# ARMY ADMINISTRATION FACILITY

Mid-Atlantic, USA

# Final Thesis Report

## Investigation of Alternate Systems

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Mechanical Option

Advisor: Dr. Stephen Treado

Date: April 4, 2012

# ARMY ADMINISTRATION FACILITY

Mid-Atlantic, USA

Alexander Quercetti | Mechanical

## Project Team

*Architects*:
Perkins + Will & BCRA
*Construction Manager*:
Suffolk Construction Co.
*Landscape Architects*:
Studio 39
*MEP & Fire Protection*:
Southland Industries
*Structural Engineer*:
ODEH
*Electrical Engineer*:
M.C. Dean
*Civil Engineer*:
VHB

## Building Statistics

*Size*:
97,000 Square Feet
*Project Cost*:
30 Million Dollars
*Levels*:
4 Above Ground
*Construction Dates*:
Sept. 2010-Sept. 2011
*Delivery Method*:
Design-Build
*Sustainability:*
LEED Silver Certified

## Architecture

*Purpose:* Command Headquarters for the U.S. Army housing approximately 400 personnel.
*Includes*: Administrative space, an emergency operations center, a data processing center, executive office suites, a sensitive compartmented information facility, adjoining courtroom, separate above grade parking garage.
*Features*: Prefabricated brick on metal stud facade. Glazing with aluminum panels. "Invisible" penthouse behind fourth floor facade.

## Mechanical

*Ventilation*:
-Fan Powered Induction Units
-Variable Air Volume Units
-100% Dedicated Outdoor Air System
*Cold Water System*:
-315 Ton Evaporative Condensing Chiller
*Hot Water System*:
-2 Gas-Fired 1,275 MBH Boilers

## Electrical

480/277V Building Utilization Voltage.
150kVA UPS (15 minute backup capability) for all critical loads such as: Secure Networking and IT storage.
Emergency lighting powered by individual batteries
Occupancy Sensors in most spaces.
All luminaires utlize fluorescent sources.

## Structural

*Foundation:* Concrete spread footings with 4 in. slab-on-grade. Load bearing masonry foundation walls.
*Administration:* 10-1/2 in. reinforced concrete slabs with 24x32 in. concrete columns.
*Courthouse:* Steel trusses supported by wide flange girders connected to hollow structural steel columns.

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## Executive Summary

The Army Administration Facility is a new government office building located in the heart of the mid-Atlantic region, serving as a Command Headquarters for the U.S. Army. The 97,000 square foot facility will house approximately 400 personnel of the U.S. Army Legal Service Agency (USALSA) and JAG Corps. The purpose of this report is to analyze alternative solutions to the mechanical systems in the Army Administration Facility to assess possible benefits in first or annual utility costs, efficiencies, or energy consumption. Additional investigations into two non-mechanical breadth topics were also conducted. A Trane TRACE™ 700 Version 6.2 model was used to perform the energy load analysis and energy consumption per the actual design values provided in the design documents submitted by the mechanical engineers at Southland Industries. The model constructed of the existing systems was then used as a means of comparison for the mechanical redesigns.

The alternative topics of study in this report include installing a geothermal heat pump to handle the heating and cooling loads. The heating coils used throughout the Army Administration Facility are supplied by (2) gas-fired boilers and the cooling coils are fed by an evaporative condensing chiller. The replacement of the heating and cooling sources with a geothermal system decreased the annual energy usage by 4% but increased the annual utility costs by 5% due to the additional costs of electricity over natural gas. With an added initial investment of $41,170 to install the system, a ground-source heat pump system would not be recommended for this facility.

An alternative depth study was also analyzed to test the benefits provided by a chilled water thermal storage system. In conjunction with the evaporative condensing chiller, a thermal storage system could be implemented to utilize a chiller that creates and stores chilled water in a storage tank during cheaper off-peak hours to be used during peak loads. Both partial and full storage cycles were analyzed and concluded that partial storage would provide the most benefits saving 672,055 kBtu/yr and thus roughly $50,000 annually over the existing system. With an initial investment of $466,093, the partial storage system can expect to see a payback after 7 years. The full storage system saved 259,474 kBtu/yr and $39,263 annually over the existing system. With an initial investment of $527,693, the full storage system would expect to see a payback after 10 years.

Among the geothermal system, full storage and partial storage thermal storage systems, the partial storage yielded the most economical results and would be a valuable alternative.

The two breadths evaluated in this report include an acoustical and an architectural analysis. For the acoustical breadth, sound attenuation calculations through the wall between the penthouse and the adjacent offices were performed and determined that the noise criterions in the occupied spaces are acceptable per industry standards. However, if there was a desire for lower sound levels, the use of Green Glue or moving the penthouse to the roof are viable options. For the architectural breadth, the penthouse was moved to the fourth floor roof and the area where the penthouse was located was enclosed, gaining 2,700 SF of occupiable space. The ceiling heights were also raised to allow for more plenum space and a screening device was designed to hide the now visible penthouse. The stratified thermal storage tank was incorporated into the parking garage and is now an architectural feature.

# 1.0 Building Overview

Located in the heart of the mid-Atlantic region, the Army Administration Facility is a government administration building serving as a Command Headquarters for the U.S. Army. The 97,000 square foot facility will house approximately 400 personnel of the U.S. Army Legal Service Agency (USALSA) and JAG Corps. The building's four stories include administrative space, an emergency operations center, a data processing center, executive office suites, a sensitive compartmented information facility, and an adjoining courtroom, as well as a separate above grade parking garage.

The project is actually comprised of two buildings. One, a 20 million dollar, 89,000 SF building for the Office of the Chief, Army Reserve (OCAR) and the second, a 30 million dollar, 97,000 SF general administration facility for USALSA. Both buildings have their own separate above ground parking structures. This project will focus specifically on the second building for USALSA. The contract was awarded in September 2010 and its expected completion was planned for September 11, 2011 to commemorate the ten year anniversary of 9/11. With only one year to design and construct the facility, the project was considered fast tracked and needed to be design-build to keep on schedule.

An interesting feature to the building is the attached courtroom. The facility houses what could be considered the equivalent to the Supreme Court for the Army, so the majority of the main building contains legal offices. With information sensitive spaces, the building's private offices and conference rooms require floor to ceiling walls to minimize sound dispersion. The end user also requested more thermostatic control, so an RFP was written that specified that a *maximum* of three rooms can be conditioned by any one unit. Since each room is a small enclosed office, this allowed for creative designs of the mechanical systems.

The Army Administration Facility is composed mainly of a prefabricated brick and concrete masonry unit façade. The attached courtroom and adjoining spaces are also prefabricated brick and CMU, with a large percentage of double-paned glazing framed by aluminum panels. The penthouse posed some particular problems; in accordance with height restrictions, the penthouse was placed in a "well" on the fourth floor of the building. This means that a portion of the floor space on the fourth floor was designated for the penthouse, but the façade continues around the building, camouflaging the rooftop units. Only a small area was designated for the penthouse, so it needed to be specially designed as compact as possible.

The roof at this facility is composed of a reflective white roof membrane, adding to the sustainability of the facility. The building was designed and built to achieve LEED Silver certification. Such features lending to the sustainability of the design include a reflective white roof membrane, a continuous air barrier at all exterior wall assemblies to prevent infiltration and exfiltration, lowering energy consumption, and increased U-values of roof, walls, and windows past the ASHRAE 90.1 baseline minimums.

# 2.0 ASHRAE Standards and LEED Evaluation

## 2.1 ASHRAE Standard 62.1 (2007) Analysis

### *Section 5- Systems and Equipment*

***Section 5.1*** *Natural Ventilation*

This facility is engineered to meet the minimum ventilation requirements through the use of the mechanical systems. Natural ventilation is not a method used in this building.

***Section 5.2*** *Ventilation Air Distribution*

Each FPIU has an ECM that can adjust the amount of air supplied to each space. They will be correctly balanced to meet the ventilation requirements specified in Section 6 (discussed later in this report). Also, each FPIU can adjust the amount of outside air it receives from the DOAU in the penthouse by trending zone conditions and outdoor air rates.

***Section 5.3*** *Exhaust Duct Location*

The exhaust ducts in this building that convey potentially harmful contaminants are in the toilet areas. These ducts have roof mounted exhaust fans that create a negative pressure inside the ducts and will be calibrated to do so.

***Section 5.4*** *Ventilation System Controls*

Each FPIU and VAV shall be equipped with a factory-mounted stand-alone DDC controller and actuators compatible with building Energy Management and Control System (EMCS). Both the FPIUs and VAVs allow a reduction in airflow when their spaces are unoccupied and have been specified to do so. They have been calibrated with a minimum airflow no less than those specified in Section 6.

***Section 5.5*** *Airstream Surfaces*

Materials used for internal insulation exposed to the air stream in ducts shall be as specified in Section 23 3113 and in accordance with UL 181 or ASTM C 1071 erosion tests. Air-side facing shall not promote or support the growth of fungi or bacteria, in accordance with UL 181 and ASTM G21 and G22.

***Section 5.6*** *Outdoor Air Intakes*

All outdoor air intake locations comply with Table 5-1 in Standard 62.1 (*Table 1* of this report). The exhaust fans are located at a distance greater than 15 feet from the integral packaged equipment center intake. The DOAU intake is located in the penthouse, far enough away from any ground source contaminants. Outside air louvers shall be of a stormproof design and provided with a ½-inch by ½-inch galvanized bird screen. A full-size hood shall be provided for further protection from rain and snow entrainment.

Table 1- Air Intake Minimum Separation Distance

| Object | Minimum Distance, ft (m) |
|---|---|
| Significantly contaminated exhaust (Note 1) | 15 (5) |
| Noxious or dangerous exhaust (Notes 2 and 3) | 30 (10) |
| Vents, chimneys, and flues from combustion appliances and equipment (Note 4) | 15 (5) |
| Garage entry, automobile loading area, or drive-in queue (Note 5) | 15 (5) |
| Truck loading area or dock, bus parking/idling area (Note 5) | 25 (7.5) |
| Driveway, street, or parking place (Note 5) | 5 (1.5) |
| Thoroughfare with high traffic volume | 25 (7.5) |
| Roof, landscaped grade, or other surface directly below intake (Notes 6 and 7) | 1 (0.30) |
| Garbage storage/pick-up area, dumpsters | 15 (5) |
| Cooling tower intake or basin | 15 (5) |
| Cooling tower exhaust | 25 (7.5) |

Note 1: Significantly contaminated exhaust is exhaust air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor.
Note 2: Laboratory fume hood exhaust air outlets shall be in compliance with NFPA 45-1991[3] and ANSI/AIHA Z9.5-1992.[4]
Note 3: Noxious or dangerous exhaust is exhaust air with highly objectionable fumes or gases and/or exhaust air with potentially dangerous particles, bioaerosols, or gases at concentrations high enough to be considered harmful. Information on separation criteria for industrial environments can be found in the ACGIH Industrial Ventilation Manual[5] and in the *ASHRAE Handbook—HVAC Applications*.[6]
Note 4: Shorter separation distances are permitted when determined in accordance with (a) Chapter 7 of ANSI Z223.1/NFPA 54-2002[7] for fuel gas burning appliances and equipment, (b) Chapter 6 of NFPA 31-2001[8] for oil burning appliances and equipment, or (c) Chapter 7 of NFPA 211-2003[9] for other combustion appliances and equipment.
Note 5: Distance measured to closest place that vehicle exhaust is likely to be located.
Note 6: No minimum separation distance applies to surfaces that are sloped more than 45 degrees from horizontal or that are less than 1 in. (3 cm) wide.
Note 7: Where snow accumulation is expected, distance listed shall be increased by the expected average snow depth.

***Section 5.7*** *Local Capture of Contaminants*

Building exhaust ducts are vented via exhaust fans mounted on the roof and exhaust exclusively to the outdoors. Exhaust fans or ducts are equipped with backdraft dampers nearest to outside to prevent contaminant re-entry.

***Section 5.8*** *Combustion Air*

Fuel-burning appliances, such as the gas-fired boilers, are supplied with adequate air for combustion and follow combustion product removal guidelines specified by the manufacturer. All fuel-burning equipment is located in the penthouse and has direct ventilation to the outdoors.

***Section 5.9*** *Particulate Matter Removal*

In the DOAS unit, filters shall be front loaded MERV 13, in accordance with ASHRAE Test Standard 51.1-92, 4-inch pleated media type with 2-inch pleated MERV 8 pre-filters.
Each Air Terminal Unit (FPIUs and VAVs) will be supplied with 1-inch thick, minimum MERV 6, pleated disposable media, in filter rack at inlet to coil section.

***Section 5.10*** *Dehumidification Systems*

Air Terminal and DOAU Units were designed using 50% relative humidity (RH). In spaces with higher occupancies and thus a great latent heat gain, VAVs were used, rather than FPIUs, to accommodate the necessary moisture removal.
The minimum outdoor air intake is designed to be 24,000 CFM, while the building's two exhaust fans only move 8,850 CFM total. Therefore, the facility meets the exfiltration requirements set forth in Standard 62.1.

***Section 5.11*** *Drain Pans*

All drain pans shall be fabricated of 14-gauge 304 stainless steel and sloped for positive drainage of condensate.

A 1-1/4-inch diameter condensate drain connection shall be provided on one side of the unit for slab coils and on both sides of the unit for V-bank coils and shall be field trapped by others.

Condensate drain pans shall be connected using full size piping with P-trap. P-trap outlet will extend to nearest equipment or floor or hub drain or to roof. Deep seal P-trap shall be constructed as detailed on drawings at connection to drain pan and cleanouts will be installed at changes in direction, if required.

***Section 5.12*** *Finned-Tube Coils and Heat Exchangers*

The chilled water coil shall be provided with a drain pan which shall be fabricated of 14-gauge, 304 stainless steel and sloped for positive drainage of condensate.

The water heaters and heat exchangers will be using non-finned coils, so this section does not apply: The 1¼" (32mm) diameter internal tubular heat exchanger shall be designed with a large surface coil area in the lower portion of the tank to allow rapid and uniform heating of the water in the tank with a low pressure drop through the heat exchanger coil. The coil shall be designed so as to be both self-draining and self-venting, be *non-finned* with space between passes, and be tapered to allow full output from all passes of the coil.

***Section 5.13*** *Humidifiers and Water-Spray Systems*

No specification has been stated regarding humidifiers or water-spray systems so it may be assumed that this building does not use either. However, for the water used in any of the HVAC equipment, an analysis of supply water shall be performed to determine the type and quantities of chemical treatment needed to maintain the water quality as specified in "Performance Requirements" Article.

***Section 5.14*** *Access for Inspection, Cleaning, and Maintenance*

All ventilation and air-distribution equipment have been installed with clearances that allow proper access for inspection and maintenance. The penthouse, specifically, was prefabricated by Mammoth and designed by the manufacturer to allow sufficient clearances.

A full-size hinged access door shall be provided for any section requiring service access. Removable casing panels shall not be allowed. Access doors shall be thermally broken and be complete with stainless steel hinges and multiple-point, single-handle compression-type latches to provide quick access and a positive air seal. Service vestibule areas shall have minimum of (2) 24-by-24-inch service access hatches in the floor. Access panels will be located on the bottoms of terminal units for ease of access.

***Section 5.15*** *Building Envelope and Interior Surfaces*

The building includes a reflective, thermoplastic polyolefin (TPO) white roof membrane to act as a weather barrier to prevent moisture penetration into the envelope.

A continuous insulated thermal barrier will be installed to insulate the membrane roofing system. The thickness of insulation required to achieve a minimum effective thermal R-value of 30; U value of 0.05 will be used. Additional insulation thickness will be provided to compensate for losses in insulation value due to supports, configuration, gaps and tolerances within roof assemblies.

The building envelope shall include an air barrier capable of performing as a continuous vapor-retarding air barrier and as a liquid-water drainage plane flashed to discharge to the exterior incidental condensation or water penetration.

Any exterior joints, seams, or penetrations in the building envelope shall be sealed using joint sealants appropriate for size, depth, location, and fire rating (if any) of joint.

All cold water pipes and supply air and outside air duct insulation shall have a vapor barrier jacket. The vapor barrier jacket shall cover the system with a continuous, unbroken vapor seal.

***Section 5.16*** *Buildings with Attached Parking Garages*
This building does have a parking garage, however it is not attached. This section therefore does not apply.

***Section 5.17*** *Air Classification and Recirculation*
This facility does not contain any of the spaces specified in Table 5-2 in Standard 62.1. The majority of the building's air is classified as Class 1, and this air is recirculated through the plenum spaces directly into the terminal units. The Class 2 air found in the toilets and janitor's closets have their own specialized exhaust systems that ventilate the air directly to the outdoors via the roof.

***Section 5.18*** *Requirements for Buildings Containing ETS Areas and ETS-Free Areas*
The building is expecting a LEED certification; therefore the facility includes Environmental Tobacco Smoke (ETS) Control to satisfy a LEED prerequisite and satisfies all requirements for this section.

## Section 6- Procedures

The requirements set forth in Section 6 of ASHRAE Standard 62.1 are required for all buildings without natural ventilation systems. This building utilizes a Dedicated Outdoor Air System.

***Section 6.2*** *Ventilation Rate Procedure*
The following equations can be found in ASHRAE Standard 62.1 and will be necessary for ventilation analysis:

*Breathing Zone Outdoor Airflow ($V_{bz}$)*

$$V_{bz} = R_p * P_z + R_a * A_z \quad \text{(Eq. 6-1)}$$

*where,*
$A_z$ = *zone floor area*: the net occupiable floor area of the zone $m^2$ ($ft^2$)
$P_z$ = *zone population*: the largest number of people expected to occupy the zone during typical usage.
$R_p$ = outdoor airflow rate required per person as determined from Table 6-1 in ASHRAE Standard 62.1.
$R_a$ = outdoor airflow rate required per unit area as determined from Table 6-1 in ASHRAE Standard 62.1.

*Zone Outdoor Airflow ($V_{oz}$)*

$$V_{oz} = V_{bz} / E_z \quad \text{(Eq. 6-2)}$$

*where,*
$E_z$ = *zone air distribution effectiveness*: Ez=1 as determined by Table 6-2 in ASHRAE Standard 62.1.

*Outdoor Air Intake Flow ($V_{ot}$) for 100% Outdoor Air Systems*

$$V_{ot} = \sum_{all\ zones} V_{oz}$$ (Eq. 6-4)

*Primary Outdoor Air Fraction ($Z_p$)*

$$Z_p = V_{oz} / V_{pz}$$ (Eq. 6-5)

*where,*

$V_{pz}$ is the zone primary airflow from the air handler including outdoor air and recirculated return air.

*Note:* For the spaces where the expected zone population was known, the actual values were used rather than those given in ASHRAE Standard 62.1 Table 6-1.

For this system, there is a single DOAS unit that serves the entire building. Each FPIU receives a certain amount of outdoor air from the DOAS unit and the rooms each FPIU serve each get a proportion of that outside air. The results of each room's compliance with proper ventilation standards can be found in *Appendix A* of this report.

*Exhaust Ventilation*

Exhaust airflow shall be provided in accordance with the requirements in Table 6-4 in Standard 62.1. For this building, the toilets require a minimum of 70 CFM per water closet and/or urinal during periods of heavy use and janitor's closets require 1 CFM/ft$^2$. *Table 2* below shows that the Army Administration Facility meets the exhaust airflow requirements set forth in Section 6 of ASHRAE Standard 62.1.

**Table 2- Exhaust Airflow Analysis**

| Exhaust Fan | # Units | CFM/Unit | Janitor [SF] | CFM/SF | Standard 62.1 Min Airflow [CFM] | Design Min Airflow [CFM] | Compliance |
|---|---|---|---|---|---|---|---|
| EF-1 | 40 | 70 | 164 | 1 | 2964 | 4260 | Y |
| EF-2 | 1 | 70 | 0 | 1 | 70 | 100 | Y |

## *2.2 ASHRAE Standard 62.1 (2007) Summary*

All systems and equipment used for the Army Administration Facility comply with the requirements set forth in Section 5 of ASHRAE Standard 62.1, where applicable.

The minimum ventilation requirements set forth in Section 6 of ASHRAE Standard 62.1 have been met in all occupied spaces. As can be seen in *Appendix A*, the only spaces where the ventilation rates were not up to standard were storage rooms or hallways. The hall calculations could be flawed since the halls are open to other spaces and hallways and in reality share a proportion of the outside air. For the storage rooms, there could be a stipulation allowing less than the required ventilation rate since these room types are for the most part unoccupied spaces.

## 2.2 ASHRAE Standard 90.1 (2007) Analysis

### *Section 5- Building Envelope*

***Section 5.1** General*

The Army Administration Facility is located in a 4A climate zone as determined by Table B-1 in Appendix B of Standard 90.1 and *Figure 1* below. A 4A climate zone is characterized by mixed weather and humidity. The exact location of the building is being withheld per the building owner's request.

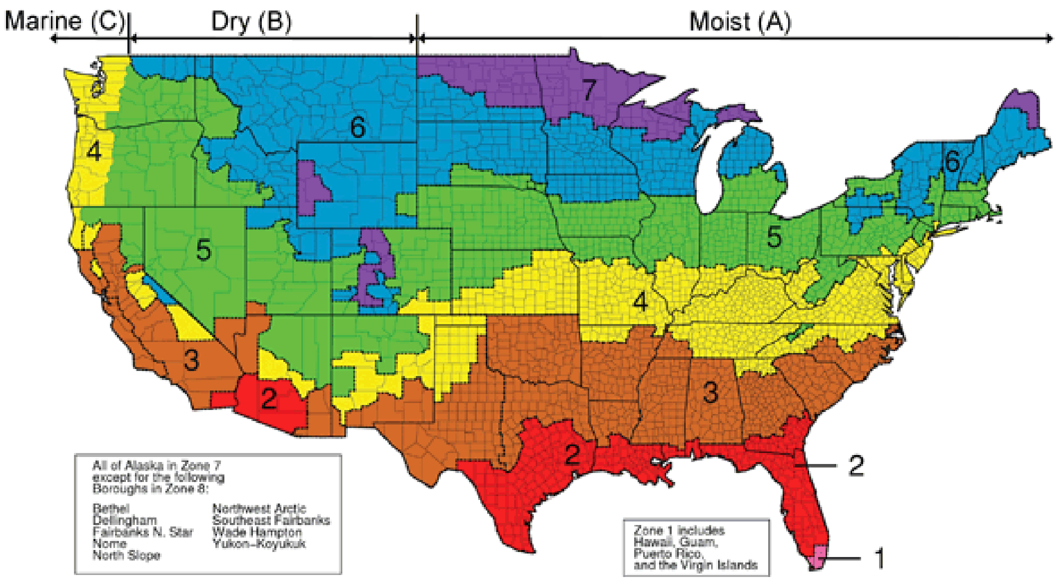



**Figure 1- ASHRAE 90.1 (2007) Climate Zone Map**

***Section 5.2** Compliance Paths*

There is no skylight fenestration in this building and the vertical fenestration area is approximately 26%, less than the 40% specified in this section as seen in *Table 3* below. Therefore, the Prescriptive Building Envelope Option will be used.

