MONGOMERY COLLEGE

Geothermal Systems with Chilled Beams

Final Report

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EXECUTIVE SUMMARY

The Montgomery College New Science Center is a direct expansion to the East Science Center located in Rockville, Maryland, a mixed-humid environment, consisting of laboratories, offices, and classrooms on every floor. In a mixed environment, both heating and cooling must be designed and integrated into the HVAC system.

Although the engineer's design accomplished all the design goals, an alternative system for this report was developed with improving the energy efficiency as the main design goal. The existing mechanical system consists of a central air handling system, central hot water system, central chilled water system, and a laboratory exhaust system. This HVAC system is a fairly typical system for laboratory buildings. Overall the New Science Center HVAC design fulfills the university's design needs and requests, but leaves room to increase the performance of the system to potentially further the energy reductions, decrease the emissions, and reduce the mechanical space needed.

This report develops and compares an open loop geothermal system coupled with chilled beams with the original design. The new design replaces the boilers, chillers, cooling tower, and air handling units, with various heat pumps. Three types of heat pumps were used. DOAS heat pumps are used to condition the laboratory and classroom ventilation air to room neutral, while water-to-water heat pumps serve chilled beams to provide space cooling and heating. The remaining heat pumps condition and supply the air to the offices.

In addition to the mechanical system redesign, both the lighting and acoustics were assessed for this report. The lighting was developed with the same energy efficiency goal as the mechanical system. Earth- Friendly-Troffers were chosen for their energy efficiency. The new lights saved 12.96% of the energy attributed to the lights. The light schedules were also altered from the original design by anticipating occupancy, maintained by occupancy schedules. The acoustics of a typical laboratory, classroom, and office were analysis based on the reverberation times, and the new active chilled beams were acoustically evaluated.

As a result of the system redesign, the energy was reduced another 27.75%, obtained two additional energy and atmosphere LEED credits, and improved the room acoustics. The new system increased in complexity and therefore increased the initial cost $2 million. With the decreased energy costs and increased initial system cost.

BUILDING BACKGROUND

Montgomery College New Science Center is a 140,700 square foot college laboratory located on the southwest sector of the Rockville Maryland Campus. The four story building is a direct addition to Science East which is also bridge connected to Science West. Each floor contains laboratories, classrooms, and offices. The majority of the building is for educational purposes. The new, bigger laboratories will allow the professors to conduct experiments they were unable to perform before and increasing the class size at the same time.

The New Science Centers transitions and gathering spaces were also designed in detail. The northwest entrance opens up to a four story atrium over looked by the roof observatory. This atrium is used as a transition to the existing Science East building and a student gathering space. A green roof surrounds the roof observatory. The observatory will be used for educational purposes, equipped with a power switch operated sliding roof. On the northeast entrance there is a small exterior amphitheatre. The amphitheatre's main purpose is to provide the students with a place to sit read and gather while keeping in touch with nature. It will also be used to tie in the existing pond. Towards the buildings LEED Gold goal, the pond will be used for water retention, collecting roof water runoff.

The New Science Center's façade transitions the existing east and west science center to a more modern feel. Some brick was used to tie the old in with the new but with building most consists of metal panels and glass.

Figure 1: Building 3D Sketch

INDOOR DESIGN CONDITIONS

The indoor design conditions used by BurtHill can be found in Table 1. These conditions were used to model The New Science Center's HVAC system within IES <VE>.

Space type	Summer Temperature Set-point & RH	Winter Temperature Set-point
Laboratories and Laboratory Support	74°F 50% +/- 5%	72°F
Classroom/Lecture Spaces	74°F 50% +/- 5%	72°F
Office and Office Support	74°F 50% +/- 5%	72°F
Conference, Lounge	74°F 50% +/- 5%	72°F
Telecommunication Spaces	74°F 50% +/- 5%	68°F
Mechanical Spaces	98°F (max)	60°F
Atrium	78°F 50% +/- 5%	68°F

Table 1: Indoor Design

The summer temperature set-point is kept higher than the winter temperature set-point by two degrees to save energy while maintaining air conditions within the thermal comfort zone. The mechanical space will typically be kept unoccupied. Maintaining the thermal comfort level for the mechanical spaces is therefore not as important and the set-points allow for much more flexibility, saving energy. The atrium and telecommunication spaces need to maintain thermal conditions but with less restrictions than typical spaces.

OUTDOOR AIR

The external design conditions used to determine load, energy use and size equipment were found in the ASHRAE Fundamentals Handbook, 2005 edition. Refer to Appendix A - ASHRAE DESIGN CONDITIONS for further detail on the location weather data.

Building location: Baltimore Maryland

Latitude: 39.17 N

Longitude: 76.67 W

Elevation: 154

Summer Outdoor Air Conditions:

The summer design conditions are based on only 1% of the summer design conditions as opposed to the typical 0.4% since the New Science Center will not typically be occupied over the summer months.

Design Dry Bulb	90.9ºF	Design Wet Bulb	76.9ºF
Mean coincident wet bulb	74.3ºF	Mean coincident dry bulb	86.4ºF

Table 2: Summer Outdoor Air Design

Winter Outdoor Air Conditions:

The winter design conditions are based an 99% of the annual percentile.

Design Dry Bulb 16.7ºF

The outdoor design wet bulb temperature for the cooling towers is 78 º F.

Design Conditions:		
Summer		Winter
Dry Bulb	Wet Bulb	Dry Bulb
92ºF	76ºF	14ºF

Table 3: Designer's Seasonal Design

DESIGN OBJECTIVES AND REQUIREMENTS

The Montgomery College New Science Center is intended to be used for general college level classes, college laboratories, and offices. The laboratory design requires the most attention to design and restrictions.

The mechanical system was designed with the following objectives:

- Energy Efficiency – LEED Silver
- Control Air-born Laboratory Contaminants
- Proper Laboratory Ventilation
- Maryland State Building

Anticipated Expansion

The Montgomery College New Science Center chilled and hot water systems were designed for future expansion. Proper piping will be installed and capped where potential additions will be made. The equipment to be installed for Phase I (The New Science Center) was also designed with the intent to be paired with the future equipment in the Phase II expansion.

Energy Efficiency

An energy model was performed using the software, IES.VE. Several alternatives were considered in the design process with the goal of energy efficiency, affordability, maintainability. In order to achieve energy efficiency a geothermal system coupled with chilled beams was selected based on case studies and end results.

Laboratory Ventilation and Contaminant Control

All laboratories are maintained at negative pressure. Negatively pressurizing the laboratories isolates the contaminants to the room and prevents them from exiting or mixing with any return air. Make-up air is transferred from the positively pressurized office area to the laboratory area to further isolate the office area from contaminants. To ensure proper ventilation, all laboratories contain localized fume hoods and are supplied ventilation air by the DOAS heat pump.

The complete ventilation calculations can be found in Appendix E- DESIGNER'S VENTILATION RATES.

ENERGY MODEL

In order to accomplish energy and load analysis IES.VE, an energy and load simulation program, was used. Both the original calculation by the engineers and the calculation completed for this report were done using the energy modeling program IES.VE. This original analysis was done in the efforts to complete an in depth understanding of both the designer's HVAC systems and the building itself, along with the associated loads in order to complete a comprehensive and educated redesign of the system.

IES.VE 5.8.5, Integrated Environmental Solution Virtual Environment was selected based level of accuracy and integration the software can provide. This program allows for a high degree of energy simulation sophistication often necessary with laboratory systems and larger buildings.

When modeling the energy and loads of a building, the more variables taken into account, the more accurate and realistic the results will be. IES.VE is one of the most inclusive programs out there today. The amount of information that can be modeled is the reason IES.VE was chosen for this energy and load analysis. Some of variable used to calculate the energy and loads of the building include:

- Façade Constructions
- Wall construction and associated location (R and U values assigned)
- Window type and associated location (SHGC, Shading Coefficient, R and U values assigned)
- Roof, floor construction and associated location (R and U values assigned)
- Interior partitions
- Ground exposed floors
- Doors
- Internal windows
- Skylights
- Location associated weather files (provides a typical weather file for the location selected on an hour by hour basis)
- Solar files based on the building orientation and location(provide lighting and solar gain values to the model)
- User defined HVAC system
- Controls used to model flow rate, temperature, etc.

- System components energy used and generated
- Three dimensional geometry of the building, room adjacency, orientation, and location
- Equipment and occupancy schedules
- Lighting energy used, internal gain created, and illumination of room (Illumination studies were not completed for this report)
- Cost assessment (was not calculated using IES.VE for this report)

Room and building usage is vital to conducting energy and load simulations. The type of building will determine the minimum ventilation rate and indirectly affect the internal gains of the room/building. The rooms were grouped together by space type in the Apache HVAC system schematic. This organizes the HVAC system while emphasizing the importance of space type relations over room adjacencies.

Appendix B describes the step by step procedure used to conduct the energy and load simulation. This procedure was used for both the base model of the engineers design for this report and the system redesign to find the energy usage and loads of the New Science Center.

COOLING AND HEATING LOADS

HEAT GAIN ASSUMPTIONS

Laboratory cooling load calculations are based on the following:

- 5 watts per square foot for laboratory equipment
- Design lighting power density unique to each room (W/SF)
- # of people determined by lab program
- 250 BTUH/person

Classroom and lecture space cooling load calculations are based on the following:

- 1 laptop computer (90 watts) per student
- Design lighting power density unique to each room (W/SF)
- # of people per architectural plans
- 250 BTUH/person

Office cooling load calculations are based on the following:

- 1.5 watt per square foot equipment load
- Design lighting power density unique to each room (W/SF)
- One person per individual offices and two people per shared office.
- 250 BTUH/person

Heat gains for spaces such as copy rooms, vending alcoves, and other miscellaneous spaces were derived from the ASHRAE fundamental handbook.

BUILDING LOAD BREAKDOWN

Analyzing the original building loads reveals over the majority of the building load goes to the chiller. Given the chiller is the main load component, creates an ideal place to begin the energy efficiency improvements.

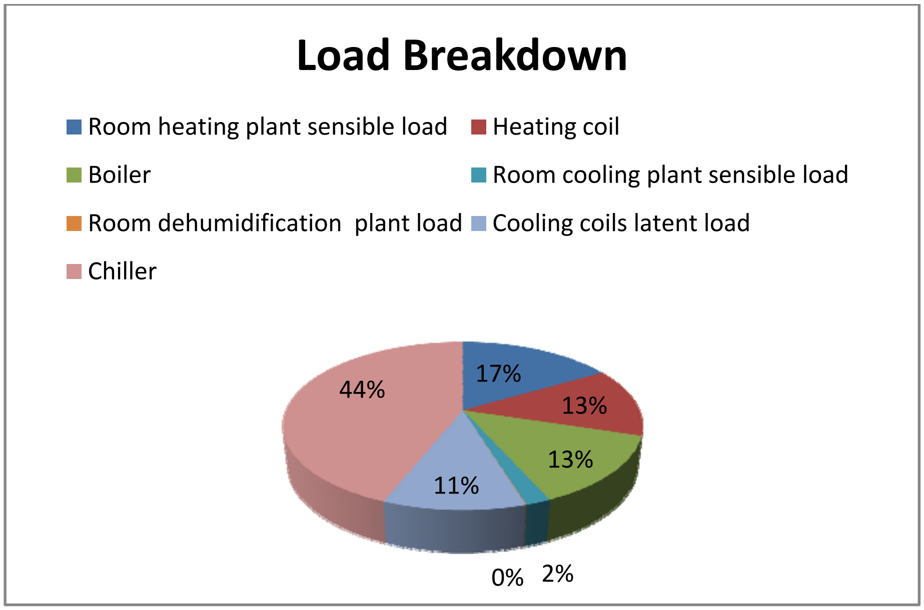

Figure 2: Load Breakdown

The New Science Center is an internal load dominated building. Looking at Classroom 105 as an example the internal gain was comprised of 85% of the load based on peak values. This type of building results in cooling for most of the year regardless of the fact the building is located in Rockville Maryland, a mixed but predominately cold climate. Due to the fact the building is cooling most of the time, the chiller resulted in the majority of the load for the building.

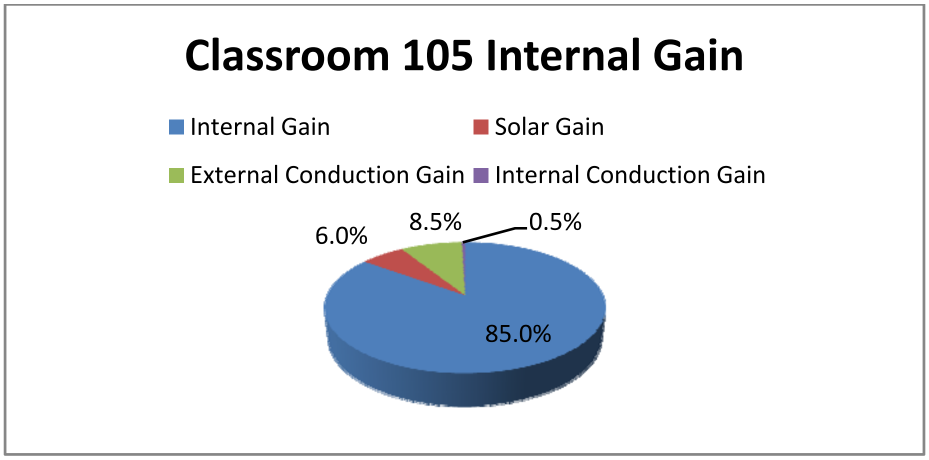

Figure 3: Classroom 105 Internal Gain

DESIGN LOAD COMPARISON

Based on the procedure mapped out in Appendix B – IES.VE MODELING PROCEDURE the energy modeling program IES.VE was used to determine the building loads. (More information on the energy modeling program IES.VE can be found under the Energy Model Section of this report.)

The overall building load reductions can be attributed to the fact the amount of outdoor air was decreased, while maintaining required ventilations rates that can be found in Appendix – E Ventilation Rates, and since the chilled beams supply the required ventilation air at room neutral. Although the building is internal load dominated the reduction of the external load, by reducing the amount of outdoor air assisted in decreasing the overall building load. When comparing the original HVAC design and the redesigned system for this report, the system redesign reduced the total building load by over 20%.

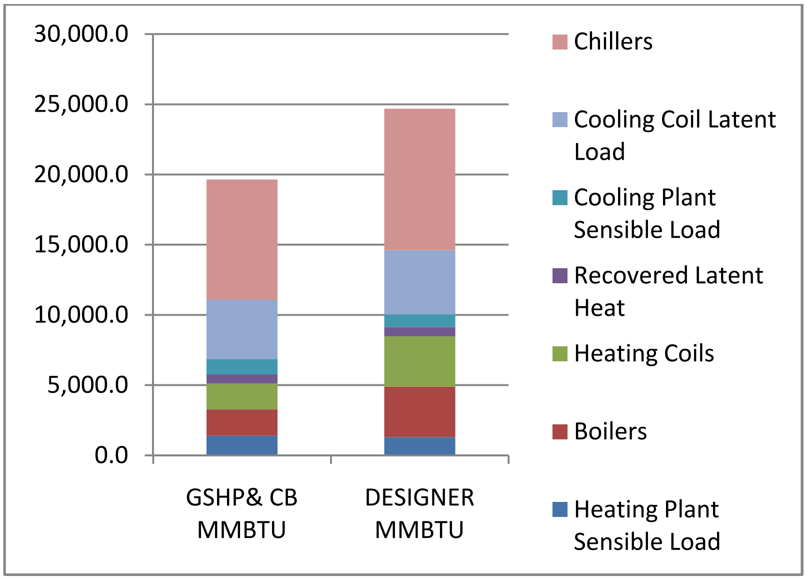

Figure 4: Building Load Comparison

Heating Load Comparison:

The boilers and heating coils saw the most significant load reduction. This high reduction was accomplished by supplying air at room neutral therefore eliminating much of the local reheat in the redesign. Reducing reheat at almost every room drastically decreased the heating load on the boilers and heating coils. Similarly the recovered latent heat load saw a small reduction from the reduced latent heating loads.

Within the model the sensible plant loads represents the chilled beams for the redesign, and the local reheat in the original design. The chilled beams took on some of the heating loads from the boiler and therefore saw an increase in comparison to the local reheat. This does not necessarily mean it added to or took away from the overall system load, but simply a movement of where the load is being applied.

Cooling Load Comparison:

Similar to the heating plant sensible load, the cooling plant sensible load was increased since the sensible load is seen by the chilled beams as opposed to the chiller. Overall the chilled beams allow the new system to supply less air to the spaces. The condition of the space is done through natural convection discussed in the chilled beam section of this report. The reduction of supply air to the space also reduced the load on the chiller and cooling coils, attributing most of the load to the chilled beams.

A detailed breakdown and comparison of the heating and cooling loads analyzed are shown below in Table 4: Loads Breakdown.

LOAD	GSHP& CB MBTU	DESIGNER MBTU	% DECREASED
Heating Plant Sensible Load	1,399.2	1,295.1	-8.03%
Boilers	1,868.2	3,594.0	48.02%
Heating Coils	1,868.2	3,594.0	48.02%
Recovered Latent Heat	635.8	666.1	4.54%
Cooling Plant Sensible Load	1,070.7	889.8	-20.33%
Cooling Coil Latent Load	4,240.4	4,580.3	7.42%
Chillers	8,559.9	10,064.5	14.95%
Summation	19,642.3	24,683.9	20.42%

Table 4: Load Breakdown

In order to complete the system redesign study, the calculated energy and load values along with the associated energy model for the original HVAC design were used as a base comparison to the system redesign for the energy and cost savings.

ORIGINAL MECHANICAL SYSTEM

The current mechanical system consists of a central air handling system, central chilled water system, a central hot water system, and a laboratory exhaust system. The central air handling system consists of two custom air handling units located on the roof.

Chilled Water System Design:

The existing 225 ton chiller with variable frequency speed control in Science East, associated cooling tower, and condenser pumps were retained. An additional two 305 ton **electric centrifugal chillers** with variable frequency drives will be added to the chilled water system to accommodate for the expansion (New Science Center).

