FINAL REPORT

LANDSCAPE BUILDING

AT

JANELIA FARM
HOWARD HUGHES MEDICAL INSTITUTE

ASHBURN, VIRGINIA

PREPARED FOR
DR. BAHNFLETH
BY
JULIE THORPE
MEHCANICAL OPTION
APRIL 7, 2006

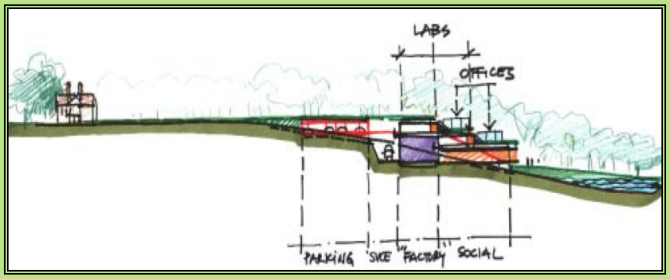
TABLE OF CONTENTS

HOWARD HUGHES MEDICAL INSTITUTE AT JANELIA FARM

Ashburn, VA

ARCHITECTURE

- ◈World Class Biomedical Research Facility to promote unconstrained scientific research.
- ◈ 546,436 SF, 3-story building carved into a hillside overlooking the Potomac River.
- ◈ Triple-glazed glass façade and green roof.



PROJECT INFORMATION

- ◈ **Owner:** Howard Hughes Medical Institute.
- ◈ **Architect**: Rafael Vinoly.PC.
- ◈ **PM:** Jacobs Facilities, Inc.
- ◈ **MEP:** Burt Hill Kosar Rittleman Assoc.
- ◈ **Structural:** Thorton Tomasetti Engr.
- ◈ **Delivery Method:** Fast-Track Bid-Build.
- ◈ **Estimated Building Cost:** $500 Million.

MECHANICAL SYSTEM

- ◈ 44,828 MBH total heating load.
- ◈ 5,479 ton total cooling load.
- ◈ VAV with reheat coils in all spaces.
- ◈ (1) 50,210 MBH & (2) 30,125 MBH boilers.
- ◈ (2) 28,339 & (1) 1,251 MBH heat exchangers.
- ◈ (7) 1,200 ton chillers & one back up.
- ◈ $3.5M Operating Cost.

ELECTRICAL SYSTEM

- ◈ Primary 34.5kV, 600A, 3Φ, 3 wire service from Old Dominion Electric.
- ◈ 4 Substations with VPI 3000kVA dray transformers step down to 277/480V, 3Φ, 4 wire service.

STRUCTURAL SYSTEM

- ◈ 6 in to 24 in Concrete Slab Floor.
- ◈ Reinforced Concrete and Masonry Walls.
- ◈ Structural and Post-Tensioned Beams and Columns.
- ◈ Structural Glass windows in the garden courtyards/atriums.

JULIE THORPE

MECHANICAL OPTION

◈ www.arche.psu.edu/thesis/eportfolio/current/portfolios/jat280/ ◈

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank those who have supported me throughout my Penn State career.

I would first like to thank my mom for raising me a Nittany Lion and instilling me the importance of a balanced education. Also, I would like to thank her for listening to my endless phone calls when school was overwhelming.

Secondly, I would like to thank the love of my life Nate Patrick for being with me every step of the way. I could not have done it without him, nor would it have been as much fun. I love you!

I have been blessed with having some of my best friends in class with me for the past four years. Roni, Pappy, and "SENK" have truly made going to school every day something to look forward to. I will always remember our crazy times together and I wish them all luck in the future.

I would like to thank Sam Snyder for his words of encouragement and willingness to help me with my thesis project.

The Architectural Engineering faculty and staff have created a wonderful environment for students to learn and grow. A special thanks to Moses who has blessed me with insight into everything from the building industry to faith, and also provided me with a paycheck for the past year and half. I need to give big thanks and hug to Sharron for feeding me and for always being a delight to talk to. Thanks for all your hard work!

I would like to thank my professional contacts for their assistance throughout the course of the thesis experience. Scott Suktis of Burt Hill and John Lecker of Jacobs Facilities for providing me with information and guidance.

My collegiate experience would not be complete without the group of people I will always feel apart of. Thank you Class of 2006. I have truly enjoyed the past five years, except for that whole "work" thing we had to do.

Lastly, I would like to give God all the credit for guiding me into the AE program and for giving me the endurance and ability to succeed.

EXECUTIVE SUMMARY

The Landscape Building at Janelia Farm Research Campus is a 546,436 square foot world-class biomedical research facility owned by Howard Hughes Medical Institute. The facility is built into the side of a large hill overlooking the Potomac River on the grounds of the historic Janelia Farm Mansion. It is currently beginning its third year of construction in Ashburn, Virginia located 45 minutes outside of Washington, D.C.

The mechanical system was designed with the goal of adequately conditioning and ventilating all spaces and at the same time being located in such a way that maintenance will never interfere with the research projects. All equipment is located outside of the laboratory area for ease of maintenance.

The mechanical system is a variable air volume system that provides 100% outdoor air. There are 15 air handling units that serve on large plenum. This plenum in tern distributes the air throughout the building. There are 5 chillers and 3 boilers that are used condition the air as well as meet other loads such as, steam for sterilizing laboratory equipment, chilled water for cold rooms, and chilled water for the data center cooling.

For the laboratory spaces alone, the total cooling load is 684 tons and the heating load is 2,602MBU. At peak load there is 181,933 CFM providing 100% outdoor air to 81,456 square feet of laboratory space. Existing design documents state 20 W/SF equipment loads for all laboratory and laboratory spaces. Lighting loads range anywhere from 0 W/SF for specialized rooms to over 5 W/SF. All lamps in the lab spaces are fluorescent.

This report examines the actual mechanical and lighting design of the laboratory spaces and their supporting spaces and compares them to the actual design criteria. It was found that most spaces are over designed and that simply following design guidelines can drastically reduce annual operation costs.

Ground coupled loops were evaluated to see if they were economically feasible. The closed-loop ground system was not feasible due to extremely large first costs, but the open-loop system utilizing two existing ponds was found to be the best option. The original campus design proved to be very conducive for installing such a system without many additional costs.

The final analysis for this report was to determine if the new equipment installed in the mechanical room presented a problem for adjacent spaces. Again, the original architectural plan proved well designed as there are no critical spaces in the vicinity of the mechanical room.

PROJECT BACKGROUND

JANELIA FARM RESEARCH CAMPUS

Figure 1

Janelia Farm Campus is designed to be a world-class biomedical research facility to achieve the long-term goal of promoting unconstrained scientific research. It is located on the outskirts of the Washington Metropolitan Area in Ashburn, VA. Howard Hughes Medical Research Medical Institute was chartered in Delaware on December 17, 1953. The charter states: "The primary purpose and objective of the HHMI shall be the promotion human knowledge within the field of the basic sciences (principally the field within the field of medical research and medical education) and the effective application thereof the benefit of mankind." The institute provides grants for international research scholars world-wide. $49.7 million in grants to strengthen education programs were awarded to colleges and medical schools, as well as to public schools, grades K-12. After 52 years of conducting research on over 70 university campuses across the United States, HHMI decided to build its own facility. The design is guided by four principles:

- Understand the researchers' needs versus their preferences
- Focus the planning effort on what will or could happen versus what is happening today
- Keep work spaces standardized and rational
- Make the work spaces adaptable over time to accommodate changes in research

In order to realize these goals, HHMI conceptualized a facility where scientists, engineers, and information technology professions from all over the world could gather and reside. There are three buildings on campus, the Landscape Building, the short-term stay Conference Center, and Long-term housing townhouses, all of which are located surrounding a pond. The focus of this thesis project will be the Landscape Building.

The Landscape Building is the laboratory/office building. The first floor contains office space, conference rooms, auditoriums, dinning facilities, a vivarium, and mechanical equipment rooms. The second and third floors are dedicated to laboratory space and adjacent offices.

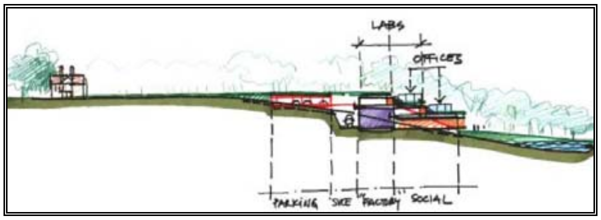


Figure 2

ARCHITECTURE

Janeilia Farm is a 281 acre farm which features a "modified French-style manor" built in 1936 by Philip Smith from Smith and Walker of Boston. It is one of Virginia's last country estates based on European country manors. The house is protected by the National Trust for Historic Preservation. In addition, the view from the dinning room window of Sugarloaf Mountain in Fredrick County, Maryland is also protected. Therefore, any building on this site needed to preserve both the house and the view.

As a result of the historic requirements for the site, the architect RVA designed the building to be an extension of the hill on which the Mansion is built. This prevents the protected view of Sugar Loaf Mountain to be maintained and essentially put the building completely underground from all but the south perspective. The view of the mountain is framed by the 4 exhaust stacks.

It is a three-story structure with two upper lab floors and a meeting-service floor at the bottom level. The lab floors are stepped back creating terrace space where the office pods are located. Two glass-encased stairs radially cross the building connecting the ground floor to the roof terrace. There is also a 300 car-parking garage located behind the labs on the third floor.

The entire length of the 900ft façade runs a glass corridor giving daylighting and picturesque views to the labs spaces opposite the corridor. The building is based on the idea of the strong relationship between lab and office space. Vinoly placed the office pods on the terraced roofs, each one having three exterior glass walls. Behind these pods are large lab spaces designed to be common space for the different research groups to share. The biochemistry lab spaces are designed to be extremely flexible, with lab equipment and chemical and gas connections easily moved around without costly renovations. Adjacent to the labs are smaller support rooms such as cold rooms, dark rooms, isotope labs, chemical storage space, along with general rooms of various sizes. Behind this support belt is the equipment service corridor that runs the length of the building. Along this corridor is a 6ft band housing all MEP equipment. It was designed so that when maintenance is necessary; all work can be done outside the lab space. This is beneficial for both the maintenance crew and scientist. The draw back is the cost to set such a great amount of space aside for MEP services. There are also large areas that will be used as future expansion space.

BUILDING SYSTEMS

STRUCTURAL

The structural system for the Landscape Building is a combination of reinforced concrete, reinforced masonry walls, structural steel, and post-tensioned steel. The foundation is comprised of trellis post footings ranging in bearing pressure from 4KSF up to 40 KSF. The slab on grade rangers from 6" to 24." For example, slab 4, zone C on the foundation level has a thickness of 2'. The majority of columns on level 1 are concrete columns with a few composite columns. The second level floor system is concrete, with radial beams primarily 18x44 and 20x42, and longitudinal beams are 16x24 with few major exceptions. A combination of steel and concrete is used in the third and fourth floor systems. The radial concrete beams as either 20x56 towards the inner area of the building and 18x44 in the outer area. There are four rows of longitudinal columns consisting of 24x56, 20x36, and 20x44 beams. All radial steel beams are 60 psi W36x135 and smaller W14x22 both 14' o.c. The longitudinal beams on the outer edge are W12x19. 45k/ft tendons are located between column lines C and E for the entire length of the building. Steel columns range in size from W14 to W30 of varying strengths.

Concrete shear walls are typically normal weight concrete wit f'c = 5000psi and are 1' thick. Typical reinforcement is #4@12. The Pod structural system is all steel. Beams range from W8x15 to W14x 53 and HSS 5x5x5/8 to HHS 10x5x5/8. There are four cantilevers in each pod roof. The auditorium has 2' thick concrete walls. For the tier construction, 1-1/2" MD + 2-1/2" concrete supported on 8" thick reinforced block wall is used. The four mechanical shafts are made with 9" thick concrete walls on the third level. On the fourth 8x8x3/8 tubular steel with HHS 8x8x1/2 columns are added.

TELECOMMUNICATIONS

The Landscape Building has a EIA/TA 568-B compliant cabling system to support high speed data applications up to and in excess of 1000Mbs including IEEE system standards+ based on TPDDI, Ethernet, Fast Ethernet, Gigabit Ethernet and ATM. Each office pod has raised access floor for the routing of cables. There are two category 6 4-pair cables to each telecommunications outlet at each workstation in the office spaces.

TRANSPORTATION

There are 6 standard elevators for human transport and one clean elevator and 1one dirty elevator for substances and animals. There is also a freight elevator. The building is divided into three equal sections by two feature staircases that go from ground level to the root-top terrace. In addition there are five service stairwells throughout the building. On the third floor there is a 300 car parking garage behind the lab spaces.

ACOUSTICS

HHMI specified three spaces types that have required NC ratings. Auditoriums need to be NC-25 and seminar rooms need to be NC-30. This is achieved by 1" thick internal acoustical lining on all low pressure ductwork (full extent downstream of terminal unit) and ½" thick internal acoustical lining on all diffuser plenums. Additionally, all ductwork in and around the space has been lined with dry wall. Conference rooms and private offices are required to be NC-35. This ductwork has 1" this internal acoustical lining, and either a) if less than 1200CFM, there is a minimum distance of 10 FT between downstream outlet of terminal unit and each diffuser or b) if greater than or equal to 1200 CFM, there is a minimum distance of 15 FT.

EXISTING MECHANICAL CONDITIONS

SYSTEM LOCATION

The need to separate the mechanical and electrical systems and equipment from the laboratory, office, and other primary occupied spaces was the principal design consideration. HHMI researched and studied many other scientific campuses around the world, such as the Medical Research Council Laboratory of Molecular Biology (MRC LMB) in Cambridge, England, Cold Spring Harbor Laboratory, the European Molecular Biology Laboratory, the Carnegie Institution of Washington's Department of Embryology, and AT&T's Bell Laboratories in Murray Hill, New Jersey. After concluding existing building studies, HHMI determined that in order for the scientists and researchers to perform at the highest levels, it would be necessary to locate all mechanical and electrical equipment and controls to isolated areas. This allows maintenance to be done without entering laboratory or office space and therefore, research can be continued uninterrupted.

As seen in the first floor rendering below, the light gray band below is the service corridor. All rooms below that corridor are mechanical space and the majority of rooms shaded gray are mechanical space as well.

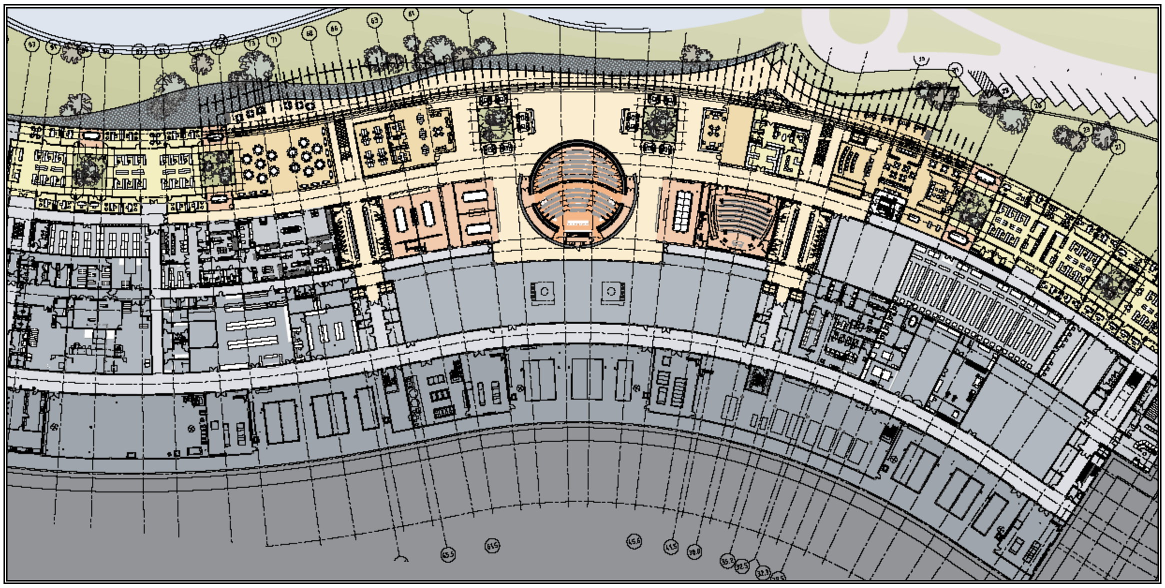


Figure 1 : First Floor Plan

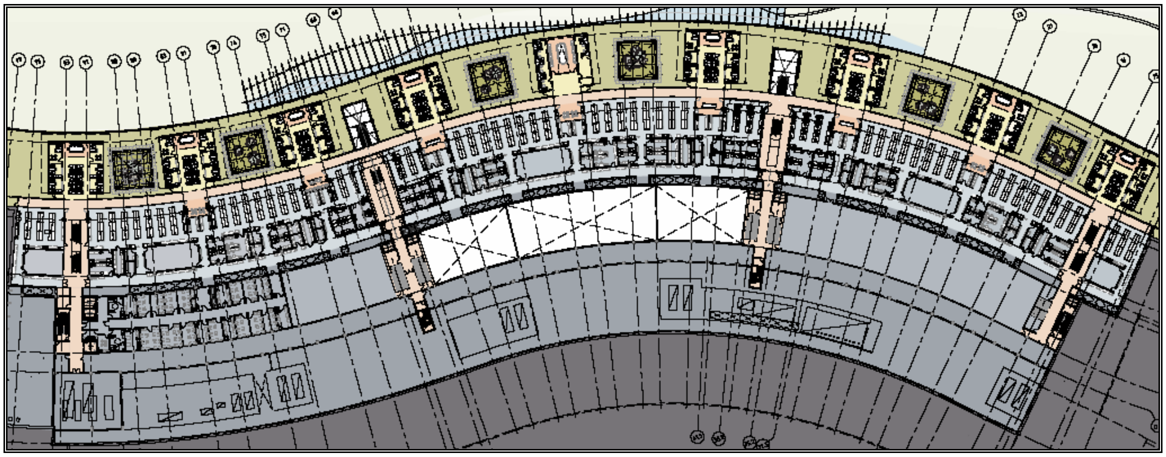


Figure 2 : Second Floor Plan

The bottom fourth of the second floor is completely dedicated to mechanical systems. The third floor is almost identical to the second. Some of the spaces are two stories in height. Approximately 220,235 square feet of useable space is dedicated to mechanical systems. This is 49.5% of the building's total area. Clearly HHMI was more concerned about providing an excellent working environment for the medical experts than the cost of using so much space for systems.

Table 1

Floor	Mechanical Area [sf]	Total Area [sf]	Percent Lost
First	147,773	240,461	61.5
Second	46,049	122,649	37.5
Third	26,413	82,013	32.2
Total	**220,235**	**445,123**	**49.5**

DESIGN OBJECTIVES

Central boiling and chiller plants are used to provide central heating and cooling to the entire building. The data rooms are the only spaces that have a parallel system to meet cooling loads. Due to the nature of the building, 100 percent outdoor air is required to dilute any hazardous matter in the air and to decrease the risk of contamination between spaces. Supply air must pass through a prefilter and filer on the upstream side with efficiencies of 30% and 95% respectively, based on ASHRAE Standard 52-76. The system has pressure-independent hot water terminal reheat variable air volume terminals and individual laboratory and office area temperature zone control. The system is also designed to maintain the proper temperature, humidity, differential pressure, outdoor air exchange rate, and acoustic criteria within the building.

The laboratory spaces are arranged with supply air distributed by multiple air handlers to ensure that fresh air is supplied 100% of the time. This concept is also applied to the exhaust fans. If one piece of equipment is not working properly or needs to be serviced, the load can be transferred to other equipment. Concentrations can be determined using methodology outlined in National Institutes of Health's (NIH) HVAC Requirements.

The facility is in the process of recruiting the very best scientists from around the world including six Nobel Prize winners at present. The research projects are centered on test mice housed in the Vivarium. The multimillion dollar mice are to be provided with excellent living environments due to ensure their health and accurate test result. The required air flow to the Vivarium spaces is not based on occupancy or space type, but the necessary air changes per hour. In addition, the animals housed in the Vivarium require warmer temperatures than do people. Accordingly, the supply air is reheated to 64^{o}F supplied 24 hours per day. Individual control is provided to each holding room, treatment room, procedures room, and operating room. The Vivarium facilities are serviced by AHU-1, AHU-2, and AHU-3(back-up) that run in parallel to heat, ventilate and provide air-conditioning. The arrangement with stand-by equipment ensures continuous operation during equipment failure and scheduled maintenance. Supply air is introduced through high-volume and uniformly drawn across the holding areas to provide uniform mixing. It is important to ensure that the system does not create drafts on the animals. The mice are involved with chronic testing which presents serious complications if people or other animals are exposed. As a result, HEPA filters are required in the exhaust air ducts. Ventilation Design Handbook on Animal Facility and Animal Facility design published by NIH and ASHRAE Application Handbook were used to design the Vivarium system.

Mechanical, electrical, elevator machine, boiler, and cage wash equipment spaces are conditioned to ensure worker comfort, to increase equipment life, and to avoid excessive heat gains/losses to adjacent occupied areas.

In compliance with NFPA Standard 90A exhaust ducts are not located in the same shaft supply and/or return air ducts. All toilet and general exhaust is discharged using systems in independent of the lab exhaust systems. For information about exhaust and/or supply duct material, please see Table 2 based on NIH Requirements.

Table 2

Minimum Duct Construction Standards			
Application	**SMACNA Pressure Classification**	**Materials of Construction**	**Field Pressure Testing**
Low-pressure Supply Ductwork	498 Pa POS	Galvanized Steel	No
Medium-Pressure Supply Ductwork Upstream of Terminal Units	1494 Pa POS	Galvanized Steel	Yes
Low-pressure Supply Ductwork Downstream of Terminal Units	498 Pa POS	Galvanized Steel	No
Low-Pressure Outdoor, Relied, Return Air Ductwork	498 Pa POS	Galvanized Steel	No
Medium-Pressure Return Ductwork Downstream of Terminal Units	747 Pa NEG	Galvanized Steel	Yes
Low-Pressure General Exhaust Ductwork	498 Pa NEG	Galvanized Steel	No
Low-Pressure Wet Process Exhaust Ductwork	498 Pa NEG	Aluminum or Stainless Steel	No
Low-Pressure Hazardous Exhaust Ductwork Upstream of Terminal Unit	498 Pa NEG	Epoxy-Coated Galvanized Steel or Stainless Steel	No
Medium-Pressure Hazardous Exhaust Ductwork Downstream of Terminal Units	Class I/Indust. 1494 Pa NEG	Epoxy-Coated Galvanized Steel or Stainless Steel	Yes
Special Hazard Exhaust Ductwork	747 Pa NEG	Stainless Steel	Yes

SYSTEM DESIGN & OPERATION

AIR SYSTEMS

The mechanical system uses a variable air volume (VAV) distribution system. As stated above, 100 percent outdoor air is required at all times.

The building is served by 15 identical custom type 45,000cfm air handling units; 14 primary and one back-up. All 15 air handling units feed into one plenum which serves the entire building. AHU-1 and AHU-2 are separated from the rest of the air handlers by volume dampers. They serve the Vivarium during typical operations with AHU-3 serving as back-up. AHU-4 thought AHU-15 serve the rest of the building through one plenum. If needed, AHU-1,2 & 3 can also be connected in parallel with the rest of the units. Lab and Vivarium spaces will receive 100% outdoor air and pass through 30% efficient prefilters, 95% efficient final filters, energy recovery coils, direct injection steam humidifiers, chilled water cooling coils, and single plenum-type fans. The supply fans operate at 88.5 BHP and the AHU supply temperature is 45.8^{o}F. The system has pressure-independent hot water variable air volume with reheat terminal devices and individual laboratory and office area temperature zone control.

Outdoor air inlet dampers in each plenum open to bring in outdoor air to mix with exhaust air to maintain a constant discharge velocity from each exhaust stack with exhaust air volume demand decreases. All radio-chemistry or perchloric acid hoods are located on the third level of the Landscape Building and are equipment with dedicated direct exhaust to the roof.

All occupied spaces are equipped with climate control which is accomplished by variable air volume terminal unit and reheat coil. Air volumes are throttled to minimum flow rate before the reheat coils are activated to heat the space. Fan powered air terminal units with reheat coil are installed in the office areas where occasional, minimal cooling requirements would result in air flows that are sufficiently low to cause air quality problems.

CHILLED WATER & STEAM

The estimated demand for each utility is 23,210 kW (6600tons) for chilled water and 26,000 kW (100,000 lb/hr) for steam. Electricity is supplied by Dominion Power. The chilled water and steam enters the lower level of the Landscape Building via the utility tunnel. There is a two-stage pressure-reducing station that supplies medium pressure steam for sterilizers, washers, and other scientific equipment. Secondary chilled water and return chilled water from air handling unit cooling coils are used for lab equipment cooling and environmental room condensers.

HYDRONIC HEATING

Heat exchangers provide hot water for variable air volume terminal reheat coils, cabinet heaters, and convectors. These units are used for secondary heating throughout the building. There are dedicated circulation variable frequency drives for each heat exchanger as well as one redundant heat exchanger/pump combination.

BOILER PLANT

The boiler plant contains three boilers and room for an addition of a fourth. Two have a capacity of 50,210 MBH and one is 30,125 MBH; a total energy input is 163,181 MBH. All three boilers have an 80% efficiency. They make 80 lbs steam and convert it to 15 lbs steam when needed. In general, two boilers run in any combination to meet desired load. The majority of the steam generated by the boilers is used by the air handler steam coils. Any remaining steam is used with the shell and tube heat exchangers (see TableA.8) XR-1 and XR-2 (back-up) are used to heat water that is pumped to reheat coils in the VAV boxes and XR-3 and XR-4 (back-up) used to heat water that is pumped to the radiant flooring in the lobby area.

CHILLER PLANT

There are six w/c centrifugal chillers and one back-up that have full load capacity of 1,200 tons each. The full load LCHWT and ECWT are 42.0^{o}F and 85.0^{o}F respectively. The full load power is 0.670 kW/ton. The condenser flow rate is 2,400 gpm and pressure drop of 13.0 ft. Remaining capacity is used for various equipment, such as the fan coil units in the data center room.

MECHANICAL SYSTEM DESIGN

PROPOSED GOALS, SCOPE & JUSTIFICATION

The Landscape Building will have an estimated yearly utility bill of $3,530,000 once it is completed. This is a direct result of the size of the building as well as the building type. Laboratory spaces have requirements that will directly increase the cost of operation. Providing 100 percent outdoor air to all laboratory spaces will increase fan energy and equipment energy because such a large amount of air must be conditioned and moved throughout the building. Air cannot be recirculated and therefore all of the air in the labs must be exhausted out of the building. Exhaust air contains a large amount of energy that escapes unused into the atmosphere. As stated in a case study of R.W. Johnson Pharmaceutical Research Institute, "Fume hoods are directly responsible for a large amount of fan energy, and they are indirectly responsible for vast amounts of heating and cooling energy because of the volume of conditioned air they continually exhaust from the labs."

The primary goal is to modify the existing HVAC system to reduce energy consumption and yearly utility costs. As energy consumption is reduced, local and utility emissions will decrease as well. Secondary goals include optimizing the artificial lighting in the laboratory spaces located on the second and third floors as well as resizing affected components of the electrical system.

The system modifications must be done without unfavorably changing the current system. As found with Technical Assignments One and Two, the Landscape Building meets ventilation requirements outlined in ASHRAE Standard 62 and lighting power allowance and building envelope compliance as outlined in ASHRAE Standard 90.1. All changes shall maintain the highest standards of the original design.

The scope of the design process includes the following:

- Modeling the existing laboratory and support spaces.
- Modeling the laboratory and support spaces based on deign requirements.
- Modeling the laboratory and support spaces based on required air changes per hour.
- Determine smallest possible system that meets load and indoor air quality requirements.
- Designing and incorporating a ground-coupled water system.

The laboratory spaces are the prime focus of this design. They make up approximately one third of the building area with mechanical rooms at approximately 50%, and vivarium, offices, and public spaces making up the remainder. It can be said that the laboratory spaces are the dominant load and energy consumer in the Landscape Building due to its 100 percent outdoor air requirement. All comparisons in the design process are in reference to the existing laboratory design only. All other areas and spaces have been excluded.

The results of this thesis provide suggestions for alternative solutions to the design of the Landscape Building at Janelia Farm. All modifications are for academic purposes and do not imply flaws in the original design (old e-studio disclaimer). All modifications are simply alternative solutions which will include one extensive modification to the mechanical system and resulting changes to the other building systems.

CONSIDERED ALTERNATIVES

COGENERATION

Cogeneration systems capture thermal energy that would otherwise be lost to the environment. These systems become increasingly economically feasible as utility rates increase and as energy consumption increases. Such systems are applicable to large facilities with large thermal loads such as the following:

- Assisted Living Facilities
- Nursing Homes
- Senior Housing
- Apartments and Condominiums
- Colleges and Institutions
- Hospitals
- Hotels
- Athletic Clubs
- Industrial and Waste Treatment Facilities
- Laundries

According to the <u>HVAC Systems and Equipment Handbook</u> published by ASHRAE, "the basic components of the cogeneration plant are

- Prime mover and its fuel system.
- Generator.
- Waste heat recovery system.
- Control system.
- Electrical and thermal transmission and distribution system.
- Connections to building mechanical and electrical services.

The design team at Burt Hill considered the feasibility of a cogeneration system to provide power and steam for the Janelia Farm Research Campus. The following three buildings on the campus were incorporated in this study:

- Landscape Building: 546,436 square foot research facility.
- Conference Housing: 42,000 square foot hotel facility with 107 guest rooms.
- Transient Housing: 48-two bedroom apartments for long term visitors.

The conceptual design included a turbine generator with adequate capacity to satisfy the minimum continuous electrical power demand for the campus. The continuous demand ranged from 2.5 to 3.0 mega-watts. The design featured 500kW gas micro-turbines that could be staged on/off to meet demand. The system was more efficient when all the turbines operated continuously. Enough heat could be recovered to operate 1-1200 ton absorption chiller which is equivalent to one of the seven current chillers. The waste heat could have met the majority of the winter heating requirements.

This study concluded an annual savings of $195,640 for the 2.5 mega-watt cogeneration system. The estimated first cost was $4,720,000. Based on this, the simple payback period would be 24 years. This was deemed beyond the limits of a reasonable payback period on such an investment.

A second study utilizing the 3.0 mega-watt system resulted with an annual cost savings of $214,400, system first cost of $7,080,000, and a 33-year pay back period. Again, this is beyond reasonable for a payback period.

Based on these results no further analysis was done. In order for cogeneration to be feasible for the Janelia Farm research campus, equipment and installation costs will have to be greatly reduced.

Note: All dollar values are from 2002.

ENERGY RECOVERY WHEELS

Another energy saving option that the design team considered was the use of enthalpy wheels or desiccant wheels. During cooling mode when outside air is hot and humid, the wheel transfers both heat and humidity from the outdoor air to the exhaust air. This decreases the cooling load on the other mechanical equipment. During the cooling season when outside air is frigid and dry, the wheel transfers heat and humidity to the incoming air from the exhaust air. This decreases the heating load required of the boiler and air handling equipment.

There are two drawbacks to including a wheel in the mechanical system in the Landscape Building. The primary reason is the risk of cross contamination. As the building is a medical research laboratory, there is a always a chance of chemicals, gases, or infectious material becoming air-borne in a space and consequently the mechanical system. One way the system manages this issue is to provide 100 percent outdoor air to all critical spaces and exhausting 100 percent of that air directly out of the building. Energy recovery wheels are able to recover energy and moisture because they are able to effectively mix the exhaust and supply air streams. Given this, contaminants will also transfer between air streams. As a result, the concept of using an enthalpy wheel was not pursed.

Desiccant wheels on the other hand do not transfer air-borne contaminants. The wheel is flushed with supply air that is deflected by a damper in the purging section of the rotor. This further helps reduce the risk of contamination. While this may work well in theory, the chance that the equipment may not work properly was a risk the owner was not willing to take. Using a desiccant wheel was not pursued.

The second more minor drawback is Howard Hughes Medical Institute did not want to pay for the equipment and additional space it would take up in the mechanical rooms.

