | GROUND BUS: FULL

ITEM	NAMEPLATE	HP	KW	FLA	PHASE	VOLTS	BRANCH CIRCUIT OVERCURRENT DEVICE		MOTOR CONTROLLER TYPE	BRANCH CIRCUIT WIRING	NOTES
							MCP	FEEDER C.B.			
1	SPARE										
2	SPARE										
3	SPARE										
4	EX-4	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
5	EX-5	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
6	EX-6	1/2		1.1	3	480	3		FVNR	SEE MOTOR WIRING SCHEDULE	
7	EX-7	1/2		1.1	3	480	3		FVNR	SEE MOTOR WIRING SCHEDULE	
8	B-1	5		7.6	3	480	15		FVNR	SEE MOTOR WIRING SCHEDULE	
9	BFD-1	200		4.2	3	480		20		3#12 & 1#12G – 3/4"C	
10	HP-1	7½		11	3	480	15		FVNR	SEE MOTOR WIRING SCHEDULE	
11	HP-2	7½		11	3	480	15		FVNR	SEE MOTOR WIRING SCHEDULE	
12	EX-4A	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
13	HV-1	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
14	EX-10	1½		3	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
15	SPARE										
16	SPARE										
17	SPACE										
18	SPACE										

Appendix D – Redesign Panel Schedule

DISTRIBUTION PANEL "D4P" SCHEDULE						
277/480 VOLTS	3 PHASE	4 WIRE				AIC: SEE SPECS
MAIN BUS SIZE: 600 AMPS	NEUTRAL: 100%			GROUND BUS: FULL		
MAIN DEVICE: 600 AMPS	MOUNTING: SURFACE					
CIRCUIT NUMBER	LOAD ITEM △2	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	AHU-2 SUPPLY (30HP)	100	90	3	SEE MOTOR WIRING SCHEDULE	
2	AHU-2 RETURN (15HP)	100	50	3	SEE MOTOR WIRING SCHEDULE	
3	AHU-1 △4	250	300	3	4#1/0 & 1#6G – 2"C	
4	SPARE	100	70	3		
5	ATS-LS	150	150	3	SEE RISER DIAGRAM	
6	PANEL R2P VIA TRANSFORMER	100	60	3	SEE RISER DIAGRAM	
7	EX-1 (40HP) VIA VFD	150	125	3	SEE MOTOR WIRING SCHEDULE	
8	EX-2 (40HP) VIA VFD	150	125	3	SEE MOTOR WIRING SCHEDULE	
9	CT-1 (25HP) VIA VFD	100	70	3	SEE MOTOR WIRING SCHEDULE	
10	PUMP-1	100	60	3	4#4 & 1#10G – 1-1/4"C	
11	SPACE					
12	SPACE					

DISTRIBUTION PANEL "D4P" SCHEDULE						
277/480 VOLTS	3 PHASE	4 WIRE				AIC: SEE SPECS
MAIN BUS SIZE: 600 AMPS	NEUTRAL: 100%			GROUND BUS: FULL		
MAIN DEVICE: 600 AMPS	MOUNTING: SURFACE					
CIRCUIT NUMBER	LOAD ITEM	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	PUMP-2	100	20	3	4#4 & 1#10G – 1-1/4"C	
2	AHU-2	100	30	3	4#4 & 1#10G – 1-1/4"C	
3	AHU-1	250	300	3	4#1/0 & 1#6G – 2"C	
4	SPARE	100	70	3		
5	ATS-LS	150	150	3	SEE RISER DIAGRAM	
6	PANEL R2P VIA TRANSFORMER	100	60	3	SEE RISER DIAGRAM	
7	EX-1 (40HP) VIA VFD	150	125	3	SEE MOTOR WIRING SCHEDULE	
8	EX-2 (40HP) VIA VFD	150	125	3	SEE MOTOR WIRING SCHEDULE	
9	CT-1 (25HP) VIA VFD	100	70	3	SEE MOTOR WIRING SCHEDULE	
10	PUMP-1	100	60	3	4#4 & 1#10G – 1-1/4"C	
11	SPACE					
12	SPACE					

DISTRIBUTION PANEL "EQD4G" SCHEDULE						
277/480 VOLTS	3 PHASE	4 WIRE				A/C: SEE SPECS
MAIN BUS SIZE: 225 AMPS	NEUTRAL: 100%		GROUND BUS: FULL			
MLO: 225 AMPS	MOUNTING: SURFACE					
CIRCUIT NUMBER	LOAD ITEM	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	PANEL EQ2G VIA TRANSFORMER	100	60	3	SEE RISER DIAGRAM	
2	CHP-2&3 (2@3HP)	20	20	3	3#12 & 1#12G – 3/4"C	
3	DUPLEX SEWAGE EJECTOR (2@1-1/2HP)	20	20	3	3#12 & 1#12G – 3/4"C	
4	DISTRIBUTION PUMP (3HP)	20	20	3	SEE MOTOR WIRING SCHEDULE	
5	DUPLEX TLW EJECTOR (2@3HP)	20	20	3	3#12 & 1#12G – 3/4"C	
6	AHU-3	100	60	3	4#4 & 1#10G – 1-1/2"C	
7	CP-1 (1/2HP)	20	20	3	SEE MOTOR WIRING SCHEDULE	
8	PANEL EQ2GA VIA TRANSFORMER	100	60	3	SEE RISER DIAGRAM	
9	AHU-3 (10HP) VIA VFD	30	30	3	SEE MOTOR WIRING SCHEDULE	
10	PUMP-2	20	20	3	4#4 & 1#10G – 1-1/4"C	
11	SPACE	20	20	3		
12	SPACE	30	30	3		

