University of Miami Interdisciplinary Laboratory

Benjamin J. Burgoyne
Mechanical Option

Spring 2007
Faculty Consultant: Jim Freihaut

University of Miami Interdisciplinary Laboratory

Miami, Florida
Ben Burgoyne
Mechanical Option
http://www.arche.psu.edu/thesis/eportfolio/2007/portfolios/bjb319/

Project Information:

-Laboratory Building
-178,000 s.f.
-10 Floors above grade, including penthouse mechanical space
-Delivery Method: Negotiated- Guaranteed Maximum Price
-Building Cost: $57 million
-Construction Dates: October 2006-May 2008

Project Team:

-Architect: Karlsberger Architecture Inc., www.karlsberger.com
-General Contractor: Moss, www.mosscm.com
-Structural Engineer: Walter P. Moore, www.walterpmoore.com
-Mechanical Engineer: Newcomb & Boyd www.newcomb-boyd.com
-Electrical Engineer: Newcomb & Boyd www.newcomb-boyd.com

Architecture:

-Exterior is in keeping with the standard University of Miami style, including a white precast concrete panel facade, with blue-green windows and glass curtain walls throughout, and palm trees in the landscaping.
-Interior design includes seven floors of laboratory space and two floors of vivarium space, along with office space througout.

Mechanical System:

-100% outdoor air system distributed by five 50,000 cfm AHUs to constant-air-volume terminal units in the laboratory and animal spaces.
-Variable-air-volume system distributed by one 23,000 cfm AHU to the office spaces.
-Heating supplied by two 10,043 MBH boilers.
-Cooling supplied by campus chilled water plant.

Electrical/Lighting System:

-Service double ended main-tie-main switchboard
-1250 KW powers all lights and receptacles, as well as the HVAC equipment and emergency power.
-Vertical bus risers serve lights and receptacles at each floor.
-Predominantly fluorescent lights used, a third of which are dimmable with day-lighting/ambient light sensors.

Structure:

-The first floor is slab on grade, with an auger cast pile foundation.
-Predominantly reinforced concrete: cast-in-place concrete slab separates the floors, supported by precast concrete joists and beams, and cast-in-place concrete columns.
-Penthouse level is steel supported.

Table of Contents

Schematics

Tables

Calculations

Executive Summary:

This report presents the current mechanical design of the University of Miami Interdisciplinary laboratory, then suggests and implements, via calculation, additions and alterations meant to make it more energy efficient. The building is 10 floors high and is 178,000 square feet. Separate mechanical systems serve the laboratory and vivarium section, the office section, the penthouse mechanical floor, and general technical and equipment rooms. The Laboratory System is the focus of enhancements because it is the largest system, and because of the large potential for improvement for the current air distribution and dehumidification processes.

The Laboratory System is controlled air volume (CAV). The change introduced is making it variable air volume (VAV). This is carried out by replacing the constant volume terminal units with variable volume terminal units. The maximum air flow is set at the existing CAV levels, and the minimum flow is set at minimum ventilation requirements according to ASHRAE Standard 62.1-2004. Energy consumption analysis is carried out through simulation. A Percent Load Profile is thereby derived and combined with the peak load, which is the calculated cooling load. The annual energy savings is 14,062 MMBtu, and the associated economic savings is $16,700 per year. The payback period is 4-5 years.

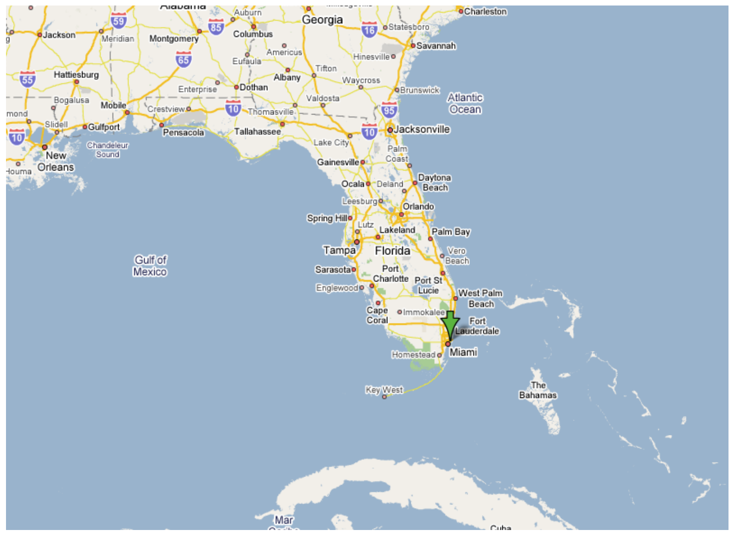
The existing system dehumidification uses cooling coils to dehumidify. The proposed change is to use a spray desiccant. Kathabar Systems produces equipment to spray a water/lithium chloride solution into the supply air stream, removing the moisture. Cooled solution cools the supply air as well. Peak cooling loads from this process are also combined with the Percent Load Profile, with both the CAV and VAV profiles. CAV Kathabar savings are 27,949 MMBtu and $33,300 per year with a 12-20 year payback. VAV Kathabar savings are 33,284 MMBtu and $39,600 per year with a 6-9 year payback. The big difference in payback between CAV Kathabar and VAV Kathabar occurs because the spray desiccant system makes terminal reheat unnecessary. Savings on that material are significant enough to cause that difference.

Structural and electrical studies are also carried out to ensure that the new Kathabar equipment will be adequately supported and receive the necessary power. New precast concrete joists are sized at12RB28, but the other structural elements are sufficient, and new circuits are run off an existing panel board.

Despite the longer payback, significant energy savings with the VAV/spray desiccant dehumidification enhancements cause that system to be the recommended alternative.

Introduction

The focus of this study is the University of Miami Interdisciplinary Laboratory, an office and research laboratory building currently being constructed on the campus of the University of Miami in Florida. Hereafter, the building shall be referred to as the UMIL. The UMIL's being located in a hot, humid climate, and its use requiring strict air conditions, make the effectiveness of the mechanical system an item of interest. Can it supply the necessary conditioning with minimal energy consumption? In this study, the design of the UMIL is analyzed with a focus on the mechanical system. Reviews of the current design strategies, equipment efficiencies, and energy consumption, as well as envelope, electrical system, and location demographic, can all reveal measures that may be taken to improve the system. This report presents the current mechanical design of the UMIL, then suggests and implements, via calculation, additions and alterations meant to improve it. The improvement shall be measured by total energy consumption with accompanying economic impacts. The results will show whether the system changes are worth implementing.



courtesy of Google Maps

Building

The UMIL is a research facility, designed for the keeping and studying of animals. It comprises approximately 10 floors and is 178,000 square feet. The first two floors contain animal vivaria, along with spaces to treat the animals, maintain and clean their confinement equipment, and store their food. Floors three through nine are typical, and they include two large general laboratories, with fume hoods, and several smaller research spaces. On all the floors, the listed science-focused spaces are located on the east side of the building. The west side contains office space. The technical spaces are located on the tenth floor, which is a mechanical penthouse, and on the first floor. The first floor footprint is significantly larger than the upper floors, which retain relatively the same perimeter dimensions. A large extension off the north side of the building is the focus of the first floor technical rooms, including general electrical and telecommunications rooms, a boiler room, and a generator room. Figure 1 shows the locations of the general space systems.

Figure 1
UMIL Systems

The typical architectural style of the University of Miami campus includes a white, concrete façade, blue-green fenestration, and palm tree dotted landscaping. The

UMIL uses the same coloring and architectural elements, thus fitting in with the surrounding structures. This style also includes a large percentage window area. Mechanically speaking, too much window area is unfavorable in the hot Miami climate. Excessive solar heat gain adds to the already high cooling load. The UMIL avoids this issue with the use of aluminum spandrels colored the same as the glass, thereby creating an illusion of windows without the solar gain. The thermal resistance of the spandrel is indeed lower than the remaining façade's concrete panel assembly. However, the spandrel, in terms of energy efficiency, is still more favorable than glass.

Less window area is acceptable even from an interior-aesthetic perspective, because the presence of windows in many of the spaces is either inappropriate or unnecessary. Those spaces include cage wash rooms, mechanical spaces, and animal holding rooms. The animal rooms, for instance, may require strict lighting and thermal conditions that can be adversely affected by a window.

In other spaces where windows are present, the extra light is used to soften the burden of electrical consumption. Automatic day lighting controls are used with the

perimeter lamps, turning them off when ambient light is sufficient. In addition, perimeter ceilings are angled in such a way as to reflect the outside light more effectively to work spaces. A building-wide 1250 kW capacity electrical system supplies the fluorescent lights as well as all receptacles, equipment, and emergency power.

In addition to its use for the façade, concrete is the primary element in the UMIL structural system. Each floor is a cast-in-place concrete slab, with the first floor being slab on grade. The upper slabs are supported by a one-way system consisting of specially made 16 inch precast concrete joists. These are mostly spaced 5'6" apart and the longest span is 33'. Supporting the joists are concrete beams and columns. The exception to the concrete norm is the roof assembly, which is held up by steel members.

The mechanical system shall be discussed in detail in the Mechanical System section.

Mechanical System

Cooling at the UMIL is supplied by a 20,000 ton campus chiller plant, and the heating by two 10,043 MBH steam boilers located in the first floor boiler room. The chilled water is supplied to UMIL at about 3,300 gpm and 44°F. It is returned at 56°F. The boilers create 80 psig steam that is used by glass and cage washing equipment and to create about 500 gpm of 180°F hot water via a heat exchanger. That hot water returns to the heat exchanger at 150°F. These plants supply four mechanical systems in the UMIL: the Office System serving the office spaces located on the first through ninth floors; the Laboratory System serving the laboratory and vivarium spaces on the first through ninth floors; the Penthouse System serving the penthouse mechanical floor; and the FCU system serving the first floor mechanical and other technical spaces. The following is a detailed description of each system.

-Office System

One 48,500 cfm air handling unit serves 50,000 square feet of office space. It is a return air system, drawing air from the spaces via ceiling plenums to mix with outside air. The supply air is cooled and dehumidified with chilled water coils, then reheated by hot water, variable volume terminal units. Dedicated exhaust systems serve the restrooms, kitchen areas, and janitor closets. The air schematic of the system is shown in Schematic S-8 and Schematic S-9.

-Laboratory System

Four 51,000 cfm air handling units supply 108,000 square feet of laboratory and vivarium space. Like the Office System, supply air is cooled and dehumidified by cooling coils, then reheated by hot water terminal units. However, the Laboratory System differs in that it supplies 100% outside air and the terminal units supply it at constant volume, adjusting the hot water flow through the coils to control the supply air temperature. All the space air is exhausted outside of the building.

There is a series of laboratory exhaust configurations for the system air. Nine risers with accompanying fans serve exclusively seven radioisotope and two necropsy rooms within the system. There is one radioisotope room located on each of the third through ninth floors. The necropsy rooms are found on the first and second floor. Additionally, there are dedicated exhaust systems for the cage wash areas and vivarium spaces on the first and second floors. The remaining laboratory spaces are served by fume hoods and a general exhaust system. The fume hoods are activated by Phoenix controls whenever the hoods are manually opened. They exhaust at constant volume.

An energy saving technique is used with the general exhaust system. It is powered by four 35,000 cfm energy recovery units, with a heat recovery runaround coil connecting these units with the Laboratory System air handling units. In the summer, this coil captures sensible heat in the hot, entering air stream and releases it into the cool, exhaust air stream. At design conditions, the runaround coil lowers entering air 10°F.

Entering that temperature difference, along with air handling unit maximum air flow rate of 204,000 cfm, into the sensible heat equation,

$$Qsensible = 1.08 \times q \times dT$$

where Q*sensible* is sensible heat (Btu/hr), q is air volume flow (cfm), and dT is temperature difference (°F), gives

$$Qsensible = 1.08 \times 204{,}000 cfm \times 10F$$
$$Qsensible = 2{,}203{,}200 Btu/hr$$
$$or$$
$$Qsensible = 183.6 tons$$

in energy saved. Even taking into account the energy required to pump the heat recovery water through the runaround coil, this can amount to significant savings. In another section, actual system flow rates will be used in energy calculation. The air schematics for this system are found in Schematic S-5, Schematic S-6, and Schematic S-7.

-Penthouse System

Two 4,000 cfm air handling units serve the12,000 square foot, tenth floor mechanical penthouse. This is a simple system, using only cooling coils and drawing in 100% return air. Because it is a non-occupied space, there are no outside air or exhaust requirements.

-FCU System

Three 1,200 cfm fan coil units (FCU's) serve the first floor technical spaces, which amount to 8,000 square feet. These are cooling coil only, and, like the Penthouse system, outside air and exhaust are non-issues.

System Enhancement-Depth

It is my supposition that a significant portion of the total building energy consumption can be saved with two changes to the Laboratory System. First, the controlled air volume (CAV) system should be changed to variable air volume (VAV). Second, a spray desiccant should be used instead of cooling coils to perform dehumidification. It is generally accepted that CAV and cooling coil dehumidification tend to be simpler to design than other air distribution and dehumidification alternatives, and that they carry lower first costs. Assuming these are correct statements, the alternatives need to not just save energy, but save enough energy, and thus money, to make up for the difference within a reasonable amount of time. This information can be determined by assessing the existing system energy consumption, followed by the energy consumed by the new system. Affixing a cost to the energy and comparing to the added first cost of the new system will reveal the time it takes to save an amount equal to the amount spent. The following sections will describe the two changes in detail, and calculate the energy consumption.

-CAV-VAV

There was no energy-related motivation to use a CAV system with the laboratory spaces. According to the design engineers, the decision to go with CAV came directly from the owner, who did not want a more complicated VAV system to be faultily designed or maintained. This is understandable; consistently maintaining design conditions is too important, especially in a laboratory setting. Evidently, bad prior experience with VAV had left the owner disinclined to try it again.