Chiller										
					Evaporator			Condenser		
Number	Tons	KW	KW/ TON	NPLV	GPM	Entering Water Temp	Leaving Water Temp	GPM	Entering Water Temp	Leaving Water Temp
2	305	204	0.669	0.448	410	60	42	580	85	100

Table 6: Chiller Schedule

The **two primary** and **two secondary** chilled water pumps have variable frequency drives, along with the two condenser pumps.

Two new **induced draft-cross flow cooling towers**, located on the roof, cool the chiller condenser water. The two towers in a two cell arrangement share a basin. Both towers have variable frequency drives for fan speed control.

Cooling Tower				
Number	GPM	Entering Air Wet Bulb	Leaving Water Temp	Entering Water Temp
2	500	78	85	100

Table 7: Cooling Tower Schedule

The two **condenser water pumps** are each sized for full flow of both towers. At ideal conditions the variable fan speed of the towers will reduce the condenser water temperature to allow the chillers to operate at peak efficiency.

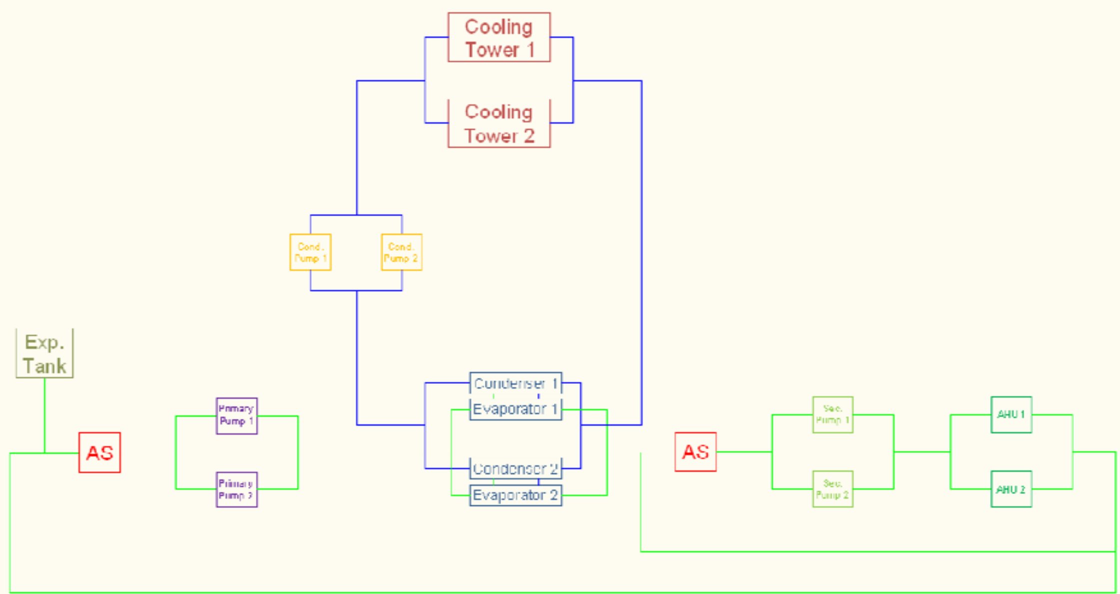

Figure 6: Cold Water Flow Diagram

Following the Cold Water Flow Diagram shown above, the **cooling towers** cool the chiller condenser water. The water is pumped by the **condenser pumps** to **chillers** where the water will be cooled to the optimal temperature. The water is then drawn through the **air separator** to ensure there is no bubbling in the water altering the pressure and **pumped** to the **air handling units**. The air handling units pull the air to be supplied to the building over the cooling coils. This process transfers the energy of the air into the water, allowing the chilled water to perform its main purpose. After leaving the air handling unit the water can then be overflowed into the **expansion tank** or continued through the cycle. The water is once again drawn through an **air**

separator by the **primary pumps** and taken back through the **chillers** on the evaporator side and back up to the **cooling towers**.

Hot Water System Design:

Two high efficiency 3 million BTU **hot water boilers** are provided for the heating plant. 3 million is the input energy; each boiler can provide 2.61 million BTUS of heat at the minimum operating efficiency of 87%. Space has been allocated in the mechanical penthouse for two additional boilers if they would be required to boost the capacity of the west hot water loop in the future.

Boiler					
Number	**MBH in**	**MBH out**	**GPM**	**Entering Water Temp**	**Leaving Water Temp**
2	**3000**	**2610**	**260**	**160**	**180**

Table 8: Boiler Schedule

The hot water system consists of two hot water **campus distribution pumps** and two building **distribution pumps**. There are no boiler pumps. The boilers are all piped in reverse return to balance out flows. Water always flows through all boilers when there is a call for heat.

Following the Hot Water Schematic shown below, the **boilers** heat the water from the **air handling units** and campus return. The hot water is then either overflowed into the **expansion tank** or continued through the cycle drawn through an **air separator** by the **campus distribution pumps**. The campus distribution pumps supply the hot water to the campus hot water loop, the air handling unit loop or back through the boilers. If the water is taken through the air handling unit loop, the water is first drawn through an **air separator** and then pumped by the **building distribution pumps** up to the **air handling units** located on the roof and back into the boiler loop.

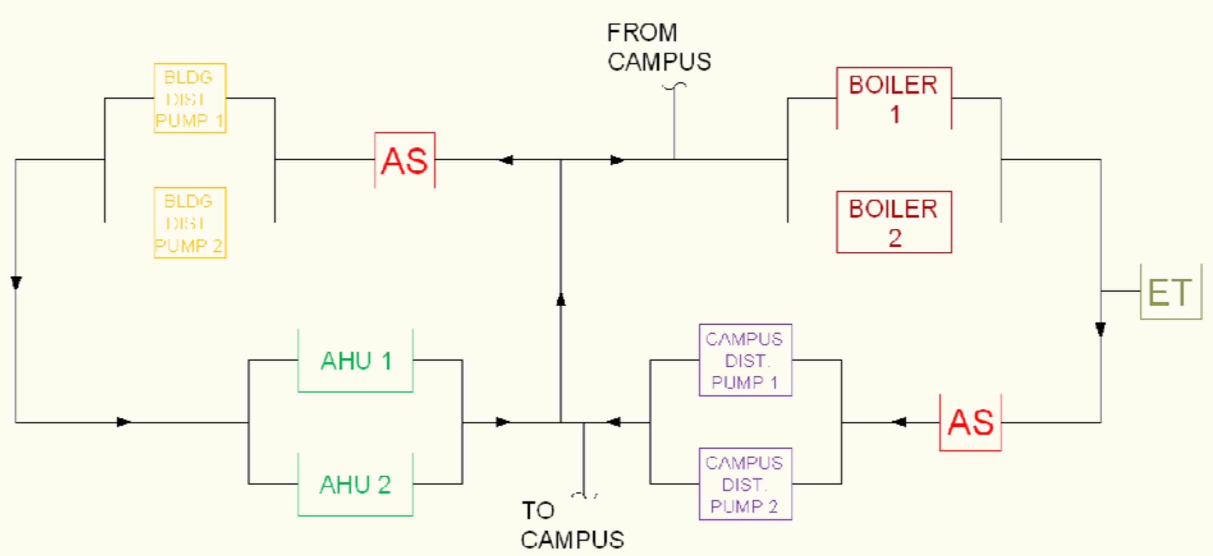

Figure 7: Hot Water Flow Diagram

This flow diagram shows that the hot water loop can be utilized locally or distributed to the west loop and/or campus loop.

Air System Design:

The central air handling system consists of two **roof top units** manifolded together by a common discharge plenum. Each unit has **dual fans** and isolation dampers to isolate one unit from the rest of the system. There is no return fan because the pressure drop across the outside air section including the **heat recovery coil** is approximately equal to the pressure drop in the plenum return system. The return air damper will modulate to maintain the pressurization of the building. Because of the high percentage of outside air, due to the amount of lab exhaust, there is no relief in the unit. The only relief is required during economizer mode. This relief will be discharged from the building through the smoke exhaust fans.

The air system schematic shows how the air handling unit is connected to the rooms. The complete schematic can be found in Appendix F – SCHEMATICS to explore the entire building air distribution breakdown. This schematic is taken directly from the designers IES energy model. IES requires that the entire HVAC system be modeled in order to run the program with the correct results.

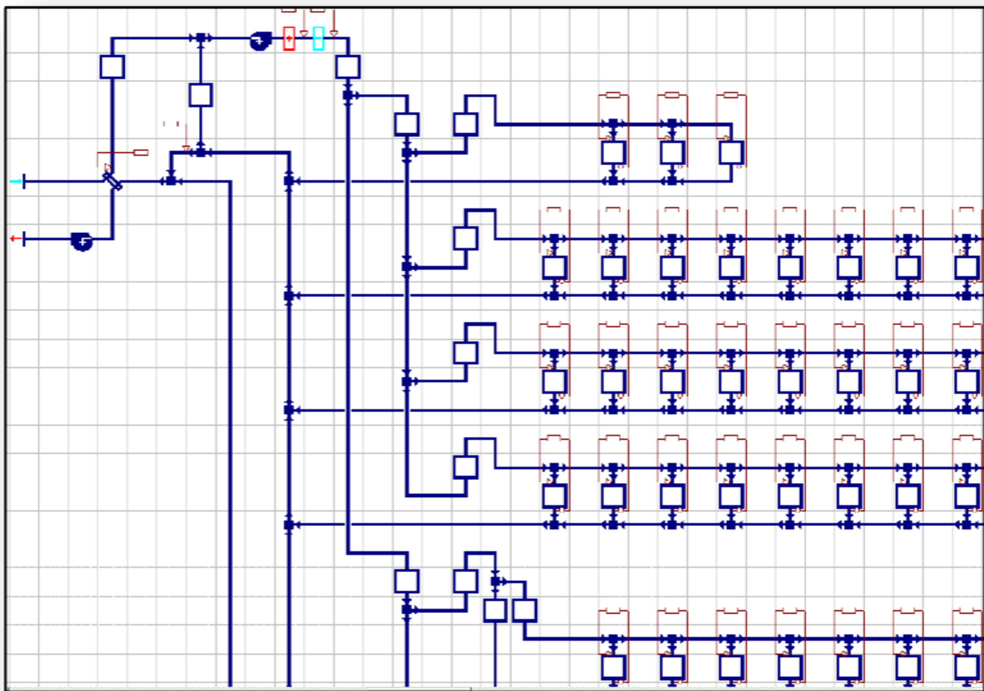

Figure 8: Air System Partial Schematic

The figure below focuses the Air System Schematic on the AHU of the system. It shows an exhaust fan, supply fan, mixing boxes, heating and cooling coils, controls, and the heat exchanger. All of these components need the corresponding values to complete the energy model. These values can be found in Appendix C- SYSTEM COMPONENTS.

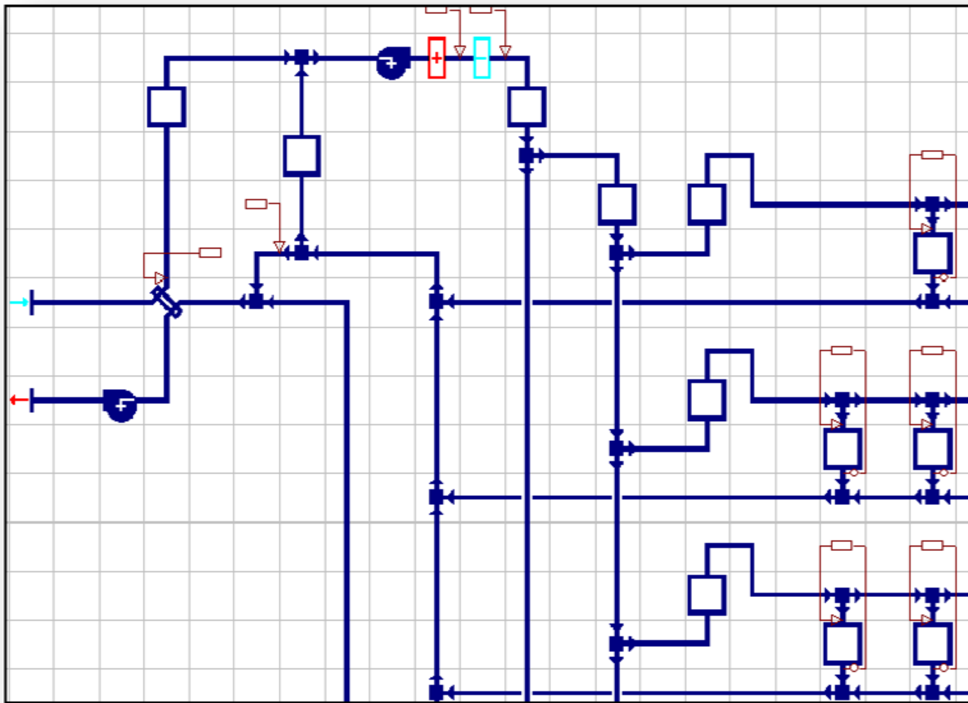

Figure 9: Air System Schematic AHU

Air Handling Unit

Number	Mark	System Type	Capacity (CFM)			Components		
			SA	Design OA	Max. Vel			
2	AHU-1	VAV	66730	47140	500	Cooling Coil	Pre-heat Coil	Heat Recovery Coil

Table 9: AHU Schedule

A 12 ft wide corridor runs between the two units connecting them. The hot water and chilled mains that serve the unit run across the ceiling of the service corridor. At the end of the corridor, there is a mechanical room that houses the rest of the equipment in the custom penthouse.

The air handling unit consists of the following sections:

- Storm Louver
- Intake section
- Pre-filter for outside air
- Heat Recovery coil
- Return mixing box with return air inlet, dampers and a pre-filter for the return air.
- Supply fan section with dual fans.
- 85% Supply air final filter
- Heating Coil
- Cooling Coil
- Isolation discharge dampers
- Discharge plenum
- Requires access sections w/ 24" service doors.

More information on the coils can be found in Appendix C- SYSTEM COMPONENTS. For full air handling unit schematic refer to Appendix F – SCHEMATICS.

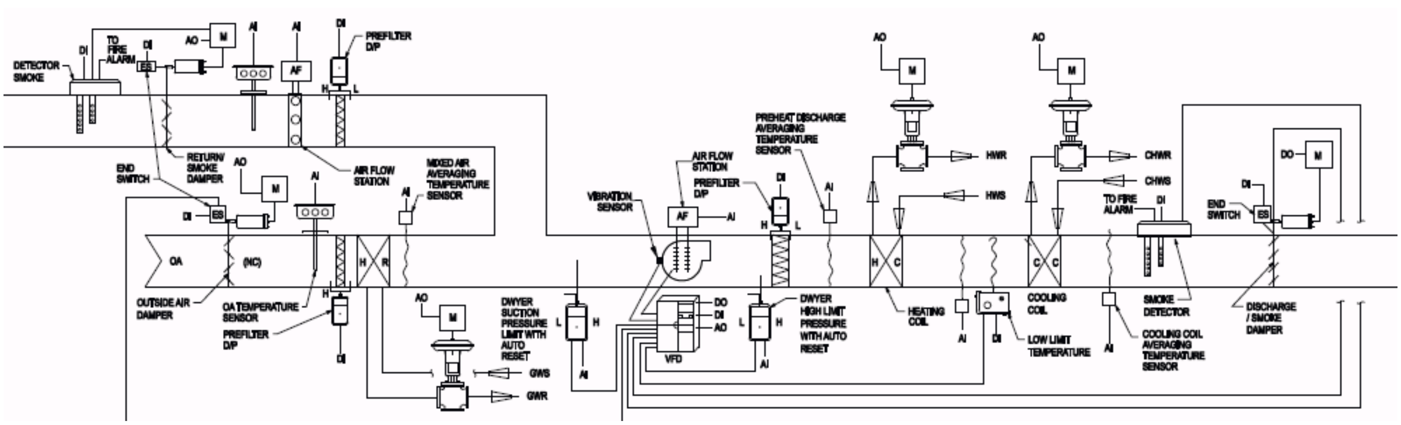

Figure 10: Partial Air Handling Unit

Central Exhaust System Design:

The laboratory exhaust system consists of four high plume exhaust fans that are connected by a common plenum. The airflow through an individual fan is constant volume to maintain a constant discharge velocity out of the exhaust fan stack. The flow of exhaust air from the building is variable volume to minimize the amount of make-up air required at all times. To compensate, there is a make-up air damper in the exhaust plenum to mix enough outside air with the exhaust air from the building to maintain a constant exhaust flow rate. When the amount of make-up air exceeds the design flow rate through one whole fan, the exhaust fan with the longest run time shall shut off and the amount of make-up air will be varied accordingly to maintain a constant flow of exhaust air through the rest of the fans in operation. Of the four fans, one is a standby fan, in the event of a failure. The fan designations will be rotated based on run time.

Laboratory Exhaust Fans				
Number	**Type**	**CFM**	**RPM**	**BHP**
4	**High Plume**	**24200**	**1000**	**38.6**

Table 10: Laboratory Exhaust Fan Schedule

The fans create a constant negative static pressure at the local exhaust plenum. Each main exhaust riser has a modulating damper that is normally 100% open. The damper modulates closed to maintain the remote duct static pressure less than the maximum duct static pressure set point in the exhaust riser.

MECHANICAL SYSTEMS EVALUATION

The Montgomery College New Science Center's original mechanical design utilizes a typical heating ventilation and air-conditioning (HVAC) system for a mixed climate zone; where controls, heat recovery, and equipment efficiency are relied on to reduce the energy use. This type of system is easy to maintain in comparison to some of the new, innovative designs of today for the building operations engineer. This system is easily incorporated into the already existing campus loops and neighboring buildings. For these reasons this system was a good design for both the university and energy reductions.

If the university would be willing to upgrade to a more complex and innovative design the building could further the energy reductions, decrease the space needed by the mechanical system, and emissions. Unfortunately, increasing the complexity of the system could also lead to an increased initial cost, and facility engineer system training.

Critiques:

The building does well in isolating the laboratory contaminants by directly exhausting all laboratories, keeping them negatively pressurized at all times along with the exhaust ducts.

The designer energy reductions may not be realistic. Comparing this reports energy model to the designer's energy model the energy reductions are found to be extremely low. Further research showed the designer's energy calculations were extreme for the energy reduction methods compared to typical laboratory design. Why these results vary so drastically will require further investigation.

