SENIOR THESIS – Spring 2006

Demand Controlled Ventilation & Energy Recovery in Laboratory

Justin Mulhollan
Mechanical Option
Margaret M. Alkek Building for Biomedical Research
Baylor College of Medicine
Houston, TX

Justin Mulhollan

Mechanical Option
Margaret M. Alkek Building for Biomedical Research
Baylor College of Medicine
One Baylor Plaza
Houston, TX

Construction

- Design-bid-build
- Construction Dates: October 2005 - Late 2007
- Ground Breaking: September 15, 2005
- Construction Cost: $75,000,000
- Total Project Cost: $110,000,000 (approx)

Architecture

- 8 Stories, 200,000 gsf Research Tower
- 5 levels of research laboratories & office space
- 2 levels of animal research facilities
- 1 level for mechanical systems
- Curtain wall facade

Project Team

- Owner: Baylor College of Medicine
- Owner Representative: Fluor Enterprises, Inc.
- Architect: Lord, Aeck & Sargent, Inc.
- Construction Manager: Vaughn Construction
- MEP: Bard, Rao + Athanas Consulting Engineers, LLC.
- Sturctural Engineers: Walter P. Moore
- Curtain Wall Consultant: Curtain Wall Design and Consulting, Inc.

Mechanical

- Campus chilled water and steam utilized
- 1300 ton centrifugal chiller replacing existing 800 ton chiller
- Heat Exchangers used to create building chilled water and steam from campus loops
- 12 packaged air handling units
- CV Laboratory & research spaces, while office space is VAV

Structural

- Built ontop of existing subterannean research facility
- Steel frame construction
- 3” 20g composite deck
- 3 1/2” lightweight concrete slab

Electrical

- Double Ended Unit Substation feeds tower & existing subterranean facility
- Substation rated 4.16 kV primary - 277/480V, 3-phase, 4 wire, 60hz secondary
- 480 to 208/120V stepdown transformer on each lab floor
- 1500 kW Emergency Generator supplied by 8000 gallon fuel oil tank to be installed

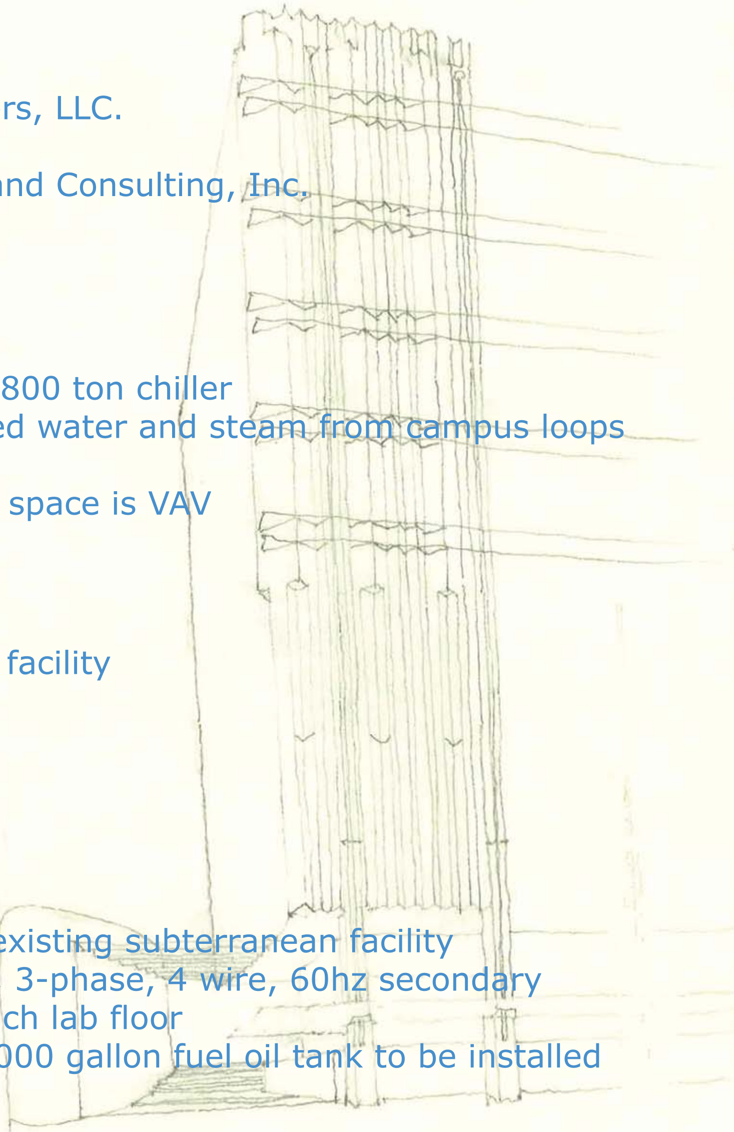


Table of Contents

Executive Summary

The Margaret M. Alkek Building for Biomedical Research is an 8 story research tower being constructed by the Baylor College of Medicine (BCM). The spaces within the tower will be made up of office space, laboratories, and vivarium space. The tower is intended to increase Baylor College of Medicine's appeal in recruiting top researchers and research programs. The research tower like most laboratory spaces uses a large amount of energy. The reason that laboratories consume so much energy is because they are designed for 100% outdoor air which means it takes more energy to condition the air to desired supply conditions. This report looks to revisit the original design of the building's mechanical systems to make design changes that will save energy while maintaining indoor air quality.

The first redesign suggestion that was made was to implement some form of energy recovery. The report discusses the different forms of energy recovery that are appropriate for laboratory and vivarium spaces. The report determined that heat pipes and runaround loops are the most appropriate type of energy recovery due to cross contamination not being a factor in either system. To implement a heat pipe system the exhaust and outdoor air streams would have to be placed close together. A study was done into the structural implications of moving the mechanical systems from the existing 3rd floor to the 8th floor so that the intake was near the exhaust on the roof. It was found that the existing structure would be able to handle the redistribution of the loads. However, the move would cause ductwork and piping to have to be extended for several systems which would increase the cost of the heat pipe recovery installation. The effectiveness of heat pipes and runaround loops are similar to ach other so it was determined that a runaround loop would be used for the vivarium and laboratory air systems.

The second design suggestion was to install a CO_2 based Demand Control Ventilation system in the office side of the building. CO_2 sensors were installed in the 5 conference rooms to monitor the amount of ventilation that is need. The reasons why CO_2 is used to determine ventilation is discussed in the report. In the upper laboratory spaces a setback based on occupancy of the space was investigated. The rooms already have occupancy sensors installed in the laboratory space to control

the lighting. The occupancy sensors would now send an occupied/unoccupied signal back to the building automation system. When the building was unoccupied the system would cut the air change rate in half.

The building was modeled in Trane's TRACE program both with the original design and the suggested redesigns. It was shown that the redesign suggestions would save approximately 20% in annual energy use. The first cost for both systems was fairly similar with the redesign being slightly higher. The 20% energy savings resulted in a short payback period of .85 years which is very attractive. Another study was done into the energy savings associated with the occupancy sensors installed to control lighting.

Building Background & Introduction

Baylor College of Medicine recently laid out their "strategic plan" in which they plan to expand at a rate comparable to other top research schools in the country. They felt as if they were not doing enough to stay competitive in research and want to remain as one of the top schools. Their plan is to expand their research programs to retain the quality researchers they have and allow them to recruit other talented researchers. The first part of their "strategic plan" was to construct a new research tower.

The Albert and Margaret Alkek Foundation donated $31.25 million dollars to the college for construction of the new tower. For their donation the research tower shall be known as the Margaret M. Alkek Building for Biomedical Research. This is the largest donation Baylor College of Medicine has ever received to fund biomedical research. The research tower promises to have top of the line facilities that can accommodate the following programs; cardiovascular sciences, diabetes and metabolic disease, cancer, pharmacogenomics, imaging, informatics, and proteomics.

Figure 1: Tower under construction (3-1-06)

Construction of the Margaret M. Alkek Building for Biomedical Research began on September 15, 2005. The Margaret M. Alkek Building for Biomedical Research is an 8 story and approximately 170,000 square foot research tower. The building is to be located between the Jewish Institute for Medical Research and the Texas Medical Center Garage #6. The research tower will be constructed on top of an existing subterranean Transgenic Mouse Facility. The building's 8 stories will include 2 levels of animal research facilities, 5 floors levels of office and flexible laboratory space and one floor to accommodate the building's mechanical spaces. Levels 4-8 contain office and laboratory spaces which are divided by the main corridor, which is pressurized and contains the elevator systems at the north end of this corridor. Level 3 contains a majority of the mechanical equipment such as air handling units, pumps, heat exchangers, steam generators, etc, as well as the electrical equipment for the building. Levels 1 and 2 will house the animal research facilities. Level 2 is strictly animal housing units and animal research space. Part of level 1 contains the lobby to the Research tower and a small amount of office space. The rest of level 1 is made up of vivarium space and the animal facility cage wash.

Building Statistics

Project Team

Owner: Baylor College Of Medicine

Owner Representative: Fluor Enterprises, Inc.

Architect: Lord, Aeck & Sargent, Inc.

Construction Manager: Vaughn Construction

MEP Engineers: Bard, Rao + Athanas Consulting Engineers, LLC.

Structural Engineers: Walter P. Moore

Curtain Wall Consultants: Curtain Wall Design and Consulting, Inc.

Structural

The Margaret M. Alkek Building for Biomedical Research is being built on a drilled pier foundation and utilizing an existing foundation by underpinning its piers. The first elevated level is supported with one-way concrete pan joists framing into massive pre-tensioned concrete transfer girders. These girders are utilized to accommodate the mismatched existing and new column grids. Levels 2-8 are typical wide flange composite steel construction. Steel post-up columns support levels 2-8 and rest on the transfer girders. The slab is 3- 1/2" lightweight concrete on 3" 20 gage composite metal deck. Most beams are W21x44 while most girders are W36x135. The lateral force resisting system is a combination of moment frames and braced frames in a staggered configuration. The frames are located along grid lines D and E, in the towers core. The mechanical platform on the roof is framed out of HSS tubes.

Electrical/Lighting

A Double Ended unit substation will be installed in the tower to supply the tower and backfeed the subterranean research facility. The substation is rated at 4.16 kW primary – 277/480V, 3-phase, 4 wire, 60hz secondary. Each lab floor has a 480 to 208/120V stepdown. An emergency generator will be connected to the tower and installed on the lower level of the near by Texas Medical Center Garage #6. The emergency generator shall be able to provide 1,500 kW and is fed from a 8000 gallon fuel oil tank. The generator is connected to the fire pump, elevators and other essential components in the case of an emergency.

All lighting in the building spaces (lab, vivarium, office space, stairwells, and corridors) is fluorescent lighting. The only exceptions to this are in level 3 mechanical there is alludescent lighting and in levels 4-8 there are incandescent lighting in the conference room in the office side of the building. Lighting levels in all the spaces were required to meet Baylor College of Medicine guidelines as well as Illuminating Engineering Society's recommendations. A majority of spaces are equipped with occupancy sensors on levels 4-8. The major laboratory spaces are equipped with ceiling mounted occupancy sensors between each research lab workstation and research bench section. Offices and meeting rooms are all equipped with wall mounted occupancy sensors light switches.

Fire Protection

Building is fully sprinklered based on NFPA 13, latest edition. Sprinkler spacing will be hazard group 1 occupancy for mechanical, laboratories and storage space and light hazard group occupancy for offices, corridor and toilet rooms. In the basement crawl space is a 5000 gallon fire protection break tank, and the jockey and fire pumps.

Plumbing

The research tower has an extensive plumbing system to support the lab and vivarium spaces. The vivarium has an animal water system that consists of two 600 gallon storage tanks, a pressurized 86 gallon storage tank and a few other tanks for treating the water. The building connects to the main water loop for domestic water use throughout the building. There is a low zone booster pump (for levels 1-3) and a high zone booster pump (for levels 4-8). The booster pumps pump up to the 3rd level where steam fired water heaters create the hot water for the building and is then sent either back to levels 1-3 or up to levels 4-8. Water purification equipment is on the 3rd floor creating Reverse Osmosis Deionized (RODI) water which is then pumped to the clean steam generator on level 3 for steam creation or to tunnel washers, glass washers, or up to the lab space for their use. There is also a lab waste which is treated in the basement level and ejected to the city sewer. The final element of the extensive piping system is natural gas and CO2 which is piped up to the lab spaces on levels 4-8 for use in experiments and research.

Transportation

The building is located right next to a parking garage which allows for easy vehicular access. Once inside the building there is a stair case on the eastside of the building. On the northern side there is a bank of 3 elevators that service the entire building as well as another set of stairs.

Existing Mechanical System Description

Design Requirements & Intent

As the owner, the Baylor College of Medicine dictated the criteria for designing the mechanical systems of the Margaret M. Alkek Building for Biomedical Research. Within the design narrative put forth by BCM it states that the mechanical designer;

"…will implement the most appropriate and cost effective schemes for various materials, methods of distribution, etc. and make recommendations to the Design Team for the most advantageous system components on the basis of first cost vs. operating cost, reliability, safety and easy of maintenance."

BCM also put forth a list of characteristics that they deemed desirable in their HVAC system components. The list includes; a modular approach, energy responsiveness, flexibility for future changes, durability; ease of maintenance, reliability, and redundancy of critical components. BCM's design narrative goes on to stress that the layout of mechanical equipment should encourage routine preventative maintenance by providing easy access. Due to the location of the tower being on campus, BCM would like the building to utilize the campus chilled water loop as well as the TECO steam loop that also exists on the Texas Medical Center (which BCM is a part of). The overriding theme of the design narrative is that the system has a low first cost and is easy to maintain.

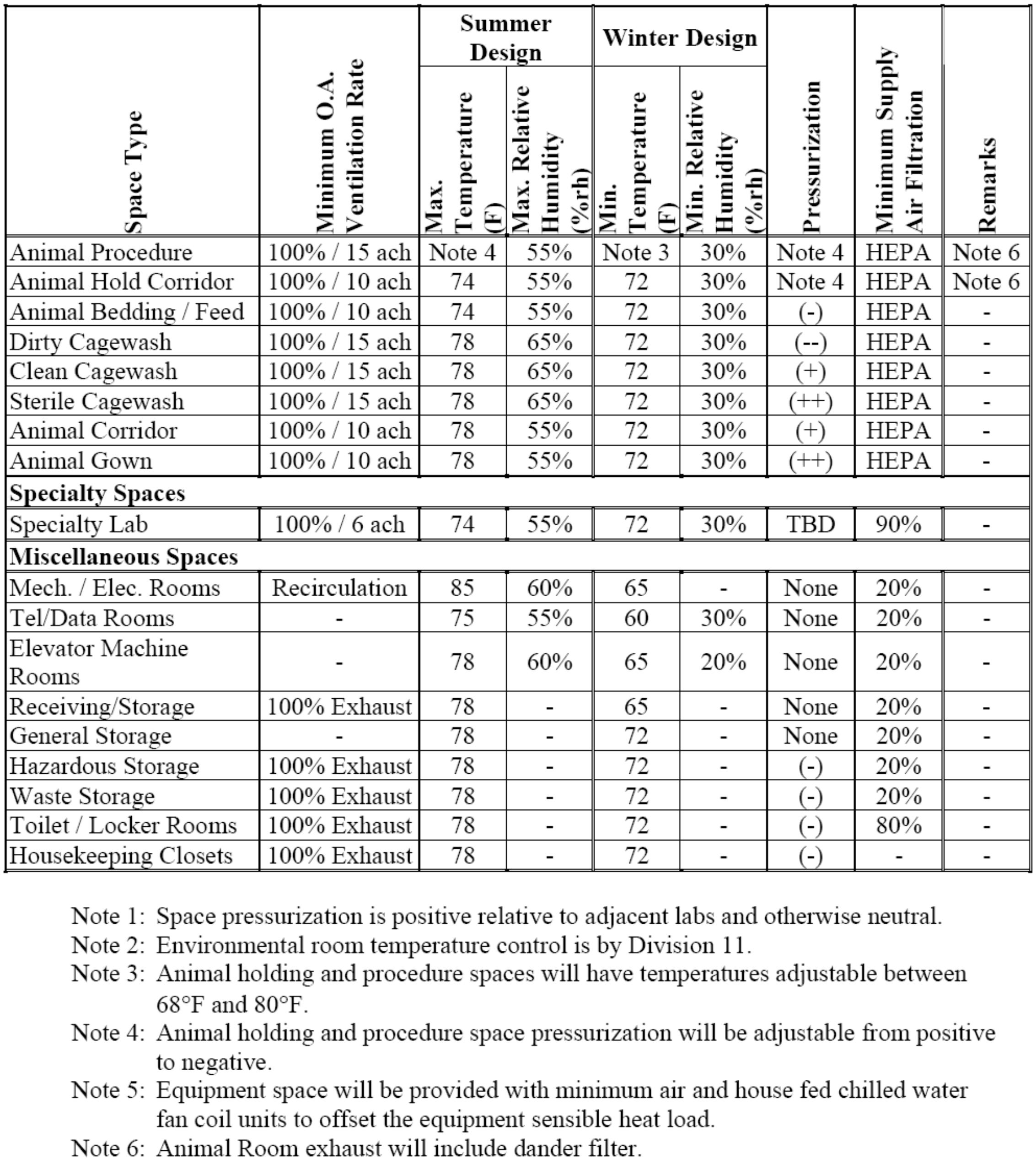
BCM's design narrative is extensive and sets many of the design conditions required for the mechanical systems in the research tower. BCM specifies the outdoor air design conditions for both winter and summer, which can be seen below in Figure 2. Also BCM puts forth requirements for internal heating loads, ventilation, pressurization and filtration for the various types of rooms in the building which can be reviewed in Figures 3 and 4.

Outside Conditions

1. Summer: 97°F db/80°F wb
2. Winter: 20°F
3. Air Cooled Condensers: 115°F db

Figure 2

Space Type	Minimum O.A. Ventilation Rate	Summer Design		Winter Design		Pressurization	Minimum Supply Air Filtration	Remarks
		Max. Temperature (F)	Max. Relative Humidity (%rh)	Min. Temperature (F)	Min. Relative Humidity (%rh)			
Public Spaces and Office Areas								
Offices	20 cfm / person	74	55%	72	30%	Note 1	90%	-
Office Support	20 cfm / person	74	155%	72	30%	-	90%	-
Common Areas / Lobbies	20 cfm / person	74	55%	72	30%	Note 1	90%	-
Conference Rooms	20 cfm / person	74	55%	72	30%	-	90%	-
Conference Center	20 cfm / person	74	55%	72	30%	-	90%	-
Coffee / Break	20 cfm / person	74	55%	72	30%	-	90%	-
Laboratory Spaces								
Lab Workstation	100% / 6 ach	74	55%	72	30%	(-)	90%	-
Open Lab	100% / 6 ach	74	55%	72	30%	(--)	90%	-
Lab Support	100% / 6 ach	74	55%	72	30%	(---)	90%	-
Tissue Culture	100% / 6 ach	74	55%	72	30%	(+)	90%	-
Microscopy	100% / 6 ach	74	55%	72	30%	(+)	90%	-
Equipment Room	100% / 6 ach	74	55%	72	30%	(---)	90%	-
Glasswash	100% / 6 ach	74	65%	72	30%	(---)	90%	-
Glasswash Equipment	100% / 6 ach	85	65%	72	30%	(---)	90%	-
Darkroom	100% / 6 ach	74	55%	72	30%	(---)	90%	-
Cold Room	0.5 cfm / sq.ft.	-	-	-	-	None	90%	Note 2
Equipment Corridor	100% / 6 ach	78	55%	72	30%	(-)	90%	Note 5
Animal Facility Spaces								
Animal Holding Rooms	100% / 15 ach	Note 4	55%	Note 3	30%	Note 4	HEPA	Note 6



Space Type	Minimum O.A. Ventilation Rate	Summer Design		Winter Design		Pressurization	Minimum Supply Air Filtration	Remarks
		Max. Temperature (F)	Max. Relative Humidity (%rh)	Min. Temperature (F)	Min. Relative Humidity (%rh)			
Animal Procedure	100% / 15 ach	Note 4	55%	Note 3	30%	Note 4	HEPA	Note 6
Animal Hold Corridor	100% / 10 ach	74	55%	72	30%	Note 4	HEPA	Note 6
Animal Bedding / Feed	100% / 10 ach	74	55%	72	30%	(-)	HEPA	-
Dirty Cagewash	100% / 15 ach	78	65%	72	30%	(--)	HEPA	-
Clean Cagewash	100% / 15 ach	78	65%	72	30%	(+)	HEPA	-
Sterile Cagewash	100% / 15 ach	78	65%	72	30%	(++)	HEPA	-
Animal Corridor	100% / 10 ach	78	55%	72	30%	(+)	HEPA	-
Animal Gown	100% / 10 ach	78	55%	72	30%	(++)	HEPA	-
Specialty Spaces								
Specialty Lab	100% / 6 ach	74	55%	72	30%	TBD	90%	-
Miscellaneous Spaces								
Mech. / Elec. Rooms	Recirculation	85	60%	65	-	None	20%	-
Tel/Data Rooms	-	75	55%	60	30%	None	20%	-
Elevator Machine Rooms	-	78	60%	65	20%	None	20%	-
Receiving/Storage	100% Exhaust	78	-	65	-	None	20%	-
General Storage	-	78	-	72	-	None	20%	-
Hazardous Storage	100% Exhaust	78	-	72	-	(-)	20%	-
Waste Storage	100% Exhaust	78	-	72	-	(-)	20%	-
Toilet / Locker Rooms	100% Exhaust	78	-	72	-	(-)	80%	-
Housekeeping Closets	100% Exhaust	78	-	72	-	(-)	-	-

Note 1: Space pressurization is positive relative to adjacent labs and otherwise neutral.
Note 2: Environmental room temperature control is by Division 11.
Note 3: Animal holding and procedure spaces will have temperatures adjustable between 68°F and 80°F.
Note 4: Animal holding and procedure space pressurization will be adjustable from positive to negative.
Note 5: Equipment space will be provided with minimum air and house fed chilled water fan coil units to offset the equipment sensible heat load.
Note 6: Animal Room exhaust will include dander filter.