***Section 5.4** Mandatory Provisions*

The fenestration products shall be determined by an accredited laboratory and labeled correctly.
Fenestration Standard: Comply with ANSI/AAMA/WDMA 101/I.S.2/NAFS-02, "North American Fenestration Standard Voluntary Performance Specification for Windows, Skylights and Glass Doors," for definitions and minimum standards of performance, materials, components, accessories, and fabrication. Comply with more stringent requirements if indicated.
The building envelope shall be sealed and weather-stripped to minimize air leakage. Type H: Low-Expansion Detailing Foam Insulation: Two-component urethane foam with low-expansion pressure, 10 percent flexibility, and 1.75 to 2.0 lb/cu. ft. density, suitable for filling gaps and voids adjacent to doors, fenestration, and louvers.
Glazed aluminum curtain walls and glazing shall have certified and labeled energy performance ratings in accordance with NFRC 100. Glazed swinging entrance doors will not exceed an air leakage of 1.0 cfm/ft$^2$.
There are three entrance vestibules in this building, all exceeding 7' door to door.

***Section 5.5*** *Prescriptive Building Envelope Option*

In order to use the prescriptive building envelope method, the building's vertical fenestration must not exceed 40% of the gross wall area. This was accomplished in this building as seen in *Table 3.*

**Table 3- Vertical Fenestration Area**

| Total Wall Area [$ft^2$] | Total Glazing Area [$ft^2$] | Fenestration [%] | ASHRAE Standard 90.1 Compliance |
|---|---|---|---|
| 38,548 | 9713.3 | 25.2% | Y |

For a breakdown of each individual space's fenestration percentage, reference *Appendix B*.

The Army Administration Facility is a *nonresidential* building in a 4A climate zone. Therefore, Table 5.5-4 in ASHRAE Standard 90.1 will be used to find appropriate U-values, R-values, C-values, F-values, and SHGC. *Table 4* summarizes the building's material properties and compares them to those in Standard 90.1.

**Table 4- Building Material Compliance**

| Opaque Element | Construction | Required- Nonresidential | | Design- Nonresidential | | Standard 90.1 Compliance |
|---|---|---|---|---|---|---|
| | | Assembly Maximum | Insulation Min. R-Value | Assembly Maximum | Insulation Minimum | |
| Roof | Insulation Entirely above Deck | U-0.048 | R-20.0 c.i. | U-0.0333 | R-30 c.i. | Y |
| Walls, Above-Grade | Mass | U-0.104 | R-9.5 c.i. | U-0.0427 | R-23.4 c.i. | Y |
| Walls, Below-Grade | Below-Grade Wall | C-1.140 | NR | Unknown | - | - |
| Floors | Mass | U-0.087 | R-8.3 c.i. | U-0.0427 | R-23.4 C.I. | Y |
| Slab-On-Grade Floors | Unheated | F-0.730 | NR | Unknown | - | - |
| **Fenestration** | **Construction** | **Required- Nonresidential** | | **Design- Nonresidential** | | **Standard 90.1 Compliance** |
| | | Assembly Max. U | Assembly Max. SHGC | Assembly Max. U | Assembly Max. SHGC | |
| Vertical Glazing, *0-40% of Wall* | Metal Framing, curtainwall | U-0.50 | SHGC-0.40 | U-0.40 | SHGC-0.28 | Y |
| Vertical Glazing, *0-40% of Wall* | Metal Framing, other | U-0.55 | SHGC-0.40 | U-0.40 | SHGC-0.28 | Y |

As is shown by the table, the values that could be found in the design documents are compliant with ASHRAE Standard 90.1.

## *Section 6- Heating, Ventilating, and Air Conditioning*

***Section 6.2*** *Compliance Paths*

ASHRAE Standard 90.1 offers two methods to evaluate equipment efficiency, the Simplified Approach Option for HVAC Systems and Mandatory Provisions with Prescriptive Path. The Simplified Approach Option for HVAC Systems would not be an option since this building is taller than two stories and larger than 25,000 $ft^2$. Therefore, the Mandatory Provisions and Prescriptive Path method will be used.

***Section 6.3*** *Simplified Approach Option for HVAC Systems*
This section does not apply to this building for the reasons mentioned in *Section 6.2*.

***Section 6.4*** *Mandatory Provisions*

*Section 6.4.1 Equipment Efficiencies, Verification, and Labeling Requirements*
This section of Standard 90.1 sets standards for equipment efficiencies that must be met. The equipment found in this building that is relevant to these standards include an evaporative condensing chiller, packaged terminal air conditioners (FPIUs and VAVs), hot water boilers, and an air-cooled condensing unit. Since this facility is a government building, it must comply with The Energy Policy ACT of 2005 (EPACT). EPACT 2005 requires all new federal buildings to meet or exceed ASHRAE Standard 90.1 by 30%. This 30% reduction is based on total building site energy use, excluding plug loads. The only equipment where efficiencies could be found in the construction documents was the gas-fired boilers. *Table 5* summarizes the design efficiencies of the boilers and compares them to the minimum required efficiencies found in Tables 6.8.1A through 6.8.1G in Standard 90.1. Any other equipment used in the building that is not found in these tables are acceptable to use.

**Table 5- Equipment Efficiencies**

| Equipment | Type | Size Category | Minimum Efficiency | Design Efficiency | Standard 90.1 Compliance |
|---|---|---|---|---|---|
| (2) Boilers, hot water | Gas-fired | ≥300,000 Btu/h and ≤2,500,000 Btu/h | 80% | 85% | Y |

As is shown by *Table 5*, the boilers were designed with an 85% efficiency each, over the requirement set by the standard.

For quality assurance, as specified by the building documents, all mechanical and electrical components, devices, and accessories shall be clearly labeled. Nameplates must be metal or plastic laminated, with data engraved or stamped, for permanent attachment on equipment.

*Section 6.4.2 Load Calculations*
All equipment was sized using modern, generally accepted engineering standards and handbooks including IMC 2006 and ASHRAE Standards 2007.

*Section 6.4.3 Controls*
Each space in the Army Administration Facility is conditioned by either a VAV or FPIU terminal unit. These units are controlled via zone thermostats. Per the owner's request, a desire for more occupant thermal control led designers to condition a maximum of three office spaces per terminal unit. Occupied mode comfort settings include a space temperature high limit set point value of 75 °F (adjustable), a space temperature low limit set point value 70 °F (adjustable), and the space dew point temperature is at or below the sensible (55F) chilled water supply temperature.
Unoccupied Mode Comfort Settings include a space temperature high limit set point value of 80 °F (adjustable), a space temperature low limit set point value of 65 °F (adjustable), and the space dew point temperature is at or below the sensible (55F) chilled water supply temperature. Both space temperature set-points have a 2 degree dead band to prevent unnecessary fan cycling.

The boilers are designed to continually establish and maintain 180°F at temperature sensor TE-HWSS located in the main Secondary Hot Water distribution supply piping and to also simultaneously maintain a minimum of 150°F at temperature sensor TE-HWRP, located in the main Primary Hot Water circulation return piping header, at all times. To support the 24/7 spaces within the building that require heating hot water and domestic hot water, the heating hot water system is expected to operate continuously once enabled by the BAS. An alarm will trip is sensor are more than 5°F (adjustable) outside tolerance. The DOAS unit heating coils will be activated when the OSA temperature is below 46°F as measured at temperature sensor TT-OSA, to maintain a leaving air temperature set-point of 48°F as sensed at temperature sensor TE-PH. When the OSA temperature dew point or dry bulb temperature is greater than 58°F (AHCM adjustable), the cooling coil control valve DOA-PCC will modulate to maintain a leaving supply air temperature of 58°F (AHCM adjustable) as sensed at temperature sensor TT-TCC.

Elevator and stair vents shall be equipped with motorized dampers for pressurization and pressure relief as required by fire and smoke detection systems.
Outdoor air supply ducts in the DOAU shall be equipped with motorized dampers that will automatically close when the spaces served are not in use.

Damper leakage rate shall not exceed 3 cfm/sq. ft. at 1 inch wg. This is less than the prescribed 10 cfm/sq. ft. at 1 inch wg specified in Table 6.4.3.4.4 of Standard 90.1.

The building utilizes a DDC system, so any system shutdowns or humidification controls will operate as specified by the software programming.

There is no space in this facility larger than 500 sq. ft. with occupancy greater than 40 people per 1000 sq. ft., so subsection 6.4.3.9 is not pertinent.

*Section 6.4.4 HVAC System Construction and Insulation*

The building envelope shall include an air barrier capable of performing as a continuous vapor-retarding air barrier and as a liquid-water drainage plane flashed to discharge to the exterior incidental condensation or water penetration. All cold water pipes and supply air and outside air duct insulation shall have a vapor barrier jacket. The vapor barrier jacket shall cover the system with a continuous, unbroken vapor seal.

Pipe Insulation shall comply with ASTM C 552, Type II, and Class 2. *Table 6* shows that the installed pipe insulation thicknesses comply with ASHRAE 90.1 standards.

**Table 6- Minimum Pipe Insulation Thickness**

| Fluid Design Operating Temp. Range (F) | Insulation Conductivity | | Nom. Pipe Size (in.) | Minimum Pipe Insulation Thickness (in.) | Design Pipe Insulation Thickness (in.) | Standard 90.1 Compliance |
|---|---|---|---|---|---|---|
| | Conductivity Btu-in./(h-ft2-F) | Mean Rating Temp. F | | | | |
| Heating Systems | | | | | | |
| 141-200 (180F) | 0.25-0.29 | 125 | 1-1/2 to < 4 | 1.0 | 1.0 | Y |
| | | | | | | |
| Cooling Systems | | | | | | |
| 40-60 (55F) | 0.22-0.28 | 100 | 1-1/2 to < 4 | 1.0 | 1.0 | Y |

All duct insulation, where applicable, shall comply with the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), which also meets the standards set forth in ASHRAE Standard 90.1.

***Section 6.5*** *Prescriptive Path*

*Section 6.5.1 Economizers*

This section discusses requirements for including an economizer. However, according to Table 6.5.1 found in ASHRAE Standard 90.1, climate zone 4A has no economizer requirement.

*Section 6.5.2 Simultaneous Heating and Cooling Limitation*

Each FPIU takes in return air directly from the plenum space rather than exhaust duct circulating the air back through an air handling unit. An FPIU has its own sensible chilled water cooling coil that modulates to space conditions and can operate independently from the main air handler for sensible loads. The volume of outdoor air supplied to these spaces has complied with ASHRAE Standard 62.1 Section 6.2.

The hot water loop is maintained with a dead band around 30°F. The supply water temperature to the building is set for 180°F and the return is programmed for 150F.
The chilled water loop utilizes an evaporative condensing chiller to maintain a temperature dead band around 12°F (55°F chilled water supply and 67°F chilled water return). The DOAS unit has an air cooled condensing unit to regulate the chilled water supplied to the DOAS.

Air is conditioned inside each terminal unit via a heating or cooling coil. However, the DOAS unit also has heating and cooling coils that will condition and dehumidify the outside air before it is circulated throughout the building. Therefore, the dehumidification section is not relevant.

*Section 6.5.3 Air System Design and Control*

Each HVAC system having a total fan system motor nameplate hp exceeding 5 hp shall meet the requirements addressed in section 6.5.3.1. *Table 7* shows the results of the fan analysis. All fans are included, whether or not they exceeded 5 hp. The only equipment over 5 hp that does not comply with Standard 90.1 is the DOAS (DOAU-1) unit.

**Table 7- Fan Power Limitation**

| Fan System Motor Nameplate hp | | | | |
|---|---|---|---|---|
| Unit | Allowable Nameplate Motor hp | Constant Volume | | Standard 90.1 Compliance |
| | | CFM | CFM x 0.0011 | |
| DOAU-1 Supply | 6.5 | 4,000 | 4.40 | N |
| EF-RP | 0.5 | 2050 | 2.26 | Y |
| EF-1 | 3 | 4260 | 4.69 | Y |
| EF-2 | 0.17 | 100 | 0.11 | N |
| FPIU-1 | 0.5 | 800 | 0.88 | Y |
| FPIU-2 | 0.5 | 800 | 0.88 | Y |
| FPIU-3 | 0.75 | 1200 | 1.32 | Y |
| FPIU-4 | 0.75 | 1200 | 1.32 | Y |
| HFCU-1 | 0.33 | 670 | 0.74 | Y |
| VFCU-1 | 0.17 | 600 | 0.66 | Y |
| VFCU-2 | 0.25 | 730 | 0.80 | Y |
| VFCU-3 | 0.5 | 1600 | 1.76 | Y |
| VFCU-4 | 0.5 | 1200 | 1.32 | Y |

The VAVs are not fan controlled, so section 6.5.3.2 is not applicable.

*Section 6.5.4 Hydronic System Design and Control*

None of the pumps in the Army Administration Facility exceed 100 ft and have a motor exceeding 50 hp. The pumps that do exceed 10 hp allow for variable flow capable of reducing pump flow rates to 50% or less as can be seen in *Table 8.*

**Table 8- Pump Schedule**

| Unit | Service | Head | Motor Size (hp) | Flow (gpm) | Min. Flow (gpm) | Flow Reduction | Standard 90.1 Compliance |
|---|---|---|---|---|---|---|---|
| CHWP-1 | Chilled Water | 90 | 15 | 334 | 80 | 24% | Y |
| CHWP-2 | Chilled Water | 90 | 15 | 334 | 80 | 24% | Y |
| CHWP-3 | Chilled Water | 90 | 15 | 334 | 80 | 24% | Y |

*Section 6.5.5 Heat Rejection Equipment*

This facility utilizes an air cooled condensing unit for the DOAS trim coils and an evaporative condensing chiller. Neither unit, however, has a motor of 7.5 hp or larger. Therefore, this section is irrelevant.

***Section 6.7** Submittals*

A complete set of construction documents including drawings, performance data, sequence of operation and maintenance manuals has been given to the building owner upon project completion in September of 2011. The project is striving for LEED Silver certification, so every piece of equipment, including each terminal unit, will be commissioned by the project's mechanical engineers, Southland Industries, and overseen by a third party, to operate as designed.

## *Section 7- Service Water Heating*

The Army Administration Facility utilizes water heating equipment for both domestic potable water and conditioning applications. Relevant equipment includes (2) gas-fired hot water boilers and an electric wall heater. *Table 9* summarizes the compliance of this equipment to ASHRAE Standard 90.1 Section 7.

**Table 9- Service Water Heater Efficiencies**

| Unit | Type | Size Category | Subcategory | Performance Required | Design Performance | Standard 90.1 Compliance |
|---|---|---|---|---|---|---|
| EWH-1 | Electric | ≤12 kW (4 kW) | Resistance ≥20 gal | 80% | 100% | Y |
| BLR-1 | Hot-water, gas | - | ≥4000 (Btu/h)/gal and ≥10 gal | 80% | 85% | Y |
| BLR-2 | Hot-water, gas | - | ≥4000 (Btu/h)/gal and ≥10 gal | 80% | 85% | Y |

EWH-1 is classified as an electric wall heater, but it is actually a solar hot water heater, with all of its input a direct source from solar gain. This unit is the primary source of the domestic hot water and thus can be seen as 100% efficient. The boilers are connected to a heat exchanger in the domestic hot water heater and act as a back-up for the domestic water system.

## *Section 8- Power*

The Army Administration facility complies with standards set by the National Electric Code (NEC) and therefore all feeder conductors shall be sized for a maximum voltage drop of 2% at design load and branch circuit conductors shall be sized for a maximum voltage drop of 3% at design load.
All electrical drawings will be provided by the electrical engineer to the owner upon project turnover. Construction documents will include electrical floor plans and single line diagrams of the building electrical distribution.

## *Section 9- Lighting*

*Section 9.2 Compliance Paths*

This section offers two methods for determining the interior lighting power allowance. For this report, the Space-by-Space Method will be used. The Space-by-Space Method involves finding the area of each space and grouping the spaces based on their occupancy types. Allowable lighting power densities (LPD) are specified in Table 9.6.1 in Standard 90.1 based on the occupancy types. Multiplying the area of each space by the allowable LPD will result in a total allowable wattage to compare to the design.

*Section 9.4 Mandatory Provisions*

This facility utilizes occupancy sensors to automatically control the lighting when a space is unoccupied. Since most of the private offices have full height partitions, every room has its own sensor that will shut the lights off within 30 minutes of an occupant leaving the space. Each room also has its own switch for the occupant to manually control the lighting.

*Section 9.6 Space-by-Space Method*

*Table 10* summarizes the results of the Space-by-Space Method. As shown, the Army Administration Facility is compliant with the allowable power density levels as specified in ASHRAE Standard 90.1. The design documents specify a 35% lighting power density reduction throughout the building prior to incorporating day lighting controls.

**Table 10- Lighting Power Densities**

| Fixture Type | Description | Building Area Type | Input Watts | Total Area ($ft^2$) | Allowable LPD ($W/ft^2$) | Allowable Wattage |
|---|---|---|---|---|---|---|
| A1 | 2'X4' LENSED DIRECT/INDIRECT FIXTURE | Office | 59 | 30,686 | 1.1 | 33754.6 |
| A2 | 2'X4' LENSED TROFFER | Storage/ Break | 58 | 6,034 | 1.3 | 7844.2 |
| A3 | 2'X4' LENSED DIRECT/INDIRECT FIXTURE | Office | 96 | 13,261 | 1.1 | 14587.1 |
| B1 | 1'X4' INDUSTRIAL FIXTURE | MEP Rooms | 59 | 1,779 | 1.2 | 2134.8 |
| D1 | 6" APERTURE DOWNLIGHT | Toilet/ Vestibules | 32 | 11,980 | 1.1 | 13178.0 |
| D1D | 6" APERTURE DOWNLIGHT | Conference | 32 | 870 | 1.3 | 1131.0 |
| D4 | 6" DOWNLIGHT | Shower | 33 | 703 | 0.6 | 421.8 |
| L1 | 1X4 DIRECT/INDIRECT | Halls | 73 | 15,541 | 0.5 | 7770.5 |
| L1D | 1X4 DIRECT/INDIRECT | Training | 73 | 2,250 | 1.4 | 3150.0 |
| V3D | COURTROOM COVE LIGHT | Courtroom | 146 | 890 | 1.9 | 1691.0 |
| V3 | COVE LIGHT | Lobby | 30 | 1,690 | 1.3 | 2197.0 |
| | | | | **Total Allowable Wattage** | | 87860.0 |
| | | | | **Total Design Wattage** | | 84967 |
| | | | | **Standard 90.1 Compliance** | | Y |

## *Section 10- Other Equipment*

This facility's equipment was analyzed previously in this report in Section 6.5 of Standard 90.1. There is no other equipment that would be relevant to this section.

## *ASHRAE Standard 90.1 (2007) Summary*

Through this analysis, it can be concluded that the Army Administration Facility is compliant with the requirements set forth in ASHRAE Standard 90.1. The only sections of concern are the larger equipment with the allowable nameplate motor hp, so these may need to be addressed. The building's goal of achieving LEED Silver has greatly impacted the energy usage designed throughout this facility.

## 2.3 LEED Analysis

The Army Administration Facility was designed and built to achieve LEED Silver certification. Such features lending to the sustainability of the design include a reflective white roof membrane, a continuous air barrier at all exterior wall assemblies to prevent infiltration and exfiltration, lowering energy consumption, and increased U-values of roof, walls, and windows past the ASHRAE 90.1 baseline minimums.

### *Energy & Atmosphere*

**EA Prerequisite 1: Fundamental Commissioning of the Building Energy Systems (Complete)**
Intent: Verify that the building's energy related systems are installed, calibrated and perform according to the owner's project requirements, basis of design, and construction documents.

Designed: To achieve this prerequisite, a commissioning team has been established by a third party commissioning agent, Flack & Kurtz, to lead, review and oversee the completion of the commissioning process activities. The mechanical design team at Southland Industries has developed a Basis of Design (BOD) that must be accomplished before completion of the facility.

**EA Prerequisite 2: Minimum Energy Performance Required (Complete)**
Intent: Establish the minimum level of energy efficiency for the proposed building and systems.

Designed: To achieve this prerequisite, the design team at Southland Industries performed an energy simulation and concluded that the Army Administration Facility, as-designed, will see an annual cost savings of 21.2% over the baseline building model. This exceeds the 14% reduction specified by the mandatory provisions and the prescriptive requirements of ASHRAE/IESNA Standard 90.1-2004.

**EA Prerequisite 3: Fundamental Refrigerant Management Required (Complete)**
Intent: Reduce ozone depletion.

Designed: To achieve this prerequisite, the Army Administration Facility uses zero CFC based refrigerants that could have harmful effects on the ozone.

**EA Credit 1: Optimize Energy Performance (4 points)**
Intent: Achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.