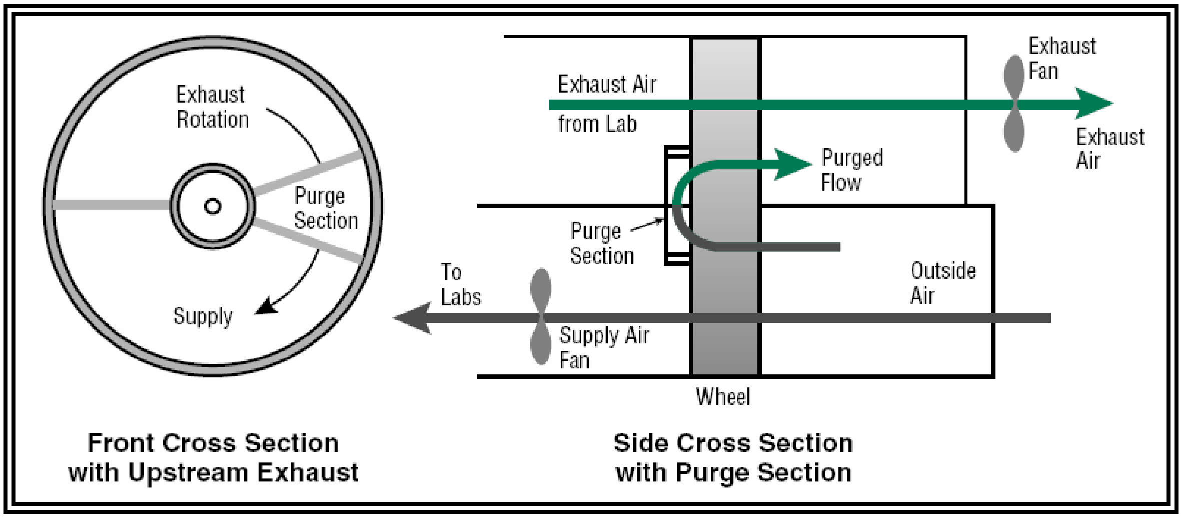


Figure 3 : Desiccant Wheel Schematic

HEAT EXCHANGERS

Two types of heat exchangers will be looked into; air-to-air and a "plate-type" heat exchanger made by ConsERV. Typical air-to-air heat exchangers only let sensible energy pass through a medium from out air stream to the other. As a result, the air streams never directly interact and contamination of the supply air cannot occur. No cross contamination is one of the primary design goals of the original design as well as this redesign. The draw back is the lack of latent energy transfer with an air-to-air heat exchanger. Humidifiers and dehumidifiers (cooling coils) will need to be introduced and sized into the system to ensure adequate humidity levels. This will add to the first cost of the system as well as energy costs.

The integration of a plate-type heat exchanger made by ConsERV will be analyzed for effectiveness and amount of energy saved. As stated in the product description, the exchanger "is a plate-type heat exchanger wherein the plates are constructed of ionomer membranes, such as sulfonated or carboxylated polymer membranes, which are capable of transferring a significant amount of moister from one side of the membrane to the other side." In other words, it is effectively a plate-frame heat exchanger, but instead of using metal or paper, a polymer membrane separates the two air streams. These membranes are able to transfer both sensible and latent energy, but the air streams remain completely isolated from each other. This is the critical feature which makes this a feasible addition to the mechanical system in the Landscape Building. The square box in the left side of Figure 5 below is the actual exchanger in one of the many possible configurations.

It is possible to model both types of heat exchangers in HAP 4.20a with product information found online.

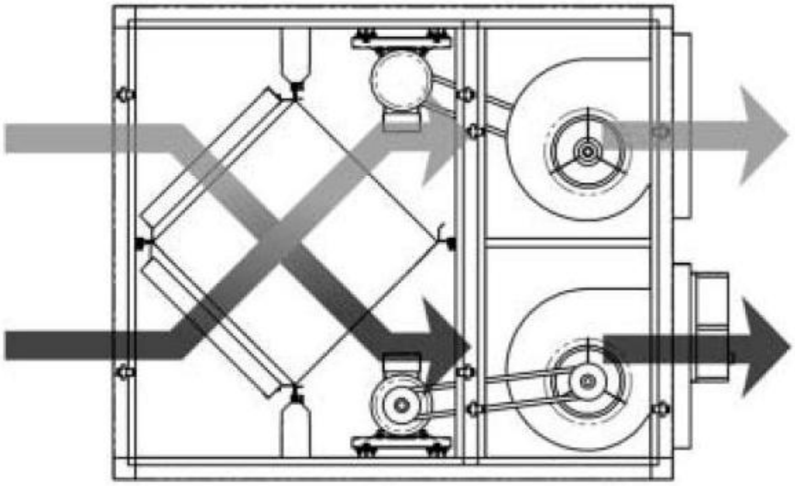


Figure 4 : Membrane Heat Exchanger Schematic

RUN-AROUND COILS

A run-around coil is a system designed to recover heat from the exhaust air stream to the outdoor air plenum and vice versa to pre-heat and pre-cool the incoming air. This is done by a fin tube coil located in the two air streams. According to the Application Team at the Lawrence Berkley Laboratory "A high-performance, run-around energy exchanger can provide a large increase in overall HVAC system effectiveness from 50 percent to nearly 70 percent, large returns on investment, typically 33 percent, and short payback periods of three years. In new building designs and retrofits, a run-around system can reduce peak heating and cooling loads as well as total heating and cooling loads. The run-around system can have a significant impact upon the boiler and chiller capacity in new HVAC designs." The A-Team also states that flow rates greater than 10,000 cfm are good for using this system. The Landscape Building has outdoor air and exhaust air flow rates in excess of 100,000 cfm and the two plenums are located parallel to each other. Installing a run-around coil may be an effective way of reducing the amount of energy needed to condition the air. It is possible to combine the run-around coil loop with the preheat coil to reduce the amount of pressure drop created by the run-around coil (labdesignnews.com). The addition of a run-around heat recovery system can be modeled in HAP 4.20a.

CASE 1 : EXISTING LOAD CALCULATIONS

The first step in the mechanical design is to model the existing laboratory spaces in Carrier's Hourly Analysis Program 4.20 as accurately as possible. The results serve as a benchmark against which all new designs are compared and analyzed.

The data that was needed included the following:

- Room dimensions and orientation.
- Wall, ceiling, and floor assemblies.
- Window and roof characteristics.
- Required supply air flow rate for each room.
- Lighting and equipment loads.
- Air system type and equipment specifications.
- System set points and controls.
- Plant characteristics and configurations.

Information was obtained from the master drawing set, specifications, design calculations, and consultants in the field. All documents were provided by the project manager from Jacobs Facilities, Inc. and a design engineer at Burt Hill.

Results from this model provided helpful information about the current design. Rooms were found to be receiving anywhere from one air change per hour to 47, indicating a great deal of over design. All spaces met ventilation requirements as outlined in ASHRAE Standard 62.1-2004. Please see Table 3 below for basic system information.

Table 3

Case 1 Mechanical System

Cooling		Heating	
Total Coil Load [ton]	**Sensible Coil Load [MBH]**	**Total Coil Load [MBH]**	**Peak Load [cfm]**
684	4,635	2,602	181,933

CASE 2 : EXISTING SPACE WITH MODIFIED EQUIPMENT LOADS AND AIR CHANGES

Before making alterations to the mechanical system, accurately modeling the existing building was important. It was also important to determine if the assumptions made during the design process were reasonable. According to a research group of scientists and engineers, "Measurements from various laboratories indicate that peak equipment load tends to be overestimated greatly (Mathew, 8). If the air system was oversized, it would be possible to reduce it to the minimum size and therefore decrease equipment size and energy usage.

Existing design documents state 20 W/SF equipment loads for all laboratory and laboratory support spaces. Typically laboratories have an equipment load of 4 W/SF for lab spaces and a range of 6 to 8 W/SF for support spaces depending on the amount of equipment (Mathew, 2).

The design equipment loads and reduced loads were simulated to compare the impact on the mechanical system and energy usage. As a result of the equipment loads for the Landscape Building being unknown, a more conservative 10 W/SF for equipment loads was used. This most likely will result in a larger cooling load and consume more energy than will the actual building. Typically laboratory equipment load schedules were taken from ASHRAE Standard 90.1-1989 because the actual schedules are not known. The occupancy schedules have been taken from the original design calculations as seen below in Table 4.

Table 4

Occupancy Schedule			
Space	**8:00 am to 4:00 pm**	**4:00 pm to 12:00 am**	**12:00 am to 8:00 am**
Open Labs	80%	55%	45%
Lab Support	80%	70%	70%

The results of the reduced load model did not have an effect on the required air flow rate as this is a function of air changes and not the load. One result of this adjustment is less energy is used by equipment than expected. Another good outcome is the room air ΔT can decrease to meet the loads with the same amount of supply air. The room temperature is set at 70°F/50%RH.

$$q = 1.08\text{cfm}\ \Delta T$$

Where q = total cooling load

ΔT = return air temperature – supply air temperature

The required supply air temperature required for the actual design is found to be 34.1°F from the following calculation.

$$8{,}028{,}000 = 1.08(181{,}933)(75 - T_{supply}) \qquad T_{supply} = 34.1^{o}F$$

With the reduced equipment loads, the supply air temperature becomes

$$6{,}276{,}000 = 1.08(181{,}933)(75 - T_{supply}) \qquad T_{supply} = 43.1\ ^{o}F$$

As it can be seen in the short calculation above, reducing the load has a major impact on the room air ΔT. A 21.8% reduction in the load raises the required supply air temperature by nine degrees. Typically, the lower practical limit to supply air temperatures is 40 °F. Therefore, it can be argued that having $T_{supply} = 34.1^{o}F$ is not reasonable.

The hand calculated supply air quantities were combined with the reduced equipment loads to produce the following results. There was a 23.7% reduction in the total coil load and a 21.7% reduction in the annual energy cost. A more comprehensive simulation result can be found in Appendix B.

Table 5

Case 2 Mechanical System			
Cooling		Heating	
Total Coil Load [ton]	Sensible Coil Load [MBH]	Total Coil Load [MBH]	Peak Load [cfm]
522	3,534	1,987	138,726

As stated above, after modeling the existing laboratory space it was found that air chances per hour ranged from 1 to almost 48. Having 48 air changes per hour is excessive and a large amount of energy could be saved by downsizing the system. Using the design standards provided by the engineer, required supply air flow rates were determined by hand calculations. Care was taken to ensure the spaces were still sized to create negative pressure using the exhaust hoods.

The owner Howard Hughes Medical Institute typically bases design requirements on The National Institute of Health's (NIH) design standards for their laboratory buildings. In this case, the laboratory spaces called for a minimum of 8 air changes per hour which is greater than the minimum requirement based on NIH design standards. Support spaces have a higher load density and therefore a minimum of 12 air changes per hour should be used.

There are spaces adjacent to the laboratories that were included in this model due to their location. They are not considered lab or support spaces and therefore do not need to be evaluated based on air changes. Instead, ASHRAE Standard 62.1 is applicable. Occupancy classification and internal loads were used to determine the minimum amount of outdoor air needed. In the original design of the building, these spaces were considered laboratory support spaces and therefore were greatly over designed.

CASE 3 : EXISTING SPACE WITH REDUCED LIGHTING LOADS

For the lighting system breath work of this report, the lighting layout and lamp selection was analyzed to determine if the load on the spaces could be reduced. It was concluded that the layout could be improved to provide a more uniform distribution as well as selecting lamps with a better lumen per watt ratio. There was a small decrease in the total coil load. It dropped from 684 tons to 677 tons. The biggest savings can from reducing the electricity use of the lights by 19.4%.For a more detailed explanation, please see Appendix C.

Table 6

Case 3 Mechanical System			
Cooling		**Heating**	
Total Coil Load [ton]	**Sensible Coil Load [MBH]**	**Total Coil Load [MBH]**	**Peak Load [cfm]**
677	3,222	2,573	181933

CASE 4 : OVERALL IMPACT OF REDUCED LOADS

Case 4 represents combining Case 3 with Case 4. The overall impact of simply designing the system to design standards and not over sizing is fairly significant. It is significant in the fact that resizing the lighting and reducing the equipment loads produced an annual savings of $241,077 which is approximately 25 percent with very little upfront cost to the owner. Comparing the original design in Case 1 to the overall results, the total coil load decreased by 28 percent. This case study clearly demonstrates the importance of knowing the use and loads of each space as much as possible during the design process. The Landscape Building was put out to bid very early in the design process with only approximately 75% of the design completed. The remainder of the design was completed by the contractors on site with the aid of shop and fabrication drawings.

Simulation results can be found in detail in Appendix D.

Table 7

Case 4 Mechanical System

Cooling		Heating	
Total Coil Load [ton]	**Sensible Coil Load [MBH]**	**Total Coil Load [MBH]**	**Peak Load [cfm]**
492	3,337	1,866	138,726

GROUD-COUPLED DESIGN

GROUND-COUPLED SYSTEMS

Ground-Coupled Heat Pumps (GCHPs) are a subset of ground-source heat pumps (GSHPs). GCHPs use a series of plastic piping buried either horizontally or vertically in the ground to discharge or gain energy. The ground may be used as a heat sink due to the relatively constant temperature by either warming the water during the summer or cooling the water in the winter. The benefit of using a GCHP system is the use of free energy which would otherwise have to be produced by mechanicals means. The downside is the large upfront cost of installing the system and the pump energy consumed during operation.

One significant design requirement is an adequate amount of land to install the system. Bores can either be horizontal or vertical. The benefit of vertical bores include a smaller plot of land is required; the soil temperature varies less at larger depths, and require the smallest amount of pipe and pumping energy (Kavanaugh 1). In addition, vertical loops are able to transfer more heat than horizontal loops. The main drawback to vertical fields is the much higher cost as compared to a comparable horizontal field. Howard Hughes Medical Institute owns 669 acres on the Janelia Farm Campus. It is probable that horizontal piping could be used if vertical bores are not necessary. This would result in a lower first cost as vertical drilling can be more expensive.

There are two options for the type of pipe loop designed; closed and open. In a closed loop, water or a refrigerant solution are circulated in a piping loop and then heat is exchanged to or from another piping loop. This prevents any possible contamination from the ground loop to cause problems in the interior piping and equipment. An open loop either uses an open well, stream, or lake as a water source and then can discharge water back. In the case of a well, at least two separate wells are required. Open loops tend to be less expensive on a per-ton basis for large systems and can require no more maintenance than a typical HVAC system is well deigned (Kavanaugh 5). With open systems there is the drawback of environmental issues that stem from dumping possibly contaminated into a nature water source.

Possible configurations include the following:

- Using the water for pre-heating coils in the air handlers.
- Using the water to directly serve the VAV boxes already in the original mechanical system design. This configuration could use the existing piping that serves the VAV boxes. In this system, the branches of the VAV piping will need to be determined as well as location and sizes of heat exchangers.
- A typical heat pump system with a central loop and pump. This application is better suited for smaller buildings. The Landscape Building is too large in size to consider using one pump to serve a system.
- One local loop, multiple heat pumps with pump and check valves on each unit.
- Multiple individual loops, heat pumps, and circulator pumps.
- Multiple units with one local pump that operates when one or more unit is on.

- Multiple units with two-way valves, one local loop, and variable speed pump.
- Heat pumps and water heater on the same loop to balance local load (Kavanaugh 4).

This thesis report will determine the best way to use GCHPs in the Landscape Building to both reduce the amount of energy required to heat and cool the laboratory spaces and reduce the operating costs.

SYSTEM DESIGN

The ground loop is replacing the cooling towers as the means for releasing and absorbing energy to and from the atmosphere, instead of designing a typical ground-coupled heat pump system. The following briefly describes the reasons for this approach:

1) After completing a rough estimate calculation on the size and number of heat pumps that would be required to serve the laboratory spaces, it was determined that too many heat pumps are required. Approximately 300 fairly large heat pumps would need to be located throughout the laboratory spaces. There actually is enough space in the building to do this. The service corridor located behind the occupied areas has 10 feet dedicated to housing MEP system equipment. While being feasibly, it did not seem reasonable to install such a large amount of equipment. The first cost on top of the cost to install the ground loops would have made the system too expensive.

2) The boilers and chiller are used for other applications besides heating and cooling the spaces. The boilers are used to generate steam and hot water that is used by another building on the site as well as supplying a means of sterilizing laboratory equipment in the wash rooms. The chiller is used to meet the loads of the cold rooms and also the data and communication rooms which operate on independent systems from the rest of the building. Therefore, replacing the current system with a heat pump system would eliminate the means to meet the loads of these specialized areas.

3) Using a heat pump system to heat and cool the building requires the heat pumps to be located near the spaces. This in turn means that the piping will travel from the space through the building, to a heat exchanger, and then into the loop in the ground. As the Landscape building is fairly long, this would require loops to be considerably large. This would increase the pressure drop in the pipes thereby requiring larger pumps that consume more energy. In addition, more energy would be lost out of the pipe.

Therefore, it was determined that connecting the ground loop water indirectly into the condenser side of the chiller will be system of choice for this report. The schematic for the system if found below in Figure 5.

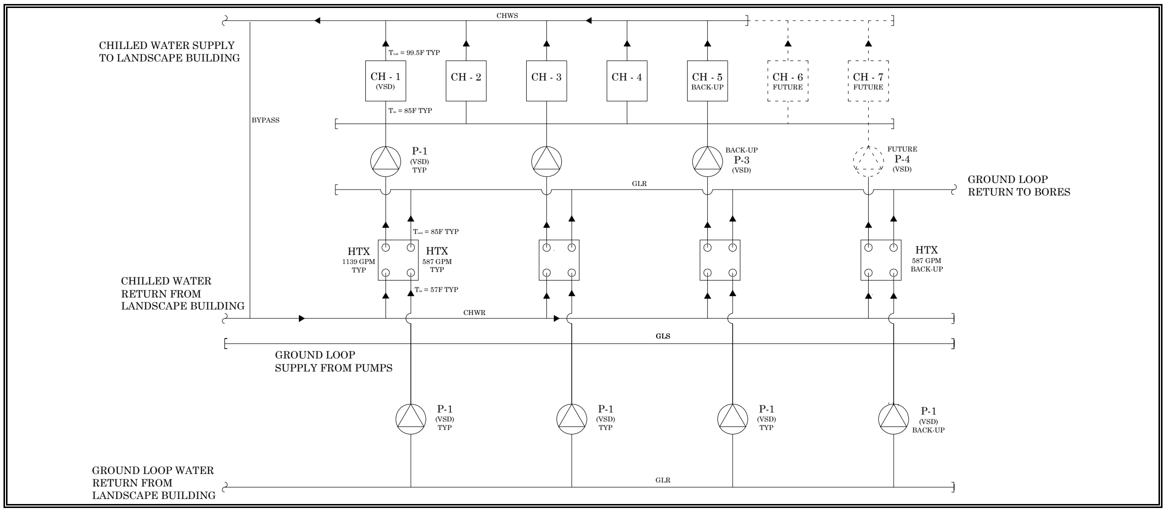


Figure 5 : Condenser Water Schematic

VERTICAL FIELD CONFIGURATIONS

Based on the size of the cooling load, vertical loops will better serve the Landscape Building. Typically, vertical bores need to be located with a minimum of 15 to 20 feet between bores to ensure heat transfer from one bore to another does not occur. It is possible to use two U-tubes per bore. While there is less heat transfer per tube, it may be economically viable due smaller first costs in drilling. An other option is whether to use parallel loops or series loops. “A parallel-piped vertical heat exchanger can utilize U-tubes with smaller diameters than a series-piped vertical heat exchanger, resulting in lower piping costs, lower antifreeze costs, and probably lower labor costs because the smaller pipe is easer to work with.” Parallel loops all have the same amount of heat transfer where as the series loops have varying heat transfer depending on the location in the series.

The bore field will be located in the field behind the Landscape Building and then extend east and west of the building. In this location, the piping can extend approximately 60 feet from mechanical room up to the ground surface, drop 120 feet, and then rise 60 feet back to the mechanical rooms. The bores will not extend up as high as the frost line to ensure that freezing is not an issue. Also, the field in which the bores are located is projected by historic preservation acts and therefore nothing substantial will ever be installed there. This ensures that the structural integrity of the soil will also not become an issue.

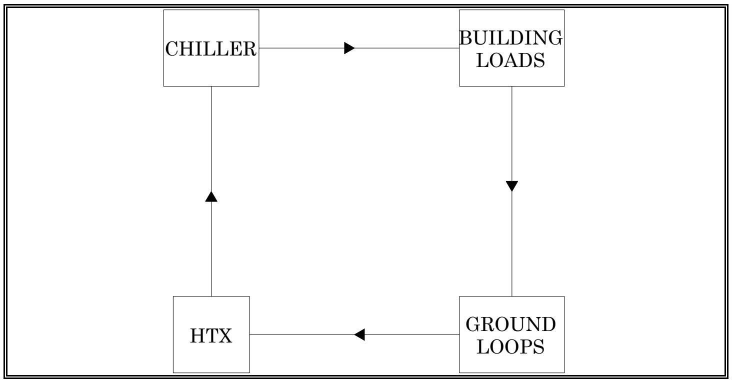


Figure 6 : Ground Loop Diagran

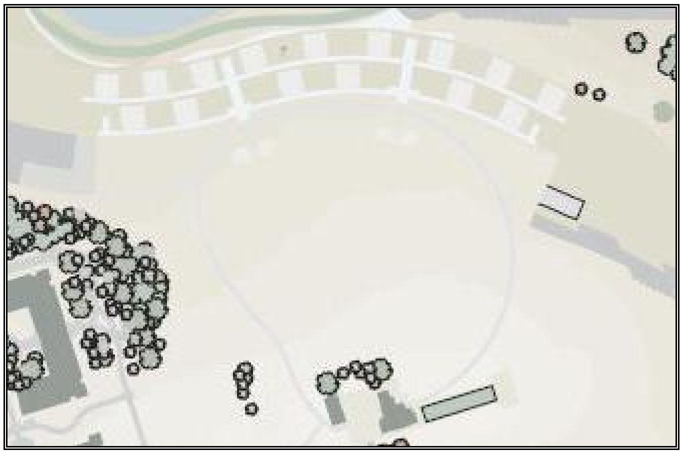


Figure 7 : Ground Loop Proposed Site

Figure 7 above is a rendering of Landscape Building and the surrounding Campus. The building is the series of squares connected by a thin white line. These squares are the office pods located on the second and third floors and are the only part of the building that is exposed. The building and cluster of trees to the left is an existing office building that is currently being used as the trailer for the project manager, architect staff, MEP engineers, and the owner's representative. It is still unknown what plans Howard Hughes Medical Institute has for these buildings. There is a good possibility that they will be demolished after construction is completed. The group of buildings at the bottom center is the Janelia Farm Mansion and out buildings. This building is a historic landmark. The view of Sugarloaf Mountain is protected, meaning nothing can be built that would impair this view. The gray loop seen in the field above is a sidewalk between the two buildings for recreational use. The area that is protected is the wedge that begins at the Mansion and extends upward over the Landscape Building. The boundaries of it are symbolically incorporated into the building as the feature stair cases represented by the two long rectangular shapes which divide the building into thirds.

It is in this area between the Mansion and the Landscape Building that the vertical bore field will be located. As calculated above, the bores will reach a depth of approximately 120 feet below ground. With 61,000 feet of piping to handle the design loads of the building, 510 bores are required. There will be 20 feet between bores in all directions to ensure that heat transfer between bores does not become a problem. A 15 x 34 bore or 300 x 680 ft array will accommodate the number of bores required. The bore array will easily fit within the limits of the field which is well over 210,000 square feet. After sizing three heat exchangers to serve the load of the building, the pipe diameter was found to be 1-1/4" using Table 5.4 found in Ground Source Heat Pumps published by ASHRAE.

All calculations can be found in Appendix E.

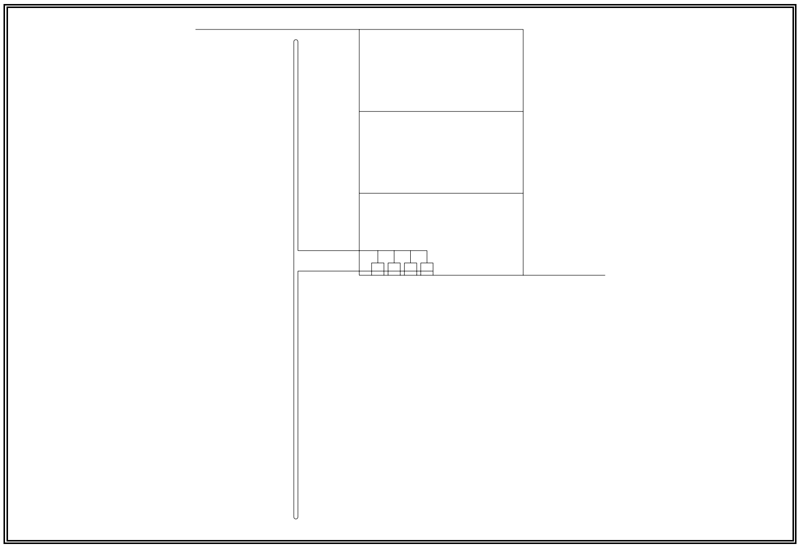


Figure 8 : Bore Diagram

Due to the new system configuration, only pumps on the ground loop side and heat exchangers needed to be sized. There are thee pumps in parallel serving the ground loops and one back-up pump. They are 4030 series variable frequency drive pumps from Armstrong, operating at 3600 rpm. The peak load efficiency is 78%. The heat exchangers were selected using computer software provided by SWEP. There are three heat exchangers in parallel with each other and in series with the pumps. They each have a flow rate of about 570 gpm. Cut sheets and pricing information can be found in Appendix I. The system components have been designed in parallel to continue the practice of allowing for easy maintenance or as a safety in case of failure. This design also connects in well with the current chiller and pump configuration.

POND LOOP CONFIGURATIONS

An alternative configuration is to use the two existing man-made ponds as heat sinks in an open loop system. These ponds are located just north of the Landscape Building and currently serve aesthetic purposes only. Figure 9 below in a rending of the Landscape Building and the two adjacent ponds.

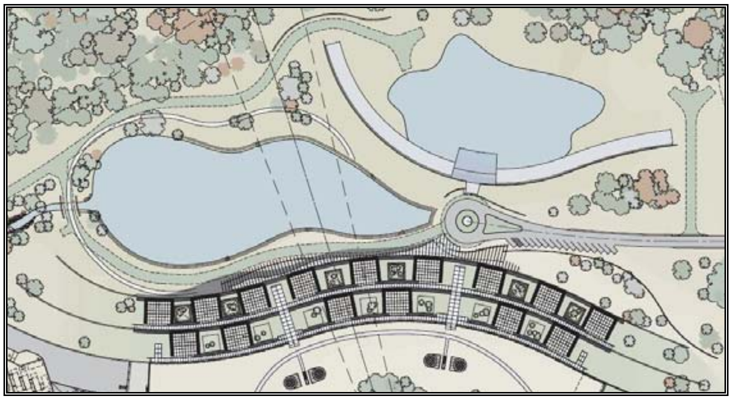


Figure 9 : Existing Ponds

The long arched building is the Conference Housing Building. This building is provides short term housing for visiting scientists and engineers. The Upper Pond is 18 feet deep with the bottom elevation of 240. The pond is 1.1 million square feet in area. The Lower Pond has a bottom elevation at 226 and is 12 feet deep. The pond is slightly smaller than the Upper Pond with an approximate area of 590,000 square feet.

The proposed system will draw water from the Upper Pond, pump in through the heat exchangers in the mechanical room in Zone F, and then be pumped through the service corridor that runs between the two buildings and empty into the Lower Pond. Water will also be pumped at the same rate from the Lower Pond to the Upper Pond to complete the full circle. The pumps that move the water between ponds will be located in existing space in the Conference Housing Building mechanical room. As the ponds are man-made and a great deal of earth work needs to be done for their construction, incorporating a series of pipes into that design is relatively simple and should not incur extra major expenses.

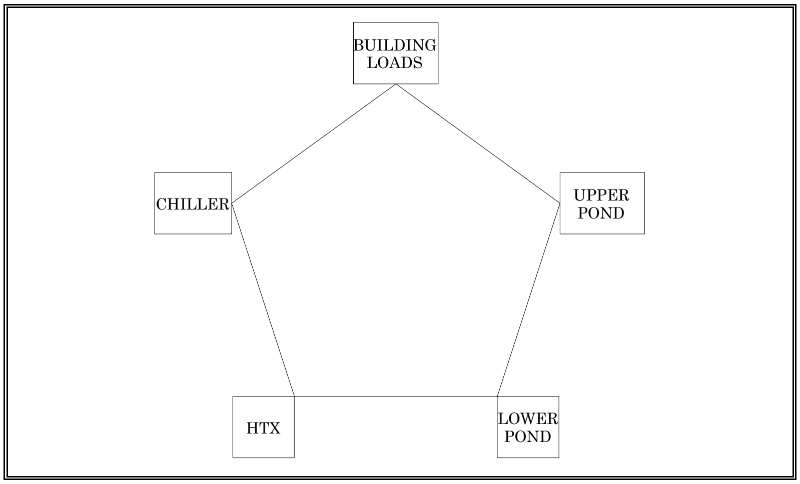


Figure 10 : Pond Loop Diagram

There are 3-1050 series pumps and one back-up pump from Bell & Gossett. They run at 1750 rpm and have a peak load efficiency of about 79%. The pumps are equipped with a VFD bypass to ensure that the heat exchangers will still receive peak load flow when the VFD is not functioning. End suction pumps were selected even though they do not have the best efficiency possible, they do prevent cavitation from occurring. The possibility of having to replace a pump early is more of an economic burden than having to account for a slightly lower efficiency. The pumps that are located between the two ponds have the same features as the pumps in the mechanical room. The only difference is that they are smaller due to small head requirements. Cut sheets can be found in Appendix I.

The ponds have been previously designed to maintain the same water level throughout the year through the use of a make-up water system. In the event that this system is not operational there is a small creek that flows into the Upper Pond. The water discharge and intakes will be located as far apart in each pond to allow the maximum amount of mixing to occur so that constant temperature water is supplied to the building. All pipe inlets and outlets will be located at the bottom of the ponds so as not to diminish their intended aesthetic quality and to provide water that has a more constant temperature. There is no data on the thermal properties of these water sources as they are small man-made ponds and therefore it is assumed that the temperature at the bottom is approximately the same as the ground temperature for calculation purposes.

Pipe is sized to 6" using System Syzer Calculator.

EMISSIONS & FUEL SAVINGS

Emissions and fuel savings is a direct result of smaller loads and more efficient systems. By designing a lighting system with lamps that provide more lumens per watt and more accurately modeling the equipment loads, the building is consuming less energy. Therefore, the operating costs are down as well as emissions rates. Appendix H has complete information on emissions and fuel consumption for each case. Case 7 uses 28.5% less electricity than the actual system. In addition, emissions decreased by approximately 30% as well.

ALTERNATIVE LIGHTING DESIGN

LIGHTING ANALYSIS

The goal of this thesis report is to reduce energy consumption. The above mechanical system analysis is only one step in the process. Consideration must be given to the lighting system as it currently consumes 8.8 percent of the Landscape Building's energy. The current laboratory and support spaces will be examined to determine a more conservative design while maintaining adequate light levels.

The power density in these spaces varies between less than 1 W/SF and 5.9 W/SF. ASHRAE Standard 90.1-2004 outlines energy conscious power densities for specific building functions. Laboratory spaces are not explicitly called out. Therefore, these spaces will be assumed to have comparable power densities to that of hospitals. As can be seen in Table 10, the suggested value is 1.2 W/SF. Recommended illuminance levels provided by the *IES Lighting Handbook* range between 50 – 200 footcandles depending on the demand for accuracy.

The Landscape Building uses an array of 96-recessed fixtures equipped with T8 florescent lamps in laboratory spaces. There are compact fluorescent down lights over desk areas and in the entrance hallway. Support spaces typically have a combination of recessed fluorescent fixtures similar to those in the laboratory and fixtures with four u-shaped T5 lamps. Hallway areas have recessed compact fluorescent fixtures. The majority of the laboratories are exactly the same in terms of area, furniture layout, fixtures, and equipment. The support spaces literally come in three arrangements; small, medium, and large. Lab 285 and the adjoining spaces will be shown in this report as the sample calculation.