The buildings hot and cold water systems were incorporated into the campus water plants with ease. The design gives the campus a lot of flexibility. The campus will be able to add to the campus loop as anticipated easily, since room was left and pipes were designed and located with the expansion in mind. The design will also integrate into the current system well, since the existing system and designed system are very similar. As a result, any combination of the campus plant or local satellite plant can be used to service any combination of the west campus loop or New Science Center.

Overall the design appears done very well, meeting and exceeding the campus expectations with a conservative system.

MECHANICAL REDESIGN SYSTEM COMPONENTS

Geothermal System Design:

Geothermal systems have been around for numerous years, but have recently increased in popularity. This system has become more and more common in analysis and in practice due to recent energy and environmental concerns. The system utilizes both renewable resources and the direct use of heat as opposed to heat generation, making the system both environmentally friendly and energy efficient.

Geothermal uses the concept of moving heat energy to or from the building as opposed to converting energy into heat. During the cooling season the heat energy is expelled to the environment. During the heating season the heat energy is brought into the building and absorbed into the mechanical system's cycle.

Approximately 4,000 miles below the earth's crust there is a stead decay of radioactive particles generating heat energy hotter than the sun's surface. This heat energy helps to maintain the earth's surface temperature, creating a constant reliable heat source at all times of the year.

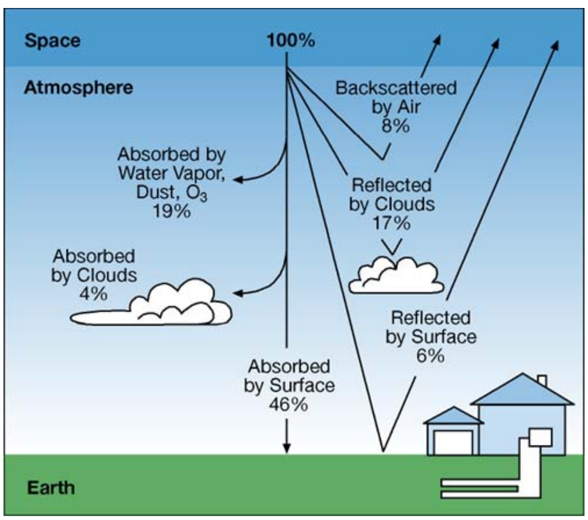

Figure 11: Solar Energy

In addition, solar energy is continuously heating the earth's surface. According to the image provided by McQuay, approximately 46% of the solar energy is absorbed by the earth in the form of heat energy, while the rest is reflected back into the environment. This constant heat energy supply in addition to the radioactive decay mentioned earlier ensures that the temperature approximately 15 feet below the earth's surface remains a constant ranging from 42ºF to 77ºF depending on the location.

A geothermal system can be designed as an open loop or closed loop system. A closed loop system uses the constant ground temperature at approximately 55°F. A water-glycol solution is pumped through pipe lines that run either vertically (bore holes) or horizontally (coiled) absorbing or expelling the heat energy. Alternatively, a closed loop system utilizes a water source and directly pumps the water to and from the building. The open loop system is the more economic choice of the two system types since removing underground piping from the design eliminates excavation costs, piping material costs, maintenance costs, the purchase of the water-glycol solution, and reduces the associated heat pump costs. Once the heat energy is transferred to or from the water the water is returned back to the water sink, maintaining the water the natural or designed water level. Closed loop systems are only more common since there is not always a water source available to tap from.

Figure 12: Geothermal Open Loop

The Montgomery New Science Center's already has a water retention pond adjacent to the building, which allows for a geothermal open loop design as a possibility. The open loop design will also allow for easy renovations or anticipated additions to the science center.

Heat Pump:

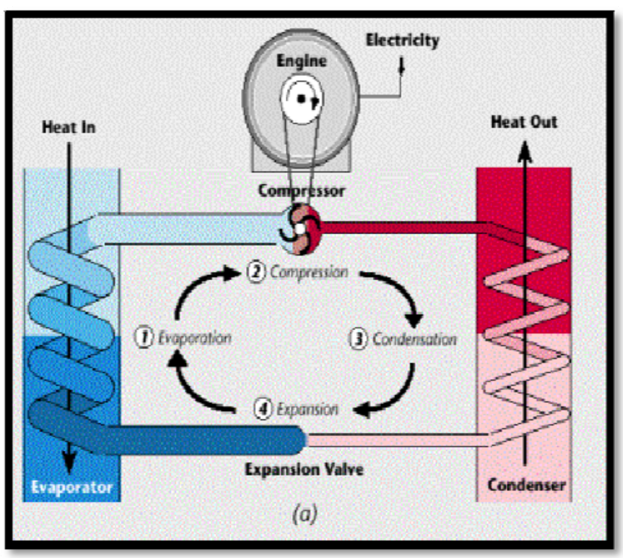

Figure 13: Heat Pump Breakdown

A heat pump could be considered the heart of a geothermal system. Utilizing a heat pump eliminates the need for a cooling tower or boiler. The heat pump is based on the standard refrigeration cycle concept equipped with all four main components, the compressor, condenser, expansion valve, and evaporator as shown. The refrigeration cycle transfers the heat energy from one heat source to the other.

Variable flow to the heat pump is ideal to decrease the amount of annual pumping power. When the compressor within the heat pump is not on the flow should also be turned off.

A heat pump eliminates the need for a boiler or cooling tower within the system; And therefore reducing the amount of electricity and fossil fuel needed, hence reducing the associated environmental impact.

Chilled Beams System Design

The use of chilled beams became popular in Europe and is working its way over to the United States more and more as time goes on. As U.S. designers are becoming more familiar with chilled beams and their benefits U.S. designers have began to use them more often in their design. Recent studies have shown that most of the in place chilled beams design in the U.S. are utilized in commercial buildings. This is due to the low investment costs and high cooling capacity of chilled beams.

There are two forms of chilled beams, active and passive, that work in place of a diffuser of a typical mechanical system. The chilled beam is recessed in, or hung from the ceiling. Cold water runs through the coils located in the chilled beam that is used to cool the room air.

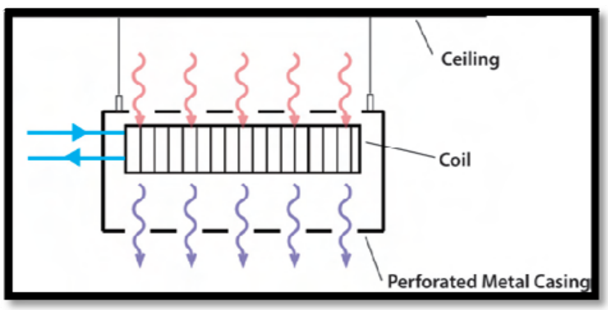

Figure 14: Passive Chilled Beam

Passive chilled beams utilize natural convention as opposed to forced air flow. As the air around the coil coils, it naturally drops into the room, cooling the room, and the warmer air rises into the chilled beam to be cooled and then redistributed into the room.

On the other hand, active chilled beams provide ventilation air in addition to the induced air flow. Ventilation air is distributed to chilled beam by small air jets. The natural convection and distributed ventilation air induce airflow over the coils, so the air can be cooled and diffused into the room to

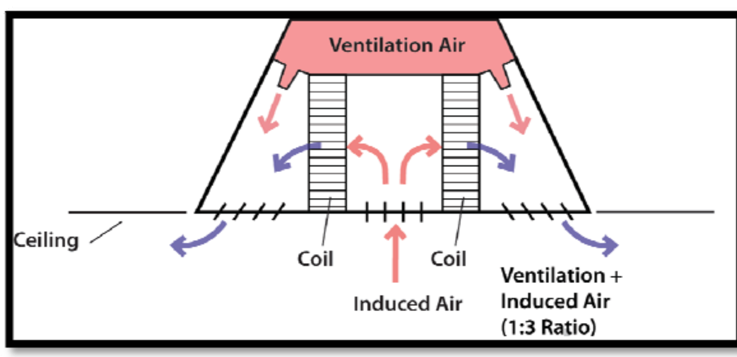

Figure 15: Active Chilled Beam

maintain thermal comfort. The combination of the natural convection and forced air increases the effect of the natural convection. The increased effect provides an added benefit of active chilled beams compared to passive chilled beams because the increased effect allows the system to have higher heating and cooling capacities over the passive chilled beam.

Although chilled beams take up more ceiling space and overall still have lower heating and cooling capacities than a typical diffuser, chilled beams allow the designer to decouple ventilation and humidity requirement from the sensible heating and cooling requirements. The air-handling units (AHUs) are then only needed for the remaining ventilation requirements.

In addition to the design benefits, economic benefit can be applied as well. Chilled beams are typically custom ordered, increasing the initial costs at first glance. Taking a closer look at the overall initial costs, chilled beam reduce the air handling size and ducting needed along with their associated costs, which typically creates an overall reduced initial cost with a chilled beam design. The total initial cost reduction for this specific application will be further assessed in the cost analysis portion of this report.

Chilled Beam Design Concerns:

Condensation:

According to an ASHRAE Journal published in 2006, there are two main concerns when designing a chilled beam system, warmer water temperature and space humidity control. A warmer water temperature provided to the coils along with the humidity control is needed to prevent condensation off the coils and into the room. Regardless of the design a drip pan designed to hold the minimum amount of condensate should be provided to ensure no condensation enters the room from the ceiling, yet ideally should never need to be used. In order to prevent condensation off the coils the water temperature to the coils should be maintained at about 55°F to 60°F (3°F to 4°F above the dew point). In addition, the room humidity should be maintained below 50°F and 55°F dew point or 50% to 55% relative humidity when the room temperature is to be maintained at 72°F. The humidity requirements can be controlled through the supplied ventilation air.

Noise Level:

Another concern that will be further evaluated in the acoustics breadth arises when active chilled beams are selected used in high ventilation conditions, is the noise level concern. Specifically in the laboratories of the Montgomery College New Science Center the required ventilation will need to be accessed in comparison to the noise level of the room. The concern becomes prevalent when a large amount of supply or ventilation air is pushed through the air jets. In order to avoid this acoustical problem the length and number of chilled beams for each room was carefully chosen while trying to maintain and economic solution.

MECHANICAL SYSTEM REDESIGN

The Montgomery College New Science Center's mechanical system was redesigned to incorporate an open loop geothermal system. The geothermal system transfers heat energy from a water retention pond in the form of chilled and hot water to the chilled beams and water-to-air heat pumps. The geothermal heat pumps will replace the original boilers and chillers of the central chilled and hot water systems. The following Figure 16 visually describes the redesigned system and should be used as a reference throughout this section of the report.

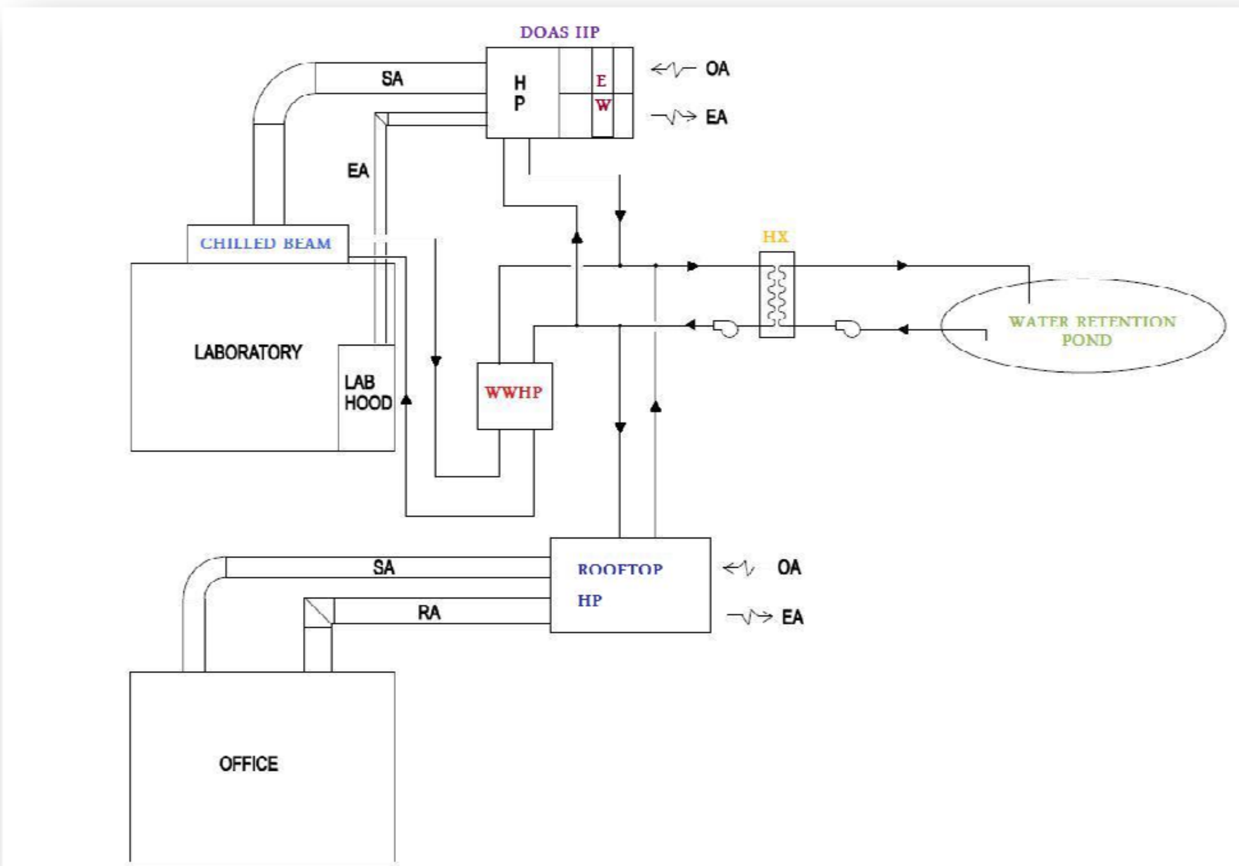

Figure 16: Redesign System Schematic

Laboratory and Classroom Design:

The mechanical system redesign is replacing the original boilers, chillers, and cooling towers, with **water to water heat pumps** and **water to air heat pumps**. Four **water to water heat pumps** are provided for the laboratories and classrooms based on the peak heating conditions of the rooms. Each individual heat pump's heating capacity provides 350 MBH with a 4.08 COP and 393 MBH with a 5.22 COP for the cooling capacity.

Labs/CB WW Heat Pumps	MBH	TONS	UNIT MBH	# OF UNITS	COP	EER	GPM
Heating	1,399	117	350	**4**	4.08	13.92	84
Cooling	1,071	89	393	3	5.22	17.80	84

Table 11: Laboratory and Classroom Water to Water

An additional water to water heat pump is used for redundancy and simultaneous heating and cooling conditions. Simultaneous heating and cooling conditions can occur during a typical heating season, when the laboratories internal loads outweigh the external conditions and would need to be cooled while other rooms within the New Science Center would need to be heated. Another simultaneous heating and cooling conditions scenario would be when solar gains are greater on the south side of the building than the north and the south would need to be cooled when the north would still need heating.

The open loop geothermal system uses the onsite **water retention pond** as the heat sink. The water is supplied to and from the **pond** to a **heat exchanger**. The **heat exchanger** decreases the overall system efficiency, but will provide more benefits to the environment and system maintenance. The geothermal system acts like a closed loop system taking water to and from the **heat exchanger** to the **water to water heat pump**, ensuring the water quality of the system.

The cooled or heated water is then distributed to the variable flow active **chilled beams**. The chilled beams induce air flow over the coils and back into the room assisted by the supplied ventilation air. The rooms typically have one or two **chilled beams** recessed within the ceiling. The maximum amount of **chilled beams** for any one room is six. The General Chemistry Lab and its associated Chemistry Lab and Prep room will have six **chilled beams**, with more than enough ceiling space, both vertically and horizontally.

Lab/CB DOAS HP	MBH	TONS	CFM	UNIT MBH	# OF UNITS	UNIT CFM	# OF UNITS	COP	EER
Heating	1,203	100	101,255	406	3	12,400	**9**	4.30	14.67
Cooling	8,154	680	101,255	916	**9**	12,400	**9**	5.33	18.20

Table 12: Laboratory and Classroom DOAS

Ventilation air is supplied to the laboratory and classroom active **chilled beams** by the **DOAS heat pump,** also known as a geothermal **water to air heat pump**. The **heat exchanger** that transfers the heat energy from the **water retention pond**, supplies the water to the **DOAS heat pump**. Air is brought from the outside to over the **enthalpy wheel**. Any dehumidification needed to the outdoor air is sensed by controls within the **DOAS heat pump**. The air is then cooled to condense water out of air to until 55% relative humidity is reached and then reheated. The **DOAS heat pump** supplies the air at room neutral (74ºF summer, 72ºF winter). The ventilation air is distributed to the rooms from the **DOAS heat pump** through the nozzles of the **chilled beams** inducing additional airflow over the coils to condition the room, while properly ventilating the room.

Nine **DOAS heat pumps** were needed to maintain ventilations requirements of the laboratories and classrooms. The **DOAS heat pumps** have a heating COP of 4.3 and a cooling COP of 5.33 and were sized at 12,400 CFM, 916 MBH for cooling and 406 MBH for heating.

All of the air from the laboratories is exhausted from the building, never re-circulated into the supply air to prevent contamination and increase the indoor air quality. The exhaust air is passed through the **enthalpy wheel** to recover heat energy. The recovered heat is used to heat the outdoor air, decreasing the load on the coils.

Office Design:

Similar to the laboratory and classroom **DOAS heat pump**, water is supplied from the **heat exchanger** to the **rooftop heat pump** where the heat energy is transferred to the air that is then supplied to the offices**.** Two **rooftop heat pumps** are placed on the roof in place of the original AHUs. The **rooftop heat pumps** will also provide any needed dehumidification as the **DOAS heat pumps** do but without the help of the **enthalpy wheel**. Air from the **rooftop heat pumps** supply 52ºF air to the local office variable-air-volume boxes and reheat coils, similar to the original HVAC design. The reheat coil's water is provided by the **water to water heat pumps**.