Figure 3

Space Type	People Load	Lighting Load	Equipment Load	Remarks
Public Spaces and Office Areas				
Offices	100 gsf/person	1.5 W/gsf	4.0 W/gsf	-
Office Support	250 gsf/person	1.5 W/gsf	4.0 W/gsf	-
Common Areas / Lobbies	250 gsf/person	1.5 W/gsf	0.5 W/gsf	-
Conference Rooms	25 gsf/person	1.5 W/gsf	2.0 W/gsf	-
Conference Center	25 gsf/person	1.5 W/gsf	0.5 W/gsf	-
Coffee / Break	25 gsf/person	1.5 W/gsf	0.5 W/gsf	-
Laboratory Spaces				
Lab Workstation	100 gsf/person	1.5 W/gsf	8 W/gsf	-
Open Lab	100 gsf/person	1.5 W/gsf	8 W/gsf	-
Lab Support	100 gsf/person	1.5 W/gsf	16 W/gsf	-
Tissue Culture	100 gsf/person	1.5 W/gsf	16 W/gsf	-
Microscopy	100 gsf/person	1.5 W/gsf	16 W/gsf	-
Equipment Room	100 gsf/person	1.5 W/gsf	16 W/gsf	-
Glasswash	200 gsf/person	1.5 W/gsf	Note 2	-
Glasswash Equipment	-	1.5 W/gsf	Note 2	-
Darkroom	100 gsf/person	1.5 W/gsf	8 W/gsf	-
Cold Room	-	-	-	-
Equipment Space	100 gsf/person	1.5 W/gsf	40W/gsf	-
Animal Facility Spaces				
Animal Holding Rooms	Note 1	1.5 W/gsf	Note 2	-
Animal Procedure	Note 1	1.5 W/gsf	Note 2	-
Animal Hold Corridor	200 gsf/person	1.5 W/gsf	-	-
Animal Bedding / Feed	200 gsf/person	1.5 W/gsf	Note 2	-
Dirty Cagewash	200 gsf/person	1.5 W/gsf	Note 2	-
Clean Cagewash	200 gsf/person	1.5 W/gsf	Note 2	-
Sterile Cagewash	200 gsf/person	1.5 W/gsf	Note 2	-
Animal Corridor	200 gsf/person	1.5 W/gsf	0.5 W/gsf	-
Animal Gown	100 gsf/person	1.5 W/gsf	0.5 W/gsf	-
Specialty Spaces				
Specialty Lab	100 gsf/person	1.5 W/gsf	8 W/gsf	
Miscellaneous Spaces				
Mech. / Elec. Rooms	-	-	-	Note 3
Tel/Data Rooms	-	1.5 W/gsf	Note 5	-
Elevator Machine Rooms	-	1.5 W/gsf	Note 2	-
Receiving/Storage	200 gsf/person	1.5 W/gsf	1.5 W/gsf	-
General Storage	200 gsf/person	1.5 W/gsf	1.5 W/gsf	-

Space Type	People Load	Lighting Load	Equipment Load	Remarks
Hazardous Storage	-	-	-	Note 4
Waste Storage	-	-	-	Note 4
Toilet / Locker Rooms	-	-	-	Note 4
Housekeeping Closets	-	-	-	Note 4

Figure 4

The building utilizes the campus chilled water loop for all chilled water production through a plate and frame heat exchanger. For domestic hot water and heating hot water the campus steam loop is utilized. Cost analyses were done for chilled water production as well as steam production for the Baylor College of Medicine campus. The electricity rate for BCM is $0.0515/kWh and the natural gas rate is $7.15/MMBTU. After the analysis was carried out it was found that steam production cost $0.0831/1000lbs of steam and chilled water production cost $0.0028/ton-hour. However, these prices did not factor into the decision to use the campus loops. BCM wants all their buildings on these loops for simplicity and that was the overriding factor.

Overview

Construction of the new research tower required BCM to replace one of the existing 800 ton chillers in the North Campus chiller plant with a 1300 ton centrifugal chiller to accommodate the extra load from the new research tower. The tower has access to the campus chilled water loop, as well as a high pressure steam loop. The campus chilled water is pumped into a plate and frame heat exchanger which is responsible for the process chilled water in the tower. The steam loop runs into 3 shell & tube clean steam generators which produce the steam needed in the building for process and humidification. The steam runs through the building in low pressure (15 psig) and medium pressure (80 psig) loops. A portion of the low pressure steam is sent to two shell & tube heat exchangers which generate the hot water for the building which feeds heating coils in the air handling units as well as all reheat coils.

There are 12 air handlers in total that supply the tower. Of the 12 air handlers 10 are located in the level 3 mechanical space and the other 2 are located on the roof. On the roof there is a 15,000 cfm and 10,000 cfm air handler which serves to pressurize the north and south stairwells, respectively. 4 25,000 cfm air handlers service the vivarium spaces, office and lab spaces on levels 1 and 2. There are 2 10,000 cfm air handlers that serve the level 3 mechanical space. The final 4 air handlers are 50,000 cfm and serve the main lab and office spaces on floors 4-8. Fan coil units are used in the emergency electrical rooms, elevator equipment room and in the eastern corridors on levels 4-8.

Levels 1 & 2 contain all of the animal research facilities and vivarium space and are served by the same 100% air system. A majority of the spaces on level 2 are variable volume however some of the vivarium and research spaces are constant volume. All the spaces on level 2 are exhausted through fume hoods or ductwork both of which are connected to exhaust fans located on the roof. Level 1 contains the lobby of the research tower. This lobby space and the attached corridor are variable volume spaces and are the only spaces on level 1 in which the air is returned instead of exhausted. However those spaces are supplied by and returned to an air system that is separate from the one that serves levels 1 and 2. Some of the vivarium spaces and animal research spaces on level 1 are constant volume, but most are variable volume however all spaces are exhausted through the same exhaust to level 2. The animal facility cagewash on level 1 is variable volume and is exhausted through exhaust diffusers as well as exhaust hoods. There is office space on level 1 which is variable volume however the air in this space is also exhausted and not returned. There are many vestibules which separate the “dirty” and “sterile” sides of level 1 which is divided by the cagewash. The “dirty” side is the office side and also where dirty cages are brought into the cagewash to be cleaned and the sterile side is the opposite side of the building where the sterile cages are removed from the cage wash.

Level 3 has only a few spaces to consider. In the northeastern corner of the building there is some storage space, corridor, glass wash and equipment service area that needs to be considers for heating and cooling. These spaces are all constant volume and exhausted. The rest of the space on level 3 is the mechanical area containing a majority of the air handlers. There are louvers along the north side of the building that allow for outdoor air to come in and feed the air handlers.

On levels 4-8 the research laboratories are variable volume, as are the office spaces on the opposite side of the floors. However not all spaces on levels 4-8 are variable volume there are a some laboratory support spaces that are constant volume, typically the presence of a fume hood will indicate constant volume. The air within the laboratory and laboratory support spaces is exhausted through exhaust fans located on the roof via exhaust risers or through fume hoods that also exhaust through the roof. The laboratory and office spaces on levels 4-8 are separated by a pressurized corridor/interaction space. Air in the office side and separating corridor/interaction space is returned.

Existing Mechanical System Operation

This section of the report will describe the operation of the four main systems throughout the building. These systems are the steam, chilled water, heating hot water and air systems within the building. Each section will describe the system and reference and accompanying schematic of the system.

Building Steam System

The Margaret M. Alkek Building for Biomedical Research has an extensive steam system. Baylor College of Medicine’s campus is located at the Texas Medical Center which produces its own steam via the Texas Medical Center Central Heating and Cooling Services Cooperative Association (TECO). The research tower utilizes this campus steam loop for many different uses.

The campus steam loop conditions are 398°F and 225 psig. The building draws in 26,000 lb/hr of steam at peak load. The amount of demand depends on the following; humidification in the air handlers, the amount of process of steam required, domestic hot water and heating hot water needs. The high pressure steam is brought into the building and then goes through a series of pressure reducing valves which creates medium pressure steam (80 psig) and low pressure steam (15 psig) loops.

The low pressure steam loop feeds two shell & tube heat exchangers (HE-1 & HE-2 on Figure 5 below) which create the heating hot water for the building. HE-2 unit is used as standby. The low pressure steam is then returned to a condensate pump (CP-1 on Figure 5 below) and then is fed back into the TECO condensate system. The high pressure return and low pressure return from the pressure reducing valves feed into a flash tank which vents off any existing steam and then connects to the same condensate pump as the low pressure steam system which again connects into the TECO condensate system.

The medium pressure steam loop goes to feed 3 clean steam generators and the domestic hot water heaters. As shown on figure 5, CSG-1 creates clean low pressure steam (CLPS) which feeds the air handling units for humidification needs. This CLPS then returns to a condensate cooler which connects to the existing water recovery system on campus. CSG-2 & CSG-3 create clean medium pressure steam which feeds all the process steam requirements throughout the building for sterilization of lab equipment and other needs. The process steam is then returned to a flash tank which then feeds clean low pressure return steam into the same condensate cooler as mentioned above which then connects to the existing water recovery system. The domestic hot water heaters connect right off of the medium pressure steam loop. All of the medium pressure return from the CSG's and domestic water heaters connects to a flash tank which connects back to CP-1 (same condensate pump as the other HPR and MPR connect into) and then into the TECO condensate system.

The amount of steam drawn off the high pressure steam loop depends entirely on the heating and steam generation needs of the building at any point in time. See the below schematic (Figure 5) for a complete view of steam usage in the building.

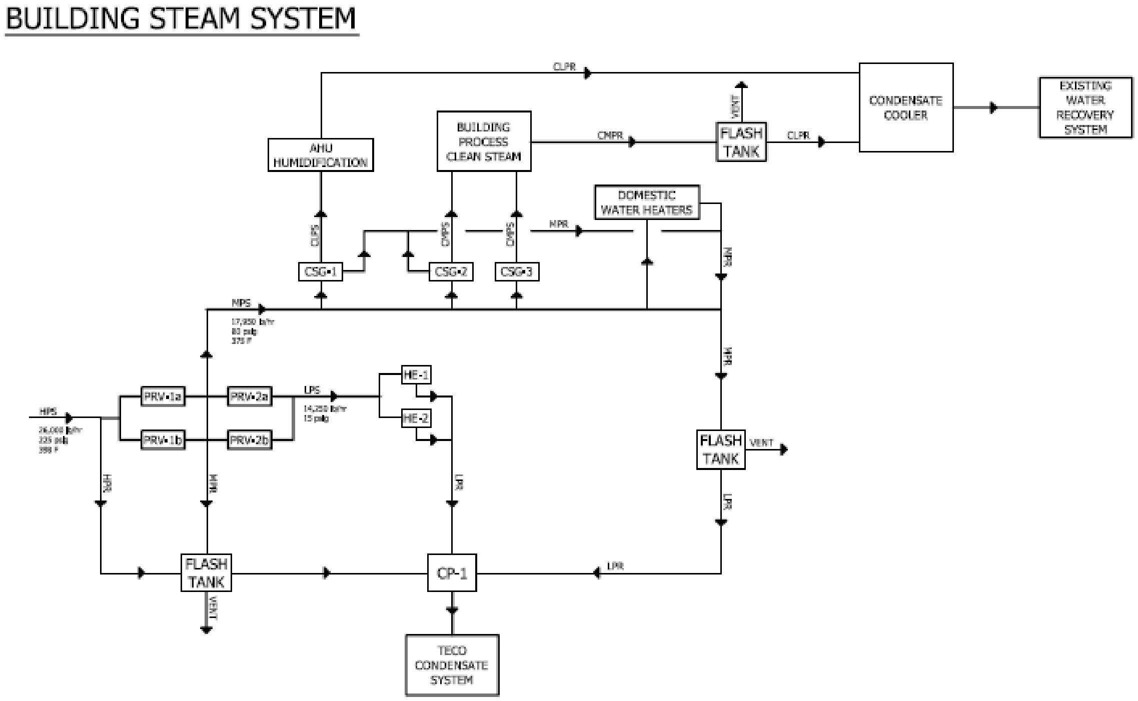


Figure 5

Building Chilled Water System

The Margaret M. Alkek Building for Biomedical Research utilizes the existing campus chilled water loop for all its chilled water needs. The chilled water is produced in the north campus chiller plant. With the addition of the new research tower, a chiller had to be replaced. An existing 800 ton centrifugal chiller was replaced with a new 1300 ton centrifugal chiller to assist in the handling of the new load on campus and for future expansion. The campus loop circulates chilled water at 45°F.

Chilled water is drawn into the building and separated into two loops. The first loop takes 45°F water through two pumps in parallel (CHP-1 & CHP-2). This chilled water is pumped to the cooling coils on the air handling units that serve levels 4-8’s office and lab space (AHU-L.1a, AHU-L.1b, AHU-L.2a and AHU-L.2b) as well as the cooling coils on the stairwell pressurization air handlers. The sensors on the coils in the air handling units connect back to the two pumps (CHP-1 & CHP-2) which are connected to variable frequency drives for control of how much chilled water is brought into the building via this loop. At peak load this loop will draw in 2750 GPM. The chilled water used by these air handlers is then returned at 60°F to the campus chilled water return loop.

The second chilled water loop created within the building feeds the air handlers for the animal research facility floors (AHU-A.1a, AHU-A.1b, AHU-A.1c and AHU-A.1d), fan coil units and process cooling throughout the building. Two parallel pumps (CHP-3 & CHP-4) draw in 1720 GPM (peak design load) of chilled water, of which, 1360 goes directly to the air handlers for the animal research facility floors. A sensor on the cooling coils connects back to the variable frequency drives attached to CHP-3 and CHP-4. The chilled water is returned from these air handlers at 60°F to the campus chilled water return loop. A 360 GPM branch breaks off to feed a plate and frame heat exchanger (PFX-1). Chilled water enters the PFX-1 at 45°F and leaves at 60°F, this water then is returned to the campus chilled water return loop. The plate and frame heat exchanger creates 50°F chilled water which then feeds fan coil units and any process cooling needs throughout the rest of the building. The water is then returned to the PFX-1 at 65°F. The schematic of this system can be seen below.

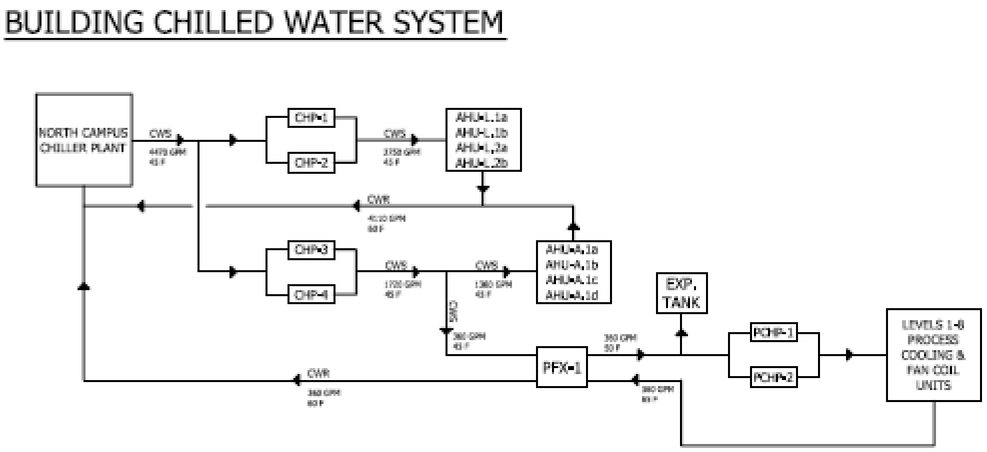


Figure 6

Building Heating Hot Water System

The research tower's heating hot water system is fairly simple. As stated above in the steam section two shell & tube heat exchangers (HE-1 & HE-2) are used for heating hot water creation for the building. HE-2 is a standby unit. At peak design HE-1 creates 950 GPM (peak design load) of heating hot water for distribution throughout the building. The two heat exchangers are connected to two parallel pumps (HWP-1 & HWP-2) which distribute the heating hot water. There are 3 loads that the heating hot water feeds; the reheat coils in the VAV/CV boxes on levels 1 and 2, the reheat coils in the VAV/CV boxes on levels 4-8 and level 3 which houses the air handling units for laboratory, office and animal research facilities. The heating hot water is distributed at 190°F and returned at 160°F.

The controls on the heating hot water are slightly more complex than the other systems. Each space (or zone) within the building has its own CV or VAV box. Each box (with the exception of cold rooms, electrical and mechanical rooms) has a reheat coil in the box. The thermostats in each room then connect to the diffusers and reheat coils. If the thermostat is set to where reheat is needed at the box, the reheat coil is turned on. The reheat coils in the boxes and heating coils in the boxes connect to the variable frequency drives connected to the pumps for control of how much heating hot water is distributed. The complete diagram can be seen below.

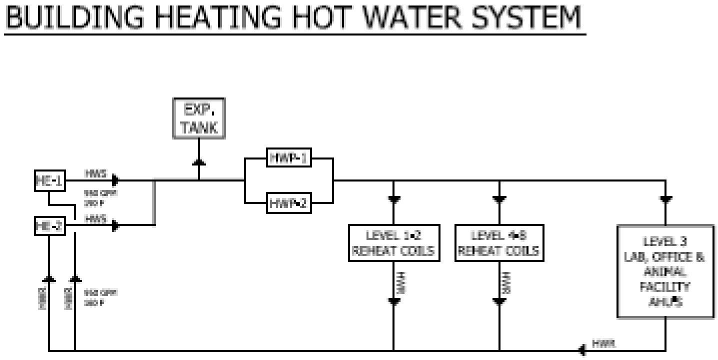


Figure 7

Building Air Side Systems

The research tower's air system is relatively simple as well. The building has three separate air systems with multiple air handling units serving each of these three systems. System 1 serves animal research facility on levels 1 and 2. System 2 serves the laboratory spaces on levels 4-8, while System 3 serves the office spaces on levels 4-8 as well as the remaining laboratory spaces not covered by System 2.