Designed: LEED v2.2 requires a 14% reduction in energy use beyond ASHRAE 90.1-2004. For every 3.5% better than 14% reduction, one LEED point will be added to the scorecard. For LEED, the energy reduction is based on total building site energy use, including plug loads. The savings percentage is calculated using ASHRAE 90.1-2004 Appendix G by comparing the proposed building to one that meets the minimum requirements of ASHRAE 90.1-2004 (baseline building). The baseline building was modeled to have an annual energy cost of about $170,208.00. The Army Administration Facility as-designed is estimated to require about $134,118.00 per year on energy costs. This is a 21.2% reduction from the ASHRAE 90.1-2004 compliant baseline building and earns 4 LEED points.

**EA Credit 2: On-Site Renewable Energy (0 points)**
Intent: Encourage and recognize increasing levels of on-site renewable energy self-supply in order to reduce environmental and economic impacts associated with fossil fuel energy use.

Designed: While the design team recognized the advantages of on-site renewable energy sources, they were unable to pursue this point. Attempts were taken with the use of a solar hot water heater, but the minimum 2.5% renewable energy minimum was not reached to receive any points.

### EA Credit 3: Enhanced Commissioning (1 point)

Intent: Begin the commissioning process early during the design process and execute additional activities after systems performance verification is completed.

Designed: The Commissioning Agent, Flack & Kurtz, as part of the Design/Build Team, provided enhanced commissioning services in addition to the services provide per prerequisite 1. These services include a commissioning design review prior to mid-constructions documents and will execute additional commissioning services within 10 months of substantial completion to comply with the RFP and with LEED prerequisite 1 requirements. Since the design and construction of the building was fast-tracked to be complete in one year, an enhanced commissioning process was necessary in order to stick to schedule. Therefore, one point was awarded.

### EA Credit 4: Enhanced Refrigerant Management (1 point)

Intent: Reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing direct contributions to global warming. The base building HVAC&R equipment shall comply with the following formula, which sets a maximum threshold for the combined contributions to ozone depletion and global warming potential:

$$[\ \Sigma\ (LCGWP + LCODP \times 105) \times Qunit\ ] / Qtotal \leq 100$$

Where:
LCODP: Lifecycle Ozone Depletion Potential (lbCFC11/Ton-Year)
LCGWP: Lifecycle Direct Global Warming Potential (lbCO2/Ton-Year)
Qunit = Cooling capacity of an individual HVAC or refrigeration unit (Tons)
Qtotal = Total cooling capacity of all HVAC or refrigeration

Designed: This credit is being met by selecting a refrigerant that minimizes or eliminates ozone depleting compounds and that meets the prescriptive requirements of this credit. All of the equipment used in the Army Administration Facility that utilizes a refrigerant uses R-410A, which keeps the combined contributions to ozone depletion and global warming potential below the threshold of 100 and earns one LEED point.

### EA Credit 5: Measurement & Verification (0 points)

Intent: Provide for the ongoing accountability of building energy consumption over time.

Designed: This credit was not pursued by the design team. The Army Administration Facility is a classified building and upon completion of the project, will be turned over completely to the owner, who is responsible for continual maintenance.

### EA Credit 6: Green Power (0 points)

Intent: Encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis.

Designed: The design of the Army Administration Facility was unable to provide at least 35% of the building’s electricity from renewable sources, so no points were awarded for this credit.

### *Indoor Environmental Quality*

**EQ Prerequisite 1: Minimum IAQ Performance (Complete)**
Intent: Establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants.

Designed: The Army Administration Facility was designed to meet the standards set forth in Sections 4 through 7 of ASHRAE 62.1-2004, Ventilation for Acceptable Indoor Air Quality. Technical Report One contains an in depth analysis of the requirements met by this facility.

**EQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control (Complete)**
Intent: Minimize exposure of building occupants, indoor surfaces, and ventilation air distribution systems to Environmental Tobacco Smoke (ETS).

Designed: The Army Administration Facility is a nonsmoking facility and specifies any designated smoking areas to be located at least 25 feet from any building openings. This prerequisite has been met.

**EQ Credit 1: Outdoor Air Delivery Monitoring (1 point)**
Intent: Provide capacity for ventilation system monitoring to help sustain occupant comfort and wellbeing.

Designed: This credit is being met with CO2 monitoring systems in densely occupied spaces and outside airflow monitoring in non-densely occupied spaces. The CO2 sensors will alarm if the conditions vary 10% or more from the setpoint, so this point is awarded.

**EQ Credit 2: Increased Ventilation (0 points)**
Intent: Provide additional outdoor air ventilation to improve indoor air quality for improved occupant comfort, well-being and productivity.

Designed: Although the Army Administration Facility utilizes a dedicated outdoor air system, it was not sized to increase the ventilation rates to 30% more than the ASHRAE Standard 62.1-2004 minimum. Therefore, no points were awarded for this credit.

**EQ Credit 3.1: Construction IAQ Management Plan: During Construction (1 point)**
Intent: Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.

Designed: All control measures during construction, where applicable, shall comply with the Sheet Metal and Air Conditioning Contractors’ National Association (SMACNA). Also, in the DOAS unit, filters shall be front loaded MERV 13, in accordance with ASHRAE Standard 52.2-1999, 4-inch pleated media type with 2-inch pleated MERV 8 pre-filters. Therefore, one point was awarded for this credit.

**EQ Credit 3.2: Construction IAQ Management Plan: Before Occupancy (1 point)**
Intent: Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.

Designed: To achieve this credit, the contractor shall perform a building flush-out prior to building occupancy by supplying a minimum air volume of 14,000 cu. ft. of outdoor air per sq. ft. of floor area.

This flush-out will be performed in conjunction with the Indoor Air Quality (IAQ) management plan set forth in EQ Credit 3.1, earning one point for this credit.

**EQ Credit 4.1: Low-Emitting Materials: Adhesives & Sealants (1 point)**
Intent: Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Designed: According to building documents and specifications, Volatile Organic Content (VOC) levels of adhesives and sealants used during construction inside the building envelope shall not exceed levels specified in the LEED requirements, earning the point for this credit.

**EQ Credit 4.2: Low-Emitting Materials: Paints & Coatings (1 point)**
Intent: Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Designed: As set forth by the building documents and specifications, "no adhesives, sealants or primers containing VOC levels in excess of the allowable VOC levels shown in the *Maximum VOC Level Chart* included in the LEED-NC v2.2 requirements shall be used inside the building envelope during construction."

**EQ Credit 4.3: Low-Emitting Materials: Carpet Systems (1 point)**
Intent: Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Designed: As set forth by the building documents and specifications, the carpet and carpet systems meet or exceed the requirements of the Carpet and Rug Institute's Green Label Indoor Air Quality Test Program, earning one point for this credit.

**EQ Credit 4.4: Low-Emitting Materials: Composite Wood & Agrifiber Products (1 point)**
Intent: Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Designed: The design specifications clearly state that no finish carpentry materials, including plywood products, medium density fiberboard (MDF) products, panel products, or casework materials, contain no added urea-formaldehyde resins. The requirements of this credit have been met.

**EQ Credit 5: Indoor Chemical & Pollutant Source Control (1 point)**
Intent: Minimize exposure of building occupants to potentially hazardous particulates and chemical pollutants.

Designed: This point is achieved by enclosing those spaces where chemicals are stored, such as janitor closets, and providing negative pressurizations for these spaces. Additionally, the entire building's supply air will be filtered with MERV 13 filters. Compatible slotted recessed walk off mats specs and slotted recessed walk off mat locations will be provided at primary entrances to achieve this credit.

**EQ Credit 6.1: Controllability of Systems: Lighting (1 point)**
Intent: Provide a high level of lighting system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and

well-being of building occupants.

Designed: To achieve this credit, the building is providing individual lighting controls for over 90% of the building occupants to suit individual task needs and preferences. Also for shared multi-occupant spaces the lighting is adjustable to meet group needs and preferences, meeting the requirements of this credit.

**EQ Credit 6.2: Controllability of Systems: Thermal Comfort (0 points)**
Intent: Provide a high level of thermal comfort system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and well-being of building occupants.

Designed: Per the owner's request, a desire for more occupant thermal control led designers to condition a maximum of three office spaces per terminal unit, controlled via zone thermostats. However, this does not meet the requirement of 50% minimum occupant control, so this point was not awarded.

**EQ Credit 7.1: Thermal Comfort: Design (1 point)**
Intent: Provide a comfortable thermal environment that supports the productivity and well-being of building occupants.

Designed: The HVAC system and the building envelope will meet ASHREA 55-2004 by providing a highly efficient building envelope that minimizes radiant heat gain and loss coupled with an air delivery system that utilizes low velocity diffusers to minimize drafts and maintain comfort temperatures. A constant supply of 55 deg ventilation air shall be supplied to the FPIUs that have their own heating and cooling coils that can adjust the air temperature supplied to the space accordingly to maximize thermal comfort.

**EQ Credit 7.2: Thermal Comfort: Verification (0 points)**
Intent: Provide for the assessment of building thermal comfort over time.

Designed: The building owner chose not to conduct a survey to determine the overall satisfaction with thermal performance and allow for a corrective plan to be developed if more than 20% of occupants are dissatisfied. This credit was not awarded.

**EQ Credit 8.1: Daylight & Views: Daylight 75% of Spaces (0 points)**
Intent: Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Designed: The Army Administration Facility can achieve a minimum glazing factor of 2% in only 25% of the building's occupied spaces. This does not meet the 75% requirement set forth in this credit, so no point was awarded.

**EQ Credit 8.2: Daylight & Views: Views for 90% of Spaces (0 points)**
Intent: Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Designed: Only about 50% of all occupied areas of the Army Administration Facility have direct line of sight to the outdoor environment via glazing, so this point was not awarded.

# 3.0 Existing Mechanical System Overview

## 3.1 Airside System

The Army Administration Facility is served by a Dedicated Outdoor Air Unit (DOAU), also known as a Dedicated Outdoor Air System (DOAS), located on the south end of the fourth level. This DOAU is a packaged unit that supplies 100% of the outside air to the building and can handle 24,000 CFM to the building. The unit features pre-heating coils, 55F chilled water pre-cooling coils, 42F DX trim cooling coils, and (6) 2,670 RPM fans. Even though each terminal unit has its own heating and cooling coils, the outdoor air is preconditioned in the DOAS for two reasons. Firstly, the cooling coil in the DOAS needs protection from freezing. The heating coil is used to raise the incoming DOAS air temperature above freezing when the ambient condition exists. Secondly, and more importantly, a constant supply air temperature of 50F is needed from the DOAS unit. Even in the dead of winter, some zones may be in cooling mode, while others may need heating. For example, there could be an interior zone, with no outside exposure and lots of computers, that needs to be cooled even in winter. At the same time, a perimeter zone with lots of exterior wall/glass might need to be heated. Because of this, 50F air needs to be provided at all times. Therefore, the heating coil can be used to raise the air temperature and then the cooling coil can be used if dehumidification is necessary. Once delivered to the terminal units, each FPIU has the ability to continue to cool using its cooling coil, or if the thermostat is calling for heat, it is able to use its heating coil to provide heated air.

A detailed image of the building's DOAS unit is shown below in *Figure 2*.

The DOAS supplies outside air that is ducted to Fan Powered Induction Units (FPIUs) that supply each space with conditioned air. The FPIU was developed by the Mechanical Engineers at Southland Industries and they serve to both cool and heat the space. This induction unit is similar to old induction units from the 1970s, but this new version utilizes a series fan powered unit controlled by an Electronically Commutated Motor (ECM) that includes an inlet control damper and an airflow ring. These new induction units also include a sensible cooling coil, an optional heating coil, and a face loading filter. The FPIU is able to produce a consistent supply of filtered dry ventilation air and requires 20% of the duct distribution as compared to a VAV system. This is made possible because an FPIU takes in return air directly from the plenum space rather than return duct circulating the air back through an air handling unit. Each FPIU has its own sensible chilled water cooling coil that modulates to space conditions and can operate independently from the main air handler for sensible loads.

There are also several Variable Air Volume (VAV) units in spaces that have a higher latent load and require more primary air. An FPIU has a limit on the amount of primary air it can handle, so larger spaces, such as the conference rooms and the courtroom require a VAV to provide more airflow.

To help increase occupant controlled thermal comfort, each FPIU serves no more than three rooms. Each room has a $CO_2$ sensor and a thermostat, but each thermostat can be manually adjusted by the occupant. The FPIUs are also capable of trending zone conditions and outdoor air rates to avoid issues with indoor air quality.

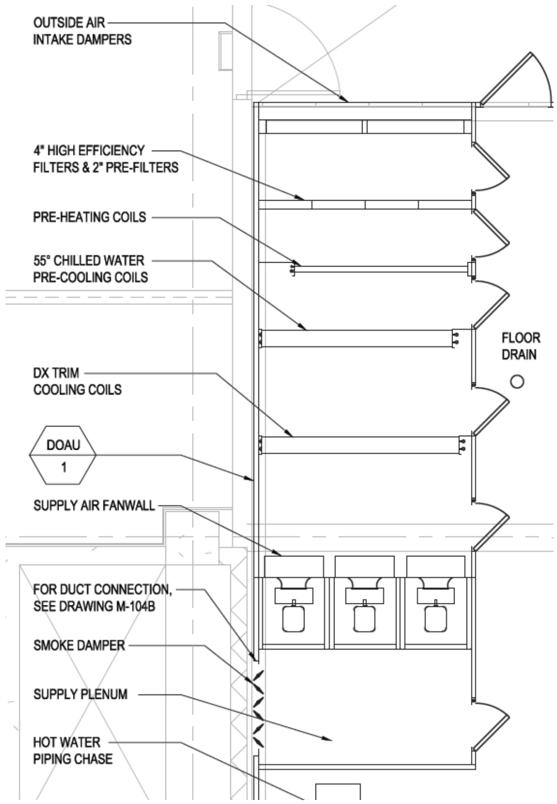



Figure 2- Dedicated Outdoor Air Unit

## 3.2 Waterside System

Each FPIU has its own sensible chilled water cooling coil that modulates to space conditions and can operate independently from the main air handler for sensible loads. They are fed by a 315 ton evaporative condensing chiller supplying 55 degree water throughout the building. The bulk of air conditioning capacity can be carried through small chilled water piping instead of ductwork, reducing infrastructure space requirements by a factor of four.

To heat each space the FPIUs also have a heating coil that is served by two 1,500 MBH gas-fired boilers in the penthouse. There is a solar hot water heater in the penthouse that provides 30% of the peak domestic hot water load. The remaining 70% of the load is provided by the boilers. However, the building will rarely reach its peak load, so the solar hot water heater should consistently provide a majority of the domestic hot water. If the solar hot water heater were to fail, the boilers in the penthouse are also connected to a heat exchanger in the domestic hot water heater as a back-up.

Drawn below are line diagrams clarifying the chilled and heating hot water systems. *Figure 3* diagrams the chilled water system from the chiller to the loads. *Figure 4* diagrams the hot water loop between the boilers and the space.

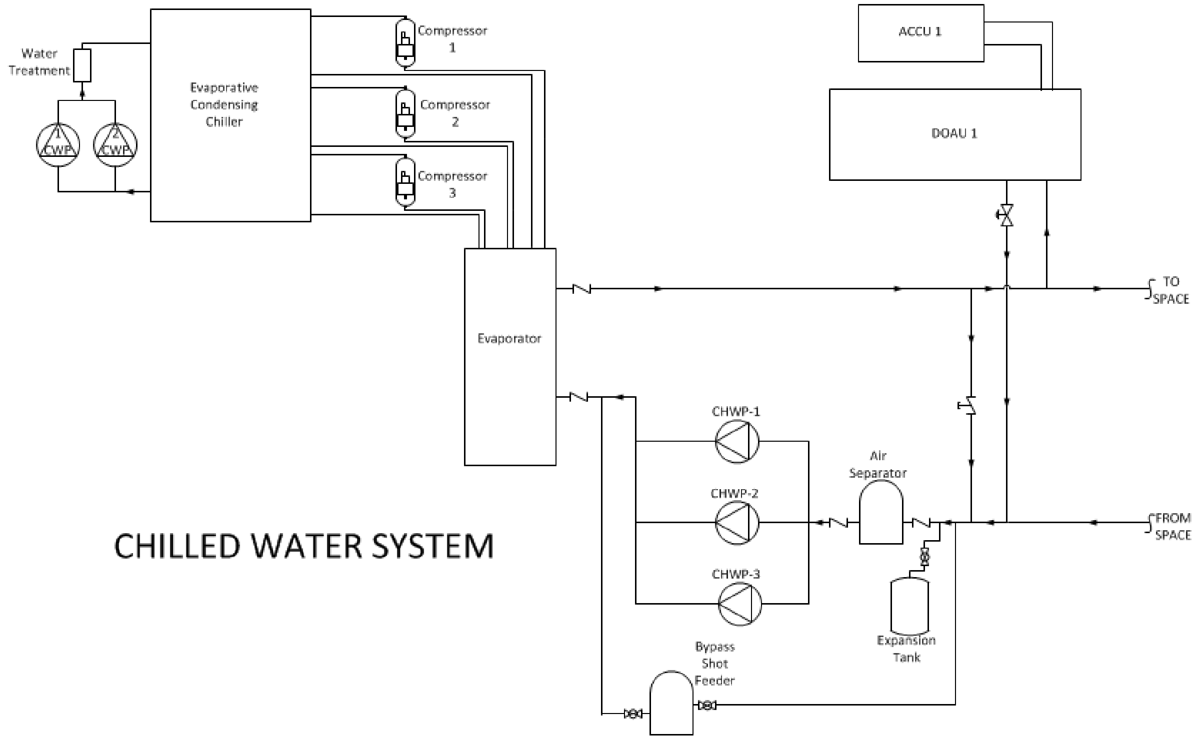



Figure 3- Chilled Water System

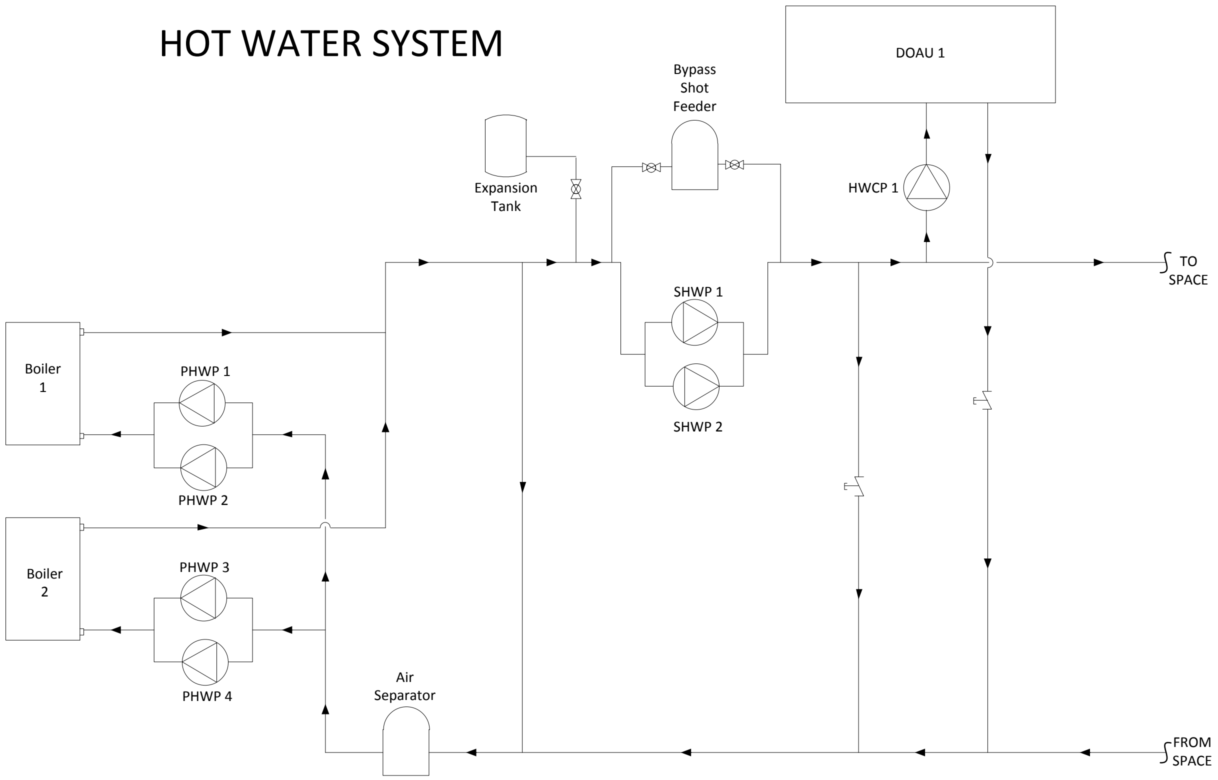



Figure 4-Heating Hot Water System

## 3.3 Mechanical Equipment Breakdown

All equipment associated with the central plant including chillers, boilers, pumps, as well as the DOAS unit are housed in a custom factory fabricated packaged unit located on the third floor roof. The DOAU provides 100% of the ventilation air required throughout the building. Its characteristics are shown below in *Table 11*.

**Table 11- DOAU Schedule**

| Air Handling Unit | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Pre-Heating Coil | | | Pre-Cooling Coil | | |
| Name | Airflow (CFM) | Ent. Air Temp (F) | Leaving Air Temp. (F) | Capacity (MBH) | Ent. DB Temp (F) | Leaving DB Temp. (F) | Capacity (MBH) |
| DOAU-1 | 24,000 | 12 | 55 | 1,115 | 91 | 60.8 | 1,557 |

The outside air passing through the air handling unit is distributed throughout the building to terminal units. The Army Administration Facility utilizes Fan Powered Induction Units (FPIUs) and Variable Air Volume (VAV) units. Their characteristics are shown below in *Table 12*.