Office Rooftop HP	BTUH	TONS	CFM	UNIT MBH	# OF UNITS	UNIT CFM	# OF UNITS	COP	EER
Heating	196,521	16	15,627	181	**2**	8,000	**2**	3.40	11.60
Cooling	405,640	34	15,627	237	**2**	8,000	**2**	4.25	14.50

Table 13: Office Rooftop Heat

Air from the offices is returned to the **rooftop heat pumps**, reducing the amount of supply air that needs conditioning, exhausting the remainder of the return air.

Open Loop Design

Water from the **water to water heat pumps**, **rooftop heat pumps**, and **DOAS heat pumps** is returned back to the **heat exchanger**. During the cooling season the systems returned water transfers the heat energy through the **heat exchanger** back to the **water retention pond** and re-circulated into the system to continue the process. In opposition, during the heating season the systems returned water absorbs energy from through the **heat exchanger** from the **water retention pond** and re-circulated back into the system.

LIGHTING BREADTH

Lighting Lamp Redesign

With energy efficiency as the primary goal of the redesign, a lighting redesign was completed with the same goal in mind. Redesigning the lighting to be more energy efficient will decrease the total annual energy usage both directly and indirectly. Directly the energy efficient lamps will decrease the energy needed to properly light the building; and indirectly the heat output of the lighting will decrease and therefore decrease the needed cooling energy of the building. Since the building is an internal load dominated building, decreasing the internal load where possible is the best place to start decreasing the overall HVAC load. In opposition, if the building was an external load based building a building envelope redesign would be a better redesign option.

Light Selection

The efficient Earth-Friendly-Troffer (EFT) was selected for the offices, laboratories, and classroom. All of the laboratories, classrooms, and offices have a drop ceiling with 2x4 Acoustical Ceiling Tile. The EFT 2x4 recessed lights, fit into the ceiling tile while leaving as much space as possible in the room. In addition, recessed lighting allows the rooms to be easily rearranged at anytime, since the lights would not be dropped into the room creating an immovable piece to the room.

The EFT lights reach up to 88.8% efficiency and 0.7 W/ft^2. The EFTs use highly reflective matte white powder coating, and precisely engineered louvers to accomplish their efficiency. In addition to their highly competitive efficiency, the Troffers are also equipped with a full 3" baffle element that illuminates while reducing the glare.

Energy Savings

The EFT lights reduced the energy used by the lights over a 185 MMBtus for a 12.96% energy savings. Since the associated heat energy produced by the lights is also reduced, both the heating and cooling were affected. The heating needed slightly increased and the cooling decreased. Similarly the fans, pumps, and controls energy saw a slight decrease since the overall annual load was slightly decreased, given that it is a laboratory building in Rockville Maryland, needs mostly cooling.

	Heating (boilers etc.)	Cooling (chillers etc.)	Fans, pumps and controls	Lights	Equip.
Lighting Redesign	8445.139	13749.672	310949.906	1247.095	4773.785
Original Lighting	8406.94	13885.029	310998.094	1432.732	4773.785

Table 14: Lighting Redesign Energy Comparison in (MMBtus)

Lighting Schedule Analysis and Redesign

In addition to the selection of the more energy efficient lamps, a lighting schedule analysis was completed to ensure that not only the lights their selves were energy efficient but that the usage was as energy efficient as possible. Analyzing the lighting schedule includes analyzing the times at which the lights are to be in use and how this could be improved. Improving the estimated usage can drastically decrease the assumed energy both by the lights and the associated cooling energy that compensates for the heat energy produced by the lights. These schedules need to be developed with the owner and anticipated occupants in order to get a realistic representation of the space usage.

For the Montgomery College New Science Center's energy model the lighting schedules have been broken down into weekday usage (Monday through Friday) and weekend usage (Saturday and Sunday), since the labs and offices do not follow the same hourly occupancy schedule over the weekend that they do over the week. Each space type's schedule was analyzed separately, since when and duration of the space usage could change with the type of usage; and therefore the lighting schedules were also broken down by the space type in addition to weekly breakdown.

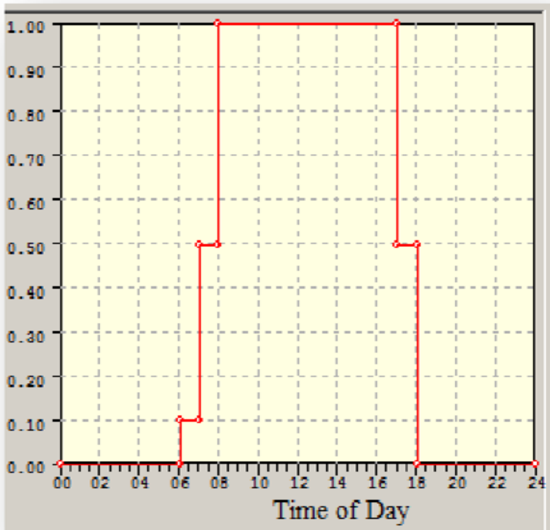

Figure 17: Office Weekday Lighting Schedule

The image above is a graphical representation of the assumed lighting schedule for the offices, Monday through Friday and will be used as an example of how the rest of the lighting schedules were evaluated. The other lighting schedules analyzed can be found in Appendix G. This schedule show that the 10% of the lights are anticipated to be used from 6:00 AM to 7:00 AM, 50% from 7:00 AM to 8:00 AM, 100% from 8:00 AM to 5:00 PM, and back down to 50% from 5:00 PM to 6:00 PM before dropping off to zero overnight until the next morning. This schedule is typical for an office, anticipating that only about 10% of the occupant will arrive as early as 6:00 AM and progressing until full occupancy at the start of a typical work day, 8:00 AM. No lights are assumed off over the lunch break, since so many of the occupants take their lunch break in the office. Half of the occupants were assumed to leave by the scheduled end of the work day, 5:00 PM, and to all have left within the following hour.

ACOUSTICAL BREADTH

In order to determine if the current acoustics of the building meet the requirements, the reverberation times were calculated for a typical classroom, laboratory, and office. The reverberation time was calculated for each occupancy type since different occupancies require different reverberation times.

In addition to the room acoustics, the chilled beams were analyzed, since as discussed earlier active chilled beams at high velocities can create a significant about of noise. Since the laboratories will need a large amount of ventilation air, the laboratory chilled beam sound curve was assessed.

Reverberation Time Calculations

In order to determine the required reverberation time Architectural Acoustics by Marshall Long was used as an acoustical reference. Looking at the three rooms under analysis, all three of the rooms should fall between 0.7 and 1.1 seconds reverberation time, which is considered the reverberation time for a lecture space.

Secondly, the reverberation times were calculated in order to determine if the rooms meet the requirements listed above. In order to find the reverberation times for the room, the room volume, surface material, and its corresponding absorption coefficient, and associated surface area. The following reverberation time and Sabine equations were used to determine the reverberation time.

$$\boldsymbol{T_{60} = \frac{0.049V}{A}} \qquad \boldsymbol{A = \Sigma(S\alpha)}$$

V: Volume of the Room (cubic feet)

A: Total area of absorption in the room (sabins)

S: Surface Area of Material (square foot)

α: Sound Absorption Coefficient

ROOM	T60 at 500 HZ	T60 at 1000 HZ
Classroom	0.66 seconds	0.65seconds
Laboratory	0.66 seconds	0.65 seconds
Office	0.46 seconds	0.34 seconds

Table 15: Original Design Reverberation Times

The table shown above proves with the current room materials, the ideal acoustical conditions were not met for any of the rooms. In order to achieve the ideal reverberation time, the room materials were changed based on the materials absorption coefficients. The following respective changes were made and are recommended to improve the room acoustics:

<u>Laboratory:</u>

1. An additional layer of 5/8" gypsum board was added to two of the walls for a total of two walls of double layer gypsum board
2. The Acoustical Ceiling Tile was replaced with Armstrong Suspended Ceiling (which can be found in Appendix H.

<u>Classroom:</u>

1. An additional layer of 5/8" gypsum board was added to one of the walls for a total of two walls of double layer gypsum board
2. The Acoustical Ceiling Tile was replaced with Armstrong Suspended Ceiling (which can be found in Appendix H.

<u>Office</u>:

1. An additional layer of 5/8" gypsum board was added to three of the walls for a total of four walls of double layer gypsum board
2. The Acoustical Ceiling Tile was replaced with Armstrong Suspended Ceiling (which can be found in Appendix H.
3. The floor was switched from carpet to the Epoxy Terrazzo that the classrooms have.
4. A light velour was added to the ceiling as decorative and acoustically functional.

ROOM	T60 at 500 HZ	T60 at 1000 HZ
Classroom	0.77 seconds	0.70 seconds
Laboratory	0.78 seconds	0.70 seconds
Office	0.73 seconds	0.71 seconds

Table 16: Redesigned Room's Reverberation Times

With the new room materials the all three of the rooms fall between the recommended 0.7 and1.1 seconds of reverberation time at both 500 Hz and 1000 Hz. A complete Breakdown of the Room Acoustics can be found in Appendix I.

Chilled Beam Acoustic Assessment

ACB40 - 4 Foot Unit Sound Levels							
Primary Airflow (CFM)	Primary Airflow Per Foot (CFM/FT)	0.2" wc Inlet Static Pressure		0.4" wc Inlet Static Pressure		0.6" wc Inlet Static Pressure	
		NC	dB(A)	NC	dB(A)	NC	dB(A)
High Nozzle Pitch							
60	15.0	16	26				
80	20.0			19	35		
100	25.0					23	42
Medium Nozzle Pitch							
80	20.0	21	29				
110	27.5			24	39		
140	35.0					32	46
Low Nozzle Pitch							
100	25.0	24	32				
140	35.0			26	43		
180	45.0					34	50

Table 17: Chilled Beam Sound Level Data

The two foot by four foot chilled beams selected for the Montgomery College New Science Center's mechanical system redesign, cannot achieve a noise criteria rating of 34 or higher at the maximum flow rate and inlet static pressure. With the given redesign the inlet static pressure should not exceed 0.4" w.c. ensuring the NC should not reach above 26. In addition, the classrooms have lower flow rating than the laboratories and should not exceed 110 CFM, keeping the office NC at 24 or below.

	NC Rating
Classrooms	25-30
Laboratories	35-40
Private Offices	30-35

Table 18: Space Noise Criteria Rating

ENERGY ANALYSIS

The New Science center original design consumes 8,444,045 kilowatt hours annually compared to 6,101,060 kilowatt hours annually for the system redesign, for an addition 27.75% energy savings. As expected, the energy required for the heat pumps is over half the amount of energy needed for the boilers and chillers. The local reheat needed, represent by the direct acting heaters in the original design and the office reheat and chilled beam heating energy for the redesign was reduced almost 90%. In addition, the lighting redesign decreased the required lighting energy. Although the pump energy almost doubled, the overall energy savings for the redesign equated to 2,342,986 kilowatt hours a year.

Redesign			Original Design		
System Component	**MMBTU**	**kwh**	**MMBTU**	**kwh**	**System Component**
Nat gas	88	25,674	5,726	1,678,087	**Fans, Controls, Plug, Misc.**
Electricity	5,404	1,583,702			
Chilled Beam HP (heating)	507	148,496	9,239	2,707,802	**Direct Acting Heater**
Office Reheat	488	142,947			
Chilled Beam HP (cooling)	953	279,242	7,273	2,131,514	**Boilers and Chillers**
DOAS HP	2,037	596,999			
Office Heat Pump	546	159,962			
Pumps	9,548	2,798,240	5,142	1,506,947	**Pumps**
Lights	1,248	365,797	1432	419,695	**Lights**
Total energy	**20,817**	**6,101,060**	**28,811**	**8,444,045**	**Total Original Energy**

Table 5: Energy Comparison – Redesigned vs. Original System

Looking at the result it is very clear that the redesigned mechanical system for this report met its goals of improved energy efficiency by far, with almost 28% improvements.

Analyzing the figure below, the majority of the energy goes to the system pumps. The redesigned system primarily replaced fans with pumps. Pumping water to every chilled beam requires more energy than using fans to supply air to the rooms. Yet, as proved above the overall energy efficiency of the system is still increased. In addition, the pump energy is required whether the building requires heating or cooling and therefore will be used all year long. The chilled beam heating and cooling season were modeling separately, but still the combination of the two only equate to approximately 5% of the energy use.

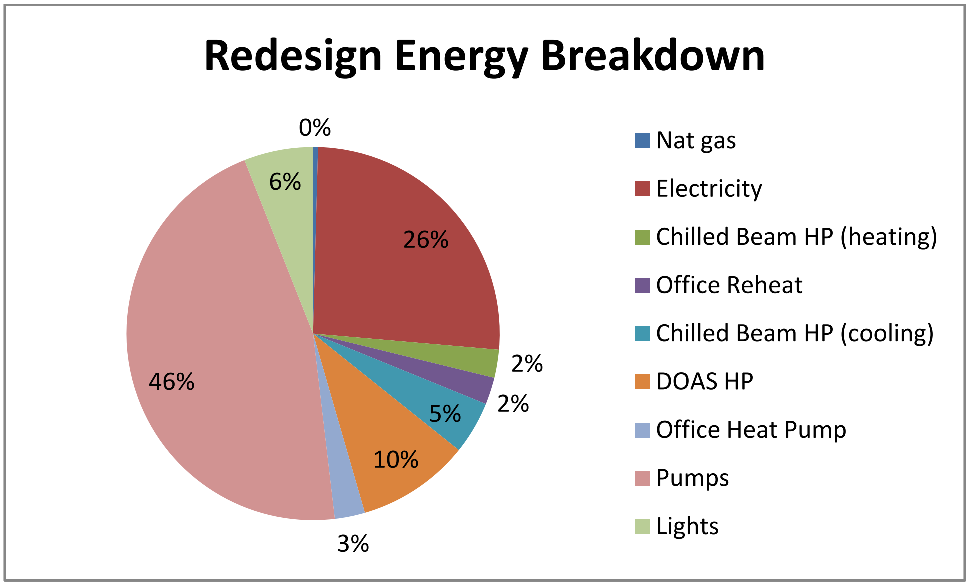

Figure 5: Energy Use Breakdown

Utility Rates

The Montgomery College New Science Center uses the following utility rates based on the rates for the entire campus:

Natural Gas: $1.54 per therm (2008)
Electric: $0.1321/kWh (2008 Projected)

These utility rates were used to compare the energy cost data and a system payback period in the cost section of this report.

COST ANALYSIS

Original Design Initial Cost

The initial or first costs of the Montgomery College New Science Center's original mechanical design were compiled from the 95% completion Cost Estimates. The unit cost estimates were summarized into 23 of the 33 CSI master format divisions, one of which being the HVAC division. This division is then broken down into the seven categories listed below. Each category is broken down into further detail, where every item, quantity, and associated cost is accounted for to receive the total first cost for the HVAC installation and equipment.

HVAC Cost Breakdown	
Building Square Footage	**140,700**
HVAC Piping	$954,940
Metal Duct	$3,208,661
Duct Accessories	$326,430
Heating and Ventilation Related Piping	$3,298,818
Heating and Cooling Equipment	$639,430
Controls and Regulations	$1,441,300
Testing and Balancing	$588,030
TOTAL HVAC FIRST COST	**$10,457,609**
HVAC Cost Per Square Foot	**$74.33**

Table 19: HVAC Cost Breakdown without

After the estimate was completed deductions were made to help mitigate the overall building cost. The majority of the deductions were accomplished by transferring parts of the budget to the FFE (Fixtures, Furnishings, and Equipment). The only other deductions to the cost were fulfilled by removing one cooling tower and selecting construction alternatives. Since a cooling tower was removed from the initial estimate the HVAC first cost was therefore recalculated.

TOTAL HVAC FIRST COST	$10,457,609
Deduction of Cooling Tower	$125,411
TOTAL HVAC FIRST COST WITH DEDUCTIONS	**$10,332,198**
HVAC Cost Per Square Foot	**$73.43**

Table 20: HVAC Cost with Deductions

The total initial HVAC cost with deductions is estimated to be $10.3 million. As a result the initial heating ventilation and air conditioning cost for the Montgomery College New Science Center results to approximately $73.43 per square foot.

Redesign Initial Cost

The redesign initial costs were calculated by a combination of manufactures quotes, engineering rules of thumb, unit costs, and assumptions made on the increased piping and decreased ductwork. Any assumptions made were based on the original 95% completion Cost Estimate.

DOAS HP	$446,400.00
ROOFTOP HP	$64,000.00
WATER TO WATER HP	$134,750.00
CHILLED BEAMS	$267,300.00
HEAT EXCHANGER	$7,500.00
PIPING	$1,909,880.00
LOOP PIPING	$96,000.00
PUMPS	$55,200.00
DUCTWORK	$3,110,880.08
AIR VALVES	$4,563,000.00
VAV BOXES	$144,000.00
CONTROLS	$1,441,300.00
TESTING AND BALANCING	$588,030.00
HVAC COSTS:	**$12,828,240.08**

Table 21: HVAC Redesign Initial Cost

The Montgomery College New Science Center mechanical system redesign was estimated at $12.8 million, approximately $91.18 per square foot. In comparison, the redesigned system will have an estimated initial cost of $2.5 million more than the original mechanical design. Therefore this system should only be selected over the original design, if the energy savings are of greater value to the owner than the initial cost of the system.

Energy Cost Comparison

The original mechanical system for the building was computed based on the $1.54 per therm and $0.1321 per kilowatt hour costs. These are the current prices per unit of energy for the entire Montgomery College Campus and would therefore directly apply to the building.

Table 22: Original Energy Cost gives a breakdown of the associated energy and cost for every component of the original design. The original design is estimated to cost the campus $1,046,706 per year in energy. The majority of the cost would be attributed to the direct acting heaters since 52^{o}F is reheated locally at every room.

In addition, the energy cost calculations were broken down into electrical cost and natural gas costs, due to the fact that the cost of electricity per MMBTU is much great, than the cost of natural gas and have varying associated costs.

