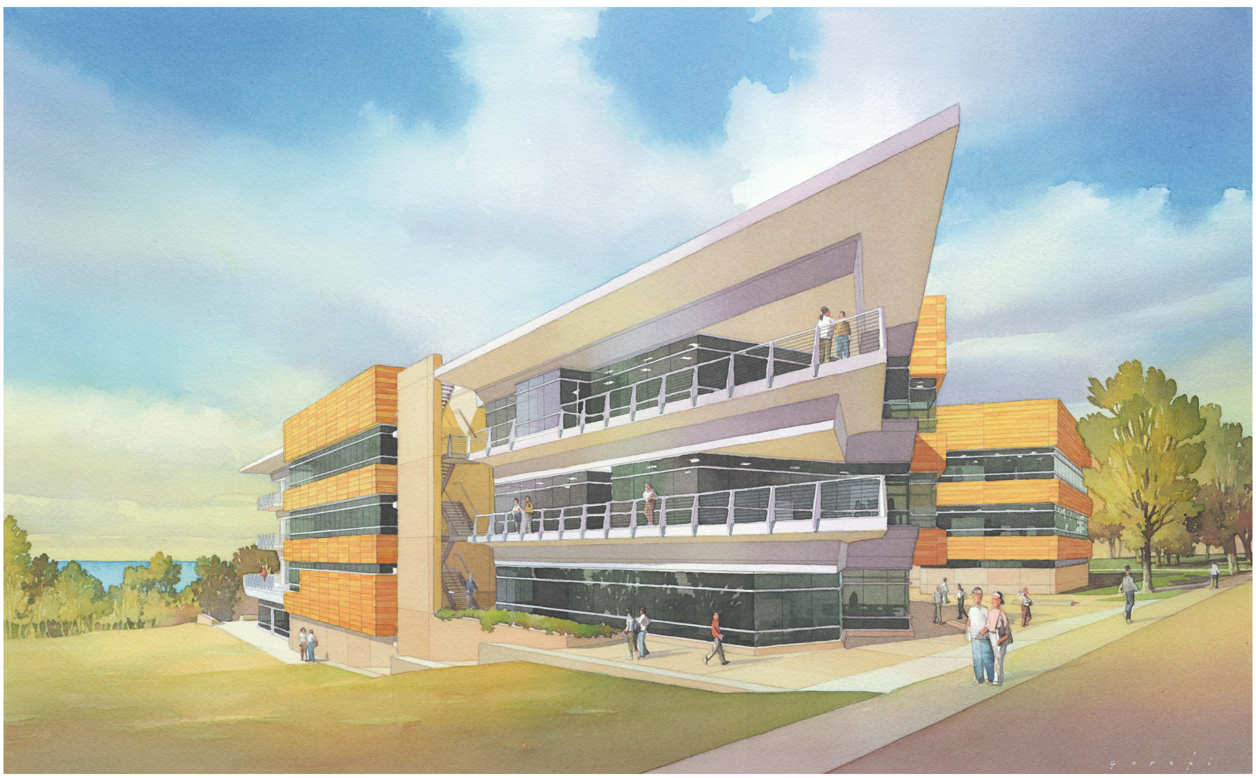
Senior Thesis Final Report

Mechanical Redesign with CM & Electrical Breadths

Mark Zuidema | Mechanical Option | Advisor: Dr. Treado



UNIVERSITY OF CALIFORNIA – SAN DIEGO

RADY SCHOOL OF MANAGEMENT

LA JOLLA, CA

Spring 2010

RADY SCHOOL OF MANAGEMENT

UNIVERSITY OF CALIFORNIA SAND DIEGO, LA JOLLA, CALIFORNIA

PROJECT TEAM:

OWNER: UNIVERSITY OF CALIFORNIA SAN DIEGO
GENERAL CONTRACTOR: PCL CONSTRUCTION SERVICES, INC.
CM: HANSCOMB, FAITHFUL, & GOULD
ARCHITECT: ELLERBE BECKET
ENGINEER: ELLERBE BECKET & NASLAND ENGINEERING
PROJECT DELIVERY METHOD: DESIGN-BID-BUILD

MECHANICAL/ELECTRICAL/PLUMBING SYSTEMS:

THREE ROOFTOP AIR HANDLERS SERVE A VAV SYSTEM

SEVEN FAN COIL UNITS SERVE AREAS OF HIGH HEAT GENERATION

BUILDING OPERATES ON 208/120V AND 480/277V

CHILLED/HIGH TEMP WATER IS DELERIVERED FROM THE UNIVERSITY'S CENTRAL UTILITY PLANT

BUILDING STATISTICS:

DATES OF CONSTRUCTION: SEPTEMBER 2005 TO FEBRUARY 2007
COST: $35,475,000
OCCUPANCY TYPE: EDUCATIONAL FACILITY
SIZE: 91,000 SF TOTAL

ARCHITECTURAL FEATURES:

THE RADY SCHOOL OF MANAGEMENT WAS DESIGNED TO BE AMONG THE TOP BUSINESS SCHOOLS IN THE NATION AND ACCOMMODATES STATE-OF-THE-ART NETWORKING AND VIDEO-CONFERENCING LEARNING FACILITIES. THE BUILDING'S DESIGN IS MEANT TO CREATE A SENSE OF COMMUNITY AND ENCOURAGE INTER-ACTION THROUGH THE USE OF GLASS. A SERIES OF STRATEGICALLY PLACE TERRACES PROVIDE SPECTACULAR VIEWS OF THE PACIFIC OCEAN AND MOUNTAINS TO THE WEST.

STRUCTURAL SYSTEM:

SPREAD FOOTINGS FORMED WITH STANDARD WEIGHT, 3,000 PSI CONCRETE

WIDE FLANGE BEAMS, GIRDERS, AND COLUMNS CONSISTING OF ASTM A992 GRADE 50 STEEL

FLOORS CONSIST OF 3" METAL, 20 GAGE GALVANIZED DECKING WITH 3" OF STANDARD WEIGHT, 4,000 PSI CONCRETE.

MARK ZUIDEMA - MECHANICAL OPTION
THE PENNSYLVANIA STATE UNIVERSITY
HTTP://WWW.ENGR.PSU.EDU/AE/THESIS/PORTFOLIOS/2010/MWZ111/INDEX.HTML

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EXECUTIVE SUMMARY

This report has been written to determine if the UCSD Rady School of Management would benefit from the incorporation of an active chilled beam (ACB) system in conjunction with a dedicated outdoor air system (DOAS). This system will be designed and compared to the existing variable air volume (VAV) system.

The report begins with an overview of the building and its various systems. The existing mechanical system design and operation are then examined to provide a basis for the redesign. My redesign proposal is presented and the process for the design is laid out.

I begin my redesign by calculating the amount of ventilation air required by ASHRAE 62.1. This value is based on occupancy loads and building area. The required ventilation rates then become the basis for my airflow rates since 100% outdoor air will be supplied. This value was found to be 36,191 CFM. A Trane TRACE 700 block analysis energy model was then created to determine the building's loads. With the loads and airflow rates established, the required supply air humidity ratio needed to handle all latent loads was determined to be 40 gr/lb of dry air. It was then found that the cooling coil capacity needed to be 77.4 tons for area A, and 141.3 tons for area B&C. The sensible cooling capacity for the supply air was determined and subtracted from the total sensible loads to find the load that will need to be handled by the ACBs. Using this information, I determined that the building would require a total of 1,396 2'x4' ACBs.

With all of this information know, I could then perform a first cost analysis. This was done by determining what components could be eliminated, and what ones needed to be added. It was concluded that one of the building's AHUs and six of the seven FCUs could be eliminated. The VAV boxes were kept to prevent overcooling to the rooms, but the majority of them were reduced in size. The required pumping power for the hot and chilled water loops was calculated, and it was found that eight 100 HP pumps would need to be installed. Using this information, it was found that the initial cost would be roughly $648,570 higher for this system. An energy analysis then found that the system would lead to an 11.4% reduction in energy costs, or $10,610 a year. This resulted in a payback period of 61 years and made it evident that this type of system would not be economically viable. Although these systems can be very beneficial under certain circumstances, it was no so in this case. With such a large payback period, the use of this type of system cannot be rationalized, and the owner would most likely favor the use of the VAV system.

Although the use of this system could not be validated, the effect it would have on the electrical system was investigated. Along with this, a construction management breadth was performed to calculate about how much time the system would take to install.

Acknowledgements

I would like to thank the following individuals for all the help they have provided me with over the past months. Without their help this project would not have been possible. I would especially like to thank them for all the selflessness they showed by devoting time to helping me with this project.

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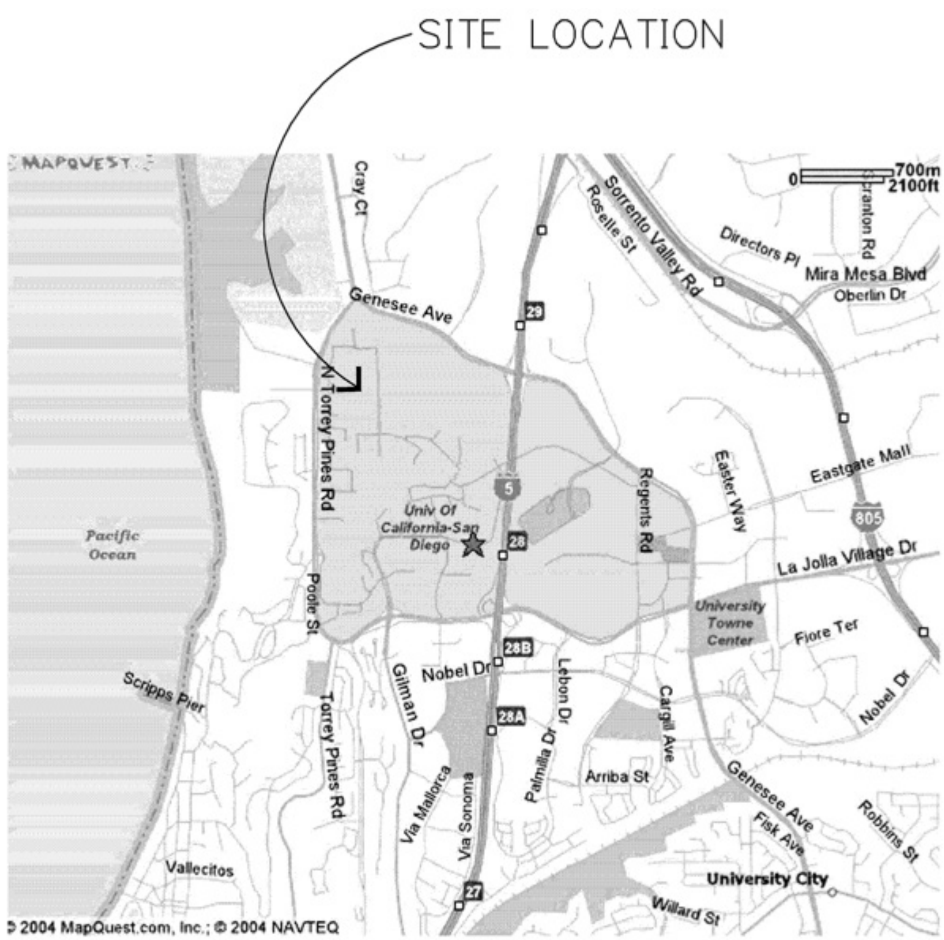
- Daniel Dickenson
  - ➔ AECOM Ellerbe Becket – Director of Mechanical Engineering
- Benjamin Fuller
  - ➔ AECOM Ellerbe Becket - Mechanical Engineer
- Atul Pathare
  - ➔ AECOM Ellerbe Becket – Project Architect
- David Tash
  - ➔ AECOM Ellerbe Becket – Mechanical Discipline Leader
- Paula Gillette
  - ➔ AECOM Ellerbe Becket – Engineering Project Director
- Anna Levitt
  - ➔ UCSD Assistant Campus Energy Manager
- Chuck Kaminski
  - ➔ UCSD Representative
- Dr. Stanley Mumma
  - ➔ PSU – Professor Emeritus of Architectural Engineering

Introduction

The University of California San Diego's Rady School of management is a 4-story, 101,000 ft^2 learning facility dedicated to the development of the next generation of science and technology business leaders. It was a design-bid-build project costing roughly $35.3 million. Construction on the facility began in September 2005 and was completed in February 2007.

This building is home to a combination of learning/research facilities, faculty offices, and student services offices. It is designed to be a state-of-the-art networking and videoconferencing facility, as well as the School of Management's education and research base. The building's mission is to develop entrepreneurs and innovators into successful science and technology leaders. To achieve this goal, its architectural design encourages interactivity between students, business leaders, and faculty. In addition to these goals, it was a requirement of the University that this facility be designed to LEED silver certification standards. Certification was never applied for, but it was designed to be a LEED silver equivalent.

The building is located in La Jolla, CA on the northern part of UCSD's campus. It is set in a beautiful landscape with picturesque views of the Pacific Ocean and surrounding mountains.



Systems Overview

Architectual System

The building's design is meant to create a sense of community and encourage interaction through the use of glass. A series of strategically place terraces provide spectacular views of the Pacific Ocean and mountains to the west. A seamless transition between the exterior and interior is accomplished through a continuation of hardscape from the courtyards and exterior plazas onto the building terraces.

Faculty offices and communal spaces are aligned along the exterior glazing to provide ample daylighting, as well as beautiful sights of campus and beyond. The building is comprised of three wings, roughly equal in size, and joined together to form a 'y' shape.

The majority of the building's façade consists of stone paneling and the glazing makes up about 20%. The glazing is double pane, low E, insulated glazing with air space.

Systems Overview (Continued)

Structural System

The foundation consists of spread footings formed with standard weight, 3,000 psi concrete. The building is constructed with wide flange beams, girders, and columns consisting of ASTM A992 grade 50 steel. Floors consist of 3” metal, 20 gage galvanized decking with 3” of standard weight, 4,000 psi concrete.