Table 10 : Based on Table 9.5.1 – ASHRAE 90.1-2004

Ligthing Power Densities

Building Area Type	[W/SF]
Convention Center	1.2
Dining: Bar Lounge/Leisure	1.3
Dining: Cafeteria/Fast Food	1.4
Dining: Family	1.6
Exercise Center	1
Gymansium	1.1
Health Care-Clinic	1
Hospital	1.2
Hotel	1
Library	1.3
Motion Picture Theater	1.2
Museum	1.1
Office	1
Parking Garage	0.3
School/University	1.2
Warehouse	0.8
Workshop	1.4

CONSIDERED ALTERNATIVES

It may be beneficial for the T8 lamps to be replaced with T5 lamps. It is possible for fewer lamps to produce the same amount of lighting and maintain the same color characteristics with a smaller wattage. It is also possible that the chosen T5 lamps have a longer rated average life. This can have a direct savings in electrical consumption and indirectly save on maintenance cost because fewer fixtures are needed. Even though T5 lamps can be more expensive than T8 lamps, the possible saving may make the equipment cost worth the investment.

One other consideration is the ALTO-series lamps from Philips Lighting. These lamps are designed with sustainability in mind. "Philips Alto fluorescent lamps combine the lowest mercury with long life and energy efficiency. The lamps contain up to 70% less mercury than other lamps. This is beneficial for the environment because mercury is a highly toxic substance. On average, the ALTO-series lamps consume 25% less energy over a longer life. This benefits the owner with a decrease in annual operating costs as well as being environmentally friendly with less waste and less pollution with energy generation due to less consumption.

LIGHTING DESIGN

AGI 32-v1dot8 was used to model the lighting design for laboratory 285. Surface reflectances were assumed based on known material properties. The existing fixture layout can be found in Appendix J.

Illuminance levels were found to be between 88 and 161 footcandles on a typically lab station. Small support spaces averaged 80 f.c. and the large support space had between 77 and 105 f.c. on the lab station. While the light on the middle of the lab station is probably adequate at 161 f.c, there is room for improvement due to the lack of lighting at the ends of the station. The support spaces are not receiving the necessary amount of light in order to do critical biomedical research. It is recommended that providing closer to 200 footcandles will greatly improve the researchers' working environment.

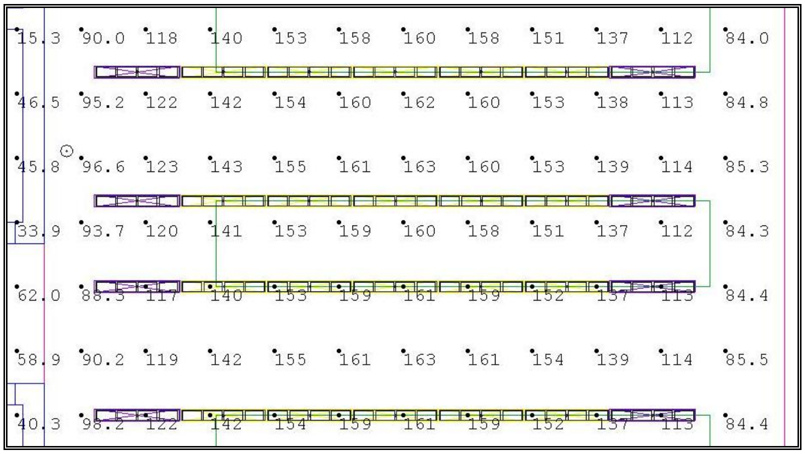


Figure 11 : Footcandels on Lab Station, Actual Design

Research was conducted to find a lamp with a greater lumens per watt ratio than the T8 currently specified for the lab. The only lamp that was found to be greater than the original 92 lumens/watt was a 98 lumen/watt T8 lamp designed by Osram Sylvania. The challenge posed by this lamp was the fact that it is eight feet long. This made the layout more complicated as it was harder to position such long lamps in rooms. Labeled as L1_A, these lamps have been placed in an array similar to that of the actual design. They directly over the edge of the lab station, and then run down the length of the room over the walking area. As can be seen in Figure 12 below, the new lamps increased the number of footcandles on the working surface and decreasing the amount of watts required by 1,228 or 17.1%

Figure 12 : Footcandels on Lab Station, New Design

The original fixtures remained in the support spaces but the 32 watt u-tube T5 lamps were replaced by half as many 40 watt standard T8 lamps. It was not possible to reach the needed illuminance level with the lumen output provided by 32 watt lamps. There are now more fixtures as a result of the original fixtures having four lamps each. Originally, the large support room had the same 32 watt T8 lamps as the lab and the same 1' x 4' louvered recessed fixtures. The new design calls for the same lamps, but with the 7" x 1' fixtures that were once in the lab. The new design provides A higher and more uniform lighting level throughout the room with less energy consumed. The entrance hallway originally had 4-6" recessed compact fluorescent fixtures which were replaced with 8Sample calculations can be found in Appendix J.

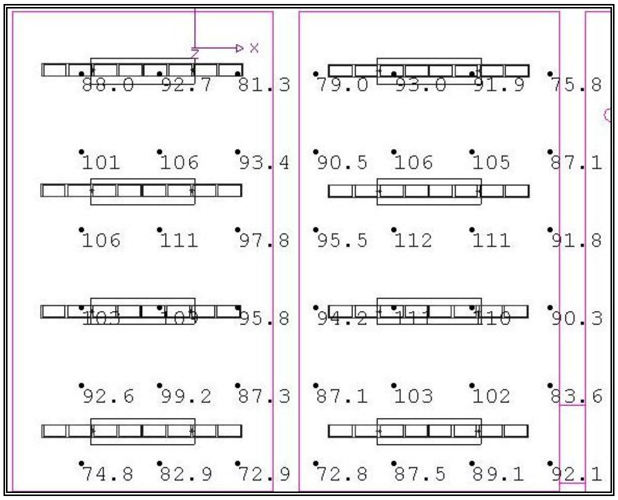


Figure 13 : Medium Support Spaces, New Design

CONCLUSION

Once Laboratory 285 and the adjacent support spaces were designed, the new design was applied to all the lab spaces. The full calculation can be found in Appendix J. Other modifications to the current lighting system were made that were not part of the Laboratory 285 calculation. The pantry, open flex, and copy supply spaces fall under the "Office" category when determining lighting power densities. The original design had those rooms at 2.84W/SF. The new design reduced that level to 1.2 W/SF. Specialized spaces such as cold rooms and isotope rooms remained unchanged as did existing shell space. The average power density is still relatively high compared to typical levels seen in office buildings and even other laboratories. This can be accounted by the high demand for precision in the research activities. More light in the spaces increases researchers' ability to perform at their highest level.

The total reduction in watts is from 199,648W to 160,933W which translates into lighting power density decrease from 2.45W/SF to 1.98 W/SF. This is a 19.4% reduction in energy cost by the lighting system alone. In addition, illuminance levels were improved either by increasing the amount of lumens or increasing the number of footcandles on the work surface.

ELECTRICAL SYSTEM

ELECTRICAL DESIGN

To understand the impact of the new lighting design on the electrical system, creating new panel board(s) configurations and making a comparison to the original system would be required. This would also facilitate a cost comparison to establish the economic feasibility of the alterations.

Unfortunately, there are too may panel boards in the Landscape Building for any of them to be illustrated in the electrical floor plans. There are other unknowns that make it impossible to create a theoretical panel for the original design. First, the types and quantity of equipment is unknown. While approximate power densities can be assumed for the HVAC load calculations, it is much more challenging to make these same assumptions for the panels. The voltage and phase requirements would need to be determined before a panel could be designed and obtaining this information for this project was impossible. Secondly, the laboratory spaces do not have typical receptacles. Instead, the lab stations are equipped with three ballards, each of which run on 120V. The load of each ballard is not specified in the design drawings and should be supplied by the contractor. This information was not able to be obtained.

The most logical design for the electric system would be for the lighting circuits to be on the same panels because florescent lights can cause distortion in the currents. This could be a potential problem for critical and expensive lab equipment. Laboratory equipment running at 120V and typical receptacles can all be put on the same panels and then specialized receptacles and equipment on their own series of panels. Panels are grouped by location. There is space running down the side of the service corridor for all of the panel boards to be located. This provides a central location for all panels for maintenance and service issues. An example of a lighting panel board and sample calculations can be found below.

Table 12 : Lighting Fixture Panel Board

Description	Load [VA]			Brk. Trip	LP 1				Brk. Trip	Load [VA]			Description
	A	B	C	[A]	Cond. Size	Ckt. #		Cond. Size	[A]	A	B	C	
Lab 285	4320			20	#12	1	2	#12	20	3,697			Lab Support 285
Lab 275		4320		20	#12	3	4	#12	20		3,697		Lab Support 275
Lab 255			4320	20	#12	5	6	#12	20			3,697	Lab Support 255
Lab Support 245	3,697			20	#12	7	8	#12	20	4320			Lab 245
Lab Support 225		3,697		20	#12	9	10	#12	20		4320		Lab 225
Lab Support 215			3,697	20	#12	11	12	#12	20			4320	Lab 215
Lab 270	1464			20	#12	13	14	#12	20	1253			Lab Support 270
Lab 265		1464		20	#12	15	16	#12	20		1253		Lab Support 265
Lab 240			1464	20	#12	17	18	#12	20			1253	Lab Support 240
Lab Suport 235	1253			20	#12	19	20	#12	20	1464			Lab 235
Lab Support 210		1525		20	#12	21	22	#12	20		1783		Lab 210
Lab Support 295			1754	20	#12	23	24	#12	20			2049	Lab 295
						25	26						
						27	28						
						29	30						
						31	32						
						33	34						
						35	36						
						37	38						
						39	40						
						41	42						

Total Load on Phase A	21468	[VA]
Total Load on Phase B	22059	[VA]
Total Load on Phase C	22554	[VA]
Load on Panel	82600	[kVA Demand]
	124.25	[A]
Voltage	277	[V]
Main Breaker	125	[A]
Feeder Size	(4) 1/0 @125A, 2"	
Panel Size	125	[A]

ACOUSTIC ANALYSIS

OF ORIGINAL SYSTEM

As stated earlier, Howard Hughes Medical Institute has adopted the National Institute of Health's design guidelines for buildings. NIH has developed recommended NC levels based on years of experience for spaces common in hospitals and medical research facilities. NC levels are based on rooms not being occupied and with all use equipment turned off. Values can be found in Table 13 below. The separation of mechanical equipment the in rear of the building helps to reduce sound transmission into occupied spaces.

Table 13

Recommended NC Levels

Area	NC Level
Auditoriums	20-25
Audiology Suites, Audio/Speech, Pathology, Phonology/Caridac	25
Chapel, Capel Mediations	25
Private Residences	25-30
Conference Rooms	25-30
Hospital Rooms	25-35
Patient Rooms	35
Executive Offices	30-35
Open-Plan Offices	35-35
Dinning Rooms, Offices, Lobbies	40
Central Sterile, Food Service/Serving	45
Operating Rooms	40-45
Research Laboratories	40-45
Corridors	45
Kitchen, Lockers, Warehouse, Shops	50
Research Animal Housing Areas	--

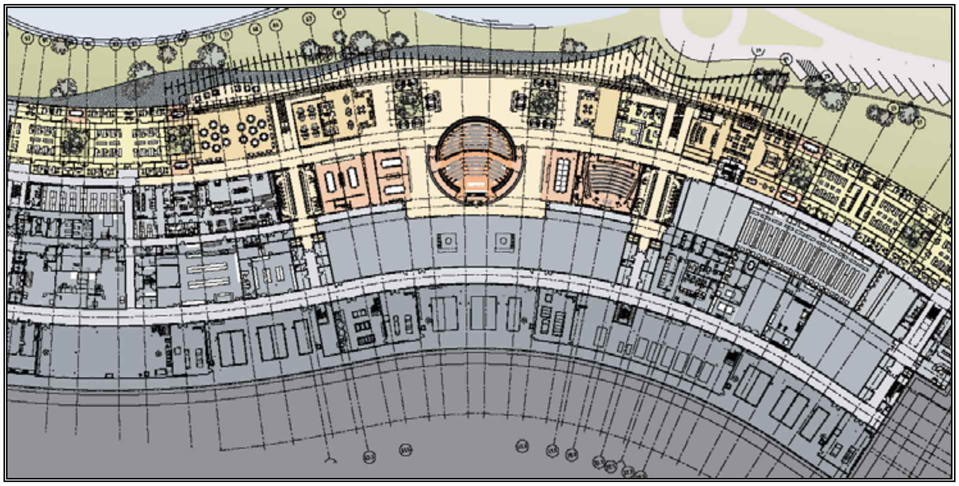


Figure 3 : First Floor Plan

Figure 14 is a rendering of the first floor plan. The area that is at the bottom of the building in gray is all mechanical space. The mechanical room in Zone F, Level One currently houses the five existing chillers, two future ones, 3 pumps and one future pump as well. This room has concrete slab floors and 8" cmu's for all interior walls. The south wall is an exterior wall that, at floor level, is approximately 60 feet below grade. The east and west walls divide the mechanical room from other mechanical rooms. On the other side of the north wall is a 15 foot wide service corridor that runs the length of the building. Directly across the hall from this mechanical room is the sterilizing room for mechanical equipment and tools. While staff does work in this room during operational hours, sound levels are not a critical issue as the room has a great deal of equipment noise itself.

The following calculation in Table 14 determines the necessary partition between the mechanical room and the corridor in order to achieve the required transmission loss. The calculation is done for both the actual equipment and for the new design with additional pumps. A major assumption that was made was that the likely noise in the corridor was comparable to that of a lobby or reception area. The table with likely noise values by space types in *Architectural Acoustics* by M. David Egan did not provide data for hallways and corridors. It would be expected that the noise in the corridor is considerably less than that of a lobby and therefore would not mask the sound from the mechanical room as well as the calculation suggests.

Table 14 : Transmission Loss Calculation

		Sound Absorption Coefficients					
Surface	**Area [SF]**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Concrete Block, painted	4600	0.1	0.05	0.06	0.07	0.09	0.08
Concrete Floor	3450	0.01	0.01	0.02	0.02	0.02	0.02
Concrete Ceiling	3450	0.01	0.01	0.02	0.02	0.02	0.02
Sides Without Walls	600	1	1	1	1	1	1
		Sound Absorption [sabins]					
Surface	**Area [SF]**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Concrete Block, painted	4600	460	230	276	322	414	368
Concrete Floor	3450	34.5	34.5	69	69	69	69
Concrete Ceiling	3450	34.5	34.5	69	69	69	69
Sides Without Walls	600	600	600	600	600	600	600
a2 [sabins]		**1129**	**899**	**1014**	**1060**	**1152**	**1106**
		Mechanical Room Noise Calculation: Actual Design					
		125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Chiller Noise (One Unit)		85	87	87	90	98	91
Chiller Noise (Five Units)		92	94	94	97	105	98
Pump Noise (One Unit)		80	82	87	86	80	77
Pump Noise (Three Units)		85	87	92	91	85	82
Total Noise in Mech Room		**93**	**95**	**96**	**98**	**105**	**98**
		Mechanical Room Noise Calculation: New Design					
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Chiller Noise (One Unit)		85	87	87	90	98	91
Chiller Noise (Five Units)		92	94	94	97	105	98
Pump Noise (One Unit)		80	82	87	86	80	77
Pump Noise (Six Units)		88	90	95	94	88	85
Total Noise in Mech Room		**93**	**95**	**97**	**99**	**105**	**98**
		Noise Reduction & Transmission Loss : Actual Design [dB]					
		125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Likely Noise in the Mech Room		93	95	96	98	105	98
Likely Noise in the Corridor		66	72	77	74	68	60
Required NR		27	23	19	24	37	38
Minus 10 log a2/S		-6	-7	-7	-6	-6	-6
Required TL		**33**	**30**	**26**	**30**	**43**	**44**
Actual Wall Assembly TL, 8" Concrete, painted		**34**	**40**	**44**	**49**	**59**	**64**
		Noise Reduction & Transmission Loss : Actual Design [dB]					
		125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Likely Noise in the Mech Room		93	95	97	99	105	98
Likely Noise in the Corridor		66	72	77	74	68	60
Required NR		27	23	20	25	37	38
Minus 10 log a2/S		-6	-7	-7	-6	-6	-6
Required TL		**33**	**30**	**27**	**31**	**43**	**44**
Actual Wall Assembly TL, 8" Concrete, painted		**34**	**40**	**44**	**49**	**59**	**64**

CONCLUSION

As it can be seen for both cases, the actual wall assembly is adequate, if not over designed for the amount of noise in the mechanical room. It can be estimated that with a lower sound level in the corridor than represented above, the partition assembly would still be adequate. Also, if the 8" cmu wall does not quite prevent the necessary amount of sound from coming in to the hall, it is not critical as there aren't spaces in the close vicinity that require carefully controlled sound levels. Therefore, it can be concluded that the addition of three more pumps to the mechanical system does not require acoustical treatment for the mechanical room.

Note: All data in Figure Table 14 were taken from data in *Architectural Acoustics* by M. David Egan.

COST ANALYSIS

COST CONSIDERATIONS

Performing a cost analysis is important in determining the best system to select for a certain application. Two different analyses have been used to determine the best "case" situation for this report. These calculations include a simple payback comparison and a 20-year life cycle cost analysis.

Cost considerations include the initial cost of the equipment, life of the equipment, and the operating costs. While a system may have a very low first cost, the annual operating cost of the system may be so large that the owner cannot afford to maintain the building. Therefore it is important to find a balance between first cost and the operating cost.

INITIAL COST OF EQUIPMENT

The initial cost of all the equipment under consideration was determined by contacting sales representatives to receive price quotes. The following table summarizes the initial costs:

Table 15

Equipment First Costs [$]

Unit	Type	Description	Manufacturer	Product No.	Unit Price [$/X]
L1	Original Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	135
L1A	Original Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	135
L8	Original Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	129
L8A	Original Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	129
L36	Original Fixture	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	81
L1	Original Lamp	(2) F32/835/XPS/ECO	OSI	21697	13.56
L1A	Original Lamp	(2) F32/835/XPS/ECO	OSI	21697	13.56
L8	Original Lamp	(2) F32/835/XPS/ECO	OSI	21697	13.56
L8A	Original Lamp	(4) FT40DL/835/RS	OSI	20585	19.1
L36	Original Lamp	(1)CF32DT/E/IN/835	OSI	20885	10.33
L1	New Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	135
L8A_A2	New Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	129
L1_A	New Fixture	Recessed Row 1'X8' 2 Lamp T8	Lithonia Lighting	RR 2 96T8 TUBI	215
L36_A	New Fixture	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	81
L1	New Lamp	(2) F32/835/XPS/ECO	OSI	21697	13.56
L8A_A2	New Lamp	(2) F40T8 TL835 60 ALTO 1LP	Philips	368340	4.89
L1_A	New Lamp	(2) FO96/835/XP/SS/ECO	OSI	22100	10.33
L36_A	New Lamp	(1) Mini Dec Twister 27W Med EL/mDT 1CT	Philips	137158	5.99
Cooling Tower	--	NC Class	Marley	NC8311J1	79,300
Pumps	Split-Coupled	Series 4300, 4x4x10	Armstrong	PT82-1-0	6,150
Pumps	End Suction	Series 1510 Model 4 BC	Bell & Gossett	--	3,050
Heat Exchanges	Plate-Frame	B56Hx200 4*2 1/2"NPT	SWEP	11487-200	6,636

As this table shows, the cooling towers are the single most expensive equipment at $79,300 each. While they are expensive, installing either the ground loop or pond loop systems is more expensive than the cooling towers.

ENERGY SOURCES & RATES

Electric service is provided by Dominion Virginia Power. Table 16 shows the expected rates for the Landscape Building. Natural Gas is provided by Washington Gas. The rates can be seen in Table 17. All data has been provided by the mechanical engineer and was used in the actual energy analysis. These rates will most likely continue to increase until the building is operational and beyond. Therefore, it is important to keep energy usage and cost in the forefront of all design considerations.

Table 16

Electricity Cost Summary	
Energy Charges	
On-peak	$0.05599 per kWh
Off-peak	$0.03166 per kWh
Supply Charge	
On-peak	$1.17150 per kW
Off-peak	$0.6320 per kW

Table 17

Natural Gas Cost Summary	
Distribution Charge	
Flat Price	$0.570 per therm

SIMPLE PAYBACK

The simple payback is a simple calculation to determine how long it would for the first cost investment to pay for itself through annual cost savings. The equation is as follows:

Simple Payback [yrs] = Change in first cost/Change in annual cost

In order to do this calculation, a base case must be chosen to which all other cases are compared. For the purposes of this report, the base case is Case 1. Table A.37 in Appendix L has all the inputs used. These include the first cost of both the mechanical system under discussion and the lighting system. In addition, the HVAC operating costs and the maintenance costs of replacing lamps over a period of 20 years plays a major role in the cost of the systems. The following table is a summary of the simple payback calculation for all important cases:

Table 18

Simple Payback

	Case 1	Case 4	Case 5	Case 6	Case 7
Relative First Cost	188,871	179,612	1,169,759	243,156	233,897
Change in First Cost	0	-9,259	980,888	54,285	45,026
Annual HVAC Operating Cost	968,542	727,465	948,796	898,891	682,818
Annual Lighting Maintanance Cost	1,640	729	1,640	1,640	729
Total Annual Cost	970,182	728,194	950,436	900,531	683,547
Chance in Annual Cost	0	-241,987	-19,746	-69,651	-286,634
Simple Payback [years]	**–**	**0.0**	**49.7**	**0.8**	**0.2**

It was determined that Case 5 is not a feasible solution. Typically, owners prefer to have a payback of less than 5 years. A payback of almost 50 years is completely out of the question. Both Cases 6 and 7 are reasonable solutions. Case 7 which has the least expensive for operating costs and the least expensive first costs for the alternative designs has a payback of about 72 days. This system is therefore selected as most economically feasible alternative to the current design.

LIFE CYCLE COST

The life cycle cost analysis was performed using Engineering Economic Analysis 3.01 by Carrier. This program uses the annual and first costs to calculate the cost of the system over a specified period of time.

Results from this analysis again show that Case 7 is the best alternative. The system has a net present worth of $7,252,521 after 20 years, as opposed to Case 1 with a NPV of $9,612,197. For full results of this analysis, please see Appendix L.

CONCLUSIONS & RECOMMENDATIONS

The major lesson that can be drawn from this study is that carefully designing the mechanical system for actual loads is of critical importance. The operating cost of the laboratory space in the Landscape Building was reduced by approximately 21.6%. This does require more communication between the owner and engineer, but the results are well worth that effort.

Secondly, optimizing the lighting design can have a significant impact on energy use and causes a 3% decrease in the cooling load.

The first recommendation for changes to the Landscape Building would be to reduce the cooling load and replace the lighting fixtures in the laboratory and laboratory support spaces. Reducing the cooling load has no up front cost and replacing the fixtures saves money. This is a relatively simple alteration that can have a major impact on annual operation and maintenance costs.

Installing a ground-loop system to replace the cooling towers is not recommended. The first cost is extremely expensive due to the length of piping required. Using the ponds as heat sink is recommended, even if only used for pre-cooling or preheating. They are existing ponds are require little alteration to integrate them into the current mechanical system.

As has been previously discussed, Case 7 has both a lower first cost and operating cost making it the most economically feasibly alternative to the current system. This can be seen in both the simple payback and life cycle costs analysis where Case 7 had the best results compared to the other designs. Therefore, it is recommended that the system designed for Case 7 should be chosen. This results in a 30% reduction in annual operating costs and satisfies the goals of this thesis report.

REFERENCES

2003 ASHRAE Handbook – HVAC Applications. ASHRAE, Inc. Atlanta, GA, 2003.

Aegis Energy Services, Inc. Benefits of Cogeneration. 2004 <http://www.aegisenergyservices.com/benefits.asp>.

ANSI/ASHRAE Standard 62.1-2004 – Ventilation for Acceptable Indoor Air Quality. ASHRAE, Inc. Atlanta, GA, 2004.

ASHRAE Standard 90.1-1989. Energy Standard for Building Except Low-Rise Residential Buildings. I-P Edition.

Ground-Coupled Heat Pump Systems for Commercial Buildings. ASHRAE, 1994

Burt Hill. Howard Hughes Medical Institute Energy Analysis Inputs.

Burt Hill. Janelia Farm Research Campus Cogeneration Feasibility Study. May 3, 2002.

Commercial/Institutional Ground-Source Heat Pump Engineering Manual. ASHRAE, 1995.

Dais Analytic Corporation. ConsERV Homepage. 2005. <www.conserv.com>

Hughes, David S. Electrical Systems in Buildings. British Columbia Technical Institute of Technology. Delmar Publishers, Inc. 1988.

Howard Hughes Medical Institute, Janelia Farm Research Campus, Landscape Building, Volume 2.1 Master Set.

Energy Design Solutions. Building Case Study: Bio Lab and Office. Energy Design Resources. <http://www.energydesignresources.com/docs/cs-biotech.pdf>.

Rae, Mark Stanley. IESNA Lighting Handbook. Illuminating Engineering Society of North America, 2000.

Janelia Farm Research Campus HVAC Description.

Janelia Farm Research Campus LEED Recommendations and Evaluation. February 14, 2002.

Janelia Farm Research Campus Program Development Report.

Jae-Weon Jeong. *AE 455 Homework 4,5 , 9, and 10*. Spring Semester 2005.

Kavanuagh, Steve. Ground Coupling Water Source Heat Pumps. The University of Alabama. Tuscaloosa, Alabama.

Ling, Moses D. F. An Energy Prediction Method for Constant and Variable Volume Laboratory Hoods. The Pennsylvania State University, 1986.

Mathew, Paul; Greenberg, Steve; Sartor, Dale; Frenze, David; Morehead, Michael; Starr, William. Right-Sizing Laboratory HVAC Systems. HPAC Engineering, October 2005.

National Institutes of Health. Reference Design and Safety Guidelines for the HVAC Designer.

Philips. Seeing the possibilities – Sustainable Lighting Solutions.

Philips Lighting. Division Webpage. 2004-2005. <www.nam.lighting.philips.com/us/>

Richichi, Chris Paul. Simulation and Parametric Study of a Direct Expansion Energy Recovery System Utilizing 100 Percent Supply and Exhaust Air. The Pennsylvania State University, 1987.

U.S. Department of Energy. Energy Efficiency and Renewable Energy. 2 December 2005. <http://www.eere.energy.gov/>

Zumtobel Staff. Company Website. <www.zumtobelstaff.us/us/en/default.htm>.

Note: Thesis Proposals were used to aid in the format and content of this report.

APPENDIX

A : EXISTING LOAD, CASE 1

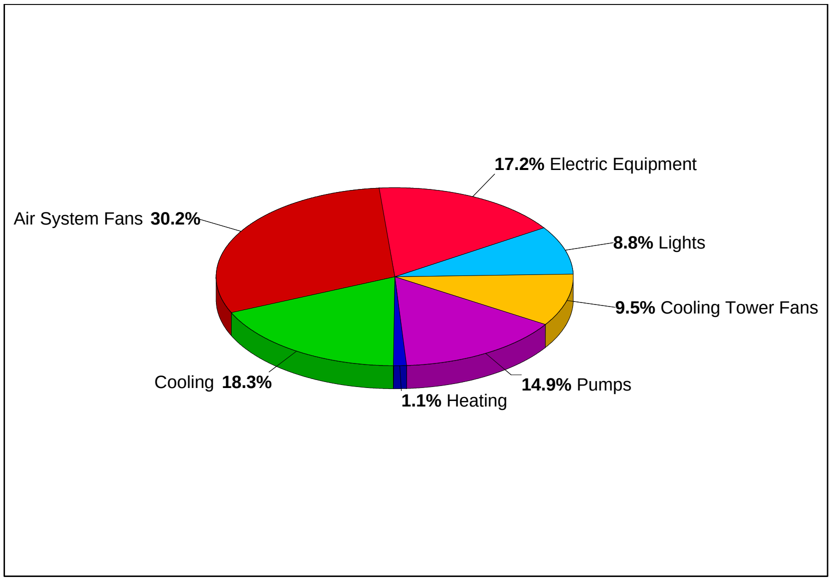


Figure A.1: Annual Component Costs, Case 1

Table A.1 : Annual Component Costs, Case 1

Case 1			
Component	**Annual Cost [$]**	**($/ft²)**	**Percent of Total [$]**
Air System Fans	292,714	3.465	30.2
Cooling	177,009	2.095	18.3
Heating	11,094	0.131	1.1
Pumps	144,445	1.71	14.9
Cooling Tower Fans	91,760	1.086	9.5
HVAC Sub-Total	**717,021**	**8.488**	**74**
Lights	85,243	1.009	8.8
Electric Equipment	166,278	1.968	17.2
Misc. Electric	0	0	0
Misc. Fuel Use	0	0	0
Non-HVAC Sub-Total	**251,521**	**2.977**	**26**
Grand Total	**968,542**	**11.465**	**100**

B : ALTERED LOAD, CASE 2

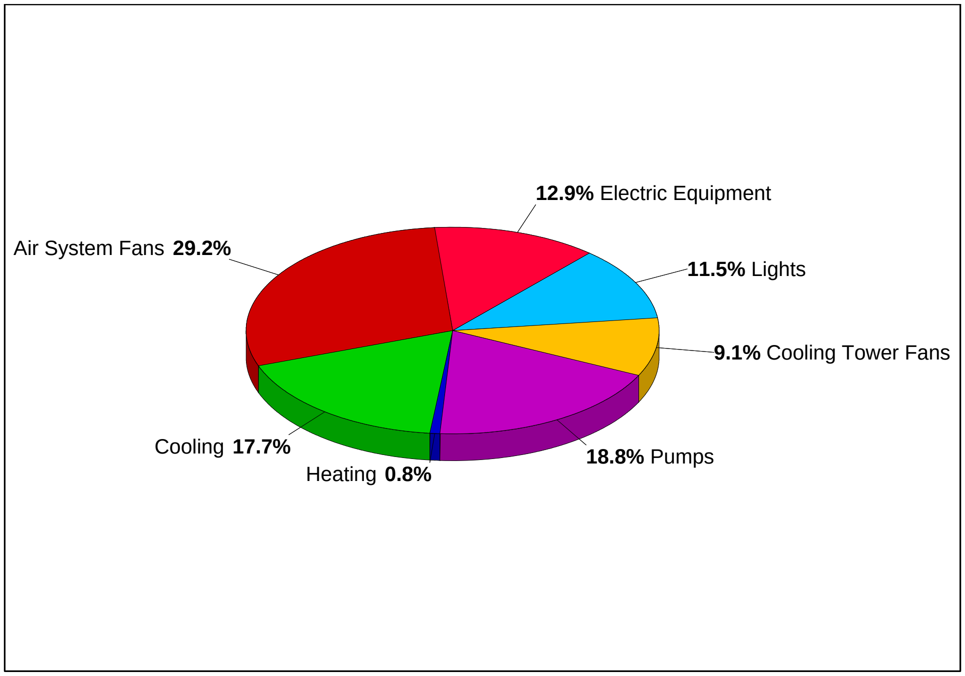


Figure A.2: Annual Component Costs, Case 2

Table A.2 : Annual Component Costs, Case 2

Case 2			
Component	**Annual Cost [$]**	**($/ft²)**	**Percent of Total [$]**
Air System Fans	221,498	2.622	29.2
Cooling	134,357	1.59	17.7
Heating	5,954	0.071	0.8
Pumps	142,650	1.689	18.8
Cooling Tower Fans	69,291	0.82	9.1
HVAC Sub-Total	**573,750**	**6.792**	**75.5**
Lights	87,521	1.036	11.5
Electric Equipment	98,300	1.164	12.9
Misc. Electric	0	0	0
Misc. Fuel Use	0	0	0
Non-HVAC Sub-Total	**185,821**	**2.2**	**24.5**
Grand Total	**759,571**	**8.991**	**100**