Original System Design			
	MMBTU	**therms**	**$1.54/therm**
boilers	2,949	29,493	$45,419.11
Total Natural Gas	**2,949**	**29,493**	**$45,419.11**
	MMBTU	**kwh**	**$0.1321/kwh**
chillers	4,324	1,267,280	$167,407.66
direct acting heaters	9,239	2,707,690	$357,685.87
fan	3,617	1,060,092	$140,038.12
pump	5,142	1,506,884	$199,059.40
equipment	2,108	617,925	$81,627.95
Lights	1,433	419,896	$55,468.24
Total Electric	**25,863**	**7,579,767**	**$1,001,287.24**
Total Energy Cost			**$1,046,706.36**

Table 22: Redesign Energy Costs

The mechanical system redesign annual energy costs were calculated in the same manner of the original mechanical system annual energy costs. Table 23: Redesign Energy Costs shows how the energy costs breakdown within the system.

As expected the pumps occupy well over the majority of the energy costs. The new system is predominately hydronic, where a significant amount of pumps will be needed.

Overall the calculated energy costs for the new system were found to be $805,257 per year. This is over a 23% reduction for every year of operation.

System Redesign			
	MMBTU	**therms**	**$1.54/therm**
Nat gas	**88**	**876**	**$1,349.33**
	MMBTU	**kwh**	**$0.1321/kwh**
Electricity	5,404	1,583,702	$209,207.06
Chilled Beam HP (heating)	507	148,496	$19,616.27
Office Reheat	488	142,947	$18,883.34
Chilled Beam HP (cooling)	953	279,242	$36,887.90
DOAS HP	2,037	596,999	$78,863.56
Office Heat Pump	546	159,962	$21,131.01
Pumps	9,548	2,798,240	$369,647.55
Lights	1,248	365,797	$48,321.81
Total energy	**20,817**	**6,076,262**	**$803,907.83**
Total Energy Cost	**-**	**-**	**$805,257.16**

Table 23: Redesign Energy Costs

LEED NC ASSESSMENT

Leadership in Energy and Environmental Design (LEED) was created by the US Green Building Council to promote buildings that are environmentally responsible and provide a health place to work and/or live. LEED provides the building industry with a rating system. The rating system creates an economical incentive for building owners to become more "green", since the rating provides concrete evidence to the employees and inhabitants that the building is healthier and more environmentally friendly.

The LEED rating system is based on five major categories:

1. Sustainable Site
2. Water Efficiency
3. Energy and Atmosphere
4. Conserving Materials and Resources
5. Enhance Indoor Environmental Quality

These categories are broken down into individual points. This report focuses on but is not limited to the Energy and Atmosphere, and Enhanced Indoor Environmental Quality categories. The New Science Center also focused on these categories, where over ¾ of the points possible for the two categories are anticipated. Overall these two categories alone accomplish 60% of the anticipated points. The original mechanical design anticipates the following LEED points shown in Table 24: Original LEED Point Distribution.

Category	Points Anticipated	Possible Points
Sustainable Site	8	14
Water Efficiency	3	5
Energy and Atmosphere	**12**	**17**
Materials and Resources	4	13
Indoor Environmental Quality	**13**	**15**
Innovation and Design	2	5
Total	**42**	**69**

Table 24: Original LEED Point Distribution

Category	Points Anticipated	Possible Points
Sustainable Site	8	14
Water Efficiency	3	5
Energy and Atmosphere	**14**	**17**
Materials and Resources	4	13
Indoor Environmental Quality	**13**	**15**
Innovation and Design	2	5
Total	**44**	**69**

Table 25: Redesign LEED Point Distribution

Energy and Atmosphere

The Montgomery College New Science Center has designed to be a LEED building from the beginning. Establishing this goal as early as possible is vital in LEED design. Every step of the design process should be done with this goal in mind and design accordingly in order to achieve the LEED rating.

The building HVAC design focused on energy efficiency and overall reduction for both the system redesign and the original design. The New Science center's original mechanical design is estimated to reduce the energy cost by 28% compared to the ASHRAE 90.1 Baseline Building. This energy cost reduction equates to 8 out of the 10 points available for the Optimize Energy Performance Credit. The original design of the HVAC system left little room for improvement in energy performance, setting the bar extremely high. In spite of this, the redesigned system was able to reduce the energy costs by 41.22% over the baseline, obtaining 10 out of the 10 Optimize Energy Performance Credit points.

Photovoltaic panels are to be added to the roof towards the 2.5% of onsite renewable energy. These panels unfortunately are not anticipated to reach the 2.5% required. The panels will be used for educational purposes and in requesting innovation design credit for the educational apparatus for both the original mechanical design and the mechanical redesign.

The proper commissioning, refrigerants, and measurements will be used to gain the respective credits. In addition the university green power contract is anticipated to cover the required 35% green power.

Enhanced Indoor Environmental Quality

The New Science Center will have CO_2 sensors, MERV 8 filters, and low volatile organic compounds (VOC) materials. These features reduce the amount of air-born contaminants creating a healthier environment for the building occupants. The building will also be flushed out before occupancy, all towards bettering the air quality.

Individual lighting controls are provided to 90% of the occupants. This allows the occupants to maintain desired lighting while minimizing the energy use.

In order to achieve the thermal comfort controllability credit, thermal controls are provided for 50% of the occupants, which will be followed up with a post-occupancy survey and corresponding modifications.

A breakdown of all the LEED points, if it will be achieved, how it is planned to be accomplished, and which category it belongs to, can be found in Appendix D – LEED CREDIT BREAKDOWN.

CONCLUSIONS

The Montgomery College New Science Center mechanical system redesign was found to be over 27% more efficient than the original mechanical system design. This energy savings result in approximately $241,550 a year. The initial cost of the redesigned system was estimated to cost $2.5 million more. Therefore the payback for the new system compared to the original design would take slightly over ten years.

The redesigned system met the goals of improving the energy performance of the building through both the mechanical system and lighting. Unfortunately, the system was found to be significantly more expensive. Therefore, the system redesign may not be a favorable alternative to the original design.

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APPENDIX A – ASHRAE DESIGN CONDITIONS

2005 ASHRAE Handbook - Fundamentals (IP)

Design conditions for BALTIMORE, MD, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	1b	1c	1d	1e	1f	1g	1h	1i
BALTIMORE	724060	39.17N	76.67W	164	14.614	-5.00	NAE	7201

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	3a	3b	4a	4b	4c	4d	4e	4f	5a	5b	5c	5d	6a	6b
1	12.3	16.7	-3.5	4.6	16.4	1.1	5.8	20.8	27.3	33.0	24.9	30.9	8.8	270

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	8	9a	9b	9c	9d	9e	9f	10a	10b	10c	10d	10e	10f	11a	11b
7	18.7	93.6	75.0	90.8	74.3	88.2	73.1	78.1	88.3	76.9	86.4	75.8	84.3	10.5	280

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	12b	12c	12d	12e	12f	12g	12h	12i	13a	13b	13c	13d	13e	13f
75.4	133.6	82.4	74.1	128.0	81.2	72.9	122.9	80.1	93.8	88.7	92.5	88.4	91.4	84.8

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	14b	14c	15	16a	16b	16c	16d	17a	17b	17c	17d	17e	17f	17g	17h
23.0	19.6	17.7	84.6	97.8	4.8	3.0	6.3	100.0	0.3	101.7	-3.4	103.4	-7.0	105.6	-11.6

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	18b	18c	18d	18e	18f	18g	18h	18i	18j	18k	18l
0.4%	64.9	58.7	70.2	56.1	80.1	62.7	86.7	68.3	90.6	71.2	94.4	74.6
1%	61.7	56.1	65.8	54.6	76.6	60.0	83.0	64.9	88.4	69.8	92.7	74.2
2%	58.2	53.1	62.1	53.4	71.1	58.0	79.2	62.9	86.2	68.9	91.0	73.7

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	18n	18o	18p	18q	18r	18s	18t	18u	18v	18w	18x
0.4%	97.8	76.6	96.1	76.1	92.7	73.6	82.9	68.3	75.3	63.9	68.3	60.0
1%	96.0	76.2	94.1	75.6	90.2	73.2	80.2	67.2	72.6	61.8	66.0	58.8
2%	94.3	76.6	92.2	76.2	87.8	72.9	77.8	66.7	69.8	60.0	62.0	55.6

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	19b	19c	19d	19e	19f	19g	19h	19i	19j	19k	19l
0.4%	60.2	63.5	60.0	66.0	64.8	77.7	68.7	80.2	74.7	86.5	78.5	88.2
1%	57.6	61.3	57.4	62.7	62.4	72.4	67.3	78.4	73.3	83.9	77.3	87.1
2%	54.4	57.8	54.4	60.0	60.0	68.6	65.6	75.9	72.0	81.7	76.3	85.8

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	19n	19o	19p	19q	19r	19s	19t	19u	19v	19w	19x
0.4%	80.3	91.2	79.5	89.0	77.3	86.2	71.5	77.8	66.6	71.3	61.7	66.5
1%	79.3	90.5	78.4	88.1	76.3	84.7	70.5	76.4	64.7	68.9	59.5	63.1
2%	78.4	89.2	77.7	87.6	75.3	83.2	69.1	74.7	63.4	67.3	56.9	60.7

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	20b	20c	20d	20e	20f	20g	20h	20i	20j	20k	20l
15.3	16.7	18.2	20.1	20.0	18.5	18.7	18.2	18.3	20.0	18.2	16.8

APPENDIX B – IES.VE MODELING PROCEDURE

I. Assigning physical properties of the Building

Step 1

The three dimension building geometry/model is loaded into IES. For this report an Autodesk Revit Model was used. The Revit model can be imported directly into the IES software.

Complications are common and should be dealt with from Revit as opposed to IES due to the limited modeling capability the Model Builder IES provides. Every room was checked with the drawing set to verify location, orientation, and square footage. As expected some of the rooms did not match exactly. Modifications were made to geometry of the model to match the drawing set.

Step 2

Select the building location and orientation. This provides the correct weather and solar files for the building. The weather files offer hour by hour outdoor air information for the respective location. The solar files are used to calculate the solar gain and lighting into the building.

IES VE attained permission to use the ASHRAE design weather data of 2005. The ASHRAE percentiles should be entered and a monthly or annual profile should be selected.

To model the Montgomery College New Science Center an annual profile at 99.6% heating and 0.4% cooling was chosen for Baltimore Maryland. The actual New Science Center is to be located in Rockville Maryland. The closest location available through IES VE was chosen in order to model the building as accurate as possible with in the program limitations.

Step 3

The wall, roof, floor, window, and partition types/assemblies are known as the construction templates within IES VE. The construction templates are assigned automatically from the Revit model. As mentioned before, numerous complications arise when importing a Revit model into IES VE. The construction templates were altered to meet the construction drawing more accurately and any additional importing errors are corrected.

II. HVAC system of the Building

Numerous HVAC systems can be created for any particular model. This allows the several different systems to be calculated for the same building. Only one HVAC system was model, the designed model, was created for this report.

The IES VE Apache HVAC: HVAC Simulation Interface is used to simulate the Montgomery College New Science Center HVAC system. IES VE also provides a generic HVAC system. The Apache HVAC system was there for chosen to model the system as accurate to the drawings as possible.

Step 4

Each room is assigned a flow rate specified by the drawing set, by the use of a controller. The controller information requires a proportional bandwidth, maximum change per time set, minimum flow rate, and a maximum flow rate.

> Proportional Bandwidth: 1.00 ˚F
> Maximum Change per Time Set: 0.2
> Minimum Flow Rate: Set at a recommended 1/3rd of the maximum (conservative way to model the minimum air flow to the room)
> Maximum Flow Rate: CFM specified by drawings based on the diffusers

Spaces that are not supplied air are not modeled in the Apache HVAC system. These spaces still apply the space loads to the model, but do not require air to be supplied to the spaces directly and therefore are not used in the Apache HVAC schematic.

Step 5

Both exhaust and supply fans are incorporated into the modeled system in order to calculate the fan energy used. The fans modeled do not regulate, model, or simulate the flow rate. The fans can only be used to model the energy used.

The Montgomery College New Science Center HVAC system only utilizes an exhaust and supply fan. No return fan is used and therefore no return fan was modeled. Air is returned to the system but only by the draw of the supply fan.

Step 6

System components such as the boilers and chillers are required to be modeled but are not represented visually in the HVAC system. Information for the boilers and chillers is taken off of the drawings.

Boilers:	Load: 5220 kbtu/h	Chillers:	Output: 7320 ktbu/h
	Efficiency: 87%		COP at Temperature 1: 5.26
	Use of CHP: No		Temperature 1: 68 ˚ F

Fuel is assigned for both the boilers and chillers to track where and how much of the energy is used in the system.

Step 7

Heating and cooling coils are modeled in the system. The boilers and chillers are assigned to the respective coils. Both coils require the specification of a maximum duty (kbtu/h). A contact factor must also be entered for the cooling coil.

The maximum duties were determined by the summation of the values found on the drawing set. The contact factor was set at 0.8 (20% bypass) as recommended by the IES manual.

Step 8

Finally schedules are created for the occupancy, lights, room equipment, HVAC equipments, etc. These schedules are assigned accordingly to model the actual use of the building and HVAC system. This is a realistic representation of the building as opposed to simulating a building with all of the equipment and system used at all times.

As an example the office schedule are described below.

Office Schedules:

Most of the office weekly schedules have a different profile for the weekday than the weekend. The offices will be occupied during the week only. Schedules assigned to the lights, people, and equipment will follow the following schedules during the week and will be modeled at zero over the weekend.

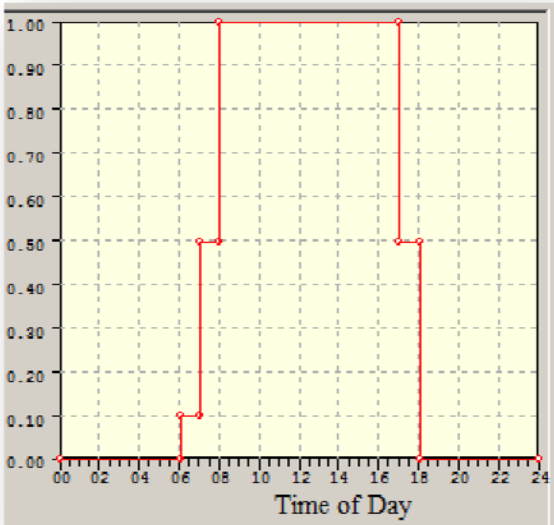


Figure 1: Lighting Schedule

This weekly profile represents the lighting schedule of the offices. The profile is progress since not all of the lights will be turned on at one particular time. Realistically all the lights will be off first thing in the morning and as more people enter the building more lights will be turned on until all of the lights are in use. 100% of the light use is estimated once the maximum occupancy has been reached at 8:00 AM.

The occupancy schedule shown above, similar to the lighting schedule is progressive to represent a more realistic progression to maximum occupancy. An estimated 20% decrease in occurs around the typical lunch hour. This schedule is used to represent the internal gain from the occupants that will be applied weekly for the entire year.

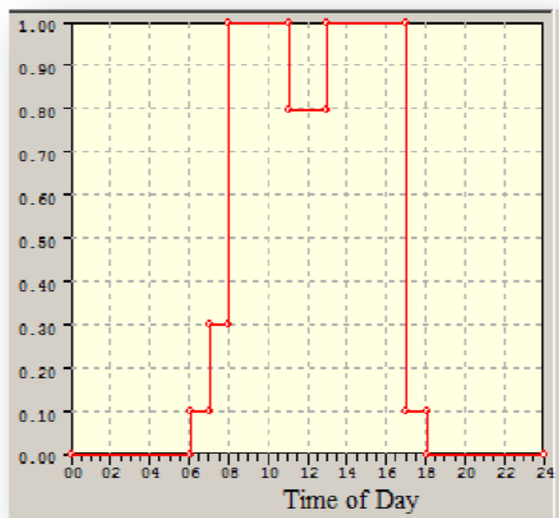


Figure 2: Occupancy Schedule

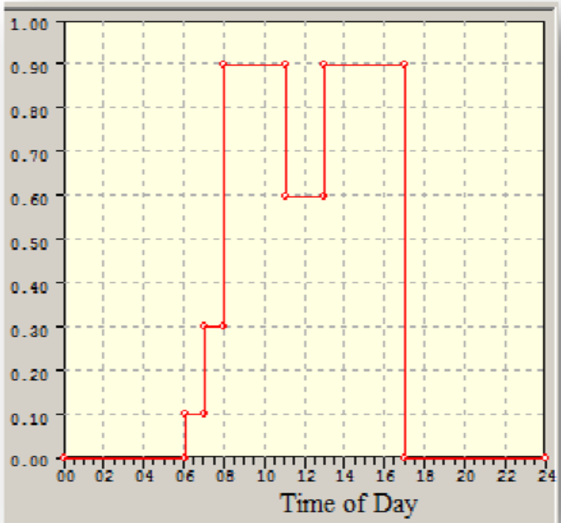


Figure 3: Equipment Schedule

The office equipment schedule follows the occupancy schedule most similarly. The only deviation is the equipment schedule drops to 60% over lunch assuming that even though some of the occupant will be in the office for lunch will not using the equipment as they would during regular business hours.

The equipment also never reaches 100% assuming that all offices computer, printers, etc. will not be used at the same time.

The cooling schedules for the rooms range from 74 degree F before and after occupancy to 77 degree F during occupancy.

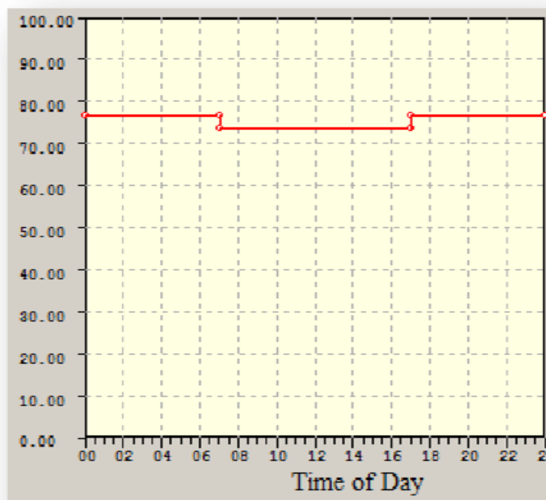


Figure 4: Cooling Schedule

The Apache HVAC system for the Montgomery College New Science Center as designed is shown below. The first four groups of rooms are the offices broken down floor by floor. The remaining four groups are the rest of the rooms of the New Science Center broken organized floor by floor in ascending order.