In this situation, making the design equipment change to VAV is not difficult. The air handling units and exhaust fans are already equipped to handle variable volume flow. Their fans run on variable frequency drives. Likewise, the air handling unit cooling coil control valves can modulate to control flow. The system maintains constant volume with the terminal units. Based on the preset supply duct air pressure, they are adjusted to allow only the preset air flow rate through. Those set flow rates, per terminal unit, are shown in Table 1. In order to change the system to variable volume, the terminal units need to be exchanged with variable volume counterparts. Aside from the return air, this new system is extremely similar to the Office System, and those same terminal units can be used.

With the new terminal units, ranges of air flow rates, instead of single flow rates, need to be determined. It is assumed that the existing system can adequately meet design conditions. Therefore, the fans and coils shall not be upsized. Also, the maximum set point for the new variable volume terminal units will equal the CAV set points. The fluctuation will occur when the system is at less than peak load. Only minimum flow rates, then, need to be determined. The lowest load a space can possibly have is zero. However, the building code requires a minimum supply of outside air. Therefore, a satisfactory minimum setpoint for the terminal units would be the standard ventilation requirement for the spaces they supply. The required rates are calculated based on ASHRAE Standard 62.1-2004. The calculation of the Laboratory System room ventilation rates is found in Table 2a, Table 2b, and Table 2c. When those flow rates are applied to the rooms' terminal units, the minimum terminal unit flow rates are achieved. These are shown in Table 1.

Based on the maximum and minimum flow rates, the associated system range is obtained. According to Table 1, the maximum is 171,710 cfm, and the minimum is 26,919 cfm. This is the extent for the system, but a building simulation needs to be carried out in order to determine how much time the system spends at different points within the that range. That information, comprising an energy load profile, can be applied over a year, and will show the energy consumption. Trace®700, a product of Trane®, is the mechanical simulation program that is used in this study. With Trace®700, an accurate model can be created with the exception of one factor. The program does not allow for 100% outdoor air, it will only simulate a return air system. For this reason, an accurate final energy consumption total is not given. However, some products of the simulation are assumed to be independent of percent outdoor air. One such product is the System Load Summary. The data in this report divides the peak load into five percentile increments. It then lists the percent of the time (per year) that the system was at each load percentile. For example, one could use the report to look up how many hours in the year the system was at 50% load. We will call the percentage part of the System Load Summary the Percent Load Profile. Table 3 shows the Percent Load Profile for the Laboratory System Trace®700 simulation. In order to approach the real system, the assumption is made that, with all else equal, the Percent Load Profile for a 100% outdoor air system is the same as for a return air system, even though the peak loads are different. Subsequent energy calculations will be based on this assumption.

% Total Load	% of Year	
	CAV	VAV
Hours off	0%	0%
0--5	0%	0%
5--10	0%	0%
10--15	0%	1%
15--20	0%	4%
20--25	0%	3%
25--30	0%	12%
30--35	1%	11%
35--40	2%	14%
40--45	3%	12%
45--50	4%	14%
50--55	6%	9%
55--60	13%	4%
60--65	15%	2%
65--70	15%	1%
70--75	13%	1%
75--80	10%	2%
80--85	14%	3%
85--90	2%	2%
90--95	0%	2%
95--100	0%	2%

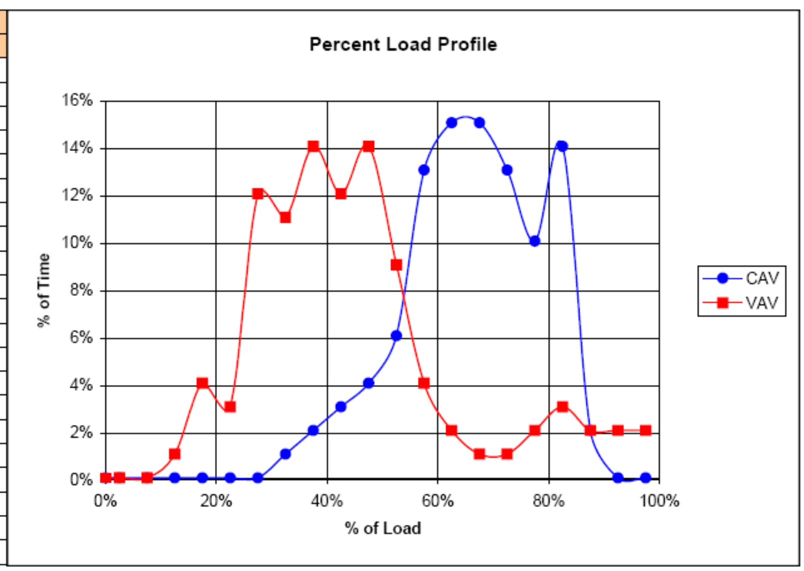


Table 3
Percent Load Profile
Laboratory System

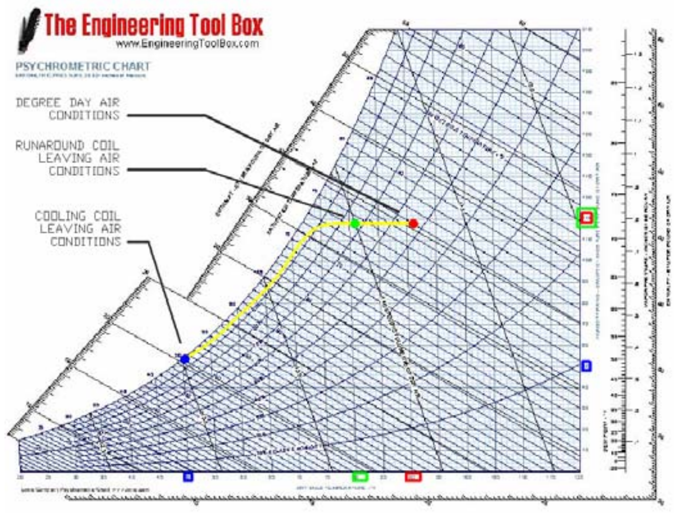


Figure 2
CAV/VAV Design Conditions
Psychrometric Chart

In order apply the Percent Load Profile, the true Laboratory system peak load needs to be determined. Here, another simulation product is used: peak supply air flow rate. For the same building and conditions, the same amount of supply air must be maintained to meet the load, regardless of whether it was partially returned or not. At the outlet stage, in both cases, the air conditions are the same. Therefore it is assumed that the peak supply air flow rate for a return air system is the same as that for a 100% outdoor air system. According to the simulation, the peak flow rate is 100,000 cfm, and it is used in the sensible and latent heat equations to determine the peak cooling load. The latent heat equation used is

$$Qlatent = 0.68 \times q \times dW$$

where Qlatent is sensible heat (Btu/hr), q is air volume flow (cfm), and dW is difference in humidity ratio (grains moisture/pounds dry air). Using the psychrometric chart, shown in Figure 2, initial conditions are determined as 81°F and 120 grains/lbmda. This condition is a cooling degree day, as given by project specifications, minus 10°F (taken care of by the runaround coil). The final condition, also taken from specifications, is 50°F and 50 grains/lbmda. This is the air leaving the cooling coil. Taking the temperature and humidity differences, and inserting them into the equations gives:

Sensible

$$Qsensible = 1.08 \times q \times dT$$
$$Qsensible = 1.08 \times 100{,}000cfm \times 31F$$
$$Qsensible = 3{,}348{,}000Btu/hr$$
or
$$Qsensible = 279tons$$

Latent

$$Qlatent = 0.68 \times q \times dW$$
$$Qlatent = 0.68 \times 100{,}000cfm \times 66gr/lbmda$$
$$Qlatent = 4{,}488{,}000Btu/hr$$
or
$$Qlatent = 374tons$$

Total

$$Qtotal = Qsensible + Qlatent$$
$$Qtotal = 3{,}348{,}000Btu/hr + 4{,}488{,}000Btu/hr$$
$$Qtotal = 7{,}836{,}000Btu/hr$$
or
$$Qtotal = 653tons$$

As shown, the total cooling load is calculated simply by adding the sensible and latent loads.

Now that the peak cooling load is determined, it is inserted into the Percent Load Profile to discover the total yearly energy consumption for each system. This is shown in Table 4, and the resulting consumptions are 45,034 MMBtu and 30,973 MMBtu for the CAV and VAV systems respectively.

As expected, the VAV system consumption is less than the CAV system. In the Economic Analysis section, the difference in resulting cost with be analyzed in detail, and a final judgment regarding system decision can be made. In preparation for that section, it is noted that this assessment only compares energy in terms of actual cooling, not in heating, reheat, fan energy, or other total energy considerations. It is the purpose of this study to determine if the savings on cooling alone would warrant a system change.

-Spray Desiccant

As stated in the Introduction, designing an effective mechanical system can be difficult in a hot, humid climate, especially with a demand for 100% outside air. Using a cooling coil for dehumidification requires the incoming air to be cooled below the desired supply set point, then to be reheated. An alternative that doesn’t require air to go through the extra cooling and reheating (which is, of course, energy consuming) is worth investigating.

Based on building use, a spray desiccant is the most appropriate alternative to cooling coil dehumidification for the UMIL. With other buildings, an enthalpy wheel would be considered; with one circular motion, the solid desiccant material would absorb heat and moisture from the incoming air stream and deposit it into the outgoing air stream. This process is known to greatly increase the efficiency of a system, and high first cost is the greatest limitation to its use. However, the unfavorable exhaust air quality of the Laboratory System discourages use of the enthalpy wheel. System air can become saturated with dangerous chemicals, biological products, and other contaminants, which necessitates 100% outside air to replace it. An enthalpy wheel exposed to such exhaust can possibly pick up that contamination and return it to the incoming stream, and is thus excluded from consideration.

A spray desiccant system would preserve incoming air quality while still creating energy savings. Such a system is offered by Kathabar® Systems. With Kathabar, a liquid desiccant solution is sprayed into the supply air stream to dehumidify as well as cool it. Figure 3 illustrates the process that the desiccant solution undergoes. The substance is a water/lithium chloride salt solution, called Kathene, which is ton-toxic. Within the conditioner unit, located in the supply air stream, the Kathene is cooled by chilled water in a heat exchanger, and is sprayed into the supply air stream. The solution cools the air

---

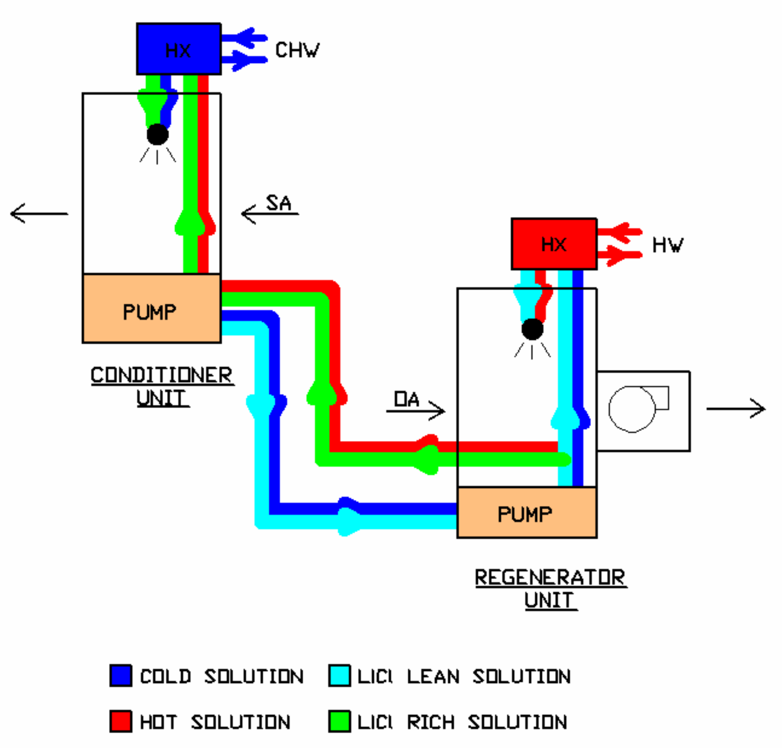


Figure 3
Kathabar System Schematic

and naturally absorbs the water vapor. It then falls from the air, and is gathered at the bottom of the unit. At this stage, the solution is lithium chloride lean (excess water). A portion is therefore pumped to the regenerator unit, located on the exterior of the building. It is heated with the hot water heat exchanger and sprayed into a forced outdoor air current. Because it is heated, the solution wants to get rid of the moisture it contains, which is taken away via evaporation. The remaining lithium chloride rich solution is gathered at the bottom of the unit and pumped back to the conditioner. In this way, the solution concentration is controlled. That concentration determines the amount of moisture removed from the air stream, and is variable, so it can adjust automatically to meet any sensible or latent load. Supply air quality is preserved because the regenerator can be placed anywhere, well away from the exhaust. Additionally, an eliminator system in the conditioner unit serves as a filter, trapping particulates. The lithium chloride carryover into the building equates to about 2 ppb when the system is adequately maintained.

It is necessary here to note that Kathabar Systems are usually applied to small spaces or special design conditions, such as industrial or refrigeration uses, where extremely cold, dry air is required. Nevertheless, the Kathabar system is analyzed for the UMIL to see if, despite the unorthodox application to a large laboratory building, sufficient energy is saved to warrant the change. The actual application to a building system, including equipment sizing and peak load determining, is shown in Kathabar literature, namely Kathabar Systems Application *Manual for Kathapac Dehumidification*. These calculations run for the Laboratory System are found in Calculation 1. In addition to the information shown there, special charts are used to obtain some of the given values. These charts are found in the manual, but because of copyright and space purposes, they are not reprinted here. Table 5 summarizes the data required to run the calculation and the ultimate information derived.