**Table 12- Terminal Unit Schedule**

| Terminal Units | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fan | Sensible Chilled Water Coil | | | | | | Hot Water Coil | | | | | |
| Name | Airflow (CFM) | Motor Size (HP) | Ent. Air Temp (F) | Leaving Air Temp. (F) | Ent. Water Temp (F) | Leaving Water Temp. (F) | Capacity (MBH) | Flow (GPM) | Ent. Air Temp (F) | Leaving Air Temp. (F) | Ent. Water Temp (F) | Leaving Water Temp. (F) | Capacity (MBH) | Flow (GPM) |
| FPIU-1 | 800 | 1/2 | 75.0 | 57.3 | 55.0 | 64.2 | 13.8 | 3.0 | - | - | - | - | - | - |
| FPIU-2 | 800 | 1/2 | 75.0 | 57.3 | 55.0 | 64.2 | 13.8 | 3.0 | 68.0 | 91.4 | 180.0 | 106.0 | 18.2 | 0.5 |
| FPIU-3 | 1,200 | 3/4 | 75.0 | 58.0 | 55.0 | 64.8 | 19.0 | 3.9 | - | - | - | - | - | - |
| FPIU-4 | 1,200 | 3/4 | 75.0 | 58.0 | 55.0 | 64.8 | 19.0 | 3.9 | 68.0 | 95.2 | 180.0 | 115.8 | 30.4 | 1.0 |
| VAV-1 | 450 | - | - | - | - | - | - | - | 52.0 | 77.4 | 180.0 | 151.8 | 12.4 | 0.9 |
| VAV-2 | 1,300 | - | - | - | - | - | - | - | 52.0 | 74.1 | 180.0 | 155.5 | 31.1 | 2.6 |
| VAV-3 | 600 | - | - | - | - | - | - | - | 52.0 | 77.0 | 180.0 | 152.3 | 16.2 | 1.2 |
| VAV-4 | 400 | - | - | - | - | - | - | - | 52.0 | 78.5 | 180.0 | 150.6 | 11.5 | 0.8 |
| VAV-5 | 1,400 | - | - | - | - | - | - | - | 52.0 | 73.4 | 180.0 | 156.3 | 32.4 | 2.8 |

Although the terminal units have their own heating (and cooling) coils, the DOAU has its own pre-conditioning coils to protect against freezing and then a separate DX coil to supply a constant air temperature of 50F to each terminal unit. The chilled water coils in both the terminal units and the air handling unit are supplied by an evaporative condensing chiller in the penthouse. The condenser section of the assembly consists of a stainless steel sump, condenser fans connected to two variable frequency drive (VFD) circuits, constant speed duplex (primary and back-up) condenser water pumps, and complete chemical free water treatment. The condenser fan VFD circuits will vary the condenser fan speed to match the connected load of the compressors. The compressor bank consists of three high efficiency rotary screw type compressors.

The chilled water side of the assembly will be connected to the condenser side of the assembly via the shell and tube heat exchanger. The compressor bank refrigerant circuits will be connected to the shell side of the exchanger. The evaporator side of the exchanger is a multiple pass tube connected to variable speed duplex (primary and back-up) primary pumping system that distributes the 55 degree chilled water to the DOAU and building loads as required. A schedule for the chiller can be referenced below in *Table 13*.

**Table 13- Evaporative Condensing Chiller Schedule**

| Evaporative Condensing Chiller | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Evaporator | | | Condenser | | |
| Name | Capacity (Tons) | Ent. Water Temp (F) | Leaving Water Temp. (F) | Flow (gpm) | Ambient Temp. (F) | Condensing Temp. (F) | Spray Flow (gpm) |
| CHLR-1 | 315 | 66.5 | 55 | 668 | 78 | 105 | 735 |

The building hot water system utilizes two gas-fired boilers sized to meet the required capacity. The plant operates at a maximum HW supply temperature of 180 deg F and a return water temperature of 150 deg F. Each boiler is provided with a primary inline circulating pump. The secondary pumping is handled by a variable speed duplex (primary and back-up) pumping system to distribute hot water to the building. Boiler characteristics can be referenced below in *Table 14*.

**Table 14- Boiler Schedule**

| Boilers | | | | | | |
|---|---|---|---|---|---|---|
| | Capacity | | | | | |
| Name | Input (MBH) | Output (MBH) | Efficiency (%) | Ent. Water Temp (F) | Leaving Water Temp. (F) | Flow (gpm) |
| BLR-1 | 1,500 | 1,275 | 85 | 150 | 180 | 80 |
| BLR-2 | 1,500 | 1,275 | 85 | 150 | 180 | 80 |

A breakdown of the pumps used throughout the mechanical system can be found in *Table 15*.

**Table 15- Pump Schedule**

| Pumps | | | | | | | |
|---|---|---|---|---|---|---|---|
| Name | Service | Flow (gpm) | Min. Flow (gpm) | Head (ft. wc) | Pump Efficiency (%) | RPM | Motor Size (Hp) |
| CWP-1 | Condenser Water | 735 | - | 20 | 74.6 | 1,750 | 7.5 |
| CWP-2 | Condenser Water | 735 | - | 20 | 74.6 | 1,750 | 7.5 |
| CHWP-1 | Chilled Water | 334 | 80 | 90 | 71.0 | 1,750 | 15.0 |
| CHWP-2 | Chilled Water | 334 | 80 | 90 | 71.0 | 1,750 | 15.0 |
| CHWP-3 | Chilled Water | 334 | 80 | 90 | 71.0 | 1,750 | 15.0 |
| PHWP-1 | Prim. Hot Water | 80 | - | 20 | 66.7 | 1,750 | 1.0 |
| PHWP-2 | Prim. Hot Water | 80 | - | 20 | 66.7 | 1,750 | 1.0 |
| PHWP-3 | Prim. Hot Water | 80 | - | 20 | 66.7 | 1,750 | 1.0 |
| PHWP-4 | Prim. Hot Water | 80 | - | 20 | 66.7 | 1,750 | 1.0 |
| SHWP-1 | Sec. Hot Water | 160 | 50 | 48 | 66.0 | 1,750 | 5.0 |
| SHWP-2 | Sec. Hot Water | 160 | 50 | 48 | 66.0 | 1,750 | 5.0 |
| HWCP-1 | HW Coil Circuator | 75 | - | 20 | 60.0 | 1,750 | 0.8 |

## 3.4 Energy Sources and Rates

The Army Administration Facility utilizes mainly gas and electric utilities for the annual heating and cooling needs. The building is self-operating with boilers and chillers and therefore is not on a district system. Local energy rates were not provided and the building has not been operational long enough to have actual utility bills, so local rates were taken from the US Energy Information Administration (EIA) website and shown in *Table 16*.

Table 16- Local Utility Rates

| | | Local Rates |
|---|---|---|
| Electricity Cost | $/kWh | 0.0798 |
| Natural Gas Cost | $/therm | 0.837 |

## 3.5 Outdoor and Indoor Design Conditions

Using the ASHRAE Handbook of Fundamentals 2009, the weather data for the Mid-Atlantic region of the country was used (exact location not disclosed per owner's request). The indoor air conditions were taken directly from the design documents and are shown below in *Table 17* and *Table 18*. Occupied mode comfort settings include a space temperature high limit set point value of 75 °F (adjustable), a space temperature low limit set point value 70 °F (adjustable), and the space dew point temperature is at or below the sensible (55F) chilled water supply temperature. These values were used for the Trane TRACE™ 700 energy simulation. A humidity ratio of 50% was also used as specified in the design documents.

Table 17- Summer Design Weather Data

| | Summer (0.4%) | | |
|---|---|---|---|
| | Indoor Design (F) | Dry Bulb Temp (F) | Wet Bulb Temp (F) |
| Vestibules | 95 | 93.2 | 75.1 |
| All Other Spaces | 75 | 93.2 | 75.1 |

Table 18- Winter Design Weather Data

| | Winter (99.6 %) | | |
|---|---|---|---|
| | Indoor Design (F) | Dry Bulb Temp (F) | Wet Bulb Temp (F) |
| Vestibules | 60 | 9.6 | - |
| All Other Spaces | 70 | 9.6 | - |

## 3.6 Design Ventilation Requirements

A comprehensive ventilation analysis was conducted in Technical Report One referencing ASHRAE Standards 62.1 and 90.1. For this system, there is a single DOAS unit that serves the entire building. Each terminal unit receives a certain amount of outdoor air from the DOAS unit and is thus proportioned to each space. The results of each room's compliance with proper ventilation standards can be found in *Appendix A* of this report. As is shown in *Appendix A*, the spaces require a total of 23,750 CFM of outdoor air and the DOAU was sized up to supply 24,000 CFM. The minimum ventilation requirements set forth in Section 6 of ASHRAE Standard 62.1 have been met in all occupied spaces. As can be seen in *Appendix A*, the only spaces where the ventilation rates were not up to standard were storage rooms or hallways. The hall calculations could be flawed since the halls are open to other spaces and hallways and in reality share a proportion of the outside air. For the storage rooms, there could be a stipulation allowing less than the required ventilation rate since these room types are for the most part unoccupied spaces.

The results of the TRACE energy analysis conducted by TRACE show that the load values calculated are within about 2 percent of the design values as documented. *Table 19* compares the computed TRACE analysis to the design loads specified in the design documents. As per design, the building requires 0.25 CFM/SF of ventilation air.

**Table 19- Computed and Designed Load Analysis**

| | Total Supply CFM/SF | Ventilation Supply CFM/SF |
|---|---|---|
| Computed | 1.03 | 0.260 |
| Designed | 1.05 | 0.250 |
| % Difference | 1.4% | 4.0% |

## 3.7 Design Heating and Cooling Loads

The project's mechanical engineers, Southland Industries, built a model in Trace and used the resulting heating and cooling loads to design the mechanical system for the Army Administration Facility. The given design heating and cooling loads are shown below in *Table 20*, as well as the comparative load analysis that was conducted for this report.

**Table 20- Heating and Cooling Load Analysis**

| | Cooling SF/ton | Heating BTUh/SF |
|---|---|---|
| Computed | 301.24 | 22.91 |
| Designed | 279.54 | 24.67 |
| % Difference | 7.8% | 7.1% |

These translate to a peak cooling load of **292 tons** and a peak heating load of **2,015,960 BTUh**. These loads were calculated using design occupancies and ventilation, infiltration rates, the weather data discussed earlier in this report, and miscellaneous loads. The largest difference is the cooling capacity at 7.8%. The percent differences could be due to many things. The most impacting factor could be differences in assumptions. For example, occupancy densities and miscellaneous loads were calculated using furniture drawings. Also, fenestration calculations were made using elevations and interpretation of a Revit model. These could all result in errors if done differently than the design engineers. Other factors could include the plants selected and omitted. The heating plant, for example, includes a solar hot water heater that could not be modeled in TRACE. It was assumed that this solar hot water heater supplies about 30% of the hot water utilized in the building, so this needs to be taken into consideration when analyzing the energy usage results. Simplifications are made when modeling block loads to make modeling the building easier, so some errors are inevitable, especially when compared to a space by space model.

## 3.8 Annual Energy Usage

An analysis of the Army Administration Facility's annual energy consumption and operating costs was also conducted. The same TRACE model that was used earlier in this report was used to perform a full year energy simulation. The building's cooling plant utilizes an evaporative condensing chiller supplying 55 degree water to the cooling coils in the terminal units. This was modeled in TRACE as an air-cooled chiller with a cooling tower, since an evaporative condensing chiller is essentially an air-cooled chiller that has an evaporative component that sprays water across the condensing unit. The heating plant utilizes two 85% efficient gas-fired boilers servicing the heating coils in the terminal units.

The TRACE model produced results shown in *Table 21*. As can be seen, the receptacle loads account for most of the building's annual energy consumption utilizing 40% of the total building energy. The smallest energy consumer in this building is the auxiliary loads from supply fans and pumps. Advantages of using FPIU units are that each unit is fed from one DOAS unit and each unit has a small ECM motor. Also, there are no return fans required since all return air is taken directly from the plenum space. This is a large reason why the auxiliary loads are low. The analysis of the annual utility consumption concluded a total energy utilization of 5,333 mmBtu/yr, about 87% of which is consumed by electric energy and the remaining 13% by gas.

Table 21- Energy Usage Breakdown

| | Electric kWh | Gas kBtu | Total Building Energy kBtu/yr | % of Total Building Energy |
|---|---|---|---|---|
| **Primary Heating** | | | | |
| Primary Heating | | 666,654 | 666,654 | 12.5% |
| Heating Accessories | 17,520 | | 59,796 | 1.1% |
| Heating Subtotal | **17,520** | **666,654** | **726,450** | **13.6%** |
| **Primary Cooling** | | | | |
| Cooling Compressor | 275,490 | | 940,247 | 17.6% |
| Tower/Cond Fans | 36,017 | | 122,926 | 2.3% |
| Condenser Pump | 31,071 | | 106,045 | 2.0% |
| Cooling Accessories | 876 | | 2,990 | 0.1% |
| Cooling Subtotal | **343,454** | **0** | **1,172,209** | **22.0%** |
| **Auxiliary** | | | | |
| Supply Fans | 6,644 | | 22,676 | 0.4% |
| Pumps | 148,529 | | 506,929 | 9.5% |
| Aux Subtotal | **155,173** | **0** | **529,605** | **9.9%** |
| **Lighting** | **232,479** | **0** | **793,451** | **14.9%** |
| **Receptacles** | **618,652** | **0** | **2,111,459** | **39.6%** |
| **Total** | **1,367,278** | **666,654** | **5,333,174** | **100.0%** |

## 3.9 Monthly Energy Consumption Breakdown

A monthly breakdown of the energy consumption for electric and gas are shown in *Table 22* below. As can be seen by the table and *Figure 5* and *Figure 6*, the electricity loads reach their peaks in the summer months, while the gas loads reach their peaks in the winter months. This is a typical trend that would be assumed since the chiller and other cooling equipment require the majority of the water and electricity. Likewise, the boilers are gas-fired and consume all of the gas loads, working at a larger load in the colder months.

**Table 22- Monthly Energy Consumption**

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric [kWh] | 95,367 | 86,851 | 108,507 | 100,962 | 127,664 | 138,070 | 140,425 | 147,252 | 118,424 | 109,410 | 101,721 | 92,626 | 1,367,279 |
| Gas [therms] | 1,465 | 1,252 | 653 | 320 | 252 | 252 | 229 | 270 | 242 | 375 | 471 | 886 | 6,667 |

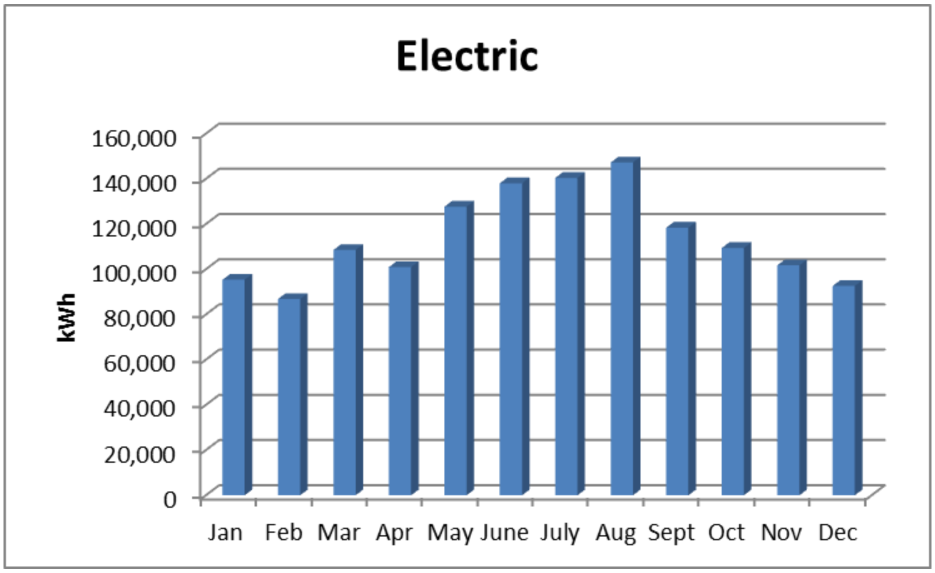



**Figure 5- Electrical Monthly Energy Consumption**

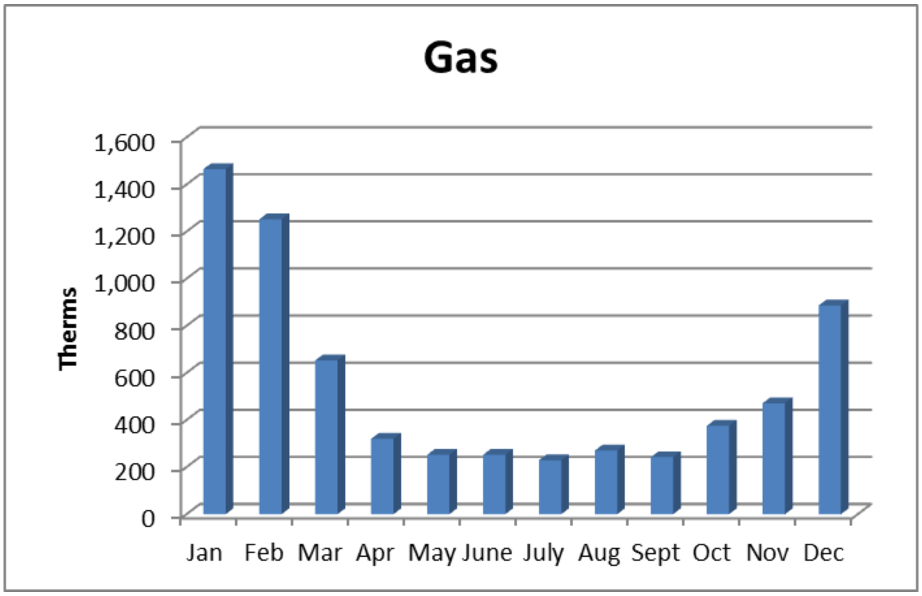



**Figure 6- Gas Monthly Energy Consumption**

## 3.10 Electrical Energy Breakdown

As was just discussed, the heating loads were a major source of the energy consumed annually in the Army Administration Facility. However, heating loads receive the majority of their energy from natural gas, as is reflected in *Table 23* and visually in *Figure 7*, a breakdown of solely the electrical power consumption by component. Primary heating is the smallest consumer of electric power in this building. Receptacles, as can be anticipated, require a large portion (45%) of the electric supply. This is most likely due to the miscellaneous loads added to each room in the TRACE model. Large receptacle loads can result from equipment such as computers, projectors, and other general office equipment that can give off heat.

**Table 23- Electric Consumption per Component**

| | Electric Consumption kWh |
|---|---|
| **Primary Heating** | 17,520 |
| **Primary Cooling** | 343,454 |
| **Auxiliary** | 155,173 |
| **Lighting** | 232,479 |
| **Receptacles** | 618,652 |
| **Total** | **1,367,278** |

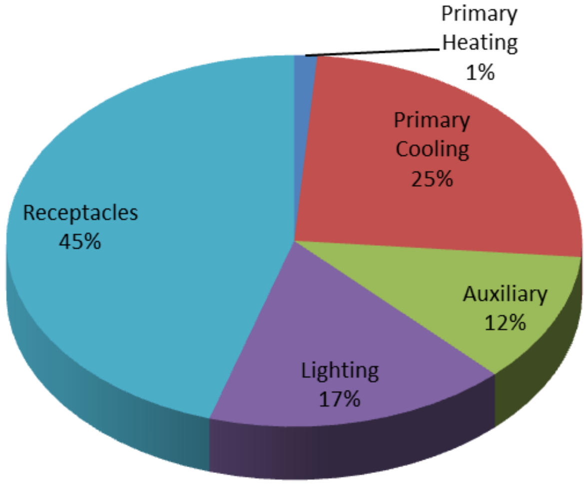



**Figure 7- Electrical Energy Consumption**

## 3.11 Cost Breakdown

### *Mechanical System First Costs*

A request has been issued to the project manager for a cost breakdown of the mechanical equipment; however, due to the confidential nature of the building, the cost breakdown has not been disclosed. They did provide the overall mechanical cost and it was just over 5 million dollars.

### *Annual Utility Costs*

Using the electricity and natural gas rates from the EIA for the local (undisclosed) area, shown in *Table 16,* it can be concluded that the Army Administration should expect to spend roughly $114,689 per year on gas and electric utilities. This translates to about $1.32 per square foot of energy consumed each year. The building uses about one and a half times more kBtu per year of electric energy than gas energy; however, due to the differences in rates, about twenty times more money is spent on electric than gas. These conclusions are summarized below in *Table 24*.

Table 24- Annual Energy Costs

| Rate= 0.0798 $/kWh | Electric Consumption kWh | Cost Per Year $ | Cost Per SF $ |
|---|---|---|---|
| **Primary Heating** | | | |
| Heating Accessories | **17,520** | **1,398** | **0.016** |
| **Primary Cooling** | | | |
| Cooling Compressor | 275,490 | 21,984 | 0.253 |
| Tower/Cond Fans | 36,017 | 2,874 | 0.033 |
| Condenser Pump | 31,071 | | |
| Cooling Accessories | 876 | 70 | 0.001 |
| Cooling Subtotal | **343,454** | **27,408** | **0.315** |
| **Auxiliary** | | | |
| Supply Fans | 6,644 | 530 | 0.006 |
| Pumps | 148,529 | 11,853 | 0.136 |
| Aux Subtotal | **155,173** | **12,383** | **0.142** |
| **Lighting** | | | |
| Lighting | **232,479** | **18,552** | **0.213** |
| **Receptacles** | | | |
| Receptacles | **618,652** | **49,368** | **0.567** |
| **Electric Subtotal** | **1,367,278** | **109,109** | **1.254** |
| | | | |
| Rate= 0.837 $/therm<br>Rate= 0.00837 $/kBtu | **Gas Consumption kBtu** | **Cost Per Year $** | **Cost Per SF $** |
| **Primary Heating** | 666,654 | 5,580 | 0.064 |
| **Primary Cooling** | 0 | 0 | 0.000 |
| **Auxiliary** | 0 | 0 | 0.000 |
| **Lighting** | 0 | 0 | 0.000 |
| **Receptacles** | 0 | 0 | 0.000 |
| **Gas Subtotal** | **666,654** | **5,580** | **0.064** |
| | | | |
| **Electric Subtotal [kBtu]** | **4,666,520** | **109,109** | **1.254** |
| **Gas Subtotal [kBtu]** | **666,654** | **5,580** | **0.064** |
| **Energy Total** | **5,333,174** | **114,689** | **1.32** |

A monthly breakdown of the energy costs for electric and gas are shown in *Table 25*. As can be seen by the table and *Figure 8*, the electricity costs reach their peaks in the summer months when the load is higher, while the gas loads reach their peaks in the winter months. These trends follow those summarized earlier in the monthly energy consumption section of this report. This is to be expected since the chiller and other cooling equipment require the majority of the electricity. Likewise, the boilers are gas-fired and consume all of the gas loads, working at a larger load in the colder months, thus acquiring higher gas costs in the winter.