C : ALTERED LOAD, CASE 3

Table A.3 Adjusted Lighting Loads by Room

ZONE	ROOM	SPACE NAME	SPACE AREA A_z [SF]	Original Design			New Design	
				Lamps	Lighting Power [W]	Lighting Power Density [W/sf]	Lighting Power [W]	Lighting Power Density [W/sf]
2A	L295	LABORATORY	1,428	40-L1A, 16-L1, 2-L36	3,648	2.55	2,818	1.97
2A	S295	FUTURE CELL ARCHIVE	693	6-A	768	1.11	768	1.11
2A/B	L285	LABORATORY	3,010	80-L1A, 32-L1, 4-L36	7,296	2.42	5,940	1.97
2A	S285C	DARK ROOM	90	2-L8A	320	3.56	320	3.56
2A	S285D	SMALL COLD ROOM	90	0	0	0.00	0	0.00
2A	S285E	LARGE COLD ROOM	189	0	0	0.00	0	0.00
2A	S285F	MEDIUM SUPPORT	210	4-L8A	640	3.05	640	3.05
2A	S285G	MEDIUM SUPPORT	210	4-L8A	640	3.05	640	3.05
2B	S285S	SHELL SPACE	945	8-A	1,024	1.08	1,024	1.08
2B	L283	PANTRY	352	4-L47, 2-L45B, 2L45	256	0.73	422	1.20
2B	L282	CENTRAL SUPPLY	90	4-L8	256	2.84	108	1.20
2B	L281	OPEN FLEX	90	4-L8	256	2.84	108	1.20
2B	L275	LABORATORY	2,905	80-L1A, 32-L1, 4-L36	7,296	2.51	5,940	2.04
2B	S275D	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2B	S275E	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2B	S275F	MEDIUM SUPPORT	160	4-L8A	640	4.00	640	4.00
2B	S275G	MEDIUM SUPPORT	160	4-L8A	640	4.00	640	4.00
2B	S275H	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2B	S275J	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2B	S275K	LARGE SUPPORT	441	16-L8	2,560	5.80	1,024	2.32
2B	S275M	MEDIUM SUPPORT	120	4-L8A	640	5.33	640	5.33
2B	S275N	MEDIUM SUPPORT	120	4-L8A	640	5.33	640	5.33
2C	L270	LABORATORY	1,020	25-LIA, 10-L1, 1-L36	2,272	2.23	2,013	1.97
2C	S270A	LARGE SUPPORT	420	16-L8	2,560	6.10	1,024	2.44
2C	S270B	MEDIUM SUPPORT	150	4-L8A	640	4.27	640	4.27
2C	S270C	MEDIUM SUPPORT	150	4-L8A	640	4.27	640	4.27
2C	S275A	DARK ROOM	90	2-L8A	320	3.56	320	3.56
2C	S275B	SMALL COLD ROOM	90	0	0	0.00	0	0.00
2C	L272	COPY SUPPLY	352	4-L47, 2-L45B, 2L45	256	0.73	422	1.20
2C	L273	CENTRAL SUPPLY	90	4-L8	256	2.84	108	1.20
2C	L271	OPEN FLEX	90	4-L8	256	2.84	108	1.20
2C	S275C	LARGE COLD ROOM	160	0	0	0.00	0	0.00
2C	L265	LABORATORY	1,020	25-LIA, 10-L1, 1-L36	2,272	2.23	2,013	1.97
2C	S265A	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2C	S265B	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2C	S265C	MEDIUM SUPPORT	130	4-L8A	640	4.92	640	4.92
2C	S265D	MEDIUM SUPPORT	125	4-L8A	640	5.12	640	5.12
2C	S265E	AUTOCLAVE/SMALL GW	150	2-N1	128	0.85	128	0.85
2C	S265F	ISOTROPE LAB	115	3-L8A	480	4.17	320	2.78
2C	L263	CENTRAL SUPPLY	105	4-L8	256	2.45	125	1.20
2C	L262	COPY SUPPLY	313	4-L47, 2-L45B, 2L45	256	0.82	375	1.20
2C	L261	OPEN FLEX	114	4-L8	256	2.25	137	1.20
2C/D	L255	LABORATORY	3,010	90-L1A, 32-L1, 4-L36	7,936	2.64	5,940	1.97
2C/D	S255G	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2C/D	S255H	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2C	S255J	LARGE COLD ROOM	189	0	0	0.00	0	0.00
2C	S255K	DARK ROOM	100	2-L8A	320	3.20	320	3.20
2C	S255M	SMALL COLD ROOM	100	0	0	0.00	0	0.00
2D	S255	SHELL SPACE	987	8-A	1,024	1.04	1,024	1.04
2D	S255E	MEDIUM SUPPORT	170	4-L8A	640	3.76	640	3.76
2D	S255F	MEDIUM SUPPORT	170	4-L8A	640	3.76	640	3.76
2D	L253	CENTRAL SUPPLY	105	4-L8	256	2.45	125	1.20
2D	L252	PANTRY	313	4-L47, 2-L45B, 2L45	256	0.82	375	1.20
2D	L251	OPEN FLEX	114	4-L8	256	2.25	137	1.20

Table A.3 (cont'd) : Adjusted Lighting Loads by Room

ZONE	ROOM	SPACE NAME	SPACE AREA A_z [SF]	Original Design			New Design	
				Lamps	Lighting Power [W]	Lighting Power Density [W/sf]	Lighting Power [W]	Lighting Power Density [W/sf]
2D	S245H	MEDIUM SUPPORT	160	4-L8A	640	4.00	640	4.00
2D	S245J	MEDIUM SUPPORT	160	4-L8A	640	4.00	640	4.00
2D	S245K	LARGE SUPPORT	441	16-L8	2,560	5.80	1,024	2.32
2D	S245M	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2D	S245N	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2E	S245A	DARK ROOM	90	2-L8A	320	3.56	320	3.56
2E	S245B	SMALL COLD ROOM	99	0	0	0.00	0	0.00
2E	S245C	LARGE COLD ROOM	189	0	0	0.00	0	0.00
2E	S245D	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2E	S245E	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2E	S245F	MEDIUM SUPPORT	193	4-L8A	640	3.32	640	3.32
2E	S245G	MEDIUM SUPPORT	193	4-L8A	640	3.32	640	3.32
2E	L243	CENTRAL SUPPLY	105	4-L8	256	2.45	125	1.20
2E	L242	COPY SUPPLY	313	4-L47, 2-L45B, 2L45	256	0.82	375	1.20
2E	L241	OPEN FLEX	114	4-L8	256	2.25	137	1.20
2E	L240	LABORATORY	1,020	25-LIA, 10-L1, 1-L36	2,272	2.23	2,013	1.97
2E	S240A	AUTOCLAVE/SMALL GW	165	2-N1	128	0.78	128	0.78
2E	S240B	ISOTOPE LAB	143	3-L8A	480	3.36	320	2.24
2E	S240C	MEDIUM SUPPORT	154	4-L8A	640	4.16	640	4.16
2E	S240D	MEDIUM SUPPORT	143	4-L8A	640	4.48	640	4.48
2E	S240E	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2E	S240F	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2E	L235	LABORATORY	1,020	25-LIA, 10-L1, 1-L36	2,272	2.23	2,013	1.97
2E	S235C	LARGE SUPPORT	441	16-L8	2,560	5.80	1,024	2.32
2F	S235A	MEDIUM SUPPORT	150	4-L8A	640	4.27	640	4.27
2F	S235B	MEDIUM SUPPORT	150	4-L8A	640	4.27	640	4.27
2F	L225	LABORATORY	3,010	90-L1A, 32-L1, 4-L36	7,936	2.64	5,940	1.97
2F	S225E	MEDIUM SUPPORT	187	4-L8A	640	3.42	640	3.42
2F	S225F	MEDIUM SUPPORT	187	4-L8A	640	3.42	640	3.42
2F	S225G	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2F	S225H	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2F	S225J	LARGE COLD ROOM	189	0	0	0.00	0	0.00
2F	S225K	DARK ROOM	100	2-L8A	320	3.20	320	3.20
2F	S225M	SMALL COLD ROOM	99	0	0	0.00	0	0.00
2F	S255S	SHELL SPACE	987	8-A	1,024	1.04	1,024	1.04
2F	L223B	CENTRAL SUPPLY	105	4-L8	256	2.45	125	1.20
2F/G	L223A	PANTRY	313	4-L47, 2-L45B, 2L45	256	0.82	375	1.20
2F/G	L221	OPEN FLEX	114	4-L8	256	2.25	137	1.20
2G	L215	LABORATORY	3,010	85-L1A, 34-L1, 4-L36	7,744	2.57	5,940	1.97
2G	S215A	MEDIUM SUPPORT	165	4-L8A	640	3.88	640	3.88
2G	S215B	MEDIUM SUPPORT	165	4-L8A	640	3.88	640	3.88
2G	S215E	LARGE COLD ROOM	189	0	0	0.00	0	0.00
2G	S215F	DARK ROOM	100	2-L8A	320	3.20	320	3.20
2G	S215G	SMALL COLD ROOM	99	0	0	0.00	0	0.00
2G	S215H	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2G	S215J	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
2G	S215K	LARGE SUPPORT	441	16-L8	2,560	5.80	1,024	2.32
2G	S215M	MEDIUM SUPPORT	226	4-L8A	640	2.84	640	2.84
2G	S215N	MEDIUM SUPPORT	226	4-L8A	640	2.84	640	2.84
2G	L210	LABORATORY	1,242	35-LIA,14-LA, 4-L36	3,264	2.63	2,451	1.97
2G	S210	SHELL SPACE	609	8-A	1,024	1.68	1,024	1.68

Table A.3(cont'd) : Adjusted Lighting Loads by Room

ZONE	ROOM	SPACE NAME	SPACE AREA A_z [SF]	Original Design			New Design	
				Lamps	Lighting Power [W]	Lighting Power Density [W/sf]	Lighting Power [W]	Lighting Power Density [W/sf]
3A	S390B	LARGE COLD ROOM	189	0	0	0.00	0	0.00
3A	S390C	MEDIUM SUPPORT	226	4-L8A	640	2.84	640	2.84
3A	S388	CHEMISTY LAB	483	12-L8	768	1.59	768	1.59
3A	L388	CENTRAL SUPPLY	90	4-L8	256	2.84	108	1.20
3A/B	L387	COPY SUPPLY	352	4-L47, 2-L45B, 2L45	256	0.73	422	1.20
3A/B	L386	OPEN FLEX	90	4-L8	256	2.84	108	1.20
3B	L380	LABORATORY	3,003	90-L1A,36-LA,3-L36	8,160	2.72	5,926	1.97
3B	S380A	CHEMISTY LAB	483	12-L8	768	1.59	768	1.59
3B	S380B	CHEMISTY LAB	483	12-L8	768	1.59	768	1.59
3B	S380C	CHEMISTY LAB	483	12-L8	768	1.59	768	1.59
3B	S380D	CHEMISTY LAB	483	12-L8	768	1.59	768	1.59
3B	S380E	CHEMISTY LAB	483	12-L8	768	1.59	768	1.59
3B	L375	PANTRY	352	4-L47, 2-L45B, 2L45	256	0.73	422	1.20
3B	L378	CENTRAL SUPPLY	90	4-L8	256	2.84	108	1.20
3B	L376	OPEN FLEX	90	4-L8	256	2.84	108	1.20
3B/C	L370	LABORATORY	2,760	75-LAI,30-LA,4-L36	6,848	2.48	5,447	1.97
3B	S370G	LARGE COLD ROOM	147	0	0	0.00	0	0.00
3B	S375	TISSUE CULTURE	441	16-L8	1,024	2.32	1,024	2.32
3B/C	S370D	MEDIUM SUPPORT	165	4-L8A	640	3.88	640	3.88
3B/C	S370E	MEDIUM SUPPORT	165	4-L8A	640	3.88	640	3.88
3C	S370A	LARGE SUPPORT	441	16-L8	2,560	5.80	1,024	2.32
3C	S370B	MEDIUM SUPPORT	140	4-L8A	640	4.57	640	4.57
3C	S370C	MEDIUM SUPPORT	140	4-L8A	640	4.57	640	4.57
3D/C	L360	LABORATORY	2,760	75-LAI,30-LA,4-L36	6,848	2.48	5,447	1.97
3C	S360D	MEDIUM SUPPORT	205	4-L8A	640	3.12	640	3.12
3C	S360E	MEDIUM SUPPORT	205	4-L8A	640	3.12	640	3.12
3C	S360F	MEDIUM SUPPORT	205	4-L8A	640	3.12	640	3.12
3C	S360G	MEDIUM SUPPORT	205	4-L8A	640	3.12	640	3.12
3C	S360H	AUTOCLAVE/SMALL GW	120	2-N1	128	1.07	128	1.07
3C	S360J	ISOTOPE LAB	120	3-L8A	480	4.00	320	2.67
3D	S360C	LARGE COLD ROOM	180	0	0	0.00	0	0.00
3D	S360A	DARK ROOM	90	2-L8A	320	3.56	320	3.56
3D	S360B	SMALL COLD ROOM	90	0	0	0.00	0	0.00
3C	L357	PANTRY	352	4-L47, 2-L45B, 2L45	256	0.73	422	1.20
3C	L358	CENTRAL SUPPLY	90	4-L8	256	2.84	108	1.20
3C	L356	OPEN FLEX	90	4-L8	256	2.84	108	1.20
3D	L350	LABORATORY	2,760	75-LAI,30-LA,4-L36	6,848	2.48	5,447	1.97
3D	S355	SHELL SPACE	882	8-A	1,024	1.16	1,024	1.16
3D	S350A	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
3D	S350B	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
3D	S350C	LARGE SUPPORT	441	16-L8	2,560	5.80	1,024	2.32
3D	S350D	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
3D	S350E	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
3D	L348	CENTRAL SUPPLY	90	4-L8	256	2.84	108	1.20
3D/E	L347	COPY SUPPLY	352	4-L47, 2-L45B, 2L45	256	0.73	422	1.20
3D/E	L346	OPEN FLEX	90	4-L8	256	2.84	108	1.20
3E	L340	LABORATORY	2,760	75-LAI,30-LA,2-L36	6,784	2.46	5,447	1.97
3E	S340A	LARGE SUPPORT	441	16-L8	1,024	2.32	1,024	2.32
3E	S340B	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
3E	S340C	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
3E	S340D	MEDIUM SUPPORT	231	4-L8A	640	2.77	640	2.77
3E	S340E	MEDIUM SUPPORT	231	4-L8A	640	2.77	640	2.77
3E	S340F	LARGE COLD ROOM	189	0	0	0.00	0	0.00
3E	S340G	DARK ROOM	100	2-L8A	320	3.20	320	3.20
3E	S340H	SMALL COLD ROOM	99	0	0	0.00	0	0.00

Table A.3 (cont'd) : Adjusted Lighting Loads by Room

ZONE	**ROOM**	**SPACE NAME**	**SPACE AREA A_z [SF]**	**Original Design**			**New Design**	
				Lamps	**Lighting Power [W]**	**Lighting Power Density [W/sf]**	**Lighting Power [W]**	**Lighting Power Density [W/sf]**
3E/F	L330	LABORATORY	2,275	75-LAI,30-LA,4-L36	6,848	3.01	4,490	1.97
3E	S330H	AUTOCLAVE/SMALL GW	100	2-N1	128	1.28	128	1.28
3E	S330J	ISOTOPE LAB	100	3-L8A	480	4.80	320	3.20
3F	S330A	DARK ROOM	100	2-L8A	320	3.20	320	3.20
3F	S330B	SMALL COLD ROOM	99	0	0	0.00	0	0.00
3F	S330C	LARGE COLD ROOM	189	0	0	0.00	0	0.00
3F	S330D	MEDIUM SUPPORT	220	4-L8A	640	2.91	640	2.91
3F	S330E	MEDIUM SUPPORT	220	4-L8A	640	2.91	640	2.91
3F	S330F	MEDIUM SUPPORT	220	4-L8A	640	2.91	640	2.91
3F	S330G	MEDIUM SUPPORT	220	4-L8A	640	2.91	640	2.91
3F	L326	OPEN FLEX	90	4-L8	256	2.84	108	1.20
3F	L327	PANTRY	352	4-L47, 2-L45B, 2L45	256	0.73	422	1.20
3F	L328	CENTRAL SUPPLY	90	4-L8	256	2.84	108	1.20
3F/G	L320	LABORATORY	2,870	80-LAI,32-LA,4-L36	7,296	2.54	5,664	1.97
3F	S325	SHELL SPACE	882	8-A	1,024	1.16	1,024	1.16
3G	S320A	DARK ROOM	100	2-L8A	320	3.20	320	3.20
3G	S320B	SMALL COLD ROOM	99	0	0	0.00	0	0.00
3G	S320C	LARGE COLD ROOM	189	0	0	0.00	0	0.00
3G	S320D	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
3G	S320E	SMALL SUPPORT	100	2-L8A	320	3.20	320	3.20
3G	L317	COPY SUPPLY	352	4-L47, 2-L45B, 2L45	256	0.73	422	1.20
3G	L318	CENTRAL SUPPLY	90	4-L8	256	2.84	108	1.20
3G	L316	OPEN FLEX	90	4-L8	256	2.84	108	1.20
3G	L315	LABORATORY	1,260	25-L1A, 10-LA, 2-L36	2,304	1.83	2,487	1.97
3G	S315	SHELL SPACE	693	8-A	1,024	1.48	1,024	1.48
TOTAL			**81,456**		**188,064**	**2.31**	**152,341**	**1.87**

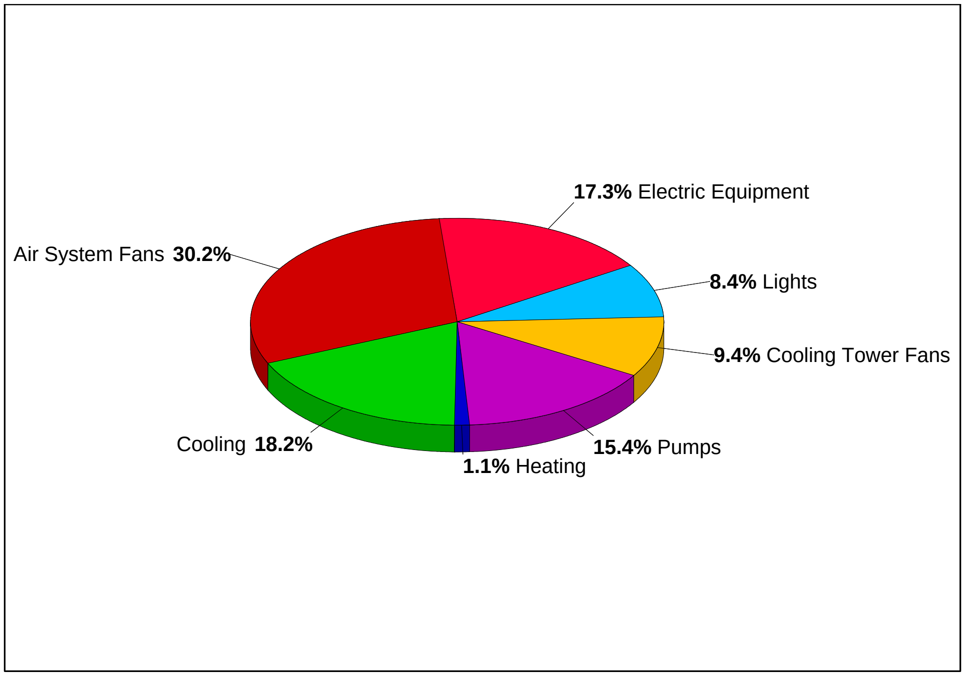


Figure A.3: Annual Component Costs, Case 3

Table A.4 : Annual Component Costs, Case 3

Case 3			
Component	**Annual Cost [$]**	**($/ft²)**	**Percent of Total [$]**
Air System Fans	290,539	3.439	30.2
Cooling	175,252	2.075	18.2
Heating	10,801	0.128	1.1
Pumps	147,764	1.749	15.4
Cooling Tower Fans	90,798	1.075	9.4
HVAC Sub-Total	**715,154**	**8.465**	**74.3**
Lights	80,959	0.958	8.4
Electric Equipment	166,321	1.969	17.3
Misc. Electric	0	0	0
Misc. Fuel Use	0	0	0
Non-HVAC Sub-Total	**247,280**	**2.927**	**25.7**
Grand Total	**962,434**	**11.393**	**100**

D : ALTERED LOAD, CASE 4

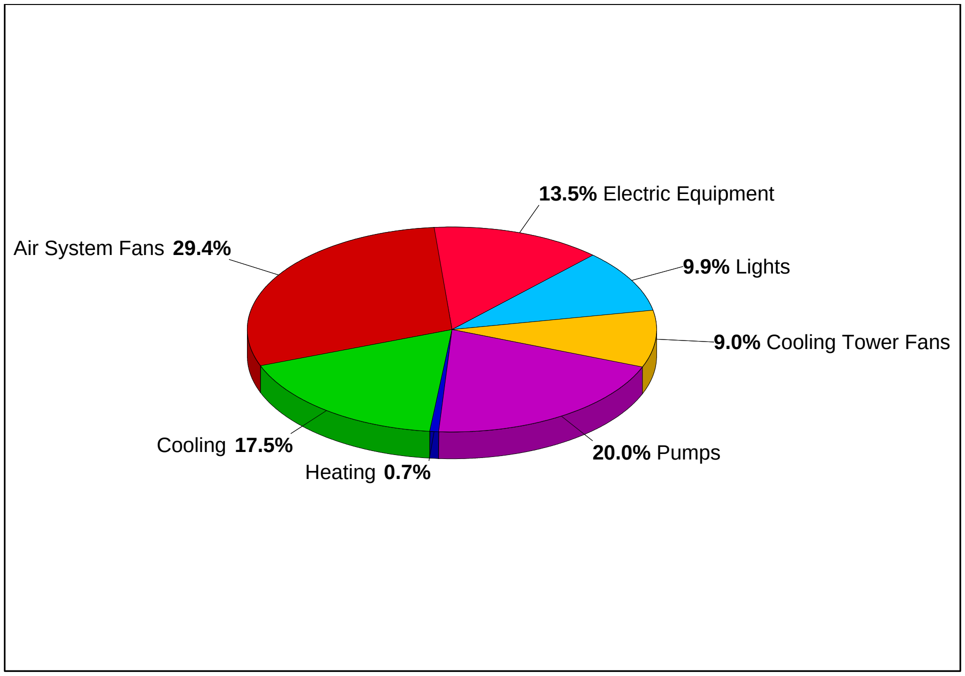


Figure A.4: Annual Component Costs, Case 4

Table A.5 : Annual Component Costs, Case 4

Case 4			
Component	**Annual Cost [$]**	**($/ft²)**	**Percent of Total [$]**
Air System Fans	213,669	2.529	29.4
Cooling	127,372	1.508	17.5
Heating	5,004	0.059	0.7
Pumps	145,725	1.725	20
Cooling Tower Fans	65,475	0.775	9
HVAC Sub-Total	**557,245**	**6.596**	**76.6**
Lights	71,930	0.851	9.9
Electric Equipment	98,290	1.164	13.5
Misc. Electric	0	0	0
Misc. Fuel Use	0	0	0
Non-HVAC Sub-Total	**170,220**	**2.015**	**23.4**
Grand Total	**727,465**	**8.611**	**100**

E : GROUND-COUPLED CALCULATION, CASE 5

RETScreen® International Ground-Source Heat Pump Project Model was used to aid in the design process. This program uses the building's heating and cooling loads, local weather data, and ground data to calculate an approximate system. The following tables summarize design information for a closed loop vertical system.

Table A.6

Ground Exchanger System	
System Type	Vertical closed-loop
Design Criteria	Cooling
Typcial Land Area Required [SF]	280,500
Ground Loop Layout	Standard
Total Bore Length [FT]	61,185

Table A.7

Cost Analysis	Quantity	Unit Cost	Total [$]
Energy Equipment			
Well Pumps	7	6,150	43,050
Heat Exchangers	4	6,636	26,544
Drilling & Backfill [ft]	61,185	3.66	223,815
Ground Loop Pipes	61,185	11	673,035
Fittings and valves [kW cooling]	2,403	12	28,841
Subtotal			**995,284**
Balance System			
Supplemental Heating System [kW]	0.0	--	0.00
Suppleme mtal Heat Rejection [kW]	0.0	--	0.00
Supplemental Cooling System [kW]	0.0	--	0.00
Internal Piping & Insulation [kW cooling]	2,403	60	144,203
Subtotal			144,203
Total First Cost			**1,139,488**

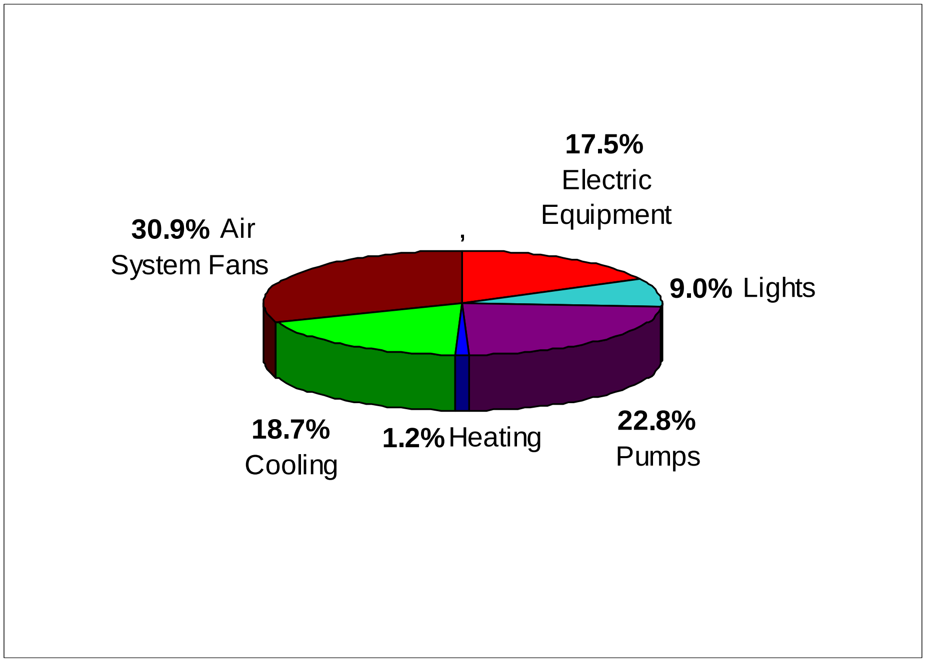


Figure A.5 : Annual Component Costs, Case 5

Table A.8 : Annual Component Costs, Case 5

Case 5			
Component	**Annual Cost [$]**	**($/ft²)**	**Percent of Total [$]**
Air System Fans	292,714	3.465	30.9
Cooling	177,009	2.095	18.7
Heating	11,094	0.131	1.2
Pumps	216,458	2.562	22.8
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**697,275**	8.254	73.5
Lights	85,243	1.009	9.0
Electric Equipment	166,278	1.968	17.5
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**251,521**	2.977	26.5
Grand Total	**948,796**	11.232	100.0

Table A.9

Ground Loop System Pump for Case 5				
	Description	**Loss**	**Units**	**Notes**
Pipe Friction Loss	Total Building Height	--	ft	Basement to pump
	Bore Length	61,184	ft	Assumed distance from Upper Pond to HTX
	Friction Rate	2.5	ft/100 ft	Assumed
	Multiplier	1.25		Accounts for piping and fittings
	Pipe friction loss	**1,912**	**ft wg**	
	Pipe friction loss = 1.25 x system length (ft) x friction rate (ft/100 ft)			
Other Head Loss	HTX Head Loss	4.8	ft wg	Given by equipment cut sheet
	Control Valve Head Loss	10	ft wg	Assumed
	Total Other Losses	**14.8**	**ft wg**	
Total Pump Head	Pipe Friction Loss	1,912	ft wg	
	Other Head Losses	14.8	ft wg	
	Subtotal	1,927	ft wg	
	Safety Factor	15	%	Assumed
	Total Pump Head	**2,216**	**ft wg**	

F : GROUND-COUPLED CALCULATION, CASE 6

Table A.10

Cost Analysis			
	Quantity	**Unit Cost**	**Total [$]**
Energy Equipment			
Well Pumps	4	3,050	12,200
Heat Exchangers	4	6,636	26,544
Drilling & Backfill [ft]	300	3.66	1,097
Fittings and valves [kW cooling]	2,403	12	28,841
Subtotal			**68,682**
Balance System			
Supplemental Heating System [kW]	0.0	--	0.00
Supplememtal Heat Rejection [kW]	0.0	--	0.00
Supplemental Cooling System [kW]	0.0	--	0.00
Internal Piping & Insulation [kW cooling]	2,403	60	144,203
Subtotal			144,203
Total First Cost			**212,885**

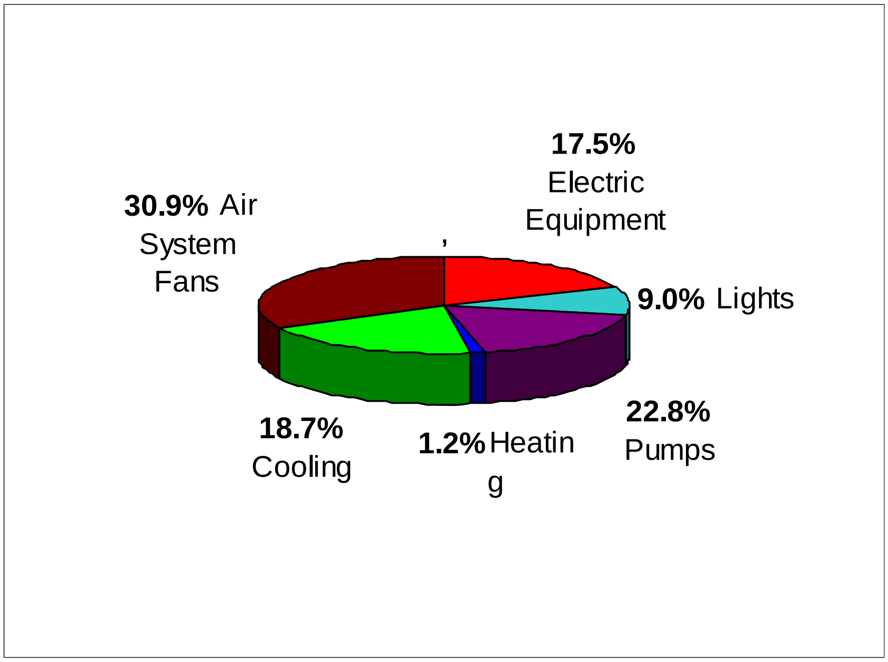


Figure A.6 : Annual Component Costs, Case 6

Table A.11 : Annual Component Costs, Case 6

Case 6			
Component	**Annual Cost [$]**	**($/ft²)**	**Percent of Total [$]**
Air System Fans	292,714	3.465	32.6
Cooling	177,009	2.095	19.7
Heating	11,094	0.131	1.2
Pumps	166,553	1.972	18.5
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**647,370**	7.664	72.0
Lights	85,243	1.009	9.5
Electric Equipment	166,278	1.968	18.5
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**251,521**	2.977	28.0
Grand Total	**898,891**	10.641	94.7

Table A.12

Ground Loop System Pump for Pond Loop

	Description	Loss	Units	Notes
Pipe Friction Loss	Total Building Height	20	ft	Bottom of Upper Pond to pump
	Supply Distance	560	ft	Assumed distance from Upper Pond to HTX
	Discharge Distance	280	ft	Assumed distance from HTX to Lower Pond
	Net Verticle Discharge Height	-34	ft	Pressure of pond on top of discharge pipe
	System Length	860		Omitting negative vertical head as a saftey
	Friction Rate	2.5	ft/100 ft	Assumed
	Multiplier	1.25		Accounts for piping and fittings
	Pipe friction loss	**26.9**	**ft wg**	
	Pipe friction loss = 1.25 x system length (ft) x friction rate (ft/100 ft)			
Other Head Loss	HTX Head Loss	10	ft wg	Given by equipment cut sheet
	Control Valve Head Loss	10	ft wg	Assumed
	Total Other Losses	**20**	**ft wg**	
Total Pump Head	Pipe Friction Loss	26.9	ft wg	
	Other Head Losses	20	ft wg	
	Subtotal	46.9	ft wg	
	Safety Factor	15	%	Assumed
	Total Pump Head	**53.9**	**ft wg**	
Pipe Friction Loss	Total Height	14	ft	Bottom of Lower Pond to Bottom of Upper Pond
	Distance	92	ft	Distance Between Ponds
	System Length	106	ft	Total Length of Pipe
	Friction Rate	2.5	ft/100 ft	Assumed
	Multiplier	1.25		Accounts for piping and fittings
	Pipe friction loss	**3.3**	**ft wg**	
	Pipe friction loss = 1.25 x system length (ft) x friction rate (ft/100 ft)			
Other Head Loss	HTX Head Loss	10	ft wg	Given by equipment cut sheet
	Control Valve Head Loss	10	ft wg	Assumed
	Total Other Losses	**20**	**ft wg**	
Total Pump Head	Pipe Friction Loss	3.3	ft wg	
	Other Head Losses	20	ft wg	
	Subtotal	23.3	ft wg	
	Safety Factor	15	%	Assumed
	Total Pump Head	**26.8**	**ft wg**	