Electrical System

The building’s power is supplied by the University’s central utility plant (CUP) and stepped down by a transformer to 480/277V before it enters the building. From there it is distributed throughout the building to each panelboard.

The building also runs at 208/120V. The 208/120V panelboards are fed by the 480/277V system, which is stepped down with a transformer before it serves these panels. In addition to these two electrical systems, there is an emergency diesel-powered generator located on the second floor. The generator is 175kVA, 480V, 3f, 4W, and serves the building’s emergency lighting system.

Lighting System

The lighting system for the building is served by 120V and also 277V. Fluorescent T5 bulbs make up the majority of the buildings lighting. There is a sophisticated lighting control system in the building to help reduce lighting loads when spaces are not occupied. The power density is 1.1 W/ft2 in the classrooms, 1.3 W/ft2 in the offices, and 0.5 W/ft2 in the hallways.

Telecommunications

There is one main cross connect located on the first floor and one intermediate cross connect located on each of the other three floors. The intermediate cross connects are hubs for each of the floors telecommunications systems, and they are all connected to the main cross connect on the first floor. This being a business building, there is state-of-the-art networking and videoconferencing equipment located throughout the building.. The overall lighting power density for the building is 0.946 W/ft2.

Fire Protection

A wet pipe sprinkler system is provided throughout the entire building. Also, occupancy A-3 rooms need to have a 2 hour fire rating if less than 20 ft from property line. Occupancy B needs to have a 4 hour fire rating if within 5 ft of property line, and 1 hour rating if less than 40 ft from property line.

Systems Overview (Continued)

Transportation

The building contains 2 elevators that are located in the center of the building at the point where all three wings connect. The elevator hoistways are 8'-8" x 7'-9".

Sustainable Features

- An irrigation system has been designed to use reclaimed and treated wastewater from the county
- The building was designed to consume 38% less energy than that stipulated in ASHRAE 90.1
- A solar array is scheduled for installation in the future
- Daylighting is supplied to 75% of interior spaces
- The building utilizes high efficacy lighting and has a sophisticated lighting control system
- All HVAC systems are free of CFCs and HCFCs

Existing Mechanical System Overview

The UCSD Rady School of Management requires a substantial amount of cooling throughout the year and minimal heating, due to its location. The existing mechanical system is your typical variable-air-volume (VAV) system. Air is distributed to the interior spaces by overhead VAV boxes with reheat coils. The VAV boxes are supplied by three AHUs, roof-mounted to maximize the usable program area. In addition to these AHUs, there are seven fan coil units (FCUs) throughout the building that utilize the chilled water loop to maintain the design temperature in rooms with high heat generation. In order to maintain a comfortable environment, utilities are supplied by the University's central utility plant (CUP), located to the south of the site.

<u>AHU's</u>

The facility utilizes three roof-mounted air handling units with variable frequency drives. The air handlers supply air at 53^{0}F through the use of chilled-water cooling coils and utilize a minimum of 30% outdoor air. They have also been oversized in order to leave room for future expansion.

AHU-1 has a capacity of 40,000 CFM and serves the northern wing of the building, serving mainly classrooms and faculty offices. The current designed air flow is 33,660 CFM at maximum load with 19,368 CFM of outdoor air required.

AHU-2A and AHU-2B are combined into one system and work together cool the other two remaining wings of the building. These AHU's are similar to AHU-1, but they have a slightly smaller capacity. They can each handle 35,000 CFM, so together the combined system can handle up to 70,000 CFM. The current designed airflow on these air handlers is only 60,610 CFM at maximum load with 22,662 CFM of outdoor air required.

<u>FCU's</u>

There are a total of seven fan coil units located throughout the building. These units are located in rooms with high amounts of heat generation such as, the server room, elevator equipment room, and main electrical room, to help maintain them at the designed temperature. They are also located in the main and intermediate cross connects, which act as hubs for connecting telecommunications equipment. The FCU's take air in at 80^{0}F, cool it down to 55^{0}F and re-circulate it throughout the room in order to maintain acceptable ambient temperature.

Existing Mechanical System Overview (Continued)

Central Utility Plant (CUP)

The CUP is designed with one 3,000 ton York OT steam turbine driven centrifugal chiller which handles the majority of cooling requirements, as well as, a 2,000 ton York YK electric centrifugal chiller to handle peak loads and off-hour requirements. The combination of a steam and electric chillers is to provide UCSD with maximum energy efficiency and flexibility.

Chilled Water System

Chilled water is supplied by the university's CUP at 42^{O}F and circulated throughout the building by a 445 GPM base-mounted pump, as well as a 50 GPM in-line pump for off-hour loads. The chilled water supplies the 3 rooftop air handlers, as well as the seven fan coil units.

Hot Water System

Hot water is supplied by a Bell & Gossett water-to-water U-tube heat exchanger. The heat exchanger can heat 145 GPM of water from 140^{O}F to 180^{O}F with the use of high temperature water supplied by the CUP at 350^{O}F and 60 GPM. The hot water is then supplied to the building's VAV reheat coils and domestic water heater by a 145 GPM base-mounted pump.

Exhaust Fans

There are a total of 6 roof-mounted exhaust fans in the building to serve the bathrooms, electrical closets, and mechanical room. The fan serving the mechanical room moves between 600 and 2,000 CFM, and all others are designed for 4,000 CFM.

Existing Mechanical System Design & Operation

Outdoor and Indoor Design Conditions

The Rady School of Management is located in La Jolla, CA, which is located adjacent to Long Beach. In order to design a suitable mechanical system, the peak heating/cooling weather conditions needed to be evaluated. The outdoor design conditions in Table 1 show the weather data used to calculate building loads, as specified by the ASHRAE Handbook 2005.

Table 1

Outdoor Design Conditions	
Latitude	32°
Longitude	117°
Elevation	50 ft
Summer Design DB	81°F
Summer Coincident WB	67°F
Summer Daily Range	10.5°F
Winter Design DB	46°F

In addition to the outdoor design conditions, the desired indoor design conditions must be established. Below, Table 2 shows what these conditions are, as specified by the design documents.

Table 2

Indoor Design Conditions	
Cooling Supply DB	75°F
Cooling Driftpoint	78°F
Heating Supply DB	75°F
Heating Supply Driftpoint	72°F
Relative Humidity	50%

Design Ventilation Requirements

ASHRAE 62.1-2007 establishes the minimum outdoor air requirements for a building. An analysis of compliance to this standard was done and it confirmed that the building does provide a sufficient amount of outdoor air to maintain a healthy indoor environment. Below, Table 3 shows the outdoor air requirements calculated as calculated by the designer.

Table 3

OA Requirements		
	AHU-1	AHU-2A&B
CFM	19,368	22,662

Also, the building was designed to exceed the standards set forth by ASHRAE 90.1 by 38%.

Lost Usable Space

An evaluation of the mechanical system layout in terms of lost usable space was done to show how well the designers maximized the program area. With the air handlers located on the roof and no on-site chillers or boilers, very little space was lost in terms of total program area. Of the roughly 101,000 ft^2 building, only 2,980 ft^2 was lost due to mechanical components. Not only that, but the main mechanical room is over-sized as of now, due to the fact that room needs to be left for expansion. Below, Table 4 shows the breakdown of lost usable space, as well as the percentage of the total building area.

Table 4

Lost Usable Space (ft^2)	
Mechanical Room	1580
Vertical Mechanical Shafts	1400
Total Lost Space	2980
% of Building Area	2.95%

Chilled Water System

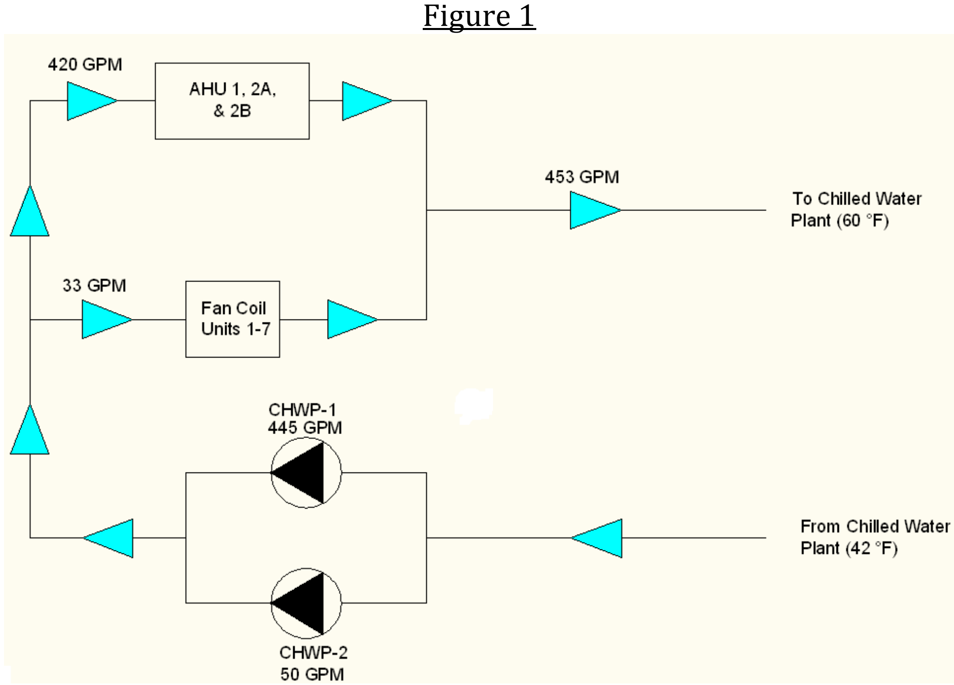
For cooling purposes, chilled water is delivered to the building, from the University's central utility plant, at 42°F and a maximum rate of 453 GPM. Two pumps, equipped with variable frequency drives (VFDs), are then used to circulated the water to the rooftop air handling units, as well as the building's seven fan coil units. One pump is base mounted and has a maximum design capacity of 445 GPM. This pump is designed to do all of the pumping during normal operational hours. To reduce electricity consumption, there is also an in-line pump with a maximum design capacity of 50 GPM to keep water circulating to any of the building's required loads during off-hour operation.

Differential pressure transmitters (DPTs) control the VFDs that regulate the pumps' flow rates. These DPTs are located on the supply and return lines coming from each of the three air handling units. There are also DPTs located on each of the VAV boxes to regulate airflow to the zones. The FCUs are regulated by thermostats and motorized control valves. Chilled water pump data can be found in Table 5 and a schematic of the loop can be found in Figure 1 below.

Table 5

Chilled Water Pump Schedule				
PUMP	SYSTEM	PUMP TYPE	DESIGN CAPACITY (GPM)	DESIGN HEAD (FT)
CHWP-1	CHILLED WATER	BASE MOUNTED	445	80
CHWP-2	CHILLED WATER	INLINE	50	35

Figure 1



Hot Water System

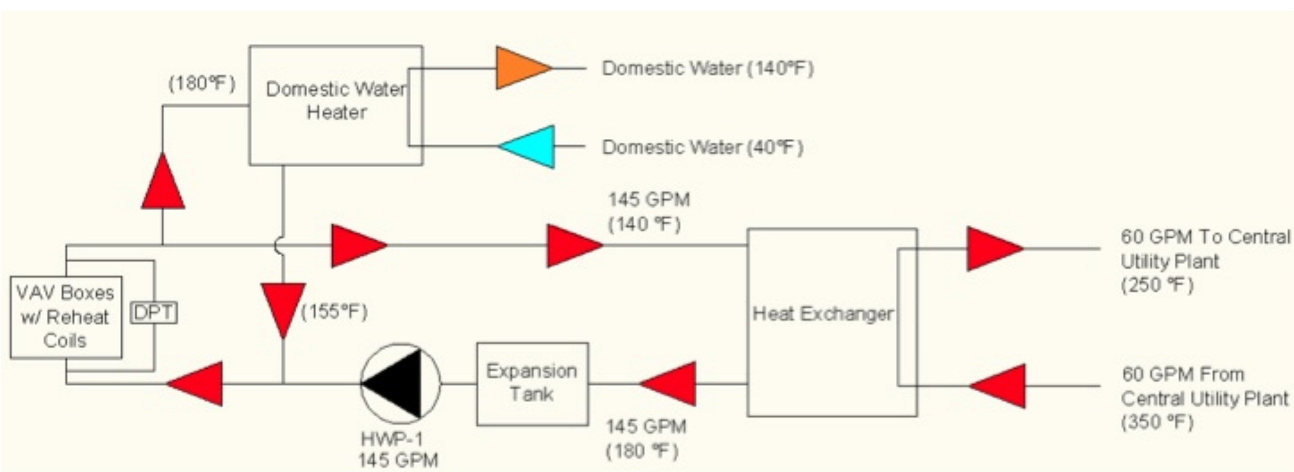
For heating purposes, high temperature water is delivered to the building, from the central utility plant, at 350ºF and a rate of 60 GPM. This high temperature water is designed to pass through the shell-side of the water-to-water U-tube heat exchanger to increase the temperature of the building's hot water that runs through the tube-side. The shell-side water leaves the heat exchanger at 250ºF and is circulated back to the CUP. On the tube side of the heat exchanger, water enters at 140ºF and a maximum rate of 145 GPM. After heat transfer between the shell and tube, the water exits the heat exchanger at 180ºF. This water is used to heat domestic water, and also supply the buildings VAV box reheat coils.

The hot water is delivered to these systems by a base mounted pump with a design capacity of 145 GPM and a VFD. The VFD regulates the pump speed based on differential pressure transmitters, just like the chilled water pumps. Data on the hot water pump is located in Table 6 and a schematic of the loop can be found in Figure 2 below.