Table 25- Monthly Energy Costs

| Consumption | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric [$] | 7,522 | 6,851 | 8,570 | 7,971 | 10,099 | 10,932 | 11,117 | 11,662 | 9,364 | 8,642 | 8,032 | 7,303 | 108,065 |
| Gas [$] | 1,217 | 1,039 | 540 | 264 | 208 | 208 | 189 | 223 | 200 | 309 | 389 | 733 | 5,519 |

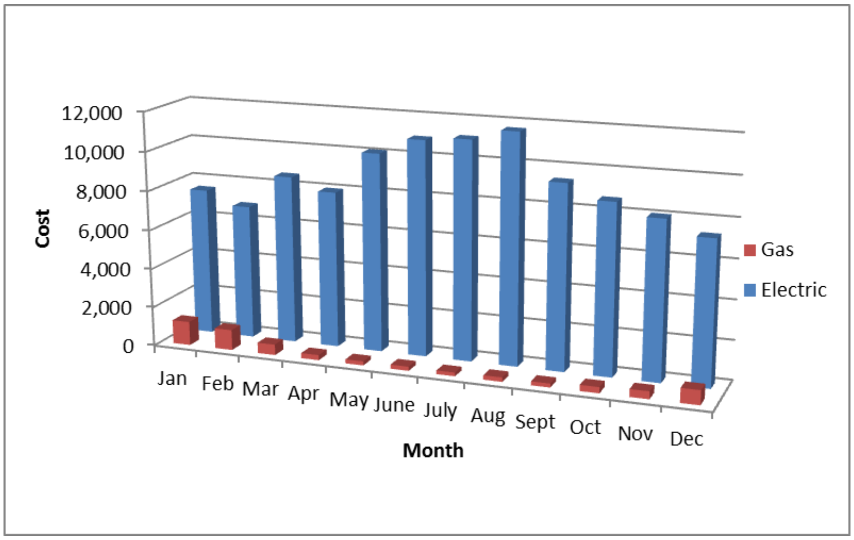



Figure 8- Electric/Gas Monthly Energy Costs

## 3.12 Emissions

Using the total electric and gas energy consumptions per year from *Table 21*, the emission rates for the pollutants $CO_2$, NOx, SOx, and particulates were calculated and are bolded in *Table 26*.

Table 26- Pollution Emission Rates

| | Delivered Electricity by Local State | | | On-Site Combustion in a Commercial Boiler | | | |
|---|---|---|---|---|---|---|---|
| Pollutant | Emission Factor lb/kWh | Electric Consumption kWh/year | Electric Total lbs/year | Emission Factor lbs/1000 $ft^3$ | Gas Consumption 1000 $ft^3$/year | Gas Total lbs/year | **Total Pollutants lbs/year** |
| $CO_{2e}$ | 1.40E+00 | 1,367,278 | 1,914,189 | 1.23E+02 | 667 | 81,998 | 1,996,187 |
| **$CO_2$** | **1.33E+00** | **1,367,278** | **1,818,480** | **1.22E+02** | **667** | **81,331** | **1,899,811** |
| $CH_4$ | 2.52E-03 | 1,367,278 | 3,446 | 2.50E-03 | 667 | 2 | 3,447 |
| $N_2O$ | 2.81E-05 | 1,367,278 | 38 | 2.50E-03 | 667 | 2 | 40 |
| **$NO_x$** | **2.67E-03** | **1,367,278** | **3,651** | **1.11E-01** | **667** | **74** | **3,725** |
| **$SO_x$** | **8.04E-03** | **1,367,278** | **10,993** | **6.32E-04** | **667** | **0** | **10,993** |
| CO | 9.74E-04 | 1,367,278 | 1,332 | 9.33E-02 | 667 | 62 | 1,394 |
| TNMOC | 8.77E-05 | 1,367,278 | 120 | - | - | - | 120 |
| VOC | - | 1,367,278 | - | 6.13E-03 | 667 | 4 | 4 |
| Lead | 1.02E-07 | 1,367,278 | 0 | 5.00E-07 | 667 | 0 | 0 |
| Mercury | 3.24E-08 | 1,367,278 | 0 | 2.60E-07 | 667 | 0 | 0 |
| **PM10** | **7.25E-05** | **1,367,278** | **99** | **8.40E-03** | **667** | **6** | **105** |
| Solid Waste | 1.47E-01 | 1,367,278 | 200,990 | - | - | - | 200,990 |

The emission factors were taken from tables found in the National Renewable Energy Laboratory (NREL) and can be referenced in *Appendix E*. As is shown, $CO_2$ pollution is expected to be the major product of both the electric and gas utilization with 1,899,811 lbs/year, while the particulate pollution rate is the smallest product emitting 105 lbs/year.

# 4.0 Alternative Systems Proposed

**Geothermal Heat Pump**

A Geothermal Heat Pump, also known as a ground-source heat pump, will be used as an alternative to the boilers and assist the chiller. The Fan Powered Induction Units as well as the DOAU will be replaced with heat pumps and the heating and cooling coils will now be fed directly from the ground-source loop and this new system will be analyzed for cost and energy savings.

Geothermal Heat Pumps use the constant temperature of the earth as the exchange medium rather than the outside air. At depths of about six feet, the ground temperature remains relatively constant throughout the year, so even on the coldest or warmest days, an efficient exchange of heat can occur between the ground and the water in the coils.

A possible disadvantage to implementing this system would include additional first costs for installation and materials; however, annual energy costs would expectedly be reduced and the addition of the boilers and possibly the chiller would be unnecessary. A vertical system, upon early investigation, would be the most probable system to implement. For a vertical system, 6 inch holes are drilled about 20 feet apart and 100–600 feet deep. Into these holes are placed two pipes that are connected at the bottom with a U-bend to form a loop. The vertical loops are connected with horizontal pipe to the heat pumps in the building. The water circulating through the building travels through the vertical loops and exchanges heat accordingly with the ground. Geothermal systems are quiet, last long, need little maintenance, and do not depend on the temperature of the outside air. *Figure 9* more clearly illustrates how the interaction of the water flowing through the tubes interacts with the ground to exchange heat.

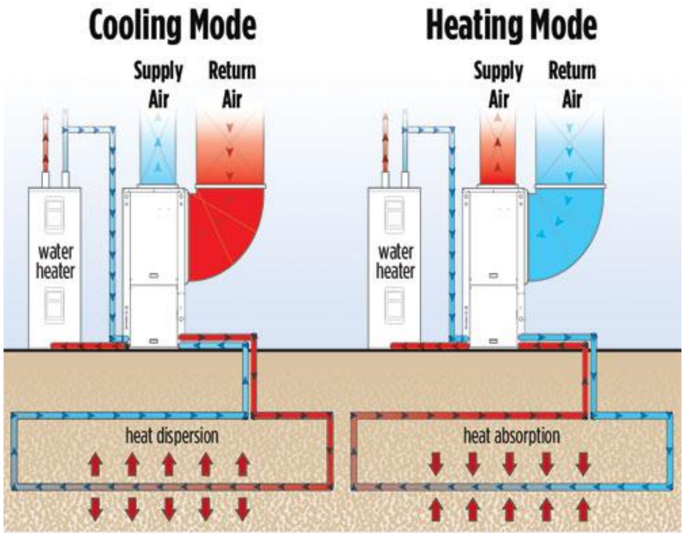



Figure 9- Geothermal Heat Pump Basics

**Thermal Storage**

A thermal storage System with chilled water storage will be installed to supplement the cooling system. A thermal storage system will still utilize chilled water distribution throughout the building; however, rather than the chiller producing chilled water for distribution to the loads, it will be stored in a storage tank. The chiller will only operate during off peak hours (night time) and supply chilled water that will be stored in storage tanks. Then during peak demand periods, the stored chilled water will be distributed to the building loads. The chiller will be operating at off peak hours when utility demand and costs are lower, so significant utility costs should be saved.

The chiller used to create the chilled water should have a higher COP because heat is discharged into colder night time air rather than warmer day time air. The chiller will be operating at off peak hours when utility demand and costs are lower, so significant utility costs should be saved. Thermal storage also reduces greenhouse gas emissions. Possible disadvantages could include increased first costs and maintenance. Also, there are some server rooms that do run 24-hours, so they could have their own, smaller, dedicated air-cooled chiller.

Both the geothermal and the thermal storage systems will be investigated as separate alternatives and compared with cost, efficiency, and feasibility in mind.

## Breadth Topics

**Acoustical**

The penthouse is located on the fourth floor and is separated only by a wall from active office spaces. An acoustical analysis of the sound attenuation through the wall from the penthouse to the offices will be performed. An analysis of the sound reduction caused by downsizing the equipment to the implementation of thermal storage or geothermal systems will also be conducted. Possible investigations into sound solutions could include altering the material properties of the separating wall or moving the penthouse to the fourth floor roof. Since the building's height restriction was removed, moving the penthouse to the fourth floor roof and enclosing the rest of the fourth floor where the penthouse was located should decrease acoustical problems.

**Architectural**

An overall building height restriction of fifty feet was originally issued. In accordance with this height restriction, the penthouse was placed in a "well" on the fourth floor of the building. This left less usable space for the penthouse, so the design team needed to design a compact, efficient penthouse. Also, since the architect still wanted the building to maintain four levels, the height restriction resulted in lower ceiling heights and subsequently smaller plenum sizes, causing coordination issues for the mechanical design team. Therefore, a goal of the design team was to design a system that utilized smaller duct sizes and terminal units, taking up less room in the plenum.

After the design was submitted, the height restriction was lifted. Therefore, an architectural study will be performed by moving the penthouse to the fourth floor roof and enclosing the fourth floor where the penthouse was located. The penthouse had to be specially designed to be compact to fit in its current position, but on the roof, there will be more room for equipment. The ceiling heights will also be raised to allow for more plenum space and a screening device will be designed to hide the now visible penthouse.

**MAE Breadth**

AE 557, Centralized Cooling Production and Distribution Systems, focuses on central chiller plants and includes discussions on thermal storage systems. Information learned from this course will be used in the implementation of a thermal ice storage system in the Army Administration Facility as well as the reduced load on the chiller. AE 558, Centralized Heating and Distribution Systems, includes an economic analysis that will be used to calculate the life cycle cost or payback period of implementing a geothermal heat pump or a thermal storage system.

## Tools and Methods

**Load and Energy Modeling**

Trane TRACE 700 will be used to model the alteration of the chilled water and heating systems. The TRACE analysis used for Technical Report Two will provide the loads needed to size the new chiller and pumps for the geothermal and thermal storage systems and will perform annual energy consumption and cost analyses.

**Architectural Modeling**

Autodesk Revit will be used to model the architecture of the building to demonstrate the locations of the proposed geothermal and thermal storage systems. Also, if the penthouse does need to be relocated as a result of the acoustical analysis, Revit will be able to model the redesign.

**Calculations**

Notes and calculations gathered in AE 557, AE 558, and AE 458 (Advanced Acoustics) will be used in conjunction with Microsoft Excel and equation solving programs such as EES or MATLAB.

**Standards**

Throughout the redesign process, ASHRAE and EPACT 2005 standards will be kept in consideration. Also, since the building is striving for LEED Silver, LEED requirements will be kept in mind and reevaluated during the alterations.

# 5.0 Depth 1: Geothermal Heat Pump

## 5.1 Objective

Replacing the existing heating and cooling sources with a geothermal system could potentially save enough gas to make the system more energy efficient. The heating/cooling provided by the earth will reduce natural gas utility costs and implementation should not be an issue since there is plenty of green space surrounding the building to allow for the necessary ground piping. A vertical loop will be used since ground temperatures do not change throughout the year at deeper borehole depths and vertical loops typically only require about 250 to 300 $ft^2$/ton.

## 5.2 Vertical vs. Horizontal Loop

Vertical ground loops use a drill rig to drill boreholes 150 to 600 ft. deep. A U-tube is dropped in the bore and grouted as depicted in *Figure 10*. Vertical loops typically require about 300 $ft^2$/ton.

Horizontal ground loops run parallel to the ground about six feet under the surface as seen in *Figure 11*. Horizontal loops generally require about 2500 $ft^2$/ton, so a much larger plot of land is required to satisfy the same loads as vertical loops.

Drilling to deep depths for vertical loops can be considerably more expensive and difficult than the trenching that is involved in horizontal loop systems. However, since ground temperatures are more stable at deeper depths, heat exchange is more efficient and vertical loops thus require less piping than horizontal loops. For these reasons, a vertical ground loop system will be used for this analysis.

Figure 10- Vertical Ground Loop System (Source: McQuay)

Figure 11- Horizontal Ground Loop System (Source: McQuay)

## 5.3 Geological Study

When designing a geothermal heat pump, the site soil is the most important element to consider. The appropriate soil resistance is necessary to facilitate adequate heat transfer. The exact location of the building is not to be disclosed per owner's request, but this geological map shows the soil characteristics of the facility site. The building is located in a Mesozoic soil region with cretaceous (65-140 Ma) partly lithified sand, clay, and sandstone. The closest soil type to this found in Table 5 in Chapter 34 of the ASHRAE Handbook- HVAC Applications 2011 is heavy clay, with heavy sand 5% water over sandstone. The properties of this soil type are shown below in *Table27*. A backfill mixture of bentonite and sand was chosen. Backfill/grout is used between the U-tube and the edge of the borehole to seal from air gaps and surface water penetration.

**Table 27- Soil Characteristics**

| Ground | Type | Dry Density lb/ft$^3$ | Conductivity Btu/h-ft-F | Diffusivity ft$^2$/day |
|---|---|---|---|---|
| Soils | Heavy Clay 5% Water | 120 | 0.6 to 0.8 | 0.5 to 0.65 |
| | Light Sand 5% Water | 80 | 0.5 to 1.1 | 0.6 to 1.3 |
| Rock | Sandstone | - | 1.2 to 2.0 | 0.7 to 1.2 |
| Grout | 15% bentonite/85% $SiO_2$ sand | - | 1.00 to 1.10 | - |

(Soil characteristics taken from *Figure 12*)

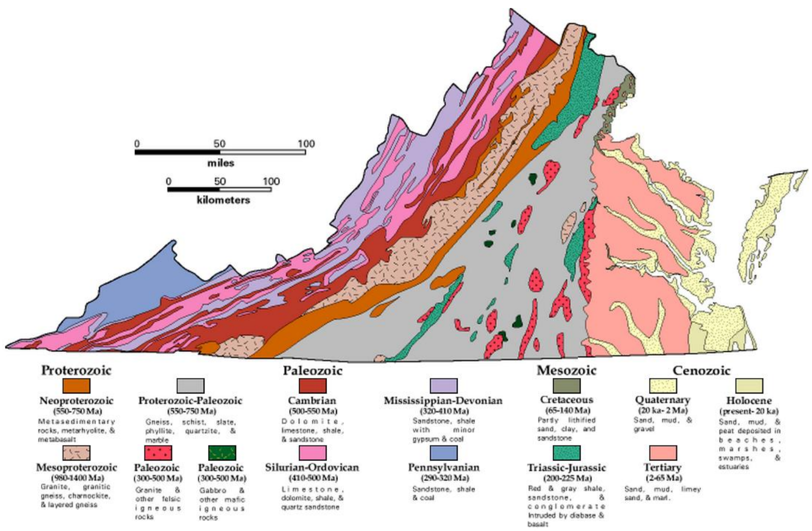



**Figure 12- Geologic Map of Building Location**

According to *Geothermal HVAC, Green Heating and Cooling*, a book recommended by ASHRAE for ground-source heat pump designs, the ground temperature for the site lies between 57F and 52F ground temperature lines as can be seen by *Figure 13*. For the purposes of this report, a ground temperature of 55F will be used.

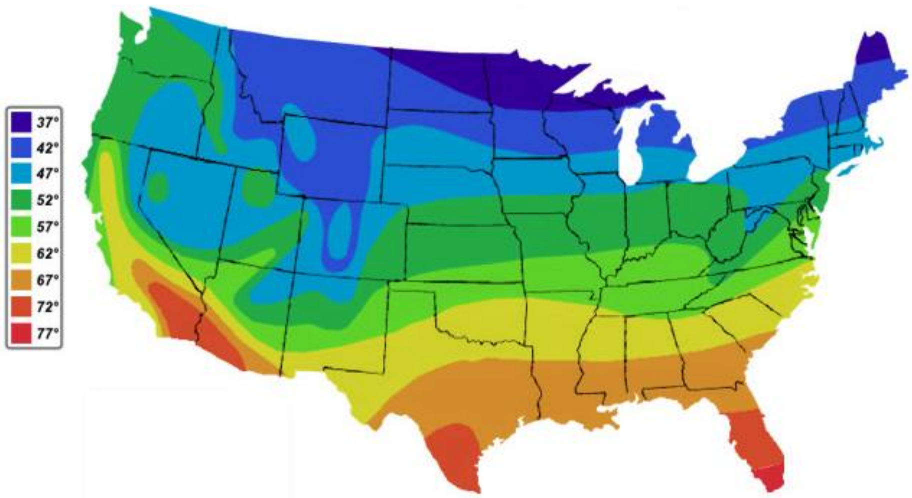



Figure 13- U.S. Ground Temperature Map

The site consists of a 5 acre lot bordered by roads with parking lots to the south, an MWR auto hobby shop to the west, undeveloped land to the north, and a large two-story building far to the east. The facility has a large parking garage directly east of the building, but there is enough land (roughly 100,000 $ft^2$) available directly south of the garage that will be suitable for placement of vertical loops needed for the geothermal system. *Figure 14* highlights the facility's plot of land and the planned location of the underground geothermal pipes.

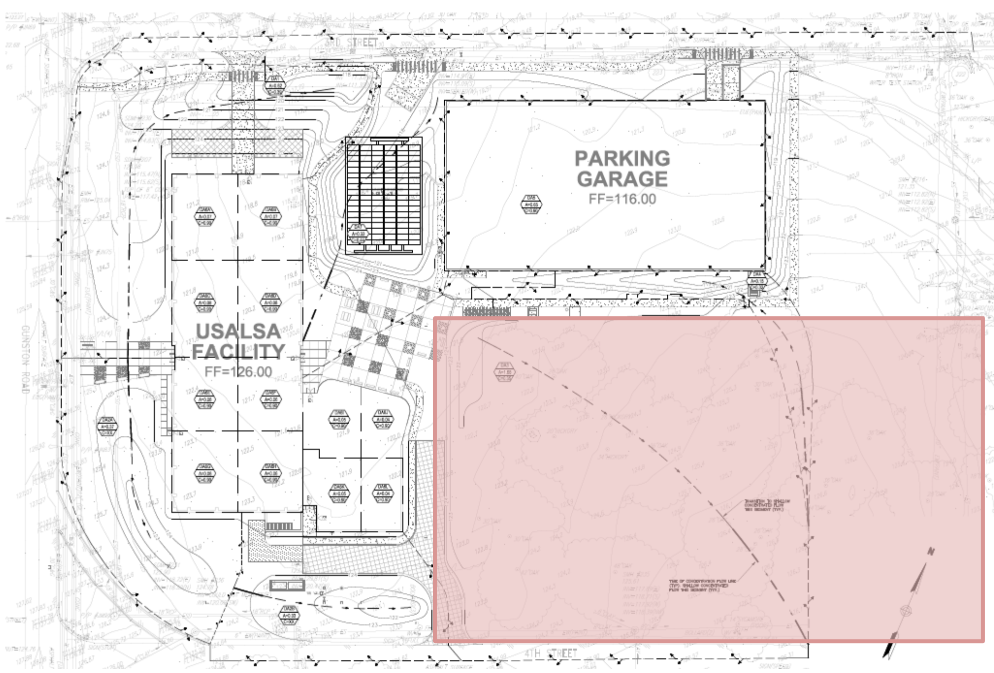



Figure 14- Site Layout

## 5.4 Bore Length Calculations

ASHRAE Handbook – HVAC Applications Chapter 34 offers equations to calculate the necessary bore length to meet the load requirements. These equations account for the variable heat rate of a ground heat exchanger by using a series of constant-heat-rate "pulses" that will be calculated later in this report as $R_{ga}$, $R_{gd}$, and $R_{gm}$.

The required length for cooling:

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41 W_c)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

The required length for heating:

$$L_h = \frac{q_a R_{ga} + (q_{lh} - 3.41 W_h)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

*where,*

$F_{sc}$ = short-circuit heat loss factor
$L_c$ = required bore length for cooling, ft
$L_h$ = required bore length for heating, ft
$PLF_m$ = part-load factor during design month
$q_a$ = net annual average heat transfer to ground, Btu/h
$q_{lc}$ = building design cooling block load, Btu/h
$q_{lh}$ = building design heating block load, Btu/h
$R_{ga}$ = effective thermal resistance of ground (annual pulse), h-ft-°F/Btu
$R_{gd}$ = effective thermal resistance of ground (peak daily pulse), h-ft-°F/Btu
$R_{gm}$ = effective thermal resistance of ground (monthly pulse), h-ft-°F/Btu
$R_b$ = thermal resistance of bore, h-ft-°F/Btu
$t_g$ = undisturbed ground temperature, °F
$t_p$ = temperature penalty for interference of adjacent bores, °F
$t_{wi}$ = liquid temperature at heat pump inlet, °F
$t_{wo}$ = liquid temperature at heat pump outlet, °F
$W_c$ = system power input at design cooling load, W
$W_h$ = system power input at design heating load, W

### *Assumptions*

***Short-Circuit Heat Loss Factor***- Considers heat transfer between the supply and return loops in each bore. Since the system will be designed with loops in parallel, there will be only one bore per loop. A flow rate of 3 gpm/ton was assumed. Using the table in ASHRAE Handbook Chapter 34 shown below in *Table 28*, a short-circuit heat loss factor of 1.04 was chosen.