One key aspect is the determination of required chilled water temperature. This depends on the difference between the air conditions entering the conditioner unit and leaving it. The existing chilled water temperature for the UMIL is 44°F. Using air coming directly from the runaround coils, assumed at 81°F maximum, the chilled water temperature required by the Kathabar calculation is less than 44°F. This deficiency can be remedied in one of two ways. A small chiller can be designed and installed to lower the

Input Data		**Outcome**		
Conditioner Entering DBT	72F	**Regenerator Unit Size**	3FP	
Conditioner Entering W	115 gr/lb	**Conditioner Unit Size**	2 x 4,000FV	
SA DBT	55F	**Regenerator Heating Load**	193,682 Btu/hr	16 tons
SA W	55 gr/lb	**Conditioner Cooling Load**	2,000,988 Btu/hr	167 tons
SA cfm	100,000 cfm	**Required CHW T**	44F	
Space DBT	75F			

Table 5
Calculation Input/Outcome
Kathabar System

campus chilled water temperature to the required level, or the supply air can be cooled further before it reaches the conditioner unit. The second option is taken in this study, because the cooling coils are already in place within the existing air handling unit assemblies. It is assumed that making use of those coils would be much simpler and more cost efficient than a whole new chiller or chillers.

Working backwards in the calculations from the desired 44°F CHW, it is determined that the necessary conditioner entering air conditions are 72°F and 115 gr/lb. At design conditions, with

$$dT = 81F - 72F$$
$$and$$
$$q = 100{,}000cfm$$

the extra required cooling becomes

$$dT = 81F - 72F$$
$$q = 100{,}000cfm$$
$$Qsensible = 1.08 \times 100{,}000 \times 9$$
$$Qsensible = 972{,}000 Btu/hr$$
$$or$$
$$Qsensible = 81 tons$$

This extra cooling is taken into account, in addition to the given Kathabar System values. Added together, they become the peak cooling load, and can therefore be input into the Percent Load Profile to obtain the energy usage. The yearly cooling energy consumptions are show in Table 6. The same Percent Load Profiles for CAV and VAV are used as before because the same expected flow rates are assumed to pass through the Kathabar system. The Kathabar system energy consumptions are 17,086 MMBtu for CAV application and 11,571 MMBtu for VAV. Again, the CAV requires more energy than the VAV Kathabar configuration.

The Kathabar System creates a significant change in the air distribution system. The air temperature leaving the conditioner unit is 55°F. The terminal units receiving this air are specified to receive 50°F air, heat it, and distribute it at 55°F. This was the reheat stage of the cooling coil dehumidification. With the supply air already at the design temperature, the reheat becomes unnecessary. Also, the original CAV system modulated the reheat water flow in order to control fluctuating space conditions. With the VAV system, the air flow becomes the modulated medium. For these reasons, a number of Laboratory System terminal units do not need heating coils with the use of Kathabar equipment. Perimeter space terminal units will keep theirs because of heating they may need to perform while other spaces are cooled. However, the materials that are saved by decreasing the hot water connections can constitute significant cost savings.

To restate from the CAV-VAV section, cooling energy (in terms of chilled water use) is the exclusive method of analysis for this study. There are heating requirements for the regenerator unit and differences in fan energy consumption. However, these factors are not addressed here.

-Comparison

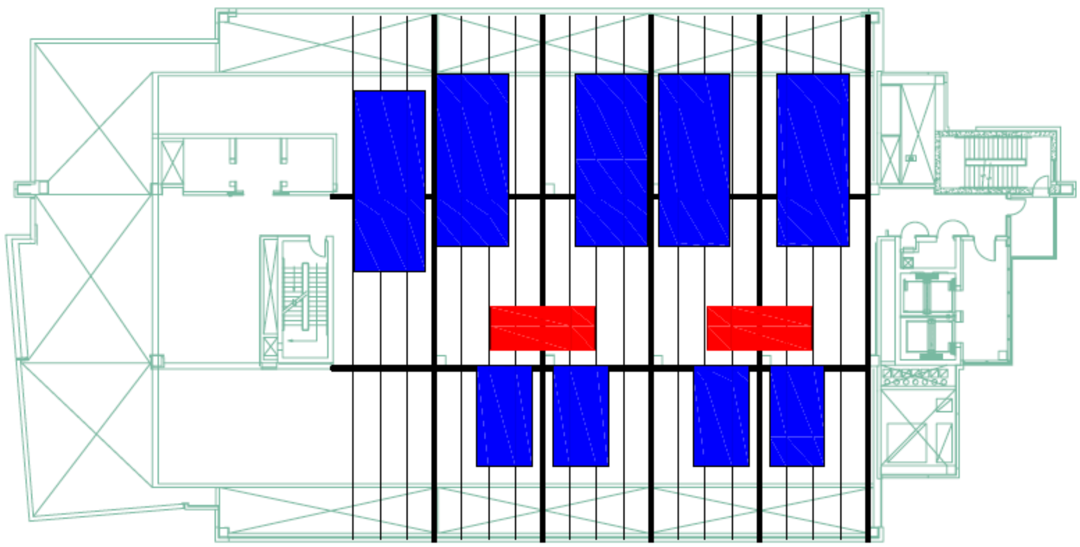
Enough energy data is now available to compare the various system enhancements. There are four possible system choices, shown with accompanying energy consumptions in Table 7. The original system is constant air volume with cooling coil dehumidification. One possible change is variable air volume with cooling coil dehumidification. Another is constant air volume with spray desiccant dehumidification. Finally, the system can be variable air volume with spray desiccant dehumidification. In terms of lowest energy expenditure, the VAV-spray desiccant system is clearly the favorite. It is followed by CAV-spray desiccant, and then VAV-cooling coil and CAV-cooling coil respectively.

		Air Flow	
	MMBtu/ yr	CAV	VAV
Dehumidification	Cooling Coil	45,035	30,973
	Spray Desiccant	17,086	11,751

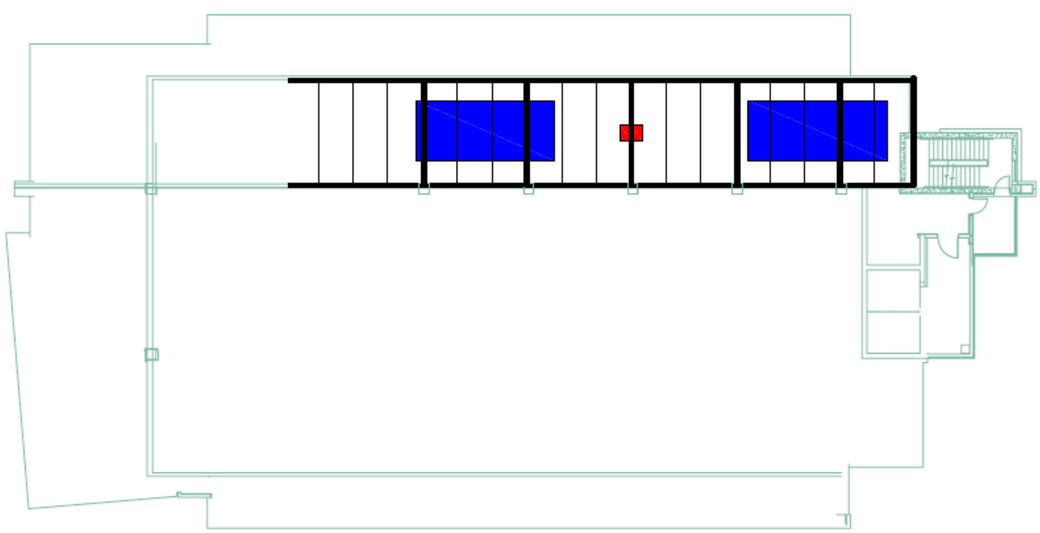
Table 7
System Energy Comparison

System Enhancement-Breadths

The addition of a Kathabar, spray-desiccant system creates more of an impact on a building than just on the mechanical system. Other elements of the building may need to be altered, upsized, or added onto in order to adjust to new requirements. Two such elements are the structure and the electrical system. The following sections discuss the structural and electrical considerations that have to be taken into account with the addition of a Kathabar system.



Penthouse Plan



Partial Roof Plan

Figure 4
Kathabar Equipment Placement

-Structure

The Kathabar equipment, namely the regenerator unit and especially the conditioner units, are significantly in size. They each contain motors, and, when operating, they hold water. These facts, along with actual manufacturer-supplied weights suggest that this equipment may be heavy enough to require special structural design. For these reasons, an analysis of the structure supporting a UMIL Laboratory Kathabar System is undertaken.

First, the placement of the equipment is ascertained. The two 4000FV conditioner units need to be placed in a location that is down the air stream from the air handling units. The configuration in the Figure 4 Penthouse Plan shows an appropriate option. The blue entities are existing equipment. Those on the plan north are air handling units, and on the plan south are energy recovery units. The red entities are the new conditioner units. They are located apart from the air handling units in order to allow for relatively straight duct run coming in. They are also out of the way of access doors and walkways.

The Partial Roof Plan shows a good location for the regenerator unit (shown in red). The blue entities are existing high induction exhaust fans. Their exhaust streams are designed to rise at least 36 feet before dissipating, so no regenerator contamination will occur there.

Now that the equipment is placed, accurate structural calculations can be carried out. Attention is paid to the joists that the new equipment sits on, the girders supporting those joists, and the columns supporting those girders. Table 8 shows the loads due to the Kathabar equipment, the air handling units, general dead and live loads, and the concrete slab self-weight. These values are taken from product specifications as well as ASCE 7-05, Chapter 4, Table 4-1. Two load cases are calculated, and the higher values for each item are highlighted.

Joists

The resulting loads are used to calculate reactions in the supporting joists and to formulate bending moment equations. This is done in Table 9. The equations are taken from the AISC Manual of Steel Construction, Third Edition, Table 5-17, 4. Simple Beam- Uniform Load Partially Distributed. It is assumed that the joists supporting the equipment are simply supported. Combining the moment equations for the different loads on the same joist, total bending moment graphs can be created. The peaks of the graphs will give the maximum bending moment on the joists. These graphs are shown in Figure 5 and Figure 6.

The roof joists are steel members, size W14x22, with a capacity of 124.5 kip-ft over 21 feet. They are sufficient. The penthouse joists are specially made precast concrete, and their capacity is unavailable. However, a sufficiently strong precast rectangular joist spanning 33 feet is a 12RB28, with 336 in.^{2} cross section and a strength

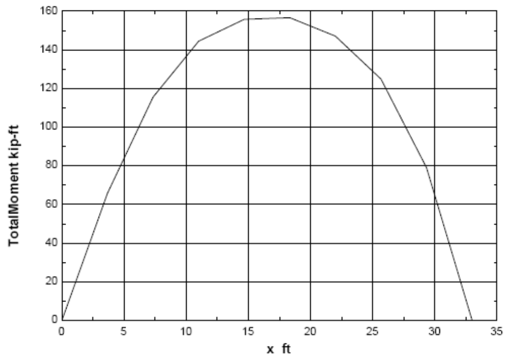


Figure 5
Penthouse Joist Bending Moments
157.4 kip-ft max

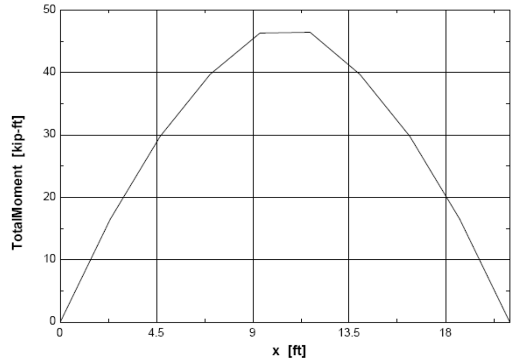


Figure 6
Roof Joist Bending Moments
47.41 kip-ft max

of 2525 plf. Referring to Table 8, the maximum plf that occurs at any time along the joist is 1,824. This joist is found in the PCI Design Handbook 6th Edition page 2-42. Because the joists are fixed to the slab they are supporting, it is assumed that they are braced along their entire length.

Girders

The resulting load on the girders supporting the joists is determined from the end reactions of the joists on those girders. These reactions are given in Table 10. R1 refers to the girder to the building south of the joist, and R2 to the girder to the building north. For the penthouse girders, the reactions double count the air handling units and slab weight to account for the reactions on the girder from the opposite direction.

Roof

	R1	R2
	kip	kip
1	6.65	6.65
2	8.05	8.05

Penthouse Floor

	R1	R2
	kip	kip
1	23.15	24.33
2	23.31	24.33

Table 10
Joist End Reactions

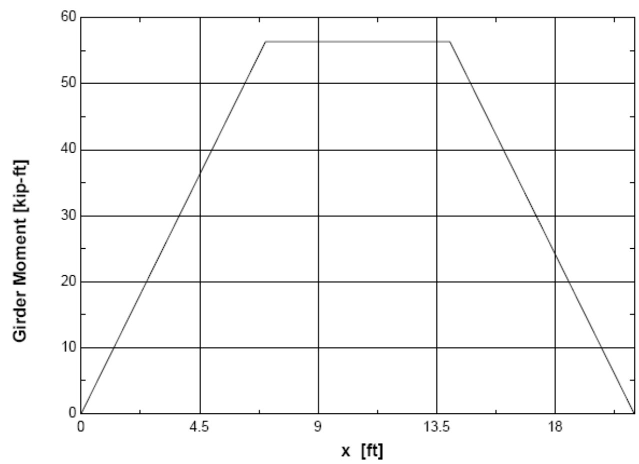


Figure 7
Roof Girder Bending Moments
56.35 kip-ft max

As shown in Figure 7, the maximum bending moment on the roof girders is 56.35 kip-ft. These members are also W14x22’s, holding up to 124.5 kip-ft. They are sufficient. Penthouse girder R1, Figure 8, is referred to in the beam schedule as SB21 and can hold 290 kip-ft and 150 kips shear. This is enough to handle the 231 kip-ft and 41.5 kips loaded on it with the new Kathabar equipment. It is sufficient. Penthouse girder R2, Figure 9, is named SB20 and can hold 275 kip-ft and 140 kips shear. It is loaded with 240 kip-ft and 41.5 kips shear. Likewise, this member will handle the extra equipment load.