Table 6

Pump Schedule				
PUMP	**SYSTEM**	**PUMP TYPE**	**DESIGN CAPACITY (GPM)**	**DESIGN HEAD (FT)**
HWP-1	HEATING WATER	BASE MOUNTED	145	20

Figure 2



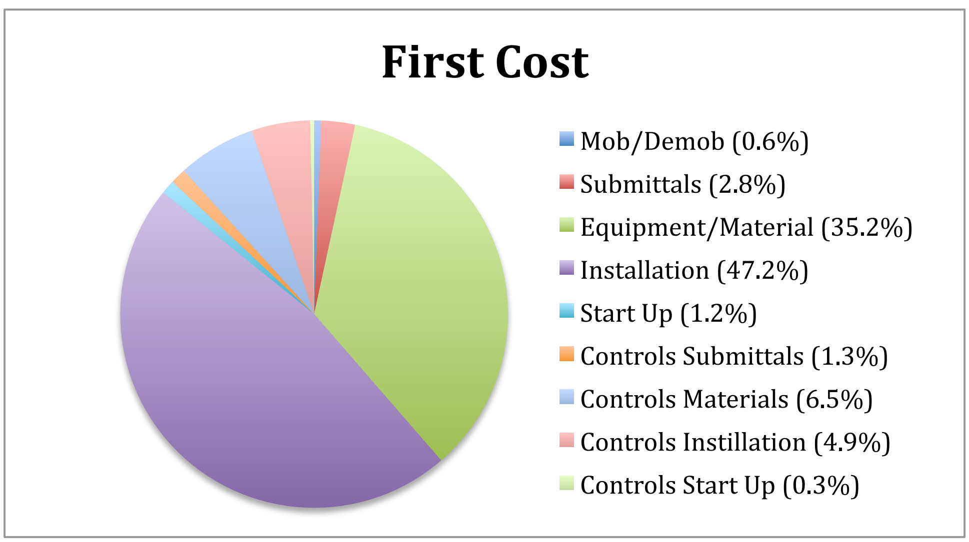
Mechanical System First Cost

Below, Table 7 shows a breakdown of the mechanical system's first cost. The mechanical system first cost was slightly over $3 million and accounted for 8.5% of the total cost of construction, which was about $3.5 million. This first cost per square foot for this facility is $47.80. This is a pretty low number in terms of the average cost of a mechanical system. This is due to the fact that there are no on-site chillers or boilers. The mechanical system is very simple and does not have many components as compared to the average facility of this size. Because of this, this system is very inexpensive. A breakdown of the HVAC system costs is provided in Figure 3.

Table 7

First Cost		
Work Activity/Equipment	Cost	Cost/ft^2
HVAC – Mob/Demob	$17,670	$0.28
HVAC – Submittals	$84,716	$1.34
HVAC – Equipment/Material	$1,060,719	$16.84
HVAC – Installation	$1,420,385	$22.55
HVAC – Start Up	$35,340	$0.56
HVAC Controls – Submittals	$39,249	$0.62
HVAC Controls – Materials	$196,247	$3.12
HVAC Controls – Instillation	$147,185	$2.34
HVAC Controls – Start Up	$9,812	$0.16
TOTAL	**$3,011,323**	**$47.80**

Figure 3



Design Heating and Cooling Loads

During the design phase, the design engineer created an energy model using EnergyPro 3.1. Below, Table 8, 9, & 10 shows the results of this model.

Table 8

Cooling	
Load (ft^2/ton)	812
Supply Air (CFM/ft^2)	1.47
Ventilation Air (CFM/ft^2)	0.67

Table 9

Heating Load	
Design (ft^2/ton)	578.3

Table 10

Annual Energy Use (kBTU/ft^2*yr)	
Space Cooling	26.49
Spacing Heating	18.92
Fans	13.73
Heat Rejection	13.01
Pumps	2.76
TOTAL	**74.91**

From the designer's model you can see that this building was designed to be very energy efficient. The total design energy consumption was calculated to be 27.9% below that of what is required by Title 24 of California's building regulations. Because it is that much lower than the Title 24 requirements it qualifies for both owner and designer incentives.

Operating History

From the assistant campus energy manager, I was able to obtain energy utilization data along with average cost rates for each type of service required for the Rady School of Management. The data supplied was from July '08 to June '09. Below, Table 11, 12, 13, & 14 summarize the monthly consumption for each service.

Table 11

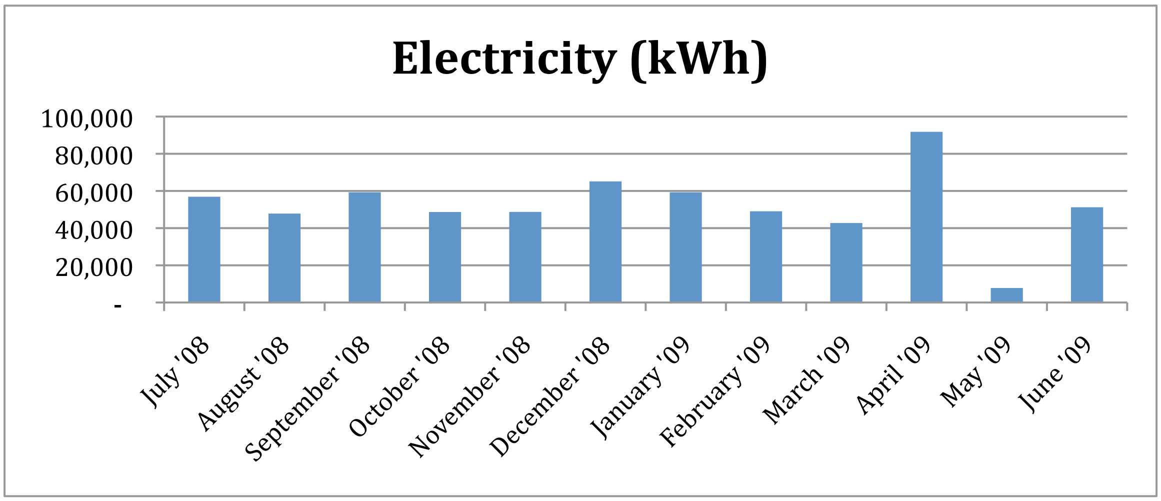


Table 12

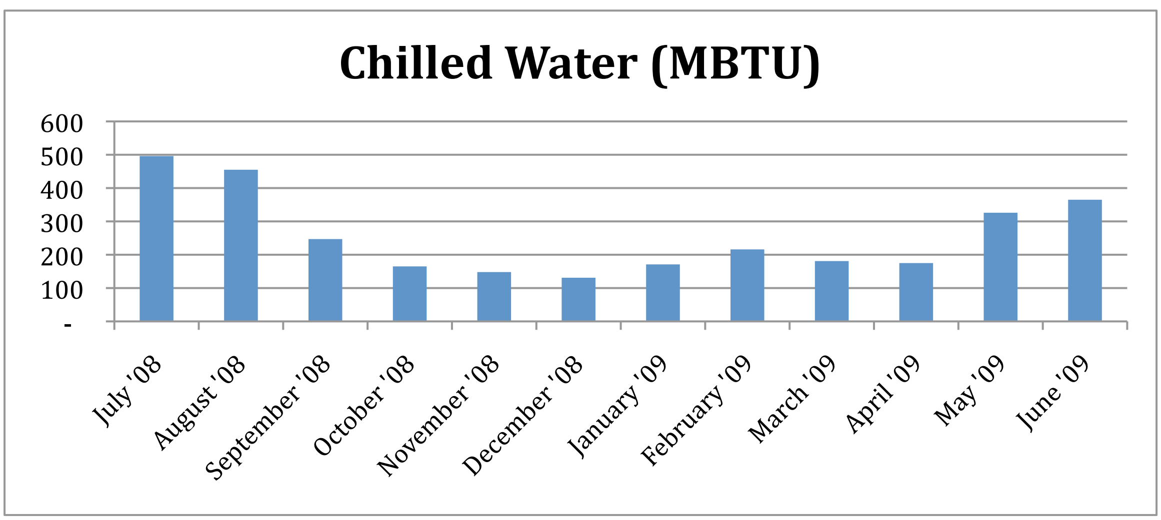


Table 13

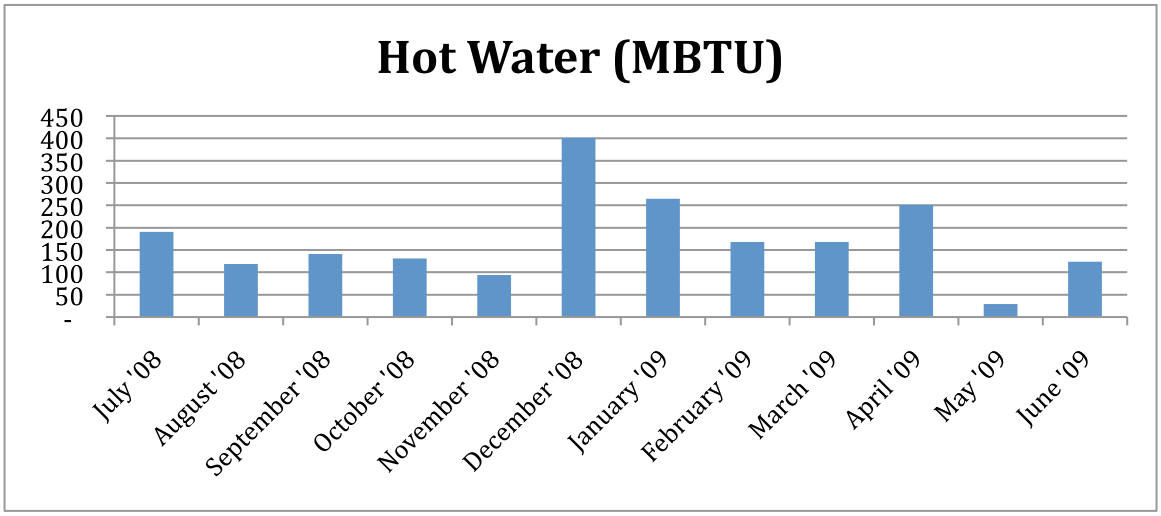
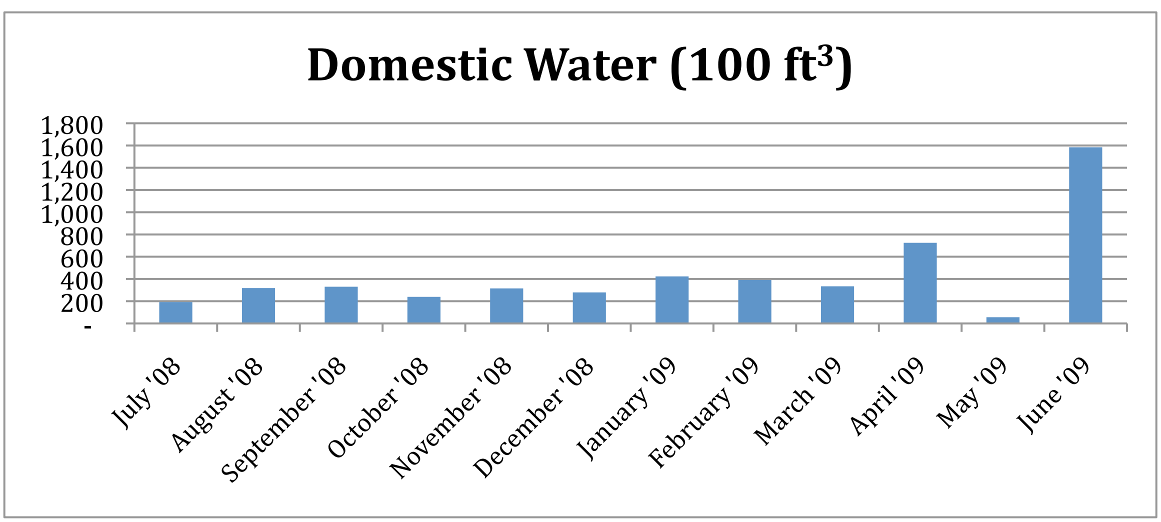


Table 14



Operating Costs

Energy Sources and Rates

Since the Rady School of Management is fed by the University's central utility plant, standard utility rates do not apply. The assistant campus energy manager was able to give me a breakdown of the rates for each service they receive. Below, Table 15 gives these utility rates as they apply to consumption data provided.

Table 15

Utility Rates	
Electricity	$.08/kWh
Chilled Water	$6/MBTU
Hot Water	$11.5/MBTU
Domestic Water	$5.7/100 ft^3

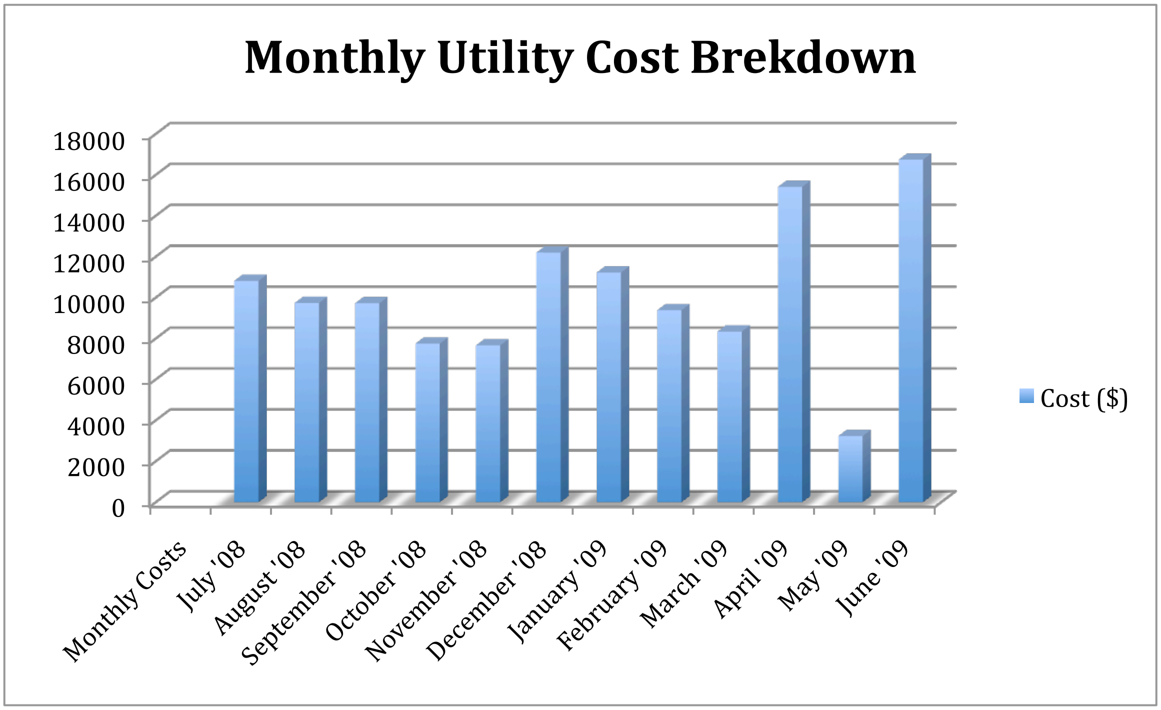
Annual Operating Cost

From rates and consumption history provided, I was able to calculate the annual cost of operation this facility from July'08 to June'09. Below, Table 16 is a chart that breaks down the annual costs for each utility service. I have also provided a monthly breakdown of the cost of running this facility in Table 17 on the next page. As you can see from the data, this building is very inexpensive to operate in comparison to other building of its size. This is due most likely due to the fact that the University's central utility plant supplies the building cheaply and efficiently. The quality of design also plays a big part. There is no doubt, that designing the building 27.9% above that required by Title 24 will pay off in the long run.