Table 28- Short-Circuit Heat Loss Factors

| | $F_{sc}$ | |
|---|---|---|
| **Bores per Loop** | **2 gpm/ton** | **3 gpm/ton** |
| 1 | 1.06 | 1.04 |
| 2 | 1.03 | 1.02 |
| 3 | 1.02 | 1.01 |

***Part Load Factor***- Since part load performance was unknown, a worst case PLF of 1.0 was used.

***Net Annual Average Heat Transfer to Ground***- This value is the sum of the cooling and heating block load. Since the cooling block load is negative since it is releasing heat into the ground, the net annual average heat transfer to the ground is the heat gained or lost by the ground due to the differences in heating and cooling loads.

***Design Cooling and Heating Block Loads***- These loads were calculated from the TRACE model presented earlier in this report. Since a 20% ethylene glycol mixture will be added to the ground water to lower freezing temperatures, correction factors of 0.992 and 0.982 were added to the cooling and heating capacities, respectively.

***Effective Thermal Resistance of Ground***- These values were calculated using equations and figures provided by the 2012 ASHRAE Handbook – HVAC Applications Chapter 34.

$$R_{ga} = \frac{(G_f - G_1)}{k_g} \qquad R_{gm} = \frac{(G_1 - G_2)}{k_g} \qquad R_{gd} = \frac{G_2}{k_g}$$

*where*,
$k_g$ = ground thermal conductivity found in Table 5 of the ASHRAE Handbook,
$G_n$ = G-Factors found in Fig. 15 in the ASHRAE Handbook using Fourier numbers:

$$Fo_f = \frac{4\alpha\tau_f}{d_b^2} \qquad Fo_1 = \frac{4\alpha(\tau_f - \tau_1)}{d_b^2} \qquad Fo_2 = \frac{4\alpha(\tau_f - \tau_2)}{d_b^2}$$

*where*,
$\alpha$ = thermal diffusivity of the ground, $ft^2$/day, found in Table 5 of the ASHRAE Handbook,
$d_b$ = bore diameter in feet. A bore diameter of 6” was chosen for this application,
$\tau$ = time of operation, days ($\tau_1$ = 3650 days, $\tau_2$ = 3680 days, $\tau_f$ = 3680.25 days)

***Thermal Resistance of Bore***- It was assumed that a 1-1/4” U-Tube would be used in a 6” borehole with a conductivity of 1.0 BTU/ h-ft-°F. Using Table 6 in the 2012 ASHRAE Handbook – HVAC Applications Chapter 34, this provides a thermal resistance ($R_b$) of 0.09 h-ft-°F/BTU.

***Undisturbed Ground Temperature***- This value was determined from the geological study using *Figure 13*.

***Temperature Penalty for Interference of Adjacent Bores-*** This value was determined using Table 7 and Table 8 of the 2012 ASHRAE Handbook – HVAC Applications Chapter 34. An $EFLH_c$ and $EFLH_h$ of 750 and 750, respectively, were used, assuming a 20 ft. bore separation.

***Liquid Temperature at Heat Pump Inlet/Outlet***- These four variables were gathered from the coil schedules. The heat pump inlet temperature would be the leaving ground water temperature and the heat pump outlet temperature would be the entering ground temperature.

***System Power Input at Design Cooling/Heating Load***- This accounts for heat added to the water from pumps.

### Results

The variables used in the bore length calculations are presented below in *Table 29*.

**Table 29- Bore Length Calculation Results**

| | | | |
|---|---|---|---|
| Required bore length for cooling | $L_c$ | **251700** | **ft** |
| Required bore length for heating | $L_h$ | **159421** | **ft** |
| Short-circuit heat loss factor | $F_{sc}$ | 1.04 | - |
| Part-load factor during design month | $PLF_m$ | 1 | - |
| Net annual average heat transfer to ground | $q_a$ | -1496295 | Btu/h |
| Building design cooling block load | $q_{lc}$ | -3475968 | Btu/h |
| Building design heating block load | $q_{lh}$ | 1979672.7 | Btu/h |
| Effective thermal resistance of ground (annual pulse) | $R_{ga}$ | 0.3166667 | ft-h-F/Btu |
| Effective thermal resistance of ground (peak daily pulse) | $R_{gd}$ | 0.183 | ft-h-F/Btu |
| Effective thermal resistance of ground (monthly pulse) | $R_{gm}$ | 0.2916667 | ft-h-F/Btu |
| Thermal resistance of bore | $R_b$ | 0.09 | ft-h-F/Btu |
| Undisturbed ground temperature | $t_g$ | 55 | F |
| Temperature penalty for interference of adjacent bores | $t_p$ | 3.4 | F |
| Liquid temperature at heat pump inlet, cooling | $t_{wi}$ | 55 | F |
| Liquid temperature at heat pump outlet, cooling | $t_{wo}$ | 68 | F |
| System power input at design cooling load | $W_c$ | 14650 | W |
| System power input at design heating load | $W_h$ | 14650 | W |

The cooling load dictated a larger length required to meet the load. To meet a 292 ton cooling load, **251,700 LF** of bores are required.

## 5.5 System Layout

Time permitting, a full well field optimization to find the most cost effective combination of bore length to number of bores was not performed. The plot of land available for the boreholes was roughly 650 ft by 320 ft, so, a well field grid of 31x16 fit appropriately on the site. Boreholes are separated 20 feet both horizontally and vertically. It is necessary to provide at least 20 feet of spacing or bores could affect the efficiency of heat transfer by changing the ground temperature around adjacent bores. The field was kept as one long loop because at peak load, the flow through the pipes will be turbulent and promote efficient heat transfer. At part load, however the flow rate will drop and the flow will drop to laminar. By keeping the field as one long loop, the surface area for heat transfer during part load is so large that the inefficient heat transfer of laminar flow would be negligible.

The water that is circulating through the ground will enter the south of the building through the basement where it will enter a heat exchanger. On the other end of the heat exchanger will be the circulating building water. From the basement, the water will be pumped up the building and distributed to each floor. The FPIUs that once occupied the space and each served three rooms will be replaced by heat pumps. The heat pumps will receive the circulating building water and through its refrigeration cycle, create the necessary cooling or heating coil temperatures to condition the return air.

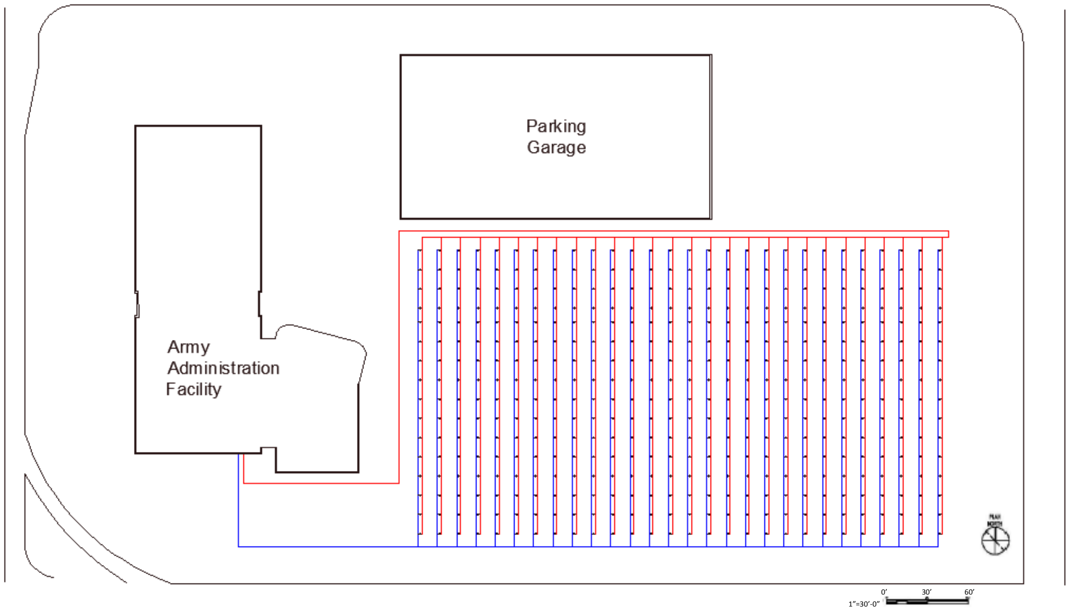



**Figure 15- Bore Field Layout**

The well field layout is diagrammed in *Figures 15 and 16*. The piping system utilizes reverse-return headers, which reduce head loss and provide pressure balancing without additional balancing equipment.

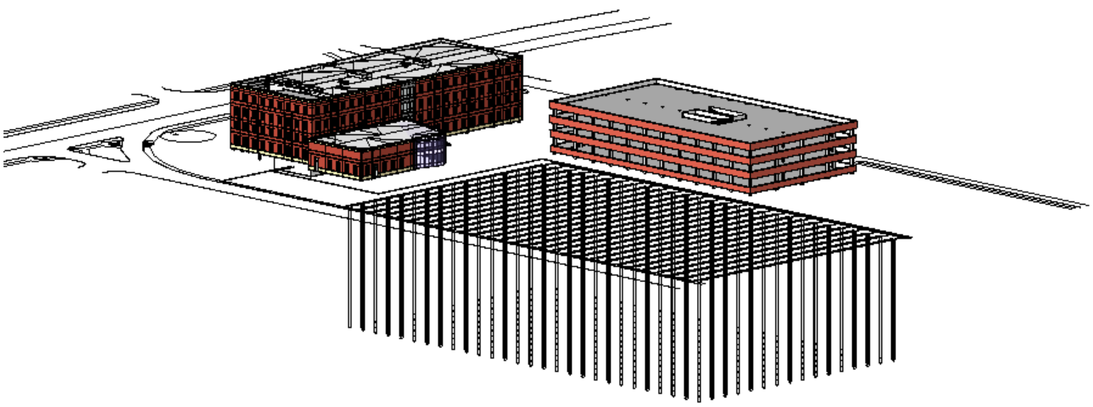


**Figure 16- 3D Bore Field Layout**

## 5.6 Heat Pump Selections

Since the terminal units require 55F water for cooling and 180F water for heating, each FPIU will be replaced with a heat pump. This way the necessary heating temperatures can be reached and if the ground temperature fluctuates, the heat pumps can adjust accordingly at the space and supply the required water temperatures. The heat pumps will be most necessary for the heating applications to get the water as close to 180F as possible. A heat pump has its own refrigeration cycle, where the ground loop acts as the condensing loop, with the ground as the heat rejection equipment. This way if the "condensing loop" has an entering water temperature of 55F and a leaving water temperature of 64F, the load side water loop can have much higher or lower temperatures, if needed, with adjusted delta T's and enthalpies. A typical heat pump is picture in *Figure 17*.

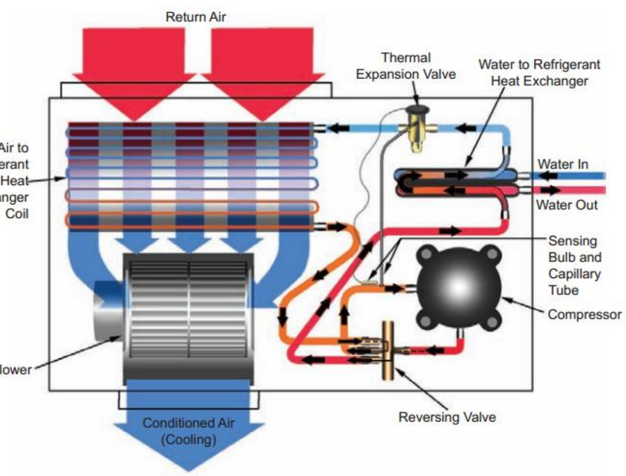



**Figure 17- Typical Heat Pump**

To size the heat pumps, the existing FPIU data can be used. There are two sizes of FPIU utilized in the facility. One has a coil capacity of 1.2 tons at 3 gpm and an airflow capacity of 720 cfm. The other has a coil capacity of 1.6 tons at 3.9 gpm and an airflow capacity of 1,030 cfm. McQuay Enfinity Horizontal Ceiling Water Source Heat Pumps were chosen because they can be mounted where the existing FPIUs are mounted and they have similar dimensions. Two models were chosen, a CCW 015 with a 15,000 BTU/h capacity and a CCW 019 with a 19,000 BTU/h capacity, scheduled in *Table 30*.

**Table 30- Heat Pump Schedule**

| HEAT PUMP SCHEDULE | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | SUPPLY FAN | | | | | CHILLED WATER COIL | | | | | | | HOT WATER COIL | | |
| SYMBOL | MANUFACTURER | MODEL | TOTAL AIRFLOW (CFM) | AIRFLOW (CFM) | ESP (IN. WC.) | MOTOR SIZE (HP) | FLA | V/PH/HZ | AIRFLOW (CFM) | TOTAL (MBH) | SENSIBLE (MBH) | EWT (°F) | LWT (°F) | FLOW (GPM) | dPW (FT WC) | EWT (°F) | LWT (°F) | FLOW (GPM) |
| HP 1 | MCQUAY | WCCW 015 | 800 | 800 | 0.3 | 1/2 | 4.1 | 277/1/60 | 720 | 15.0 | 15.0 | 55 | 64.2 | 3.0 | 13.5 | 180 | 106.0 | 0.5 |
| HP 2 | MCQUAY | WCCW 019 | 1,200 | 1,200 | 0.3 | 3/4 | 5.5 | 277/1/60 | 1,030 | 19.0 | 19.0 | 55 | 64.8 | 3.9 | 13.5 | 180.0 | 115.8 | 1.0 |
| HP DOAU | MCQUAY | WCCW 420 | 24,000 | 4,000 | 2.0 | 6 1/2 | - | 460/3/60 | 24,000 | 1,557.0 | 808.0 | 55 | 66.3 | 269.1 | 18.2 | 180.0 | 150.0 | 74.3 |

## 5.7 Pump Selections

To size the ground loop pumps (GSWP) properly, first the head pressure must be calculated**.** The loop will be piped in a reverse-return layout, so each bore will have the same length of run. Because of this, any bore location can be used for the calculation. The flow rates through each loop and a pipe diameter can be used to find head loss per 100 ft of length. The pipe diameter of each loop is 1-1/4" and the header diameter, since it needs to supply 31 branches of loops, was sized up to 6". Since head loss is ft/ 100 ft, the equivalent length of a run must be taken into consideration to find total head loss for both the header and the branches/loops. The equivalent length is the sum of the actual length of the pipe and the equivalent lengths caused by the fittings and valves. *Figure 18* represents the longest length of pipe in any loop. The loop has (16) 90° angles, (62) tees, and (2) gate valves. The aforementioned calculations for the loop can be found in *Appendix C* and the results are displayed in *Table 31*.

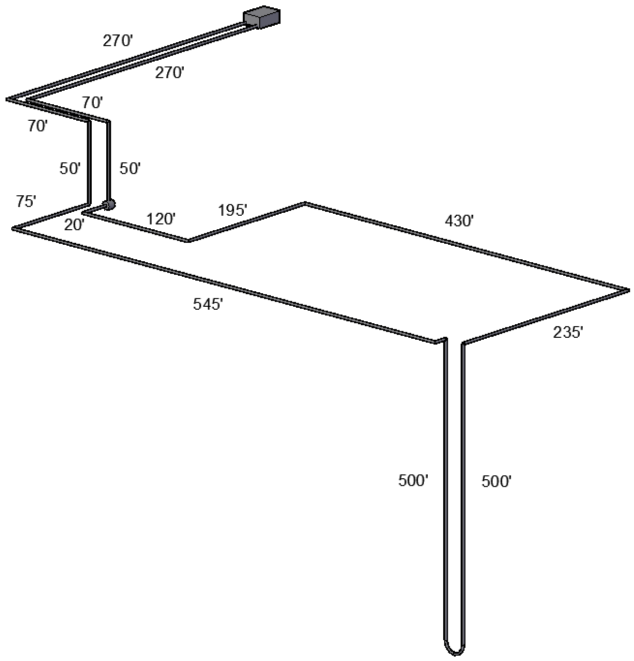



Figure 18- Longest Run of Pipe

Table 31- Pump Size

| Pump | |
|---|---|
| Capacity [gpm] | 876 |
| Total Head [ft water] | 113 |

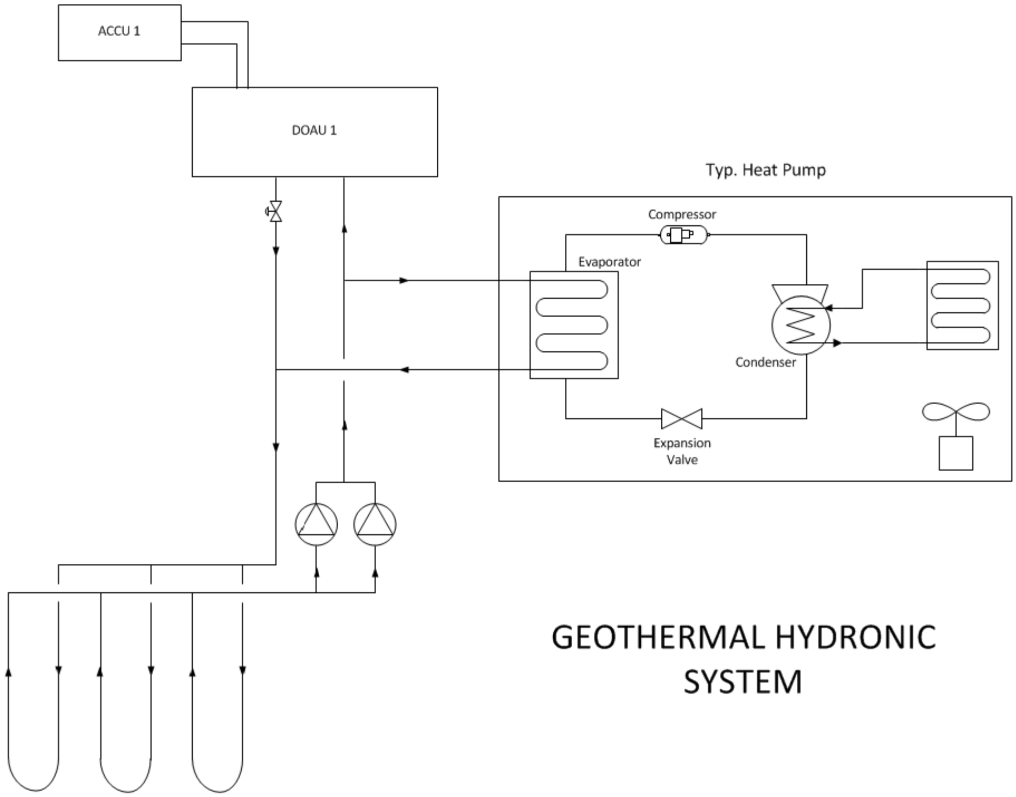
For redundancy reasons, (2) pumps will be used, each to handle the full load. This way the pumps can cycle to increase pump life or if one pump needs to be serviced or has problems, the other can run. The pump schedule is shown in *Table 32* and a photo of the chosen pump type is shown in *Figure 19*.

Table 32- Ground-Source Pump Schedule

| GSWP PUMP SCHEDULE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID TAG | MANUFACTURER/ SERIES | MODEL | SERVICE | FLUID TYPE | FLOW (gpm) | HEAD (ft wc) | PUMP EFFICIENCY (%) | RPM | PUMP MOTOR | | | EMER. POWER |
| | | | | | | | | | SHAFT POWER (Bhp) | MOTOR SIZE (Hp) | Volt/Hz/Ph | |
| GSWP-1 | BELL & GOSSETT | SERIES 1510 1-1/2AC | GROUND LOOP WATER | CHW | 876 | 113 | 73.0% | 3,550 | 34.2 | 22.9 | 460/60/3 | NO |
| GSWP-2 | BELL & GOSSETT | SERIES 1510 2BC | GROUND LOOP WATER | CHW | 876 | 113 | 73.0% | 3,550 | 34.2 | 22.9 | 460/60/4 | NO |

Figure 19- Bell & Gossett Series 1510 Pump

## 5.8 Schematic



## 5.9 Energy and Cost Analysis

An analysis of the proposed ground-source heat pump annual energy consumption and operating costs was conducted using Trane TRACE 700.

### *Total Energy Consumption*

The TRACE model produced results shown in *Table 33*. Both the energy consumption of the existing system and the geothermal system are shown as a measure for comparison. As can be seen, the geothermal system saves 666,654 kBTU/yr of gas but it uses more electricity. This is because the geothermal loop is so large that the pumping power required to operate the loops is not offset by the loss of the chiller and boilers. The receptacle loads require the most energy (41% of the total building energy) and the smallest energy consumer in this system is the heating loads, even though the ground loop assumes the loads previously handled by the boilers.

Overall, however, the excess electrical energy required by the geothermal system outweighs the savings in gas energy. As a result, the geothermal system requires 190,960 kBtu/yr **more** than the existing system.