System 1: AHU-A.1a, AHU-A.1b, AHU-A.1c & AHU-A.1d

System 1 serves the animal facilities on levels 1 & 2. This system consists of four 25,000 CFM air handlers; AHU-A.1a, AHU-A.1b, AHU-A.1c and AHU-A1.d. The animal facilities on the first floor are made up of animal housing rooms in which animals to conduct experiments on are held. Connected to the animal housing rooms are procedure rooms where the experiments or preparation for experiments can be carried out. A majority of the space on level 1 is taken up by a cage wash facility for cleansing of all the cages in which animals are stored. Level 2 consists almost exclusively of the aforementioned animal housing rooms and adjacent procedure rooms.

System 1's four air handlers are stacked in a 2x2 configuration and "dump" all their supply air into a supply plenum where air from all 4 air handlers is mixed. Air is then supplied from there to the appropriate spaces on levels 1 & 2. The system is 100% outdoor air, this is due to needing the air as clean as possible so as to not influence experiments or spread contaminants/sickness. The air is exhausted from these spaces through four separate means; biological safety cabinets (similar to fume hoods), an exhaust riser dedicated to animal spaces, toilet exhaust and an exhaust for the cagewash exhaust which is a "wet" exhaust because of the steam used to sterilize during cleaning.

The thermostats determine how much air is required for these spaces which connect back to the variable frequency drives connected to the fans of the air handling unit as well as the VAV/CV boxes. The exhaust tracks the supply so that pressurization required in certain rooms are maintained. Many of the spaces within this system are constant volume to maintain pressurization due to the fume hoods and biological safety cabinets which draw a constant amount of air from the room. The diagram of this system can be seen below in Figure 8.

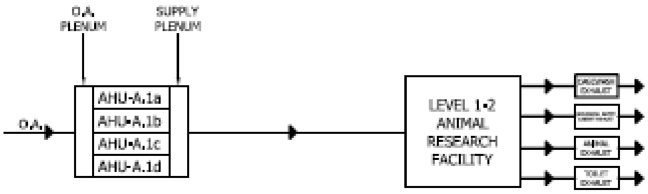


Figure 8

System 2: AHU-L.2a & AHU-L.2b

System 2 serves the laboratory spaces on levels 4-8. This system consists of air handlers; AHU-L.2a and AHU-L.2b. The laboratory spaces on these levels are for research purposes at the college. The adjacent spaces are laboratory support and are made up of spaces such as fume hood rooms, equipment rooms, microscopy and general lab support rooms. The air handlers are stacked on top of each other and supply into a supply plenum similar to system 1. This system is also 100% outdoor air for the same reasons as system 1.

System 2 is controlled the same as System 1. The difference being that much fewer spaces are constant volume due to only a few fume hoods being present (and in specific rooms). The spaces are exhausted via exhaust risers that connect to four exhaust fans connected in parallel. The diagram of this system can be seen below.

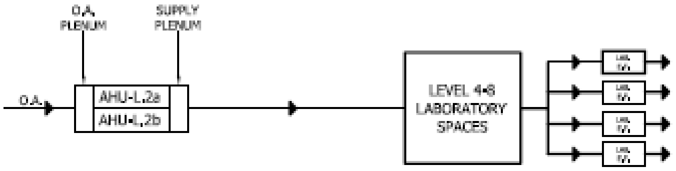


Figure 9

System 3: AHU-L.1a & AHU-L.1b

System 3 is the only system in the research tower that uses recirculated air. This system serves the rest of the laboratory spaces on levels 4-8 not covered by system 2, the office spaces on levels 4-8 and the main lobby and attached corridor on level 1. This system is made up of air handling units AHU-L.1a and AHU-L.1b. These units are also stacked one on top of the other and use the supply plenum like the other 2 systems. Air in the laboratory spaces on these floors is exhausted through the roof of the building. The office side of levels 4-8 and few level 1 spaces are the spaces that are returned. The system is approximately 50% outdoor air.

The controls on System 3 are similar to the other 2 systems. In this case return tracks the supply in the office spaces that return air. There are no constant volume spaces (outside of the restrooms) in this system because the few laboratory spaces that are covered by this system do not require it. The laboratory spaces are exhausted by exhaust fans located on the roof via duct risers. The diagram of this system can be seen below in Figure 10.

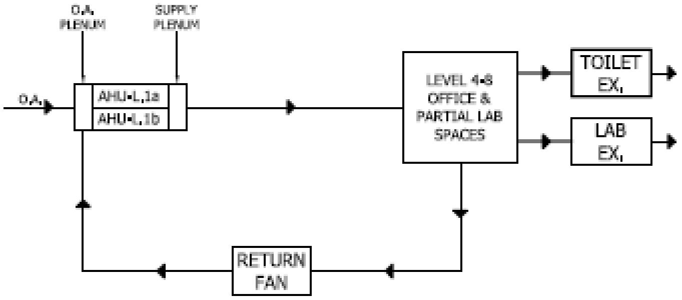


Figure 10

Proposed Redesign

Scope

The proposed redesign intends to address the energy consumption and indoor air quality issues of the building. Currently the solution to controlling the indoor air quality is to use 100% outdoor air systems which contribute to the energy consumption of the building. Using 100% outdoor air means there is no return air which means there is no energy savings through mixing of air. The basic premise of the redesign will be using air quality sensors placed before and after filters in what is currently the exhaust stream to track the air quality and then when it is acceptable either return the air or use an energy recovery device such as an enthalpy, sensible or desiccant wheel in an attempt to cut down on the energy consumption of the building.

The first issue to deal with will be implementation of filters and the indoor air quality controls. The system will need to be able to monitor what will become an exhaust/return stream and determine when the air is acceptable to use or when it needs to be exhausted. It appears as though this sort of system is somewhat rare.

A fair amount of information will need to be gathered to set up controls like this. The first bit of information will be what sort of particles do mice release since the main animal being used for experimentation is mice. Also information on what sort of toxins and particles are typically released during the types of experiments that are going to be conducted in the research labs. Information on particles and pollutants that are in the outdoor air in Houston, Texas should be gathered. Then it needs to be determined what are acceptable levels of each for occupants of the buildings then the control system can begin to be constructed.

Once this information is gathered the next issue to address will be to look into what would be the best device to use for energy recovery in the system. It needs to be determined whether a sensible wheel, enthalpy wheel, desiccant wheel, direct return or a combination of those energy recovery devices will need to be looked at.

The redesign looks to address the indoor air quality and energy consumption issues associated with research labs. The current answer to this is to ignore the energy consumption and go with a 100% outdoor air system to ensure there are no problems with indoor air quality. This redesign will look to see if active controls in indoor air quality monitoring is a better design idea.

Justification

The redesign will allow for an opportunity to learn more about controls in the less than ordinary application of indoor air quality monitoring. This will also allow for a look at research lab design from an “outside the box” perspective. Also the redesign looks to save energy consumption which will become a bigger issue as natural resources deplete.

Integration & Coordination

The biggest integration and coordination concern for the proposed redesign of the Margaret M. Alkek Building for Biomedical Research will be finding space and a location for the energy recovery devices. Currently the mechanical systems are on level 3. This means that the exhaust streams for levels 1-2 pass through the mechanical systems floor but not levels 4-8 exhaust streams. So to allow for energy recovery on all exhaust streams it is proposed that the top level (level 8) research floor be switched in place with the level 3 mechanical systems floor. This allows for the energy recovery devices to have access to all exhaust streams as well as the air handling units that supply all the lower levels.

Then there is the issue of saving space on this floor by consolidating the current 2x2 or one on top of the other stacked design of air handlers into one air handler for each of the 3 above air-side systems. This should allow for some more room for energy recovery devices and the extra duct risers that will run through this floor. Another possible idea for saving floor area is to look into placing radiant ceiling panels into spaces to cut down on some of the air handling units load for cooling and thus being able to size them down.

Breadth Areas of Redesign

A main point of the redesign will involve switching Level 8 which is currently a research lab with Level 3 which is currently the mechanical systems floor. The biggest concern here will be the moving of that load from a lower floor to the upper floor. Once new equipment is in place a structural analysis will need to be done to ensure that the structure can handle the redistributed load or if the structural members will need to be resized (whether larger or smaller).

The new equipment will need be analyzed from a cost perspective versus the existing design. The cost of the extra or changed equipment and the energy savings will be analyzed to see how much of a savings it presents. It will then be determined whether the proposed redesign would be a reasonable alternative, cost wise. Also, the building's electrical system may need to be looked at with the moving around of the equipment.

Alternate Redesigns Considered

There were two alternative redesigns considered before settling on the proposed redesign. The two ideas were first to use an absorption chiller instead of the campus chilled water loop and the other was a combined heat and power system.

The campus chiller plant has an 800 ton chiller that is replaced by a 1300 ton chiller to accommodate the extra load on the campus' chilled water system as well as to have some room for future expansion. The first redesign idea is to install an absorption chiller to produce the building's chilled water instead of replacing the 800 ton chiller in the north campus chiller plant and using the plate and frame heat exchanger to create the building's chilled water. The absorption chiller would have utilized the existing campus steam loop to drive it. This was considered not an indepth enough redesign to devote a semester to. The only areas to study would be cost and energy consumption of adding the absorption chiller versus the existing design. The mechanical floor also is very much full at this point so there is no room to place an absorption chiller.

The second alternative was to put in a combined heat and power system. There were several problems with this idea. Since the building has not been constructed yet there are no load profiles available. Energy analysis and other activities so far have been conducted under an assumed profile for comparison sake. For a combined heat and power system a detailed load profile needs to be available to test the feasibility of the system. Typically offices are not considered to have good profiles for a CHP system. Also it is assumed that a laboratory would have a similar load profile as an office. Also there is little room for a turbine and an absorption chiller within the building for this equipment. Another floor would have to be added or perhaps a penthouse for these systems which would cost way more than using an absorption chiller driven by exhaust gases would save over any number of years.

There was also two common problems with each of these redesign ideas. The first is that both designs take measures to remove the buildings mechanical systems from the existing campus loops. Since the building is being constructed on campus it does not make sense to remove it from the existing available loops. The main problem with both redesign ideas is that neither addresses the real issues involved with the building. The building, as with most research buildings, consumes a large amount of energy and indoor air quality is also a big concern. Neither of these designs takes any real measures to address these issues so neither was seriously pursued.

Mechanical Redesign

A variety of ideas were initially entertained during the redesign of the mechanical system for the Margaret M. Alkek Building for Biomedical Research, however after conducting more research, only some of the initially proposed ideas were implemented. The proposal called for a monitoring of indoor air quality in laboratory and vivarium spaces to determine when and how much air is to be exhausted and returned. This ended up not being a reasonable thing to do and will be discussed later in the report. A CO_2 based demand controlled ventilation system was explored in the office side of the building. Office spaces lend itself to a demand controlled ventilation scheme. To implement the DCV scheme as well as meet the owner's requirements the laboratory spaces on system 3 had to be moved to system 2. Energy recovery was used on the vivarium and laboratory air system. After research it was determined that the original proposal for the type of energy recovery was not reasonable. The best options were either a heat pipe system or a runaround loop system. After a study was done it was determined that the runaround loop would be the best option based on first cost and effectiveness. The details of this study and the rest of the changes in design to the building will now be discussed.

Air System Zone Rearrangement

The first change in the design that was addressed is the zones associated with each air handling system. System 3 currently has both office and laboratory spaces on the same air handling unit systems. This conflicts with the owner's design narrative in two separate ways. The first problem is that the owner requested 100% outside air and 6 air changes per hour for all laboratory spaces. System 3 is a 75% outdoor air system and the rooms are being supplied for 6 air changes per hour but since the air is only 75% outdoor air the rooms are not getting 6 air changes of outdoor air. The owner also calls for redundancy of "critical components". For this reason System 3 consists of two 50,000 CFM AHU's to supply the office and laboratory spaces. However office spaces can hardly be considered a "critical component" or a "critical zone". The rest of the laboratory spaces on levels 4-8 are served by System 2. The laboratory spaces on systems 2 and 3 are actually the same spaces. The main research laboratory and attached lab workstations are served by system 2 and 3 which means that as a whole space (which there are no partitions between the areas of the room served by system 2 and 3) is not receiving 100% outdoor air as well. For these reasons the laboratory spaces will be moved from system 3 to system 2. This will allow for system 3 to only serve the office spaces, this allows for the implementation of the demand controlled ventilation system. The other benefits of changing the zoning is that the office can have only one AHU serving those spaces since redundancy is not required for an office space. The last benefit is that the laboratory spaces will be receiving 100% outdoor air.

Energy Recovery Systems in Laboratories

A problem with the design of many laboratories is the building's consumption of energy. Many universities and other types of owners want their laboratory spaces to be designed with 100% outdoor air systems. The reason is they do not want to take any chances with indoor air quality and ruining the experiments being conducted within the building. Conditioning of 100% outdoor air to desired supply conditions versus a typical VAV system with recirculation causes the energy consumption to become such a problem.

The Margaret M. Alkek building has two critical research areas to consider. The two areas are the general laboratory spaces on levels 4-8 and the vivarium on levels 1-2. These spaces are both served by 100% outdoor air systems. These systems are perfect candidates to install an energy recovery system. A major concern when selecting an energy recovery system for laboratories or vivariums is cross-contamination. There are four types of energy recovery systems that are applicable for laboratory design. Here is a brief overview of the heat recovery systems considered.

Runaround Loop

A runaround loop heat recovery system is an air-to-air sensible heat transfer system. A runaround loop consists of a coil in the outdoor air stream and in the exhaust air stream. The coils are connected by piping and a pump. Typically the working fluid is a glycol solution to prevent freezing, in the right type of climate, water could be used as the working solution. The pumping and piping require maintenance to be maintained at its peak working order. This sort of system means that the outdoor and exhaust streams do not need to be adjacent to each other, and can be as far apart as piping and pump budget will allow. The typical effectiveness of these systems are about 55-65%.

Plate Exchanger

The plate exchanger is also an air-to-air sensible heat exchanger. A plate exchanger requires the outdoor and exhaust air streams to be adjacent to each other. There are two types of plate exchangers either; cross-flow or counter-flow. Cross-flow means that the outdoor and exhaust streams will run perpendicular each other. Counterflow means that the flows run parallel and in opposite directions of each others. The air flows are separated by the plates, so the chances of cross contamination are controlled by the integrity of the plate. Maintenance is minimal. The efficiency of the plate exchanger is between 45 and 65%.

Heat Pipe

A heat pipe is yet another air-to-air sensible heat recovery system. The heat pipe is a coil consisting of a series of individual finned tubes that are sealed and filled with refrigerant. The coil is placed so that both the exhaust and outdoor air streams pass through the coil. This means that the air streams have to be adjacent to each other. The two ends of the heat pipe system that are in each air stream are completely sealed off to prevent any form of cross-contamination. There is also a heat pipe system made by Heat Pipe Technologies called a split case system. The system allows for a booster pump to be added so that temperature difference is not the only force driving the refrigerant flow. Their system allows for the coils to be up to 200 feet apart horizontally or 25 feet vertically. The heat pipe coils could be further apart vertically however this would require a multi-state pumping set up. The effectiveness of heat pipes are 45-65%.

Total Energy Wheel

A total energy wheel is the final air-to-air device looked at; however this one exchanges both sensible and latent energy. The exhaust and outdoor air streams must be adjacent to each other and the energy wheel will rotate between the two air streams. Cross-contamination is always a concern with total energy wheels. However, newer technologies can cut down on cross-contamination but there is no way to completely eliminate it. Typical efficiency is between 70-78%.

The need to prevent cross-contamination narrowed down the choices to either a heat pipe system or a runaround loop. The effectiveness of these two systems is essentially the same. The difference is the location of the outdoor and exhaust air streams relative to one another. For a heat pipe system to be implemented the 3rd floor which contains all of the mechanical systems would have to be switched with the 8th floor to allow for the outdoor air intakes to be close enough to the exhaust air streams to use a split case heat pipe system. A typical heat pipe system would be impossible to use since the exhaust stream is on the roof and runs nowhere near the outdoor air intakes. A study was then set up to check the impact this move would have on the structure of the building as well as the first cost. The results of this study can be read in the “Structural Breadth/Energy Recovery Systems Study” section of this report. The conclusions of this report were that the runaround loop system would be cheaper to install and since the effectiveness of each system is the same then it makes the runaround loop the more appealing option. The runaround loops will be implemented in the air handling systems serving the vivarium spaces as well as the laboratory spaces.

As stated above a runaround loop consists of two coils, piping and a pump. The coils were selected using Heatcraft’s Coil Calc program. The options for the coil such as rows, material, etc, were selected in this program. A working fluid of water and 30% ethylene glycol was used. An ethylene glycol solution will prevent the solution from freezing in cold conditions. The vivarium air system and the level 4-8 laboratory spaces have separate runaround loops. However, each system the same size of coils, with 3 coils per bank to fill the duct spaces. Each system has the coil in the outdoor air stream placed in the duct connecting the outdoor air louvers to the supply plenum. The exhaust air coils were placed in the exhaust air ducts on the roof for each of the respective systems. The fluid flows through each coil were determined using a Trace model (that will be discussed later in the report) and the equation;

$$Q = 500 \times GPM \times \Delta T$$

The Q was determined by the reduction in heating energy found using two trace models, one for the original design and one for the redesign. The delta T portion of the equation was assumed to be 20 degrees. The results of this equation stated that the runaround loop for the vivarium needs a flow rate of 51 GPM and the laboratory loop needs a flow rate of 86 GPM. Each system needs approximately 190 feet of piping to cover the rise the piping will need to cover from the level 3 location of the mechanical systems to the roof where each systems respective exhaust ducts are located and manifolded. A pump was then sized based off of the following information; the pressure drop through the coils, the friction loss (4’ / 100’ of pipe) for the 190 ft length of pipe and the 80 vertical rise. The Pump-Flo.com online pump selector was used to determine the size of the pump. It was determined that for the laboratory loop a 5 hp pump was needed and a 3 hp pump was used for the vivarium loop. The selection sheets for the coils and pumps can be found in Appendix A of this report. These sheets will give the details and model #'s of the coils and pumps to be used for the runaround loops.

System 1: Air Quality Monitoring Issues

The proposed redesign suggested that the exhaust ducts have filters and then be monitored based on composition of mouse emissions. The monitoring system would then send a signal to recirculate the air when the mouse emissions were at a low enough level to be acceptable for recirculation. This idea was not practical enough to actually be used in a building. Data for mouse emissions would change based on the type and size of mice, as well as what experiments were being conducted on the mice. Another problem is actually determining what to monitor for in the exhaust stream. While mice emission data could be found this is not the only contaminate that would have to be monitored. The experiments taking place within the animal procedure rooms would not always be the same and thus mean that different contaminates would have to be dealt with. This would involve a rather elaborate sensor configuration which would get rather expensive and more than likely have a poor payback period. The final reason against this active monitoring scheme is to not influence experiments or harm the mice in experiments. It was discovered that some of the 2nd, 3rd and later generation mice in an experiment can be worth up to $600 a piece. This would lead to having to exhaust most of the air and thus having a very poor payback period for the elaborate sensor configuration that would be needed. The owner, Baylor College of Medicine, requested 100% outdoor air and 15 air changes per hour and this is the criteria that levels 1 and 2 were designed to. So because of the critical nature of the animal housing spaces it was determined not to revisit the design of the vivarium spaces air system in terms of air quality.

Demand Controlled Ventilation

Research into a control strategy for active monitoring revealed Demand Controlled Ventilation (DCV) based on CO_2 levels. CO_2 is a bioeffluent that is generated by people. The rate of which this is generated depends on several factors; such as size, age, activity level, etc, etc. CO_2 is tracked to control ventilation for two reasons. The first is that since CO_2 is generated by people you can make an estimate of how many people need to be ventilated for based off of the CO_2 concentration. The people component of ASHRAE Standard 62.1 is ultimately responsible for the removal of odorous bioeffluents from a space. This leads to the second reason why CO_2 is good for controlling ventilation. The generation of CO_2 is proportional to the amount of odorous bioeffluents generated by a person. Thus, if you control the CO_2 levels you should be controlling the odorous bioeffluents in a space. So as the occupancy level goes up in a space the concentration of CO_2 and odorous bioeffluents should go up as well. It then becomes necessary to bring in more outdoor air to ventilate the space.