Table 16

Annual Operating Cost	
Electricity (41.1%)	$50,266.80
Chilled Water (15.1%)	$18,456.00
Hot Water (19.6%)	$23,943.00
Domestic Water (24.2%)	$29,560.20
TOTAL	$122,226.00
TOTAL/ft²	$1.91

Table 27


Monthly Utility Cost Brekdown
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Monthly Costs
July '08
August '08
September '08
October '08
November '08
December '08
January '09
February '09
March '09
April '09
May '09
June '09
Cost ($)

Proposal

The proposed redesign for the Rady School of Management's mechanical system is to replace the existing VAV system with a dedicated outdoor air system (DOAS) in conjunction with active chilled beams (ACBs). The DOAS is designed and sized to handle all of the latent loads on the building, while the ACBs handle what is left of the sensible load.

Once these systems are installed, they tend to be quite beneficial due to higher energy efficiency as compared to a typical VAV system. They are also desirable due to ease of maintenance, increase in usable program area, and increased indoor air quality. This increased indoor air quality is because the DOAS helps prevent the spread of contamination by using 100% outdoor air. Also, if designed right, they can provide better thermal comfort levels.

Through my research and calculations, I will try to prove that this type of system could be beneficial to the owners of the building. There is typically an increased initial cost for these systems due to the cost of the ACBs and increased pumping requirements. By eliminating the need of some of the FCUs and AHUs, as well as reducing the size of VAV boxes and fans, I will try and offset these extra costs enough to create a relatively short payback period.

I will begin by calculating the amount of outdoor air required and use this as the basis for my airflow rates. Using these rates and my latent load calculations, I will be able to find the required humidity ratio for the supply air. Once this is found, the sensible cooling capacity of the air will be subtracted from the sensible heat gains to find the load that will need to be handled by the ACBs. With this information, new mechanical equipment can be selected and the cost of operation calculated. Once this is complete, I will be able to find payback period and hopefully determine that this type of system would be a feasible and desirable option.

Once this is complete, I will take a look at the effect it will have on the electrical system. Eliminating and adding mechanical components will require the panelboards to be redesigned, as well as the wiring and circuit breakers to be resized. Along with this, a construction management breadth will be done in order to calculate how much time would be needed to install these new components and how many work crews it will take.

Mechanical Redesign

Overall, the current mechanical system for the Rady School of Management is pretty well designed for a VAV system. Unfortunately, VAV system efficiency is limited by the use of use of air to cool spaces. In an ACB system, system efficiency can increase drastically due to the fact that water has a much higher heating capacity than air. This means a much lower quantity of water must be supplied (as compared to air in a VAV system) to create the same amount of heat removal/addition.

Supply air is still need to meet the requirements set forth by ASHRAE standard 62.1 and to meet the space's latent load, but this quantity of air is much less than would be required in a VAV system. This will lead to smaller ducts, increasing usable program area and minimizing the space requirement for the interstitial space. Along with this, fan power can be greatly reduced and AHUs can be downsized. The downside of these types of systems is that they usually require more pumping power and more piping, but generally the benefits more than make up for this increase in cost.

Another benefit to this system is the increased air quality due to the dedicated outdoor air system. In your typical VAV system, it is very difficult to verify if ASHRAE standard 62.1 is actually being met. With a DOAS, this uncertainty is eliminated and indoor air quality should benefit greatly. With improved indoor air quality, productivity and health of the building's occupants should increase. This is another big factor to how these systems can quickly repay any extra initial costs. Also, if maintained properly, the ease of maintenance on these systems should be another big benefit.

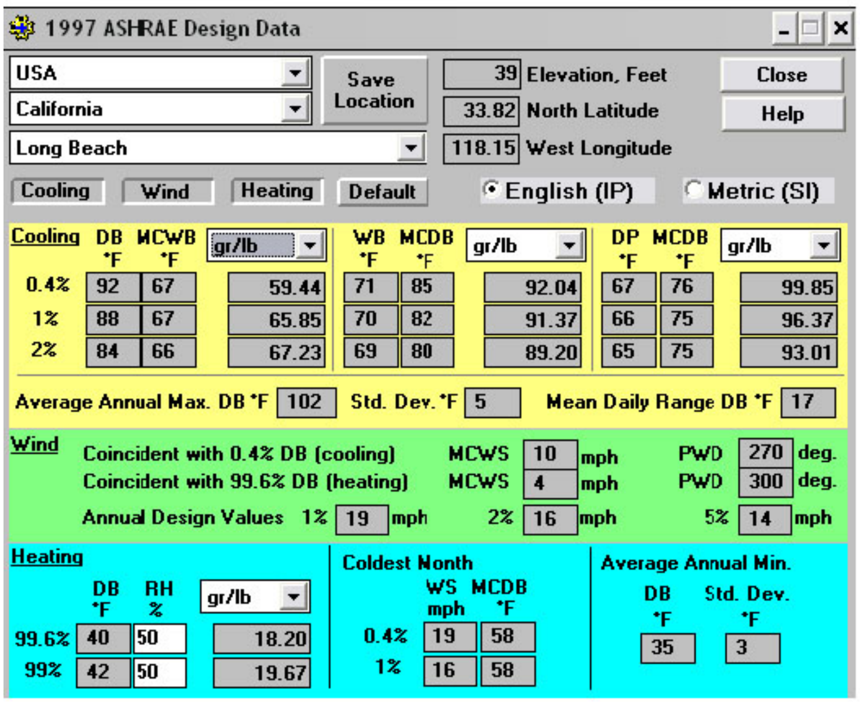
Design of the new system needs to be done carefully to ensure that all latent loads are met, and that the spaces are not overcooled by the supply air. In an ideal situation, the ventilation air required by ASHRAE 62.1 would handle all of the latent load and as much of the sensible load as possible without over cooling. The ACBs will then make up the rest of the sensible loads. This is sometimes a hard balance to achieve, especially when there are large sensible/latent load differences throughout the building.

The following pages describe how I determined the required amount of supply air and sensible cooling from the ACBs.

Outdoor Air Design Conditions

The first step to designing this new system was to determine what my design temperature should be. To determine these conditions, Bin Maker Plus was used. The location chosen was Long Beach, CA, as it is only a few miles from La Jolla. Below, Figure 4 shows the values provided by Bin Maker Plus.

Figure 4



Bin Maker Plus provides you with a few different sets of design temperatures and humidity levels. In determining which set of temperatures to use, I chose the set of values that led to the highest outdoor air enthalpy from the 0.4% column. This was done, because the cooling coil is sized based on how much enthalpy must be removed from the air before it is supplied to the spaces. Using the temperatures provided, the values that resulted in the highest enthalpy were WB/MCDB temperatures of 71°F/85°F, respectively. The enthalpy value was found to be 34.84 BTU/lb.

Target Space Conditions

Based on my research, the typical space dry bulb temperature for an ACB system can be a few degrees higher than your typical VAV system. This is because of an increase in radiation transfer from the human body to the ACBs. This increase in radiation transfer allows for an increased dry bulb temperature without effecting occupant comfort. Based on this knowledge, the building target indoor air temperature for cooling will be 79°F and 50% RH. This results in a humidity ratio of 74.35 gr/lb of dry air and a dew point temperature of 58.8°F throughout the building. In order to avoid condensation and the problems that are associated with it, it is necessary to make sure that the ACBs are maintained above this dew point temperature.

In researching ACB manufacturers and product data, I found that a temperature difference of about 16°F between the ACB mean water temperature and room temperature to be a fairly typical value. This would result in a value of 63°F for the beams. Below, Table 28 summarizes the indoor design conditions.

Table 28

Indoor Design Conditions	
Space Dry Bulb Temp.	79°F
Space Relative Humidity	50%
Space Humidity Ratio	74.35 gr/lb
Space Dew Point Temp.	58.8°F
ACB Surface Temp.	63°F

Required Ventilation Rates

The next step to the process was to determine the necessary ventilation rates based on ASHRAE 62.1. This would be the basis for sizing the DOAS unit. First off, occupancy levels were determined based on typical occupancy densities and the amount of floor area. Then the amount of ventilation air was calculated based on the CFM/person and CFM/ft^2 quantities established in the standard. The total outdoor air required was then the sum of all the required ventilation air to each space, plus the make-up air required for the exhaust systems.

The internal generation loads were also calculated along with this. Latent loads were determined based on level of occupancy and the type of activity that takes place in each space. Sensible loads were determined based on lighting density, equipment loads, and occupancy level. These values can be found in Appendix A.

Determining Supply Air Humidity Ratio

The next step in the design process involved determining the supply air humidity ratio. Using the required ventilation air as the set volume of air being supplied to each room, the required humidity ratios to control latent loads were calculated using equation 1. These calculations can also be found in Appendix A.

Equation 1: $Q_L=0.68V_{SA}(\Delta W)$, or $\mathbf{W_{SA}=W_{SP}-Q_L/(0.68V_{SA})}$

W_{SA}= Supply Air Humidity Ratio (gr/lb of dry air)
W_{SP}= Space Humidity Ratio (gr/lb of dry air)
Q_L= Space Latent Load (BTU/hr)
V_{SA}= Supply Air Flow Rate (CFM)

Once the required humidity ratios are determined, the space with the lowest value is the critical space. In this case, it was the library. The required humidity ratio for the library was found to be 23.09 gr/lb of dry air. This was well below the requirements of any other space in the building, so airflow to this room was increased. This resulted in a humidity ratio similar to the other spaces, and made it so the air could be supplied at a humidity ratio of **40.0 gr/lb of dry air** to the entire building. After these calculations were finished the total supply air quantity was found to be **36,191 CFM**.

The next step was to calculate how much of the sensible load was eliminated through the ventilation air. To do so I used equation 2.

Equation 2: $\mathbf{Q_S=1.08V_{SA}(\Delta T)}$

Q_S= Space Sensible Load (BTU/hr)
V_{SA}= Supply Air Flow Rate (CFM)
ΔT= Difference between Room Air DB and Supply Air DB (°F)

The total sensible cooling loads were calculated based on design drawing specifications. External sensible loads were calculated using a Trane TRACE 700 block analysis and added into this total. Then, by subtracting the sensible heating value calculated with equation 2, I was able to find the required sensible cooling required by the ACB. Based on Dr. Mumma's articles, air will be supplied at 45°F to reduce the amount of reheat and have more of an effect on sensible loads. With this information, I was able to calculate how many ACBs I would need in each space based on manufacturer's data. In some spaces, the ventilation air was enough to handle the sensible load as well, and no ACBs were needed. I found that the max flow rate in the system would be **1,508 GPM** with **3,211 ft of head**. The cut sheet for the ACBs that I used is located in Appendix B and calculations in Appendix C.

Cooling Coil Load

My next step was to design the cooling coil for the DOAS unit. To do this I used equation 1.

Equation 3: $Q_{CC}=.06\rho V_{SA}(\Delta H)$

Q_{CC}= Cooling Coil Load (kBTU/hr)
ρ = Average Density of Air (lb/ft^3)
V_{SA}= Total Supply Air Volume (CFM)
ΔH= Required Change in Enthalpy Across the Coil (BTU/lb)

To solve this equation, I needed to calculate the enthalpy of the outdoor air after it has already passed through an enthalpy wheel. The incoming outdoor air has an enthalpy of 34.84 BTU/lb and the return air has an enthalpy of 30.6 BTU/lb. Assuming that the enthalpy wheel is 85% effective, after the wheel the air should have about 31.24 BTU/lb. I then calculated the average density of air to be about .07544 lb/ft^3 over the coil. Using these values, I calculated the load on cooling coils for areas A and then areas B & C. For area A, the cooling coil needs to have a capacity of 929 kBTU/hr, or **77.4 tons**. For area B & C, the cooling coil needs to have a capacity of 1,695 kBTU/hr, or **141.3 tons**.

After that I needed to calculate the amount of sensible reheat required to supply the air at 45°F. This was done using equation 2. Since the air leaves the coil with 40 gr/lb in a saturated condition. I found the dry bulb temperature to be 42.3°F, making ΔT=2.7°F. I then calculated this load to be .116 MBH of heating.

Heating Requirements

The majority of the time will only require cooling, but there are some spaces that will require heating as well, during certain times of the year. I calculated this heating load based on my Trane TACE 700 results. Then using the manufacturer data, I was able to calculate how many GPM would be required of heating water. The cut sheet specifies water with an inlet and outlet temperature difference of 4°F. Also, my average ACB temp needs to be 95°F, so water enters at 97°F and leaves at 93°F. Along with flow rate, a pressure drop was also calculated. The total head loss for the system was found to be **1,121 ft** at **1,213 GPM**. Using equation 3 again, it was found that **5.7 MBH** of heating would be required at peak load. A table with these calculations can be found in Appendix D.