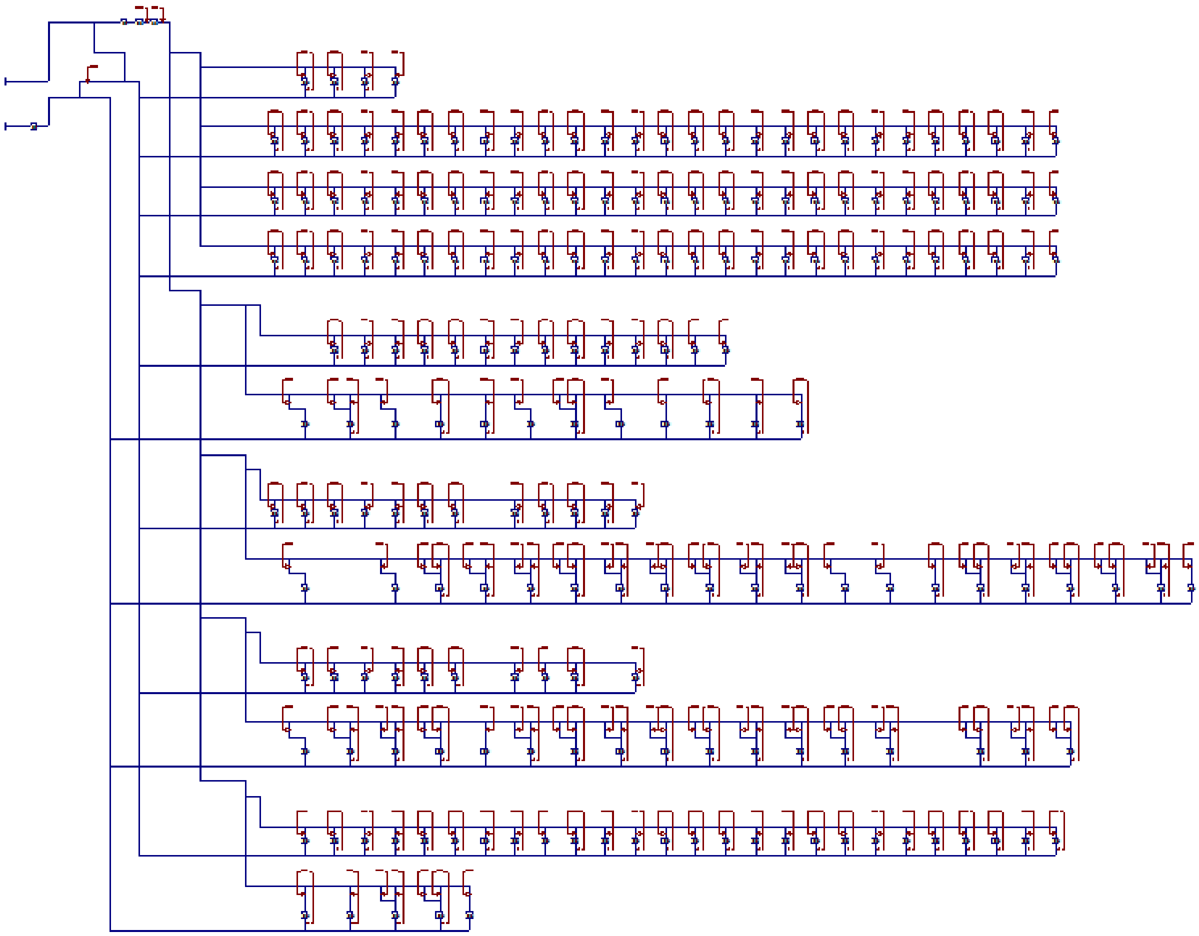


Figure 5: Apache HVAC System

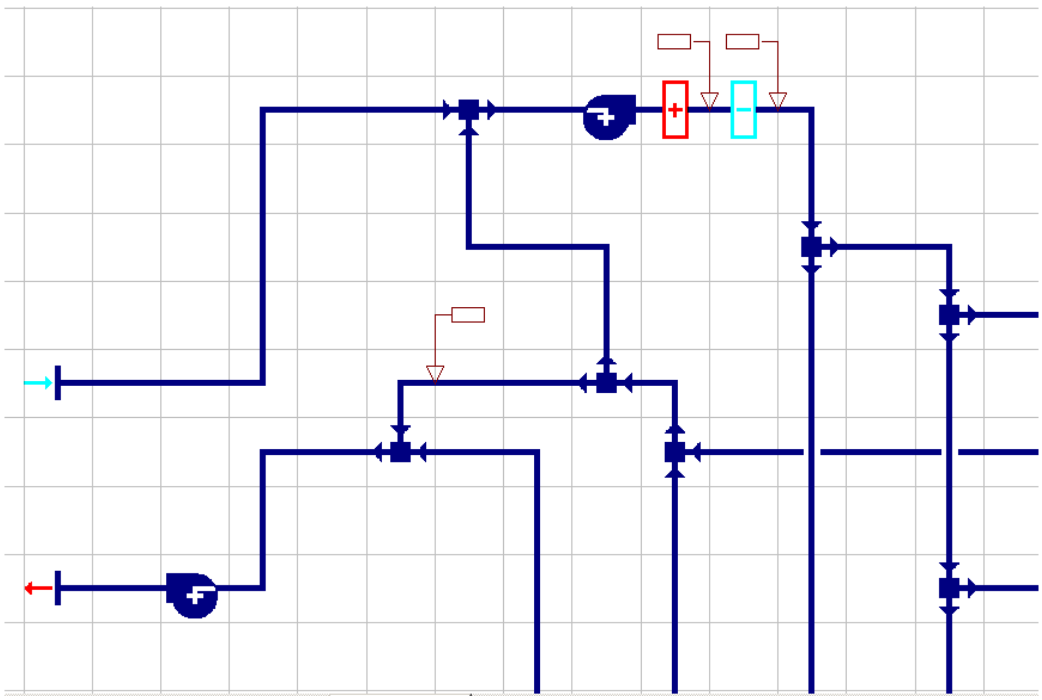


Figure 6: Enlarged HVAC Schematic – AHU View

The representative AHU shows one exhaust fan, supply fan, heating coil, and cooling coil. The components of the system were summed and represented by one component within the model.

In general the rooms were modeled as shown, where the control measures the flow rate across the room.

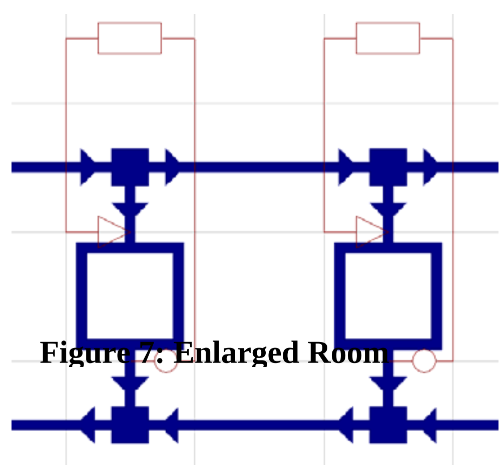


Figure 7: Enlarged Room

APPENDIX C – SYSTEM COMPONENTS

Air Handling Unit

Number	Mark	System Type	Capacity (CFM)			Components		
			SA	Design OA	Max. Vel			
2	AHU-1	VAV	66730	47140	500	Cooling Coil	Pre-heat Coil	Heat Recovery Coil

Cooling Coil

Number	CFM	Sensible kbtuh	Total kbtuh	Entering Dry Bulb	Entering Wet Bulb	Leaving Dry Bulb	Leaving Wet Bulb	Entering Water Temp	Leaving Water Temp	GPM
2	66730	2567	4264	85.3	71.8	52	52	42	60	474

Heating Coil

Number	CFM	Coil Capacity MBH	Entering Dry Bulb	Leaving Dry Bulb	Entering Water Temp	Leaving Water Temp	GPM
2	60270	951.5	35.9	65	180	160	95

Heat Recovery Coil								
Summer								
Number	Function	CFM	Coil Capacity MBH	Temp Efficiency	Entering Exhaust Air	Leaving Exhaust Air	Entering Outdoor Air	Leaving Outdoor Air
2	preheat	47140	537	51.3			95	84.7
2	heating	44000	537	55.5	75	86.1		
Winter								
Number	Function	CFM	Coil Capacity MBH	Temp Efficiency	Entering Exhaust Air	Leaving Exhaust Air	Entering Outdoor Air	Leaving Outdoor Air
2	preheat	32730	1266	61.7			14	49.8
2	heating	32730	1266	46.2	72	45.2		

Chiller										
					Evaporator			Condenser		
Number	Tons	KW	KW/ TON	NPLV	GPM	Entering Water Temp	Leaving Water Temp	GPM	Entering Water Temp	Leaving Water Temp
2	305	204	0.669	0.448	410	60	42	580	85	100

Boiler					
Number	MBH in	MBH out	GPM	Entering Water Temp	Leaving Water Temp
2	3000	2610	260	160	180

Cooling Tower				
Number	GPM	Entering Air Wet Bulb	Leaving Water Temp	Entering Water Temp
2	500	78	85	100

Laboratory Exhaust Fans				
Number	Type	CFM	RPM	BHP
4	High Plume	24200	1000	38.6

APPENDIX D – LEED CREDIT BREAKDOWN

		LEED™ Credit Description	Possible Credits	Expected Score	Under Review	Not Possible
Sustainable Sites	SSp 1	Erosion and Sedimentation Control		R		
	SS 1	Site Selection - Avoid Inappropriate Sites	1	1		
	SS 2	Development Density & Community Connectivity	1		1	
	SS 3	Brownfield Development	1			1
	SS 4.1	Alternative Transportation- Public Access	1	1		
	SS 4.2	Alternative Transportation- Bicycles	1	1		
	SS 4.3	Alternative Transportation- Fuel-efficient vehicles	1	1		
	SS 4.4	Alternative Transportation- Parking	1	1		
	SS 5.1	Reduced Site Disturbance- Habitat	1		1	
	SS 5.2	Reduced Site Disturbance- Development	1		1	
	SS 6.1	Storm Water Management- Rate & Quantity	1		1	
	SS 6.2	Storm Water Management- Quality Control	1		1	
	SS 7.1	Reduce Heat Island- Non-roof	1	1		
	SS 7.2	Reduce Heat Island- Roof	1	1		
	SS 8	Light Pollution Reduction	1	1		
		SUBTOTAL - SS POINTS	14	8	5	1

Water	WE 1.1	Water Efficient Landscaping- 50% reduction	1	1		
	WE 1.2	Water Efficient Landscaping- No potable	1	1		
	WE 2	Innovative Wastewater Technologies	1			1
	WE 3.1	Water Use Reduction	1	1		
	WE 3.2	Water Use Reduction	1			1
		SUBTOTAL - WE POINTS	5	3	0	2

		LEED™ Credit Description	Possible Credits	Expected Score	Under Review	Not Possible
Energy and Atmosphere	EAp 1	Fundamental Commissioning		R		
	EAp 2	Minimum Energy Performance		R		
	EAp 3	CFC Reduction in HVAC&R Equipment		R		
	EA 1	Optimize Energy Performance (10.5% - 42%)	10	9	1	
	EA 2.1	Renewable Energy- 2.5%	1		1	
	EA 2.2	Renewable Energy- 7.5%	1			1
	EA 2.3	Renewable Energy- 12.5%	1			1
	EA 3	Enhanced Commissioning	1	1		
	EA 4	Enhanced Refrigerant Management	1	1		
	EA 5	Measurement & Verification	1	1		
	EA 6	Green Power	1	1		
		SUBTOTAL - EA POINTS	17	13	2	2
Conserving Materials & Resources	MRp 1	Storage and Collection of Recyclables		R		
	MR 1.1	Building Reuse- 75% Shell	1			1
	MR 1.2	Building Reuse- 95% Shell	1			1
	MR 1.3	Building Reuse- 50% nonshell	1			1
	MR 2.1	Construction Waste- 50%	1	1		
	MR 2.2	Construction Waste- 75%	1	1		
	MR 3.1	Resource Reuse- 5%	1			1
	MR 3.2	Resource Reuse- 10%	1			1
	MR 4.1	Recycled Content- 10%	1	1		
	MR 4.2	Recycled Content- 20%	1		1	
	MR 5.1	Regional Materials- 10%	1	1		
	MR 5.2	Regional Materials- 20%	1		1	
	MR 6	Rapidly Renewable Materials	1		1	
	MR 7	Certified Wood	1		1	
		SUBTOTAL - MR POINTS	13	4	4	5

		LEED™ Credit Description	Possible Credits	Expected Score	Under Review	Not Possible
Enhance Indoor Environmental Quality	EQp 1	Minimum IAQ Performance		R		
	EQp 2	Environmental Tobacco Smoke Control		R		
	EQ 1	Outdoor Air Delivery Monitoring	1	1		
	EQ 2	Increased Ventilation	1	1		
	EQ 3.1	Construction IAQ- During Construction	1	1		
	EQ 3.2	Construction IAQ- Before Occupancy	1	1		
	EQ 4.1	Low-Emitting Materials- Adhesives/Sealants	1	1		
	EQ 4.2	Low-Emitting Materials- Paints and Coatings	1	1		
	EQ 4.3	Low-Emitting Materials- Carpet	1	1		
	EQ 4.4	Low-Emitting Materials- Composite wood/agrifiber	1	1		
	EQ 5	Indoor Chemical Pollution Source Control	1	1		
	EQ 6.1	Controllability of Systems- Lighting	1	1		
	EQ 6.2	Controllability of Systems- Thermal Comfort	1	1		
	EQ 7.1	Thermal Comfort- Design	1			1
	EQ 7.2	Thermal Comfort- Verification	1	1		
	EQ 8.1	Daylighting	1			1
	EQ 8.2	Views	1		1	
		SUBTOTAL - EQ POINTS	15	12	1	2
Innovation in Design	ID 1.1	Innovation Credit	1	1		
	ID 1.2	Innovation Credit	1		1	
	ID 1.3	Innovation Credit	1		1	
	ID 1.4	Innovation Credit	1			1
	ID 2	LEED accredited Designer	1	1		
		SUBTOTAL - ID POINTS	5	2	2	1
		TOTAL POINTS	69	42	14	13
LEED	Certified	26 - 32 Points				
	Silver	33 - 38 Points				
	Gold	39 - 51 Points				
	Platinum	52 or more Points				

APPENDIX E – DESIGNER VENTILATION RATES

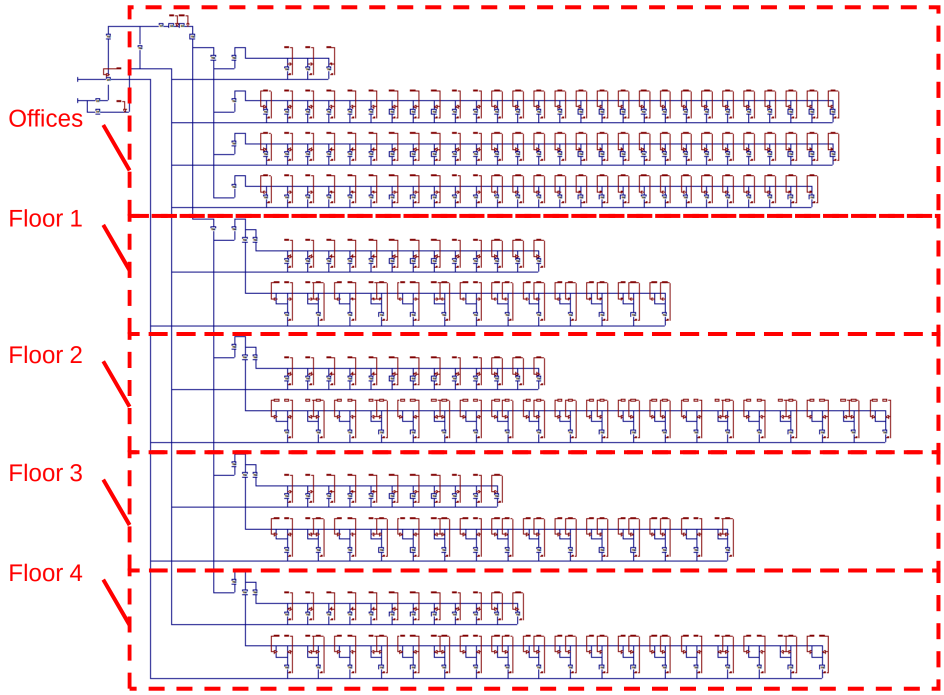
Room Information						Hood calculation					Airflow		
Level	Room Name	Room No.	SF	Occup.	Clg. Hgt.	# Large Hoods	Hood L.F.	# Small Hoods	Hood L.F.	Hood CFM (150 CFM/L.F.)	Design Airflow (CFM)	Design Airflow w/ Perimeter (CFM)	Min Set Point 25% of Max (CFM)
1	Lounge	A109	400 NSF		9.50						300.0	330.0	82.5
1	Vending	A110	168 NSF		9.50						126.0	138.6	34.7
1	Bio Tech Office	A121a	100 NSF	1	9.50						75.0	82.5	20.6
1	Animal Receiving	A121b	90 NSF		9.50						213.8	235.1	58.8
1	Animal Holding	A121c	92 NSF		9.50						218.5	240.4	60.1
1	Green House	A122	744 NSF		9.50						558.0	613.8	153.5
1	Head House/Storage	A122a	294 NSF		9.50						220.5	242.6	60.6
1	Biology Stock Room	B126	748 NSF		9.50						561.0	617.1	154.3
1	Classroom (30 seats)	A105	713 NSF	30	9.50						552.0	552.0	138.0
1	Classroom (50 seats)	A106	878 NSF	50	9.50						869.2	869.2	217.3
1	Classroom (30 seats)	A107	635 NSF	30	9.50						533.2	533.2	133.3
1	Environmental Science Lab Recitation	B124	842 NSF	24	9.50						459.0	459.0	114.7
1	Anatomy / Physiology Lab Recitation	B140	842 NSF	24	9.50						459.0	459.0	114.7
1	Environmental Recitation	B142	842 NSF	24	9.50						459.0	459.0	114.7
1	Biology Lab Preparation	A121	532 NSF		9.50	2	6.0			1,800.0	1,800.0	1,980.0	495.0
1	Environmental Science Lab	B123	1,283 NSF	24	9.50	1	6.0			900.0	1,555.2	1,710.7	427.7
1	Environmental Science Lab	B125	1,283 NSF	24	9.50	1	6.0			900.0	1,555.2	1,710.7	427.7
1	Volatile Chemistry Storage & Dispensary	B132	119 NSF		9.50			1.0	4.0	0.0	142.8	157.1	39.3
1	Anatomy / Physiology Lab	B139	1,283 NSF	24	9.50					0.0	1,555.2	1,710.7	427.7
1	Anatomy / Physiology Lab	B141	1,283 NSF	24	9.50					0.0	1,555.2	1,710.7	427.7
1	General Biology Lab	B143	1,283 NSF	24	9.50	1	6.0			900.0	1,555.2	1,710.7	427.7
1	House Keeping	A114	103 NSF		9.50						77.3	85.0	21.2
1	Server Room	B127	188 NSF		9.50						141.0	155.1	38.8
1	IT Staging & Repair	B129	307 NSF		9.50						230.3	253.3	63.3
1	Hazardous Material Waste	B131	117 NSF		9.50						87.8	96.5	24.1
1	Hazardous Material Supply	B133	117 NSF		9.50						87.8	96.5	24.1
1	Receiving	B134	604 NSF		9.50						453.0	498.3	124.6
1	Skeleton Closet	B138	167 NSF		9.50						125.3	137.8	34.4
1	Conference Room	A108	286 NSF	12	9.50						214.5	236.0	59.0
	Totals		15,808	315		5		1		4,500	16,739.8	18,080.4	