Demand controlled ventilation is a control strategy. The following is a DCV design procedure set forth in ASHRAE Standard 62.1's user manual. To set up the controls one must do the ASHRAE Standard 62 ventilation rate procedure twice. The first time the procedure is done is for design conditions of all the rooms, this value for V_{ot} will be the maximum amount of outdoor air that is needed. Then the procedure is done a second time with an occupancy of zero for the critical zones. This time the V_{ot} value will be the minimum amount of outdoor air that is brought in. The next step is to determine the maximum CO_2 level for the rooms that are monitored, the minimum value is determined by a CO_2 sensor at the outdoor air intake location or an assumed value is used. The equation to determine the maximum CO_2 value is found in the User's Manual for ASHRAE Standard 62.1. The equation is as follows;

$$C_{room} = C_{oa} + \frac{8400 \cdot E_z \cdot m}{R_p + \frac{R_a \cdot A_z}{P_z}}$$

Where C_{oa} is the CO_2 concentration in the outdoor air and m is the metabolic rate (typically 1.2 for office work) of the people within the space. The rest of the variables are the same as in the ventilation rate procedure. As CO_2 concentrations increase the outdoor air damper and recirculation damper position will modulate between the minimum outdoor air and the maximum outdoor air calculated above. It is up to the designer's discretion on how to modulate between the two points. The only extra equipment needed for a demand controlled ventilation system is CO_2 sensors. The CO_2 sensors will be installed in the critical zones above to monitor the zones' level. Another sensor could be installed in the outdoor intake air to monitor the ambient CO_2 levels. This makes the CO_2 sensor selection and location critical to having a properly operating demand controlled ventilation system.

There are two main types of CO_2 sensors, Non-Dispersive Infrared detection or ones that use Photo-Acoustic detection. Non-Dispersive Infrared detection (NDID) looks for an increase or decrease in the amount of light at the wavelength where CO_2

absorption takes place. There are two main causes of sensor drift with this type of detection. The first being particle build up over time on the sensor that will effect the readings. This problem can be corrected by using a gas permeable membrane that will cause diffusional movement of gas molecules but block out large particulates that could block the sensor. The second cause of sensor drift is aging of the infrared source, but this can be corrected by selecting a infrared source with stable characteristics and incorporating a corrective algorithm to account for aging. Photo-Acoustic detection like flashes infrared light specific to CO_2 absorption wavelength like NDID, however Photo-Acoustic uses a microphone to record the vibration of the CO_2 molecules as they absorb infrared energy. Microprocessors in the sensor then compute the CO_2 concentration from these measurements. The drawbacks of this type of sensor are much more problematic than an NDID sensor. Photo-Acoustic sensors are sensitive to vibrations and pressure changes, the pressure changes problem can be corrected by attaching a pressure sensor to detect the current pressure the sensor is located within.

Location of the CO_2 sensors is the final major factor in putting together an effective DCV system. A decision has to be made whether to monitor CO_2 levels in every zone or just in the critical zone(s) (defined by the zone with the maximum Z_p value). The type of return will decide whether the CO_2 sensor will be an induct type sensor or if the sensor will be wall mounted. If the return is ducted, an induct sensor located in the return ducts right above the zone to be monitored would be most appropriate. However, if there is a plenum return a wall mounted sensor would be more appropriate. An induct sensor in a plenum return scheme would take into account zones other than the critical zone and would give an average concentration. Yet another factor to take into account is the size of the room. If the room is of a large square footage, multiple CO_2 sensors may be required and the highest concentration reported by any of the sensors would control for that room. If the room has a high ceiling a wall mounted sensor would be more appropriate over an induct sensor since the room may not be well mixed, depending on the air distribution. There are many factors that affect the location of CO_2 sensors. The critical zone(s), size of the room or zone and air distribution type will all play a key roll in determining where the most affective CO_2 monitoring point will be located.

Demand Controlled Ventilation is most effective in areas of varying occupancy and where people are the only concern in regards to ventilation. The office side of the research tower offered the best opportunity to implement this style of control. The laboratory side would not be an effective control strategy because throughout the day the occupancy in a laboratory space tends to remain fairly consistent. Also, in the laboratory spaces the main source of contaminants is not occupancy and CO_2 concentration would not be an accurate gauge of ventilation needs. Originally active ventilation was suggested for the laboratory spaces however this would be difficult for several reasons. Since the building is not yet constructed, the labs are not yet being occupied. Thus, it is difficult to know what research is being conducted and the sort of contaminants that need to be monitored. Also the laboratory spaces are designed to accommodate all sorts of different types of research. Each laboratory space could have different research and thus different contaminates to worry about and when one research project and a new one moves into the space all the sensors would have to be changed. For all these reasons it was decided that any form of active controls in the laboratory spaces would not be appropriate. However, the office side allowed an opportunity to implement the demand controlled ventilation controls strategy.

System 2: Occupancy Sensor Setback

As stated above the laboratory spaces are not the ideal place to install an active controls sort of system for various reasons. The CO_2 based demand controlled ventilation system that was investigated was not an appropriate strategy for the laboratory area. In a laboratory space the main concern in regards to ventilation is not to eliminate bioeffluents, it is to control harmful chemicals or emissions from experiments conducted within space. The goal is to keep the people and their research they are conducting safe. A new strategy had to be employed to try and save energy while ensuring indoor air quality is maintained.

In the May 2005 issue of the ASHRAE Journal an article on “Energy-Efficient Laboratory Design” discussed a type of energy savings method that involved setting back the air change rate based on whether the spaces were occupied. The Concordia University Science Complex is a laboratory that was designed by Pageau Morel and Associates based out of Montreal. The laboratory was designed for 10 air changes per hour (ACH). The designers at Pageua Morel and Associates came up with the following control scheme for the laboratory to save energy. Since there were already occupancy sensors installed for lighting control the designers decided to use them as a resource. During the daytime hours if the occupancy sensors send a signal to the building automation system saying there is no one in the spaces the air change rate falls to 6 air changes per hour. At night, if unoccupied, the air change rate falls even further down to 3 air changes per hour. However, if this space is occupied at any time the air change rate moves back to the designed 10 air changes per hour. This design strategy seemed as though it could be utilized in the Margaret M. Alkek Building for Biomedical Research.

Occupancy sensors are already installed in all the laboratory and laboratory support spaces on levels 4-8 to control the lighting within these spaces. These occupancy sensors could be connected into the building automation system to control the air change rate as in the scheme above by adding relays. However, the laboratory and laboratory support spaces are all designed for 6 ACH instead of 10 ACH. This could be due to the laboratory spaces in the Margaret M. Alkek Building for Biomedical Research being designed for less critical research or could just be an owner's preference. The control strategy for the laboratory and laboratory support spaces will employ a 6/3 turn down.

All the spaces in laboratories in levels 4-8 are variable air volume except for the fume hood rooms located on each floor. This lends itself to having few problems with the implementation of the setback. However, since the fume hood rooms are constant volume this will need to be changed to ensure that the rooms retain their balance with each other. Each room in the laboratory spaces has a supply and exhaust box connected to it. The supply boxes on the fume hood rooms will be changes to match the VAV supply boxes on every other room in the laboratory spaces. The exhaust hood valves will be replaced with Medium Pressure Accel II Venturi Valves, which are analog control valves by Phoenix. The fume hoods will also be equipped with Phoenix X30 Series Fume Hood Monitors. The monitors will read the sash position and control face velocity. The monitors tie into the hood exhaust valves. The hood exhaust valves also tie into the supply VAV box for the space. The Fume Hood Monitor and supply box will dictate the position of the exhaust valve to maintain the balance for the fume hood rooms. In case of the situation where all the fume hoods are left on and the laboratory spaces are in the unoccupied setback mode, the OA damper will adjust to allow for the extra air that is being pulled in through the fume hoods while maintaining 3 air changes per hour.

To implement the occupancy sensor setback scheme the existing occupancy sensors will need to have relays installed to allow for the occupied/unoccupied to be sent to the building automation system. The building automation system (BAS) will need to read an unoccupied signal before turning down the air changes from 6 to 3. However, the BAS will only need to read an occupied signal for 10 minutes before turning the air change rate for the system back up to 6 air changes. This should prevent the system from cycling too often and burning out the system. These time values would be adjustable in the buildings automation system.

The final change to the laboratory air system was mentioned above. The laboratory zones that were on the system 3 (office side) air system will be removed from that system and put on system 2. The reason for this was that System 3 was designed for 75% outdoor air instead of 100%. The air is being supplied to the large laboratory spaces that are also being supplied by the 100% outdoor air lab system as well as some of the support spaces. So these spaces added to the amount of CFM that the System 2 air handling system needed to be able to supply. The new amount ended up being 170,000 CFM. The air handling units for System 2 will be the same custom built up units as originally used. The amount of AHU’s serving the spaces will increase from 2 – 50,000 CFM units to 2 – 55,000 CFM units and a 60,000 CFM unit. This configuration will meet the requirement of critical equipment having redundancy incase of one of the AHU’s in System 2 goes down. The new schematic of System 2 can be seen below in Figure 11.

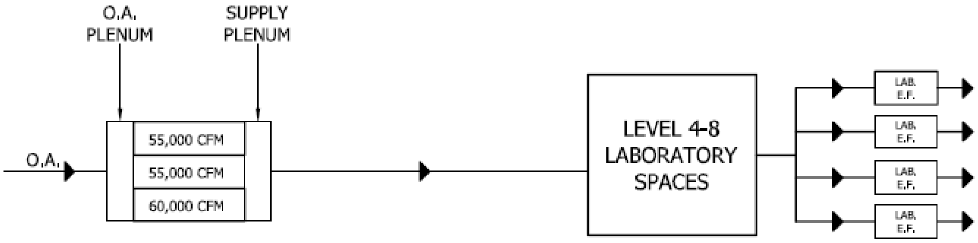


Figure 11: Redesign System 2 Schematic

System 3: Demand Controlled Ventilation Implementation

System 3 has been rezoned so that the spaces that the system is supplying are strictly the office side of levels 4-8. The office spaces consist of meeting rooms, private offices, a break area, corridors/open offices and a conference room. Each floor has 2 meeting rooms, 1 conference room and 1 break area, each of these spaces will have their CO_2 levels monitored. The nature of these spaces lends themselves to being monitored since a majority of the time they will be unoccupied or less than design occupancy. A control strategy was then developed for the research tower that differs from the one suggest in Standard 62.1's user manual. Standard 62.1's Ventilation Rate Procedure calculation was ran with the monitored spaces unoccupied to determine the minimum outdoor air needed. The spreadsheet that was set up for the Standard 62.1 calculation (both minimum and design) can be found in Appendix B. The amount of outdoor air needed when the critical zones are unoccupied is 4,054 CFM. More importantly for the strategy for this building the minimum uncorrected outdoor air per floor was 730 CFM. The idea for this control strategy is to set up a graph and determine an equation for each space to correlate V_{ou} in each space with CO_2 concentration. The CO_2 levels for each space as occupancy goes from 0 to design occupancy was then determined with the equation described above (with $m=1.2$ for office work) in the DCV section. Along side this was the calculation for Vou and then it was plotted and a trendline was added. The graph below in Figure 12 shows an example of how the equation would be found for the conference room (this calculation done for each of the other 2 room types).

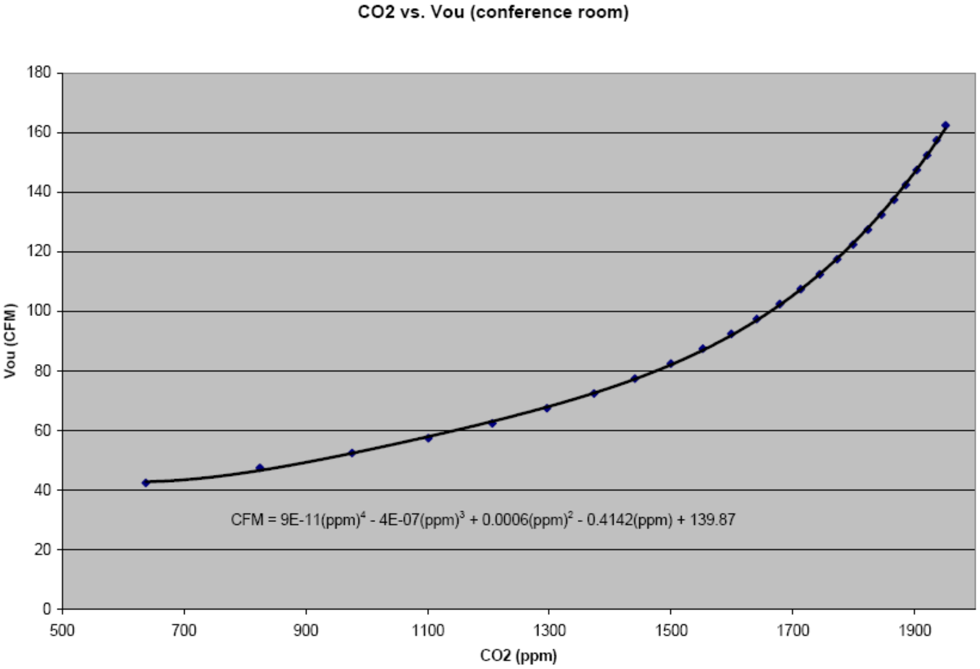

CO2 vs. Vou (conference room)

Figure 12

If the CO_2 reading is below the minimum level for this equation then no outdoor air is added to the uncorrected outdoor air amount. Each space will add their V_{ou} output to the total uncorrected V_{ou} level and the controller will use the E_v value to calculate the total outdoor air to supply (V_{ot}). The conference room at design occupancy has a max Zp of .325. This would cause the Ev value to change from .9 in the minimum calculation to .8. The VAV boxes will be modulating based on the amount of supply air needed to control room temperatures. So having that value divide by the Vou level determined from the above equation in the conference room will determine when the max Z_p goes above .25 and thus needs to be changed to .9.

The location of each sensor within the space had to be determined. The return on the office side is a plenum return. Meaning that, there are 2 large ducts that pull in all the air from each side of the office. This means that a wall mounted CO_2 sensor needs to be utilized. Plenum return makes using a duct mounted CO_2 sensor useless. The CO_2 sensor that will be installed is an Air Test TR9290 CO_2 sensor (Data sheet for this monitor can be found in Appendix B). The sensor is a gold plated non-dispersive infrared optical sensor, which as stated above has fewer problems than the photo-acoustic sensors. Two other attractive features of the Air Test model are that the system is self-calibrating meaning no maintenance needed and that it is very accurate reading with +/- of 30ppm with only another 3% reading error possible over that. The sensor comes in a wall mounted and duct mounted version. One wall mounted sensor will be placed in each critical space while, one duct mounted sensor will be located in the outdoor air intake duct to get a baseline reading on outdoor conditions.

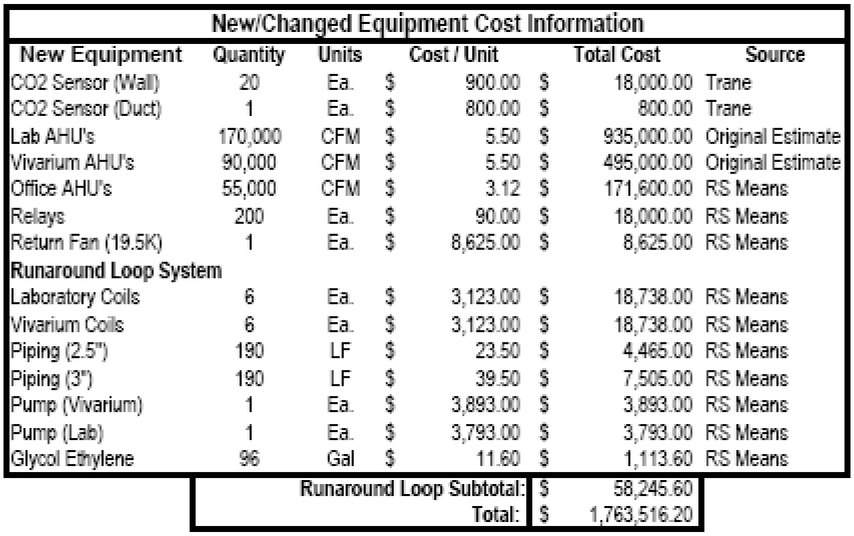
Load calculations had been ran to determine the design supply air for each space in the office side of levels 4-8. The new zoning scheme requires a unit that could supply 55,000 CFM to the office spaces (the load calculation spread sheets can be seen in Appendix B of this report). An air handling unit was created in Carrier's AHU Builder program. The unit will have a mixing plenum and an air flow station to measure the amount of outdoor air being drawn into the unit. There is also a pre-heat and cooling coil section as well. No HEPA filtration is required on this unit since it is supplying simple office space. Also since office spaces are not considered "critical" no redundancy was required. The information on this AHU can be found in Appendix B.

Trace Analysis of System Redesign

Trane's TRACE 700 was used to analyze the redesign changes. The building's original design conditions (as were described in the existing conditions sections of this report) were entered into the program and then simulated. The design changes for the system were then entered into the program and simulated. The demand controlled ventilation system was simulated by entering the max outdoor air percentage ($V_{ot,design}$/Design Supply Air) in the ventilation tab of each space associated with that system. Schedules for ventilation and occupancy were created for each space with a sensor located within. The schedules were then used to modulate the % of outdoor air being brought into the building based on the occupancy (which is closely related to CO_2 levels). This simulates the movement of people in and out of the spaces. Schedules were extremely important in putting together an energy model for the building. Also using Trace allowed for the vivarium and laboratory air systems to be modeled with the runaround loop systems. The runaround loops were easily modeled by using the energy recovery options when creating the air systems in the simulation. The energy consumption for each building was determined by total source energy used in kBTU/year. The design changes resulted in a reduction of 20.6% (7,523,858 kBTU/year) of source energy consumption. This equates to an annual savings of 2,205,025 kWh.

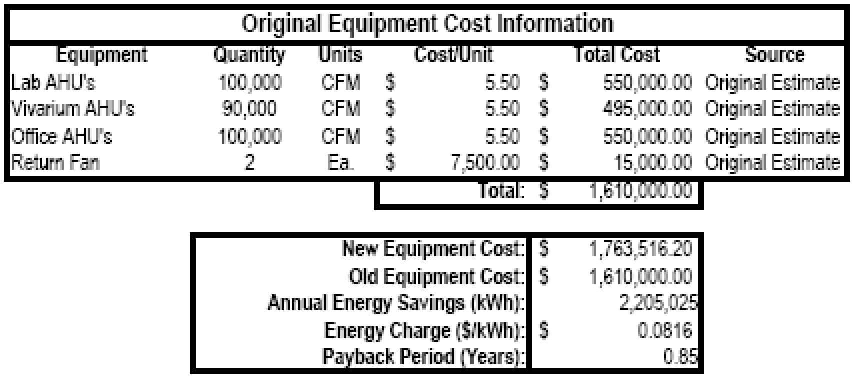
Cost Analysis

The final aspect to look at before deciding on whether to implement the redesign is the cost of the redesign system versus the original system. Pricing information was gathered from various sources; manufacturers, R.S. means and the original estimate for the building were the main source of pricing. The runaround loop pricing was gathered from RS Means 2006 Mechanical Cost Data based off of the sizing information that was described above and in Appendix A. The air handling units for Systems 1 and 2 remained the same style of custom built up units. The air flows were not changed other than a 3rd AHU being added to support the additional laboratory spaces on system 2. This mean that the estimate put together for the original design remains valid and $5.50 per CFM was used. The DCV AHU was different and simpler than the other AHU's so RS Means was used to determine an approximate price for this new unit. The CO_2 sensor estimates were given by Ron Pruden at Trane which include both the unit price and cost of installation. Table 2 below shows the cost comparison as well as the payback period.