DISTRIBUTION PANEL "EQD4P" SCHEDULE						
277/480 VOLTS	3 PHASE	4 WIRE				A/C: SEE SPECS
MAIN BUS SIZE: 400 AMPS	NEUTRAL: 100%		GROUND BUS: FULL			
MAIN DEVICE: 400 AMPS	MOUNTING: SURFACE					
CIRCUIT NUMBER	LOAD ITEM	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	CHILLER 2	225	200	3	4#4/0 & 1#6G – 2"C	
2	EX-3A (7-1/2HP)	50	30	3	SEE MOTOR WIRING SCHEDULE	
3	EX-3 (7-1/2HP)	50	30	3	SEE MOTOR WIRING SCHEDULE	
4	B-2 (3/4HP)	50	20	3	SEE MOTOR WIRING SCHEDULE	
5	PANEL EQD4G	225	150	3	SEE RISER DIAGRAM	
6	PANEL EQD2P VIA TRANSFORMER	225	200	3	SEE RISER DIAGRAM	
7	SPACE					
8	SPACE					
9	SPACE					
10	SPACE					
11	SPACE					
12	PUMP-1	100	60	3	4#4 & 1#10G – 1-1/4"C	

MAIN DISTRIBUTION PANEL "MSB" SCHEDULE						
277/480 VOLTS		3 PHASE	4 WIRE			A/C: SEE SPECS
MAIN BUS SIZE: 2000 AMPS		NEUTRAL: 100%		GROUND BUS: FULL		
MAIN DEVICE: 2000 AMPS		MOUNTING: SURFACE				
CIRCUIT NUMBER	LOAD ITEM (4)	OVERCURRENT DEVICE			FEEDER SIZE	REMARKS
		FRAME	TRIP	POLE		
1	ELEVATOR (75HP)	250	200	3	SEE MOTOR WIRING SCHEDULE	GROUND FAULT
2	D4G	800	800	3	SEE RISER DIAGRAM	GROUND FAULT
3	ATS-EQ	800	400	3	SEE RISER DIAGRAM	GROUND FAULT
4	MCCP	800	600	3	SEE RISER DIAGRAM	GROUND FAULT
5	D4P	800	600	3	SEE RISER DIAGRAM	GROUND FAULT
6	D42	800	600	3	SEE RISER DIAGRAM	GROUND FAULT
7	D41	800	600	3	SEE RISER DIAGRAM	GROUND FAULT
8	CHILLER 1	400	400	3	4#4/0 & 1#4G – 2-1/2"C	GROUND FAULT
9	SPACE					
10	SPACE					
11	SPACE					
12	SPACE					

MOTOR CONTROL CENTER "MCCG" SCHEDULE (FOR ADDITIONAL INFORMATION REFER TO ELECTRICAL SPECIFICATIONS)											
277/480 VOLTS					3 PHASE	3 WIRE					A/C: SEE SPECS
MAIN BUS SIZE: 225 AMPS						NEUTRAL: ---			GROUND BUS: FULL		
ITEM	NAMEPLATE	HP	KW	FLA	PHASE	VOLTS	BRANCH CIRCUIT OVERCURRENT DEVICE		MOTOR CONTROLLER TYPE	BRANCH CIRCUIT WIRING	NOTES
							MCP	FEEDER C.B.			
1	CHP-1	20		27	3	480	50		FVNR	SEE MOTOR WIRING SCHEDULE	
2	CWP-1	15		21	3	480	30		FVNR	SEE MOTOR WIRING SCHEDULE	
3	EX-8	1½		3	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
4	HV-1	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
5	CH/CW-P1	15		21	3	480	30		FVNR	SEE MOTOR WIRING SCHEDULE	
6	SPARE										
7	SPARE										
8	SPACE										

MOTOR CONTROL "MCCP" CENTER SCHEDULE

(FOR ADDITIONAL INFORMATION REFER TO ELECTRICAL SPECIFICATIONS)

277/480 VOLTS 3 PHASE 3 WIRE A/C: SEE SPECS

MAIN BUS SIZE: 600 AMPS NEUTRAL: --- GROUND BUS: FULL

ITEM	NAMEPLATE	HP	KW	FLA	PHASE	VOLTS	BRANCH CIRCUIT OVERCURRENT DEVICE		MOTOR CONTROLLER TYPE	BRANCH CIRCUIT WIRING	NOTES
							MCP	FEEDER C.B.			
1	SPARE										
2	SPARE										
3	SPARE										
4	EX-4	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
5	EX-5	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
6	EX-6	1/2		1.1	3	480	3		FVNR	SEE MOTOR WIRING SCHEDULE	
7	EX-7	1/2		1.1	3	480	3		FVNR	SEE MOTOR WIRING SCHEDULE	
8	B-1	5		7.6	3	480	15		FVNR	SEE MOTOR WIRING SCHEDULE	
9	BFD-1	200		4.2	3	480		20		3#12 & 1#12G – 3/4"C	
10	HP-1	7½		11	3	480	15		FVNR	SEE MOTOR WIRING SCHEDULE	
11	HP-2	7½		11	3	480	15		FVNR	SEE MOTOR WIRING SCHEDULE	
12	EX-4A	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
13	HV-1	2		3.4	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
14	EX-10	1½		3	3	480	7		FVNR	SEE MOTOR WIRING SCHEDULE	
15	SPARE										
16	SPARE										
17	SPACE										
18	SPACE										

Appendix F – List of Tables

Appendix G – List of Figures