First Cost Analysis

With this new design in place, there were several components of the mechanical system that could be changed. First and foremost, there is no longer a need for three air handlers. One of the 35,000 CFM air handlers would be sufficient to supply the entire building. However, this building is designed for expansion, so keeping an extra AHU would be wise. Below, Table 29 shows the change in CFM requirement as compared to the original design. As you can see there was a drastic reduction in required airflow. Table 30 shows the new design's required airflow to each area of the building.

Table 29

Required Airflow (CFM)	
Original Design	94,270
Redesign	36,191
% Difference	61.6%

Table 30

Required Air Flow (CFM)		
	Area A	Area B & C
1st Floor	4,259	11,190
2nd Floor	2,108	6,490
3rd Floor	3,295	2,829
4th Floor	3,152	2,868
Total	**12,814**	**23,377**

Also, six of the seven fan coil units that were in the building will no longer be required. It was found that in the elevator equipment room there is not enough ceiling area to handle the entire load, so I would recommend keeping the FCU for this room. The VAV boxes should probably still remain present in order to properly regulate the amount of air into each space and allow for reheat to prevent over cooling, but the sizes of these boxes can be reduced. Along with that, duct sizes can be reduced significantly, leading to more usable program area. Below, Table 31 and 32 show the savings that could be seen in terms of VAV and FCU units. The cost values for this analysis are based off of RS Means data and data received from manufacturers.

Table 31

Savings on VAV Units				
	Old	New	Cost/Unit	Total Savings
A	0	55	$762	-$41,910
B	4	0	$773	$3,092
C	15	0	$773	$11,595
D	10	0	$810	$8,100
E	1	0	$810	$810
G	21	0	$908	$19,068
H	7	0	$1,035	$7,245
J	1	0	$1,119	$1,119
				$9,119

Table 32

Savings on FCUs			
	# of Units	Cost/Unit	Total Savings
1/2 ton	5	$1,139	$5,695
12.5 tons	1	$4,795	$4,795
			$10,490

Along with the VAVs and FCUs, the Fans in the AHUs will also lead to savings. With this design, the 32,000 CFM fan could be eliminated and the 28,000 CFM fan can be replaced with a 15,000 CFM fan. Below, Table 33 shows the savings that could be seen.

Table 33

Fan Savings	
	Savings
28,000 CFM, 20 hp	$8,355
32,000 CFM, 20 hp	$10,725
15,000 CFM, 10 hp	-$5,565
	$13,515

While the air side of the system will be reduced, the water side needs to be increased. With the new system in place the chilled water loop will be able to move **2,150 GPM** with **3,650 feet of head**. The new hot water loop will need to move **1,450 GPM** with **1,300 feet of head**. These values were determined by adding the old flow requirement to the new ones. The calculated values for the new system were increased by 10% to avoid under sizing the pumps. The chilled water loop will require five 100 hp pumps, and another 3 will be required by the hot water loop. The pump performance curve can be found in Appendix E. Due to the fact that the mechanical room was intentionally oversized for expansion, finding room for these new pumps will not be a problem. I was unable to receive cost data for these pumps, so I was unable to create a precise estimate of the total cost. Based on the costs of smaller pumps, I believe this cost should not exceed $200,000. A rough calculation of these costs is shown below in Table 34.

Table 34

Pump Costs		
	# of Units	Total Cost
1 HP, Inline	1	-$3,351
15 HP, Centrifugal	1	-$9,930
5 HP Centrifugal	1	-$7,425
100 HP, Centrifugal	8	$200,000
		$179,294

The savings based on the AHUs was also hard to estimate due to the fact that I could not find RS Means data for AHUs like the ones in the building. In order to create a first cost estimate though, I assumed that one of them would be removed and that they have a typical cost of $56,000. Also, precise ACB costs could not be found, but in talking with a manufacturer I was told that a Price active chilled beam costs about $400 per unit including installation. Manufacturer data on the ACBs can be found in Appendix B. Using this value, I was able to estimate the cost of the 1,396 ACBs that would be required. Below, Table 35 shows the breakdown of the costs for the new system.

Table 35

Extra Cost	
Equipment Type	Cost
AHUs	-$56,000
VAV Boxes	-$9,119
FCUs	-$10,490
Pumps	$179,294
Fans	-$13,515
ACBs	$558,400
	$648,570

Operating Cost Analysis

My next step was to calculate the cost of operation of this new system. In order to accomplish this, I used the data from my Trane TRACE 700 energy model. It is hard to accurately model this type of system in the program, but I did my best and the results seem to be fairly accurate. Below, Table 36 shows the result as compared to the designer's energy model of the old system.

Table 36

Annual Energy Use (kBTU/ft^2*yr)		
	Old	New
Space Cooling	26.49	22.78
Space Heating	18.92	12.87
Fans	13.73	8.24
Pumps	2.76	10.93
TOTAL	**61.90**	**54.81**

According to this energy usage data, the new system will consume only 88.6% of the energy of the old system. That means there is an **11.4% reduction** in energy consumption. Below, Table 37 shows the savings that could be seen by reducing energy consumption with the new system.

Table 37

Energy Cost	
Old	$92,666
New	$82,056
Difference	**$10,610**

As you can see from the data, there is not a huge reduction in operating costs. This is probably due to the fact that the building is supplied by the campus' central utility plant at a very low cost.

Conclusion

When analyzing all of this data, it appears that this system would not be very beneficial in this case. Based on the information that is shown above, the system would have a payback period of 61 years, and therefore this approach would probably not be a viable option. However, it was difficult to get an accurate estimate of the added initial costs. One reason for this was due to the fact that I could not get a hold of detailed bidding documents. This meant I had to estimate typical costs based on RS Means data and not actual values. Also, in some cases it was difficult to find equipment in RS Means that was similar to that in the building such as the pumps and the air handling units. In addition to this, it would have been possible to eliminate another AHU, but in order to leave room for expansion I only accounted for eliminating one, instead of two. For these reasons, I believe this system would be paid back sooner than 61 years, but I do not believe that they could have made enough of a difference to make this system desirable.

During my initial proposal, I thought that the elimination and reduction of FCUs, AHUs, and VAV boxes would lead to a larger reduction in cost then it actually did. Although the system did not prove to be economically beneficial, ACB systems in conjunction with a DOAS can have many other benefits. These benefits include:

- ➔ Possible reduction in interstitial space due to a reduction in duct sizes. This can lead to a reduction in architectural materials required and reduce first costs further.
- ➔ ACBs are easier to maintain than FCUs and can save maintenance costs.
- ➔ These systems tend to have better thermal comfort levels than a typical VAV system.
- ➔ Dedicated outdoor air systems lead to better indoor air quality than standard HVAC systems.

For these reasons, these types of mechanical systems can be very successful. Probably the most important aspect of these systems is the increased indoor air quality because it can greatly improve the productivity of the building's occupants. The DOAS is also a sure way to verify that ASHRAE Standard 62.1 has been met. Unfortunately, these systems are not viable in all cases. There is a litany of benefits to them, but in the end it usually comes down to money. In this case, the existing VAV system would probably be the preferred mechanical system for most owners who have to think economically.

Mechanical Equipment Connections

Along with all of the modifications to the mechanical system, there will also need to be modifications to the electrical systems. Due to the existing design of the electrical system these changes were fairly simple and straightforward. I started out by analyzing the equipment connection schedule. This existing equipment connection schedule can be found in Appendix F. Below, Table 38 shows the existing connections and wiring for the equipment that would be replaced if this DOAS/ACB system were to be used.

Table 38

Existing Equipment Connections						
Equipment	HP	Volts	PH	Fuse/Pole	Source	Wire Size
AHU-1	50	480	3	150A/3P	4MCC/1,2,3	1.25"C - 3 #2 & 1 #6 GND
RF-1	20	480	3	50A/3P	4MCC/10,11,12	3/4"C - 3 #10 & 1 #10 GND
RF-2A	20	480	3	50A/3P	4MCC/13,14,15	3/4"C - 3 #10 & 1 #10 GND
FCU-1	1/8	120	1	20A/1P	1EPB1/1	3/4"C - 3 #12 & 1 #12 GND
FCU-2	1/12	120	1	20A/1P	1EPB1/3	3/4"C - 3 #12 & 1 #12 GND
FCU-3	1/12	120	1	20A/1P	1EPB1/5	3/4"C - 3 #12 & 1 #12 GND
FCU-4	1/12	120	1	20A/1P	1EPB1/2	3/4"C - 3 #12 & 1 #12 GND
FCU-5	1/12	120	1	20A/1P	1EPB1/4	3/4"C - 3 #12 & 1 #12 GND
FCU-7	2	480	1	20A/3P	1EHA/13,15,17	3/4"C - 3 #12 & 1 #12 GND
CHWP-1	15	480	3	40A/3P	1MCC/1,2,3	1"C - 3 #8 & 1 #10 GND
CHWP-2	1	480	3	20A/3P	1EHA1/2,4,6	3/4"C - 3 #12 & 1 #12 GND
HWP-1	5	480	3	20A/3P	1MCC/10,11,12	3/4"C - 3 #12 & 1 #12 GND

From the table above, you can see that most of the large mechanical equipment connections are made in the main cross connect. The equipment that is not connected in the MCC is connected in other panelboards throughout the building. The redesign of these panelboards was simple due to the fact that most of them are dedicated to the mechanical equipment that is connected there. Panelboard 1EPB1 contains the connections for FCUs 1-5 and the rest of the available circuits are left as spares. This means the FCU connections can be eliminated and turned into more spares without needing to resize anything. This is also true for the panelboards containing the connections for CHWP-1 and FCU-7.

After analyzing what equipment could be removed, it was necessary to analyze the needed electrical connections for the new equipment. Again this was fairly straightforward due to the existing design. Below, Table 39 shows the new connections that must be made and where they will be made.

Table 39

New Equipment Connections						
Equipment	HP	Volts	PH	Fuse/Pole	Source	Wire Size
New RF-2A	10	480	3	40A/3P	4MCC/13,14,15	1"C - 3 #8 & 1 #10 GND
New CHWP-1	100	480	3	150A/3P	1MCC/1,2,3	1.25"C - 3 #2 & 1 #6 GND
New CHWP-2	100	480	3	150A/3P	1MCC/4,5,6	1.25"C - 3 #2 & 1 #6 GND
New CHWP-3	100	480	3	150A/3P	1MCC/7,8,9	1.25"C - 3 #2 & 1 #6 GND
New CHWP-4	100	480	3	150A/3P	1MCC/10,11,12	1.25"C - 3 #2 & 1 #6 GND
New CHWP-5	100	480	3	150A/3P	1MCC/13,14,15	1.25"C - 3 #2 & 1 #6 GND
New HWP-1	100	480	3	150A/3P	1MCC/16,17,18	1.25"C - 3 #2 & 1 #6 GND
New HWP-2	100	480	3	150A/3P	1MCC/19,20,21	1.25"C - 3 #2 & 1 #6 GND
New HWP-3	100	480	3	150A/3P	1MCC/22,23,24	1.25"C - 3 #2 & 1 #6 GND

The addition and subtraction of the required equipment ended up having very little effect on the overall design of the electrical system. The biggest change was to the wiring. The new system requires less wiring, but the average size of these wires needed to be increased to serve the large pumps that were added. The other change that needed to be made was to the number and rating of the circuit breakers. Below, Table 40 shows the rating and number of breakers that needed to be added/subtracted for the new system.

Table 40

Breaker Changes			
	Old	New	Total
20A/1P	5	0	-5
20A/3P	3	0	-3
40A/3P	1	1	0
50A/3P	2	0	-2
150A/3P	1	8	+7

Construction Management Breadth

In order to determine the time and cost of installing all of the new components into the building I used RS Means data. In the process of doing this, I realized that this would raise a few problems. One problem was that there were no listings for 100 HP pumps, so I tried to estimate the value based off of the costs of smaller pumps. I also realized that there is no RS Means data for ACBs, so I had no way of estimating the time of installation. Because of this I left them out. I realize that due to the large number of them that they would take up the most time and largest cost, but I could not find a way around it. However a rough cost of the ACBs was done in the first cost analysis, based on data from the manufacturer. In the end, I believe I was able to give a reasonable estimate of how long it would take to install all of the other new components and how much they would cost. Assuming the circuit breakers and pump installation can be done concurrently, the total time of installation would be 3 days with 21 crews and cost roughly $243,092. This time was dictated by the eight 100 HP pumps. If the ACBs were included it would probably take a great deal longer and require many more crews. Below Table 41 shows the RS Means data collected, and Table 42 shows the time and cost calculations.