New/Changed Equipment Cost Information

New Equipment	Quantity	Units	Cost / Unit	Total Cost	Source
CO2 Sensor (Wall)	20	Ea.	$ 900.00	$ 18,000.00	Trane
CO2 Sensor (Duct)	1	Ea.	$ 800.00	$ 800.00	Trane
Lab AHU's	170,000	CFM	$ 5.50	$ 935,000.00	Original Estimate
Vivarium AHU's	90,000	CFM	$ 5.50	$ 495,000.00	Original Estimate
Office AHU's	55,000	CFM	$ 3.12	$ 171,600.00	RS Means
Relays	200	Ea.	$ 90.00	$ 18,000.00	RS Means
Return Fan (19.5K)	1	Ea.	$ 8,625.00	$ 8,625.00	RS Means
Runaround Loop System					
Laboratory Coils	6	Ea.	$ 3,123.00	$ 18,738.00	RS Means
Vivarium Coils	6	Ea.	$ 3,123.00	$ 18,738.00	RS Means
Piping (2.5")	190	LF	$ 23.50	$ 4,465.00	RS Means
Piping (3")	190	LF	$ 39.50	$ 7,505.00	RS Means
Pump (Vivarium)	1	Ea.	$ 3,893.00	$ 3,893.00	RS Means
Pump (Lab)	1	Ea.	$ 3,793.00	$ 3,793.00	RS Means
Glycol Ethylene	96	Gal	$ 11.60	$ 1,113.60	RS Means
			Runaround Loop Subtotal:	$ 58,245.60	
			Total:	$ 1,763,516.20	



Original Equipment Cost Information							
Equipment	Quantity	Units	Cost/Unit		Total Cost		Source
Lab AHU's	100,000	CFM	$	5.50	$	550,000.00	Original Estimate
Vivarium AHU's	90,000	CFM	$	5.50	$	495,000.00	Original Estimate
Office AHU's	100,000	CFM	$	5.50	$	550,000.00	Original Estimate
Return Fan	2	Ea.	$	7,500.00	$	15,000.00	Original Estimate
				Total:	$	1,610,000.00	

New Equipment Cost:	$	1,763,516.20
Old Equipment Cost:	$	1,610,000.00
Annual Energy Savings (kWh):		2,205,025
Energy Charge ($/kWh):	$	0.0816
Payback Period (Years):		0.85

Table 2

Final Recommendation

The redesign ideas proposed has been shown to have an energy savings of about 2 million kilowatt hours per year (20.6%). The first cost of the redesign is only $153,516 more than the first cost of the original design. This equated to an extremely short payback period. The recommendation is that the proposed redesign would be a good option to implement to lower the energy consumption of the laboratory. The redesign meets the criteria set forth in the proposal that says the building should have good indoor air quality and lower energy consumption.

Occupancy Sensor Lighting Control Breadth Study

Above this report discussed how the occupancy sensors would be used to control the air change rate for the laboratory air system. However, the original intent of these occupancy sensors was to control the lighting in the office area and laboratory spaces on levels 4-8. Occupancy sensors are put on lighting systems to eliminate the possibility of lights being left on when the space is unoccupied. The implementation of this lighting control strategy is an energy savings measure. Occupancy sensors have an adjustable delay on them. This delay is the amount of time that the occupancy sensor must sense no occupants before the lighting is shut off. The typical value for this delay is 15 minutes. However as stated before this value is adjustable. It is best not to set the value too low as turning the lights on and off can shorten the life of the lamps.

Since the occupancy sensor lighting control strategy is being utilized to save energy, it is natural to ask, “How much energy is being saved?” A simple study was set up to take a look at the energy savings associated with the existing occupancy sensor strategy for controlling the lights in the research tower. There are 4 spaces that utilize the occupancy sensor lighting control strategy; laboratories, open office, private offices and meeting rooms. Details on the specific occupancy sensors used could not be located so sensors were spec’d out for the project. For the laboratory spaces a passive infrared ceiling mounted sensor (Leviton Model #OSC04-I0W) was chosen. In the office spaces a wall mounted passive infrared (Leviton Model #PR180-1LW) light switch was chosen. These models were chosen because the amount of square feet that they covered best matched the layout provided on the electrical drawings. Pricing information was then found for each model. Approximate information on installation and labor cost was gathered from Penn State’s Office of the Physical Plant.

The calculations are based on the following information. There were two styles of lighting used in the offices and laboratory spaces. In the offices there was a suspended direct/indirect fixture that held 3 lamps at 28 watts a piece (referred to as FP1). In the laboratory spaces it was the same fixture however over lab benches it was 2 lamps at 32 watts a piece (referred to as FP2) while on the workstations on the outer part of the labs have the same configuration as the office spaces. Each laboratory area has 20 occupancy sensors, while the office and meeting room spaces have one occupancy sensor a piece. Since the building has yet to be constructed occupancy schedules have to be assumed. The spaces within the building are assumed to be used 50 weeks out of the year, 5 days a week. The building is assumed to be occupied 10 hours a day and without lighting controls it is assumed the lights would be on all 10 hours of the day. Since it is not known without logging the lighting data how much energy would actually be, the spreadsheet is takes into account different amounts of hours of lighting saved up to 4 hours in half hour time steps. The spreadsheet also calculates the payback period for the installation of occupancy sensors. The payback period for the entire building depends upon the number of lighting hours saved per day. Based off of the calculations done in the spreadsheet it seems that a conservative estimate for the payback period (with the assumed occupancy schedule) would be 7-14 years, but there are many factors that play into this number. The full spreadsheet of the calculations can be found in Appendix D of this report.

Structural Breadth & Energy Recovery Systems Study

As stated above in the ‘Energy Recovery Systems in Laboratories’ section the choices in energy recovery systems came down to a heat pipe or runaround loop. The main differences between the two systems were the first cost and the location of the exhaust and outdoor air streams. The mechanical systems and outdoor air intakes are located on the 3rd floor while the exhaust fans and ducts are located on the roof. To use a heat pipe system the mechanical equipment would need to be located on the 8th floor where it would be possible to have the outdoor air stream located next to the exhaust air streams. However, even with moving the mechanical system to the 8th floor the outdoor air stream and exhaust air stream are not located next to each other. It is not possible to run the exhaust ductwork next to the outdoor ductwork to install a traditional heat pipe system. A split case heat pipe system from Heat Pipe Technologies was used. The typical heat pipe uses the temperature difference between the two airstreams to create the flow between the two sides of the heat pipe. The split case heat pipe has a single stage pump module which helps the fluid move further by not relying strictly on the temperature difference, however unlike a runaround loop these pumps are very small. A problem with split case heat pipe systems is that they are much more expensive than traditional heat pipe system. The pumps only accommodate either a 200 ft horizontal difference between heat pipe coils or a 25 foot rise. The runaround loop with the piping and pumps connecting the 2 coils allows for the mechanical systems to remain where they are currently located using a larger pump than the split case heat pipe system and a different working fluid. Generally speaking, the effectiveness of the runaround loop and the heat pipe systems is similar, but the first cost of the runaround loop is slightly higher due to the piping, pump and larger amount of working fluid required. However this is not the case with a split case heat pipe system. A study was done to give an idea of the extra costs associated with exchanging the 3rd floor with the 8th floor to allow for the airstreams being close enough to for use of the split case heat pipe system as well as to see if the structure could handle the change of the loads.

The first issue to consider with exchanging the 3rd floor to the 8th floor was the building’s structure and the changing of the loads. The building’s structural layout and loads were entered into Ram v10.0. Initially the building was laid out with the original floor arrangement. The loading was switched between the 3rd and the 8th floor. Ram was then run to size the columns and beams needed for this loading arrangement. The suggested beam and column sizes were checked against the current beams and columns in the building. Originally it was thought that the columns would have to be upsized to accommodate the shifting of loads within the building. However this was not the case. The building's structural system was fine as is for either floor arrangement. The RAM model for the Margaret M. Alkek Building for Biomedical Research can be seen below in Figure 13 below.

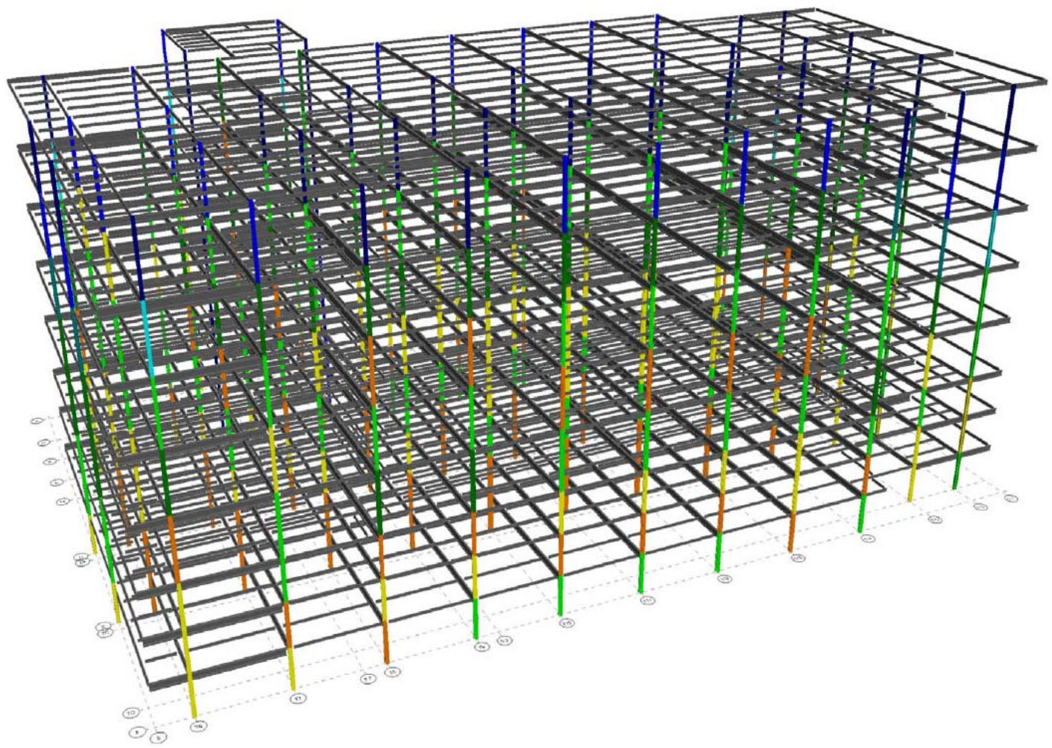


Figure 13

The final area to examine the impact of moving the mechanical systems to the 8th floor was on the mechanical system itself. Riser diagrams, shaft diagrams and floor plans were used to determine which ducts, piping and other mechanical equipment would be impacted by this move. When the mechanical systems were moved to the 8th floor the supply duct going down to the viviarium (levels 1&2) needed to be extended 85 feet. Also there was a return duct that had to be extended approximately 85 feet as well. The rest of the duct work serving the upper levels would remain the same length since the mechanical systems would just be moving from below the run to above it. The next area that was looked at was the extensive piping system that serves all the mechanical equipment. This area was significant. The campus chilled water supply/return as well as the campus steam loop piping need to be extended up since the heat exchangers being fed to make the buildings chilled water and steam are now located on the 8th floor. The low pressure steam that is being created on the mechanical floor must be extended down to the vivarium once again which is another pipe that needs to be extended. Other piping that is impacted includes hot water supply/return, chilled water supply/return and medium pressure steam return. The table below shows the cost of the heat pipe system versus the runaround loop which ultimately led to the choice to use the runaround loop mainly due to the exurbanite price of the split case heat pipe system.

Split Case Heat Pipe Installation Costs

Item	Quantity	Total Cost
Duct Work	170 feet	$ 19,496
Chilled Water Piping	200 feet	$ 10,914
Process Chilled Water	190 feet	$ 3,032
Hot Water Piping	170 feet	$ 5,950
Steam Main Piping	85 feet	$ 7,225
Condensate Return	125 feet	$ 2,125
Laboratory Heat Pipe	1 system	$ 366,000
Vivarium Heat Pipe	1 system	$ 190,000
	Total:	$ 604,742

Runaround Loop Installation Costs

Item	Quantity	Total Cost
Laboratory Coils	6 coils	$ 18,738
Vivarium Coils	6 coils	$ 18,738
Piping (2.5")	190 feet	$ 4,465
Piping (3")	190 feet	$ 7,505
Pump (Vivarium)	1 pump	$ 3,893
Pump (Lab)	1 pump	$ 3,793
Glycol Ethylene	96 Gallons	$ 1,114
	Total:	$ 58,246

* Pricing for all piping per linear foot was taken from original estimate done for the research tower

**Split case heat pipe system estimated byRick Galie at Air Tectonics

Table 3

Acknowledgements

Consultants/Faculty

Dr. Freihaut
Dr. Bahnfleth
"JJ" Jae-Weon Jeong, Ph.D.
Kurt Shank, BR+A
Wade Conlan, GRG
Rick Galie, Air Tectonics
Ron Pruden, Trane
Matthew Rooke

Special Thanks

Parents *...for forcing me to go to college, it was probably for the best*
Brothers *...for remaining lovingly indifferent as brother are supposed to*
Grandparents and extended family
Julie Sarantapoulas
Dave Melfi
Ingrid Londoño
Myself (someone had to do the work, right?)

Also Thanks to

Since I will probably never release an album or write the accompanying liner notes for it... these past 5 years have been my album and these are my liner notes. Those that have influenced the situation for better or worse; Penn State University, The entire AE Department (students, staff, faculty), Elizabeth Hostutler, Rebecca Spotts, Anthony Fernandez & 5th Faction, Josh "Cuz" Springer, "British" Chris Davies, Queens Brooklyn and all the 5 boroughs, Michael "T-rox" Troxell, Chris "Shelows" Shelow, Steven T. Puchek, the city of Boston, Bill "Ballin' Ass" Reynolds, Erik DeMarco, Raoul Duke, The Duece, Tony Daniels, Jack Daniels and the rest of the Daniels family, Lauren "Gidget" McKee, the commonwealth of Pennsylvania, Dave and all the Zeno's staff, Shooter, The Brewery, Mike Patton, Roger Waters and David Gilmore, Dr. Hunter S. Thompson, Christopher Wallace, "The Fundamentally Sound" Noah Ashbaugh a.k.a. "The Voice of Reason", the City of New Orleans, the city of Chicago, Kingston Mines, Big James & The Chicago Playboys, Linsey Alexander, Ram, Raphen, etc, etc... the list goes on. These people and many more have had some sort of influence (whether it be big or small) on the past 5 years. To anyone I left out, who may be offended, or any memory I forgot at the time of writing this, thank you as well.

- JPM

References

Amborn, R and Pete Shelquist. ASHRAE Journal. “Ventilation Control Strategies”. September 2001.

American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. *Standard 62.1-2004: Ventilation for Acceptable Indoor Air Quality.* (2004).

American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. *62.1’s User Manuel.* (2004).

Brodrick, J, Dieckmann, J and Kurt Roth. ASHRAE Journal. “Demand Control Ventilation”. July 2003.

Charneux, R and Nicolas Lemire. ASHRAE Journal. “Energy-Efficient Laboratory Design”. May 2005.

Charneux, Roland. ASHRAE Journal. “Innovative Laboratory Design”. June 2001.

“Internet Pump Selection at Pump-Flo.com”. Engineered Software, Inc. 2006. <www.pump-flo.com>.

Int-Hout, D. and Mike Schell. ASHRAE Journal. “Demand Controlled Ventilation using CO_2”. February 2001.

Joesten, Eric. R&D Magazine. “Energy Recovery Applications for Animal Facilities”. November 2004.

McIntosh, B.D. Dorgan, E. Dorgan. ASHRAE Laboratory Design Guide. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. 2001.

Reilly, Sue and Otto Van Geet. ASHRAE Journal. “Ventilation Heat Recovery For Laboratories”. March 2006.

RS Means Company. *2006 RS Means Electrical Cost Data*. (2006).

RS Means Company. *2006 RS Means Mechanical Cost Data*. (2006).

Appendix A – Runaround Loop Component Information

Pump Data Sheet - MEPCO

Company: PSU
Name: Justin
Date: 3/30/2006

MEPCO
MARSHALL ENGINEERED PRODUCTS CO.

Pump:

Size: RP06-15

Type: IN-LINE
Synch speed: 3600 rpm

Speed: 3500 rpm
Dia: 5.25 in

Curve: PC1147

Impeller:

Specific Speeds:

Ns: ---
Nss: ---

Dimensions:

Suction: 1.5 in
Discharge: 1.5 in

Search Criteria:

Flow: 51 US gpm

Head: 92.5 ft

Near miss: 5 % of Head

Fluid:

Water
Density: 62.25 lb/ft³
Viscosity: 1.105 cP

Temperature: 60 °F
Vapor pressure: 0.2563 psi a
Atm pressure: 14.7 psi a

NPSHa: 80 ft

Pump Limits:

Temperature: --- °F
Pressure: --- psi g
Sphere size: --- in

Power: --- hp
Eye area: --- in²

Motor:

Standard: NEMA
Enclosure: TEFC

Size: 3 hp
Speed: 3600
Frame: 182T

Sizing criteria: Max Power on Design Curve

---- Data Point ----

Flow:	51 US gpm
Head:	93 ft
Eff:	57%
Power:	2.05 hp
NPSHr:	6.25 ft

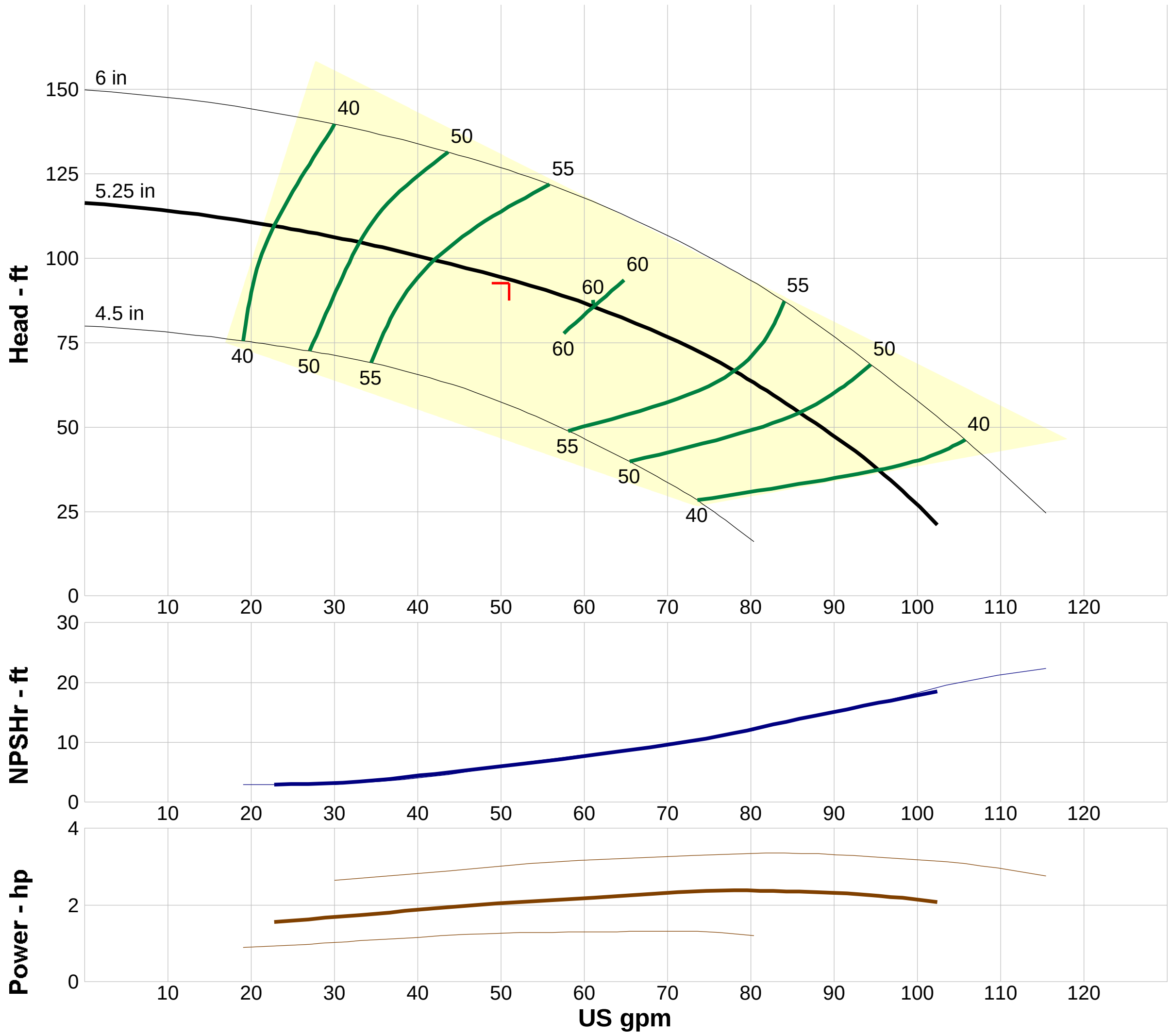
---- Design Curve ----

Shutoff head:	116 ft
Shutoff dP:	50.3 psi
Min flow:	--- US gpm

BEP: 60% @ 61.1 US gpm
NOL power:
2.38 hp @ 78 US gpm

-- Max Curve --

Max power:
3.36 hp @ 84 US gpm



Performance Evaluation:

Flow US gpm	Speed rpm	Head ft	Efficiency %	Power hp	NPSHr ft
61.2	3500	85.6	60	2.2	7.93
51	3500	93	57	2.05	6.25
40.8	3500	100	54	1.89	4.59
30.6	3500	106	48	1.7	3.33
20.4	3500	110	38	1.53	2.99

Selected from catalog: Mepco Pumps.60 Vers: 1

CERTIFIED DRAWING

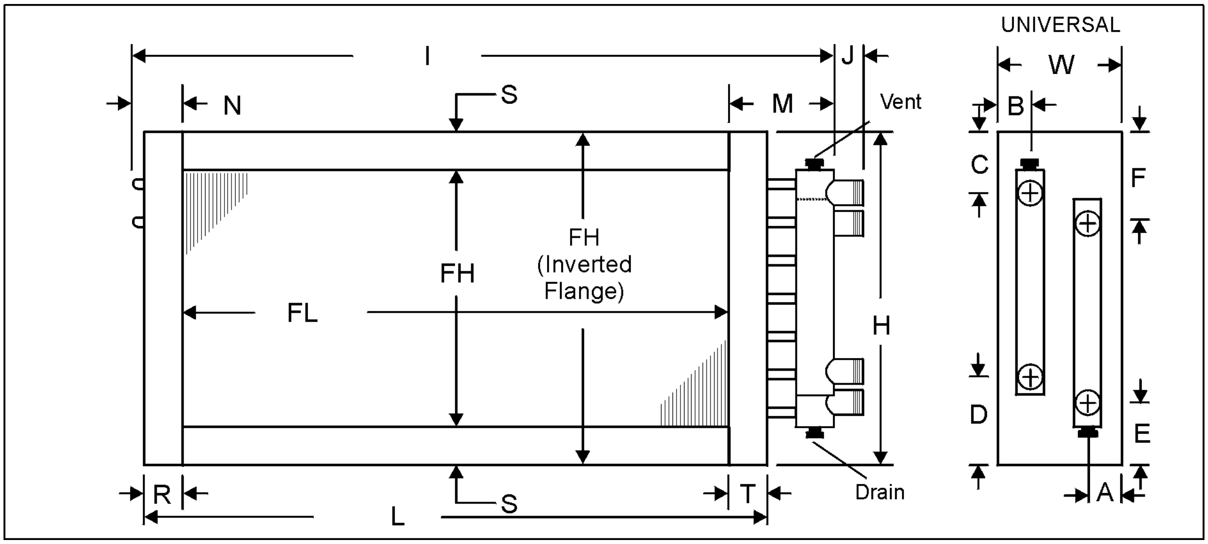
5.00.15.1

Customer:
Contact:
Telephone:
Fax:
Job:

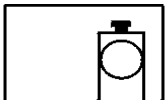
Date: 3/29/2006
From:
Company:
Return Tel:
Return Fax:

		MODEL NUMBER						
ITEM	**QTY**	**TYPE**	**FPI**	**ROWS**	**FIN**	**FH (IN)**	**FL (IN)**	**HAND**
Supply	1	5WS	08	06	A	30.00	80.00	Universal

MATERIALS OF CONSTRUCTION		OPTIONS			
Fins	.0075 Aluminum	**Casing Type**	Flanged	**Label Kit**	No
Tubes	.020 Copper	**Vent/Drain**	.50 FPT on End Cap	**Corrosion Resistant**	Yes
Casing	Galvanized Steel			**Mounting Holes**	No
Connection	2 MPT Carbon Steel			**Turbospirals**	No
				Drain Headers	No



Vent/Drain Location



DIMENSIONAL DATA (IN)															
CONNECTION												FLANGES			
SIZE	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**I**	**J**	**L**	**M**	**N**	**R**	**S**	**T**	**W**
2	1.753	1.75	2.51	4.76	2.51	4.76	33.00	87.50	3.00	83.00	5.00	2.50	1.50	1.50	1.50	10.00

Notes:

GENERAL NOTES

1. All dimensions are in inches.
2. One intermediate tube support fabricated from heavy gauge stock of the same material as the fins will be provided.
3. Cap all unused connections.
4. The supply line should be connected to the lower connection on the leaving air side for counterflow operation.
5. Coils will vent and drain through factory-installed vent and drain fittings when mounted level for horizontal flow.
6. Connection location other than standard could affect vent and drain locations. Consult factory.

CERTIFIED DRAWING

Customer:

Contact:

Telephone:

Fax:

Job:

Date: 3/29/2006

From:

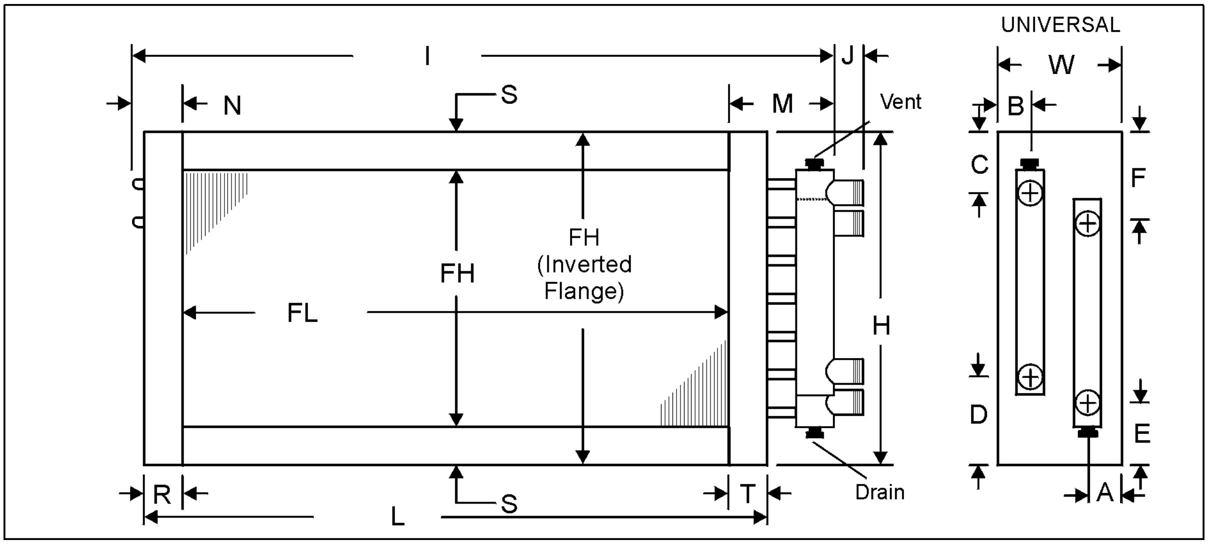
Company:

Return Tel:

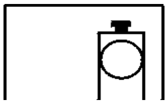
Return Fax:

		MODEL NUMBER						
ITEM	**QTY**	**TYPE**	**FPI**	**ROWS**	**FIN**	**FH (IN)**	**FL (IN)**	**HAND**
Exhaust	1	5WS	08	06	A	30.00	80.00	Universal

MATERIALS OF CONSTRUCTION		OPTIONS			
Fins	.0075 Aluminum	**Casing Type**	Flanged	**Label Kit**	No
Tubes	.020 Copper	**Vent/Drain**	.50 FPT on End Cap	**Corrosion Resistant**	Yes
Casing	Galvanized Steel			**Mounting Holes**	No
Connection	2 MPT Carbon Steel			**Turbospirals**	No
				Drain Headers	No



Vent/Drain Location



DIMENSIONAL DATA (IN)																
CONNECTION													FLANGES			
SIZE	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**I**	**J**	**L**	**M**	**N**	**R**	**S**	**T**	**W**
2	1.753	1.75	2.51	4.76	2.51	4.76	33.00	87.50	3.00	83.00	5.00	2.50	1.50	1.50	1.50	10.00

Notes:

GENERAL NOTES

1. All dimensions are in inches.
2. One intermediate tube support fabricated from heavy gauge stock of the same material as the fins will be provided.
3. Cap all unused connections.
4. The supply line should be connected to the lower connection on the leaving air side for counterflow operation.
5. Coils will vent and drain through factory-installed vent and drain fittings when mounted level for horizontal flow.
6. Connection location other than standard could affect vent and drain locations. Consult factory.

DIMENSIONS SCHEDULE

Customer:
Contact:
Telephone:
Fax:
Job:

Date: 3/29/2006
From:
Company:
Return Tel:
Return Fax:

CP 1063same_end_universal

Item	Qty	Model	FH x FL	Hand	Conn Size	A	B	C	D	E	F	H	I	J	L	M	N	R	S	T	W
Supply	1	5WS0806A	30.00x80.00	U	2.00	1.75	1.75	2.51	4.76	2.51	4.76	33.00	87.50	3.00	83.00	5.00	2.50	1.50	1.50	1.50	10.00
Exhaust	1	5WS0806A	30.00x80.00	U	2.00	1.75	1.75	2.51	4.76	2.51	4.76	33.00	87.50	3.00	83.00	5.00	2.50	1.50	1.50	1.50	10.00

Heatcraft

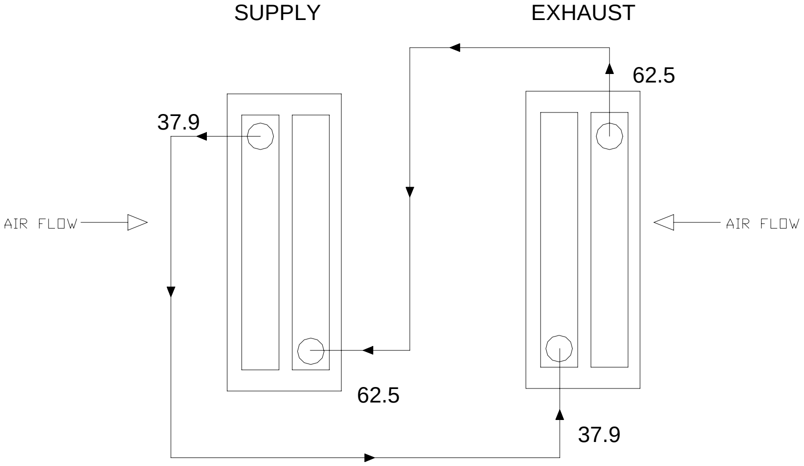
FLUID RUN AROUND

5.00.15.1

Customer:
Contact:
Telephone:
Fax:
Job:

Date: 3/29/2006
From:
Company:
Return Tel:
Return Fax:

Season: Winter
Three Way Valve Required: No



	UOM	SUPPLY COIL	EXHAUST COIL
Item		Supply	Exhaust
Coils per Bank		3	3
Allow Opposite End		No	No
Tube OD		5/8	5/8
Coil Duty		Heat-Return Bend	Cool-Standard
Fins Per Inch		8	8
Rows		6	6
Circuiting		Single	Single
Fin Surface		A	A
Fin Height x Finned Length	IN	30.00 x 80.00	30.00 x 80.00
Turbospirals		No	No
Tube wall thickness & Material		0.020 Copper	0.020 Copper
Fin thickness & Material		0.0075 Aluminum	0.0075 Aluminum
Connection Quantity & Size	IN	(1) 2	(1) 2
Fluid Type		Ethylene	Ethylene
Percent Glycol		30	30
Entering Fluid Temp.	°F	62.46	37.93
Fluid Flow Rate	GPM	51.00	51.00
Altitude	FT	.00	.00
Air Flow Rate	SCFM/SCFM	95,000.00	95,000.00
Face Velocity	FPM	1,900.00	1,900.00
Entering Air Temp. DB / WB	°F	20.00 / N/A	75.00 / 63.94
Model Number		5WS0806A	5WS0806A
Total / Sensible Capacity	MBH	573.48 / N/A	572.81 / 497.80
Leaving Air Temp. DB / WB	°F	25.57 / N/A	70.21 / 62.06
Air Pressure Drop	IN WG	3.10	3.10
Leaving Fluid Temp.	°F	37.91	62.46
Fluid Pressure Drop	FT H20	.98	.99
Fluid Flow Rate	GPM	51.00	51.00
Fluid Velocity	FPS	.92	.92
Weight - (Dry) / (w/Fluid)	LB	302.16 / 432.44	302.16 / 432.47
Notes		BCEL	BEL

B) Rated In Compliance With ARI 410.
C) Coil Not Within Certified ARI Directory.
E) Specified Condition(s) Out Of ARI Range.
L) Coil rating valid for Heatcraft coils only.

Pump Data Sheet - MEPCO

Company: PSU
Name: Justin
Date: 3/30/2006

MEPCO
MARSHALL ENGINEERED PRODUCTS CO.

Pump:

Size: RB06-15

Type: BASE-MOUNTED
Synch speed: 3600 rpm

Speed: 3500 rpm
Dia: 5 in

Curve: PC1103

Impeller:

Specific Speeds:

Ns: ---
Nss: ---

Dimensions:

Suction: 2 in
Discharge: 1.5 in

Search Criteria:

Flow: 85 US gpm

Head: 92.5 ft

Near miss: 5 % of Head

Fluid:

Water
Density: 62.25 lb/ft³
Viscosity: 1.105 cP

Temperature: 60 °F
Vapor pressure: 0.2563 psi a
Atm pressure: 14.7 psi a

NPSHa: 80 ft

Pump Limits:

Temperature: --- °F
Pressure: --- psi g
Sphere size: --- in

Power: --- hp
Eye area: --- in²

Motor:

Standard: NEMA
Enclosure: TEFC

Size: 5 hp
Speed: 3600
Frame: 184T

Sizing criteria: Max Power on Design Curve

---- Data Point ----

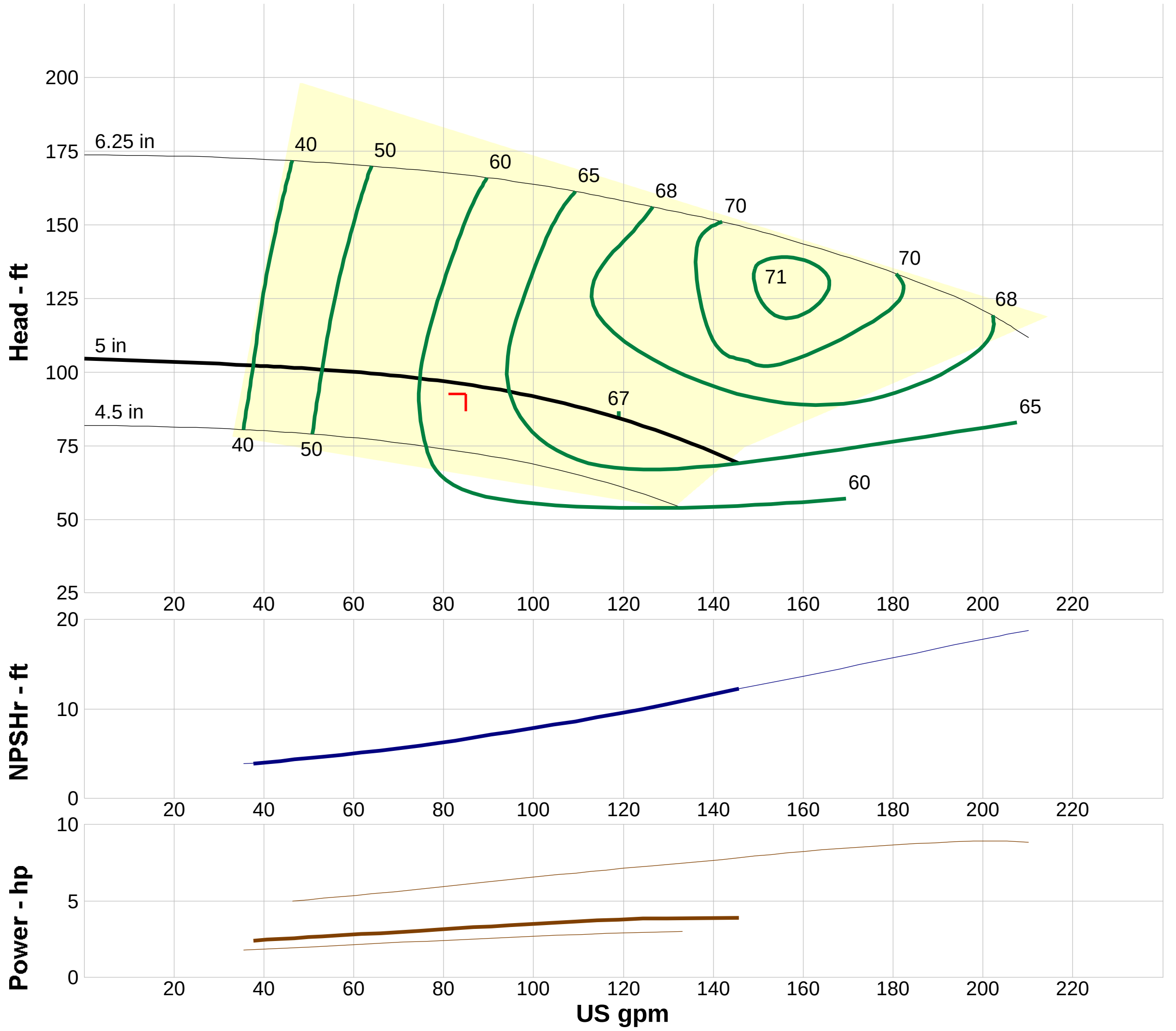
Flow: 85 US gpm
Head: 95.5 ft
Eff: 63%
Power: 3.25 hp
NPSHr: 6.71 ft

---- Design Curve ----

Shutoff head: 105 ft
Shutoff dP: 45.2 psi
Min flow: --- US gpm
BEP: 67% @ 119 US gpm
NOL power:
3.9 hp @ 146 US gpm

-- Max Curve --

Max power:
8.93 hp @ 202 US gpm



Performance Evaluation:

Flow US gpm	Speed rpm	Head ft	Efficiency %	Power hp	NPSHr ft
102	3500	90.6	65	3.54	8.09
85	3500	95.5	63	3.25	6.71
68	3500	98.8	57	2.95	5.53
51	3500	101	49	2.65	4.6
34	3500	102	38	2.35	3.92