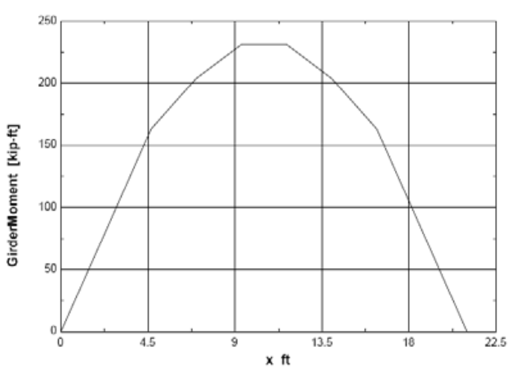


Figure 8
Penthouse Girder R1 Bending Moments
231 kip-ft max

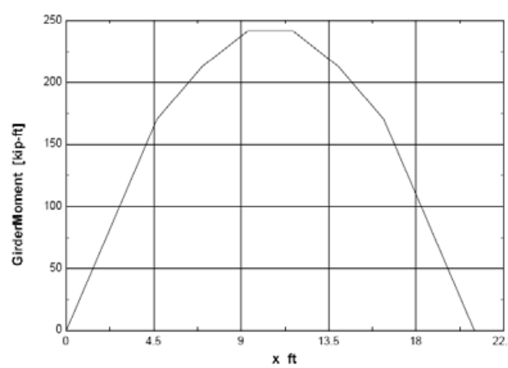


Figure 9
Penthouse Girder R2 Bending Moments
240 kip-ft max

Columns

The columns supporting the extra penthouse equipment are designated as C1 in the column schedule. They are 24”x24” and are 4ksi concrete. As shown in Table 8, the collective pressure, including new equipment, of the greatest tributary area to each of these columns is 0.33 ksi, well below the limit. These columns are near the top of the building, so additional weight from higher spaces will not likely be an issue. These columns are acceptable.

The columns supporting the roof where the regenerator unit will be located are steel members, namely HSS 12x8x5/8. According to the AISC Manual of Steel Construction Third Edition, Table 4-13, the axial design strength, at an effective length of 18 feet, is

$$DesignStrength = 766kips \times \phi c$$

$$\phi c = 0.85$$

$$DesignStrength = 651.1kips$$

The load on each column, as shown in Table 8, is 103 kips. These columns are sufficient.

Conclusion

To sum up the structural findings, all existing joists, girders, and columns are strong enough to support the extra Kathabar System equipment. The exception to this is the precast concrete penthouse joists, whose strength is unknown. A satisfactory rectangular joist size, however, has been identified to carry the extra load.

-Electrical System

In addition to the structure, the new Kathabar equipment affects the UMIL electrical system. Motors contained in that equipment require sufficient electrical power with an adequate conductor. These motors drive a pump in each conditioner unit and a pump and fan in the regenerator unit. Naturally, these motors were not taken into account during the initial electrical system design, but space was kept on a number of panelboards in lieu of future electrical expansion such as this.

A close panelboard with spare circuits is EHEQPB. It currently serves the high induction and cage wash exhaust fans, which take up only 400 of the 600 amp capacity. The panelboard is located on the penthouse level, on the east end, which is the closest panelboard to where the Kathabar equipment will be placed. Offering eighteen spare poles, it is a suitable possibility.

Table 11 outlines the steps for design of the circuit assemblies that serve the Kathabar equipment. A branch circuit is used for each conditioner pump, and one branch circuit for both the regenerator pump and fan. The designed circuits are shown in Figure 10 and Figure 11. Aluminum conductors are used, as opposed to copper, because of the rising copper prices.

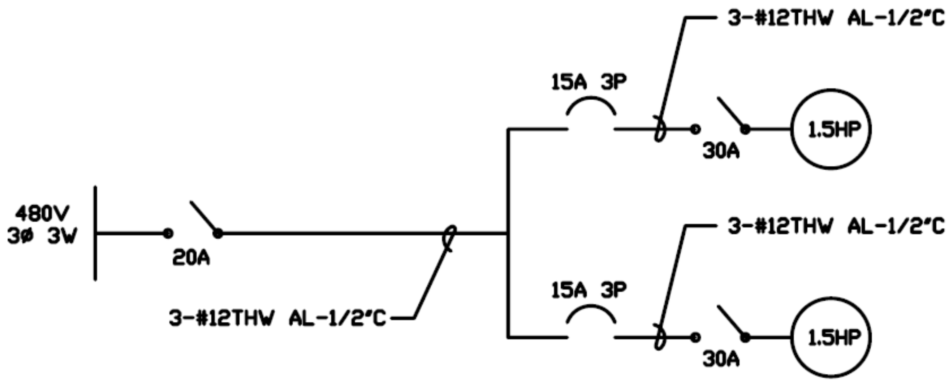


Figure 10
Regenerator Unit Branch Circuit

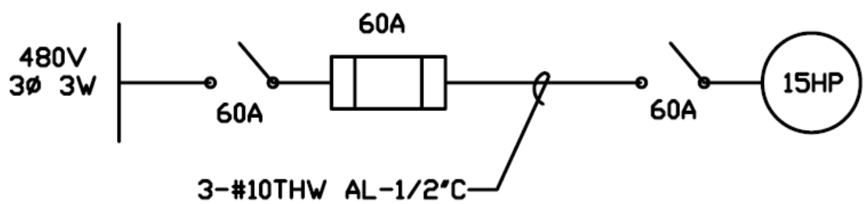


Figure 11
Conditioner Unit Branch Circuit

If there is a significant length between the panelboard and the equipment, voltage drop may become a factor. Voltage drop calculations for the new branch circuits are shown in Table 12. Conductor sizes are determined based on 2% maximum allowable

---

Conditioner Unit Pump	
Length:	96'
FLC:	34 A
Amp-ft/1,000 ft:	3.264
	9.6 V l-n
2% Voltage Drop of 480 V:	5.55 V l-l
V drop/1,000 Amp-ft:	1.7
Conduit:	Magnetic
P.F.	90%
Conductor:	#10
Covered?	**Yes**

Regenerator Unit Pump/Fan	
Length:	62'
FLC:	7 A
Amp-ft/1,000 ft:	0.434
	9.6 V l-n
2% Voltage Drop of 480 V:	5.55 V l-l
V drop/1,000 Amp-ft:	12.8
Conduit:	Magnetic
P.F.	90%
Conductor:	Any
Covered?	**Yes**

Table 12
Voltage Drops
Kathabar Equipment Branch Circuits

voltage drop, then are compared to the already established sizes. In both cases, the sizes are already adequate to limit the voltage drop to 2%. No change is necessary.

These circuits are then inserted into the panelboard. Table 12 shows the updated panelboard, highlighting the added circuits. The extra load comprises 52 amps, which keeps the total of 452 amps well below the 600 amp capacity.

PANEL:	EHEQPB	AMP:	600	AIC RATING:	65,000A
VOLTAGE:	480Y/277	MAIN:	MLO	ENCLOSURE:	NEMA 1
PHASE/WIRE:	3P/4W	NEUTRAL:	100%	MOUNTING:	SURFACE

EQUIPMENT	kVA	CB	CKT	A	B	C	CKT	CB	kVA	EQUIPMENT
F-M-1	18.0	100/3	1	32.4			2	90/3	14.4	F-M-4
	18.0		3		32.4		4		14.4	
	18.0		5			32.4	6		14.4	
F-M-2	18.0	100/3	7	32.4			8	90/3	14.4	F-M-5
	18.0		9		32.4		10		14.4	
	18.0		11			32.4	12		14.4	
F-M-3	18.0	100/3	13	32.4			14	90/3	14.4	F-M-6
	18.0		15		32.4		16		14.4	
	18.0		17			32.4	18		14.4	
F-M-8	5.8	50/3	19	13.1			20	60/3	7.3	CONDITIONER 1 PUMP
	5.8		21		13.1		22		7.3	
	5.8		23			13.1	24		7.3	
F-M-9	5.8	50/3	25	13.1			26	60/3	7.3	CONDITIONER 2 PUMP
	5.8		27		13.1		28		7.3	
	5.8		29			13.1	30		7.3	
REGEN PUMP/FAN	1.9	20/3	31	1.9			32			SPACE
	1.9		33		1.9		34			SPACE
	1.9		35			1.9	36			SPACE
SPACE			37	0			38			SPACE
SPACE			39		0		40			SPACE
SPACE			41			0	42			SPACE
PHASE TOTALS				125	125	125				

CONNECTED AMPS: 452 CONNECTED kVAL: 376

Table 13

Exhaust Fan/Kathabar Equipment Panelboard

Economic Analysis

All the information that is used to determine the total system costs is found in Calculation 2. Prices of mechanical, structural, and electrical materials added or removed are given. These are used to determine system first costs. The annual energy consumption values, which are cooling loads, are combined with the COP of the campus chilled water plant to give the amount of electricity, in kilowatt-hours, that is expended. That electricity is multiplied by the price per kilowatt hour to determine the annual system operation costs. Florida Power & Light is the UMIL utility company, from which that price is obtained.

Once the system first costs and operation costs are given, pay back periods are determined using two methods: the simple payback method and the net present value method. With both, a system change is compared to the original system. The new operation cost is subtracted from the old to obtain a yearly payback amount. With simple payback, the new system cost is divided by that yearly payback, giving the number of years it will take for the system to pay for itself. The net present value method uses the same numbers, but also incorporates interest. For this study, 5% interest is used. With each succeeding year down the timeline, the present value of that future amount decreases more and more because of the interest factor. This method is more conservative, resulting in a greater payback period than that given by the simple payback method.

The values just discussed are summarized in Table 14. It shows that the VAV, coil dehumidification system has the lowest payback period, followed by the VAV, spray desiccant system and the CAV, spray desiccant system.

System	1st Cost	Cooling Energy Demanded MMBtu	Electricity Consumption kWhr	Operation Cost	Payback - Years	
					Simple	NPV
Original	--------	45,035	2,251,750	$53,636.69	--------	--------
VAV, Coil	$65,815.00	30,973	1,548,650	$36,888.84	3.93	5
CAV, Spray Desiccant	$409,011.16	17,086	854,300	$20,349.43	12.29	20
VAV, Spray Desiccant	$260,831.41	11,751	587,550	$13,995.44	6.58	9

Table 14
Economic Analysis Summary

Conclusion

Reviewing the various mechanical systems of the UMIL led to a focus on the Laboratory System for enhancement. The Penthouse and FCU Systems are not large or significant compared to the others, and they are relatively simple in makeup. With those, the logical equipment is used to accomplish basic condition requirements. The Office System is much closer to the Laboratory System in terms of square footage served and complexity. It is actually the difference between those two strategies that inspires the change in the Laboratory System. Contrary to the Laboratory System, the Office System employs return air and variable air volume distribution. It is correctly inferred that the Laboratory System has much higher energy consumption. What can be done to offset that difference?

The procedures carried out to answer that question were changing the Laboratory System from constant air volume to variable volume and using a spray desiccant instead of cooling coils to dehumidify. Three system alternatives to the existing CAV with cooling coil dehumidification were thereby created: VAV with cooling coil dehumidification, CAV with spray desiccant dehumidification, and VAV with spray desiccant dehumidification. These enhancements were carried out, with their perspective cooling loads as the means of quantifying and comparing them. Other types of energy expenditures, such as for hot water, pumps, and fans, could also be factored in to the total, but they were not included, in an effort to minimize variables and assumptions. With the difficulties in these systems' simulations, using more basic results would hopefully be more reliable. Additionally, including those extra elements would increase economic and energy savings, so the present estimates are conservative.

Results show that VAV with spray desiccant dehumidification is the most energy saving, but the VAV with cooling coil dehumidification has the shortest payback period. An owner would probably favor the shorter payback at first. However, the VAV with spray desiccant dehumidification carries such a large energy saving in operation, that it would still be the wiser choice. The drastic first cost pushes back the payback period, but once it is reached, the money saved just keeps adding and adding. That factor is compounded by the outlook of escalating energy costs in the future. Also, the environmental element is satisfied with the lower energy consumption. With these arguments in mind, I recommend the VAV with spray desiccant dehumidification system.

Acknowledgements

I'd like to thank all those who have helped me in any way with this project. They have taught me that engineering really is a team sport.