Table 41

RS Means Data						
Equipment	Crew	Daily Output	Hours	Material	Labor	Total
10 HP Fan	Q-9	2	8	$5,225	$340	$5,565
100 HP Pump	Q-2	1.2	21	$24,000	$1,670	$25,670
10 HP Motor Conn.	1 Elec	4.2	1.905	$16	$90	$105
100 HP Motor Conn.	1 Elec	1.5	5.333	$194	$251	$445
10 HP Motor Ckt. Brkr.	1 Elec	3.2	2.5	$430	$118	$548
100 HP Motor Ckt. Brkr.	2 Elec	1.6	10	$2,050	$470	$2,520
#2 Wire	2 Elec	4	4	$258	$188	$446
#6 Wire	2 Elec	4.4	3.636	$168	$171	$339
#8 Wire	2 Elec	4.8	3.2	$128	$153	$281
#10 Wire	2 Elec	5.2	2.8	$108	$135	$243

Table 42

Cost/Time of Installation					
Equipment	# of Units	Days/Crew	# of Crews	Days	Cost
10 HP Fan	1	0.5	1	0.5	$5,565
100 HP Pump	8	6.7	4	1.7	$205,360
10 HP Motor Conn.	1	0.2	1	0.2	$105
100 HP Motor Conn.	8	5.3	4	1.3	$3,560
10 HP Motor Ckt. Brkr.	1	0.3	1	0.3	$548
100 HP Motor Ckt. Brkr.	8	5.0	4	1.3	$20,160
#2 Wire	12	3.0	3	1.0	$5,352
#6 Wire	4	0.9	1	0.9	$1,356
#8 Wire	3	0.6	1	0.6	$843
#10 Wire	1	0.2	1	0.2	$243

Appendix A

Room	Area	Occupant Density (ft²/person)	Occupants	Sens. Load per Person (Watts)	Lat. Load per Person (BTU/hr)	Lighting Load (W/ft²)	School/Office Equip. (W/ft²)	Misc. Equip. (Watts)	Internal Sens. Load (Watts)	Lat. Load (BTU/hr)
Hallways/Lobbies	3,376	0	0	0	0	0.5	0	0	1,688.0	0
Electric Room	1,706	300	6	8.1	275	0.946	0	4455	6,117.5	1,650
Breakout	171	15	12	7.3	205	1.1	0.22	0	313.3	2,460
Breakout	171	15	12	7.3	205	1.1	0.22	0	313.8	2,460
Breakout	171	15	12	7.3	205	1.1	0.22	0	313.8	2,460
Classroom	2,415	20	121	7.3	205	1.1	0.22	0	4,070.4	24,805
Classroom	2,415	20	121	7.3	205	1.1	0.22	0	4,070.4	24,805
Elevator Room	100	300	1	8.1	275	0.946	0	1231	1,333.7	275
Make-up Air	-	0	0	0	0	0	0	0	-	0
Breakout	172	15	12	7.3	205	1.1	0.22	0	314.6	2,460
Breakout	172	15	12	7.3	205	1.1	0.22	0	314.6	2,460
Engineering Office	172	15	12	7.3	205	1.3	0.22	0	349.0	2,460
Mechanical Room	1,580	300	6	8.1	275	0.946	0	0	1,543.3	1,650
Main Cross Connect	1,050	300	4	8.1	275	0.946	0	229	1,254.7	1,100
Classroom	2,818	20	141	7.3	205	1.1	0.22	0	4,749.1	28,905
Classroom	2,818	20	141	7.3	205	1.1	0.22	0	4,749.1	28,905
Dining	1,838	15	123	8.1	275	0.946	0	0	2,735.0	33,825
Kitchen	700	200	4	8.1	275	0.946	0	0	694.6	1,100
Make-up Air	-	0	0	0	0	0	0	0	-	0
Changing Room	500	50	10	7.3	205	0.946	0	0	546.0	2,050
Changing Room	500	50	10	7.3	205	0.946	0	0	546.0	2,050
Offices 2A	3,365	100	34	7.3	205	1.3	0.5	0	6,305.2	6,970
Reception	460	15	31	7.2	155	0.946	0	0	658.4	4,805
Make-up Air	-	0	0	0	0	0	0	0	-	0
Library	2,500	15	167	7.2	205	1.1	0.5	0	5,202.4	34,235
ICC	100	300	1	8.1	275	0.946	0	100	202.7	275
Locker Room	368	15	25	7.3	205	0.946	0	0	530.6	5,125
Breakout/Seminar	781	15	53	7.3	205	1.1	0.22	0	1,417.2	10,865

Room	Area	Occupant Density (ft²/person)	Occupants	Sens. Load per Person (Watts)	Lat. Load per Person (BTU/hr)	Lighting Load (W/ft²)	School/Office Equip. (W/ft²)	Misc. Equip. (Watts)	Internal Sens. Load (Watts)	Lat. Load (BTU/hr)
Breakout/Seminar	781	15	53	7.3	205	1.1	0.22	0	1,417.2	10,865
Multi-Purpose Room	1,951	20	98	7.3	205	1.1	0.22	0	3,290.7	20,090
Student Commons	3,070	15	205	7.3	205	0.946	0.22	0	5,076.1	42,025
Make-up Air	-	0	0	0	0	0	0	0	-	0
Tiered Classroom	1,154	20	58	7.3	205	1.1	0.22	0	1,946.7	11,890
Flat Classroom	687	20	35	7.3	205	1.1	0.22	0	1,161.9	7,175
Flat Classroom	687	20	35	7.3	205	1.1	0.22	0	1,161.9	7,175
Flat Classroom	687	20	35	7.3	205	1.1	0.22	0	1,161.9	7,175
Seminar Room	403	15	27	7.3	205	1.1	0.22	0	729.1	5,535
Seminar Room	403	15	27	7.3	205	1.1	0.22	0	729.1	5,535
Make-up Air	-	0	0	0	0	0	0	0	-	0
ICC	100	300	1	8.1	275	0.946	0	100	202.7	275
Server Room	240	300	1	8.1	275	0.946	0	100	335.1	275
Offices 3B&C	8,801	100	89	7.3	205	1.3	0.5	0	16,491.5	18,245
Make-up Air	-	0	0	0	0	0	0	0	-	0
Breakout	220	15	15	7.3	205	1.1	0.22	0	399.2	3,075
Breakout	220	15	15	7.3	205	1.1	0.22	0	399.2	3,075
Breakout	220	15	15	7.3	205	1.1	0.22	0	399.2	3,075
Catering	220	30	8	7.3	205	0.946	0.22	0	314.3	1,640
Classroom	1,960	20	98	7.3	205	1.1	0.22	0	3,302.6	20,090
Offices 4A	1,420	100	15	7.3	205	1.3	0.5	0	2,665.5	3,075
Reception	575	15	39	7.2	155	0.946	0	0	824.8	6,045
Make-up Air	-	0	0	0	0	0	0	0	-	0
ICC	100	300	1	8.1	275	0.946	0	100	202.7	275
Reception	200	15	14	7.2	155	0.946	0	0	290.0	2,170
Offices 4B&C	8,636	100	87	7.3	205	1.3	0.5	0	16,179.9	17,835
Make-up Air	-	0	0	0	0	0	0	0	0	0

Room	CFM/person	CFM/ft²	V.A. (CFM)	Lat. Load (BTU/hr)	Req. S.A. Humidity Ratio	Internal Sens. Load (Watts)	Internal Sens. Load (BTU/hr)	External Sens. Load (BTU/hr)	Total Sens Load (BTU/hr)
Hallways/Lobbies	0	0.06	203	0	74.20	1688	57595	0	57595
Electric Room	10	0.06	162	1650	59.25	6117.476	208728	294	209022
Breakout	7.5	0.06	110	2460	41.40	313.32	10690	130	10820
Breakout	7.5	0.06	110	2460	41.40	313.76	10705	130	10835
Breakout	7.5	0.06	110	2460	41.40	313.76	10705	130	10835
Classroom	7.5	0.06	1,105	24805	41.19	4070.44	138883	836	139719
Classroom	7.5	0.06	1,105	24805	41.19	4070.44	138883	836	139719
Elevator Room	10	0.06	50	275	66.11	1333.7	45506	21	45527
Make-up Air	0	0	1,303	0	74.20	0	0	0	0
Breakout	7.5	0.06	110	2460	41.42	314.64	10736	87	10823
Breakout	7.5	0.06	110	2460	41.42	314.64	10736	87	10823
Engineering Office	7.5	0.06	110	2460	41.42	349.04	11909	87	11996
Mechanical Room	10	0.06	155	1650	58.53	1543.28	52657	272	52929
Main Cross Connect	10	0.06	103	1100	58.49	1254.7	42810	181	42991
Classroom	7.5	0.06	1,288	28905	41.20	4749.06	162038	1260	163298
Classroom	7.5	0.06	1,288	28905	41.20	4749.06	162038	1260	163298
Dining	7.5	0.18	1,504	33825	41.13	2735.048	93320	554	93874
Kitchen	7.5	0.18	156	1100	63.83	694.6	23700	212	23912
Make-up Air	0	0	6,365	0	74.20	0	0	0	0
Changing Room	5	0.12	110	2050	46.79	546	18630	163	18793
Changing Room	5	0.12	110	2050	46.79	546	18630	163	18793
Offices 2A	5	0.06	372	6970	46.64	6305.2	215133	1488	216621
Reception	5	0.06	219	4805	41.95	658.36	22463	68	22531
Make-up Air	0	0	1,297	0	74.20	0	0	0	0
Library	5	0.06	1,478	34235	40.13	5202.4	177506	1052	178558
ICC	10	0.06	16	275	48.92	202.7	6916	14	6930
Locker Room	5	0.12	237	5125	42.38	530.628	18105	51	18156
Breakout/Seminar	7.5	0.06	489	10865	41.51	1417.16	48353	162	48515

Room	CFM/person	CFM/ft²	V.A. (CFM)	Lat. Load (BTU/hr)	Req. S.A. Humidity Ratio	Internal Sens. Load (Watts)	Internal Sens. Load (BTU/hr)	External Sens. Load (BTU/hr)	Total Sens Load (BTU/hr)
Breakout/Seminar	7.5	0.06	489	10865	41.51	1417.16	48353	162	48515
Multi-Purpose Room	7.5	0.06	895	20090	41.18	3290.72	112279	792	113071
Student Commons	7.5	0.06	1,894	42025	41.57	5076.12	173197	397	173594
Make-up Air	0	0	994	0	74.20	0	0	0	0
Tiered Classroom	7.5	0.06	529	11890	41.17	1946.68	66421	693	67114
Flat Classroom	7.5	0.06	319	7175	41.11	1161.9	39644	693	40337
Flat Classroom	7.5	0.06	319	7175	41.11	1161.9	39644	693	40337
Flat Classroom	7.5	0.06	319	7175	41.11	1161.9	39644	693	40337
Seminar Room	7.5	0.06	238	5535	40.00	729.06	24876	729	25605
Seminar Room	7.5	0.06	238	5535	40.00	729.06	24876	729	25605
Make-up Air	0	0	1,333	0	74.20	0	0	0	0
ICC	10	0.06	16	275	48.92	202.7	6916	14	6930
Server Room	10	0.06	24	275	57.63	335.14	11435	34	11469
Offices 3B&C	5	0.06	973	18245	46.63	16491.5	562690	2097	564787
Make-up Air	0	0	1,816	0	74.20	0	0	0	0
Breakout	7.5	0.06	138	3075	41.49	399.24	13622	184	13806
Breakout	7.5	0.06	138	3075	41.49	399.24	13622	184	13806
Breakout	7.5	0.06	138	3075	41.49	399.24	13622	184	13806
Catering	7.5	0.06	73	1640	41.24	314.337	10725	184	10909
Classroom	7.5	0.06	895	20090	41.20	3302.6	112685	578	113263
Offices 4A	5	0.06	160	3075	45.97	2665.5	90947	2114	93061
Reception	5	0.06	275	6045	41.92	824.75	28140	81	28221
Make-up Air	0	0	1,333	0	74.20	0	0	0	0
ICC	10	0.06	16	275	48.92	202.7	6916	14	6930
Reception	5	0.06	98	2170	41.77	290	9895	28	9923
Offices 4B&C	5	0.06	953	17835	46.68	16179.9	552058	2039	554097
Make-up Air	0	0	1,800	0	74.20	0	0	0	0

Appendix B

Two - Sided Active Chilled Beam
ACBL2

Product Features

Models

Linear Active Chilled Beam ACBL

The Price Linear Active Chilled Beam combines fresh air supply with high heating and cooling capacities and is designed for performance, ease of installation and low maintenance. The ACBL induces room air through the heat exchanger, mixes it with supply air and delivers the combined air streams into the occupied zone via slots along the length of the beam. The ACBL lends itself to many different installation configurations and the low profile makes it suitable in both new and refurbished buildings. Chilled beams can be easily integrated into suspended and drywall ceilings.

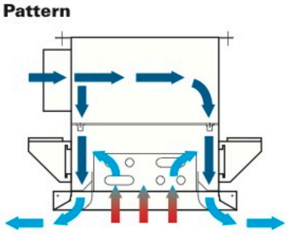
Features
- Adjustable mounting brackets for ease of installation
- Hinged access face to allow easy room-side access to the coil and any control component
- Inlet damper option for easy balancing
- Pressure port for balancing and monitoring
- Black plenum option hides beam internal elements
- Standard perforated face
  - Grille face option

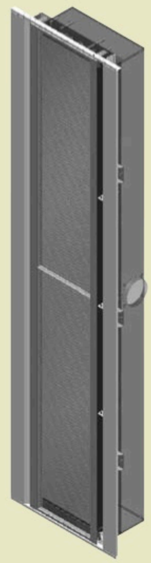
Casing Construction
- Heavy duty aluminum face
- Steel plenum
- White powder coat finish

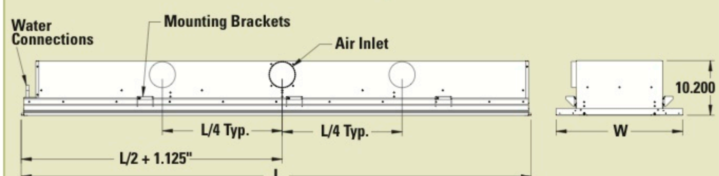
Water Coil Construction
- Extruded aluminum fins
- Pressure tested copper piping

Water Connection Type
- Standard Connection Options:
  - 1/2" SWT
  - 1/2" NPT (female)
- Other connection types available

Air Pattern







Dimensional Data - Imperial [Metric]

	Nominal Size	Actual Size (L)
Width	24	23.750 (603)

	Nominal Size	Actual Size (L)
Length	48	47.750 (1213)
Length	60	59.750 (1518)
Length	72	71.750 (1822)
Length	84	83.750 (2127)
Length	96	95.750 (2432)
Length	108	107.750 (2737)
Length	120	119.750 (3042)

✓ Product Selection Checklist

1] Select chilled beam size based on piping system and desired performance characteristics
2] Select face style and finishing options

Example: ACBL / 24 / 72 / 2-Way / 1/2" SWT / 2-Pipe / B12

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimetre.

price

Performance Data

Cooling - 24" x 48" ACB2 (Two-Way)