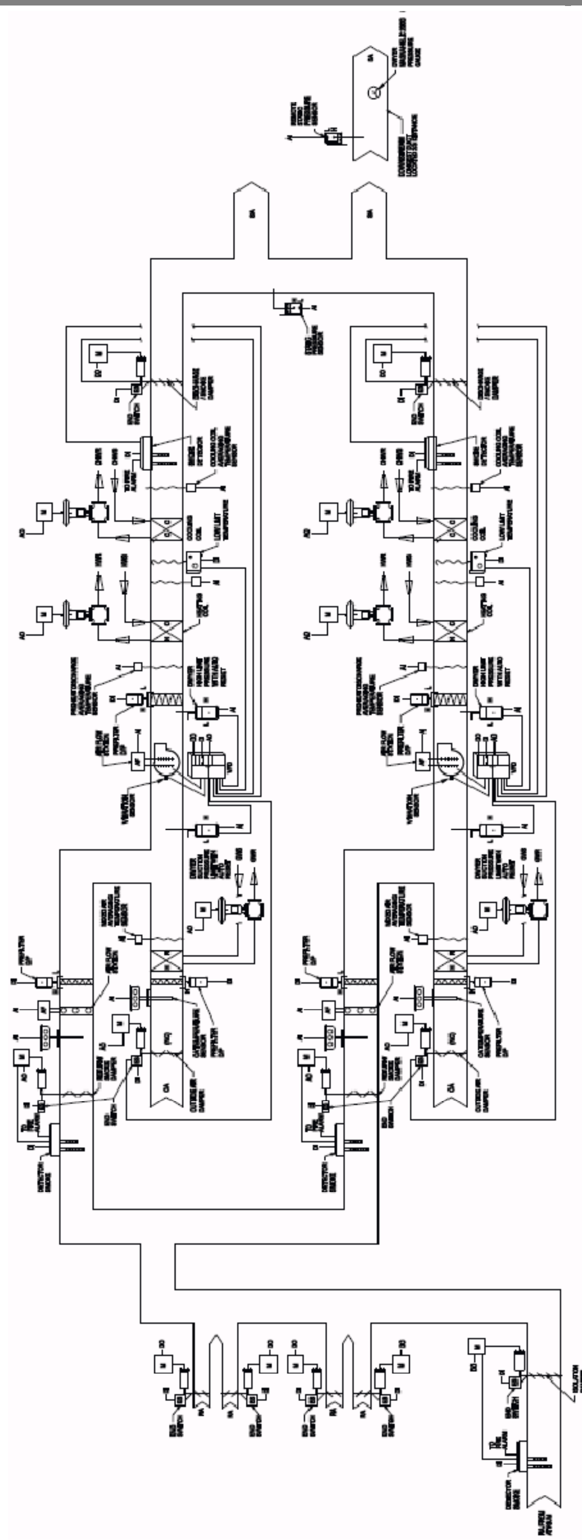
Room Information						Hood calculation					Airflow			
Level	Room Name	Room No.	SF	Occup.	Clg. Hgt.	# Large Hoods	Hood L.F.	# Small Hoods	Hood L.F.	Hood CFM (150 CFM/L.F.)	Design Airflow (CFM)	Design Airflow w/ Perimeter (CFM)	Min Set Point 25% of Max (CFM)	Reheat (kBtu/hr)
2	Bio Tech Office	A202a	113 NSF	1	9.50						84.8	93.2	23.3	2.0
2	Bio Tech Office	A206a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Part-Time Faculty Office	A207a	115 NSF	2	9.50						86.3	94.9	23.7	2.0
2	Bio Part-Time Faculty Office	A207b	115 NSF	2	9.50						86.3	94.9	23.7	2.0
2	Bio Part-Time Faculty Office	A207c	115 NSF	2	9.50						86.3	94.9	23.7	2.0
2	Bio Part-Time Faculty Office	A207d	115 NSF	2	9.50						86.3	94.9	23.7	2.0
2	Bio Faculty Office	A208a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208b	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208c	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208d	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208e	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208f	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208g	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208h	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208i	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208j	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208k	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208l	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208m	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208n	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208o	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208p	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208q	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Faculty Office	A208r	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Administrative Assistant	A209	112 NSF	1	9.50						84.0	92.4	23.1	2.0
2	Bio Chair	A210	237 NSF	1	9.50						177.8	195.5	48.9	4.2
2	Bio Receptionist	A211	214 NSF	1	9.50						160.5	176.6	44.1	3.8
2	Bio Work Room	A213	100 NSF		9.50						75.0	82.5	20.6	1.8
2	Process Room	A222a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Tech Office	B226a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Bio Study / Reference	B229	367 NSF	12	9.50						275.3	302.8	75.7	6.5
2	Bio Tech Office	B232a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
2	Microbiology Genetics Recitation	A204	664 NSF	24	9.50						464.3	464.3	116.1	10.0
2	Environmental Recitation	B224	635 NSF	24	9.50						457.3	457.3	114.3	9.9
2	Biology Recitation	B228	638 NSF	24	9.50						458.0	458.0	114.5	9.9
2	Environmental Recitation	B234	623 NSF	24	9.50						454.4	454.4	113.6	9.8
2	Microbiology Lab Preparation	A202	985 NSF		9.50	2	6.0			1,800.0	1,800.0	1,980.0	495.0	42.8
2	Biology Lab Preparation	A206	524 NSF		9.50	2	6.0			1,800.0	1,800.0	1,980.0	495.0	42.8
2	Biology Lab Preparation	B226	525 NSF		9.50	2	6.0			1,800.0	1,800.0	1,980.0	495.0	42.8
2	Biology Lab Preparation	B232	525 NSF		9.50	2	6.0			1,800.0	1,800.0	1,980.0	495.0	42.8
2	Microbiology Lab	A203	1,285 NSF	24	9.50	4	6.0			3,600.0	3,600.0	3,960.0	990.0	85.5
2	Genetics Lab	A205	1,285 NSF	24	9.50	3	6.0			2,700.0	2,700.0	2,970.0	742.5	64.2
2	Biology Student / Facility Project Lab	A222	622 NSF	12	9.50			1	4.0	600.0	746.4	821.0	205.3	17.7
2	Cold Room	A222b	211 NSF	1	9.50			2	4.0	1,200.0	1,200.0	1,320.0	330.0	28.5
2	General Biology Lab	B223	1,281 NSF	24	9.50	1	6.0			900.0	1,537.2	1,690.9	422.7	36.5
2	General Biology Lab	B225	1,284 NSF	24	9.50	1	6.0			900.0	1,540.8	1,694.9	423.7	36.6
2	General Biology Lab	B227	1,299 NSF	24	9.50	1	6.0			900.0	1,558.8	1,714.7	428.7	37.0
2	General Biology Lab	B230	1,287 NSF	24	9.50	3	6.0			2,700.0	2,700.0	2,970.0	742.5	64.2
2	General Biology Lab	B231	1,282 NSF	24	9.50	3	6.0			2,700.0	2,700.0	2,970.0	742.5	64.2
2	General Biology Lab	B233	1,282 NSF	24	9.50	2	6.0			1,800.0	1,800.0	1,980.0	495.0	42.8
2	General Biology Lab	B235	1,281 NSF	24	9.50	2	6.0			1,800.0	1,800.0	1,980.0	495.0	42.8
2	Bio File Storage	A212	100 NSF		9.50						75.0	82.5	20.6	1.8
	Totals		21,421	371		28		3		27,000	33,844.4	37,045.4		

Room Information						Hood calculation					Airflow			
Level	Room Name	Room No.	SF	Occup.	Clg. Hgt.	# Large Hoods	Hood L.F.	# Small Hoods	Hood L.F.	Hood CFM (150 CFM/L.F.)	Design Airflow (CFM)	Design Airflow w/ Perimeter (CFM)	Min Set Point 25% of Max (CFM)	Reheat (kBtu/hr)
3	Chem Tech Office	A306a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Part-Time Faculty Office	A307a	115 NSF	2	9.50						86.3	94.9	23.7	2.0
3	Chem Part-Time Faculty Office	A307b	115 NSF	2	9.50						86.3	94.9	23.7	2.0
3	Chem Part-Time Faculty Office	A307c	115 NSF	2	9.50						86.3	94.9	23.7	2.0
3	Chem Part-Time Faculty Office	A307d	115 NSF	2	9.50						86.3	94.9	23.7	2.0
3	Chem Faculty Office	A308a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308b	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308c	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308d	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308e	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308f	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308g	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308h	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308i	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308j	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308k	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308l	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308m	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308n	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308o	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308p	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Faculty Office	A308q	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chem Admin	A309	112 NSF	1	9.50						84.0	92.4	23.1	2.0
3	Chem Chair	A310	237 NSF	1	9.50						177.8	195.5	48.9	4.2
3	Chem Receptionist	A311	214 NSF	1	9.50						160.5	176.6	44.1	3.8
3	Chem Work Room	A313	100 NSF		9.50						75.0	82.5	20.6	1.8
3	Chem Tech Office	A322a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chemistry Oxbridge Room	B329	367 NSF	12	9.50						275.3	302.8	75.7	6.5
3	Tech Office	B332a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
3	Chemistry Recitation	A304	701 NSF	24	9.50						473.2	473.2	118.3	10.2
3	Chemistry Recitation	A306	632 NSF	24	9.50						457.3	457.3	114.3	9.9
3	Chemistry Recitation	B324	635 NSF	24	9.50						127.1	127.1	31.8	2.7
3	Chemistry Lab Prep	A322	620 NSF		9.50			1.0	4.0	600.0	744.0	818.4	204.6	17.7
3	Chemistry / Stock Room	A322b	202 NSF		9.50			1.0	4.0	600.0	600.0	660.0	165.0	14.3
3	Chemistry Stock Room	B326	642 NSF		9.50			1.0	4.0	600.0	770.4	847.4	211.9	18.3
3	Organic Chemistry Instrumentation	B328	640 NSF		9.50			1.0	4.0	600.0	768.0	844.8	211.2	18.2
3	Chemistry Prep	B332	502 NSF		9.50			1.0	4.0	600.0	602.4	662.6	165.7	14.3
3	Chem Lab Prep	B334	525 NSF		9.50			1.0	4.0	600.0	630.0	693.0	173.3	15.0
3	Chemistry Student / Facility Project Lab & Prep	A302	1,202 NSF		9.50			2.0	4.0	1,200.0	1,442.4	1,586.6	396.7	34.3
3	General Chemistry Lab	A303	1,287 NSF	24	9.50	6	6.0	1.0	4.0	6,000.0	6,000.0	6,600.0	1,650.0	142.6
3	General Chemistry Lab	A305	1,285 NSF	24	9.50	6	6.0	1.0	4.0	6,000.0	6,000.0	6,600.0	1,650.0	142.6
3	General Chemistry Lab	B323	1,285 NSF	24	9.50	6	6.0	1.0	4.0	6,000.0	6,000.0	6,600.0	1,650.0	142.6
3	General Chemistry Lab	B325	1,286 NSF	24	9.50	6	6.0	1.0	4.0	6,000.0	6,000.0	6,600.0	1,650.0	142.6
3	Organic Chemistry Lab	B327	1,328 NSF	24	9.50	5	6.0	1.0	4.0	5,100.0	5,100.0	5,610.0	1,402.5	121.2
3	Organic Chemistry Lab	B330	1,287 NSF	24	9.50	7	6.0	1.0	4.0	6,900.0	6,900.0	7,590.0	1,897.5	163.9
3	Organic Chemistry Lab	B331	1,308 NSF	24	9.50	8	6.0	1.0	4.0	7,800.0	7,800.0	8,580.0	2,145.0	185.3
3	General Chemistry Lab	B333	1,284 NSF	24	9.50	6	6.0	1.0	4.0	6,000.0	6,000.0	6,600.0	1,650.0	142.6
3	General Chemistry Lab	B335	1,282 NSF	24	9.50	6	6.0	1.0	4.0	6,000.0	6,000.0	6,600.0	1,650.0	142.6
3	Chem File	A312	100 NSF		9.50						75.0	82.5	20.6	1.8
	Totals		21,523	331		56		17		60,600	65,107.3	71,512.2		

Room Information						Hood calculation					Airflow			
Level	Room Name	Room No.	SF	Occup.	Clg. Hgt.	# Large Hoods	Hood L.F.	# Small Hoods	Hood L.F.	Hood CFM (150 CFM/L.F.)	Design Airflow (CFM)	Design Airflow w/ Perimeter (CFM)	Min Set Point 25% of Max (CFM)	Reheat (kBtu/hr)
4	Phy/EE Tech Office	A402a	98 NSF	1	9.50						73.5	80.9	20.2	1.7
4	Phy/EE Part-Time Faculty Office	A407a	115 NSF	2	9.50						86.3	94.9	23.7	2.0
4	Phy/EE Part-Time Faculty Office	A407b	115 NSF	2	9.50						86.3	94.9	23.7	2.0
4	Phy/EE Part-Time Faculty Office	A407c	115 NSF	2	9.50						86.3	94.9	23.7	2.0
4	Phy/EE Part-Time Faculty Office	A407d	115 NSF	2	9.50						86.3	94.9	23.7	2.0
4	Phy/EE Faculty Office	A408a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408b	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408c	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408d	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408e	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408f	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408g	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408h	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408i	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408j	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408k	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408l	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408m	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408n	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408o	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408p	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Faculty Office	A408q	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Phy/EE Admin	A409	112 NSF	1	9.50						84.0	92.4	23.1	2.0
4	Phy/EE Chair	A410	237 NSF	1	9.50						177.8	195.5	48.9	4.2
4	Phy/EE Receptionist	A411	214 NSF	1	9.50						160.5	176.6	44.1	3.8
4	Phy/EE Work Room	A413	100 NSF		9.50						75.0	82.5	20.6	1.8
4	Phy/EE Tech Office	A422a	100 NSF	1	9.50						75.0	82.5	20.6	1.8
4	Tech Office	B427a	101 NSF	1	9.50						75.8	83.3	20.8	1.8
4	EE / Phy Oxbridge Room	B429	368 NSF	8	9.50						276.0	303.6	75.9	6.6
4	Astronomy Computer Lab	A404	665 NSF	24	9.50						464.5	464.5	116.1	10.0
4	Engineering Science Computer	B424	848 NSF	24	9.50						508.8	508.8	127.2	11.0
4	Engineering Science Computer Lab / Studio	B425a	414 NSF	12	9.50						252.0	252.0	63.0	5.4
4	Engineering Science Computer	B425b	855 NSF	24	9.50						510.5	510.5	127.6	11.0
4	Physics Recitation	B432	630 NSF	24	9.50						456.1	456.1	114.0	9.9
4	Geosciences Lab Prep Room	A402	768 NSF		9.50					0.0	921.6	1,013.8	253.4	21.9
4	Geosciences Reference / Workroom	A402b	311 NSF		9.50					0.0	373.2	410.5	102.6	8.9
4	Lapidary / Power Tool Room	A406	630 NSF		9.50					0.0	756.0	831.6	207.9	18.0
4	Physics Lab Prep Room	A422	834 NSF		9.50	1	6.0			900.0	1,000.8	1,100.9	275.2	23.8
4	Physics Student Workroom	B423a	414 NSF		9.50					0.0	496.8	546.5	136.6	11.8
4	Engineering Lab Shop	B427	1,068 NSF		9.50					0.0	1,281.6	1,409.8	352.4	30.5
4	Engineering Prep Lab	B428a	428 NSF		9.50					0.0	513.6	565.0	141.2	12.2
4	Engineering Student/Faculty Project Lab	B428b	640 NSF		9.50					0.0	768.0	844.8	211.2	18.2
4	Astronomy / Physical Science Lab	A403	1,287 NSF	24	9.50					0.0	1,544.4	1,698.8	424.7	36.7
4	Astronomy / Physical Science Lab	A405	1,287 NSF	24	9.50					0.0	1,544.4	1,698.8	424.7	36.7
4	EE / Phy Lab	B430	1,287 NSF	24	9.50					0.0	1,544.4	1,698.8	424.7	36.7
4	General Physics Lab	B431	1,285 NSF	24	9.50					0.0	1,542.0	1,696.2	424.1	36.6
4	General Physics Lab	B433	1,284 NSF	24	9.50					0.0	1,540.8	1,694.9	423.7	36.6
4	Geology / Collections Room	B434	638 NSF	6	9.50					0.0	765.6	842.2	210.5	18.2
4	Geology / Meterology Lab	B435	1,284 NSF	24	9.50					0.0	1,540.8	1,694.9	423.7	36.6
4	Phy/EE File	A412	100 NSF		9.50						75.0	82.5	20.6	1.8
4	Physics / Engineering Stock Room	B423b	855 NSF		9.50						641.3	705.4	176.3	15.2
4	Laptop Storage	B426a	99 NSF		9.50						74.3	81.7	20.4	1.8
4	Engineering Project Storage	B426b	312 NSF		9.50						234.0	257.4	64.4	5.6
			0	0		1				900	20,943.4	22,818.6		