Jim Freihaut- Faculty Consultant

Jeff Linde- Newcomb & Boyd

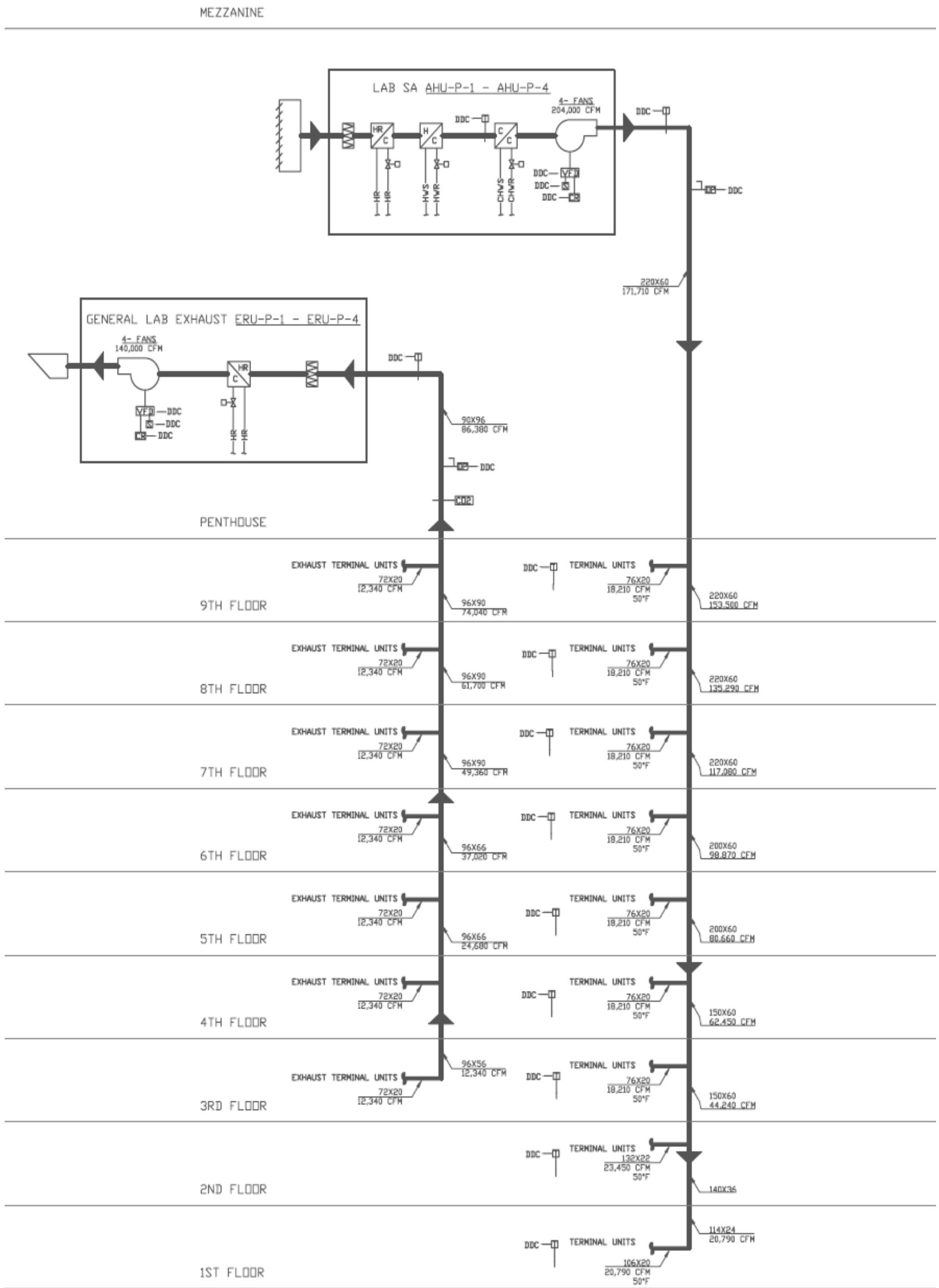
John Shaw- Newcomb & Boyd

The people at Kathabar Systems

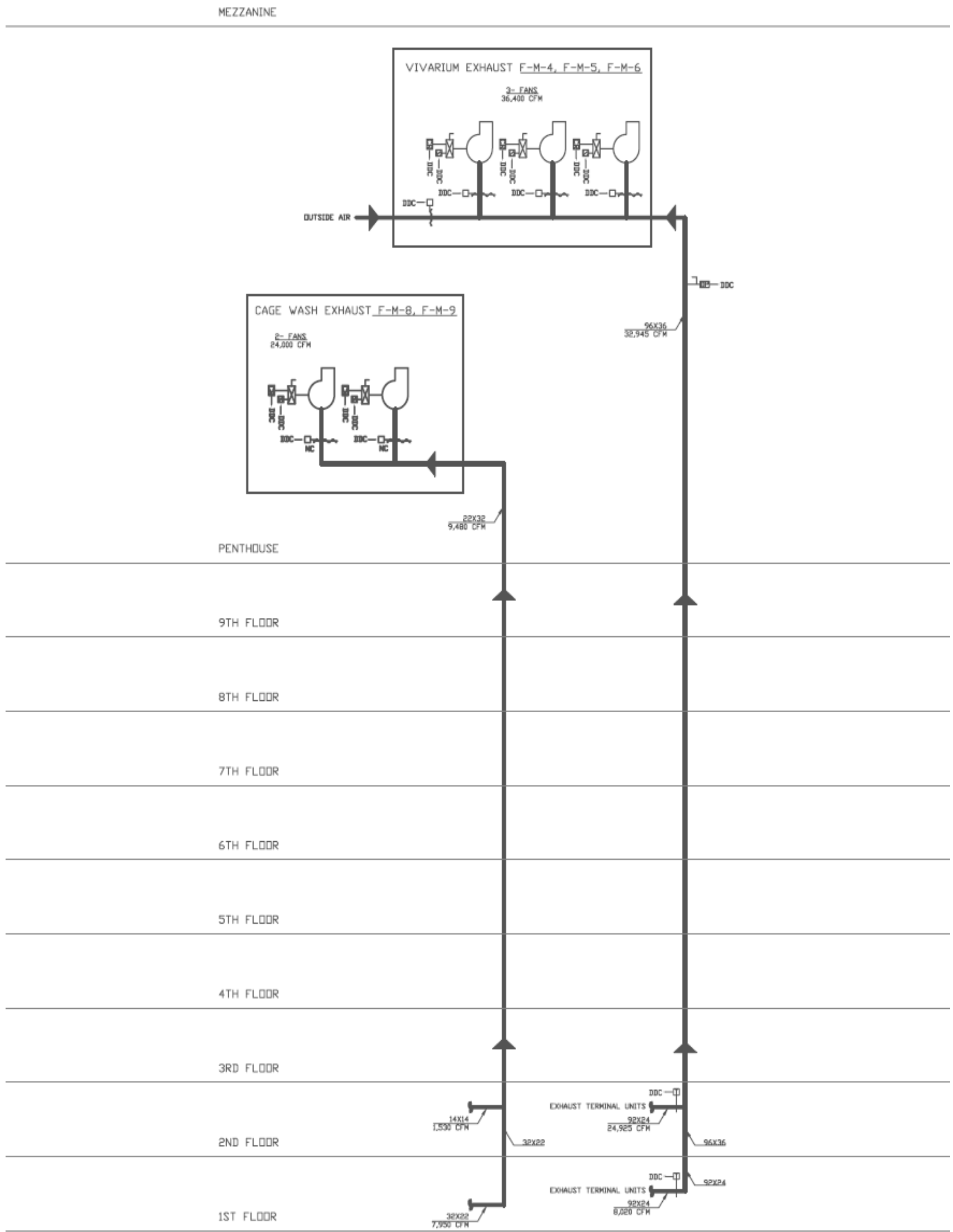
Jonathan Williams- Structural Option

Jennifer Sanborn- Lighting/Electrical Option

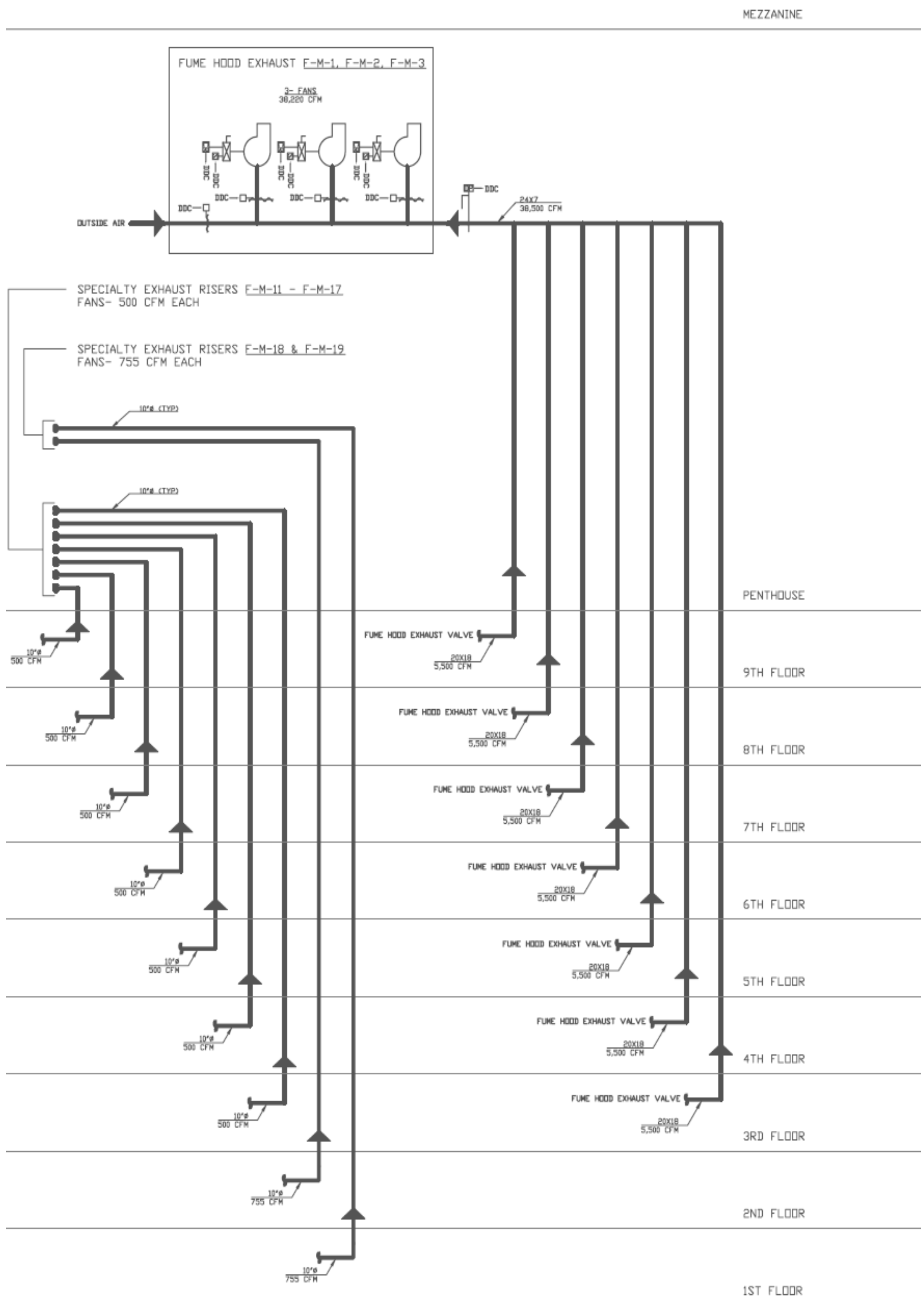
Appendix A
Schematics



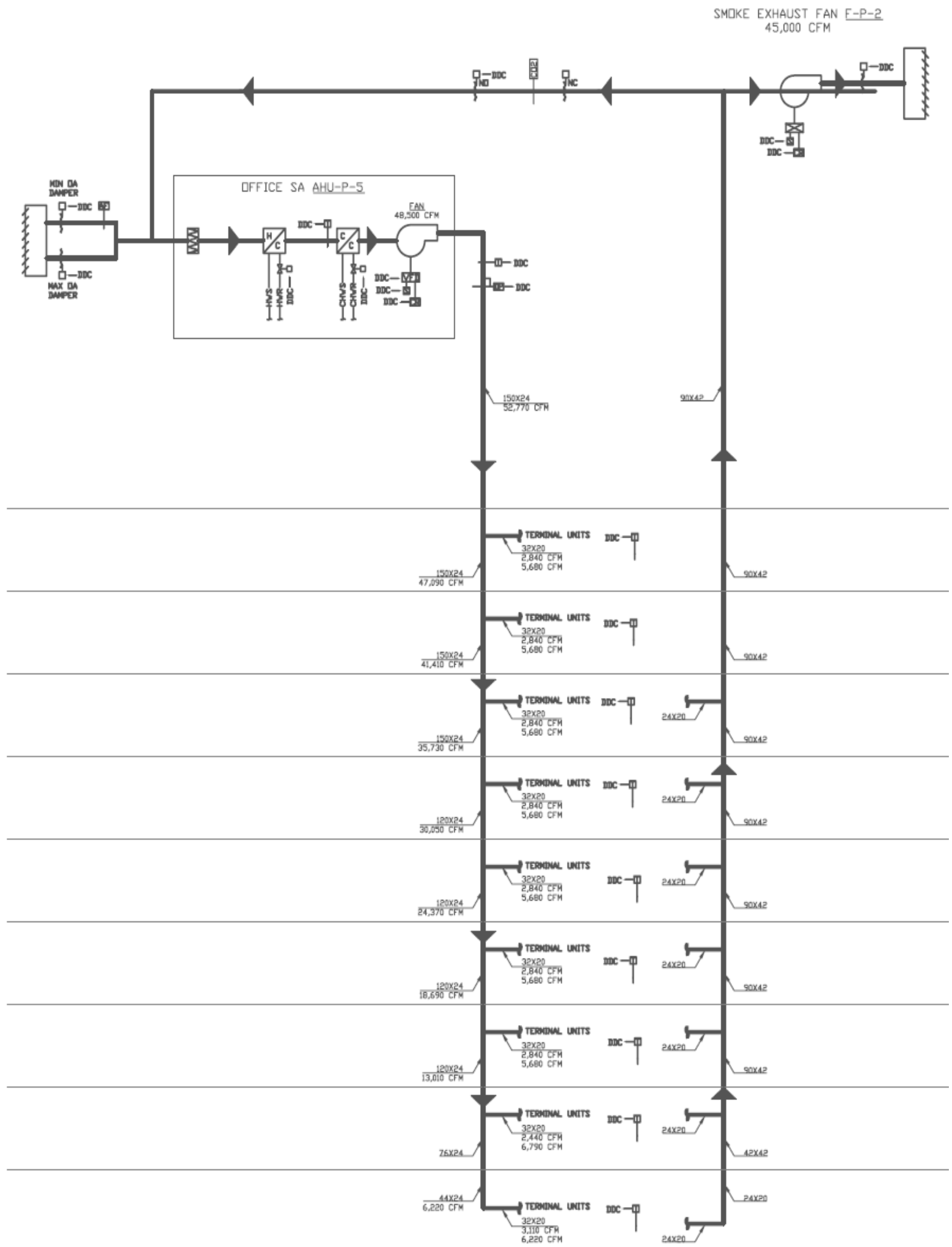
S.5 LAB SUPPLY, GENERAL LAB EXHAUST SCHEMATIC