Primary Airflow (cfm)	Primary Inlet Size (in)	Nozzle Size	Air Side Pressure Loss (in. w.c.)	Water Side Cooling Capacity (BTU/hr)	Primary Air Cooling Capacity (BTU/hr)	Total Cooling Capacity (BTU/hr)	Cooling Water Flow Rate (usgpm)	Cooling Water Pressure Drop (ft head)	NC
8	4	3	0.19	921	173	1094	0.46	0.5	--
10	4	3	0.29	1,117	216	1333	0.56	0.7	--
15	4	3	0.64	1,607	324	1931	0.8	1.3	--
10	4	4	0.12	962	216	1178	0.48	0.5	--
15	4	4	0.27	1271	324	1595	0.64	0.9	--
20	4	4	0.47	1,581	432	2013	0.79	1.3	--
25	4	4	0.72	1,890	540	2430	0.95	1.8	--
18	4	5	0.2	1207	389	1596	0.6	0.8	--
20	4	5	0.25	1317	432	1749	0.66	0.9	--
25	4	5	0.38	1,593	540	2133	0.8	1.3	--
30	4	5	0.54	1,868	648	2516	0.93	1.7	--
35	4	5	0.73	2,143	756	2899	1.07	2.3	--
22	4	6	0.16	1242	475	1717	0.62	0.8	--
25	4	6	0.2	1354	540	1894	0.68	1.0	--
30	4	6	0.28	1,539	648	2187	0.77	1.2	--
35	4	6	0.38	1,725	756	2481	0.86	1.5	--
40	4	6	0.49	1,911	864	2775	0.96	1.8	--
45	4	6	0.62	2,096	972	3068	1.05	2.2	--
30	4	7	0.18	1346	648	1994	0.67	0.9	--
35	4	7	0.25	1509	756	2265	0.75	1.2	--
40	4	7	0.32	1,672	864	2536	0.84	1.4	--
45	4	7	0.4	1,836	972	2808	0.92	1.7	--
50	4	7	0.5	1,999	1080	3079	1	2.0	--
55	5	7	0.57	2,162	1188	3350	1.08	2.3	--
36	4	8	0.17	1374	778	2152	0.69	1.0	--
40	4	8	0.21	1477	864	2341	0.74	1.1	--
45	4	8	0.26	1,606	972	2578	0.8	1.3	--
50	4	8	0.32	1,735	1080	2815	0.87	1.5	--
55	5	8	0.36	1,864	1188	3052	0.93	1.7	--
60	5	8	0.42	1,993	1296	3289	1	2.0	--
65	5	8	0.49	2,122	1404	3526	1.06	2.2	--
70	5	8	0.57	2,251	1512	3763	1.13	2.5	--

Performance Notes:

1. Water Side Capacity in BTU/hr is based on 16°F temperature difference. (Room Temp – Mean Water Temp).
2. Primary Air Capacity in BTU/hr is based on 20°F temperature difference between the primary air and the room air.
3. Heating & Cooling Capacity is based on a 4°F temperature difference between entering water and leaving water.
4. Blanks "--" indicate a sound level less than 15 NC.
5. Sound data NC values are based on a room absorption of -10 dB, re 10^{-12} watts

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimetre.

Performance Data

Heating - 24" x 48" ACB2 (Two-Way)

Primary Airflow (cfm)	Primary Inlet Size (in)	Nozzle Size	Air Side Pressure Loss (in. w.c.)	Water Side Heating Capacity (BTU/hr)	Primary Air Cooling Capacity (BTU/hr)	Total Cooling Capacity (BTU/hr)	Heating Water Flow Rate (usgpm)	Heating Water Pressure Drop (ft head)	NC
8	4	3	0.19	1029	173	1094	0.51	0.2	--
10	4	3	0.29	1,159	216	1333	0.58	0.3	--
15	4	3	0.64	1,485	324	1931	0.74	0.5	--
10	4	4	0.12	1066	216	1178	0.53	0.2	--
15	4	4	0.27	1344	324	1595	0.67	0.4	--
20	4	4	0.47	1,623	432	2013	0.81	0.5	--
25	4	4	0.72	1,901	540	2430	0.95	0.7	--
18	4	5	0.2	1370	389	1596	0.69	0.4	--
20	4	5	0.25	1470	432	1749	0.73	0.4	--
25	4	5	0.38	1,719	540	2133	0.86	0.6	--
30	4	5	0.54	1,968	648	2516	0.98	0.8	--
35	4	5	0.73	2,217	756	2899	1.11	1.0	--
22	4	6	0.16	1402	475	1717	0.7	0.4	--
25	4	6	0.2	1513	540	1894	0.76	0.5	--
30	4	6	0.28	1,700	648	2187	0.85	0.6	--
35	4	6	0.38	1,886	756	2481	0.94	0.7	--
40	4	6	0.49	2,072	864	2775	1.04	0.9	--
45	4	6	0.62	2,258	972	3068	1.13	1.0	--
30	4	7	0.18	1538	648	1994	0.77	0.5	--
35	4	7	0.25	1706	756	2265	0.85	0.6	--
40	4	7	0.32	1,874	864	2536	0.94	0.7	--
45	4	7	0.4	2,042	972	2808	1.02	0.8	--
50	4	7	0.5	2,210	1080	3079	1.11	1.0	--
55	5	7	0.57	2,378	1188	3350	1.19	1.1	--
36	4	8	0.17	1571	778	2152	0.79	0.5	--
40	4	8	0.21	1694	864	2341	0.85	0.6	--
45	4	8	0.26	1,848	972	2578	0.92	0.7	--
50	4	8	0.32	2,001	1080	2815	1	0.8	--
55	5	8	0.36	2,155	1188	3052	1.08	0.9	--
60	5	8	0.42	2,308	1296	3289	1.15	1.1	--
65	5	8	0.49	2,462	1404	3526	1.23	1.2	--
70	5	8	0.57	2,615	1512	3763	1.31	1.3	--

Performance Notes:

1. Water Side Capacity in BTU/hr is based on 46°F temperature difference. (Mean Water Temp - Room Temp)
2. Primary Air Capacity in BTU/hr is based on 0°F temperature difference between the primary air and the room air.
3. Heating & Cooling Capacity is based on a 4°F temperature difference between entering water and leaving water.
4. Blanks "--" indicate a sound level less than 15 NC.
5. Sound data NC values are based on a room absorption of -10 dB, re 10^{-12} watts.

CHILLED BEAMS

All Metric dimensions ( ) are soft conversion.
Imperial dimensions are converted to metric and rounded to the nearest millimetre.

Appendix C

Room	Area	V.A. (CFM)	Lat. Load (BTU/hr)	Sens Cooling by VA	Total Sens Load (BTU	Load on ACB (BTU/hr)
Hallways/Lobbies/Bathrooms	3,376	203	0	7438	57595	50,157
Electric Room	1,706	162	1650	5962	209022	203,060
Breakout	171	110	2460	4050	10820	6,771
Breakout	171	110	2460	4051	10835	6,785
Breakout	171	110	2460	4051	10835	6,785
Classroom	2,415	1,105	24805	40575	139719	99,144
Classroom	2,415	1,105	24805	40575	139719	99,144
Elevator Room	100	50	275	1836	45527	43,691
Make-up Air	-	1,303	0	47846	0	-47,846
Breakout	172	110	2460	4052	10823	6,770
Breakout	172	110	2460	4052	10823	6,770
Engineering Office	172	110	2460	4052	11996	7,944
Mechanical Room	1,580	155	1650	5684	52929	47,244
Main Cross Connect	1,050	103	1100	3782	42991	39,209
Classroom	2,818	1,288	28905	47292	163298	116,006
Classroom	2,818	1,288	28905	47292	163298	116,006
Dining	1,838	1,504	33825	55227	93874	38,647
Kitchen	700	156	1100	5728	23912	18,183
Make-up Air	-	6,365	0	233723	0	-233,723
Changing Room	500	110	2050	4039	18793	14,753
Changing Room	500	110	2050	4039	18793	14,753
Offices 2A	3,365	372	6970	13656	216621	202,965
Reception	460	219	4805	8046	22531	14,485
Make-up Air	-	1,297	0	47626	0	-47,626
Library	2,500	1,478	34235	54254	178558	124,304
Intermediate Cross Connect	100	16	275	588	6930	6,343
Locker Room	368	237	5125	8696	18156	9,460
Breakout/Seminar	781	489	10865	17947	48515	30,568

Room	# of Panels	Panel Area	% of Ceiling Area	GPM	Head Loss (ft)
Hallways/Lobbies/Bathrooms	24	192	5.69%	25.92	55.2
Electric Room	94	752	44.08%	101.52	216.2
Breakout	4	32	18.71%	4.32	9.2
Breakout	4	32	18.68%	4.32	9.2
Breakout	4	32	18.68%	4.32	9.2
Classroom	46	368	15.24%	49.68	105.8
Classroom	46	368	15.24%	49.68	105.8
Elevator Room	0	0	0.00%	0	0
Make-up Air					
Breakout	4	32	18.60%	4.32	9.2
Breakout	4	32	18.60%	4.32	9.2
Engineering Office	4	32	18.60%	4.32	9.2
Mechanical Room	22	176	11.14%	23.76	50.6
Main Cross Connect	19	152	14.48%	20.52	43.7
Classroom	54	432	15.33%	58.32	124.2
Classroom	54	432	15.33%	58.32	124.2
Dining	18	144	7.83%	19.44	41.4
Kitchen	9	72	10.29%	9.72	20.7
Make-up Air					
Changing Room	7	56	11.20%	7.56	16.1
Changing Room	7	56	11.20%	7.56	16.1
Offices 2A	94	752	22.35%	101.52	216.2
Reception	7	56	12.17%	7.56	16.1
Make-up Air					
Library	58	464	18.56%	62.64	133.4
Intermediate Cross Connect	3	24	24.00%	3.24	6.9
Locker Room	5	40	10.87%	5.4	11.5
Breakout/Seminar	15	120	15.37%	16.2	34.5

Room	Area	V.A. (CFM)	Lat. Load (BTU/hr)	Sens Cooling by VA	Total Sens Load (BTU	Load on ACB (BTU/hr)
Breakout/Seminar	781	489	10865	17947	48515	30,568
Multi-Purpose Room	1,951	895	20090	32852	113071	80,219
Student Commons	3,070	1,894	42025	69543	173594	104,051
Make-up Air	-	994	0	36500	0	-36,500
Tiered Classroom	1,154	529	11890	19441	67114	47,672
Flat Classroom	687	319	7175	11709	40337	28,628
Flat Classroom	687	319	7175	11709	40337	28,628
Flat Classroom	687	319	7175	11709	40337	28,628
Seminar Room	403	238	5535	8740	25605	16,865
Seminar Room	403	238	5535	8740	25605	16,865
Make-up Air	-	1,333	0	48948	0	-48,948
Intermediate Cross Connect	100	16	275	588	6930	6,343
Server Room	240	24	275	896	11469	10,573
Offices 3B&C	8,801	973	18245	35731	564787	529,056
Make-up Air	-	1,816	0	66684	0	-66,684
Breakout	220	138	3075	5076	13806	8,730
Breakout	220	138	3075	5076	13806	8,730
Breakout	220	138	3075	5076	13806	8,730
Catering	220	73	1640	2687	10909	8,222
Classroom	1,960	895	20090	32873	113263	80,390
Offices 4A	1,420	160	3075	5883	93061	87,178
Reception	575	275	6045	10113	28221	18,109
Make-up Air	-	1,333	0	48948	0	-48,948
Intermediate Cross Connect	100	16	275	588	6930	6,343
Reception	200	98	2170	3613	9923	6,310
Offices 4B&C	8,636	953	17835	35000	554097	519,097
Make-up Air	-	1,800	0	66096	0	-66,096
TOTALS		**36,191**				

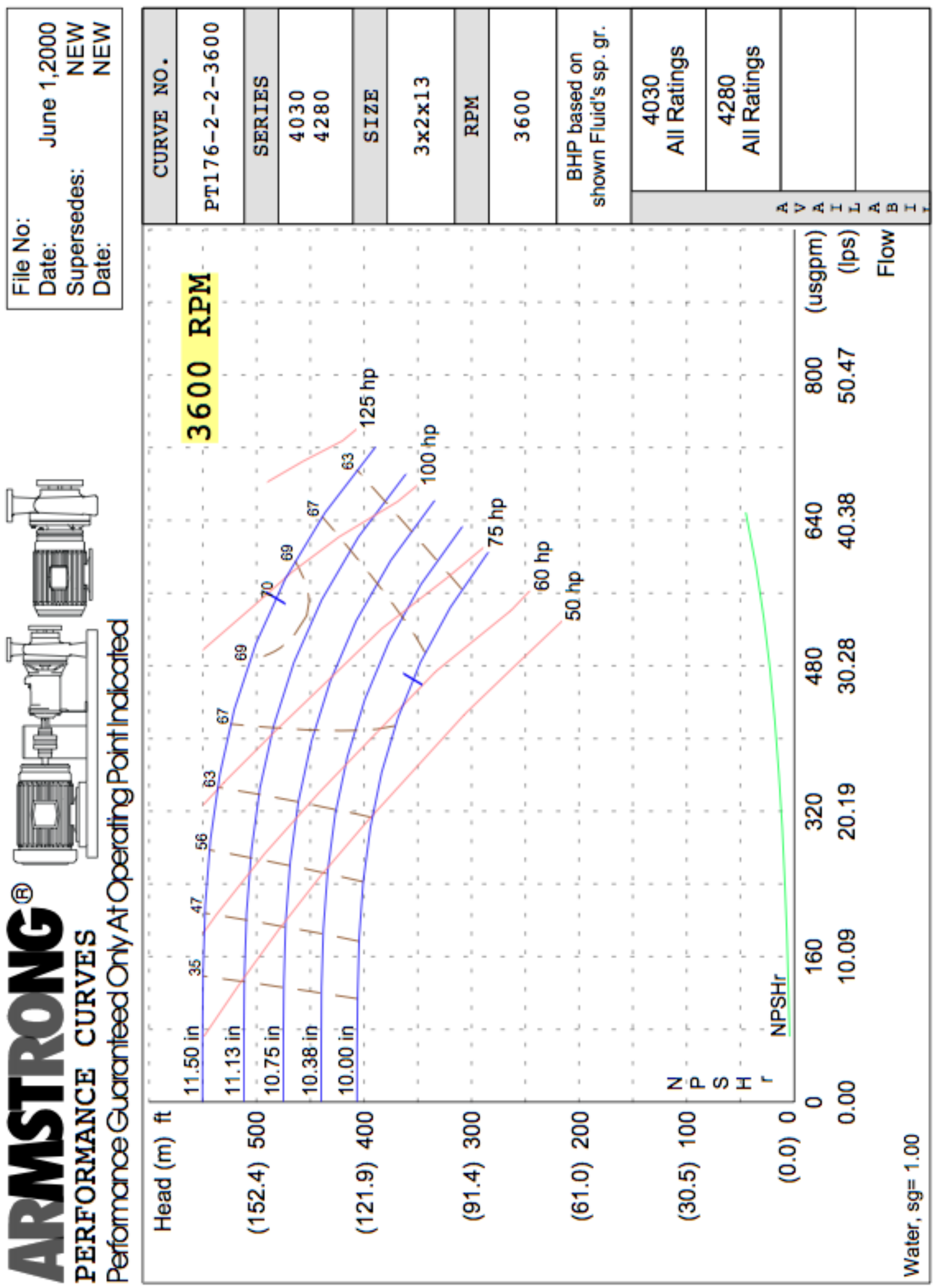
Room	# of Panels	Panel Area	% of Ceiling Area	GPM	Head Loss (ft)
Breakout/Seminar	15	120	15.37%	16.2	34.5
Multi-Purpose Room	38	304	15.58%	41.04	87.4
Student Commons	49	392	12.77%	52.92	112.7
Make-up Air					
Tiered Classroom	23	184	15.94%	24.84	52.9
Flat Classroom	14	112	16.31%	15.12	32.2
Flat Classroom	14	112	16.31%	15.12	32.2
Flat Classroom	14	112	16.31%	15.12	32.2
Seminar Room	8	64	15.88%	8.64	18.4
Seminar Room	8	64	15.88%	8.64	18.4
Make-up Air					
Intermediate Cross Connect	3	24	24.00%	3.24	6.9
Server Room	5	40	16.67%	5.4	11.5
Offices 3B&C	245	1960	22.27%	264.6	563.5
Make-up Air					
Breakout	5	40	18.22%	5.4	11.5
Breakout	5	40	18.22%	5.4	11.5
Breakout	5	40	18.22%	5.4	11.5
Catering	4	32	14.58%	4.32	9.2
Classroom	38	304	15.51%	41.04	87.4
Offices 4A	41	328	23.10%	44.28	94.3
Reception	9	72	12.52%	9.72	20.7
Make-up Air					
Intermediate Cross Connect	3	24	24.00%	3.24	6.9
Reception	3	24	12.00%	3.24	6.9
Offices 4B&C	241	1928	22.33%	260.28	554.3
Make-up Air					
TOTALS	**1,396**			**1,508**	**3,211**