G : GROUND-COUPLED CALCULATION, CASE 7

Table A.13

Cost Analysis			
	Quantity	**Unit Cost**	**Total [$]**
Energy Equipment			
Well Pumps	4	3,050	12,200
Heat Exchangers	4	6,636	26,544
Drilling & Backfill [ft]	300	3.66	1,097
Fittings and valves [kW cooling]	1,729	12	20,753
Subtotal			**60,595**
Balance System			
Supplemental Heating System [kW]	0.0	--	0.00
Supplememtal Heat Rejection [kW]	0.0	--	0.00
Supplemental Cooling System [kW]	0.0	--	0.00
Internal Piping & Insulation [kW cooling]	1,729	60	103,767
Subtotal			103,767
Total First Cost			**164,362**

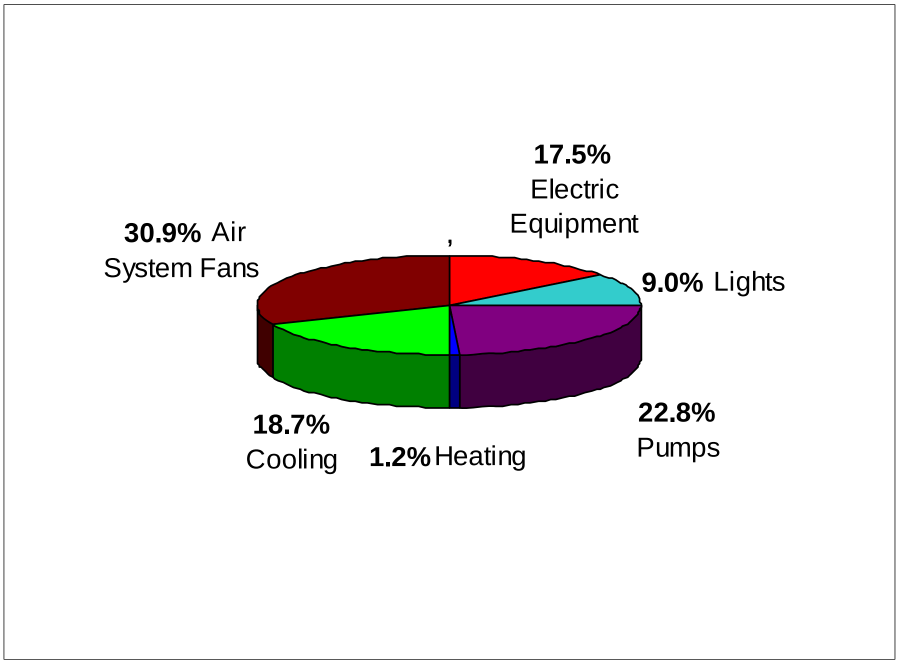


Figure A.7 : Annual Component Costs, Case 7

Table A.14 : Annual Component Costs, Case 7

Case 7			
Component	**Annual Cost [$]**	**($/ft²)**	**Percent of Total [$]**
Air System Fans	213,669	2.529	31.3
Cooling	127,372	1.508	18.7
Heating	5,004	0.059	0.7
Pumps	166,553	1.972	24.4
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**512,598**	6.068	75.1
Lights	71,930	0.852	10.5
Electric Equipment	98,290	1.164	14.4
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**170,220**	2.015	24.9
Grand Total	**682,818**	8.083	100.0

H : EMISSIONS

CASE 1

Table A.15

Annual Energy Consumption : Case 1	
HVAC Components	
Electric [kWh]	9,353,516
Natural Gas [Therm]	19,462
Non-HVAC Components	
Electric [kWh]	3,502,690
Totals	
Electric [kWh]	12,856,210
Natural Gas [Therm]	19,462

Table A.15

Emissions : Case 1	
CO2 [lb]	17,767,460
SO2 [kg]	43,968
NOx [kg]	25,863

CASE 4

Table A.16

Annual Energy Consumption : Case 4	
HVAC Components	
Electric [kWh]	7,366,263
Natural Gas [Therm]	8,780
Non-HVAC Components	
Electric [kWh]	2,375,036
Totals	
Electric [kWh]	9,741,298
Natural Gas [Therm]	8,780

Table A.17

Emissions : Case 4	
CO2 [lb]	13,454,910
SO2 [kg]	33,316
NOx [kg]	19,590

CASE 5

Table A.18

Annual Energy Consumption : Case 5	
HVAC Components	
Electric [kWh]	9,200,894
Natural Gas [Therm]	19,462
Non-HVAC Components	
Electric [kWh]	3,502,690
Totals	
Electric [kWh]	12,703,584
Natural Gas [Therm]	19,462

Table A.19

Emissions : Case 1	
CO2 [lb]	17,037,615
SO2 [kg]	42,166
NOx [kg]	24,802

CASE 6

Table A.20

Annual Energy Consumption : Case 6	
HVAC Components	
Electric [kWh]	8,581,234
Natural Gas [Therm]	19,462
Non-HVAC Components	
Electric [kWh]	3,502,690
Totals	
Electric [kWh]	12,083,924
Natural Gas [Therm]	19,462

Table A.21

Emissions : Case 6	
CO2 [lb]	16,149,600
SO2 [kg]	39,966
NOx [kg]	23,508

CASE 7

Table A.22

Annual Energy Consumption : Case 7	
HVAC Components	
Electric [kWh]	6,817,169
Natural Gas [Therm]	8,780
Non-HVAC Components	
Electric [kWh]	2,375,036
Totals	
Electric [kWh]	9,192,205
Natural Gas [Therm]	8,780

Table A.23

Emissions : Case 7	
CO2 [lb]	12,357,992
SO2 [kg]	30,600
NOx [kg]	17,993

I : CUT SHEETS

- Original Design
    - Marley NC Class Cooling Tower
- Ground Loop Design
    - Armstrong Series 4300 Split Coupled Pumps
    - SWEP Heat Exchanger Diagram
- Pond Loop Design
    - Bell & Gossett 1050 Series 4BC Pumps
    - Bell & Gossett 1050 Series 5A Pumps

Marley UPDATE™ Version 4.7.0
Product Data: 3/22/2006

4/1/2006 8:16:53 PM

Job Information

Thesis
Julie Thorpe
State College

Selected By

Penn State
104 Engineering Unit A
University Park, PA
wpb5@psu.edu

PSUAE
Tel 814-863-2076

SPX Cooling Technologies Contact

H & H Associates, Inc.
4510 Westport Drive
Mechanicsburg, PA 17055
frank@hhassociates.com

Tel 717-796-2401
Fax 717-796-9717

Cooling Tower Definition

Manufacturer	Marley	Fan Motor Speed	1800 rpm
Product	NC Class	Fan Motor Capacity per cell	75.00 BHp
Model	NC8311J1	Fan Motor Output per cell	75.00 BHp
Cells	1	Fan Motor Output total	75.00 BHp
CTI Certified	Yes	Air Flow per cell	258300 cfm
Fan	11.00 ft, 7 Blades	Air Flow total	258300 cfm
Fan Speed	323 rpm, 11162 fpm	ASHRAE 90.1 Performance	46.0 gpm/Hp
Fans per cell	1		

Sound Pressure Level 84 dBA/Cell, 5.00 ft from Air Inlet Face. See sound report for details.

Conditions

Tower Water Flow	2400 gpm	Air Density In	0.07094 lb/ft³
Hot Water Temperature	99.50 °F	Air Density Out	0.07053 lb/ft³
Range	14.50 °F	Humidity Ratio In	0.01712
Cold Water Temperature	85.00 °F	Humidity Ratio Out	0.03323
Approach	7.00 °F	Wet-Bulb Temp. Out	91.93 °F
Wet-Bulb Temperature	78.00 °F	Estimated Evaporation	34 gpm
Relative Humidity	50 %	Total Heat Rejection	17332000 Btu/h

- This selection meets your design conditions.

Weights & Dimensions

	Per Cell	Total
Shipping Weight	17220 lb	17220 lb
Max Operating Weight	36620 lb	36620 lb
Width	22.42 ft	22.42 ft
Length	11.90 ft	11.90 ft
Height	19.81 ft	
Static Lift	19.07 ft	

Minimum Enclosure Clearance

Clearance required on air inlet sides of tower without altering performance. Assumes no air from below tower.

Solid Wall	9.49 ft
50 % Open Wall	7.31 ft

Weights and dimensions do not include options; refer to sales drawings. For CAD layouts refer to file NC8311.dxf

Cold Weather Operation

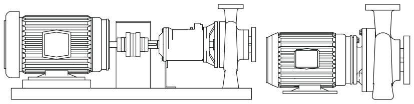
Heater Sizing (to prevent freezing in the collection basin during periods of shutdown)

Heater kW/Cell	24.0	18.0	15.0	12.0	9.0	7.5	6.0
Ambient Temperature °F	-15.76	-0.75	6.76	14.26	21.77	25.52	29.27

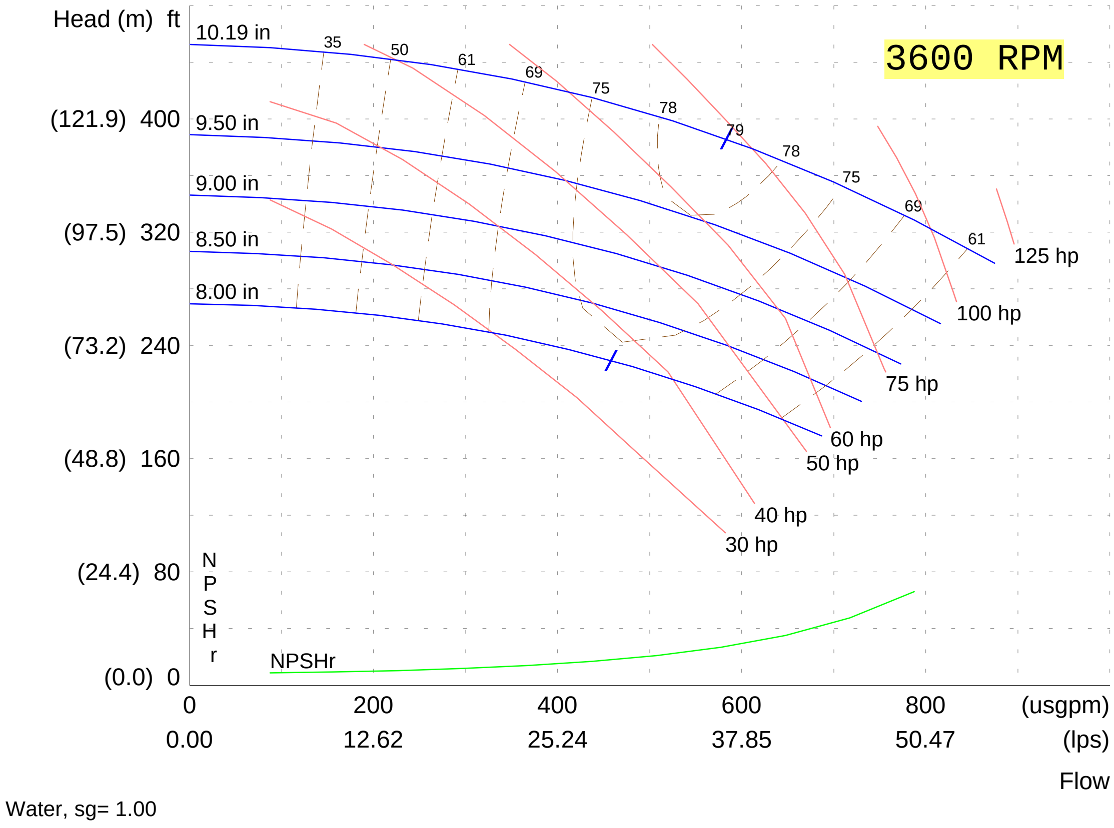
ARMSTRONG®

PERFORMANCE CURVES

Performance Guaranteed Only At Operating Point Indicated



File No:	
Date:	June 1,2000
Supersedes:	NEW
Date:	NEW



CURVE NO.
PT53-1-0-3600
SERIES
4030 4280
SIZE
3x2.5x10
RPM
3600
BHP based on shown Fluid's sp. gr.

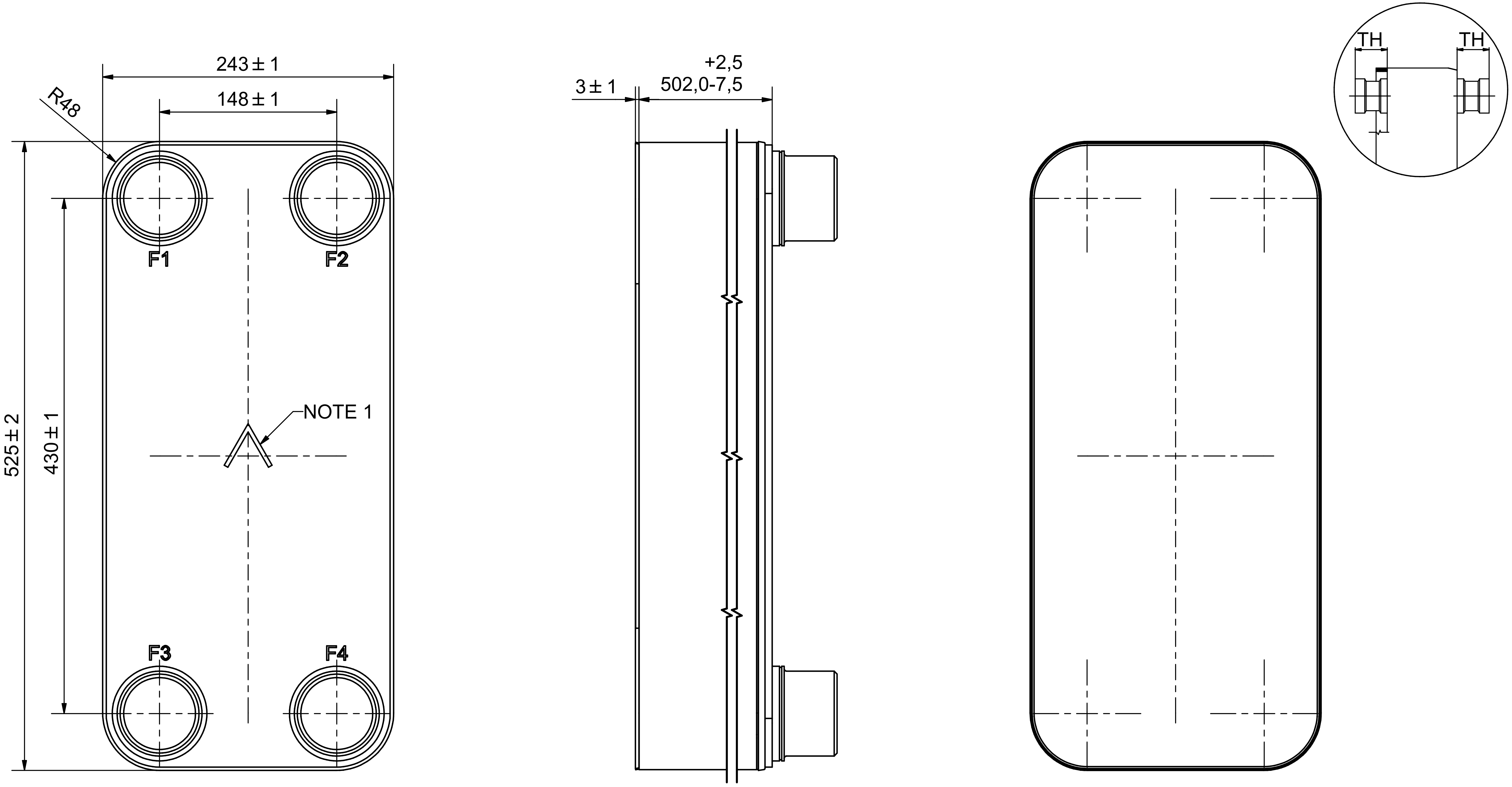
AVAILABI	
	4030 All Ratings
	4280 All Ratings

S.A. Armstrong Limited
23 Bertrand Ave.
Toronto, Ontario
Canada, M1L 2P3
Tel: (416) 755-2291
Fax: (416) 759-9101
Visit us at www.armstrongpumps.com

Armstrong Pumps Limited
Peartree Road, Stanway
Colchester, Essex
United Kingdom, C03 5JX
Tel: 01206-579491
Fax: 01206-760532

Armstrong Pumps Inc.
93 East Avenue
Buffalo, New York
USA, 14120-6594
Tel: (716) 693-8813
Fax: (716) 693-8970

Armstrong Darling Inc.
2200 Place Transcanadienne
Montreal, Quebec
Canada, H9P 2X5
Tel: (514) 421-2424
Fax: (514) 421-2436



NOTE 1 ALTERNATE MARKING: STICKER OR STAMP

Pos	Article No	Title / Denomination, code, material, dimension etc	Drawing No./ref
F1	46098	NPT 2 1/2-8, TH = 54,2	CD000295
F2	46098	NPT 2 1/2-8, TH = 54,2	CD000295
F3	46098	NPT 2 1/2-8, TH = 54,2	CD000295
F4	46098	NPT 2 1/2-8, TH = 54,2	CD000295

Pos	Article No	Title / Denomination, code, material, dimension etc	Drawing No./ref

Title
B56Hx200/1P-SC-S 4*2 1/2"NPT

A DOVER COMPANY

Created Date
2006-03-31

Created By
AU

Article/Configuration number
11487-200

Drawing number
AU00005186

Bell & Gossett

SUBMITTAL

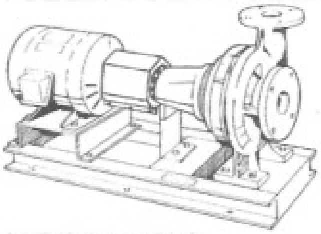
B-225.1F

JOB: Thesis Report
REPRESENTATIVE: Cummins-Wagner Co., Inc.

UNIT TAG: P-3
ENGINEER:
CONTRACTOR:

ORDER NO.
SUBMITTED BY:
APPROVED BY:

DATE: 3/31/2006
DATE:
DATE:



4BC
Series 1510
Centrifugal Pumps - Base Mounted

SPECIFICATIONS

FLOW 570 (GPM) HEAD 54 (FT)
HP 15 RPM 1800
VOLTS 230/460
CYCLE 60 PHASE 3
Lincoln ODP Inverter Duty
APPROX. WEIGHT 439
SPECIALS Special Coupling(Dodge Paraflex)

Note: Equipped with EPDM coupling

MATERIALS OF CONSTRUCTION

☒ BRONZE FITTED ☐ ALL IRON

FEATURES

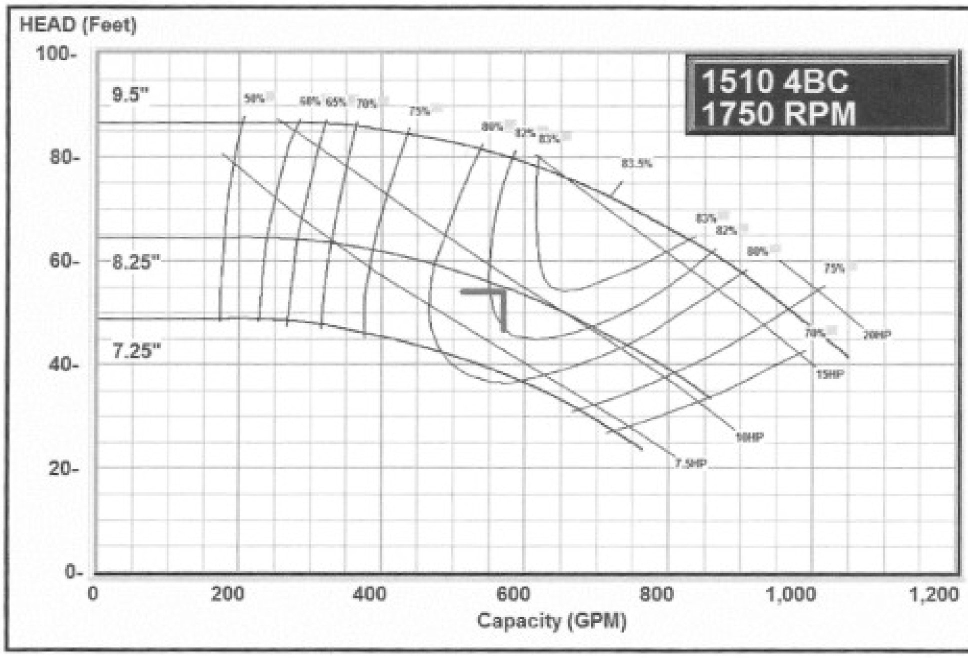
- ☒ ANSI/OSHA Coupling Guard
- ☒ Center Drop Out Spacer Coupling
- ☒ Fabricated Heavy Duty Baseplate

MAXIMUM WORKING PRESSURE

☒ 175 psi (12 bar) W.P.
w/ 125# ANSI flange drilling

TYPE OF SEAL

- ☒ 1510 Standard Seal
  (Buna-Carbon/Ceramic)
- ☐ 1510 -F Standard Seal w/ Flush Line
  (Buna-Carbon/Ceramic)
- ☐ 1510 -S Stuffing Box construction w/ Flushe
  Mechanical Single Seal
  (EPR-Tungsten Carbide/Carbon)
- ☐ 1510 -D Stuffing Box construction w/
  Flushed Double Mechanical Seal
  (EPR-Carbon/Ceramic)
  Requires external water source
- ☐ 1510 -PF Stuffing Box Construction w/
  Packing
  (Graphite Impregnated Teflon)



Design Capacity =570.0 GPM
Design Head =54.0 Feet

Suction Size = 5 "
Suct. Velocity = 9.1 fps
Discharge Size = 4 "
Disc. Velocity = 14.4 fps

Min. Imp. Dia. = 7.25 "
Max. Imp. Dia. = 9.5 "
Cut Dia. = 8.25 "

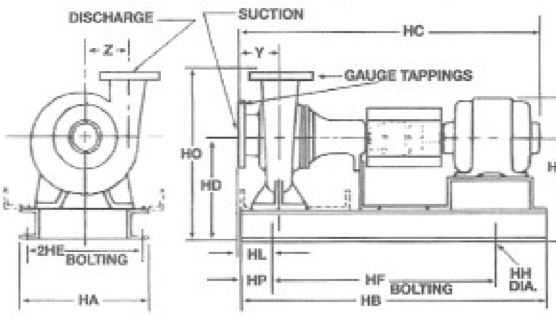
Max. Flow = 892 GPM
B.E.P. Flow = 607 GPM

Eff. @ Duty-Point = 82.32 %
Motor Size =15 HP

B.H.P. @
Duty-Point = 9.55 BHP
Max. B.H.P. for
Imp. Cut = 10.45 BHP

Series 1510 4BC Centrifugal Pump Submittal

B-225.1F



FLANGE DIMENSIONS IN INCHES (MM)			
	SIZE	THICKNESS	O.D.
Discharge	4" (102)	1-1/4" (32)	9-1/2" (241)
Suction	5" (127)	1-3/8" (35)	10-3/4" (273)

FLANGES ARE 125# ANSI - STANDARD

DIMENSIONS – Inches (mm) STANDARD SEAL 1510, 1510-F

MOTOR FRAME	HA	HB	HC MAX	HD	2HE	HF	HH	HL	HM MAX	HO	HP	Y	Z
	"S" FRAME												
213T	14-5/8 (371)	34-5/8 (879)	37-3/4 (959)	12-3/4 (324)	12-7/8 (327)	28-5/8 (727)	3/4 (19)	4 (102)	18-5/8 (473)	20-3/4 (527)	3 (76)	5 (127)	7 (178)
215T	14-5/8 (371)	34-5/8 (879)	39-1/4 (997)	12-3/4 (324)	12-7/8 (327)	28-5/8 (727)	3/4 (19)	4 (102)	18-5/8 (473)	20-3/4 (527)	3 (76)	5 (127)	7 (178)
➡ 254T	14-5/8 (371)	39-3/8 (1000)	43 (1092)	12-3/4 (324)	12-7/8 (327)	33-3/8 (848)	3/4 (19)	4 (102)	19-5/8 (498)	20-3/4 (527)	3 (76)	5 (127)	7 (178)
	"L" FRAME												
256T	16 (406)	46-1/2 (1181)	49-1/8 (1248)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	5-1/8 (130)	20-7/8 (530)	22 (559)	5 (127)	5 (127)	7 (178)
284TS	16 (406)	46-1/2 (1181)	48-1/2 (1232)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	5-1/8 (130)	22 (559)	22 (559)	5 (127)	5 (127)	7 (178)
286TS	16 (406)	46-1/2 (1181)	50 (1270)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	5-1/8 (130)	22 (559)	22 (559)	5 (127)	5 (127)	7 (178)
324TS	16 (406)	51-3/4 (1314)	51-7/8 (1318)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	5-1/8 (130)	23-1/8 (587)	22 (559)	5 (127)	5 (127)	7 (178)
326TS	16 (406)	51-3/4 (1314)	53-5/8 (1362)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	5-1/8 (130)	23-1/8 (587)	22 (559)	5 (127)	5 (127)	7 (178)
364TS	24 (610)	56 (1422)	55-1/4 (1403)	16-1/2 (419)	21-1/2 (546)	44 (1118)	1 (25)	5-3/4 (146)	26-3/4 (679)	24-1/2 (622)	6 (152)	5 (127)	7 (178)
365TS	24 (610)	56 (1422)	55-7/8 (1419)	16-1/2 (419)	21-1/2 (546)	44 (1118)	1 (25)	5-3/4 (146)	26-3/4 (679)	24-1/2 (622)	6 (152)	5 (127)	7 (178)
404TS	24 (610)	56 (1422)	58-1/8 (1476)	16-1/2 (419)	21-1/2 (546)	44 (1118)	1 (25)	5-3/4 (146)	28-3/8 (721)	24-1/2 (622)	6 (152)	5 (127)	7 (178)

STUFFING BOX 1510-PF, 1510-S, 1510-D

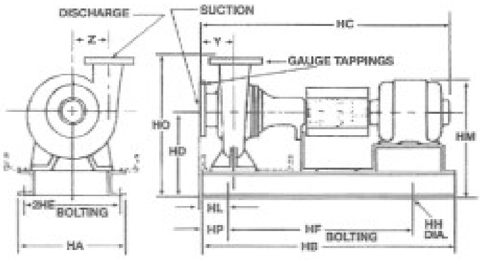
MOTOR FRAME	HA	HB	HC MAX	HD	2HE	HF	HH	HL	HM MAX	HO	HP	Y	Z
	"L" FRAME												
213T	16 (406)	46-1/2 (1181)	44-1/2 (1130)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	5-1/8 (130)	19-7/8 (505)	22 (559)	5 (127)	5 (127)	7 (178)
215T	16 (406)	46-1/2 (1181)	46 (1168)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	5-1/8 (130)	19-7/8 (505)	22 (559)	5 (127)	5 (127)	7 (178)
254T	16 (406)	51-3/4 (1314)	49-3/4 (1264)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	5-1/8 (130)	20-7/8 (530)	22 (559)	5 (127)	5 (127)	7 (178)
256T	16 (406)	51-3/4 (1314)	51-1/2 (1308)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	5-1/8 (130)	20-7/8 (530)	22 (559)	5 (127)	5 (127)	7 (178)

Dimensions are subject to change. Not to be used for construction purposes unless certified.
Box type pumps should not be operated at 3500 RPM.

ITT Industries

Series 1510 5A Centrifugal Pump Submittal

B-225.4B



FLANGE DIMENSIONS IN INCHES (MM)	SIZE	THICKNESS	O.D.
Discharge	5" (127)	1-3/8 (35)	10-3/4 (273)
Suction	6" (152)	1-7/16 (37)	12-1/8 (308)

FLANGES ARE 125# ANSI - STANDARD
250# ANSI - AVAILABLE

DIMENSIONS - Inches (mm)

STANDARD SEAL 1510, 1510-F

MOTOR FRAME	HA	HB	HC MAX	HD	2HE	HF	HH	HL	HM MAX	HO	HP	Y	Z
	"S" FRAME												
182T	14-5/8 (371)	31 (787)	36-1/4 (921)	12-3/4 (324)	12-7/8 (327)	25 (635)	3/4 (19)	5-3/4 (146)	18 (457)	21-1/4 (540)	3 (76)	5-13/16 (148)	6-1/4 (159)
184T	14-5/8 (371)	31 (787)	37 (940)	12-3/4 (324)	12-7/8 (327)	25 (635)	3/4 (19)	5-3/4 (146)	18 (457)	21-1/4 (540)	3 (76)	5-13/16 (148)	6-1/4 (159)
➡ 213T	14-5/8 (371)	34-5/8 (879)	39-1/2 (1003)	12-3/4 (324)	12-7/8 (327)	28-5/8 (727)	3/4 (19)	5-3/4 (146)	18-5/8 (473)	21-1/4 (540)	3 (76)	5-13/16 (148)	6-1/4 (159)
215T	14-5/8 (371)	34-5/8 (879)	41 (1041)	12-3/4 (324)	12-7/8 (327)	28-5/8 (727)	3/4 (19)	5-3/4 (146)	18-5/8 (473)	21-1/4 (540)	3 (76)	5-13/16 (148)	6-1/4 (159)
	"L" FRAME												
254T	16 (406)	46-1/2 (1181)	49-1/8 (1248)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	6-7/8 (175)	20-7/8 (530)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
256T	16 (406)	46-1/2 (1181)	50-7/8 (1292)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	6-7/8 (175)	20-7/8 (530)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
284TS	16 (406)	46-1/2 (1181)	50-1/4 (1276)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	6-7/8 (175)	22 (559)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
286TS	16 (406)	46-1/2 (1181)	51-3/4 (1314)	14 (356)	14 (356)	36-1/2 (927)	7/8 (22)	6-7/8 (175)	22 (559)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
324TS	16 (406)	51-3/4 (1314)	53-5/8 (1362)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (175)	23-1/8 (587)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
326TS	16 (406)	51-3/4 (1314)	55-3/8 (1407)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (175)	23-1/8 (587)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
364TS	16 (406)	51-3/4 (1314)	57 (1448)	14-1/4 (362)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (175)	24-1/4 (616)	22-3/4 (578)	5 (127)	5-13/16 (148)	6-1/4 (159)

STUFFING BOX 1510-PF, 1510-S, 1510-D

MOTOR FRAME	HA	HB	HC MAX	HD	2HE	HF	HH	HL	HM MAX	HO	HP	Y	Z
	"S" FRAME												
182T	14-5/8 (371)	34-5/8 (879)	39-3/4 (1010)	12-3/4 (324)	12-7/8 (327)	28-5/8 (727)	3/4 (19)	5-3/4 (146)	18 (457)	21-1/4 (540)	3 (76)	5-13/16 (148)	6-1/4 (159)
184T	14-5/8 (371)	34-5/8 (879)	37 (940)	12-3/4 (324)	12-7/8 (327)	28-5/8 (727)	3/4 (19)	5-3/4 (146)	18 (457)	21-1/4 (540)	3 (76)	5-13/16 (148)	6-1/4 (159)
213T	14-5/8 (371)	39-3/8 (1000)	43-1/8 (1095)	12-3/4 (324)	12-7/8 (327)	33-3/8 (848)	3/4 (19)	5-3/4 (146)	18-5/8 (473)	21-1/4 (540)	3 (76)	5-13/16 (148)	6-1/4 (159)
215T	14-5/8 (371)	39-3/8 (1000)	44-5/8 (1133)	12-3/4 (324)	12-7/8 (327)	33-3/8 (848)	3/4 (19)	5-3/4 (146)	18-5/8 (473)	21-1/4 (540)	3 (76)	5-13/16 (148)	6-1/4 (159)
	"L" FRAME												
254T	16 (406)	51-3/4 (1314)	51-1/2 (1308)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (174)	20-7/8 (530)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
256T	16 (406)	51-3/4 (1314)	53-1/4 (1353)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (174)	20-7/8 (530)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
284TS	16 (406)	51-3/4 (1314)	52-5/8 (1337)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (174)	22 (559)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
286TS	16 (406)	51-3/4 (1314)	54-1/8 (1375)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (174)	22 (559)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
324TS	16 (406)	51-3/4 (1314)	56 (1422)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (174)	23-1/8 (587)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
326TS	16 (406)	51-3/4 (1314)	57-3/4 (1467)	14 (356)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (174)	23-1/8 (587)	22-1/2 (572)	5 (127)	5-13/16 (148)	6-1/4 (159)
364TS	16 (406)	51-3/4 (1314)	59-3/8 (1508)	14-1/4 (362)	14 (356)	41-3/4 (1060)	7/8 (22)	6-7/8 (174)	24-1/4 (616)	22-3/4 (578)	5 (127)	5-13/16 (148)	6-1/4 (159)

Dimensions are subject to change. Not to be used for construction purposes unless certified.

