depth 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. Counter-flow 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.

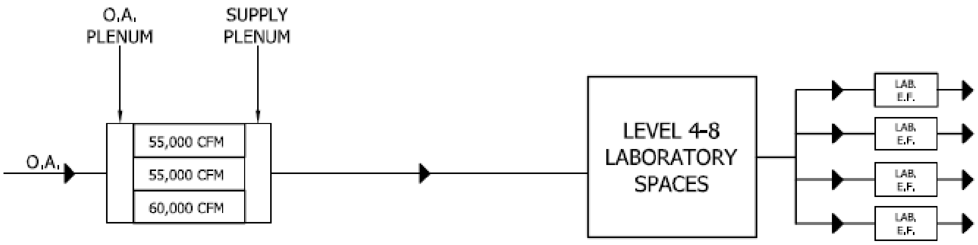


Figure 11: Redesign System 2 Schematic

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).

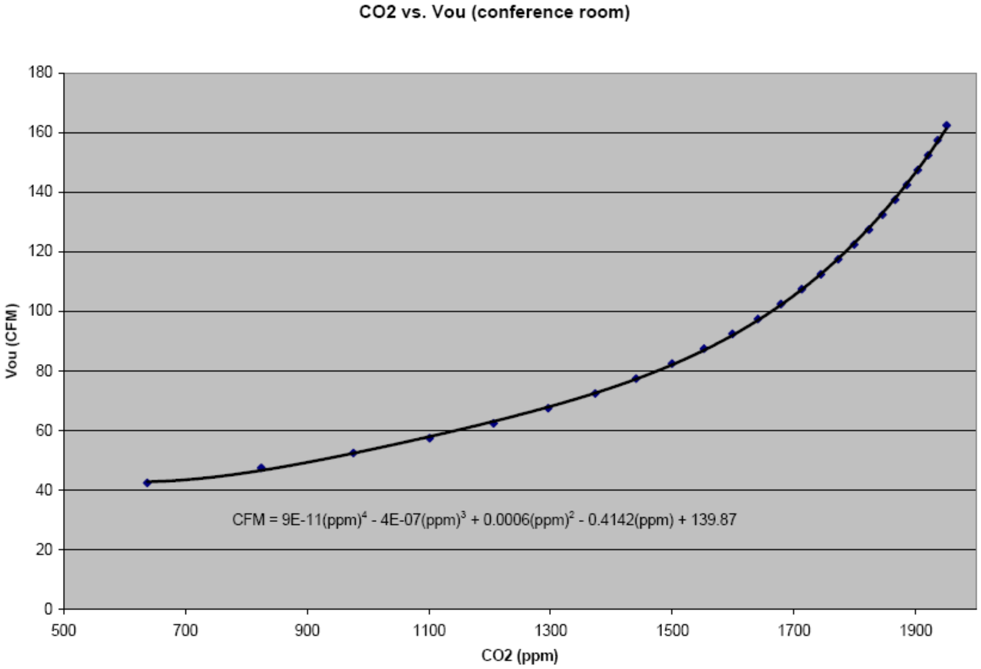


Figure 12

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.

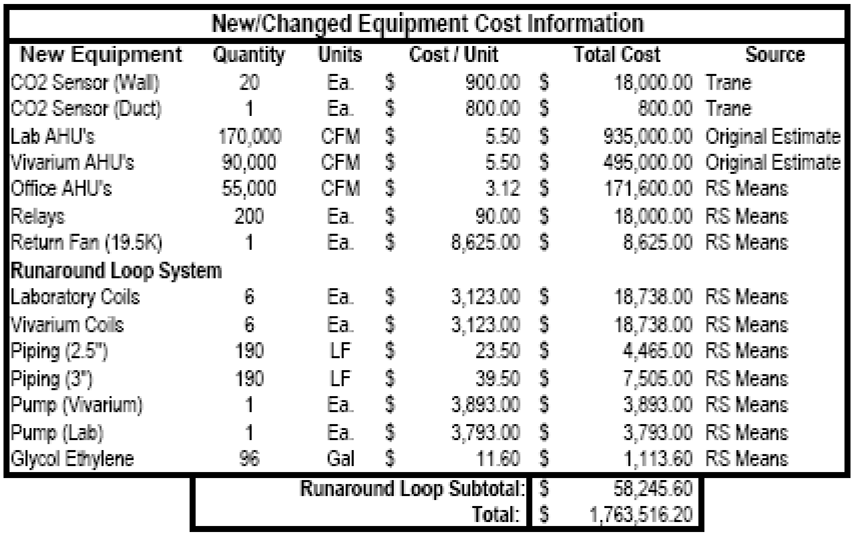
Load calculations had been ran to determine the design supply air for each space in the office side of levels 4-8. The new zoning scheme requires a unit that could supply 55,000 CFM to the office spaces (the load calculation spread sheets can be seen in Appendix B of this report). An air handling unit 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.

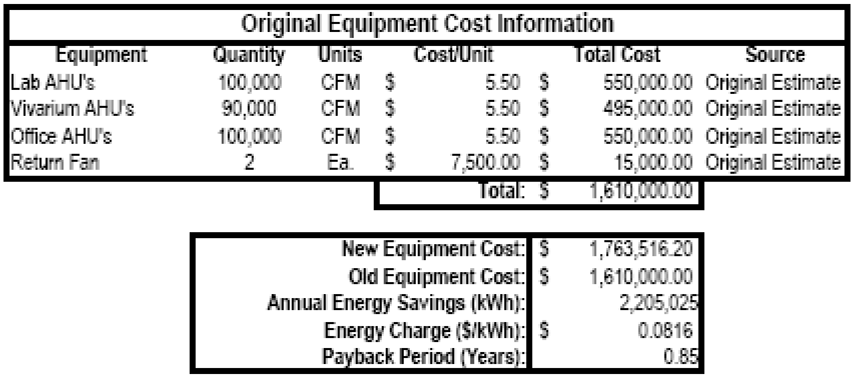
Cost Analysis

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.