Appendix D

Room	Area	V.A. (CFM)	Heating Load (BTU/hr)	GPM	Head Loss (ft)
Hallways/Lobbies/Bathrooms	3,376	203	40892	20.5	18.9
Electric Room	1,706	162	0	0.0	0.0
Breakout	171	110	7590	3.8	3.5
Breakout	171	110	7601	3.8	3.5
Breakout	171	110	7601	3.8	3.5
Classroom	2,415	1,105	98607	49.3	45.6
Classroom	2,415	1,105	98607	49.3	45.6
Elevator Room	100	50	0	0.0	0.0
Make-up Air	-	1,303	0	0.0	0.0
Breakout	172	110	7622	3.8	3.5
Breakout	172	110	7622	3.8	3.5
Engineering Office	172	110	8456	4.2	3.9
Mechanical Room	1,580	155	0	0.0	0.0
Main Cross Connect	1,050	103	30395	15.2	14.1
Classroom	2,818	1,288	115047	57.6	53.2
Classroom	2,818	1,288	115047	57.6	53.2
Dining	1,838	1,504	66257	33.2	30.6
Kitchen	700	156	16827	8.4	7.8
Make-up Air	-	6,365	0	0.0	0.0
Changing Room	500	110	13227	6.6	6.1
Changing Room	500	110	13227	6.6	6.1
Offices 2A	3,365	372	152745	76.4	70.7
Reception	460	219	15949	8.0	7.4
Make-up Air	-	1,297	0	0.0	0.0
Library	2,500	1,478	126029	63.1	58.3
Intermediate Cross Connect	100	16	4910	2.5	2.3
Locker Room	368	237	12855	6.4	5.9
Breakout/Seminar	781	489	34331	17.2	15.9
Breakout/Seminar	781	489	34331	17.2	15.9
Multi-Purpose Room	1,951	895	79718	39.9	36.9
Student Commons	3,070	1,894	122970	61.5	56.9
Make-up Air	-	994	0	0.0	0.0
Tiered Classroom	1,154	529	47159	23.6	21.8
Flat Classroom	687	319	28147	14.1	13.0
Flat Classroom	687	319	28147	14.1	13.0
Flat Classroom	687	319	28147	14.1	13.0
Seminar Room	403	238	17662	8.8	8.2
Seminar Room	403	238	17662	8.8	8.2
Make-up Air	-	1,333	0	0.0	0.0
Intermediate Cross Connect	100	16	4910	2.5	2.3
Server Room	240	24	8119	4.1	3.8

Room	Area	V.A. (CFM)	Heating Load (BTU/hr)	GPM	Head Loss (ft)
Offices 3B&C	8,801	973	399510	199.9	184.8
Make-up Air	-	1,816	0	0.0	0.0
Breakout	220	138	9672	4.8	4.5
Breakout	220	138	9672	4.8	4.5
Breakout	220	138	9672	4.8	4.5
Catering	220	73	7615	3.8	3.5
Classroom	1,960	895	80006	40.0	37.0
Offices 4A	1,420	160	64572	32.3	29.9
Reception	575	275	19980	10.0	9.2
Make-up Air	-	1,333	0	0.0	0.0
Intermediate Cross Connect	100	16	4910	2.5	2.3
Reception	200	98	7025	3.5	3.2
Offices 4B&C	8,636	953	391961	196.1	181.3
Make-up Air	-	1,800	0	0.0	0.0
TOTALS	**63,150**	**36,191**	**2,423,012**	**1,213**	**1,121**

Appendix E


ARMSTRONG®
PERFORMANCE CURVES
Performance Guaranteed Only At Operating Point Indicated
File No:
Date: June 1,2000
Supersedes: NEW
Date: NEW
3600 RPM
CURVE NO.
PT176-2-2-3600
SERIES
4030
4280
SIZE
3x2x13
RPM
3600
BHP based on shown Fluid's sp. gr.
4030 All Ratings
4280 All Ratings
AVAILABILITY
Head (m) ft
(152.4) 500
(121.9) 400
(91.4) 300
(61.0) 200
(30.5) 100
(0.0) 0
NPSHr
11.50 in
11.13 in
10.75 in
10.38 in
10.00 in
35
47
56
63
67
69
70
125 hp
100 hp
75 hp
60 hp
50 hp
0 160 320 480 640 800 (usgpm)
0.00 10.09 20.19 30.28 40.38 50.47 (lps)
Flow
Water, sg= 1.00

Appendix F

EQUIPMENT CONNECTION SCHEDULE

LINE NO.	ITEM	DESCRIPTION	LOCATION	HP	KW	VOLTS	FLA	PH	FIELD MTD DEVICES: MTR STR SIZE	FIELD MTD DEVICES: MTR STR TYPE	FIELD MTD DEVICES: SWITCH/ FUSE(A)	BRANCH CIRCUIT: SOURCE	BRANCH CIRCUIT: UPS "U"	BRANCH CIRCUIT: WIRE SIZE	NOTES	LINE NO.
1	AHU-1	ROOF TOP UNIT SUPPLY	ROOF	50		480		3		VFD	–	4MCC/1,2,3		1.25"C – 3 #2 & 1 #6 GND		1
2	AHU-2A	ROOF TOP UNIT SUPPLY	ROOF	40		480		3		VFD	–	4MCC/4,5,6		1.25"C – 3 #3 & 1 #8 GND		2
3	AHU-2B	ROOF TOP UNIT SUPPLY	ROOF	40		480		3		VFD	–	4MCC/7,8,9		1.25"C – 3 #3 & 1 #8 GND		3
4																4
5	RF-1	ROOF TOP UNIT RETURN	ROOF	20		480		3		VFD	–	4MCC/10,11,12		3/4"C – 3 #10 & 1 #10 GND		5
6	RF-2A	ROOF TOP UNIT RETURN	ROOF	20		480		3		VFD	–	4MCC/13,14,15		3/4"C – 3 #10 & 1 #10 GND		6
7	RF-2B	ROOF TOP UNIT RETURN	ROOF	20		480		3		VFD	–	4MCC/16,17,18		3/4"C – 3 #10 & 1 #10 GND		7
8																8
9																9
10	E-2	EXHAUST FAN	ROOF-MECH ROOM	1		480		3		VFD		4MCC/22,23,24		3/4"C – 3 #12 & 1 #12 GND		10
11	E-3	EXHAUST FAN	ROOF-KITCHEN (FUTURE)	1.5		480		3	00		20/3	4MCC/25,26,27		3/4"C – EMPTY		11
12	E-4	EXHAUST FAN	ROOF-DISHWASHER (FUTURE)	0.5		120		1	MSS		20	4PC1/26		3/4"C – EMPTY		12
13	E-5	EXHAUST FAN	ROOF-AREA A TOILET	2		480		3	00		20/3	4MCC/28,29,30		3/4"C – 3 #12 & 1 #12 GND		13
14	E-6	EXHAUST FAN	ROOF-AREA B TOILET	2		480		3	00		20/	4MCC/31,32,33		3/4"C – 3 #12 & 1 #12 GND		14
15	E-7	EXHAUST FAN	ROOF-AREA A ELEC ROOM	2		480		3	00		20/3	4MCC/34,35,36		3/4"C – 3 #12 & 1 #12 GND		15
16	E-8	EXHAUST FAN	ROOF-AREA B ELEC ROOM	2		480		3	00		20/3	4MCC/37,38,39		3/4"C – 3 #12 & 1 #12 GND		16
17	E-9	EXHAUST FAN	ROOF-AREA C ELEC ROOM	2		480		3	00		20/3	4MCC/40,41,42		3/4"C – 3 #12 & 1 #12 GND		17
18																18
19	FCU-1	FAN COIL UNIT	LEVEL 1– MCC	1/8		120		1	MSS		20	1EPB1/1		3/4"C – 3 #12 & 1 #12 GND		19
20	FCU-2	FAN COIL UNIT	LEVEL 2– ICC	1/12		120		1	MSS		20	1EPB1/3		3/4"C – 3 #12 & 1 #12 GND		20
21	FCU-3	FAN COIL UNIT	LEVEL 3– ICC	1/12		120		1	MSS		20	1EPB1/5		3/4"C – 3 #12 & 1 #12 GND		21
22	FCU-4	FAN COIL UNIT	LEVEL 3– SERVER	1/12		120		1	MSS		20	1EPB1/2		3/4"C – 3 #12 & 1 #12 GND		22
23	FCU-5	FAN COIL UNIT	LEVEL 4– ICC	1/12		120		1	MSS		20	1EPB1/4		3/4"C – 3 #12 & 1 #12 GND		23
24	FCU-6	FAN COIL UNIT	LEVEL 1– ELEVATOR EQUP.	0.5		120		1	MSS		20	1PB1/7		3/4"C – 3 #12 & 1 #12 GND		24
25	FCU-7	FAN COIL UNIT	LEVEL 1– MAIN ELECTRICAL ROOM	2		480		3	00		20/3	1EHA/13,15,17		3/4"C – 3 #12 & 1 #12 GND		25
26																26
27	CHWP-1	CHILLER WATER PUMP	MECHANICAL ROOM	15		480		3		VFD	–	1MCC/1,2,3		1"C – 3 #8 & 1 #10 GND		27
28	CHWP-2	CHILLER WATER PUMP	MECHANICAL ROOM	1		480		3		VFD	–	1EHA1/2,4,6		3/4"C – 3 #12 & 1 #12 GND		28
29	CHWP-3	CHILLER WATER PUMP	MECHANICAL ROOM (FUTURE)	20		480		3		VFD	–	1MCC/4,5,6		3/4"C – EMPTY		29
30	CHWP-4	CHILLER WATER PUMP	MECHANICAL ROOM (FUTURE)	1		480		3	0		20/3	1MCC/7,8,9		3/4"C – EMPTY		30
31																31
32	HWP-1	HOT WATER PUMP	MECHANICAL ROOM	5		480		3		VFD	–	1MCC/10,11,12		3/4"C – 3 #12 & 1 #12 GND		32
33	HWP-2	HOT WATER PUMP	MECHANICAL ROOM (FUTURE)	7.5		480		3	1		20/3	1MCC/13,14,15		3/4"C – EMPTY		33
34																34
35																35
36	DWRP-1	DOMESTIC WATER PUMP	MECHANICAL ROOM	1/12		120		1	MSS		20	1PB1/10		3/4"C – 3 #12 & 1 #12 GND		36
37	DWRP-2	DOMESTIC WATER PUMP	MECHANICAL ROOM (FUTURE)	1/8		120		1	MSS		20	1PB1/12		3/4"C – EMPTY		37
38	DWRP-3	DOMESTIC WATER PUMP	MECHANICAL ROOM (FUTURE)	1/8		120		1	MSS		20	1PB1/14		3/4"C – EMPTY		38
39																39
40	EWH-1	ELECTRIC WATER HEATER	WORKROOM – LEVEL 4, AREA B			208	20	1				4PB1/13,15,17		3/4"C – 3 #12 & 1 #12 GND		40
41	EWH-2	ELECTRIC WATER HEATER	POWDER ROOM – LEVEL 4, AREA B			208	20	1				4PB1/14,16,18		3/4"C – 3 #12 & 1 #12 GND		41
42	EWH-3	ELECTRIC WATER HEATER	WORKROOM – LEVEL 4, AREA C			208	20	1				4PC1/25,227,29		3/4"C – 3 #12 & 1 #12 GND		42
43																43

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