ITT Industries

Bell & Gossett

SUBMITTAL

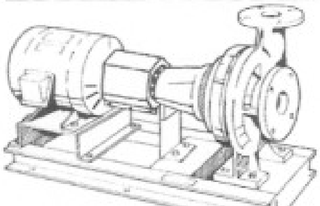
B-225.4E

JOB: Thesis Report
REPRESENTATIVE: Cummins-Wagner Co., Inc.

UNIT TAG: P-5
ENGINEER:
CONTRACTOR:

ORDER NO.
SUBMITTED BY:
APPROVED BY:

DATE: 3/31/2006
DATE:
DATE:



5A
Series 1510
Centrifugal Pumps - Base Mounted

SPECIFICATIONS

FLOW 570 (GPM) HEAD 27 (FT)
HP 7.5 RPM 1800
VOLTS 230/460
CYCLE 60 PHASE 3
Lincoln TEFC Inverter Duty
APPROX. WEIGHT 452
SPECIALS Special Coupling(Dodge Paraflex)

Note: Equipped with EPDM coupling

MATERIALS OF CONSTRUCTION

☒ BRONZE FITTED ☐ ALL IRON

FEATURES

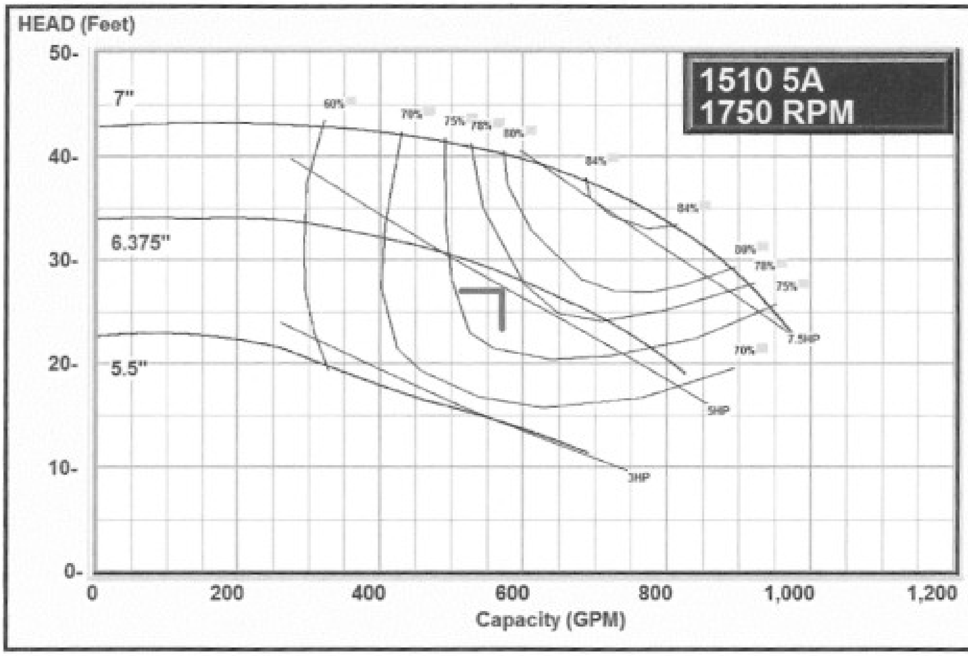
☒ ANSI/OSHA Coupling Guard
☒ Center Drop Out Spacer Coupling
☒ Fabricated Heavy Duty Baseplate

MAXIMUM WORKING PRESSURE

☒ 175 psi (12 bar) W.P.
w/ 125# ANSI flange drilling
☐ 250 psi (17 bar) W.P.
w/ 250# ANSI flange drilling (requires 1510-S)

TYPE OF SEAL

☒ 1510 Standard Seal (Buna-Carbon/Ceramic)
☐ 1510 -F Standard Seal w/ Flush Line (Buna-Carbon/Ceramic)
☐ 1510 -S Stuffing Box construction w/ Flushe Mechanical Single Seal (EPR-Tungsten Carbide/Carbon)
☐ 1510 -D Stuffing Box construction w/ Flushed Double Mechanical Seal (EPR-Carbon/Ceramic) Requires external water source
☐ 1510 -PF Stuffing Box Construction w/ Packing (Graphite Impregnated Teflon)



Design Capacity =570.0 GPM
Design Head =27.0 Feet

Suction Size = 6 "
Suct. Velocity = 6.3 fps
Discharge Size = 5 "
Disc. Velocity = 9.1 fps

Min. Imp. Dia. = 5.5 "
Max. Imp. Dia. = 7 "
Cut Dia. = 6.375 "

Max. Flow = 845 GPM
B.E.P. Flow = 654 GPM

Eff. @ Duty-Point = 77.27 %
Motor Size =7.5 HP

B.H.P. @
Duty-Point = 5.18 BHP
Max. B.H.P. for
Imp. Cut = 5.59 BHP

J : LIGHTING ANALYSIS

ORIGINAL LIGHTING DESIGN

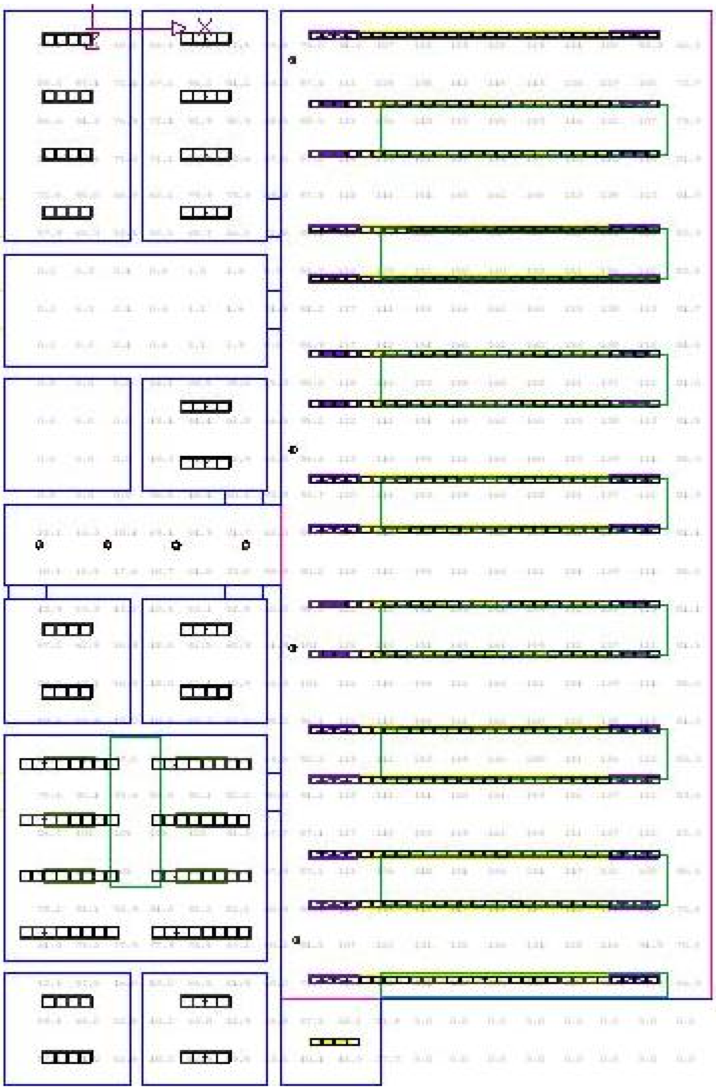


Figure A.8 : Original Lighting Layout for Laboratory 285 and Support Spaces

Figure A.9 : Original Laboratory 285 Rendering

Figure A.10 : Large Support Space Rendering, Original Design

Figure A.11 : Hallway Rendering, Original Design

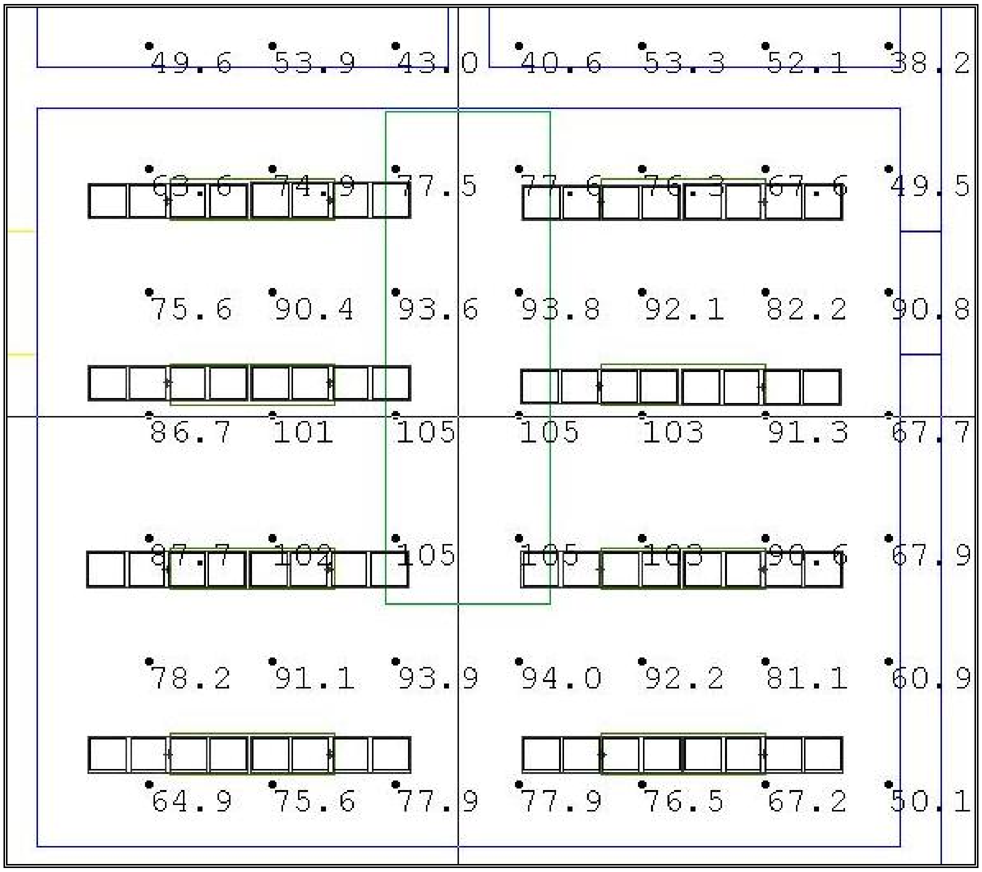


Figure A.12 : Large Support Space Illuminance Levels, Original Design

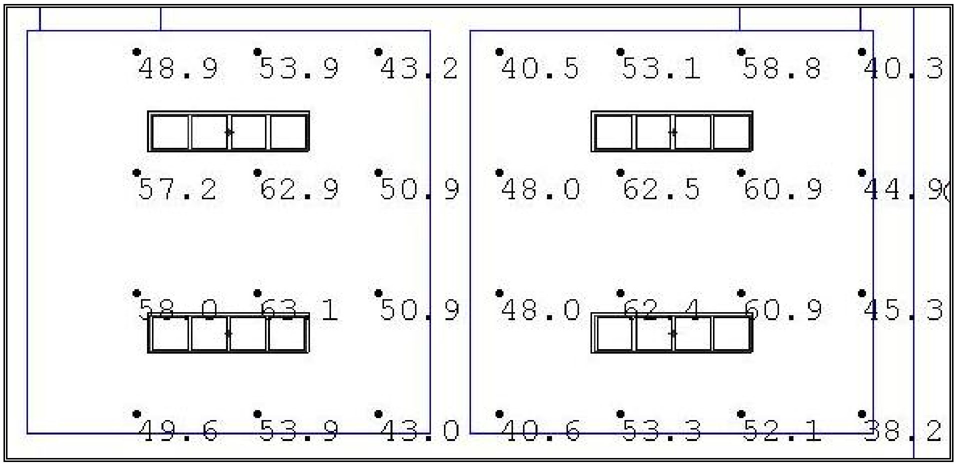


Figure A.13 : Small Support Space Illuminance Levels, Original Design

NEW LIGHTING DESIGN

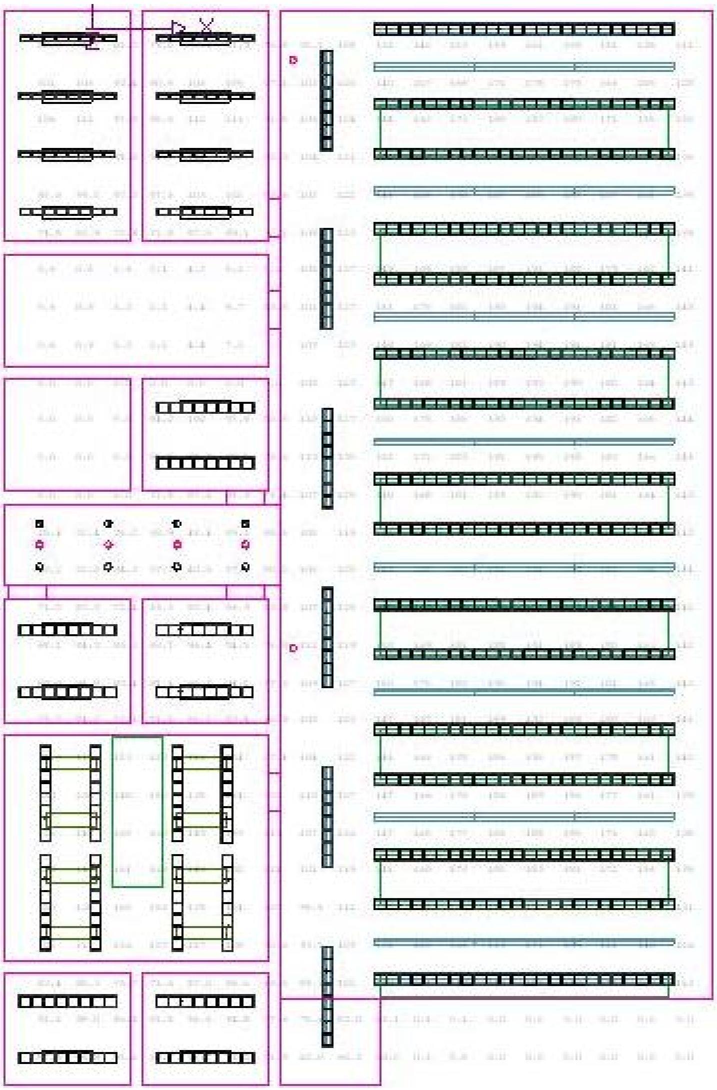


Figure A.14 : Lighting Layout for Laboratory 285, New Design

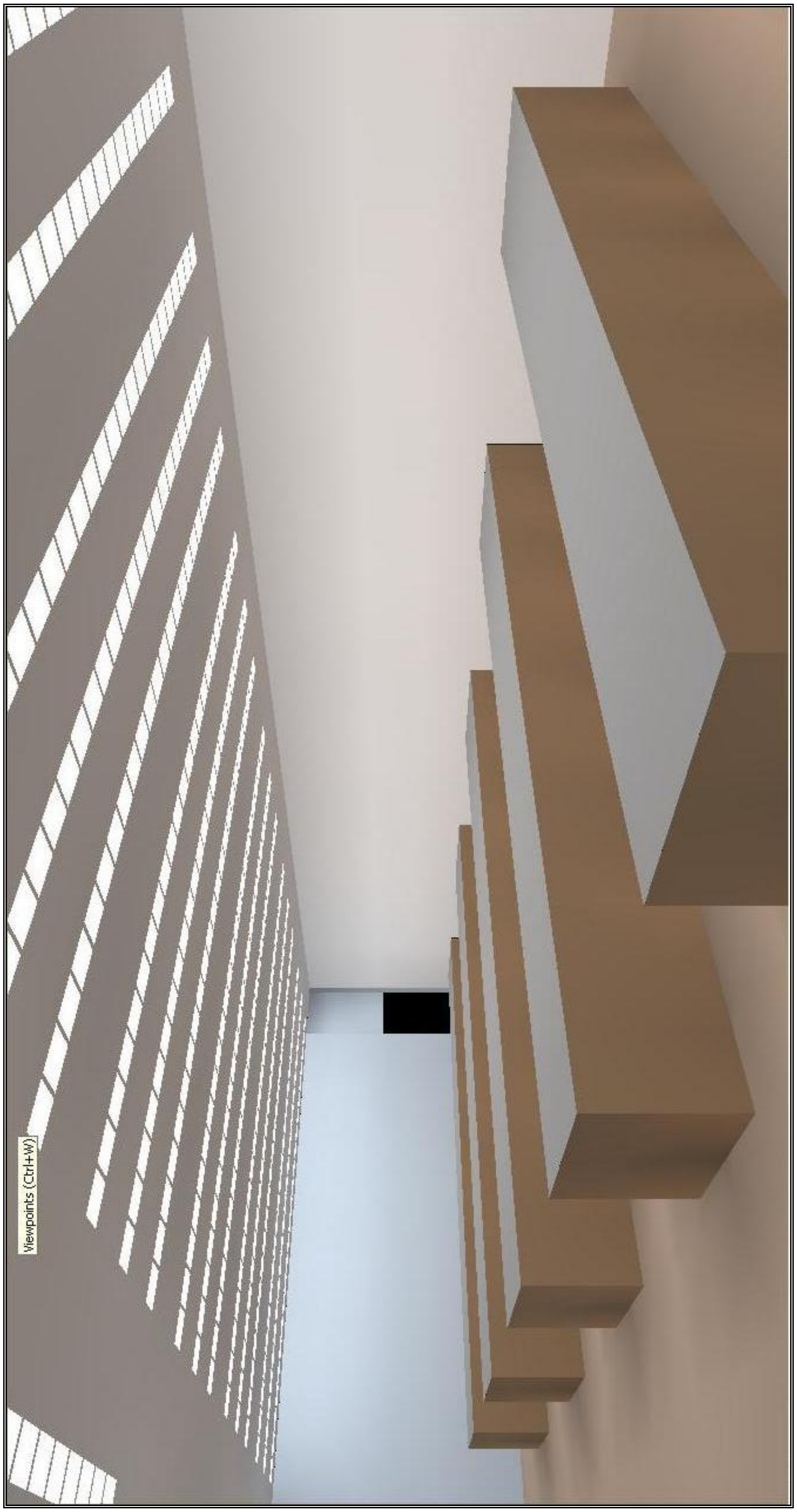


Figure A.15 : New Laboratory 285 Rendering

Figure A.16 : New Laboratory 285 Rendering

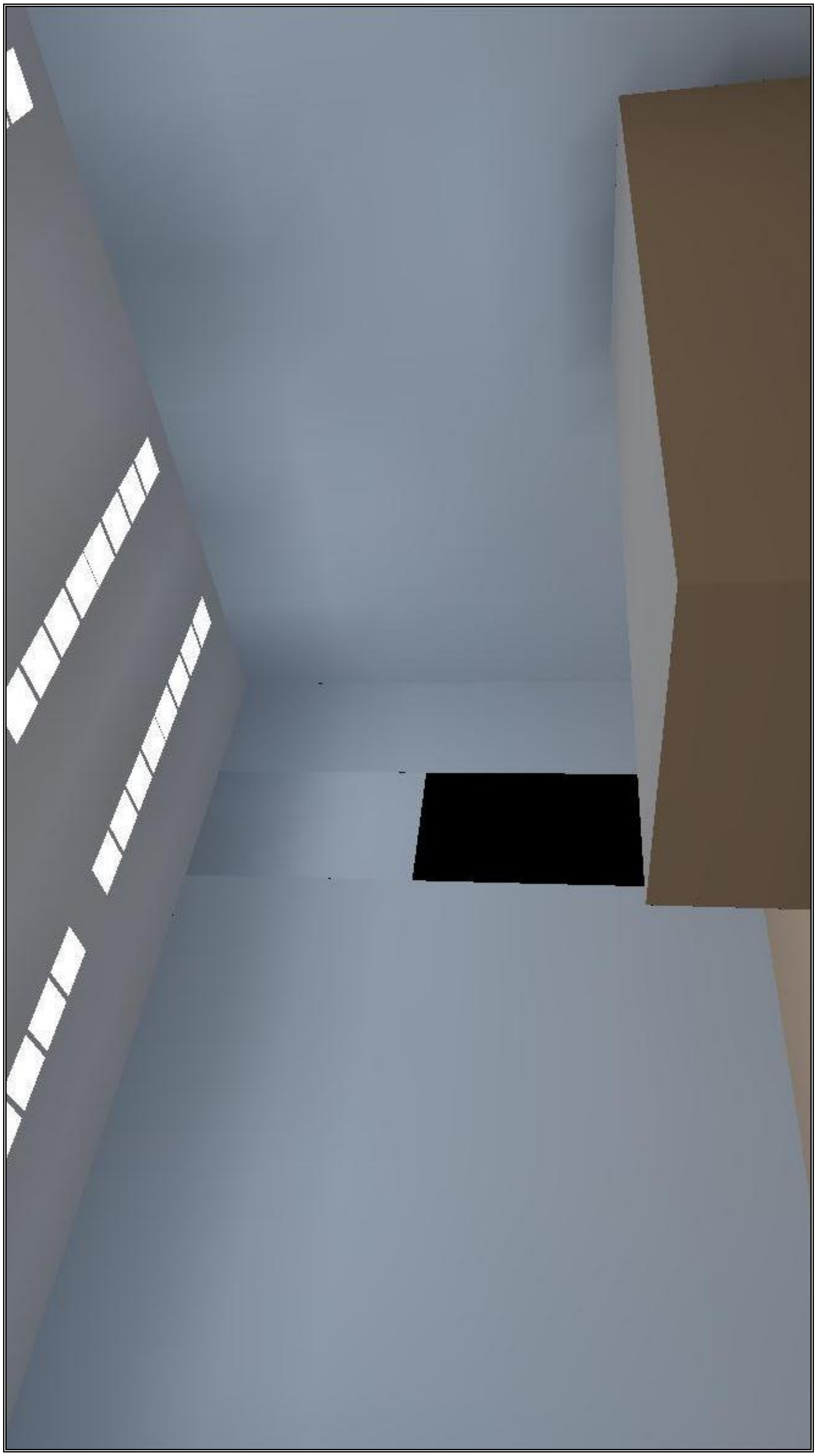


Figure A.17 : Large Support Space Rendering, New Design

Figure A.18 : Hallway Rendering, New Design

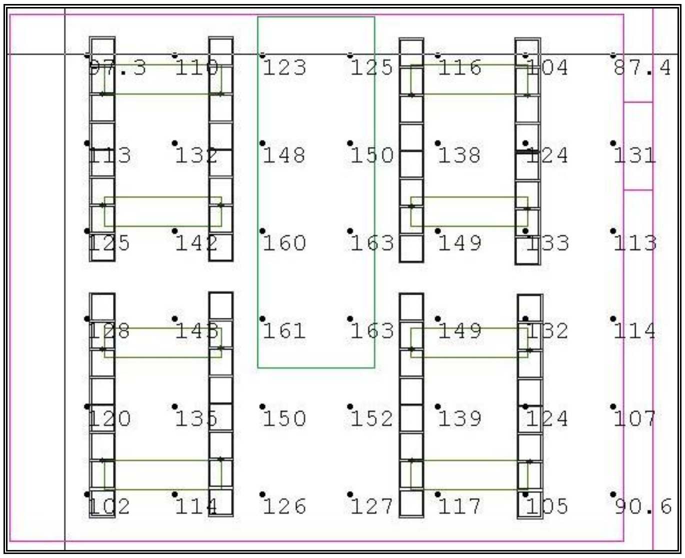


Figure A.19 : Large Support Space, New Design

ORIGINAL LIGHTING SCHEDULE

Table A.24

Fixture						
Tag	**Discription**	**Manufacturer**	**Product No.**	**Power**	**Lamps**	**Voltage**
L1	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	2/32W	T8	277
L1A	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423283	2/32W	T8	277
L8	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	2/32W	T8	277
L8A	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	4/40W	T5	277
L36	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	1/32W	Vert CFL	120/277

Table A.25

Lamp				
Tag	**Discription**	**Manufacturer**	**Product No.**	**Avg Rated Life**
L1	(2) F32/835/XPS/ECO	OSI	21697	30000
L1A	(2) F32/835/XPS/ECO	OSI	21697	30000
L8	(2) F32/835/XPS/ECO	OSI	21697	30000
L8A	(4) FT40DL/835/RS	OSI	20585	20000
L36	(1)CF32DT/E/IN/835	OSI	20885	12000

Table A.26

Lamp						
Tag	**Base**	**Watts**	**Bulb**	**CRI**	**CCT**	**Mean Lumens/Lamp**
L1	Medium Bipin	32	T8	85	3500	2945
L1A	Medium Bipin	32	T8	85	3500	2945
L8	Medium Bipin	32	T8	85	3500	2945
L8A	2G11	40	T5	82	3500	2709
L36	GX24Q-3	32	T4	82	3500	2064

Table A.27

Ballast					
Tag	**Discription**	**Product No.**	**Ballast Factor**	**PF**	**Lamp No.**
L1	QT2X32T8277ISNSC	49,914	0.9	0.97	2
L1A	QT2X32T8277ISNSC	49,914	0.9	0.97	2
L8	QT2X32T8277ISNSC	49,914	0.9	0.97	2
L8A	QT2X40/277DL	49,644	1.0	0.97	2
L36	QTP 1/2CF/UNV TM	51,768	1.0	0.98	1

Table A.28

Layout Summary				
Tag	**Number of Fixtures**	**Total Lumens**	**Total Watts**	**Lumens/Watt**
L1	112	659,680	7,168	92.03
L1A	32	188,480	2,048	92.03
L8	16	94,240	1,024	92.03
L8A	18	195,048	2,880	67.73
L36	8	16,512	256	64.50
Total	**186**	**1,153,960**	**13,376**	

NEW LIGHTING SCHEDULE

Table A.29

Fixture						
Tag	**Discription**	**Manufacturer**	**Product No.**	**Power**	**Lamps**	**Voltage**
L1	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	2/32W	T8	277
L8A_A2	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	2/40W	T8	277
L1_A	Recessed Row 1'X8' 2 Lamp T8	Lithonia Lighting	RR 2 96T8 TUBI	2/40W	T8	277
L36_A	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	1/32W	Vert CFL	120/277

Table A.30

Lamp				
Tag	**Discription**	**Manufacturer**	**Product No.**	**Avg Rated Life**
L1	(2) F32/835/XPS/ECO	OSI	21697	30000
L8A_A2	(2) F40T8 TL835 60 ALTO 1LP	Philips	368340	20000
L1_A	(2) FO96/835/XP/SS/ECO	OSI	22100	18000
L36_A	(1) Mini Dec Twister 27W Med EL/mDT 1CT	Philips	137158	137158

Table A.31

Lamp						
Tag	**Base**	**Watts**	**Bulb**	**CRI**	**CCT**	**Mean Lumens/Lamp**
L1	Medium Bipin	32	T8	85	3500	2945
L8A_A2	Medium Bipin	40	T8	86	3500	3500
L1_A	Single Pin	55	T8	82	3500	5415
L36_A	Med	27	EL	82	3500	1750

Table A.32

Ballast					
Tag	**Discription**	**Product No.**	**Ballast Factor**	**PF**	**Lamp No.**
L1	QT2X32T8277ISNSC	49,914	0.9	0.97	2
L8A_A2	QT2X32T8277ISNSC	49,914	0.9	0.97	2
L1_A	QT2X32T8277ISNSC	49,914	0.9	0.97	2
L36_A	QTP 1/2CF/UNV TM	51,768	1.0	0.98	1

Table A.33

Layout Summary				
Tag	**Number of Fixtures**	**Total Lumens**	**Total Watts**	**Lumens/Watt**
L1	16	94,240	1,024	92.03
L8A_A2	36	252,000	2,880	87.50
L1_A	54	584,820	5,940	98.45
L36_A	8	14,000	256	54.69
Total	**114**	**945,060**	**10,100**	

Table A.34

Layout Comparison			
	Number of Fixtures	**Total Lumens**	**Total Watts**
Original	186	1,153,960	13,376
New	114	945,060	10,100
Difference	**-72**	**-208,900**	**-3,276**

Table A.34 : Linear Fluorescent Lamp Comparison

Discription	Manufacturer	Product No.	Watts	Mean Lumens/Lamp	Lumen/Watt
39W/830 WW Min Bipin HO UNP	Philips	290221	39	NA	--
54W/835 WH Min Bipin HO UNP	Philips	290288	54	NA	--
F17T8 TL735 24 ALTO 1LP	Philips	368084	17	1200	70.59
F32T8 25W ADV835 XEW LL ALTO 1LP	Philips	137828	25	2280	91.20
F32T8 30W ADV835 EW ALTO 1LP	Philips	387811	30	2710	90.33
F32T8 TL835 48 ALTO BLK	Philips	272336	32	2800	87.50
F34T12 34W/836 ADV835 Med Bipin EW ALTO	Philips	142588	34	2790	82.06
F40T12 ADV835 48 ALTO 1LP	Philips	266312	40	3250	81.25
F40T8 TL835 60 ALTO 1LP	Philips	368340	40	3500	87.50
F48T12 60W SPEC35 HO 1LP	Philips	218974	60	3830	63.83
F48T8 44W TL835 HO ALTO 1LP	Philips	388090	44	3600	81.82
F72T12 85W SPEC35 HO 1LP	Philips	300012	85	6000	70.59
F72T8 65W TL835 HO ALTO 1LP	Philips	388215	65	5490	84.46
F96T12 110W SPEC35 HO 1LP	Philips	276816	110	8375	76.14
F96T12 95W SPEC35 HO/EW 1LP	Philips	221176	95	7500	78.95
F96T8 59W TL835 ALTO Plus 1LP	Philips	388017	59	5490	93.05
F96T8 86W TL835 HO ALTO Plus 1LP	Philips	388272	86	7625	88.66
FB32T8/6 TL735 22.44 ALTO 1LP	Philips	378935	32	2370	74.06
PL-L 80W/835 2G11/4P 1CT	Philips	386987	80	6000	75.00
Slimline F72T12 56W 35U ALTO 1LP	Philips	366187	56	4550	81.25
Slimline F96T12 58W SPEC35 EW ALTO 1LP	Philips	134372	58	4900	84.48
Slimline F96T12 75W SPEC35 ALTO 1LP	Philips	366484	75	6050	80.67
FP39/835/HO/ECO	OSI	20933	39	2883	73.92
F32/835/XPS/ECO	OSI	21697	32	2945	92.03
FP54/835/HO/ECO	OSI	20904	54	4138	76.63
FP80/835/HO/ECO	OSI	20936	80	5719	71.49
FP35/835/ECO	OSI	20926	35	3069	87.69
FO96/835/XP/SS/ECO	OSI	22100	55	5415	98.45
FO96/835/XP/ECO	OSI	22034	59	5795	98.22
FO30/835/XP/SS/ECO	OSI	22060	30	2710	90.33
FO96/835/XP	OSI	21740	59	5795	98.22
FO96/835/HO/ECO	OSI	22206	86	7380	85.81
FO40/735/ECO	OSI	22103	40	3150	78.75
FBO30/835XP/6/SS/ECO	OSI	22171	30	2660	88.67

Table A.35 : Compact Fluorescent Lamp Comparison

Discription	Manufacturer	Product No.	Watts	Mean Lumens/Lamp	Lumen/Watt
Mini Dec Twister 27W Med EL/mDT 1CT	Philips	137158	27	1750	64.81
20W Med EL/A G40 ALTO 1CT	Philips	145151	20	1100	55.00
Decorative Twister 23W Med EL/DT 1BC	OSI	381111	23	1400	60.87
Decorative Twister 42W Med EL/DT 1BC	OSI	139477	42	2800	66.67
Universals 25W Med SLS ALTO 1BC	OSI	371153	25	1750	70.00
CF23ELMINITWISTDAYBL1 5/CS 1/SKU	OSI	29417	23	1247	54.22
CF42DT/E/IN/835	OSI	20871	42	2752	65.52
CF57DT/E/IN/835	OSI	20897	57	3698	64.88
CF32DT/E/IN/835	OSI	20885	32	2064	64.50
42W TWIST 2700K CD	Westinghouse	36645	42	2800	66.67