**Table 33- Geothermal Annual Energy Consumption**

| Geothermal Heat Pump vs. Existing System | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Electric kWh | | Gas kBtu | | Total Building Energy kBtu/yr | | % of Total Building Energy | |
| **System** | **Existing** | **Geothermal** | **Existing** | **Geothermal** | **Existing** | **Geothermal** | **Existing** | **Geothermal** |
| **Primary Heating** | | | | | | | | |
| Primary Heating | | 23,754 | 666,654 | | 666,654 | 81,072 | 12.5% | 1.6% |
| Heating Accessories | 17,520 | 20 | | | 59,796 | 68 | 1.1% | 0.0% |
| Heating Subtotal | **17,520** | **23,774** | **666,654** | **0** | **726,450** | **81,141** | 13.6% | **1.6%** |
| **Primary Cooling** | | | | | | | | |
| Cooling Compressor | 275,490 | 241,754 | | | 940,247 | 825,106 | 17.6% | 16.0% |
| Tower/Cond Fans | 36,017 | 7,096 | | | 122,926 | 24,219 | 2.3% | 0.5% |
| Condenser Pump | 31,071 | | | | 106,045 | 0 | | |
| Cooling Accessories | 876 | 199 | | | 2,990 | 679 | 0.1% | 0.0% |
| Cooling Subtotal | **343,454** | **249,049** | **0** | **0** | **1,172,209** | **850,004** | 22.0% | **16.5%** |
| **Auxiliary** | | | | | | | | |
| Supply Fans | 6,644 | 208,125 | | | 22,676 | 710,331 | 0.4% | 13.8% |
| Pumps | 148,529 | 170,123 | | | 506,929 | 580,630 | 9.5% | 11.3% |
| Aux Subtotal | **155,173** | **378,248** | **0** | **0** | **529,605** | **1,290,960** | 9.9% | **25.1%** |
| **Lighting** | | | | | | | | |
| Lighting | **232,479** | **232,479** | **0** | **0** | **793,451** | **793,451** | **0** | **15.4%** |
| **Receptacles** | | | | | | | | |
| Receptacles | **618,652** | **623,105** | **0** | **0** | **2,111,459** | **2,126,657** | **0** | **41.4%** |
| **Total** | **1,367,278** | **1,506,655** | **666,654** | **0** | **5,333,174** | **5,142,214** | **100.0%** | **100.0%** |
| **Geothermal Savings** | **-139,377** | | **666,654** | | **190,960** | | **-** | **-** |

### *Monthly Energy Consumption Breakdown*

A monthly breakdown of the energy consumption for electric and gas are shown in *Table 34* below. As can be seen by the table and *Figure 20*, the electricity loads reach their peaks in the summer months, while the gas loads reach their peaks in the winter months. This same trend is followed by both systems but geothermal uses more electricity than the existing system each month, especially in the winter. On the other hand, the geothermal system uses zero gas energy for heating.

Table 34- Geothermal Monthly Energy Consumption

| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric [kWh] | Existing System | 95,367 | 86,851 | 108,507 | 100,962 | 127,664 | 138,070 | 140,425 | 147,252 | 118,424 | 109,410 | 101,721 | 92,626 | 1,367,279 |
| | Geothermal System | 114,761 | 103,779 | 125,196 | 114,016 | 138,008 | 143,377 | 138,225 | 150,830 | 127,472 | 124,508 | 116,720 | 109,762 | 1,506,654 |
| | Geothermal Savings | -19,394 | -16,928 | -16,689 | -13,054 | -10,344 | -5,307 | 2,200 | -3,578 | -9,048 | -15,098 | -14,999 | -17,136 | -139,375 |
| Gas [therms] | Existing System | 1,465 | 1,252 | 653 | 320 | 252 | 252 | 229 | 270 | 242 | 375 | 471 | 886 | 6,667 |
| | Geothermal System | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| | Geothermal Savings | 1,465 | 1,252 | 653 | 320 | 252 | 252 | 229 | 270 | 242 | 375 | 471 | 886 | 6,667 |

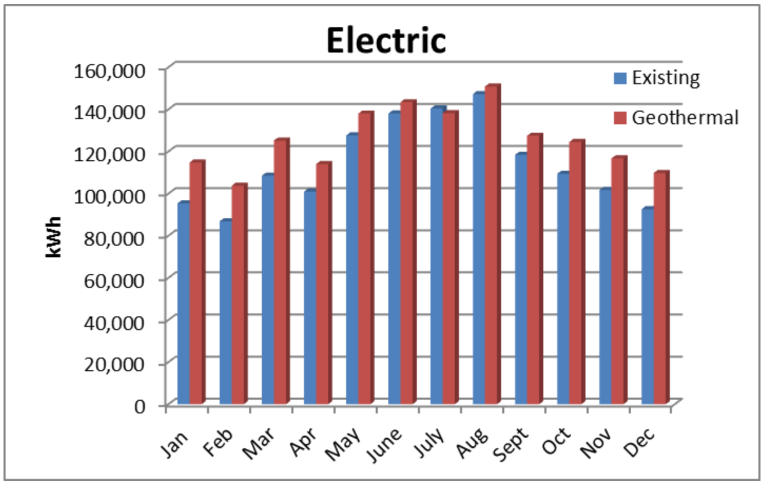



Figure 20- Existing vs. Geothermal System Monthly Energy Consumption

## *Electrical Energy Breakdown*

The gas loads were a large source of the energy consumed annually in the Army Administration Facility by the existing system. Geothermal, however, handles the heating load without the use of gas boilers. *Table 35* and *Figure 21* show a breakdown of solely the electrical power consumption by component. Primary heating is still the smallest consumer of electric power in this building even though the geothermal system now handles the heating load completely. Receptacles, as can be anticipated, require a large portion (41%) of the electric supply. This is most likely due to the miscellaneous loads added to each room in the TRACE model. Large receptacle loads can result from equipment such as computers, projectors, and other general office equipment that can give off heat.

Table 35- Geothermal Electric Consumption per Component

| | Electrical Consumption kWh | |
|---|---|---|
| | Existing System | Geothermal System |
| **Primary Heating** | 17,520 | 23,774 |
| **Primary Cooling** | 343,454 | 249,049 |
| **Auxiliary** | 155,173 | 378,248 |
| **Lighting** | 232,479 | 232,479 |
| **Receptacles** | 618,652 | 623,105 |
| **Total** | **1,367,278** | **1,506,655** |

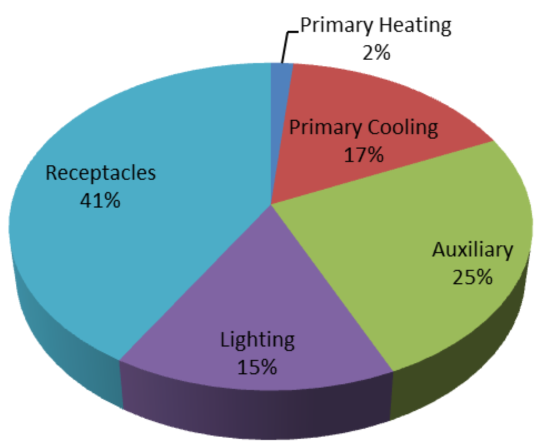



Figure 21- Geothermal Electric Energy Breakdown

## *Initial Costs*

For a full cost breakdown of the geothermal system, reference *Appendix C*. Costs were taken from RSMeans 2012 Mechanical Cost Data or were provided by the manufacturer. The total cost of installation for the system would be around $653,372 as shown in *Table 36*. This value includes a $51/ton state incentive for implementing a geothermal system. When considering the cost of the equipment in the existing system that is not necessary for a geothermal system, $612,204 is saved as seen in *Table 37*. Therefore the actual cost of the geothermal system over the existing system is roughly $41,170.

**Table 36- Geothermal Initial Costs**

| | COST | | |
|---|---|---|---|
| | MAT. | INST. | TOTAL |
| **GEOTHERMAL HEAT PUMP SYSTEM 300 TON, VERTICAL LOOP** | 483,233.64 | 185,031.32 | **653,372.96** |

**Table 37- Existing System Unused Equipment Costs**

| System Components | MAT. COST PER UNIT | INST. COST PER UNIT | QUANTITY | UNIT | COST MAT. | COST INST. | COST TOTAL |
|---|---|---|---|---|---|---|---|
| **Existing System Components** | | | | | | | |
| Water Chiller, integral air cooled condenser, 300 ton | 172000.00 | 8475.00 | 1 | Ea. | 172,000.00 | 8,475.00 | 180,475.00 |
| Gas-fired boiler | 15700.00 | 5300.00 | 2 | Ea. | 31,400.00 | 10,600.00 | 42,000.00 |
| Fan Powered Induction Unit | 1000.00 | 1400.00 | 150 | Ea. | 150,000.00 | 210,000.00 | 360,000.00 |
| Hot water pump, 80 gpm | 3590.00 | 437.00 | 2 | Ea. | 7,180.00 | 874.00 | 8,054.00 |
| Condenser pump, 750 gpm | 6200.00 | 1025.00 | 3 | Ea. | 18,600.00 | 3,075.00 | 21,675.00 |
| Total | | | | | 379,180.00 | 233,024.00 | **612,204.00** |

## *Cost Breakdown*

Using the electricity and natural gas rates from the EIA for the local (undisclosed) area, shown in *Table 16*, it can be concluded that the Army Administration Facility with a geothermal system should expect to spend roughly $120,231 per year on utilities. This is roughly $5,542 more per year than the existing system, which translates to about $0.06 per square foot more each year than the existing system. These conclusions are summarized below in *Table 38*.

**Table 38- Geothermal Annual Cost Analysis**

| Equipment | Electric Consumption [kWh] Existing System | Electric Consumption [kWh] Geothermal System | Cost Per Year [$] Existing System | Cost Per Year [$] Geothermal System | Cost Per SF [$] Existing System | Cost Per SF [$] Geothermal System |
|---|---|---|---|---|---|---|
| **Primary Heating** | | | | | | |
| Heating Accessories | **17,520** | **23,774** | **1,398** | **1,897** | **0.016** | **0.022** |
| **Primary Cooling** | | | | | | |
| Cooling Compressor | 275,490 | 241,754 | 21,984 | 19,292 | 0.253 | 0.222 |
| Tower/Cond Fans | 36,017 | 7,096 | 2,874 | 566 | 0.033 | 0.007 |
| Condenser Pump | 31,071 | 0 | 2,479 | 0 | 0.028 | 0.000 |
| Cooling Accessories | 876 | 199 | 70 | 16 | 0.001 | 0.000 |
| Cooling Subtotal | **343,454** | **249,049** | **27,408** | **19,874** | **0.315** | **0.228** |
| **Auxiliary** | | | | | | |
| Supply Fans | 6,644 | 208,125 | 530 | 16,608 | 0.006 | 0.191 |
| Pumps | 148,529 | 170,123 | 11,853 | 13,576 | 0.136 | 0.156 |
| Aux Subtotal | **155,173** | **378,248** | **12,383** | **30,184** | **0.142** | **0.347** |
| **Lighting** | | | | | | |
| Lighting | **232,479** | **232,479** | **18,552** | **18,552** | **0.213** | **0.213** |
| **Receptacles** | | | | | | |
| Receptacles | **618,652** | **623,105** | **49,368** | **49,724** | **0.567** | **0.571** |
| **Electric Subtotal** | **1,367,278** | **1,506,655** | **109,109** | **120,231** | **1.254** | **1.382** |
| **Geothermal Savings** | **-139,377** | | **-11,122** | | **-0.128** | |

| System | Gas Consumption [kBtu] Existing System | Gas Consumption [kBtu] Geothermal System | Cost Per Year [$] Existing System | Cost Per Year [$] Geothermal System | Cost Per SF [$] Existing System | Cost Per SF [$] Geothermal System |
|---|---|---|---|---|---|---|
| **Primary Heating** | 666,654 | 0 | 5,580 | 0 | 0.064 | 0.000 |
| **Primary Cooling** | 0 | 0 | 0 | 0 | 0.000 | 0.000 |
| **Auxiliary** | 0 | 0 | 0 | 0 | 0.000 | 0.000 |
| **Lighting** | 0 | 0 | 0 | 0 | 0.000 | 0.000 |
| **Receptacles** | 0 | 0 | 0 | 0 | 0.000 | 0.000 |
| **Gas Subtotal** | **666,654** | **0** | **5,580** | **0** | **0** | **0** |
| **Geothermal Savings** | **666,654** | | **5,580** | | **0.064** | |

| | Energy Consumption [kBtu] Existing System | Energy Consumption [kBtu] Geothermal System | Cost Per Year [$] Existing System | Cost Per Year [$] Geothermal System | Cost Per SF [$] Existing System | Cost Per SF [$] Geothermal System |
|---|---|---|---|---|---|---|
| **Electric Subtotal [kBtu]** | **4,666,520** | **5,142,214** | **109,109** | **120,231** | **1.254** | **1.382** |
| **Gas Subtotal [kBtu]** | **666,654** | **0** | **5,580** | **0** | **0.064** | **0.000** |
| **Energy Total** | **5,333,174** | **5,142,214** | **114,689** | **120,231** | **1.32** | **1.38** |
| **Geothermal Savings** | **190,960** | | **-5,542** | | **-0.064** | |

Despite the geothermal system saving 190,960 kBtu/yr, the cost of electricity is much more than natural gas, so the financial savings from gas do not offset the extra gain in electric costs. The geothermal systems would end up costing $5,542 extra per year for utilities.

A monthly breakdown of the energy costs for electric and gas are shown in *Table 39* below. As can be seen by the table and *Figure 22*, the electricity costs reach their peaks in the summer months when the load is higher, while the gas loads reach their peaks in the winter months. These trends follow those summarized earlier in the monthly energy consumption section of this report.

**Table 39- Existing vs. Geothermal System Monthly Cost Analysis**

| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric $ | Existing System | 7,610 | 6,931 | 8,659 | 8,057 | 10,188 | 11,018 | 11,206 | 11,751 | 9,450 | 8,731 | 8,117 | 7,392 | 109,110 |
| | Geothermal System | 9,158 | 8,282 | 9,991 | 9,098 | 11,013 | 11,441 | 11,030 | 12,036 | 10,172 | 9,936 | 9,314 | 8,759 | 120,230 |
| | Geothermal Savings | -1,548 | -1,351 | -1,332 | -1,041 | -825 | -423 | 176 | -285 | -722 | -1,205 | -1,197 | -1,367 | -11,120 |
| Gas $ | Existing System | 1,226 | 1,048 | 546 | 267 | 211 | 211 | 191 | 226 | 203 | 314 | 394 | 742 | 5,579 |
| | Geothermal System | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| | Geothermal Savings | 1,226 | 1,048 | 546 | 267 | 211 | 211 | 191 | 226 | 203 | 314 | 394 | 742 | 5,579 |

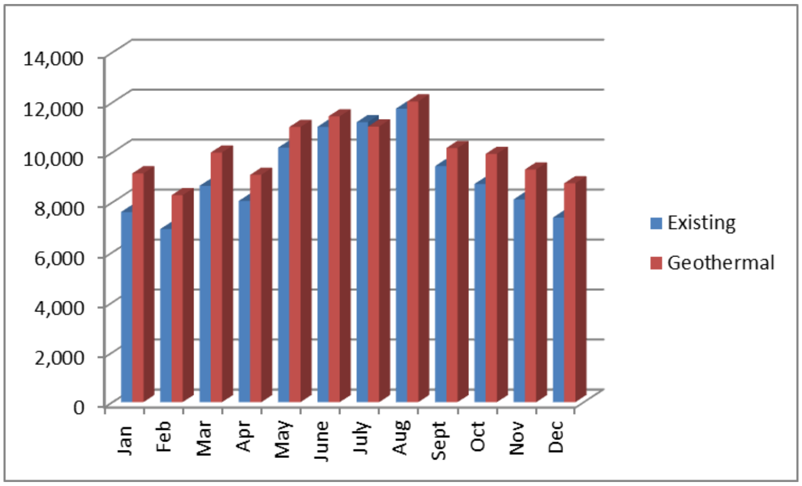



**Figure 22- Existing vs. Geothermal System Monthly Costs**

Since the geothermal system would have a greater initial and annual utility cost, it would never pay back. Therefore, a life cycle cost analysis was not performed because it would be impractical.

## 5.10 Emissions

The emission levels created by the extra electricity of the geothermal system also outweighs the gas saved as is seen in *Table 40*. It can be argued that the emissions created on-site would be virtually none now with no boilers, but the emissions off-site at the power plant need to be considered. A lot of emissions are created when producing electricity, and apparently the geothermal system produces 104,040 lbs/yr $CO_2$, 298 lbs/yr $NO_X$, 1,120 lbs/yr $SO_X$, and 5 lbs/yr PM10 *more* than the existing system.

**Table 40- Pollution Emission Rates**

| | Delivered Electricity by Local State | | | On-Site Combustion in a Commercial Boiler | | | |
|---|---|---|---|---|---|---|---|
| Pollutant | Emission Factor lb/kWh | Electric Consumption kWh/year | Electric Total lbs/year | Emission Factor lbs/1000 $ft^3$ | Gas Consumption 1000 $ft^3$/year | Gas Total lbs/year | **Total Pollutants lbs/year** |
| $CO_{2e}$ | 1.40E+00 | 1,506,655 | 2,109,317 | 1.23E+02 | 0 | 0 | 2,109,317 |
| **$CO_2$** | **1.33E+00** | 1,506,655 | **2,003,851** | **1.22E+02** | **0** | **0** | **2,003,851** |
| $CH_4$ | 2.52E-03 | 1,506,655 | 3,797 | 2.50E-03 | 0 | 0 | 3,797 |
| $N_2O$ | 2.81E-05 | 1,506,655 | 42 | 2.50E-03 | 0 | 0 | 42 |
| **$NO_x$** | **2.67E-03** | 1,506,655 | **4,023** | **1.11E-01** | **0** | **0** | **4,023** |
| **$SO_x$** | **8.04E-03** | 1,506,655 | **12,114** | **6.32E-04** | **0** | **0** | **12,114** |
| CO | 9.74E-04 | 1,506,655 | 1,467 | 9.33E-02 | 0 | 0 | 1,467 |
| TNMOC | 8.77E-05 | 1,506,655 | 132 | - | - | - | 132 |
| VOC | - | - | - | 6.13E-03 | 0 | 0 | 0 |
| Lead | 1.02E-07 | 1,506,655 | 0 | 5.00E-07 | 0 | 0 | 0 |
| Mercury | 3.24E-08 | 1,506,655 | 0 | 2.60E-07 | 0 | 0 | 0 |
| **PM10** | **7.25E-05** | 1,506,655 | **109** | **8.40E-03** | **0** | **0** | **109** |
| Solid Waste | 1.47E-01 | 1,506,655 | 221,478 | - | - | - | 221,478 |

## 5.11 Depth 1 Analysis Conclusion

A ground-source heat pump installation that could support the full building load is not recommended.

If the cost of natural gas went up from $0.84 to $1.70 / therm, then the geothermal system would start to save money since it uses less total energy per year than the existing system. However, with the current cost of utilities and the system as it was proposed, a geothermal redesign would not be financially beneficial for the building in any way. A geothermal system that can handle the *full* capacity of this building would require (500) 500 ft. bores with an initial investment of $653,373. Although the system saves on total energy each year, it will cost about $5,500 more on utilities. The system would also generate more emissions due to excess generation of electricity. Therefore, unless the building owner is adamant on building a ground-source heat pump system, it would be ill-advised to install one that can handle the full load of this facility in this location.

# 6.0 Depth 2: Thermal Chilled Water Storage

## 6.1 Objective

A thermal storage system utilizing chilled water will be installed to supplement the cooling system; however, rather than the chiller producing chilled water for distribution to the loads directly, it will be stored in a storage tank. The chiller will only operate during off peak hours (nighttime) and supply chilled water that will be stored in storage tanks. Then during peak demand periods, the stored chilled water will be distributed to the building loads. The chiller will be operating at off peak hours when utility demand and costs are lower, so significant utility costs should be saved.

## 6.2 Chilled Water vs. Ice Storage

Cool storage media include chilled water, ice, or other aqueous or phase-changing materials. Chilled water thermal storage requires less energy from the chillers, since it does not require changing the water into ice, and water has a high specific heat, so it is still effective for sensible energy storage applications. Creating ice requires significantly more energy from the chiller, but it has a high heat of fusion (thermal energy capacity), so ice storage would be more effective in the heat transfer process and tanks can thus be much smaller than chilled water tanks. It is difficult with ice, however, to control the appropriate amount of heat transfer necessary to alternately freeze and melt the ice, so a more knowledgeable and capable maintenance staff is necessary. Thus, chilled water storage is cheaper to install and maintain and space for a large tank is not an issue on the site, so chilled water thermal storage will be used for this analysis.

## 6.3 Full Storage vs. Partial Storage

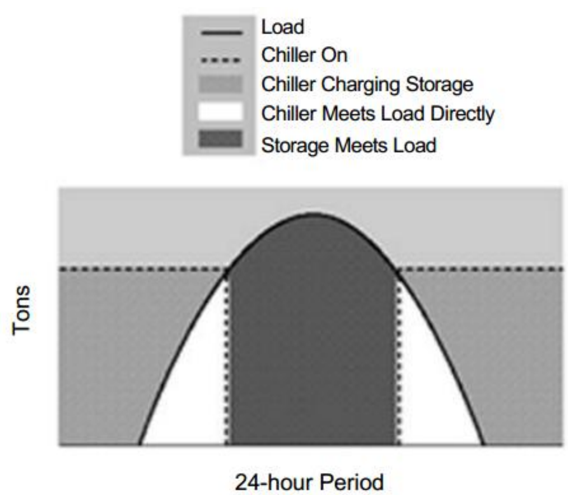



Figure 23- Full Storage Load Profile (Source: ASHRAE)

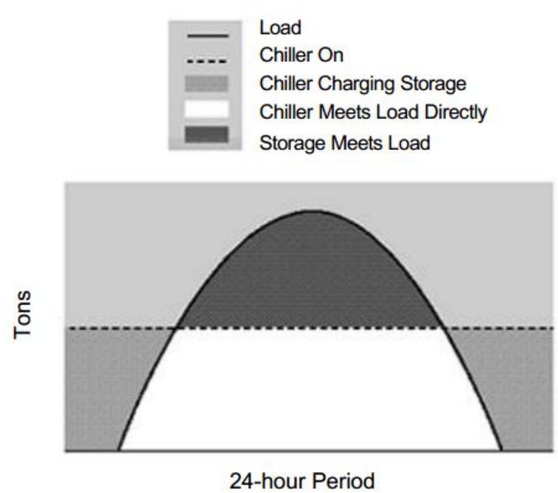



Figure 24- Partial Storage Load Profile (Source: ASHRAE)

Full Storage shifts the entire on-peak cooling load to off-peak hours. The chiller will operate at full load during off-peak hours, when utility rates are typically cheaper, and create enough storage capacity to supply the full load during on-peak hours. This system would require a relatively large chiller and storage tank. Full storage is illustrated in *Figure 23*.