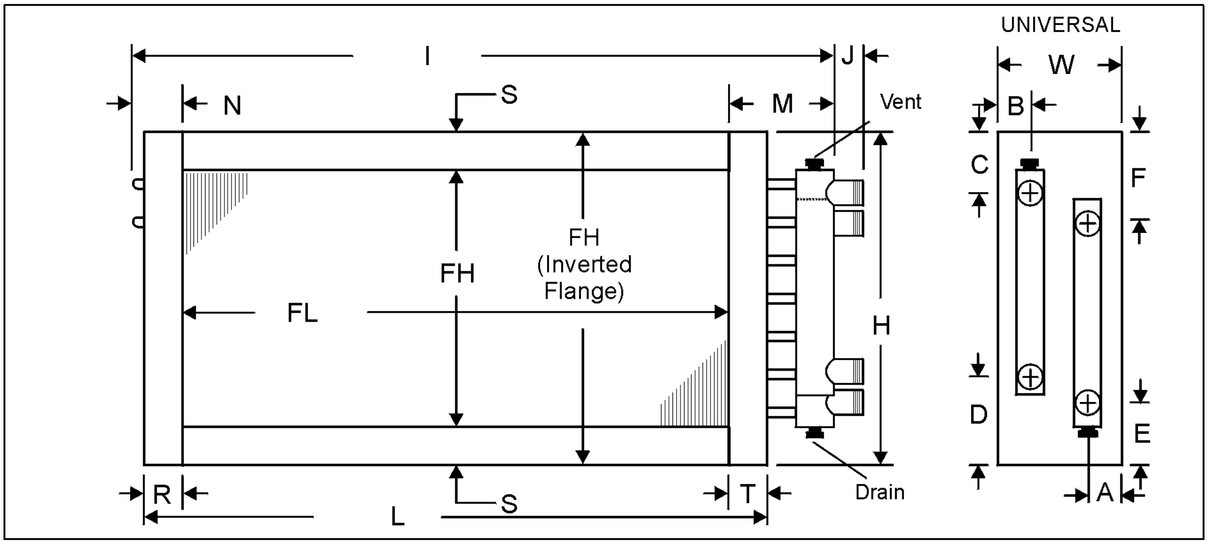
Selected from catalog: Mepco Pumps.60 Vers: 1

Heatcraft CERTIFIED DRAWING 5.00.15.1

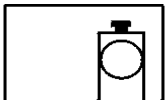
Customer:	BCM	Date:	3/29/2006
Contact:		From:	
Telephone:		Company:	
Fax:		Return Tel:	
Job:	Thesis	Return Fax:	

		MODEL NUMBER						
ITEM	**QTY**	**TYPE**	**FPI**	**ROWS**	**FIN**	**FH (IN)**	**FL (IN)**	**HAND**
Supply	1	5WS	08	06	A	30.00	60.00	Universal

MATERIALS OF CONSTRUCTION		**OPTIONS**			
Fins	.0075 Aluminum	**Casing Type**	Flanged	**Label Kit**	No
Tubes	.020 Copper	**Vent/Drain**	.50 FPT on End Cap	**Corrosion Resistant**	Yes
Casing	Galvanized Steel			**Mounting Holes**	No
Connection	2.000 MPT Carbon Steel			**Turbospirals**	No
				Drain Headers	No



Vent/Drain Location



DIMENSIONAL DATA (IN)																
CONNECTION													**FLANGES**			
SIZE	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**I**	**J**	**L**	**M**	**N**	**R**	**S**	**T**	**W**
2.00	1.753	1.75	2.51	4.76	2.51	4.76	33.00	67.50	3.00	63.00	5.00	2.50	1.50	1.50	1.50	10.00

GENERAL NOTES

1. All dimensions are in inches.
2. Corrosion Resistant coated coils require a longer lead-time since they must be re-tested after coating.
3. One intermediate tube support fabricated from heavy gauge stock of the same material as the fins will be provided.
4. Cap all unused connections.
5. The supply line should be connected to the lower connection on the leaving air side for counterflow operation.
6. Coils will vent and drain through factory-installed vent and drain fittings when mounted level for horizontal flow.
7. Connection location other than standard could affect vent and drain locations. Consult factory.

Heatcraft

CERTIFIED DRAWING

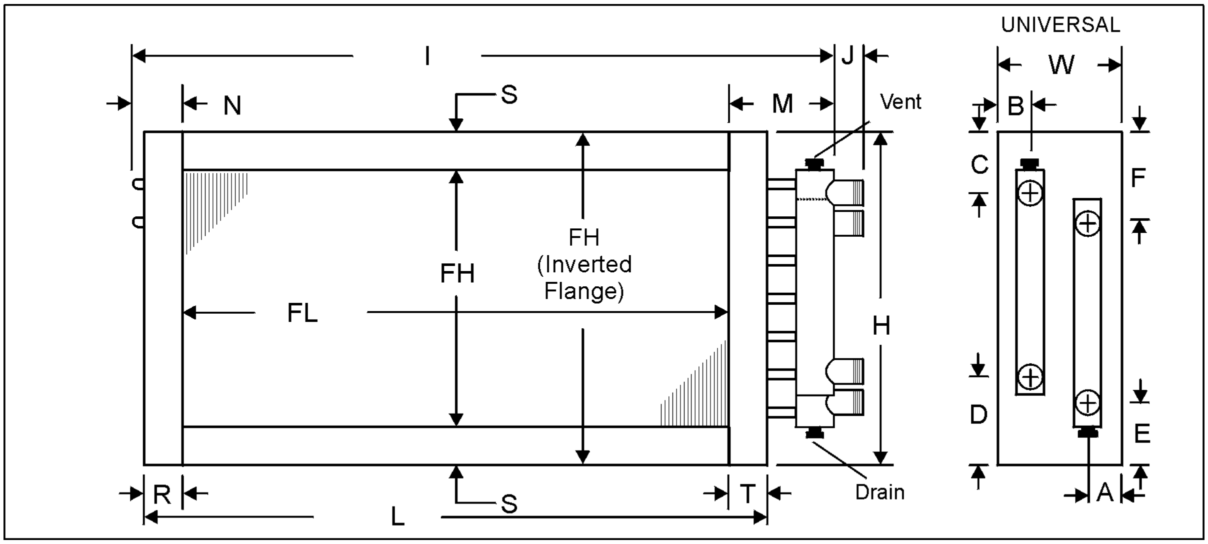
5.00.15.1

Customer: BCM
Contact:
Telephone:
Fax:
Job: Thesis

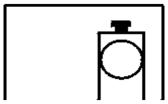
Date: 3/29/2006
From:
Company:
Return Tel:
Return Fax:

		MODEL NUMBER						
ITEM	**QTY**	**TYPE**	**FPI**	**ROWS**	**FIN**	**FH (IN)**	**FL (IN)**	**HAND**
Exhaust	1	5WS	08	06	A	30.00	60.00	Universal

MATERIALS OF CONSTRUCTION		OPTIONS			
Fins	.0075 Aluminum	**Casing Type**	Flanged	**Label Kit**	No
Tubes	.020 Copper	**Vent/Drain**	.50 FPT on End Cap	**Corrosion Resistant**	Yes
Casing	Galvanized Steel			**Mounting Holes**	No
Connection	2 MPT Carbon Steel			**Turbospirals**	No
				Drain Headers	No



Vent/Drain Location



DIMENSIONAL DATA (IN)															
CONNECTION												FLANGES			
SIZE	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**I**	**J**	**L**	**M**	**N**	**R**	**S**	**T**	**W**

Notes:

GENERAL NOTES

1. All dimensions are in inches.
2. One intermediate tube support fabricated from heavy gauge stock of the same material as the fins will be provided.
3. Cap all unused connections.
4. The supply line should be connected to the lower connection on the leaving air side for counterflow operation.
5. Coils will vent and drain through factory-installed vent and drain fittings when mounted level for horizontal flow.
6. Connection location other than standard could affect vent and drain locations. Consult factory.

DIMENSIONS SCHEDULE

Customer: BCM
Contact:
Telephone:
Fax:
Job: Thesis

Date: 3/29/2006
From:
Company:
Return Tel:
Return Fax:

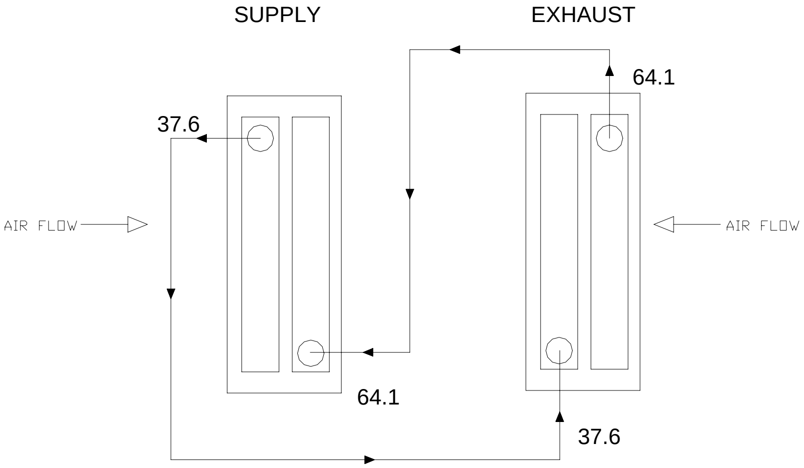
CP 1063same_end_universal

Item	Qty	Model	FH x FL	Hand	Conn Size	A	B	C	D	E	F	H	I	J	L	M	N	R	S	T	W
Supply	1	5WS0806A	30.00x60.00	U	2.00	1.75	1.75	2.51	4.76	2.51	4.76	33.00	67.50	3.00	63.00	5.00	2.50	1.50	1.50	1.50	10.00
Exhaust	1	5WS0806A	30.00x60.00	U	2.00	1.75	1.75	2.51	4.76	2.51	4.76	33.00	67.50	3.00	63.00	5.00	2.50	1.50	1.50	1.50	10.00

FLUID RUN AROUND

Customer:	BCM	Date:	3/29/2006
Contact:		From:	
Telephone:		Company:	
Fax:		Return Tel:	
Job:	Thesis	Return Fax:	

Season: Winter
Three Way Valve Required: No

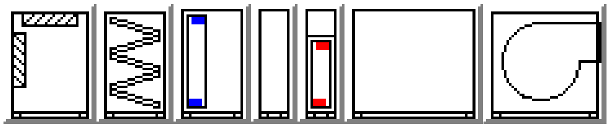


	UOM	SUPPLY COIL	EXHAUST COIL
Item		Supply	Exhaust
Coils per Bank		3	3
Allow Opposite End		No	No
Tube OD		5/8	5/8
Coil Duty		Heat-Return Bend	Cool-Standard
Fins Per Inch		8	8
Rows		6	6
Circuiting		Single	Single
Fin Surface		A	A
Fin Height x Finned Length	IN	30.00 x 80.00	30.00 x 80.00
Turbospirals		No	No
Tube wall thickness & Material		0.020 Copper	0.020 Copper
Fin thickness & Material		0.0075 Aluminum	0.0075 Aluminum
Connection Quantity & Size	IN	(1) 2	(1) 2
Fluid Type		Ethylene	Ethylene
Percent Glycol		30	30
Entering Fluid Temp.	°F	64.12	37.60
Fluid Flow Rate	GPM	85.00	85.00
Altitude	FT	.00	.00
Air Flow Rate	SCFM/SCFM	163,000.00	163,000.00
Face Velocity	FPM	3,260.00	3,260.00
Entering Air Temp. DB / WB	°F	20.00 / N/A	76.00 / 64.79
Model Number		5WS0806A	5WS0806A
Total / Sensible Capacity	MBH	1,031.82 / N/A	1,032.04 / 882.79
Leaving Air Temp. DB / WB	°F	25.84 / N/A	71.05 / 62.85
Air Pressure Drop	IN WG	7.71	7.71
Leaving Fluid Temp.	°F	37.62	64.12
Fluid Pressure Drop	FT H20	2.44	2.47
Fluid Flow Rate	GPM	85.00	85.00
Fluid Velocity	FPS	1.54	1.54
Weight - (Dry) / (w/Fluid)	LB	302.16 / 432.42	302.16 / 432.46
Notes		BCEL	BEL

B) Rated In Compliance With ARI 410.
C) Coil Not Within Certified ARI Directory.
E) Specified Condition(s) Out Of ARI Range.
L) Coil rating valid for Heatcraft coils only.

Appendix B – DCV System Information/Calculations

Job Name DCV AHU
Mark for Untitled 4/ 5/2006 12:49 PM



Unit Parameters

Unit Size: Size 85 39RN
2" Double Wall Construction
Painted Exterior
Interior Finish: Galvanized
Painted Exterior

Mixing Box

Door Right Side
Door Left Side
Damper: Top Premium Opposed 100 % Coverage
Damper: Rear Premium Parallel 100 % Coverage

Angle Filter

Door Right Side
Angle Filter 4In. Side Loading
Field Supplied 4in. Throwaway Filter
Qty (8) 12in. x 24in.
Qty (40) 24in. x 24in.

Cooling Coil

Chilled Water 85.3 sq.ft 8 Row 10 FPI Double Circuit
Coil Connection Right Side
5/8 in. Tube Diameter
AL fins Stainless Steel Casing
5.125" Header Size
4.0" Coil Connection

Cooling Performance Ratings

Altitude, ft	0	EWT, °F	45.00
Face Vel., fpm	527.5	LWT, °F	60.00
Site Airflow, CFM	45000	Rise, °F	15.0
Std. Airflow, CFM	45000	Cv Rating	243.8
Total Clg. Cap, MBH	4094.75	EADB, °F	97.00

Sen. Clg. Cap, MBH	2018.51	EAWB, °F	80.00
Flow Rate, gpm	545.2	LADB, °F	55.66
Fluid PD, ft wg	11.2	LAWB, °F	55.34
Fluid Vel., ft/s	4.7	Air Friction, in wg	1.17

15in. Long Plenum/Access Section

Inspection Panel Right Side

Heating Coil

Hot Water 53.3 sq.ft 2 Row 8 FPI Full Circuit
Coil Connection Right Side
5/8 in. Tube Diameter
AL fins Stainless Steel Casing
3.125" Header Size
2.5" Coil Connection

Heating Performance Ratings

Altitude, ft	0	EWT, °F	190.00
Face Vel., fpm	844.3	LWT, °F	160.0
Site Airflow, CFM	45000	Drop, °F	30.0
Std. Airflow, CFM	45000	Cv Rating	83.5
Heating Cap., MBH	2726.12	EAT, °F	20.00
Flow Rate, gpm	186.7	LAT, °F	75.86
Fluid PD, ft wg	7.6	Air Friction, in wg	0.28
Fluid Vel., ft/s	5.2		

35in. Long Plenum/Access Section

Door with Viewport Right Side
Door Left Side
Light Right Side with with Outlet

Draw-Thru Supply Fan

Horizontal
Rear Inlet
Door Right Side
Door Left Side
Light Right Side with with Outlet

Performance Ratings

Site Airflow, CFM	45000	Htg. Coil Static, in wg	0.28
Altitude, ft	0	Other Losses, in wg	0.00
Std. Airflow, CFM	45000	Accessories Static, in wg	0.72
Upstream Ext. Static, in wg	1.00	Total Static, in wg	12.17
DownStream Ext. Static, in wg	9.00	Calculated Fan Speed, rpm	1494
Clg. Coil Static, in wg	1.17	Calculated Motor BHP	121.7

Acoustic Data:

Freq.	Disch.	Inlet	Casing				
63 hz	105	102	98	1000 hz	95	89	83
125 hz	108	105	100	2000 hz	88	83	77
				4000 hz	84	79	73

250 hz	107	101	95	8000 hz	79	74	69
500 hz	100	94	90				

1494 FanRPM Class III

AirFoil Standard Wheel AFTC01402

Top Horiz. Front Discharge

Right Side Fan Motor Location

125 HP Premium Efficiency ODP 460 3Ph 60Hz 1800 RPM

1.5 Service Factor

Fixed Pitch Drive

Weights and Dimensions **

(LxWxH in ft in) 24' 0" x 12' 0" x 9' 9" **
Operating 14385 LB **

Ordering Information

39RJ17085KVYV21FBC	**Qty 1**
39RJ2-JN18DBBWWH23	**Qty 1**
39RJ3BKED4R49RRGDM	**Qty 1**
39RJ4-K-B97NHHHE26	**Qty 1**
39RJ567NJSL-M9T45J	**Qty 1**
39RJ6TR52SKMLK1C-G	**Qty 1**
39RJ7G-----------Q	**Qty 1**

** Weights and Dimensions are approximate. Weights include base unit weight, coils (wet & dry), fans and fan motors, and other components, but does not include filters, drives and skids. Approximate dimensions are provided primarily for shipping purposes, for exact dimensions, refer to submittal drawings. Shipping skids are not included.

Standard 62.1 - Office DCV AHU

Level		Room #'s	Box	CFM Max	CFM Min	Design Occupancy (ft^2/person)	Area (ft^2)	P_z Occup.	R_p (cfm/per)	R_a (cfm/ft^2)	V_{bz} (cfm)	E_z	V_{oz} (cfm)	Z_p
1	Lobby + Elevator Lobby	R100,R100B	S2	1350	675	250	1350	5	5	0.06	108	1	108	0.160
1	Corridor	R1C1	S40	1225	625	250	855	3	5	0.06	68	1	68	0.109
4-8	Meeting Room		S1	950	475	25	240	10	5	0.06	62	1	62	0.131
4-8	Office (3)	R402-R404	S2	675	350	100	385	4	5	0.06	42	1	42	0.121
4-8	Interaction space/Elevator Lobby	R400B,R400A	S3,S12	1250	625	250	1250	5	5	0.06	100	1	100	0.160
4-8	Office (4)		S4	1100	550	100	490	5	5	0.06	54	1	54	0.098
4-8	Conference Room	R408	S5	975	500	25	630	25	5	0.06	164	1	164	0.328
4-8	Corridor/Open Office	R4C7.R421,R 4C1	S6	675	350	150	555	4	5	0.06	52	1	52	0.148
4-8	Corridor/Open Office	R4C6	S7	725	375	100	700	7	5	0.06	77	1	77	0.205
4-8	Office (3)	R411-R413	S8	825	425	100	350	4	5	0.06	39	1	39	0.091
4-8	Meeting Room	R414	S9	950	475	25	240	10	5	0.06	62	1	62	0.131
4-8	Office (3)	R415-R417	S10	975	500	100	345	3	5	0.06	38	1	38	0.076
4-8	Men's Restroom/Women's Restroom	R418,R419	S11	325	325	N/A	320	0	0	0.06	19	1	19	0.059
4-8	Interaction space/Break Area	R422,R400C	S12	1100	550	100	1100	11	5	0.06	121	1	121	0.220

Max Z_p = 0.328
V_{ou} = 1007
E_v = 0.8
Per Floor V_{ot} = 1258
System $V_{ot,design}$ = 6292

Standard 62.1 - Office DCV AHU

Level		Room #'s	Box	CFM Max	CFM Min	Design Occupancy (ft^2/person)	Area (ft^2)	P_z Occup.	R_p (cfm/per)	R_a (cfm/ft^2)	V_{bz} (cfm)	E_z	V_{oz} (cfm)	Z_p
1	Lobby + Elevator Lobby	R100,R100B	S2	1350	675	250	1350	5	5	0.06	108	1	108	0.160
1	Corridor	R1C1	S40	1225	625	250	855	3	5	0.06	68	1	68	0.109
4-8	Meeting Room		S1	950	475	25	240	0	5	0.06	14	1	14	0.030
4-8	Office (3)	R402-R404	S2	675	350	100	385	4	5	0.06	42	1	42	0.121
4-8	Interaction space/Elevator Lobby	R400B,R400A	S3,S12	1250	625	250	1250	5	5	0.06	100	1	100	0.160
4-8	Office (4)		S4	1100	550	100	490	5	5	0.06	54	1	54	0.098
4-8	Conference Room	R408	S5	975	500	25	630	0	5	0.06	38	1	38	0.076
4-8	Corridor/Open Office	R4C7.R421,R 4C1	S6	675	350	150	555	4	5	0.06	52	1	52	0.148
4-8	Corridor/Open Office	R4C6	S7	725	375	100	700	7	5	0.06	77	1	77	0.205
4-8	Office (3)	R411-R413	S8	825	425	100	350	4	5	0.06	39	1	39	0.091
4-8	Meeting Room	R414	S9	950	475	25	240	0	5	0.06	14	1	14	0.030
4-8	Office (3)	R415-R417	S10	975	500	100	345	3	5	0.06	38	1	38	0.076
4-8	Men's Restroom/Women's Restroom	R418,R419	S11	325	325	N/A	320	0	0	0.06	19	1	19	0.059
4-8	Interaction space/Break Area	R422,R400C	S12	1100	550	100	1100	0	5	0.06	66	1	66	0.120

Max Z_p = 0.205

V_{ou} = 730

E_v = 0.9

Per Floor V_{ot} = 811

System $V_{ot,min}$ = 4054

Zone	Room Description	Area ft2	Ceiling Height	Interior Load Information			ACH Criteria		50% Turndown	MAX CFM	MIN CFM
				CFM	CFM/ft2	ACH	ACH	CFM			
1	Conference Room	630	10	975	1.5	9	0	0	500	975	500
2	Office (R402-R404)	385	10	675	1.8	11	0	0	350	675	350
3	Break Area/Interaction Space	1100	10	1100	1.0	6	0	0	550	1100	550
4	Meeting Room (R405)	240	10	950	4.0	24	0	0	475	950	475
5	Offices (R406-R409)	490	10	1100	2.2	13	0	0	550	1100	550
6	Office (R411-R413)	375	10	825	2.2	13	0	0	425	825	425
7	Meeting Room (R414)	240	10	950	4.0	24	0	0	475	950	475
8	Corridor/Open Office	555	10	675	1.2	7	0	0	350	675	350
9	Corridor/Open Office	700	10	725	1.0	6	0	0	375	725	375
10	Men's/Women's Restroom	320	10	325	1.0	6	6	325	175	325	325
11	Elevator Lobby/Interaction	1250	10	1250	1.0	6	0	0	625	1250	625
12	Level 1: Elevator Lobby	1350	10	1350	1.0	6	0	0	675	1350	675
13	Level 1: Corridor (R1C1)	855	10	1225	1.4	9	0	0	625	1225	625

Zone	Room Description	Area ft^2	Ceiling Height	People ft^2/person	Lighting W/ft^2	Equip. W/ft^2	Total Room Load (BTUH)	Solar Load (BTUH)	Cooling Load (CFM)	Cooling Load (1 CFM/ft^2)
1	Conference Room	630	10	25	1.5	2.0	20000	0	975	650
2	Office (R402-R404)	385	10	100	1.5	4.0	9133	4668	675	400
3	Break Area/Interaction Space	1100	10	125	1.5	2.0	17496	0	875	1100
4	Meeting Room (R405)	240	10	25	1.5	2.0	7619	11750	950	250
5	Offices (R406-R409)	490	10	100	1.5	4.0	11624	10923	1100	500
6	Office (R411-R413)	375	10	100	1.5	4.0	8896	7928	825	375
7	Meeting Room (R414)	240	10	25	1.5	2.0	7619	11750	950	250
8	Corridor/Open Office	555	10	92.5	1.5	4.0	13388	0	675	575
9	Corridor/Open Office	700	10	233	1.5	4.0	14627	0	725	700
10	Men's/Women's Restroom	320	10	200	1.5	0.0	2430	0	125	325
11	Elevator Lobby/Interaction	1250	10	250	1.5	1.5	15274	10322	1250	1250
12	Level 1: Elevator Lobby	1350	10	250	1.5	0.5	11888	15620	1350	1350
13	Level 1: Corridor (R1C1)	855	10	250	1.5	0.5	7529	17123	1225	875

AirTest™
Sensors That Make Buildings Smart!