Figure A.20 : L1 & L1A Fixture

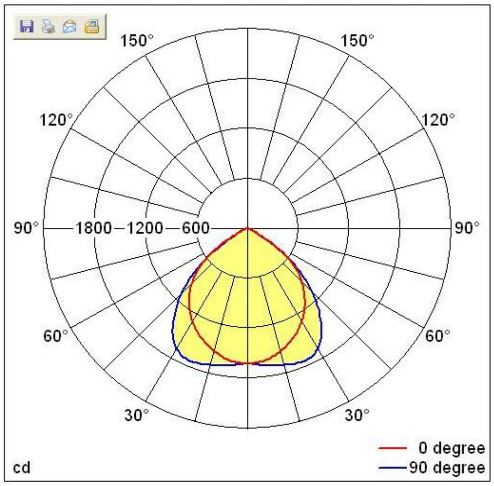


Figure 21 : L1 & L1A Photometric Distribution

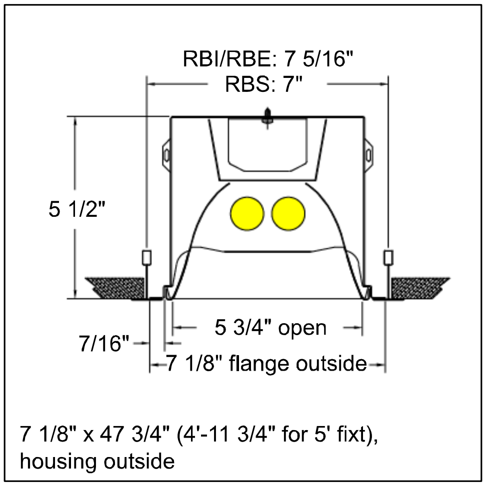
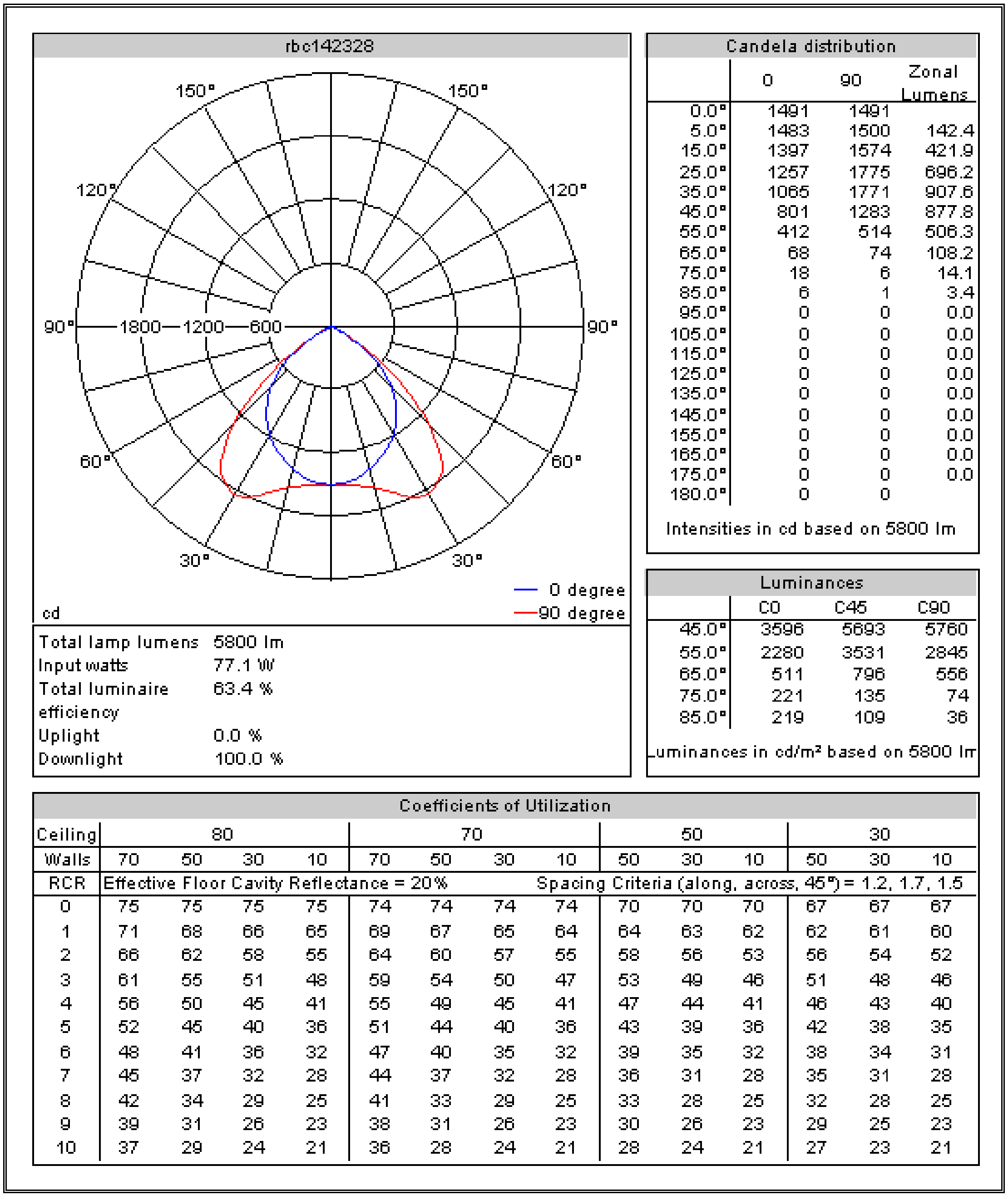


Figure A.22 : L1 & L1A Fixture



Candela distribution	0	90	Zonal Lumens
0.0°	1491	1491	
5.0°	1483	1500	142.4
15.0°	1397	1574	421.9
25.0°	1257	1775	696.2
35.0°	1065	1771	907.6
45.0°	801	1283	877.8
55.0°	412	514	506.3
65.0°	68	74	108.2
75.0°	18	6	14.1
85.0°	6	1	3.4
95.0°	0	0	0.0
105.0°	0	0	0.0
115.0°	0	0	0.0
125.0°	0	0	0.0
135.0°	0	0	0.0
145.0°	0	0	0.0
155.0°	0	0	0.0
165.0°	0	0	0.0
175.0°	0	0	0.0
180.0°	0	0	

Intensities in cd based on 5800 lm

Total lamp lumens	5800 lm
Input watts	77.1 W
Total luminaire efficiency	63.4 %
Uplight	0.0 %
Downlight	100.0 %

Luminances	C0	C45	C90
45.0°	3596	5693	5760
55.0°	2280	3531	2845
65.0°	511	796	556
75.0°	221	135	74
85.0°	219	109	36

Luminances in cd/m² based on 5800 lm

Coefficients of Utilization

Ceiling	80				70				50			30		
Walls	70	50	30	10	70	50	30	10	50	30	10	50	30	10
RCR	Effective Floor Cavity Reflectance = 20%						Spacing Criteria (along, across, 45°) = 1.2, 1.7, 1.5							
0	75	75	75	75	74	74	74	74	70	70	70	67	67	67
1	71	68	66	65	69	67	65	64	64	63	62	62	61	60
2	66	62	58	55	64	60	57	55	58	56	53	56	54	52
3	61	55	51	48	59	54	50	47	53	49	46	51	48	46
4	56	50	45	41	55	49	45	41	47	44	41	46	43	40
5	52	45	40	36	51	44	40	36	43	39	36	42	38	35
6	48	41	36	32	47	40	35	32	39	35	32	38	34	31
7	45	37	32	28	44	37	32	28	36	31	28	35	31	28
8	42	34	29	25	41	33	29	25	33	28	25	32	28	25
9	39	31	26	23	38	31	26	23	30	26	23	29	25	23
10	37	29	24	21	36	28	24	21	28	24	21	27	23	21

Figure A.23 : L8 Photometric Data

Figure A.24 : L8 Fixture

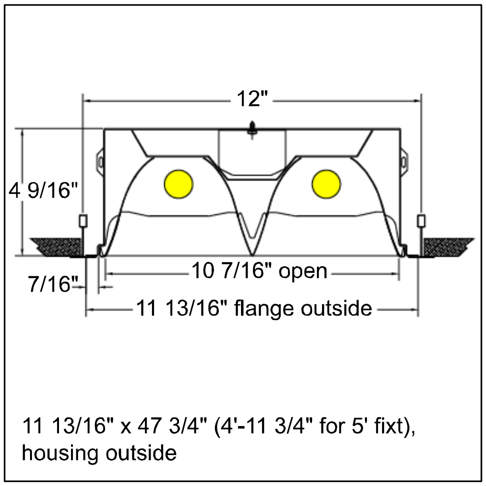
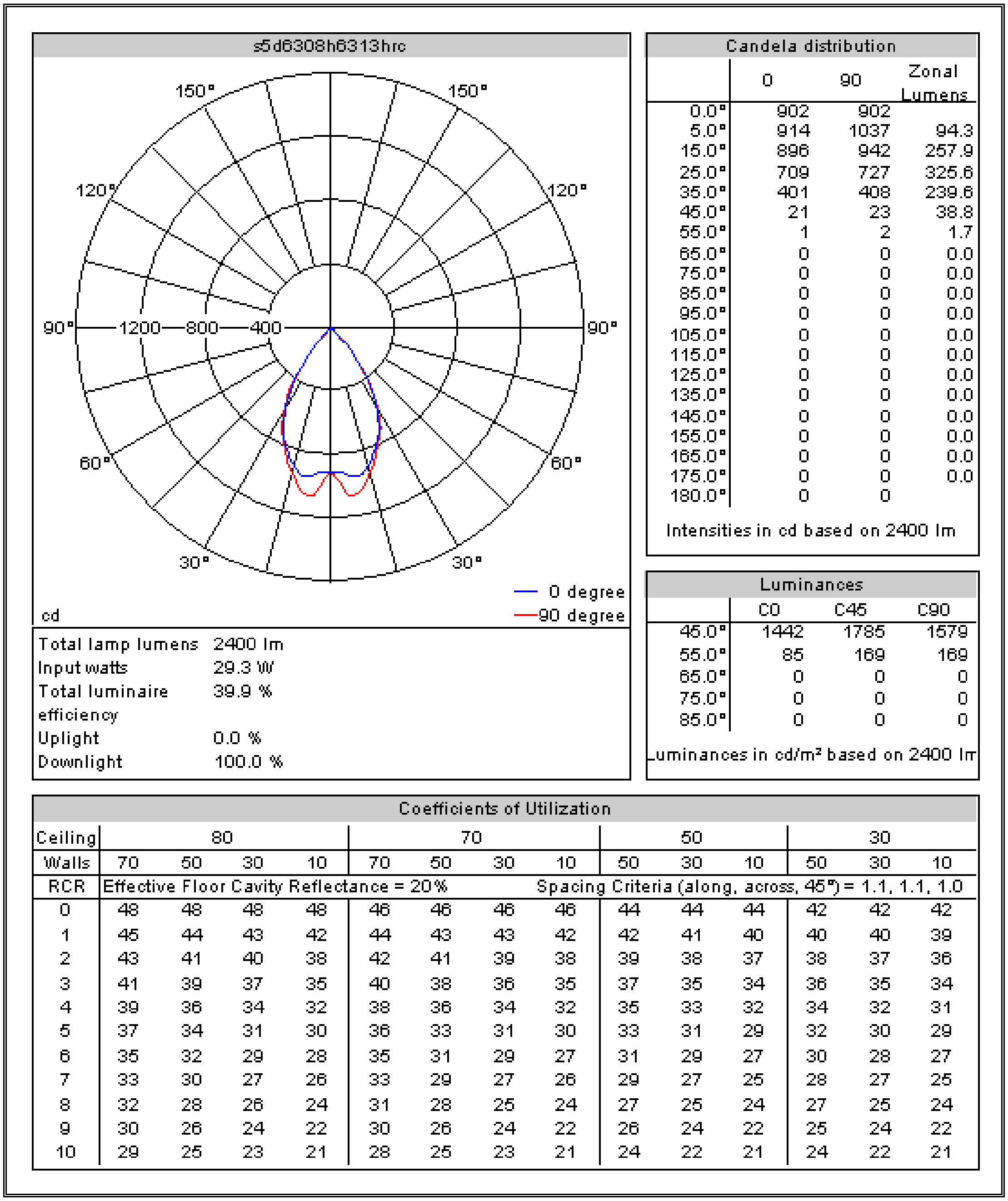


Figure A.25 : L8 Fixture



Total lamp lumens	2400 lm
Input watts	29.3 W
Total luminaire efficiency	39.9 %
Uplight	0.0 %
Downlight	100.0 %

Candela distribution

	0	90	Zonal Lumens
0.0°	902	902	
5.0°	914	1037	94.3
15.0°	896	942	257.9
25.0°	709	727	325.6
35.0°	401	408	239.6
45.0°	21	23	38.8
55.0°	1	2	1.7
65.0°	0	0	0.0
75.0°	0	0	0.0
85.0°	0	0	0.0
95.0°	0	0	0.0
105.0°	0	0	0.0
115.0°	0	0	0.0
125.0°	0	0	0.0
135.0°	0	0	0.0
145.0°	0	0	0.0
155.0°	0	0	0.0
165.0°	0	0	0.0
175.0°	0	0	0.0
180.0°	0	0	

Intensities in cd based on 2400 lm

Luminances

	C0	C45	C90
45.0°	1442	1785	1579
55.0°	85	169	169
65.0°	0	0	0
75.0°	0	0	0
85.0°	0	0	0

Luminances in cd/m² based on 2400 lm

Coefficients of Utilization

Ceiling	80				70				50			30		
Walls	70	50	30	10	70	50	30	10	50	30	10	50	30	10
RCR	Effective Floor Cavity Reflectance = 20%								Spacing Criteria (along, across, 45°) = 1.1, 1.1, 1.0					
0	48	48	48	48	46	46	46	46	44	44	44	42	42	42
1	45	44	43	42	44	43	43	42	42	41	40	40	40	39
2	43	41	40	38	42	41	39	38	39	38	37	38	37	36
3	41	39	37	35	40	38	36	35	37	35	34	36	35	34
4	39	36	34	32	38	36	34	32	35	33	32	34	32	31
5	37	34	31	30	36	33	31	30	33	31	29	32	30	29
6	35	32	29	28	35	31	29	27	31	29	27	30	28	27
7	33	30	27	26	33	29	27	26	29	27	25	28	27	25
8	32	28	26	24	31	28	25	24	27	25	24	27	25	24
9	30	26	24	22	30	26	24	22	26	24	22	25	24	22
10	29	25	23	21	28	25	23	21	24	22	21	24	22	21

Figure A.26 : L36 Photometric Data

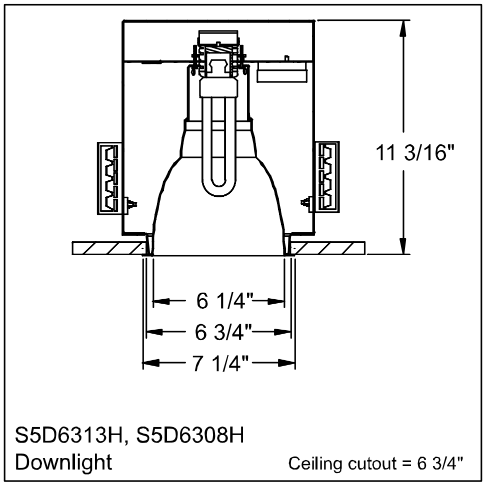


Figure A.27 : L36 Fixture

Figure A.28 : L36 Fixture

K : ACOUSTIC CALCULATION

Table A.36

		Sound Absorption Coefficients					
Surface	**Area [SF]**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Concrete Block, painted	4,600	0.10	0.05	0.06	0.07	0.09	0.08
Concrete Floor	3,450	0.01	0.01	0.02	0.02	0.02	0.02
Concrete Ceiling	3,450	0.01	0.01	0.02	0.02	0.02	0.02
Sides Without Walls	600	1.00	1.00	1.00	1.00	1.00	1.00

		Sound Absorption [sabins]					
Surface	**Area [SF]**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Concrete Block, painted	4,600	460	230	276	322	414	368
Concrete Floor	3,450	34.5	34.5	69	69	69	69
Concrete Ceiling	3,450	34.5	34.5	69	69	69	69
Sides Without Walls	600	600	600	600	600	600	600
a_2 [sabins]		**1129**	**899**	**1014**	**1060**	**1152**	**1106**

	Noise Reduction & Transmission Loss [dB]					
	125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Likely Noise in the Mech Room	86	85	84	83	82	80
Likely Noise in the Corridor	66	72	77	74	68	60
Required NR	20	13	7	9	14	20
Minus 10 log a_2/S	-6	-7	-7	-6	-6	-6
Required TL	**26**	**20**	**14**	**15**	**20**	**26**
Actual Wall Assembly TL, 8" Concrete, painted	**34**	**40**	**44**	**49**	**59**	**64**

L : LIFE CYCLE COST ANAYLSIS

Table A.37

System Cost										
Case	**System**	**Unit**	**Type**	**Description**	**Manufacturer**	**Product No.**	**Rated Life**	**Quantity**	**Unit Price**	**Cost [$]**
Case 1	**Lighting**	L1	Original Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	--	112	135	15,120
		L1A	Original Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	--	32	135	4,320
		L8	Original Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	--	16	129	2,064
		L8A	Original Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	--	18	129	2,322
		L36	Original Fixture	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	--	8	81	648
		Fixture Subtotal						**186**		**24,474**
		L1	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	224	13.56	3,037
		L1A	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	64	13.56	868
		L8	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	32	13.56	434
		L8A	Original Lamp	FT40DL/835/RS	OSI	20585	20,000	72	19.1	1,375
		L36	Original Lamp	CF32DT/E/IN/835	OSI	20885	12,000	8	10.33	83
		Lamp Subtotal						**400**		**5,797**
	HVAC	Cooling Tower	--	NC Class	Marley	NC8311J1	--	2	79,300	158,600
		HVAC Subtotal								**158,600**
		Case 1 Total								**188,871**
Case 4	**Lighting**	L1	New Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	--	16	135	2,160
		L8A_A2	New Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	--	36	129	4,644
		L1_A	New Fixture	Recessed Row 1'X8'	Lithonia Lighting	RR 2 96T8 TUBI	--	54	215	11,610
		L36_A	New Fixture	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	--	8	81	648
		Fixture Subtotal						**516**		**19,062**
		L1	New Lamp	F32/835/XPS/ECO	OSI	21697	30,000	32	13.56	434
		L8A_A2	New Lamp	F40T8 TL835 60 ALTO 1LP	Philips	368340	20,000	72	4.89	352
		L1_A	New Lamp	FO96/835/XP/SS/ECO	OSI	22100	18,000	108	10.33	1,116
		L36_A	New Lamp	Mini 27W Med EL/mDT 1CT	Philips	137158	137,158	8	5.99	48
		Lamp Subtotal						**736**		**1,950**
	HVAC	Cooling Tower	--	NC Class	Marley	NC8311J1	--	2	79,300	158,600
		HVAC Subtotal								**158,600**
		Case 2 Total								**179,612**
Case 5	**Lighting**	L1	Original Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	--	112	135	15,120
		L1A	Original Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	--	32	135	4,320
		L8	Original Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	--	16	129	2,064
		L8A	Original Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	--	18	129	2,322
		L36	Original Fixture	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	--	8	81	648
		Fixture Subtotal						**186**		**24,474**
		L1	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	224	13.56	3,037
		L1A	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	64	13.56	868
		L8	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	32	13.56	434
		L8A	Original Lamp	FT40DL/835/RS	OSI	20585	20,000	72	19.1	1,375
		L36	Original Lamp	CF32DT/E/IN/835	OSI	20885	12,000	8	10.33	83
		Lamp Subtotal						**400**		**5,797**
	Ground Loop	Pumps	Split-Coupled	Series 4300, 4x4x10	Armstrong	PT82-1-0	--	7	6,150	43,050
		Heat Exchanges	Plate-Frame	B56Hx200 4*2 1/2"NPT	SWEP	11487-200	--	4	6,636	26,544
		As Calculated by RETStreen GSHP3		Drilling & Backfill	--	--	--	61,185	3.66	223,815
				Ground Loop Pipes	--	--	--	61,185	11	673,035
				Fittings and valves	--	--	--	2,403	12	28,841
				Internal Piping & Insulation	--	--	--	2,403	60	144,203
		Ground Loop Sub Total								**1,139,488**
		Case 5 Total								**1,169,759**
Case 6	**Lighting**	L1	Original Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	--	112	135	15,120
		L1A	Original Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	--	32	135	4,320
		L8	Original Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	--	16	129	2,064
		L8A	Original Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	--	18	129	2,322
		L36	Original Fixture	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	--	8	81	648
		Fixture Subtotal						**186**		**24,474**
		L1	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	224	13.56	3,037
		L1A	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	64	13.56	868
		L8	Original Lamp	F32/835/XPS/ECO	OSI	21697	30,000	32	13.56	434
		L8A	Original Lamp	FT40DL/835/RS	OSI	20585	20,000	72	19.1	1,375
		L36	Original Lamp	CF32DT/E/IN/835	OSI	20885	12,000	8	10.33	83
		Lamp Subtotal						**400**		**5,797**
	Ground Loop	Pumps	End Suction	Series 1510 Model 4 BC	Bell & Gossett	--	--	4	3,050	12,200
		Heat Exchanges	Plate-Frame	B56Hx200 4*2 1/2"NPT	SWEP	11487-200	--	4	6,636	26,544
		As Calculated by RETStreen GSHP3		Drilling & Backfill	--	--	--	300	3.66	1,097
				Fittings and valves	--	--	--	2,403	12	28,841
				Internal Piping & Insulation	--	--	--	2,403	60	144,203
		Ground Loop Sub Total								**212,885**
		Case 6 Total								**243,156**

Table A.38

System Cost										
Case	**System**	**Unit**	**Type**	**Description**	**Manufacturer**	**Product No.**	**Rated Life**	**Quantity**	**Unit Price**	**Cost [$]**
Case 7	**Lighting**	L1	New Fixture	Recessed Bivergence 7"	Zumtovbel Staff	RBNIC7423282	--	16	135	2,160
		L8A_A2	New Fixture	Recessed Bivergence 1'	Zumtovbel Staff	RBIC1423282	--	36	129	4,644
		L1_A	New Fixture	Recessed Row 1'X8'	Lithonia Lighting	RR 2 96T8 TUBI	--	54	215	11,610
		L36_A	New Fixture	6" Recessed DL	Zumtovbel Staff	S5D6308HU6313HRC	--	8	81	648
		Fixture Subtotal						**114**		**19,062**
		L1	New Lamp	F32/835/XPS/ECO	OSI	21697	30,000	32	13.56	434
		L8A_A2	New Lamp	F40T8 TL835 60 ALTO 1LP	Philips	368340	20,000	72	4.89	352
		L1_A	New Lamp	FO96/835/XP/SS/ECO	OSI	22100	18,000	108	10.33	1,116
		L36_A	New Lamp	Mini 27W Med EL/mDT 1CT	Philips	137158	137,158	8	5.99	48
		Lamp Subtotal						**334**		**1,950**
		Lighting Subtotal								**21,012**
	Ground Loop	Pumps	End Suction	Series 1510 Model 4 BC	Bell & Gossett	--	--	4	3,050	12,200
		Heat Exchanges	Plate-Frame	B56Hx200 4*2 1/2"NPT	SWEP	11487-200	--	4	6,636	26,544
		As Calculated by RETStreen GSHP3		Drilling & Backfill	--	--	--	300	3.66	1,097
				Fittings and valves	--	--	--	2,403	12	28,841
				Internal Piping & Insulation	--	--	--	2,403	60	144,203
		Mechanical System Subtotal								**212,885**
		Case 7 Total								**233,897**

Lifecycle Summary

Project: Model 1
Prepared By: Penn State

4/3/2006
12:45:17 PM

Copy (1) of Landscape Building, Laboratory Space

Model 1

Type of Analysis .... Private Sector Lifecycle Analysis
Type of Design Alternatives .... Mutually Exclusive
Length of Analysis .... 20 yrs
Minimum Attractive Rate of Return .... 10.00 %
Income Taxes .... Not Considered

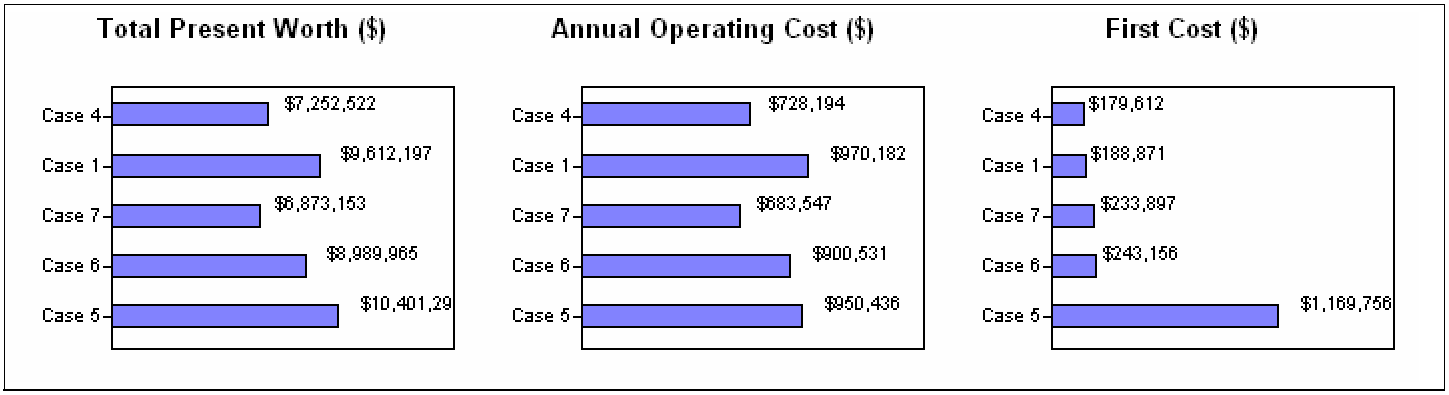


Table 1. Executive Summary

Economic Criteria	Best Design Case for Each Criteria	Value ($)
Incremental NPW Savings Analysis	Case 7	-
Lowest Total Present Worth	Case 7	$6,873,152
Lowest Annual Operating Cost	Case 7	$683,547
Lowest First Cost	Case 4	$179,612

Table 2. Design Cases Ranked by First Cost

Design Case Name	Design Case Short Name	Total Present Worth ($)	Annual Operating Cost ($/yr)	First Cost ($)
Case 4	Case 4	$7,252,521	$728,194	$179,612
Case 1	Case 1	$9,612,197	$970,182	$188,871
Case 7	Case 7	$6,873,152	$683,547	$233,897
Case 6	Case 6	$8,989,965	$900,531	$243,156
Case 5	Case 5	$10,401,290	$950,436	$1,169,756

Table 3. Incremental Analysis Data

Challenger	Base Case	Additional First Cost ($)	NPW Savings ($)	IRR (%)	Payback Period (yrs)
Case 1	Case 4 [Winner]	$9,259	$-2,359,676	n/a	n/a
Case 7 [Winner]	Case 4	$54,285	$379,369	85.89	1.3
Case 6	Case 7 [Winner]	$9,259	$-2,116,813	n/a	n/a
Case 5	Case 7 [Winner]	$935,859	$-3,528,138	n/a	n/a

Analysis Details

Project: Model 1 4/3/2006
Prepared By: Penn State 12:45:18 PM

Copy (1) of Landscape Building, Laboratory Space

Model 1

Type of Analysis .... Private Sector Lifecycle Analysis
Type of Design Alternatives .... Mutually Exclusive
Length of Analysis .... 20 yrs
Minimum Attractive Rate of Return .... 10.00 %
Income Taxes .... Not Considered

1A. Summary of Results

Base Case **[Winner]**	Case 4 [Case 4]
Challenger	Case 1 [Case 1]
[Case 4] Total Present Worth ($)	$7,252,521
[Case 1] Total Present Worth ($)	$9,612,197
Net Present Worth Savings ($)	$-2,359,676
Internal Rate of Return	n/a
Payback Period (yrs)	n/a

1B. Comparative Analysis Details

		Cash Flow (Present Worth $)			SIR and Payback Calculation (Present Worth $)				
Year	**Date**	**[Case 4] Cash Flow ($)**	**[Case 1] Cash Flow ($)**	**Net Present Worth Savings ($)**	**Operating Cost Savings ($)**	**Cumulative Operating Cost Savings ($)**	**Additional Investment Cost ($)**	**Cumulative Additional Investment Cost ($)**	**Year-End SIR**
0	Initial	179,612	188,871	-9,259	0	0	9,259	9,259	0.000
1	1	675,234	899,623	-224,389	-224,389	-224,389	0	9,259	-24.235
2	2	626,126	834,196	-208,070	-208,070	-432,459	0	9,259	-46.707
3	3	580,590	773,527	-192,937	-192,937	-625,396	0	9,259	-67.545
4	4	538,365	717,271	-178,906	-178,906	-804,301	0	9,259	-86.867
5	5	499,211	665,106	-165,894	-165,894	-970,196	0	9,259	-104.784
6	6	462,905	616,734	-153,829	-153,829	-1,124,025	0	9,259	-121.398
7	7	429,239	571,881	-142,642	-142,642	-1,266,666	0	9,259	-136.804
8	8	398,022	530,290	-132,268	-132,268	-1,398,934	0	9,259	-151.089
9	9	369,075	491,723	-122,648	-122,648	-1,521,582	0	9,259	-164.335
10	10	342,233	455,961	-113,728	-113,728	-1,635,311	0	9,259	-176.618
11	11	317,343	422,801	-105,457	-105,457	-1,740,768	0	9,259	-188.008
12	12	294,264	392,051	-97,788	-97,788	-1,838,555	0	9,259	-198.570
13	13	272,863	363,539	-90,676	-90,676	-1,929,231	0	9,259	-208.363
14	14	253,018	337,099	-84,081	-84,081	-2,013,312	0	9,259	-217.444
15	15	234,617	312,583	-77,966	-77,966	-2,091,278	0	9,259	-225.864
16	16	217,554	289,850	-72,296	-72,296	-2,163,574	0	9,259	-233.673
17	17	201,732	268,770	-67,038	-67,038	-2,230,612	0	9,259	-240.913
18	18	187,060	249,223	-62,163	-62,163	-2,292,775	0	9,259	-247.627
19	19	173,456	231,098	-57,642	-57,642	-2,350,417	0	9,259	-253.852
20	20	0	0	0	0	-2,350,417	0	9,259	-253.852
Totals		7,252,521	9,612,197	-2,359,676	-2,350,417		9,259		

Analysis Details

Project: Model 1 4/3/2006
Prepared By: Penn State 12:45:18 PM

2A. Summary of Results

Base Case	Case 4 [Case 4]
Challenger **[Winner]**	Case 7 [Case 7]
[Case 4] Total Present Worth ($)	$7,252,521
[Case 7] Total Present Worth ($)	$6,873,152
Net Present Worth Savings ($)	$379,369
Internal Rate of Return	85.9 %
Payback Period (yrs)	1.3 years

2B. Comparative Analysis Details

		Cash Flow (Present Worth $)			SIR and Payback Calculation (Present Worth $)				
Year	**Date**	**[Case 4] Cash Flow ($)**	**[Case 7] Cash Flow ($)**	**Net Present Worth Savings ($)**	**Operating Cost Savings ($)**	**Cumulative Operating Cost Savings ($)**	**Additional Investment Cost ($)**	**Cumulative Additional Investment Cost ($)**	**Year-End SIR**
0	Initial	179,612	233,897	-54,285	0	0	54,285	54,285	0.000
1	1	675,234	633,834	41,400	41,400	41,400	0	54,285	0.763
2	2	626,126	587,737	38,389	38,389	79,789	0	54,285	1.470
3	3	580,590	544,993	35,597	35,597	115,386	0	54,285	2.126
4	4	538,365	505,357	33,008	33,008	148,394	0	54,285	2.734
5	5	499,211	468,604	30,608	30,608	179,002	0	54,285	3.297
6	6	462,905	434,524	28,382	28,382	207,384	0	54,285	3.820
7	7	429,239	402,922	26,318	26,318	233,701	0	54,285	4.305
8	8	398,022	373,618	24,404	24,404	258,105	0	54,285	4.755
9	9	369,075	346,446	22,629	22,629	280,733	0	54,285	5.171
10	10	342,233	321,250	20,983	20,983	301,716	0	54,285	5.558
11	11	317,343	297,886	19,457	19,457	321,173	0	54,285	5.916
12	12	294,264	276,222	18,042	18,042	339,215	0	54,285	6.249
13	13	272,863	256,133	16,730	16,730	355,945	0	54,285	6.557
14	14	253,018	237,505	15,513	15,513	371,458	0	54,285	6.843
15	15	234,617	220,232	14,385	14,385	385,843	0	54,285	7.108
16	16	217,554	204,215	13,339	13,339	399,181	0	54,285	7.353
17	17	201,732	189,363	12,369	12,369	411,550	0	54,285	7.581
18	18	187,060	175,591	11,469	11,469	423,019	0	54,285	7.793
19	19	173,456	162,821	10,635	10,635	433,654	0	54,285	7.988
20	20	0	0	0	0	433,654	0	54,285	7.988
Totals		7,252,521	6,873,152	379,369	433,654		54,285		