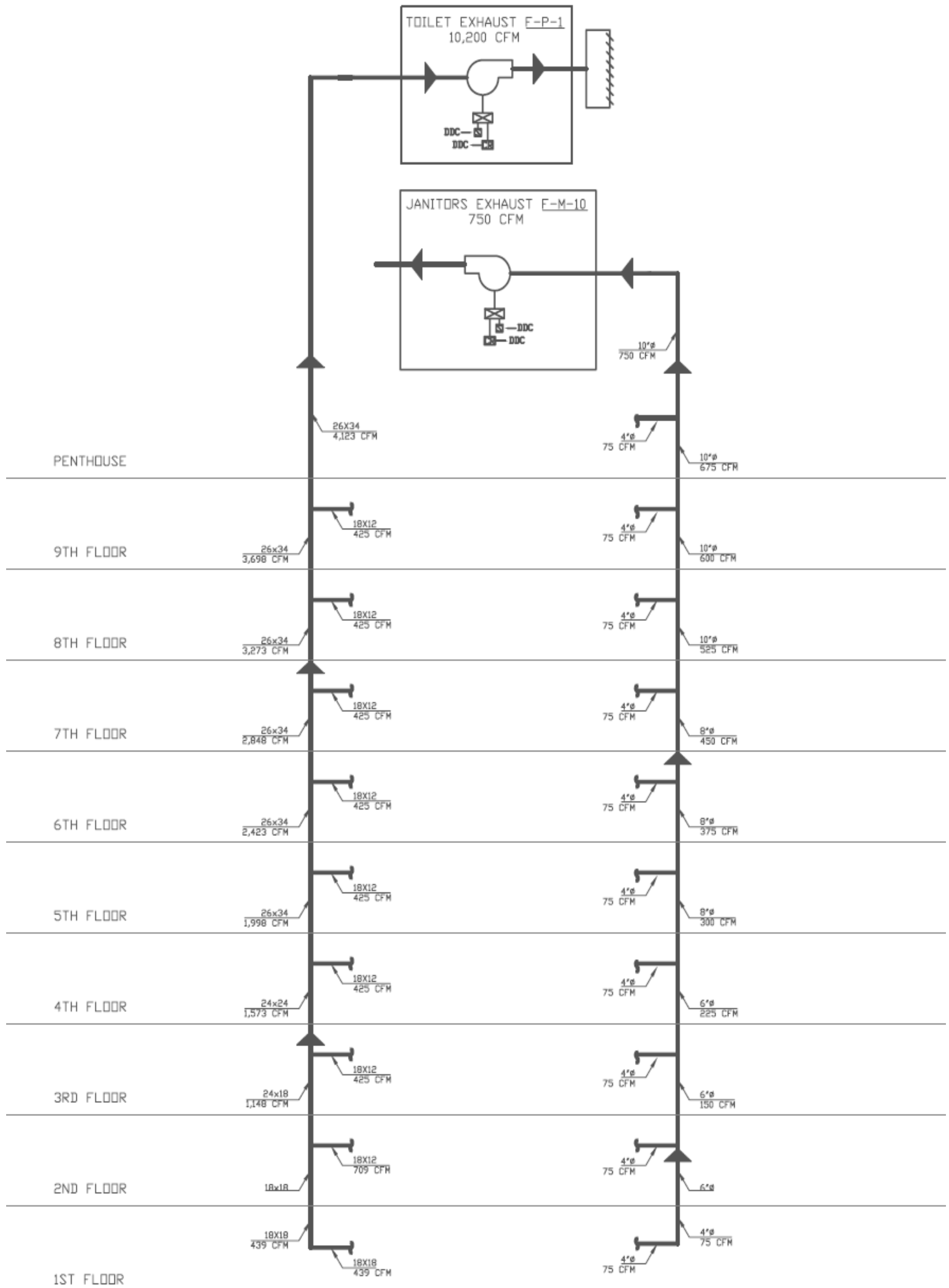
S.6 VIVARIUM, CAGEWASH EXHAUST SCHEMATIC



S.7 FUME HOOD, SPECIALTY EXHAUST SCHEMATIC



S.8 OFFICE SUPPLY, RETURN SCHEMATIC



S.9 TOILET, JANITORS EXHAUST SCHEMATIC

Appendix B
Tables

ZONES	Supply cfm MAX	Flow	SPACE	62.1 Required Ventilation cfm (VAV Min)
3rd-9th				
S914	900	CV	941	199.07
S915	1360	CV	East Elevator Lobby	11.73
S916	470	CV	923	44.425
S917	350	CV	935	29.9
S918	900	CV	941	199.07
S919	850	CV	934.1	27.1
S920	900	CV	941	199.07
S921	720	CV	934	57.1
S922	470	CV	933	42.3
S923	850	CV	932.1	27.1
S924	900	CV	941	199.07
S925	720	CV	932	109.615
S926	650	CV	931	44.3
S927	900	CV	941	199.07
S928	150	W	Electrical	15
S929	470	CV	929	35.1
S930	450	W	Telecom	12.6
S931	200	CV	930	18
S932	330	CV	926,927,928	45.33
S933	670	CV	925	56.7
S934	1000	CV	924	995.35
S935	1000	CV	924	199.07
S936	1000	CV	924	199.07
S937	1000	CV	924	199.07
S938	1000	CV	924	199.07
Per Floor:	18210			3363.28
Total:	127470			23542.96

ZONES	Supply cfm MAX	Flow	SPACE	62.1 Required Ventilation cfm (VAV Min)
2nd				
S214	1840	CV	244	178.2
S215	1360	CV	East Elevator Lobby	11.73
S216	420	CV	246	25.92
S217	190	CV	240	25.39
S218	950	CV	238	21.6
S219	550	CV	248	94
S220	520	CV	235	50.07
S221	510	CV	236	50.07
S222	2100	W	239,243	78.015
S223	530	CV	234	50.07
S224	190	CV	241	25.39
S225	950	CV	230	89.25
S226	190	CV	242	25.39
S227	530	CV	233	50.07
S228	520	CV	232	50.07
S229	510	CV	231	50.07
S230	570	CV	223	53.94
S231	870	CV	219	86.55
S232	530	CV	218	50.97
S233	510	CV	217	50.97
S234	320	CV	225	41.01
S235	330	CV	228	41.01
S236	150	W	Electrical	15
S237	720	CV	226	56.46
S238	450	W	Telecom	12.6
S239	720	CV	229	56.46
S240	380	CV	264	39.9
S241	390	CV	265	39.9
S242	590	CV	261	52.52
S243	390	CV	262	39.9
S244	380	CV	263	39.9
S245	390	CV	260	39.9
S246	380	CV	259	39.9
S247	590	CV	256	52.52
S248	380	CV	257	39.9
S249	390	CV	258	39.9
S250	380	CV	253	39.9
S251	390	CV	254	39.9
S252	590	CV	250	52.52
S253	380	CV	252	39.9
S254	420	CV	251	47.4
Total:	23450			1984.135

ZONES	Supply cfm MAX	Flow	SPACE	62.1 Required Ventilation cfm (VAV Min)
1st				
S112	100	CV	140	10.08
S113	750	CV	133	65.82
S114	750	CV	134	65.82
S115	750	CV	135	65.82
S116	750	CV	136	65.82
S117	1,140	CV	137	93.9
S118	360	CV	138	45.24
S119	1,050	CV	119	35.1
S120	270	CV	139	23.94
S121	240	CV	117	36.6
S122	90	CV	116	13.68
S123	1,000	CV	123	115
S124	800	CV	118	85.8
S125	200	CV	125	7.92
S126	220	CV	143	37.125
S127	230	CV	142	25.74
S128	1,990	CV	131	120.67
S129	1,980	CV	131	120.67
S130	1,980	CV	131	120.67
S131	2,000	CV	129	98.56
S132	2,000	CV	129	98.56
S133	1,360	CV	East Elevator Lobby	11.73
S134	780	CV	N.E.Exit Corridor	27.36
Total:	20,790			1391.625
Total:	171,710			26,918.72

Table 1
Terminal Unit CFM's
CAV/VAV Systems

SPACE		Type	Length (ft)	Width (ft)	Area (sf)	Occupancy	Occupancy	Ra	Rp	Vbz	Room	Ez	Voz
												AHU-P-1 thru 4	
	3rd-9th Floors										3rd-9th		
900.1	Alcove	Corridor	7	6	42	0	0	0.06	0	2.52	900.1	1.0	2.52
925	Auxiliary	Science Laboratory	21	15	315	0	0	0.18	10	56.7	925	1.0	56.7
927	Auxiliary	Science Laboratory	10.5	10.5	110.25	0	0	0.18	10	19.845	927	1.0	19.845
928	Auxiliary	Science Laboratory	10.5	11.5	120.75	0	0	0.18	10	21.735	928	1.0	21.735
930	Auxiliary	Science Laboratory	10	10	100	0	0	0.18	10	18	930	1.0	18
936	Cold Room	Science Laboratory	13	10	130	0	0	0.18	10	23.4	936	1.0	23.4
901	Corridor	Corridor	21	5	105	0	0	0.06	0	6.3	901	1.0	6.3
911	Corridor	Corridor	11	5	55	0	0	0.06	0	3.3	911	1.0	3.3
926	Corridor	Corridor	12.5	5	62.5	0	0	0.06	0	3.75	926	1.0	3.75
	East Elevator Lobby	Lobby	23	8.5	195.5	0	0	0.06	5	11.73		1.0	11.73
	Electrical	Storage	12.5	10	125	0	0	0.12	0	15		1.0	15
923	Equipment	Science Laboratory	23.5	10.5	246.75	0	0	0.18	10	44.415	923	1.0	44.415
929	Equipment	Science Laboratory	26	7.5	195	0	0	0.18	10	35.1	929	1.0	35.1
933	Equipment	Science Laboratory	23.5	10	235	0	0	0.18	10	42.3	933	1.0	42.3
931	Glasswash	Science Laboratory	13.5	10	135	2	2	0.18	10	44.3	931	1.0	44.3
	Janitor	Storage	11	5.5	60.5	0	0	0.12	0	7.26		1.0	7.26
924	Laboratory	Science Laboratory	105	31.5	3307.5	40	40	0.18	10	995.35	924	1.0	995.35
941	Laboratory	Science Laboratory	105	31.5	3307.5	40	40	0.18	10	995.35	941	1.0	995.35
937	Linear Equipment Room	Science Laboratory	129	8	1032	0	0	0.18	10	185.76	937	1.0	185.76
935	Radioisotope	Science Laboratory	10.5	10	105	1	1	0.18	10	28.9	935	1.0	28.9
	Telecom	Storage	10.5	10	105	0	0	0.12	0	12.6		1.0	12.6
932	Tissue Culture	Science Laboratory	20.5	23.5	386.75	4	4	0.18	10	109.615	932	1.0	109.615
932.1	Tissue Culture	Science Laboratory	10	9.5	95	1	1	0.18	10	27.1	932.1	1.0	27.1
934	Tissue Culture	Science Laboratory	20.5	23.5	95	4	4	0.18	10	57.1	934	1.0	57.1
934.1	Tissue Culture	Science Laboratory	10	9.5	95	1	1	0.18	10	27.1	934.1	1.0	27.1
							93					Vot:	2794.53
							651					x7 Floors	19561.71

Note: Floors 3 through 8 (identical to 9) are accounted for in the totaling.