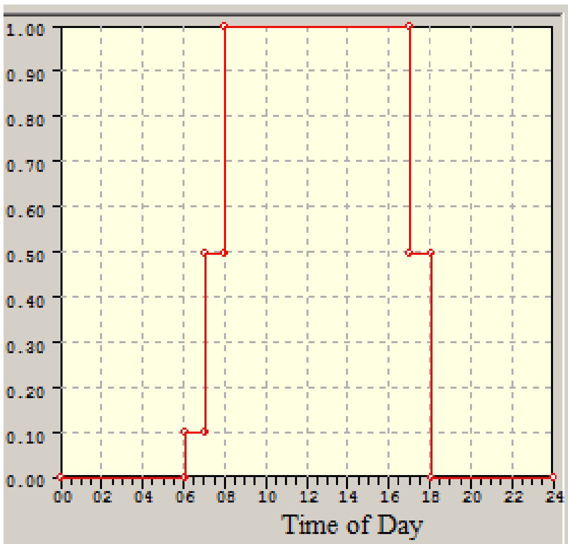
APPENDIX F – SCHEMATICS





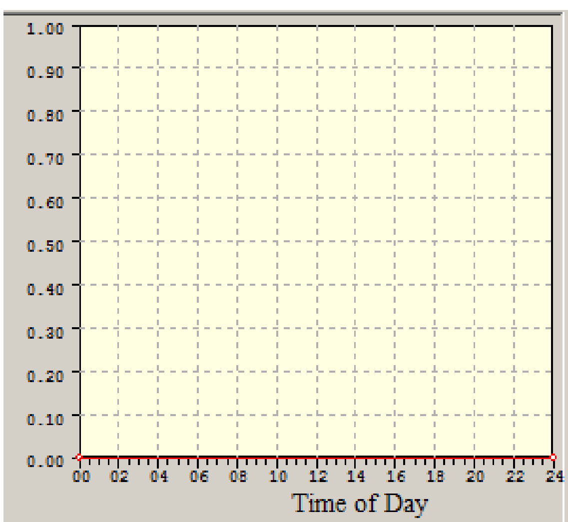
APPENDIX G – LIGHTING SCHEDULES

Office Weekday Lighting Schedule



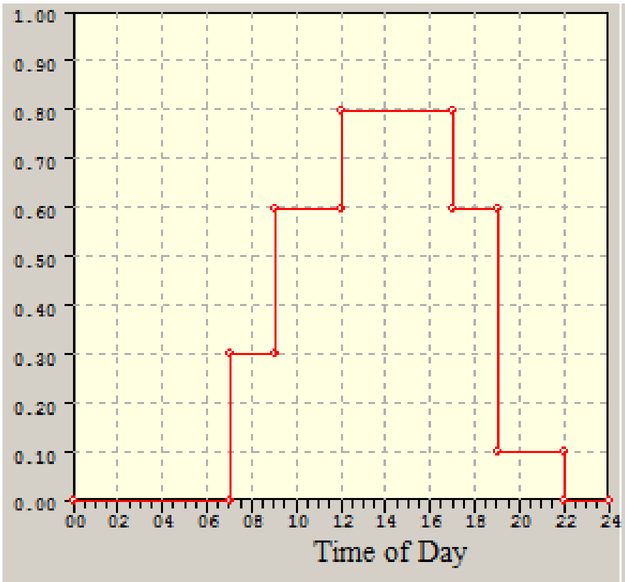
0%	12:00 AM - 6:00 AM
10%	6:00 AM - 7:00 AM
50%	7:00 AM - 8:00 AM
100%	8:00 AM – 5:00 PM
50%	5:00 PM – 6:00 PM
0%	6:00 PM – 12:00 AM

Office Weekend Lighting Schedule



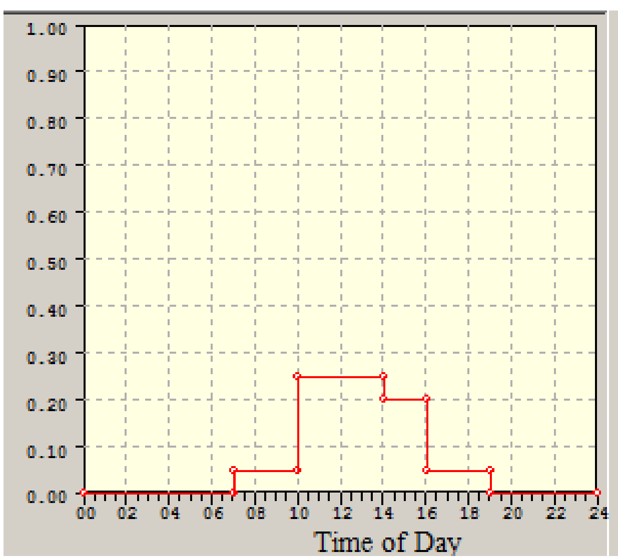
0%	12:00 AM – 12:00 AM

Lab Weekday Lighting Schedule



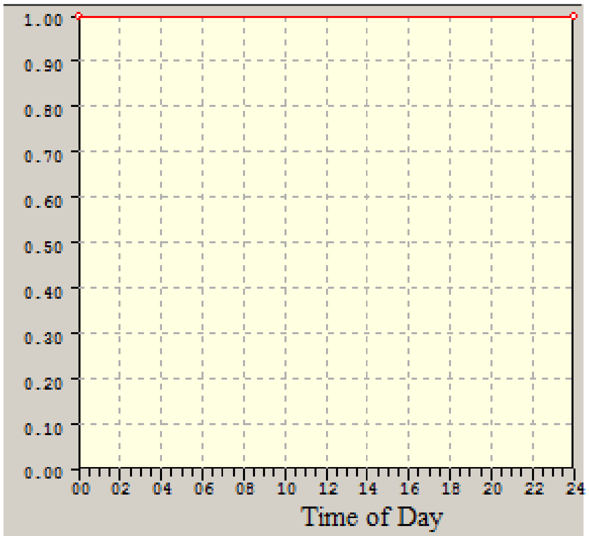
0%	12:00 AM - 7:00 AM
30%	7:00 AM - 9:00 AM
60%	9:00 AM – 12:00 PM
80%	12:00 PM – 5:00 PM
60%	5:00 PM – 7:00 PM
10%	7:00 PM – 10:00 AM
0%	10:00 PM -12:00 AM

Lab Weekend Lighting Schedule



0%	12:00 AM – 7:00 AM
5%	7:00 AM – 10:00 AM
25%	10:00 AM – 2:00 PM
20%	2:00 PM – 4:00 PM
5%	4:00 PM – 7:00 PM
0%	7:00 PM – 12:00 AM

Corridor/ Utility Lighting Schedule



100%	12:00 AM – 12:00 AM

APPENDIX H – ACOUSTICAL TILE

Armstrong

SUSPENDED CEILINGS

DATASHEET

CASA

PRIMA PRODUCT RANGE SUSPENDED CEILING BOARDS

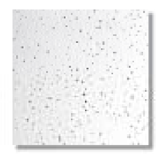
PRODUCT DESCRIPTION

Mineral wool suspended ceiling boards, with fillers like: pearlite, cellulose, clay and starch. The boards are covered with dispersion paints, colorless on their back side, with white micro-perforated surface.

APPLICATION

ARMSTRONG suspended ceilings have a wide scope of application in building industry: in residential, administrative and industrial buildings such as offices, banks, trading centers, hotels, restaurants, sports halls, fitness centers, education buildings, etc.

SPECIFIC PROPERTIES OF ARMSTRONG SUSPENDED CEILINGS



- 10 years manufacturer's guarantee for PRIMA product range suspended ceiling.
- Long term aesthetic appearance;
- Notable improvement of acoustics and good indoor environment;
- Fast and easy to assemble;
- Considerable increase in fire resistance time of the buildings;
- Harmless to man, no requirements for special means of protection;
- Not an environment for rodents and micro-organisms;
- Dimensionally stable;
- Lightweight and easily handled.

PACKING

Cardboard boxes, with the name of the manufacturer and the basic product data printed on the label.

DIMENSIONS, PRODUCT RANGE AND PACKING

Edge Details	Symbol	Thickness (mm)	Length (mm)	Width (mm)	m²/pack	Weight / m²
	Board	15	600	600	5.76	3.50
		15	1200	600	7.20	3.50
	Tegular	15	600	600	5.04	3.50
	Microlook	15	600	600	5.76	3.50

TECHNICAL PARAMETERS

<table>
<tr><th>Typical Features</th><th>Symbol</th><th colspan="3">Value</th><th colspan="3">Unit</th><th>Standard</th></tr>
<tr><td>Reaction to fire</td><td>A_1</td><td colspan="3">Non combustible</td><td colspan="3">-</td><td>EN 13501-1</td></tr>
<tr><td>Fire resistance of horisontal carrier construction</td><td>-</td><td colspan="3">60</td><td colspan="3">min</td><td>EN 13501-2</td></tr>
<tr><td>Relative humidity at 40° C</td><td>RH</td><td colspan="3">95</td><td colspan="3">%</td><td>ISO 7724-2</td></tr>
<tr><td>Light reflection</td><td>100 Lux</td><td colspan="3">83</td><td colspan="3">%</td><td>DIN 5036, Part. 3</td></tr>
<tr><td>Stability of sizes 48h, 35°C</td><td>-</td><td colspan="3">≤ 1</td><td colspan="3">%</td><td>EN 1604</td></tr>
<tr><td>Water absorption 24h short dipping</td><td>W_p</td><td colspan="3">≤ 1</td><td colspan="3">kg/m²</td><td>EN 1609</td></tr>
<tr><td>Thermal resistance coefficient</td><td>λ_D</td><td colspan="3">0.052 - 0.057</td><td colspan="3">W / m.K</td><td>EN 12667/ISO 8302</td></tr>
<tr><td rowspan="2">Sound absorption coefficient α_s (20cm suspended ceiling)</td><td>Hz</td><td>125</td><td>250</td><td>500</td><td>1000</td><td>2000</td><td>4000</td><td rowspan="2">EN ISO 20354</td></tr>
<tr><td>α_s / δ = 15mm</td><td>0.35</td><td>0.40</td><td>0.50</td><td>0.60</td><td>0.60</td><td>0.55</td></tr>
<tr><td>Average sound absorption coefficient</td><td>α_w</td><td colspan="3">0.60</td><td colspan="3">-</td><td>EN ISO 20354</td></tr>
<tr><td>Average noise reduction coefficient</td><td>NRC</td><td colspan="3">0.55</td><td colspan="3">-</td><td>ASTM C 423 REV A</td></tr>
<tr><td>Acoustic insulation coefficient</td><td>Dncw</td><td colspan="3">35</td><td colspan="3">dB</td><td>EN ISO 20 140 - 9</td></tr>
<tr><td>Bulgarian Technical Approval</td><td colspan="3">Protocol № 04.65 / 01.12.2004г.</td><td colspan="4">SRICM, Sofia</td><td>EN 13 964</td></tr>
<tr><td>Sanitary Permit</td><td colspan="8">RD № 856/13.12.2004 by Bulgarian Ministry of Health</td></tr>
<tr><td>Quality Management System</td><td colspan="3">Certificate № 653562 / 07.05.2002</td><td colspan="4">Lloyd's Register Quality Assurance (LRQA)</td><td>ISO 9001:2000</td></tr>
</table>

Any information contained in this datasheet describes the product properties applicable as at the time of issue. With respect to continuous development of these materials, changes to their properties may take place from time to time.

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SIPER

APPENDIX I – ROOM ACOUSTICS BREAKDOWN

0.7- 1.1		Area	Absorbtion Coefficient		Sα	
Typical Laboratory B335	**Material**	**square feet**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**
Wall 1	1 Layer of 5/8" gypboard	405.27	0.08	0.04	32.42	16.211
Wall 2	1 Layer of 5/8" gypboard	299.25	0.08	0.04	23.94	11.97
Wall 3	Wood Door	45	0.05	0.04	2.25	1.8
	1 Layer of 5/8" gypboard	360.27	0.08	0.04	28.82	14.411
Wall 4	Glass	142.5	0.18	0.12	25.65	17.1
	1 Layer of 5/8" gypboard	156.75	0.08	0.04	12.54	6.27
Ceiling	2x4 Acoustical Ceiling Tile	1343.79	0.6	0.65	806.3	873.46
Floor	Trowel Epoxy	1343.79	0.015	0.02	20.16	26.876
Volume	**12,766.01**	**cubic feet**		A:	952.1	968.1
				T60:	**0.66**	**0.65**

0.7- 1.1	NEW	Area	Absorbtion Coefficient		Sα	
Typical Laboratory B335	**Material**	**square feet**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**
Wall 1	1 Layer of 5/8" gypboard	405.27	0.08	0.04	32.42	16.211
Wall 2	2 Layer of 5/8" gypboard	299.25	0.04	0.02	11.97	5.985
Wall 3	Wood Door	45	0.05	0.04	2.25	1.8
	1 Layer of 5/8" gypboard	360.27	0.08	0.04	28.82	14.411
Wall 4	Glass	142.5	0.18	0.12	25.65	17.1
	2 Layer of 5/8" gypboard	156.75	0.04	0.02	6.27	3.135
Ceiling	Armstrong Suspended Ceiling	1343.79	0.5	0.6	671.9	806.27
Floor	Trowel Epoxy	1343.79	0.015	0.02	20.16	26.876
Volume	**12,766.01**	**cubic feet**		A:	799.4	891.79
				T60:	**0.78**	**0.70**

0.7- 1.1		Area	Absorbtion Coefficient		Sα	
Typical Classroom	Material	square feet	500 Hz	1000 Hz	500 Hz	1000 Hz
Wall 1	Glass	25	0.18	0.12	4.5	3
	Wood Door	70	0.05	0.04	3.5	2.8
	2 Layers of 5/8" gypboard	194.75	0.04	0.02	7.79	3.895
Wall 2	1 Layer of 5/8" gypboard	334.4	0.08	0.04	26.75	13.376
Wall 3	Glass	80	0.18	0.12	14.4	9.6
	1 Layer of 5/8" gypboard	209.75	0.08	0.04	16.78	8.39
Wall 4	1 Layer of 5/8" gypboard	334.4	0.08	0.04	26.75	13.376
Ceiling	2x4 Acoustical Ceiling Tile	1073	0.6	0.65	643.8	697.45
Floor	Epoxy Terrazzo	1073	0.015	0.02	16.1	21.46
Volume	10,193.50	cubic feet		A:	760.4	773.35
				T60:	0.66	0.65

0.7 - 1.1	NEW	Area	Absorbtion Coefficient		Sα	
Typical Classroom	Material	square feet	500 Hz	1000 Hz	500 Hz	1000 Hz
Wall 1	Glass	25	0.18	0.12	4.5	3
	Wood Door	70	0.05	0.04	3.5	2.8
	2 Layers of 5/8" gypboard	194.75	0.04	0.02	7.79	3.895
Wall 2	1 Layer of 5/8" gypboard	334.4	0.08	0.04	26.75	13.376
Wall 3	Glass	80	0.18	0.12	14.4	9.6
	2 Layer of 5/8" gypboard	209.75	0.04	0.02	8.39	4.195
Wall 4	1 Layer of 5/8" gypboard	334.4	0.08	0.04	26.75	13.376
Ceiling	Armstrong Suspended Ceiling	1073	0.5	0.6	536.5	643.8
Floor	Epoxy Terrazzo	1073	0.015	0.02	16.1	21.46
Volume	10,193.50	cubic feet		A:	644.7	715.5
				T60:	0.77	0.70

0.7- 1.1		Area	Absorbtion Coefficient		Sα	
Typical Office A208C	Material	square feet	500 Hz	1000 Hz	500 Hz	1000 Hz
Wall 1	1 Layer of 5/8" gypboard	114	0.08	0.04	9.12	4.56
Wall 2	Wood door	22.5	0.05	0.04	1.125	0.9
	1 Layer of 5/8" gypboard	72.5	0.08	0.04	5.8	2.9
Wall 3	1 Layer of 5/8" gypboard	114	0.08	0.04	9.12	4.56
Wall 4	glass	25.5	0.18	0.12	4.59	3.06
	2 Layers of 5/8" gypboard	69.5	0.04	0.02	2.78	1.39
Ceiling	2x4 Acoustical Ceiling Tile	120	0.6	0.65	72	78
Floor	Carpet Tile	120	0.14	0.57	16.8	68.4
Volume	1140	cubic feet		A:	121.335	163.77
				T60:	0.46	0.34

0.7- 1.1	NEW	Area	Absorbtion Coefficient		Sα	
Typical Office A208C	Material	square feet	500 Hz	1000 Hz	500 Hz	1000 Hz
Wall 1	2 Layer of 5/8" gypboard	114	0.04	0.02	4.56	2.28
Wall 2	Wood door	22.5	0.05	0.04	1.125	0.9
	2 Layer of 5/8" gypboard	72.5	0.04	0.02	2.9	1.45
Wall 3	2 Layer of 5/8" gypboard	114	0.04	0.02	4.56	2.28
Wall 4	glass	25.5	0.18	0.12	4.59	3.06
	2 Layers of 5/8" gypboard	69.5	0.04	0.02	2.78	1.39
Ceiling	Light velour, 10oz/yd2	16	0.11	0.17	1.76	2.72
	Armstrong Suspended Ceiling	104	0.5	0.6	52	62.4
Floor	Epoxy Terrazzo	120	0.015	0.02	1.8	2.4
Volume	1140	cubic feet		A:	76.075	78.88
				T60:	0.73	0.71