Analysis Details

Project: Model 1 4/3/2006
Prepared By: Penn State 12:45:18 PM

3A. Summary of Results

Base Case **[Winner]**	Case 7 [Case 7]
Challenger	Case 6 [Case 6]
[Case 7] Total Present Worth ($)	$6,873,152
[Case 6] Total Present Worth ($)	$8,989,965
Net Present Worth Savings ($)	$-2,116,813
Internal Rate of Return	n/a
Payback Period (yrs)	n/a

3B. Comparative Analysis Details

		Cash Flow (Present Worth $)			SIR and Payback Calculation (Present Worth $)				
Year	**Date**	**[Case 7] Cash Flow ($)**	**[Case 6] Cash Flow ($)**	**Net Present Worth Savings ($)**	**Operating Cost Savings ($)**	**Cumulative Operating Cost Savings ($)**	**Additional Investment Cost ($)**	**Cumulative Additional Investment Cost ($)**	**Year-End SIR**
0	Initial	233,897	243,156	-9,259	0	0	9,259	9,259	0.000
1	1	633,834	835,038	-201,203	-201,203	-201,203	0	9,259	-21.731
2	2	587,737	774,308	-186,570	-186,570	-387,774	0	9,259	-41.881
3	3	544,993	717,995	-173,002	-173,002	-560,775	0	9,259	-60.565
4	4	505,357	665,777	-160,420	-160,420	-721,195	0	9,259	-77.891
5	5	468,604	617,357	-148,753	-148,753	-869,948	0	9,259	-93.957
6	6	434,524	572,458	-137,934	-137,934	-1,007,882	0	9,259	-108.854
7	7	402,922	530,825	-127,903	-127,903	-1,135,785	0	9,259	-122.668
8	8	373,618	492,219	-118,601	-118,601	-1,254,386	0	9,259	-135.477
9	9	346,446	456,421	-109,975	-109,975	-1,364,361	0	9,259	-147.355
10	10	321,250	423,227	-101,977	-101,977	-1,466,338	0	9,259	-158.369
11	11	297,886	392,447	-94,561	-94,561	-1,560,899	0	9,259	-168.582
12	12	276,222	363,905	-87,683	-87,683	-1,648,582	0	9,259	-178.052
13	13	256,133	337,440	-81,306	-81,306	-1,729,889	0	9,259	-186.833
14	14	237,505	312,898	-75,393	-75,393	-1,805,282	0	9,259	-194.976
15	15	220,232	290,142	-69,910	-69,910	-1,875,192	0	9,259	-202.526
16	16	204,215	269,041	-64,826	-64,826	-1,940,018	0	9,259	-209.528
17	17	189,363	249,474	-60,111	-60,111	-2,000,129	0	9,259	-216.020
18	18	175,591	231,331	-55,739	-55,739	-2,055,868	0	9,259	-222.040
19	19	162,821	214,507	-51,686	-51,686	-2,107,554	0	9,259	-227.622
20	20	0	0	0	0	-2,107,554	0	9,259	-227.622
Totals		6,873,152	8,989,965	-2,116,813	-2,107,554		9,259		

Analysis Details

4A. Summary of Results

Base Case **[Winner]**	Case 7 [Case 7]
Challenger	Case 5 [Case 5]
[Case 7] Total Present Worth ($)	$6,873,152
[Case 5] Total Present Worth ($)	$10,401,290
Net Present Worth Savings ($)	$-3,528,138
Internal Rate of Return	n/a
Payback Period (yrs)	n/a

4B. Comparative Analysis Details

		Cash Flow (Present Worth $)			SIR and Payback Calculation (Present Worth $)				
Year	**Date**	**[Case 7] Cash Flow ($)**	**[Case 5] Cash Flow ($)**	**Net Present Worth Savings ($)**	**Operating Cost Savings ($)**	**Cumulative Operating Cost Savings ($)**	**Additional Investment Cost ($)**	**Cumulative Additional Investment Cost ($)**	**Year-End SIR**
0	Initial	233,897	1,169,756	-935,859	0	0	935,859	935,859	0.000
1	1	633,834	881,313	-247,479	-247,479	-247,479	0	935,859	-0.264
2	2	587,737	817,218	-229,480	-229,480	-476,959	0	935,859	-0.510
3	3	544,993	757,784	-212,791	-212,791	-689,750	0	935,859	-0.737
4	4	505,357	702,672	-197,315	-197,315	-887,065	0	935,859	-0.948
5	5	468,604	651,569	-182,965	-182,965	-1,070,031	0	935,859	-1.143
6	6	434,524	604,182	-169,658	-169,658	-1,239,689	0	935,859	-1.325
7	7	402,922	560,242	-157,320	-157,320	-1,397,009	0	935,859	-1.493
8	8	373,618	519,497	-145,878	-145,878	-1,542,887	0	935,859	-1.649
9	9	346,446	481,715	-135,269	-135,269	-1,678,156	0	935,859	-1.793
10	10	321,250	446,681	-125,431	-125,431	-1,803,587	0	935,859	-1.927
11	11	297,886	414,195	-116,309	-116,309	-1,919,896	0	935,859	-2.051
12	12	276,222	384,072	-107,850	-107,850	-2,027,746	0	935,859	-2.167
13	13	256,133	356,140	-100,006	-100,006	-2,127,753	0	935,859	-2.274
14	14	237,505	330,238	-92,733	-92,733	-2,220,486	0	935,859	-2.373
15	15	220,232	306,221	-85,989	-85,989	-2,306,475	0	935,859	-2.465
16	16	204,215	283,951	-79,735	-79,735	-2,386,210	0	935,859	-2.550
17	17	189,363	263,300	-73,936	-73,936	-2,460,146	0	935,859	-2.629
18	18	175,591	244,151	-68,559	-68,559	-2,528,706	0	935,859	-2.702
19	19	162,821	226,394	-63,573	-63,573	-2,592,279	0	935,859	-2.770
20	20	0	0	0	0	-2,592,279	0	935,859	-2.770
Totals		6,873,152	10,401,290	-3,528,138	-2,592,279		935,859		

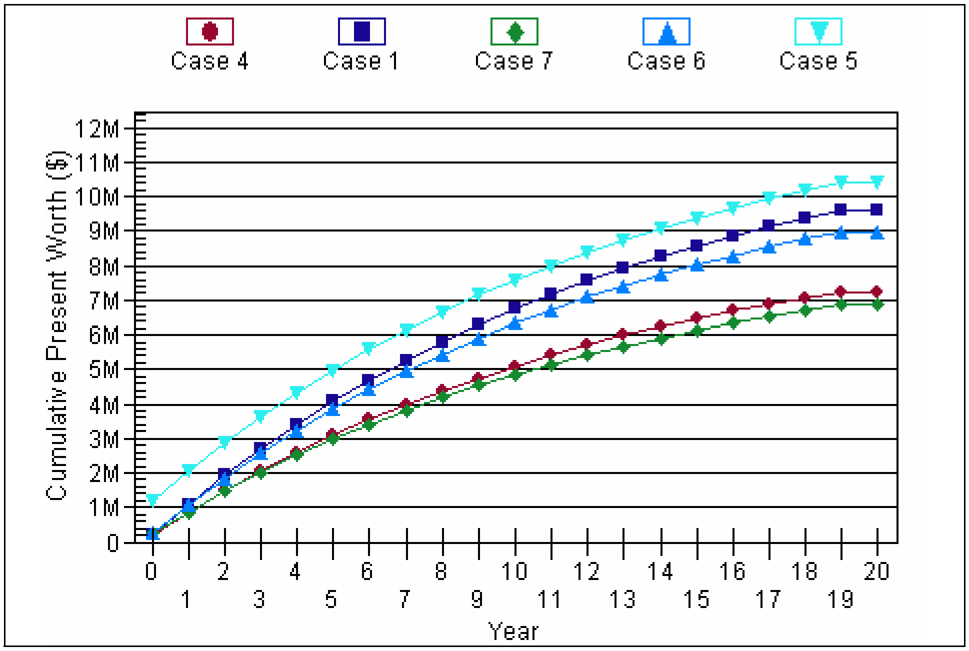
Total Present Worth Profiles

Project: Model 1 4/3/2006
Prepared By: Penn State 12:45:26 PM

Copy (1) of Landscape Building, Laboratory Space

Model 1

Type of Analysis .... Private Sector Lifecycle Analysis
Type of Design Alternatives .... Mutually Exclusive
Length of Analysis .... 20 yrs
Minimum Attractive Rate of Return .... 10.00 %
Income Taxes .... Not Considered



Design Cases Ranked by First Cost

Design Case Name	Design Case Short Name	Total Present Worth ($)	Annual Operating Cost ($/yr)	First Cost ($)
Case 4	Case 4	$7,252,521	$728,194	$179,612
Case 1	Case 1	$9,612,197	$970,182	$188,871
Case 7	Case 7	$6,873,152	$683,547	$233,897
Case 6	Case 6	$8,989,965	$900,531	$243,156
Case 5	Case 5	$10,401,290	$950,436	$1,169,756

Cash Flow Details

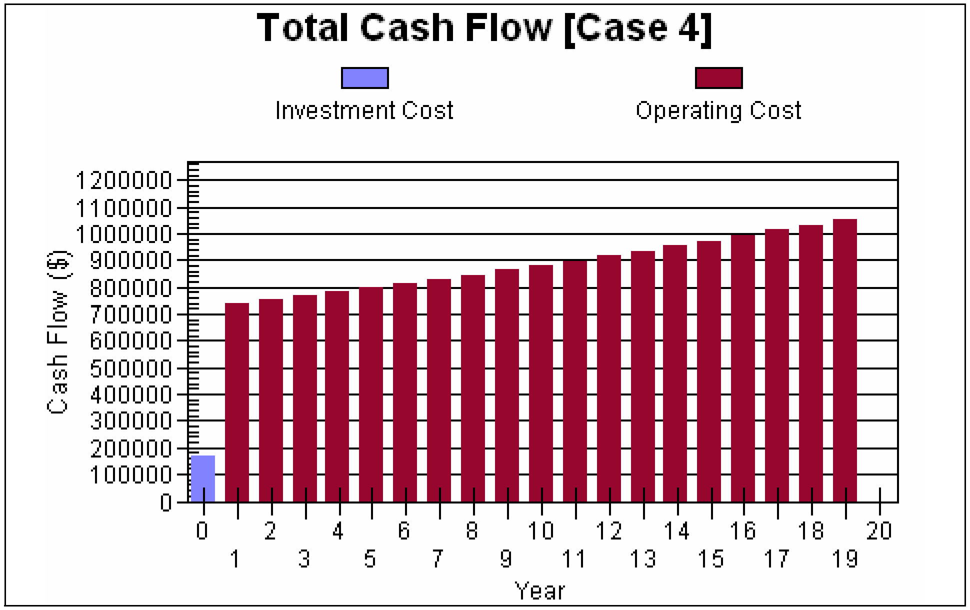
Project: Model 1
Prepared By: Penn State

4/3/2006
12:45:19 PM

Copy (1) of Landscape Building, Laboratory Space

Model 1

Type of Analysis .... Private Sector Lifecycle Analysis
Type of Design Alternatives .... Mutually Exclusive
Length of Analysis .... 20 yrs
Minimum Attractive Rate of Return .... 10.00 %
Income Taxes .... Not Considered



1A. Component Cash Flows [Case 4], Actual Value

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
0	Initial	179,612	0	0	179,612	0	0	0	179,612
1	1	0	0	0	0	742,758	0	742,758	742,758
2	2	0	0	0	0	757,613	0	757,613	757,613
3	3	0	0	0	0	772,765	0	772,765	772,765
4	4	0	0	0	0	788,221	0	788,221	788,221
5	5	0	0	0	0	803,985	0	803,985	803,985

Cash Flow Details

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
6	6	0	0	0	0	820,065	0	820,065	820,065
7	7	0	0	0	0	836,466	0	836,466	836,466
8	8	0	0	0	0	853,195	0	853,195	853,195
9	9	0	0	0	0	870,259	0	870,259	870,259
10	10	0	0	0	0	887,664	0	887,664	887,664
11	11	0	0	0	0	905,418	0	905,418	905,418
12	12	0	0	0	0	923,526	0	923,526	923,526
13	13	0	0	0	0	941,997	0	941,997	941,997
14	14	0	0	0	0	960,837	0	960,837	960,837
15	15	0	0	0	0	980,053	0	980,053	980,053
16	16	0	0	0	0	999,654	0	999,654	999,654
17	17	0	0	0	0	1,019,647	0	1,019,647	1,019,647
18	18	0	0	0	0	1,040,040	0	1,040,040	1,040,040
19	19	0	0	0	0	1,060,841	0	1,060,841	1,060,841
20	20	0	0	0	0	0	0	0	0
Totals		179,612	0	0	179,612	16,965,004	0	16,965,004	17,144,616

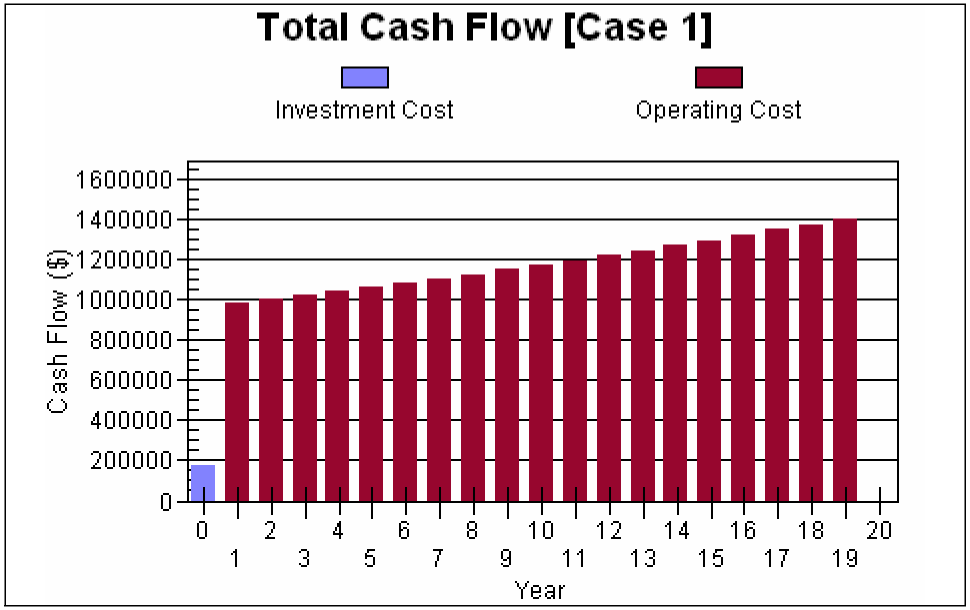
1B. Present Worth Cash Flows [Case 4]

Year	Date	Total Investment Cost ($)	Total Operating Cost ($)	Total Present Worth ($)
0	Initial	179,612	0	179,612
1	1	0	675,234	675,234
2	2	0	626,126	626,126
3	3	0	580,590	580,590
4	4	0	538,365	538,365
5	5	0	499,211	499,211
6	6	0	462,905	462,905
7	7	0	429,239	429,239
8	8	0	398,022	398,022
9	9	0	369,075	369,075
10	10	0	342,233	342,233
11	11	0	317,343	317,343
12	12	0	294,264	294,264
13	13	0	272,863	272,863
14	14	0	253,018	253,018
15	15	0	234,617	234,617
16	16	0	217,554	217,554

Cash Flow Details

Year	Date	Total Investment Cost ($)	Total Operating Cost ($)	Total Present Worth ($)
17	17	0	201,732	201,732
18	18	0	187,060	187,060
19	19	0	173,456	173,456
20	20	0	0	0
Totals		179,612	7,072,907	7,252,519

Cash Flow Details



2A. Component Cash Flows [Case 1], Actual Value

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
0	Initial	188,871	0	0	188,871	0	0	0	188,871
1	1	0	0	0	0	989,586	0	989,586	989,586
2	2	0	0	0	0	1,009,377	0	1,009,377	1,009,377
3	3	0	0	0	0	1,029,565	0	1,029,565	1,029,565
4	4	0	0	0	0	1,050,156	0	1,050,156	1,050,156
5	5	0	0	0	0	1,071,159	0	1,071,159	1,071,159
6	6	0	0	0	0	1,092,583	0	1,092,583	1,092,583
7	7	0	0	0	0	1,114,434	0	1,114,434	1,114,434
8	8	0	0	0	0	1,136,723	0	1,136,723	1,136,723
9	9	0	0	0	0	1,159,457	0	1,159,457	1,159,457
10	10	0	0	0	0	1,182,646	0	1,182,646	1,182,646
11	11	0	0	0	0	1,206,299	0	1,206,299	1,206,299
12	12	0	0	0	0	1,230,425	0	1,230,425	1,230,425
13	13	0	0	0	0	1,255,034	0	1,255,034	1,255,034
14	14	0	0	0	0	1,280,135	0	1,280,135	1,280,135

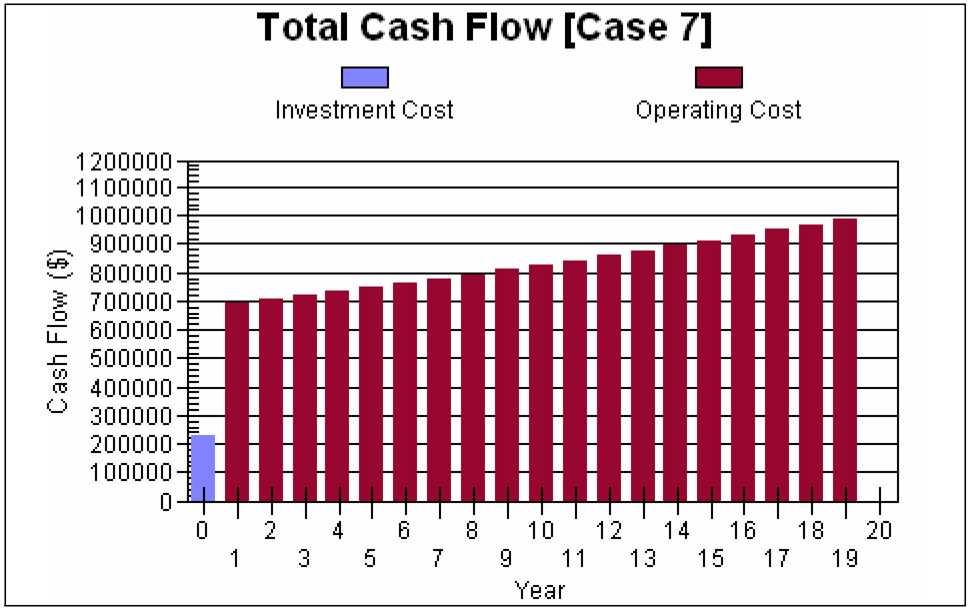
Cash Flow Details

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
15	15	0	0	0	0	1,305,737	0	1,305,737	1,305,737
16	16	0	0	0	0	1,331,852	0	1,331,852	1,331,852
17	17	0	0	0	0	1,358,489	0	1,358,489	1,358,489
18	18	0	0	0	0	1,385,659	0	1,385,659	1,385,659
19	19	0	0	0	0	1,413,372	0	1,413,372	1,413,372
20	20	0	0	0	0	0	0	0	0
Totals		188,871	0	0	188,871	22,602,688	0	22,602,688	22,791,559

2B. Present Worth Cash Flows [Case 1]

Year	Date	Total Investment Cost ($)	Total Operating Cost ($)	Total Present Worth ($)
0	Initial	188,871	0	188,871
1	1	0	899,623	899,623
2	2	0	834,196	834,196
3	3	0	773,527	773,527
4	4	0	717,271	717,271
5	5	0	665,106	665,106
6	6	0	616,734	616,734
7	7	0	571,881	571,881
8	8	0	530,290	530,290
9	9	0	491,723	491,723
10	10	0	455,961	455,961
11	11	0	422,801	422,801
12	12	0	392,051	392,051
13	13	0	363,539	363,539
14	14	0	337,099	337,099
15	15	0	312,583	312,583
16	16	0	289,850	289,850
17	17	0	268,770	268,770
18	18	0	249,223	249,223
19	19	0	231,098	231,098
20	20	0	0	0
Totals		188,871	9,423,326	9,612,197

Cash Flow Details



3A. Component Cash Flows [Case 7], Actual Value

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
0	Initial	233,897	0	0	233,897	0	0	0	233,897
1	1	0	0	0	0	697,218	0	697,218	697,218
2	2	0	0	0	0	711,162	0	711,162	711,162
3	3	0	0	0	0	725,386	0	725,386	725,386
4	4	0	0	0	0	739,893	0	739,893	739,893
5	5	0	0	0	0	754,691	0	754,691	754,691
6	6	0	0	0	0	769,785	0	769,785	769,785
7	7	0	0	0	0	785,181	0	785,181	785,181
8	8	0	0	0	0	800,884	0	800,884	800,884
9	9	0	0	0	0	816,902	0	816,902	816,902
10	10	0	0	0	0	833,240	0	833,240	833,240
11	11	0	0	0	0	849,905	0	849,905	849,905
12	12	0	0	0	0	866,903	0	866,903	866,903
13	13	0	0	0	0	884,241	0	884,241	884,241
14	14	0	0	0	0	901,926	0	901,926	901,926

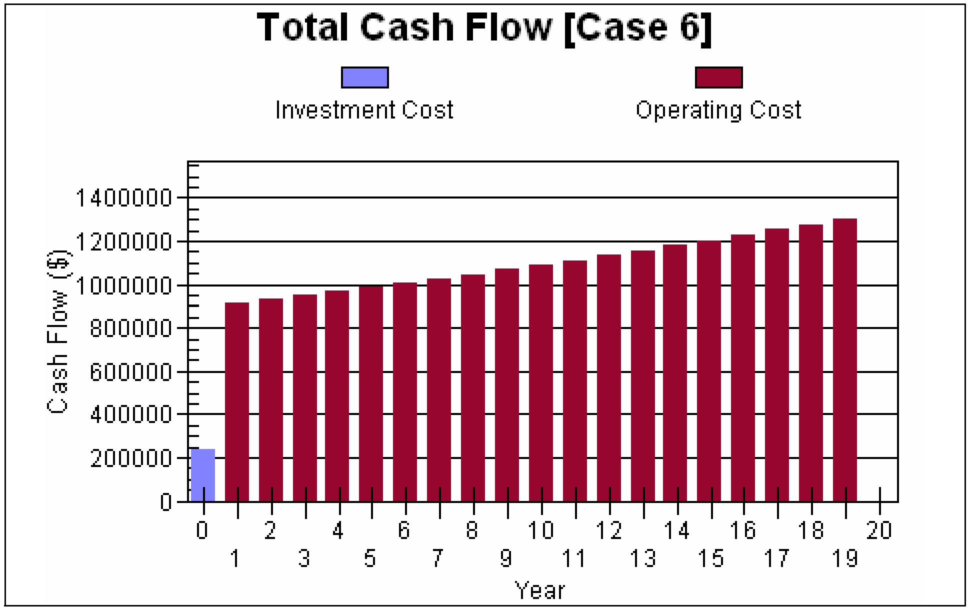
Cash Flow Details

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
15	15	0	0	0	0	919,964	0	919,964	919,964
16	16	0	0	0	0	938,364	0	938,364	938,364
17	17	0	0	0	0	957,131	0	957,131	957,131
18	18	0	0	0	0	976,273	0	976,273	976,273
19	19	0	0	0	0	995,799	0	995,799	995,799
20	20	0	0	0	0	0	0	0	0
Totals		233,897	0	0	233,897	15,924,848	0	15,924,848	16,158,745

3B. Present Worth Cash Flows [Case 7]

Year	Date	Total Investment Cost ($)	Total Operating Cost ($)	Total Present Worth ($)
0	Initial	233,897	0	233,897
1	1	0	633,834	633,834
2	2	0	587,737	587,737
3	3	0	544,993	544,993
4	4	0	505,357	505,357
5	5	0	468,604	468,604
6	6	0	434,524	434,524
7	7	0	402,922	402,922
8	8	0	373,618	373,618
9	9	0	346,446	346,446
10	10	0	321,250	321,250
11	11	0	297,886	297,886
12	12	0	276,222	276,222
13	13	0	256,133	256,133
14	14	0	237,505	237,505
15	15	0	220,232	220,232
16	16	0	204,215	204,215
17	17	0	189,363	189,363
18	18	0	175,591	175,591
19	19	0	162,821	162,821
20	20	0	0	0
Totals		233,897	6,639,253	6,873,150

Cash Flow Details



4A. Component Cash Flows [Case 6], Actual Value

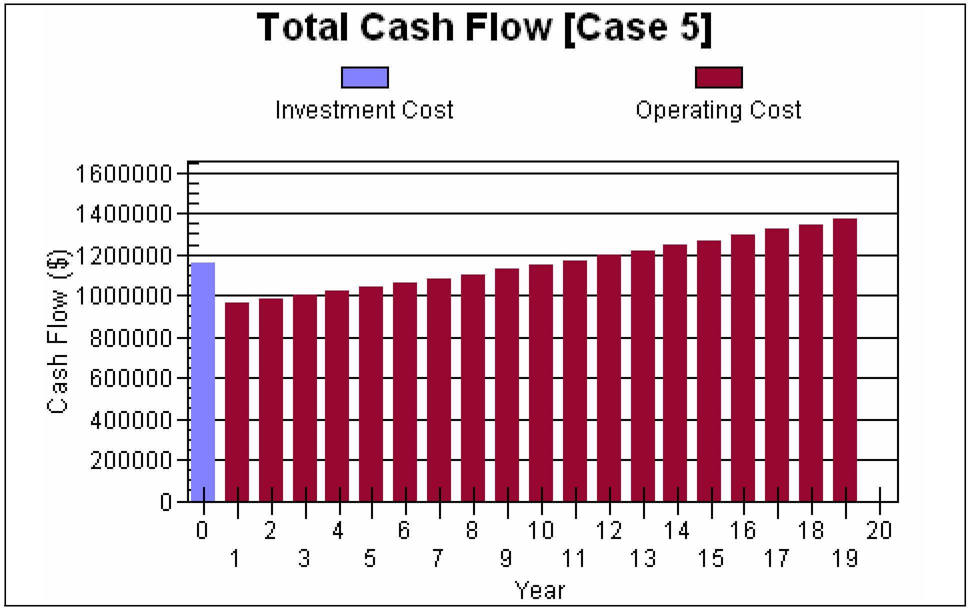
Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
0	Initial	243,156	0	0	243,156	0	0	0	243,156
1	1	0	0	0	0	918,542	0	918,542	918,542
2	2	0	0	0	0	936,912	0	936,912	936,912
3	3	0	0	0	0	955,651	0	955,651	955,651
4	4	0	0	0	0	974,764	0	974,764	974,764
5	5	0	0	0	0	994,259	0	994,259	994,259
6	6	0	0	0	0	1,014,144	0	1,014,144	1,014,144
7	7	0	0	0	0	1,034,427	0	1,034,427	1,034,427
8	8	0	0	0	0	1,055,116	0	1,055,116	1,055,116
9	9	0	0	0	0	1,076,218	0	1,076,218	1,076,218
10	10	0	0	0	0	1,097,742	0	1,097,742	1,097,742
11	11	0	0	0	0	1,119,697	0	1,119,697	1,119,697
12	12	0	0	0	0	1,142,091	0	1,142,091	1,142,091
13	13	0	0	0	0	1,164,933	0	1,164,933	1,164,933
14	14	0	0	0	0	1,188,232	0	1,188,232	1,188,232

Cash Flow Details

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
15	15	0	0	0	0	1,211,996	0	1,211,996	1,211,996
16	16	0	0	0	0	1,236,236	0	1,236,236	1,236,236
17	17	0	0	0	0	1,260,961	0	1,260,961	1,260,961
18	18	0	0	0	0	1,286,180	0	1,286,180	1,286,180
19	19	0	0	0	0	1,311,904	0	1,311,904	1,311,904
20	20	0	0	0	0	0	0	0	0
Totals		243,156	0	0	243,156	20,980,005	0	20,980,005	21,223,161

4B. Present Worth Cash Flows [Case 6]

Year	Date	Total Investment Cost ($)	Total Operating Cost ($)	Total Present Worth ($)
0	Initial	243,156	0	243,156
1	1	0	835,038	835,038
2	2	0	774,308	774,308
3	3	0	717,995	717,995
4	4	0	665,777	665,777
5	5	0	617,357	617,357
6	6	0	572,458	572,458
7	7	0	530,825	530,825
8	8	0	492,219	492,219
9	9	0	456,421	456,421
10	10	0	423,227	423,227
11	11	0	392,447	392,447
12	12	0	363,905	363,905
13	13	0	337,440	337,440
14	14	0	312,898	312,898
15	15	0	290,142	290,142
16	16	0	269,041	269,041
17	17	0	249,474	249,474
18	18	0	231,331	231,331
19	19	0	214,507	214,507
20	20	0	0	0
Totals		243,156	8,746,810	8,989,966



5A. Component Cash Flows [Case 5], Actual Value

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
0	Initial	1,169,756	0	0	1,169,756	0	0	0	1,169,756
1	1	0	0	0	0	969,445	0	969,445	969,445
2	2	0	0	0	0	988,834	0	988,834	988,834
3	3	0	0	0	0	1,008,610	0	1,008,610	1,008,610
4	4	0	0	0	0	1,028,782	0	1,028,782	1,028,782
5	5	0	0	0	0	1,049,358	0	1,049,358	1,049,358
6	6	0	0	0	0	1,070,345	0	1,070,345	1,070,345
7	7	0	0	0	0	1,091,752	0	1,091,752	1,091,752
8	8	0	0	0	0	1,113,587	0	1,113,587	1,113,587
9	9	0	0	0	0	1,135,859	0	1,135,859	1,135,859
10	10	0	0	0	0	1,158,576	0	1,158,576	1,158,576
11	11	0	0	0	0	1,181,748	0	1,181,748	1,181,748
12	12	0	0	0	0	1,205,383	0	1,205,383	1,205,383
13	13	0	0	0	0	1,229,490	0	1,229,490	1,229,490
14	14	0	0	0	0	1,254,080	0	1,254,080	1,254,080

Cash Flow Details

Year	Date	Cash Investment ($)	Loan Principal ($)	Loan Interest ($)	Total Investment Cost ($)	Annual Operating Cost ($)	Non-Annual Operating Cost ($)	Total Operating Cost ($)	Total Cash Flow ($)
15	15	0	0	0	0	1,279,162	0	1,279,162	1,279,162
16	16	0	0	0	0	1,304,745	0	1,304,745	1,304,745
17	17	0	0	0	0	1,330,840	0	1,330,840	1,330,840
18	18	0	0	0	0	1,357,457	0	1,357,457	1,357,457
19	19	0	0	0	0	1,384,606	0	1,384,606	1,384,606
20	20	0	0	0	0	0	0	0	0
Totals		1,169,756	0	0	1,169,756	22,142,659	0	22,142,659	23,312,415

5B. Present Worth Cash Flows [Case 5]

Year	Date	Total Investment Cost ($)	Total Operating Cost ($)	Total Present Worth ($)
0	Initial	1,169,756	0	1,169,756
1	1	0	881,313	881,313
2	2	0	817,218	817,218
3	3	0	757,784	757,784
4	4	0	702,672	702,672
5	5	0	651,569	651,569
6	6	0	604,182	604,182
7	7	0	560,242	560,242
8	8	0	519,497	519,497
9	9	0	481,715	481,715
10	10	0	446,681	446,681
11	11	0	414,195	414,195
12	12	0	384,072	384,072
13	13	0	356,140	356,140
14	14	0	330,238	330,238
15	15	0	306,221	306,221
16	16	0	283,951	283,951
17	17	0	263,300	263,300
18	18	0	244,151	244,151
19	19	0	226,394	226,394
20	20	0	0	0
Totals		1,169,756	9,231,535	10,401,291