Now With Thermistor/RTD Temperature Measurement Option

ISO 9001 Manufactured For Quality

TR9290 "No-Frills" - Self Calibrating - CO_2 Transmitter

Wall Mount
TR9290-L

Wall Mount
TR9290

In-Duct Mount
TR9291

Aspiration Duct Probe
TR9292-L

The "No-Frills" CO_2 Transmitter

Now With Temperature Option!

The TR9290 is a valued engineered CO_2 transmitter targeted at applications where all that is needed is a dependable CO_2 sensor with a 0-10 volt output. A temperature thermistor options is also available. This sensor utilizes the identical and proven infrared CO_2 sensor technology used in AirTest's popular TR-9220 CO_2 transmitter.

- ✓ Self-calibrating sensor eliminates calibration & maintenance requirements. No calibration required for life of the sensor (rated at 15 years).
- ✓ Attractive wall mount display with locking, snap-on cover.
- ✓ Inexpensive duct mount enclosure designed to mount directly in the duct. No tubes to clog, no filters to clean. In-duct mounting also means fast response. Aspiration probe also available.
- ✓ Gold plated optical sensor ensures long-term durability and stability.
- ✓ Purposefully built for quality – one of the few CO_2 sensors designed and built using Internationally Certified ISO 9001 processes to ensure consistent quality.

Why Active Ventilation Control With CO_2?

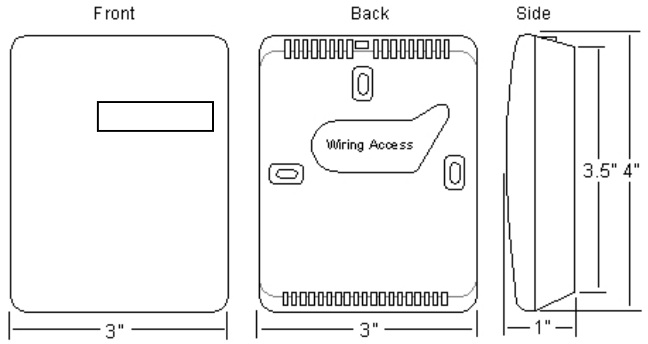
Ventilation control with CO_2 is a viable and energy efficient way of controlling ventilation to target cfm/person levels based on actual occupancy. This approach offers many advantages over the traditional approach of providing fixed ventilation based on maximum occupancy.

- ⇨ Reduce ventilation and energy costs in applications with variable occupancy.
- ⇨ In static occupancy applications, owner can continuously control ventilation rates to reflect current occupancy conditions.
- ⇨ Actively control ventilation to eliminate unintended over and under ventilation conditions resulting from post commissioning adjustment of outside air quantities.
- ⇨ Monitor and control zone ventilation efficiency and take advantage of using preconditioned transfer air from under occupied spaces for ventilation.
- ⇨ Documented CO_2 levels can provide ongoing verification that code-required ventilation rates are being maintained.

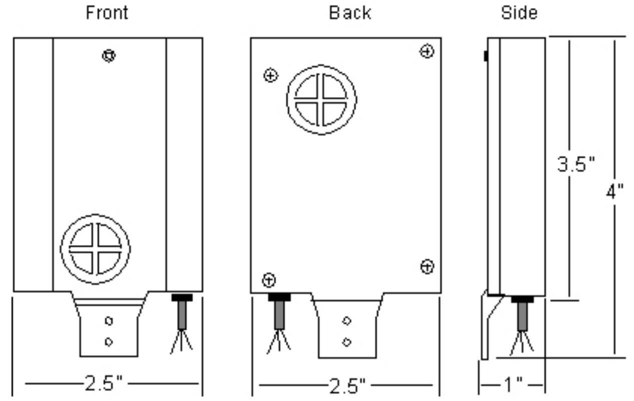
Now With Thermistor/RTD Option

If you need to measure temperature and CO$_2$, you can now get the TR9290 with a wide variety of temperature sensors (wall mount only). Just add the desired temperature sensor to the end of the product number when you order. Thermistor options include: 1.8K, 2.2K, 3K, 3.3K, 10K-2, 10K-3, 10K-3(11K), 20K, 47K, 50K, 100K. Other options possible.

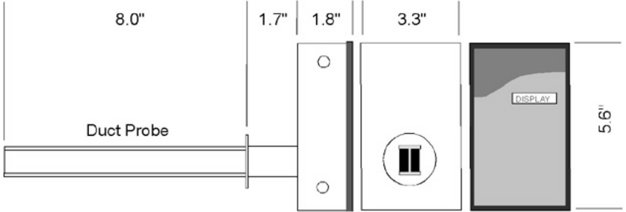
Dimensions: TR-9290 (Wall)



Dimensions: TR-9291 (In-Duct)



Dimesions: TR9292 (Aspiration Duct Probe)



Order Options

Type	Model No	With Temp
Wall Mount		
Without Display	**TR9290**	+ Add thermistor value to Model No
With CO2 Display	**TR9290-L**	+ Add thermistor value to Model No
In Duct		
Without Display	**TR9291**	Not Available
Aspiration Duct Probe		
Without Display	**TR9292**	+ Add thermistor value to Model No
With CO2 Display	**TR9292-L**	+ Add thermistor value to Model No

Distributed By:

Specifications

General

CO$_2$ Detection Method: Gold Plated Non-Dispersive Infrared Optical Sensor with Automatic Baseline Correction for Self-Calibration. Diffusion Sampling.

Certification: CE, EMC89/336/EEC, CA Energy Commission, ISO 9001 Manufactured for Quality & Consistancy.

Transmitter Rated Life: 15 years

Operating Conditions: 32 to 122º F (0 to 50ºC), 0 to 95% RH

Storage Conditions: -40 to 158º F (-40 to 70º C

Performance

CO$_2$ Measurement Range: 0-2000 ppm (factory set),

CO$_2$ Accuracy: +/- 1% of measurement range + 5% of measured value.

Calibration: Self Calibrating, Calibration Not Required

Response Time: T90 = <2 minutes (diffusion)

Power

Input: 18-30 VAC, 50-60 hz (half-wave rectified)

Average Power Consumption: ≤ 3 Watts average

Ground: Must share common ground with control system

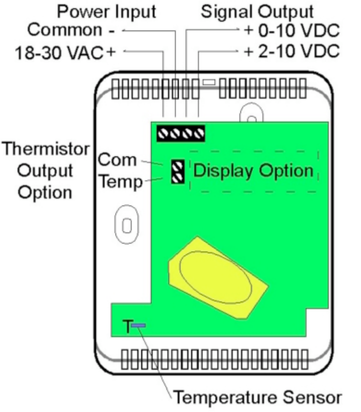
Outputs

Linear Analog Output: 0 to 10, 2-10 VDC ROUT < 100 ohm
Note: 0-5V option available – contact factory.

Thermistor Options: 1.8K, 2.2K, 3K, 3.3K, 10K-2, 10K-3, 10K-3(11K), 20K, 47K, 50K, 100K

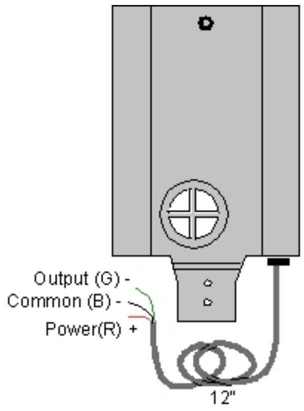
Wiring Access: Wall: remove front panel of transmitter to access wiring terminals and mounting plate.
Duct: 12” cable with 3-wire connection.

Wall/Duct Probe Wiring



Note: Common ground allows for 3 or 4 wire connection (wall mount)

In-Duct Mount Wiring



Covered By US Patents: 6194735, 6016203, other patents pending

AirTest™ Technologies Inc. specializes in the application of cost effective, state-of-the-art air monitoring technology to ensure the comfort, security, health and energy efficiency of buildings.

Sensors That Make Buildings Smart!

Specifications Subject To Change Without Notice *8/13/04*

Appendix C – Occupancy Sensor Lighting Control Calculations

Lighting w/ Occupancy Sensors		
Standard Office/Meeting Room Installation		
Labor	$ 10.00	
Leviton Model# PR180-1L	$ 27.00	
Total	$ 37.00	/ space
Labortory Installation		
Labor	$ 800.00	
Leviton Model #OSC04-I0V	$ 1,600.00	
Total	$ 2,400.00	/ lab space
Open Office Installation		
Labor	$ 160.00	
Leviton Model #OSC04-I0V	$ 320.00	
Total	$ 480.00	/ open office
Energy	$ 0.0816	/ kWh

Energy Savings w/ Occupancy Sensors Lighting Control Strategy

Space	*FP1 Fixtures*	*FP2 Fixtures*	*Hours**	*Daily Hours Saved*	*Cost*	*84 watts each (FP1) Energy Before*	*64 watts each (FP2) Energy Before*	*Energy After*	*Annual Savings*	*Savings*	*Simple Payback*
Typical Office	2	0	10	0.5	$ 37.00	420 kWh	0 kWh	399 kWh	21 kWh	$ 1.71	21.59
Typical Office	2	0	10	1	$ 37.00	420 kWh	0 kWh	378 kWh	42 kWh	$ 3.43	10.80
Typical Office	2	0	10	1.5	$ 37.00	420 kWh	0 kWh	357 kWh	63 kWh	$ 5.14	7.20
Typical Office	2	0	10	2	$ 37.00	420 kWh	0 kWh	336 kWh	84 kWh	$ 6.85	5.40
Typical Office	2	0	10	2.5	$ 37.00	420 kWh	0 kWh	315 kWh	105 kWh	$ 8.57	4.32
Typical Office	2	0	10	3	$ 37.00	420 kWh	0 kWh	294 kWh	126 kWh	$ 10.28	3.60
Typical Office	2	0	10	3.5	$ 37.00	420 kWh	0 kWh	273 kWh	147 kWh	$ 12.00	3.08
Typical Office	2	0	10	4	$ 37.00	420 kWh	0 kWh	252 kWh	168 kWh	$ 13.71	2.70
Meeting Room	7	0	10	0.5	$ 37.00	1470 kWh	0 kWh	1397 kWh	74 kWh	$ 6.00	6.17
Meeting Room	7	0	10	1	$ 37.00	1470 kWh	0 kWh	1323 kWh	147 kWh	$ 12.00	3.08
Meeting Room	7	0	10	1.5	$ 37.00	1470 kWh	0 kWh	1250 kWh	221 kWh	$ 17.99	2.06
Meeting Room	7	0	10	2	$ 37.00	1470 kWh	0 kWh	1176 kWh	294 kWh	$ 23.99	1.54
Meeting Room	7	0	10	2.5	$ 37.00	1470 kWh	0 kWh	1103 kWh	368 kWh	$ 29.99	1.23
Meeting Room	7	0	10	3	$ 37.00	1470 kWh	0 kWh	1029 kWh	441 kWh	$ 35.99	1.03
Meeting Room	7	0	10	3.5	$ 37.00	1470 kWh	0 kWh	956 kWh	515 kWh	$ 41.98	0.88
Meeting Room	7	0	10	4	$ 37.00	1470 kWh	0 kWh	882 kWh	588 kWh	$ 47.98	0.77
Open Office	18	0	10	0.5	$ 480.00	3780 kWh	0 kWh	3591 kWh	189 kWh	$ 15.42	31.12
Open Office	18	0	10	1	$ 480.00	3780 kWh	0 kWh	3402 kWh	378 kWh	$ 30.84	15.56
Open Office	18	0	10	1.5	$ 480.00	3780 kWh	0 kWh	3213 kWh	567 kWh	$ 46.27	10.37
Open Office	18	0	10	2	$ 480.00	3780 kWh	0 kWh	3024 kWh	756 kWh	$ 61.69	7.78
Open Office	18	0	10	2.5	$ 480.00	3780 kWh	0 kWh	2835 kWh	945 kWh	$ 77.11	6.22
Open Office	18	0	10	3	$ 480.00	3780 kWh	0 kWh	2646 kWh	1134 kWh	$ 92.53	5.19
Open Office	18	0	10	3.5	$ 480.00	3780 kWh	0 kWh	2457 kWh	1323 kWh	$ 107.96	4.45
Open Office	18	0	10	4	$ 480.00	3780 kWh	0 kWh	2268 kWh	1512 kWh	$ 123.38	3.89
Laboratory	25	80	10	0.5	$ 2,400.00	5250 kWh	12800 kWh	17148 kWh	903 kWh	$ 73.64	32.59
Laboratory	25	80	10	1	$ 2,400.00	5250 kWh	12800 kWh	16245 kWh	1805 kWh	$ 147.29	16.29
Laboratory	25	80	10	1.5	$ 2,400.00	5250 kWh	12800 kWh	15343 kWh	2708 kWh	$ 220.93	10.86
Laboratory	25	80	10	2	$ 2,400.00	5250 kWh	12800 kWh	14440 kWh	3610 kWh	$ 294.58	8.15
Laboratory	25	80	10	2.5	$ 2,400.00	5250 kWh	12800 kWh	13538 kWh	4513 kWh	$ 368.22	6.52
Laboratory	25	80	10	3	$ 2,400.00	5250 kWh	12800 kWh	12635 kWh	5415 kWh	$ 441.86	5.43
Laboratory	25	80	10	3.5	$ 2,400.00	5250 kWh	12800 kWh	11733 kWh	6318 kWh	$ 515.51	4.66
Laboratory	25	80	10	4	$ 2,400.00	5250 kWh	12800 kWh	10830 kWh	7220 kWh	$ 589.15	4.07

*Assumed Value

Energy Savings Per Floor

# of spaces per floor	*Type of Space*	*Installation Cost*	*Daily Hours Saved*	*Annual Energy Saved*	*Annual Saving ($)*
12	Typical Office	$ 444.00	0.5	252 kWh	$ 20.56
2	Meeting Room	$ 74.00	0.5	147 kWh	$ 12.00
1	Open Office	$ 480.00	0.5	189 kWh	$ 15.42
2	Laboratory	$ 4,800.00	0.5	1805 kWh	$ 147.29
				Total Installation Cost:	$ 5,798.00
				Total Savings ($):	$ 195.27
				Simple Payback (years):	29.7
12	Typical Office	$ 444.00	1	504 kWh	$ 41.13
2	Meeting Room	$ 74.00	1	294 kWh	$ 23.99
1	Open Office	$ 480.00	1	378 kWh	$ 30.84
2	Laboratory	$ 4,800.00	1	3610 kWh	$ 294.58
				Total Installation Cost:	$ 5,798.00
				Total Savings ($):	$ 390.54
				Simple Payback (years):	14.8
12	Typical Office	$ 444.00	1.5	756 kWh	$ 61.69
2	Meeting Room	$ 74.00	1.5	441 kWh	$ 35.99
1	Open Office	$ 480.00	1.5	567 kWh	$ 46.27
2	Laboratory	$ 4,800.00	1.5	5415 kWh	$ 441.86
				Total Installation Cost:	$ 5,798.00
				Total Savings ($):	$ 585.81
				Simple Payback (years):	9.9
12	Typical Office	$ 444.00	2	1008 kWh	$ 82.25
2	Meeting Room	$ 74.00	2	588 kWh	$ 47.98
1	Open Office	$ 480.00	2	903 kWh	$ 73.64
2	Laboratory	$ 4,800.00	2	7220 kWh	$ 589.15
				Total Installation Cost:	$ 5,798.00
				Total Savings ($):	$ 793.03
				Simple Payback (years):	7.3
12	Typical Office	$ 444.00	2.5	1260 kWh	$ 102.82
2	Meeting Room	$ 74.00	2.5	735 kWh	$ 59.98
1	Open Office	$ 480.00	2.5	945 kWh	$ 77.11
2	Laboratory	$ 4,800.00	2.5	9025 kWh	$ 736.44
				Total Installation Cost:	$ 5,798.00
				Total Savings ($):	$ 976.34
				Simple Payback (years):	5.9
12	Typical Office	$ 444.00	3	1512 kWh	$ 123.38
2	Meeting Room	$ 74.00	3	882 kWh	$ 71.97
1	Open Office	$ 480.00	3	1134 kWh	$ 92.53
2	Laboratory	$ 4,800.00	3	10830 kWh	$ 883.73
				Total Installation Cost:	$ 5,798.00
				Total Savings ($):	$ 1,171.61
				Simple Payback (years):	4.9
12	Typical Office	$ 444.00	3.5	1764 kWh	$ 143.94
2	Meeting Room	$ 74.00	3.5	1029 kWh	$ 83.97
1	Open Office	$ 480.00	3.5	1323 kWh	$ 107.96
2	Laboratory	$ 4,800.00	3.5	12635 kWh	$ 1,031.02
				Total Installation Cost:	$ 5,798.00
				Total Savings ($):	$ 1,366.88
				Simple Payback (years):	4.2
12	Typical Office	$ 444.00	4	2016 kWh	$ 164.51
2	Meeting Room	$ 74.00	4	1176 kWh	$ 95.96
1	Open Office	$ 480.00	4	1512 kWh	$ 123.38
2	Laboratory	$ 4,800.00	4	14440 kWh	$ 1,178.30
				Total Installation Cost:	$ 5,798.00
				Total Savings ($):	$ 1,562.15
				Simple Payback (years):	3.7