Table 2a

Room Required Ventilation CFMs- 3rd-9th Floors

ASHRAE Std. 62.1-2004

SPACE		Type	Length (ft)	Width (ft)	Area (sf)	Occupancy	Occupancy	Ra	Rp	Vbz	Room	AHU-P-1 thru 4	
												Ez	Voz
	2nd Floor										2nd		
238	Anteroom	Science Laboratory	16	7.5	120	0	0	0.18	10	21.6	238	1.0	21.6
245	Cage Stage	Science Laboratory	18	9	162	0	0	0.18	10	29.16	245	1.0	29.16
244	Clean Cage Storage	Science Laboratory	33	30	990	0	0	0.18	10	178.2	244	1.0	178.2
201	Corridor	Corridor	8.5	5	42.5	0	0	0.06	0	2.55	201	1.0	2.55
214	Corridor	Corridor	21	4.5	94.5	0	0	0.06	0	5.67	214	1.0	5.67
224	Corridor	Corridor	22	8	176	0	0	0.06	0	10.56	224	1.0	10.56
227	Corridor	Corridor	52.5	7	367.5	0	0	0.06	0	22.05	227	1.0	22.05
237	Corridor	Corridor	34	7	238	0	0	0.06	0	14.28	237	1.0	14.28
255	Corridor	Corridor	103	7	721	0	0	0.06	0	43.26	255	1.0	43.26
	East Elevator Lobby	Lobby	23	8.5	195.5	0	0	0.06	0	11.73		1.0	11.73
	Electrical	Storage	12.5	10	125	0	0	0.12	0	15		1.0	15
217	Holding	Science Laboratory	21	11.5	241.5	1	1	0.18	7.5	50.97	217	1.0	50.97
218	Holding	Science Laboratory	21	11.5	241.5	1	1	0.18	7.5	50.97	218	1.0	50.97
223	Holding	Science Laboratory	21.5	12	258	1	1	0.18	7.5	53.94	223	1.0	53.94
226	Holding	Science Laboratory	17	16	272	1	1	0.18	7.5	56.46	226	1.0	56.46
229	Holding	Science Laboratory	17	16	272	1	1	0.18	7.5	56.46	229	1.0	56.46
231	Holding	Science Laboratory	21.5	11	236.5	1	1	0.18	7.5	50.07	231	1.0	50.07
232	Holding	Science Laboratory	21.5	11	236.5	1	1	0.18	7.5	50.07	232	1.0	50.07
233	Holding	Science Laboratory	21.5	11	236.5	1	1	0.18	7.5	50.07	233	1.0	50.07
234	Holding	Science Laboratory	21.5	11	236.5	1	1	0.18	7.5	50.07	234	1.0	50.07
235	Holding	Science Laboratory	21.5	11	236.5	1	1	0.18	7.5	50.07	235	1.0	50.07
236	Holding	Science Laboratory	21.5	11	236.5	1	1	0.18	7.5	50.07	236	1.0	50.07
252	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	252	1.0	39.9
253	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	253	1.0	39.9
254	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	254	1.0	39.9
257	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	257	1.0	39.9
258	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	258	1.0	39.9
259	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	259	1.0	39.9
260	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	260	1.0	39.9
262	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	262	1.0	39.9
263	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	263	1.0	39.9
264	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	264	1.0	39.9
265	Holding	Science Laboratory	15	12	180	1	1	0.18	7.5	39.9	265	1.0	39.9
242	Iso. No. 1	Science Laboratory	9.5	9	85.5	1	1	0.18	10	25.39	242	1.0	25.39
241	Iso. No. 2	Science Laboratory	9.5	9	85.5	1	1	0.18	10	25.39	241	1.0	25.39
240	Iso. No. 3	Science Laboratory	9.5	9	85.5	1	1	0.18	10	25.39	240	1.0	25.39
239	Isolation	Science Laboratory	16.5	6.5	107.25	1	1	0.18	10	29.305	239	1.0	29.305
	Janitor	Storage	11	5.5	60.5	0	0	0.12	0	7.26		1.0	7.26
247	Lobby	Lobby	29	9.5	275.5	2	2	0.06	5	26.53	247	1.0	26.53
248	Necropsy	Science Laboratory	16	10.5	168	1	1	0.5	10	94	248	1.0	94
219	Procedure	Science Laboratory	34.5	19	397.5	1	1	0.18	15	86.55	219	1.0	86.55
225	Procedure	Science Laboratory	17	8.5	144.5	1	1	0.18	15	41.01	225	1.0	41.01
228	Procedure	Science Laboratory	17	8.5	144.5	1	1	0.18	15	41.01	228	1.0	41.01
230	Procedure	Science Laboratory	33	12.5	412.5	1	1	0.18	15	89.25	230	1.0	89.25
250	Procedure	Science Laboratory	24	11	264	1	1	0.18	15	62.52	250	1.0	62.52
256	Procedure	Science Laboratory	24	11	264	1	1	0.18	15	62.52	256	1.0	62.52
261	Procedure	Science Laboratory	24	11	264	1	1	0.18	15	62.52	261	1.0	62.52
251	Quarantine	Science Laboratory	15	12	180	1	1	0.18	15	47.4	251	1.0	47.4
246	Storage/Food	Storage	16	13.5	216	0	0	0.12	0	25.92	246	1.0	25.92
	Telecom	Storage	10.5	10	105	0	0	0.12	0	12.6		1.0	12.6
266	Vestibule	Corridor	13	7	91	0	0	0.06	0	5.46	266	1.0	5.46
243	Work Area	Science Laboratory	14.5	11	159.5	2	2	0.18	10	48.71	243	1.0	48.71
							39					Vot:	2180.915

Table 2b

Room Required Ventilation CFMs- 2^{nd} Floor

ASHRAE Std. 62.1-2004

SPACE		Type	Length (ft)	Width (ft)	Area (sf)	Occupancy	Occupancy	Ra	Rp	Vbz	Room	Ez (AHU-P-1 thru 4)	Voz (AHU-P-1 thru 4)
	1st Floor										1st		
127	Animal Cold Room	Science Laboratory	17	10.5	178.5	0	0	0.18	10	32.13	127	1.0	32.13
139	Animal Prep	Science Laboratory	14	9.5	133	0	0	0.18	10	23.94	139	1.0	23.94
142	Bedding	Storage	17	13	214.5	0	0	0.12	0	25.74	142	1.0	25.74
129	Clean Cagewash Area	Science Laboratory	42	25	984	2	2	0.18	10	197.12	129	1.0	197.12
107	Copy/Work	Storage	10	10	100	0	0	0.12	0	12	107	1.0	
100	Corridor	Corridor	58	8	784	0	0	0.06	0	47.04	100	1.0	
C100	Corridor	Corridor	44	5.5	242	0	0	0.06	0	14.52	C100	1.0	
106	Corridor	Corridor	26	6.5	169	0	0	0.06	0	10.14	106	1.0	
112	Corridor	Corridor	29	5.5	159.5	0	0	0.06	0	9.57	112	1.0	
115	Corridor	Corridor	46.5	8	372	0	0	0.06	0	22.32	115	1.0	22.32
124	Corridor	Corridor	32.5	7	227.5	0	0	0.06	0	13.65	124	1.0	13.65
128	Corridor	Corridor	43	7	301	0	0	0.06	0	18.06	128	1.0	18.06
130	Corridor	Corridor	32	12	384	0	0	0.06	0	23.04	130	1.0	23.04
132	Corridor	Corridor	46.5	7.5	348.75	0	0	0.06	0	20.925	132	1.0	20.925
	Delivery	Shipping/Receiving	73	64	4672	0	0	0.12	0	560.64		1.0	560.64
131	Dirty Cagewash Area	Science Laboratory	65	32	1900	2	2	0.18	10	362	131	1.0	362
	East Elevator Lobby	Lobby	23	8.5	195.5	0	0	0.06	5	11.73		1.0	11.73
	Emergency Elec.		20	16	320	0	0			0		1.0	0
	Fire Pump Room		16	15	240	0	0			0		1.0	0
143	Food	Science Laboratory	17	12.5	206.25	0	0	0.18	10	37.125	143	1.0	37.125
141	Food Cold Room	Science Laboratory	12.5	9	112.5	0	0	0.18	10	20.25	141	1.0	20.25
140	Food Storage	Storage	12	7	84	0	0	0.12	0	10.08	140	1.0	10.08
	FP&L Vault		32	19	608	0	0			0		1.0	0
	Generator Room		32	19	608	0	0			0		1.0	0
133	Holding	Science Laboratory	24	13.5	324	1	1	0.18	7.5	65.82	133	1.0	65.82
134	Holding	Science Laboratory	24	13.5	324	1	1	0.18	7.5	65.82	134	1.0	65.82
135	Holding	Science Laboratory	24	13.5	324	1	1	0.18	7.5	65.82	135	1.0	65.82
136	Holding	Science Laboratory	24	13.5	324	1	1	0.18	7.5	65.82	136	1.0	65.82
137	Holding	Science Laboratory	24	20	480	1	1	0.18	7.5	93.9	137	1.0	93.9
	Janitor	Storage	11	5.5	60.5	0	0	0.12	0	7.26		1.0	7.26
125	Laundry	Storage	11	6	66	0	0	0.12	0	7.92	125	1.0	7.92
	Main Elec.		24	14.5	348	0	0			0		1.0	0
	Main Telecom		14.5	12	174	0	0			0		1.0	0
	N.E.Exit Corridor	Corridor	57	8	456	0	0	0.06	0	27.36		1.0	27.36
123	Necropsy	Science Laboratory	12	17.5	210	1	1	0.5	10	115	123	1.0	115
118	Operating Room	Science Laboratory	20	15.5	310	1	1	0.18	30	85.8	118	1.0	85.8
138	Procedure	Science Laboratory	21	8	168	1	1	0.18	15	45.24	138	1.0	45.24
117	Recovery	Science Laboratory	12	10	120	1	1	0.18	15	36.6	117	1.0	36.6
116	Scrub	Science Laboratory	10	8	76	0	0	0.18	10	13.68	116	1.0	13.68
119	Sterile	Science Laboratory	15	13	195	0	0	0.18	10	35.1	119	1.0	35.1
101.1	Storage	Storage	4	2.5	10	0	0	0.12	0	1.2	101.1	1.0	1.2
	Vivarium Receiving	Shipping/Receiving	34	12.5	425	0	0	0.12	0	51		1.0	51
							13					Vot:	2162.09
												Total Vot (cfm):	23,905

Table 2c

Room Required Ventilation CFMs- 1st Floor and Total

ASHRAE Std. 62.1-2004

% Total Load	CAV Cooling Load			VAV Cooling Load			Totals	
	tons	hours	%	tons	hours	%	CAV Cooling	VAV Cooling
0--5	16.325	0	0%	16.325	0	0%	0	0
5--10	48.975	0	0%	48.975	0	0%	0	0
10--15	81.625	0	0%	81.625	115	0%	0	9386.875
15--20	114.275	0	0%	114.275	360	1%	0	41139
20--25	146.925	0	0%	146.925	296	4%	0	43489.8
25--30	179.575	6	0%	179.575	1036	3%	1077.45	186039.7
30--35	212.225	65	0%	212.225	934	12%	13794.625	198218.15
35--40	244.875	214	1%	244.875	1192	11%	52403.25	291891
40--45	277.525	285	2%	277.525	1078	14%	79094.625	299171.95
45--50	310.175	386	3%	310.175	1197	12%	119727.55	371279.475
50--55	342.825	548	4%	342.825	828	14%	187868.1	283859.1
55--60	363.721	1174	6%	363.721	367	9%	427008.454	133485.607
60--65	408.125	1325	13%	408.125	180	4%	540765.625	73462.5
65--70	440.775	1327	15%	440.775	83	2%	584908.425	36584.325
70--75	473.425	1174	15%	473.425	122	1%	555800.95	57757.85
75--80	506.075	898	13%	506.075	170	1%	454455.35	86032.75
80--85	538.725	1223	10%	538.725	270	2%	658860.675	145455.75
85--90	571.375	135	14%	571.375	187	3%	77135.625	106847.125
90--95	604.025	0	2%	604.025	170	2%	0	102684.25
95--100	653.00	0	0%	653.00	175	2%	0	114275
Hours off	0	0	0%	0	0	2%	0	0
		8760			8760			

Yearly Load Btu:	**45,034,808,448**	**30,972,722,484**

Table 4
Yearly Energy Consumption
CAV/VAV Systems

% Total Load	CAV Cooling Load			VAV Cooling Load			Totals	
							CAV	VAV
	tons	hours	%	tons	hours	%	Cooling	Cooling
0--5	6.19375	0	0%	6.19375	0	0%	0	0
5--10	18.58125	0	0%	18.58125	0	0%	0	0
10--15	30.96875	0	0%	30.96875	115	0%	0	3561.40625
15--20	43.35625	0	0%	43.35625	360	1%	0	15608.25
20--25	55.74375	0	0%	55.74375	296	4%	0	16500.15
25--30	68.13125	6	0%	68.13125	1036	3%	408.7875	70583.975
30--35	80.51875	65	0%	80.51875	934	12%	5233.71875	75204.5125
35--40	92.90625	214	1%	92.90625	1192	11%	19881.9375	110744.25
40--45	105.2938	285	2%	105.2938	1078	14%	30008.71875	113506.6625
45--50	117.6813	386	3%	117.6813	1197	12%	45424.9625	140864.4563
50--55	130.0688	548	4%	130.0688	828	14%	71277.675	107696.925
55--60	137.9968	1174	6%	137.9968	367	9%	162008.1845	50644.80725
60--65	154.8438	1325	13%	154.8438	180	4%	205167.9688	27871.875
65--70	167.2313	1327	15%	167.2313	83	2%	221915.8688	13880.19375
70--75	179.6188	1174	15%	179.6188	122	1%	210872.4125	21913.4875
75--80	192.0063	898	13%	192.0063	170	1%	172421.6125	32641.0625
80--85	204.3938	1223	10%	204.3938	270	2%	249973.5563	55186.3125
85--90	216.7813	135	14%	216.7813	187	3%	29265.46875	40538.09375
90--95	229.1688	0	2%	229.1688	170	2%	0	38958.6875
95--100	247.75	0	0%	247.75	175	2%	0	43356.25
Hours off	0	0	0%	0	0	2%	0	0
		8760			8760			

Yearly Load Btu:	17,086,330,464	11,751,136,287

Table 6
Yearly Energy Consumption
Kathabar CAV/VAV Systems

Penthouse Floor

	Weight	Area	Weight	Load	Width	Linear Load	Mu		Vu		Columns		PLF	
							Load Factors							
							1	2	1	2	1	2	1	2
							1.4 dead	1.2 Dead + 1.6 live	1.4 dead	1.2 Dead + 1.6 live	1.4 dead	1.2 Dead + 1.6 live	1.4 dead	1.2 Dead + 1.6 live
	lb	sf	pcf	psf	ft	PLF	PLF	PLF	kip	kip	kip	kip	kip	kip
AHU's	80000	462		173.1602	5.25	909.09	1272.727	1090.909091	12.09091	10.36364	70.64242	60.55065	1272.727	1090.909
Conditioners	22500	210		107.1429	5.25	562.50	787.5	675	6.559875	5.62275	26.25	22.5	787.5	675
Dead			150	75	5.25	393.75	551.25	472.5	18.19125	15.5925	74.41875	63.7875	551.25	472.5
Live				20	5.25	105.00	0	168	0	5.544	0	22.68	0	168
Joists			150			100.00	140	120	4.62	3.96	16.94	14.52		
						Total	691.25	760.5	41.46203	41.08289	188.2512	184.0381	2,611.48	2,406.41
								Column Pressure (ksi) :			0.326825	0.319511	1823.977	1731.409
													1338.75	1315.5

Roof

	Weight	Area	Weight	Load	Width	Linear Load	1.4 dead	1.2 Dead + 1.6 live	1.4 dead	1.2 Dead + 1.6 live	1.4 dead	1.2 Dead + 1.6 live
	lb	sf	pcf	psf	ft	PLF	PLF	PLF	kip	kip	kip	kip
Regenerator	1600	14.38889		111.1969	7	778.38	1089.73	934.0540541	3.378162	2.895568	45.36389	38.88334
Dead			150	45	7	315.00	441	378	9.261	7.938	44.65125	38.2725
Live				20	7	140.00	0	224	0	4.704	0	22.68
Joists						22.00	30.8	26.4	0.6468	0.5544	3.7268	3.1944
						Total	471.8	628.4	13.28596	16.09197	93.74194	103.0302
								Column Pressure (ksi) :			0.195296	0.214646

Table 8
Structural Loads

Uniformly Distributed Loads

Penthouse Floor

	w	l	x	M-max (center)	Mx	R
	kips/ft	ft	ft	kip-ft	kip-ft	kip
1	0.69125	33	16.5	94.10	94.09641	11.40563
2	0.7605	33	16.5	103.52	103.5231	12.54825

Roof

	w	l	x	M-max (center)	Mx	R
	kips/ft	ft	ft	kip-ft	kip-ft	kip
1	0.4718	21	10.5	26.01	26.00798	4.9539
2	0.6284	21	10.5	34.64	34.64055	6.5982

Uniform Loads Partially Distributed

Conditioner

	w	l	a	b	c	x	R1	R2
	kips/ft	ft	ft	ft	ft	ft	kips	kips
1	0.7875	33	3.5	8.33	21.17		5.03619494	1.52368
2	0.675	33	3.5	8.33	21.17		4.31673852	1.306011

AHU

	w	l	a	b	c	x	R1	R2
	kips/ft	ft	ft	ft	ft	ft	kips	kips
1	1.27272727	33	23.5	9.5	0		1.74035813	10.35055
2	1.09090909	33	23.5	9.5	0		1.49173554	8.871901

Regenerator

	w	l	a	b	c	x	R1	R2
	kips/ft	ft	ft	ft	ft	ft	kips	kips
1	1.08972973	21	9	3.1	9		1.69712432	1.697124
2	0.93405405	21	9	3.1	9		1.45467799	1.454678

Table 9
Moment/Reaction Calculations
Joists

Conditioner Unit Pump
15 HP Motor
480V 3ph 3W

Reference	Factors	Outcome
NEC Table 430-150	15 HP	21 Amp FLC
	480 V	
NEC Table 430-152	Non-time delay fuse	250% FLC
	Reduced Voltage Starting	
		= 52.5 Amp FLC
NEC Table 7-1	52.5 Amp FLC	60 A Fuse
NEC Table 250-95	52.5 Amp FLC	60 A Ckt Bkr
NEC Table 13.4	480 V	60 A/30 A Switch Size
	Non-time delay fuse	
	15 HP	
NEC 310-16	FLC = 21 A x 1.25 = 26.25 A	#10 THW AL
Conduit Table	#10 THW AL	1/2" Conduit
	3 W	

Regenerator Unit Pump/Fan
2 x 1.5 HP Motors
480V 3ph 3W

Reference	Factors	Outcome
NEC Table 430-150	1.5 HP	3 Amp FLC
	480 V	
NEC Table 430-152	Non-time delay fuse	250% FLC
	Reduced Voltage Starting	
		= 7.5 Amp FLC
NEC Table 7-1	7.5 Amp FLC	20 A Fuse
NEC Table 250-95	7.5 Amp FLC	20 A Ckt Bkr
NEC Table 13.4	480 V	
	Non-time delay fuse	
	1.5 HP	
NEC 310-16	FLC = (3 A x 1.25) + 3 = 7 A FLC	#12 THW AL
Conduit Table	#12 THW AL	1/2" Conduit
	3 W	

Table 11
Circuit Design Steps
Regenerator and Conditioner Units

Appendix C
Calculations

Kathabar Equipment Performance and Utilities Requirements

Outside air requirements	26,891.00	SCFM				
Outside air summer design	91	DB	77	WB		
Post economizer air	81	DB	74.5	WB		
Space maintained conditions	75	F	50%	R.H.	64	Gr.Lb
Internal Sensible Load	2,160,000.00	BTU/Hr				
Internal Latent Load	210,960.00	BTU/Hr				
Maximum diffusion temperature difference	20	F				
Available Coolant	44	F chilled water				
Available Heat source	180	F hot water				

A.

Determine conditioner leaving air temperature and flow

Leaving temperature = 75 - 20

= 55 F

Airflow = 2,160,000.00 / 1.08 x 20 F

= 100,000.00 SCFM

B.

Select conditioner size from engineering data table, Page 10

2 x unit size 4000's will handle 96,000 SCFM

C.

Determine maximum diffusion humidity difference

Difference = 210,960.00 / 0.68 x 100,000.00

= 3.10 Gr/Lb

D.

Determine conditioner leaving air humidity

Leaving air humidity = 64 - 3.10 Gr/Lb

= 55.00 Gr/Lb

E.

Check conditioner leaving air temperature and humidity

At 55F DBT and 55 Gr/Lb W, the condition falls just within the range of the Kathabar System.

Calculation 1

Kathabar System

F.
Determine air temperature and humidity entering conditioner.

100% OA situation

Post economizer conditions: **72** F DB **71** F WB **115** Gr/Lb

G.
Determine maximum coolant supply temperature

Air temperature depression =	72	-	55	F
=	**17**	F		
Air humidity depression =	115	-	55.00	Gr/Lb
=	**60.00**	Gr/Lb		
FV Approach:	**11**	F		
Coolant temperature =	55	-	11	F
=	**44**	F		
FH Approach:	**15**	F		
Coolant temperature =	55	-	15	F
=	**40**	F		

The FV approach works because of the available 44F chilled water from the campus plant.

H.
Determine the design moisture removal (MR) load

MR =	60.00	x 0.643 x	3.72
=	**143.47**	Lbs/Hr	

*used SA/requiredOA

I.
Deteremine regenerator capacity

Air leaving conditioner:	**55**	F	**55.00**	Gr/Lb
	80%	RH		
Regenerator capacity =	**77**	Lbs/Hr/sf		

J.
Calculate minimum regenerator face area

Min. Face area =	143.47	/	77
=	**1.86**	sf	

Calculation 1
Kathabar System
(continued)

K.
Select regenerator with sufficient face area

3 FP Regenerator with 3 sf face area

L.
Determine regenerator load

Regenerator load =	143.47	/	3	
=	**47.82**	Lbs/Hr/sf		

M.
Determine regenerator heat requirements

Regenerator load =	47.82	Lbs/Hr/sf		
Conditioner leaving humidity =	80%	RH		
Conditioner leaving temp. =	55	F		
Regenerator heat input =	1,350.00	x	143.47	
=	**193,681.90**	BTU/Hr		
=	**16.14**	tons		

N.
Determine conditioner cooling load

Sensible cooling load =	100,000.00	x 1.08 x	17	
=	**1,836,000.00**	BTU/hr		

Latent cooling load:

Regenerator load =	47.82	Lbs/Hr/sf		
Conditioner leaving humidity =	80%	RH		
Conditioner leaving temp. =	55	F		
L Factor =	**1150**	BTU/LB MR		
Latent cooling load =	143.47	x	1150	
=	**164,988.29**	BTU/hr		
Total Cooling Load =	1,836,000.00	+	164,988.29	BTU/Hr
=	**2,000,988.29**	BTU/Hr		
=	**166.75**	tons		

Calculation 1
Kathabar System
(continued)

Electrical

	Item	Unit	#	Cost	Total
Conductors	#12 THW AL	CFL	0.62	$ 50.00	$ 31.00
	#10 THW AL	CFL	0.87	$ 58.00	$ 50.46
Conduit	1/2" AL	LF	62	$ 6.85	$ 424.70
Ckt Bkrs	15 HP Motor	each	2	$ 535.00	$ 1,070.00
	60 A	each	2	$ 650.00	$ 1,300.00
Switches	30 A	each	3	$ 385.00	$ 1,155.00
	60 A	each	4	$ 495.00	$ 1,980.00
				Total	$ 6,011.16

Structural

	Rect. Beam	A (s.i.)	Length (ft.)	cubic ft.	Unit	#	Cost	Total
Penthouse Joists	12RB28	336	33	77	each	11	$ 1,000.00	$ 11,000.00

Calculation 2
Economic Analysis

Mechanical

VAV System

	#	Part	Unit	Cost	VAV/Kathabar	VAV Only
(Existing) HW Piping	-2005	Pipe, copper, tubing, solder, 1-1/2", coupling & clevis hanger	LF	$ 16.95	($33,984.75)	$ -
	-1434	Elbow, 90 Deg., copper, wrought, copper x copper, 1-1/2"	each	$ 44.00	($63,096.00)	$ -
	-422	Tee, copper, wrought, copper x copper, 1-1/2"	each	$ 74.50	($31,439.00)	$ -
VAV Boxes	76	300-600 cfm	each	$ 390.00	$29,640.00	$ -
	54	500-1000 cfm	each	$ 425.00	$22,950.00	$ -
	1	1100-2000 cfm	each	$ 460.00	$460.00	$ -
					($75,469.75)	$ -
(Existing) CAV Terminal Units	-22	200 cfm	each	$ 730.00	($16,060.00)	($16,060.00)
	-31	400 cfm	each	$ 745.00	($23,095.00)	($23,095.00)
	-44	600 cfm	each	$ 745.00	($32,780.00)	($32,780.00)
	-36	800 cfm	each	$ 785.00	($28,260.00)	($28,260.00)
	-89	1000 cfm	each	$ 785.00	($69,865.00)	($69,865.00)
	-1	1250 cfm	each	$ 885.00	($885.00)	($885.00)
	-9	1500 cfm	each	$ 885.00	($7,965.00)	($7,965.00)
	-7	2000 cfm	each	$ 1,025.00	($7,175.00)	($7,175.00)
VAV Terminal Units with Reheat	23	200 cfm	each	$ 975.00	$22,425.00	$22,425.00
	15	400 cfm	each	$ 1,025.00	$15,375.00	$15,375.00
	24	600 cfm	each	$ 1,025.00	$24,600.00	$102,500.00
	12	800 cfm	each	$ 1,100.00	$13,200.00	$72,600.00
	31	1000 cfm	each	$ 1,100.00	$34,100.00	$34,100.00
	3	1250 cfm	each	$ 1,225.00	$3,675.00	$4,900.00
					($72,710.00)	
				Total	**($148,179.75)**	**$65,815.00**

Kathabar System

	#	Part	Unit	Cost	Total
Conditioner Unit	2	4000FV Unit size, 48,000 cfm	each	$ 156,000.00	$312,000.00
Regenerator Unit	1	3FP Unit size, 1,200 acfm	each	$ 80,000.00	$80,000.00
				Total	**$ 392,000.00**

Calculation 2

Economic Analysis

(continued)

Economic

CAV-VAV

System Enhancement 1st Cost	$65,815.00

		Cooling Load (MMBtu)	COP (kW/ton)	kWhr	Cost ($/kWhr)
Existing Yearly Operational Cost	$53,636.69	45,035	0.6	2,251,750.00	$0.02
Enhanced System Operational Cost	$36,888.84	30,973		1,548,650.00	

	Simple	NPV
Pay-Back Period	**3.93**	**5**

CAV-Kathabar CAV

System Enhancement 1st Cost	$409,011.16

		Cooling Load (MMBtu)	COP (kW/ton)	kWhr	Cost ($/kWhr)
Existing Yearly Operational Cost	$53,636.69	45,035	0.6	2,251,750.00	$0.02
Enhanced System Operational Cost	$20,349.43	17,086		854,300.00	

	Simple	NPV
Pay-Back Period	**12.29**	**20**

CAV-Kathabar VAV

System Enhancement 1st Cost	$260,831.41

		Cooling Load (MMBtu)	COP (kW/ton)	kWhr	Cost ($/kWhr)
Existing Yearly Operational Cost	$53,636.69	45,035	0.6	2,251,750.00	$0.02
Enhanced System Operational Cost	$13,995.44	11,751		587,550.00	

	Simple	NPV
Pay-Back Period	**6.58**	**9**

Calculation 2
Economic Analysis
(continued)

CAV-VAV

Interest Rate	NPV	Costs	Years
5%	$6,375.61	($65,815.00)	--
		$16,747.84	1
		$16,747.84	2
		$16,747.84	3
		$16,747.84	4
		$16,747.84	5

CAV-Kathabar CAV

Interest Rate	NPV	Costs	Years				
5%	$5,544.44	($409,011.16)					
		$33,287.26	1	$33,287.26	9	$33,287.26	17
		$33,287.26	2	$33,287.26	10	$33,287.26	18
		$33,287.26	3	$33,287.26	11	$33,287.26	19
		$33,287.26	4	$33,287.26	12	$33,287.26	20
		$33,287.26	5	$33,287.26	13		
		$33,287.26	6	$33,287.26	14		
		$33,287.26	7	$33,287.26	15		
		$33,287.26	8	$33,287.26	16		

CAV-Kathabar VAV

Interest Rate	NPV	Costs	Years		
5%	$19,934.75	($260,831.41)			
		$39,641.24	1	$39,641.24	9
		$39,641.24	2		
		$39,641.24	3		
		$39,641.24	4		
		$39,641.24	5		
		$39,641.24	6		
		$39,641.24	7		
		$39,641.24	8		

Calculation 2
Economic Analysis
(continued)