Partial Storage, load-leveling requires the chiller to run 24 hours, but the chiller capacity can be much lower. During off-peak hours, when the load is less than the chiller output, the excess is stored. During on-peak hours, the storage will supply some of the needed load and the rest is met by the chiller. This method allows for smaller chiller and storage capacity. Load leveling is illustrated in *Figure 24*.

Both full and partial storage will be analyzed to assess the most economical strategy.

## 6.4 Sensible Storage Devices

There are four common designs for chilled water thermal separation devices: thermal stratification, flexible diaphragm, multiple tanks, and labyrinth tanks.

In stratified storage, less dense warm water floats over denser cold water. During off-peak hours, cold water coming from the chiller(s) enters the tank at the bottom and forces the warm water at the top of the tank out to the chiller(s). When the system is discharging during on-peak hours, the flow reverses and the cold water at the bottom leaves the tank to be distributed to the loads while the warm return water enters the top of the tank as shown in *Figure 25*. The contact of the warm with the cold water creates what is called a thermocline, which is an area where the water temperature and density changes greatly. The thermocline acts like a barrier to inhibit mixing of the warm and cool water. For this reason, it is preferable for thermal stratification tanks to be more vertical than horizontal.

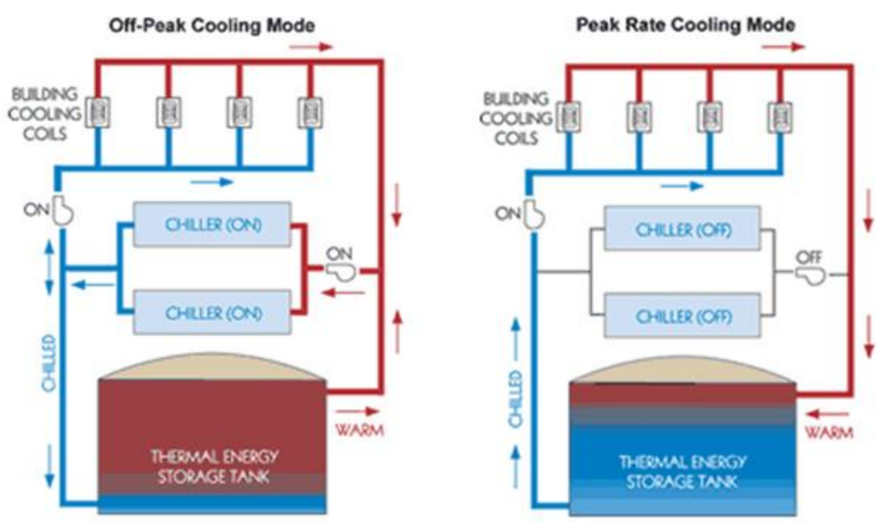



**Figure 25- Thermal Storage Schematic (Stratified Tank)**

Flexible diaphragm storage is similar to thermal stratification, but instead of having the thermocline act as a barrier between the warm and cool water, a physical barrier (usually rubber) is placed in the middle of the tank to separate the warm from the cold water. The reliability of this flexible diaphragm to move with the changing water levels is sometimes questionable, so the effectiveness of this method is often not the best.

The multiple tank method utilizes separate tanks piped in series. Warmer and cooler water never occupy the same tank at the same time. Water flows through the compartments in series, where one of the full compartments empties while the empty compartment is filled.

Labyrinth tank utilizes successive cubicles with high and low ports. When charging, water will flow from a high port to a low port, and vice versa for discharge.

Thermal stratification is the most common method used in practice because of its efficiency, reliability, simplicity, and low costs. For these reasons, thermal stratification will be used for the purpose of this analysis.

## 6.5 Loads

**Table 41- Design Day Load Profile**

| Design Day | | | | |
|---|---|---|---|---|
| Hour | Cooling Load (tons) | Cooling Load (kW) | June-Sept | Oct-May |
| 1 | 4.9 | 17.23 | OFF-PEAK | OFF-PEAK |
| 2 | 3.9 | 13.72 | | |
| 3 | 3.1 | 10.90 | | |
| 4 | 2.7 | 9.50 | | |
| 5 | 2.3 | 8.09 | | |
| 6 | 2.1 | 7.39 | | |
| 7 | 3.1 | 10.90 | | ON-PEAK |
| 8 | 193.1 | 679.13 | | |
| 9 | 193.8 | 681.59 | | |
| 10 | 208.7 | 734.00 | ON-PEAK | |
| 11 | 229.6 | 807.50 | | |
| 12 | 251.3 | 883.82 | | |
| 13 | 262.9 | 924.62 | | |
| 14 | 271.7 | 955.57 | | |
| 15 | 280.9 | 987.93 | | |
| 16 | 279.9 | 984.41 | | |
| 17 | 273.0 | 960.14 | | |
| 18 | 243.3 | 855.69 | | |
| 19 | 11.8 | 41.50 | | |
| 20 | 18.2 | 64.01 | | |
| 21 | 14.7 | 51.70 | | |
| 22 | 12.6 | 44.31 | | |
| 23 | 9.5 | 33.41 | OFF-PEAK | OFF-PEAK |
| 24 | 8.4 | 29.54 | | |
| **Ton-hrs** | 2786 | | | |

The TRACE analysis was able to produce a summary of the design day for the building location. Using this data, a maximum capacity of 2,786 ton-hrs was calculated in *Table 41*. Using local utility rates and schedules, it was concluded that for full storage, a max capacity of 232 tons must be met by the chiller and for partial storage, only a 116 ton chiller would be needed, as seen by the load profiles in *Figures 26 and 27*.

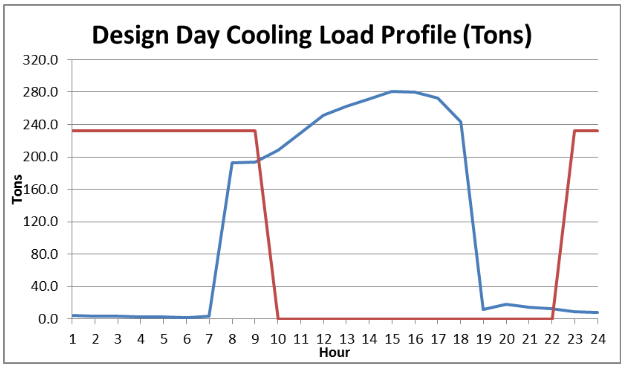



Figure 26- Full Storage Load Profile

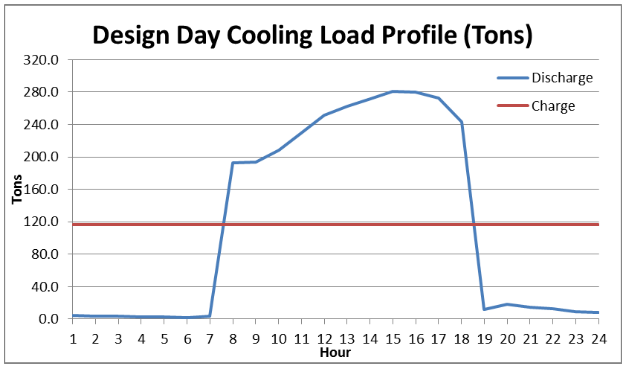



Figure 27- Partial Storage Load Profile

## 6.6 Tank Sizing

A tank needs to be selected that can handle the peak load. The gallons of the tank are dependent upon the heat capacity and ultimately the ton-hrs. The following equation can be used for the tank size:

$$V[gal] = 1440 * \frac{S[ton-hr]}{FoM * \Delta T[F]}$$

*where,*
*S*= the peak day load in ton-hrs
*FoM*= figure of merit, assumed to be 0.9 (according to ASHRAE, a well-designed tank should have a figure of merit of at least 0.9 typically)
*ΔT*= the temperature difference entering and exiting the storage tank

$$V[gal] = 1440 * \frac{2786[ton-hr]}{0.9 * (75 - 55\,[F])}$$

$$V[gal] = \mathbf{222,800\ gal}$$

Since the parking garage and the building are both 50 ft. high, it would be preferable aesthetically to keep the tank height below this height. Since the tank is more effective when it is more vertical than horizontal, a tank with a height of 50 ft. and a diameter of 28 ft. was chosen.

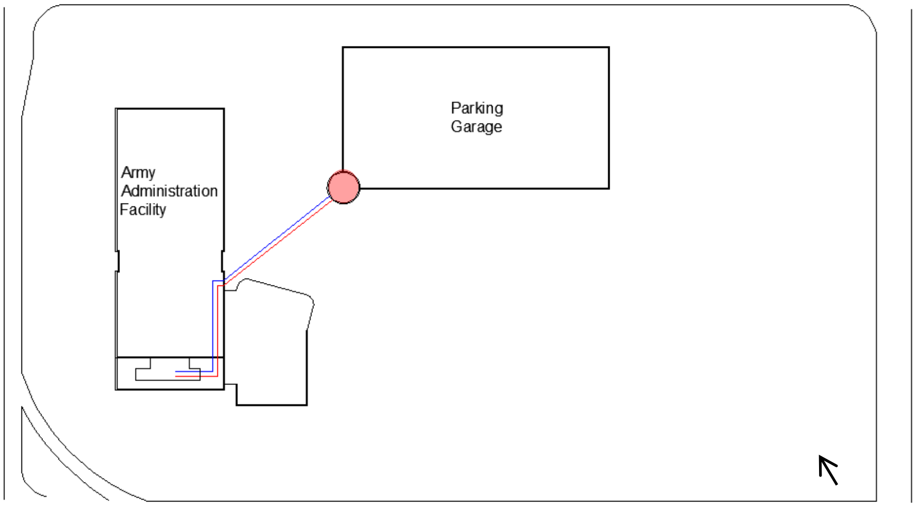



Figure 28- Stratified Tank Location

Keeping the tank as close to the building as possible would be better to keep pumping power down. Therefore, assimilating the tank into the southwest corner of the parking garage will place the tank 120 feet away from the building. Supply and return lines will travel underground from the tank to the building, then travel up the exterior wall to the fourth floor and follow the floor slab to the chiller in the penthouse.

## 6.6 Chiller Selections

The original chiller was sized to 315 tons to handle the full load of 292 tons. However, load leveling allows the chiller to be much smaller since thermal storage assists the chiller during on-peak hours. A 2,786 ton-hr load over a 24 hour period will allow the chiller to be sized as small as 116 tons and a full storage system with 12-hours overnight storage will require a 232 ton chiller.

### *Partial Storage*

**Table 42- Partial Storage Chiller Schedule**

| CHILLER SCHEDULE | | | | | | | | EVAPORATOR (FLOODED SHELL & TUBE) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID TAG | MANUFACTURER/ MODEL | TYPE | LOCATION | SERVICE | NOMINAL CAPACITY (Tons) | REFRIG TYPE | REFRIG QUANTITY (lbs) | FLUID TYPE | CAPACITY (TONS) | FLOW (gpm) | EWT (°F) | LWT (°F) | dPW (ft wc) |
| CHLR-1 | MAMMOTH | EVAPORATIVE CONDENSING | IPEC | CHILLED WATER | 120 | R-134A | 800 | FRESH WATER | 135 | 407 | 66.5 | 55 | 8.8 |

| CHILLER SCHEDULE (cont.) — CONDENSER | | | | | | | | | | | ELECTRICAL | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COMP. TYPE | # OF COMP. (qty) | SPRAY FLOW (gpm) | BLEED FLOW (gpm) | MAKE-UP FLOW (gpm) | SUMP CAP. (gal) | AMBIENT DB (°F) | CONDENSING TEMP (°F) | SUCTION TEMP (°F) | COND. FANS (qty) | COND FAN CFM / HP (ea) | POWER (kW) | RLA | MCA | MFS | Volt/Hz/Ph |
| SCREW | 3 | 448 | 4.6 | 13.8 | 460 | 78 | 105 | 47 | 6 | 67,164 / 3.0 | 232.9 | 51 | 244 | 600 | 460/60/3 |

With a max capacity of 116 tons, a partial storage system would be able to utilize a 120 ton chiller. The same type of evaporative condensing chiller from Mammoth was used, just sized down appropriately. The chiller schedule is represented in *Table 42*.

### *Full Storage*

**Table 43- Full Storage Chiller Schedule**

| CHILLER SCHEDULE | | | | | | | | EVAPORATOR (FLOODED SHELL & TUBE) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID TAG | MANUFACTURER/ MODEL | TYPE | LOCATION | SERVICE | NOMINAL CAPACITY (Tons) | REFRIG TYPE | REFRIG QUANTITY (lbs) | FLUID TYPE | CAPACITY (TONS) | FLOW (gpm) | EWT (°F) | LWT (°F) | dPW (ft wc) |
| CHLR-1 | MAMMOTH | EVAPORATIVE CONDENSING | IPEC | CHILLED WATER | 240 | R-134A | 1100 | FRESH WATER | 245 | 600 | 66.5 | 55 | 8.8 |

| CHILLER SCHEDULE (cont.) — CONDENSER | | | | | | | | | | | ELECTRICAL | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COMP. TYPE | # OF COMP. (qty) | SPRAY FLOW (gpm) | BLEED FLOW (gpm) | MAKE-UP FLOW (gpm) | SUMP CAP. (gal) | AMBIENT DB (°F) | CONDENSING TEMP (°F) | SUCTION TEMP (°F) | COND. FANS (qty) | COND FAN CFM / HP (ea) | POWER (kW) | RLA | MCA | MFS | Volt/Hz/Ph |
| SCREW | 3 | 660 | 4.6 | 13.8 | 680 | 78 | 105 | 47 | 6 | 67,164 / 3.0 | 232.9 | 420 | 449 | 600 | 460/60/3 |

At full storage the peak load is 232 tons. Mammoth makes an evaporative condensing chiller that can support 240 tons. The full storage chiller schedule is represented in *Table 43*.

## 6.7 Pump Selections

To size the ground loop properly, first the head pressure must be calculated**.** The flow rate through the loop can be used to find an appropriate pipe diameter. From here, the head loss through the whole run of pipe can be found per 100 ft. Since head loss is ft/100ft, the equivalent length of a run must be taken into consideration to find total head loss. The equivalent length is the sum of the actual length of the pipe and the equivalent lengths caused by the fittings and valves. *Figure 29* represents the longest length of run through the system. The loop has (12) 90° angles, and (2) gate valves.

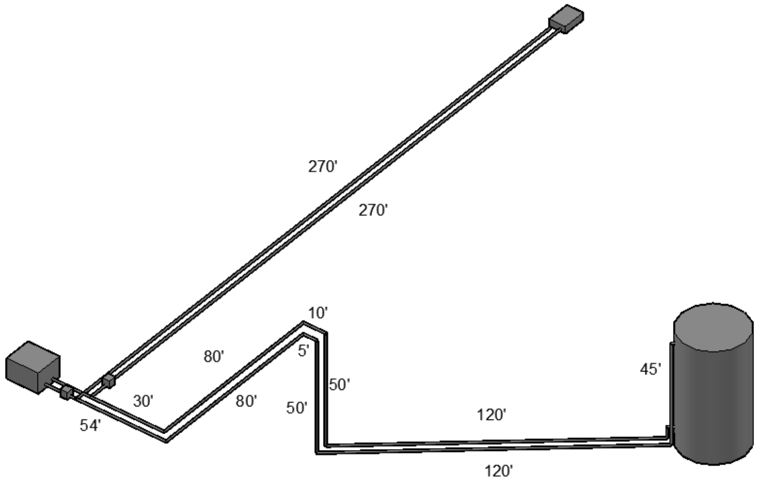



Figure 29- Longest Run of Pipe

### *Partial Storage*

For the system configuration, (2) pumps will be required; one that will circulate water all the way to the heat pumps during on-peak hours (*Figure 30*), and one that only requires a capacity to flow the water between the chiller and the storage tank during off-peak hours (*Figure 31*). The loop for the partial storage system would require a flow rate of 407 gpm.

Figure 30- Discharge Cycle (On-Peak Hours)

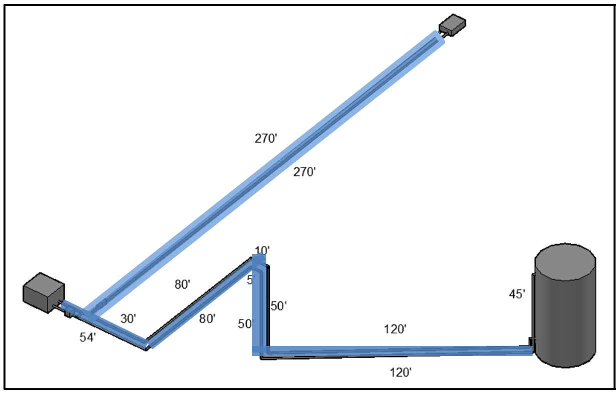
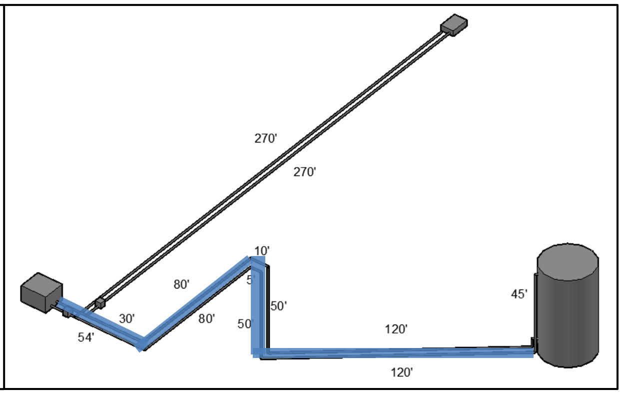


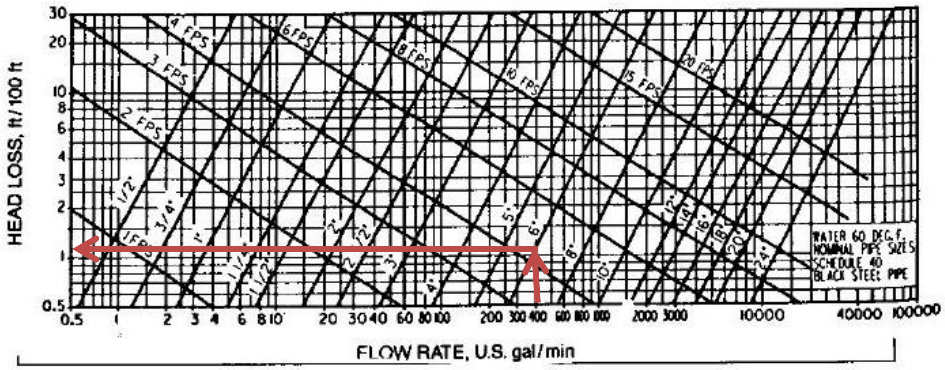
Figure 31- Charge Cycle (Off-Peak Hours)



Loop Head Pressure:

$\dot{Q}_{,gpm} = 407\ gpm$

$D_{pipe}$ = 6”




Head loss through pipe = 1.1 ft / 100 ft

For Nominal Size 6”, $ft$= 0.015

| | | |
|---|---|---|
| 90° elbow: | K = 30 $ft$, | $ft$=0.015 |
| | K = 30(0.015) = 0.45 | |
| | L= 15 ft | |
| Gate valve: | $K_1$ = 8 $ft$ | $ft$=0.015 |
| | $K_1$ = 8(0.015) = 0.12 | |
| | L= 3.5 ft | |

Total Equivalent Length Discharge Pump:

| | |
|---|---|
| Actual pipe length | 1135 ft |
| (12) 90° elbows | 180 ft |
| (2) Gate Valves | 7 ft |
| Total | 1322 ft |

$\frac{1.1\ ft}{100\ ft} * 1322\ ft$ = 15 ft + 45 ft (to top of tank) = **60 ft Head**

Total Equivalent Length Charge Pump:

| | |
|---|---|
| Actual pipe length | 623 ft |
| (10) 90° elbows | 150 ft |
| (2) Gate Valves | 7 ft |
| Total | 780 ft |

$\frac{1.1\ ft}{100\ ft} * 780\ ft$ = 8 ft + 45 ft (to top of tank) = **53 ft Head**

The partial storage system would require pumps that can handle a flow rate of 407 gpm with heads of 60 ft. and 53 ft. Conveniently, the same pump can be used at both locations, as diagrammed in *Table 44*. Four pumps would be installed for redundancy.

Pump:

**Table 44- Partial Storage Pump Schedule**

| PARTIAL STORAGE PUMP SCHEDULE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID TAG | MANUFACTURER/ SERIES | MODEL | SERVICE | FLUID TYPE | FLOW (gpm) | HEAD (ft wc) | PUMP EFFICIENCY (%) | RPM | PUMP MOTOR | | | EMER. POWER |
| | | | | | | | | | SHAFT POWER (Bhp) | MOTOR SIZE (Hp) | Volt/Hz/Ph | |
| CHW-1 | BELL & GOSSETT | SERIES 1510 3BC | GROUND LOOP WATER | CHW | 407 | 60 | 78.5% | 1,750 | 7.5 | 6.2 | 460/60/3 | NO |
| CHW-2 | BELL & GOSSETT | SERIES 1510 3BC | GROUND LOOP WATER | CHW | 407 | 60 | 78.5% | 1,750 | 7.5 | 6.2 | 460/60/4 | NO |
| CHW-3 | BELL & GOSSETT | SERIES 1510 3BC | GROUND LOOP WATER | CHW | 407 | 53 | 78.0% | 1,750 | 6.6 | 5.4 | 460/60/4 | NO |
| CHW-4 | BELL & GOSSETT | SERIES 1510 3BC | GROUND LOOP WATER | CHW | 407 | 53 | 78.0% | 1,750 | 6.6 | 5.4 | 460/60/4 | NO |

(Pump diagram can be found in *Appendix D*)

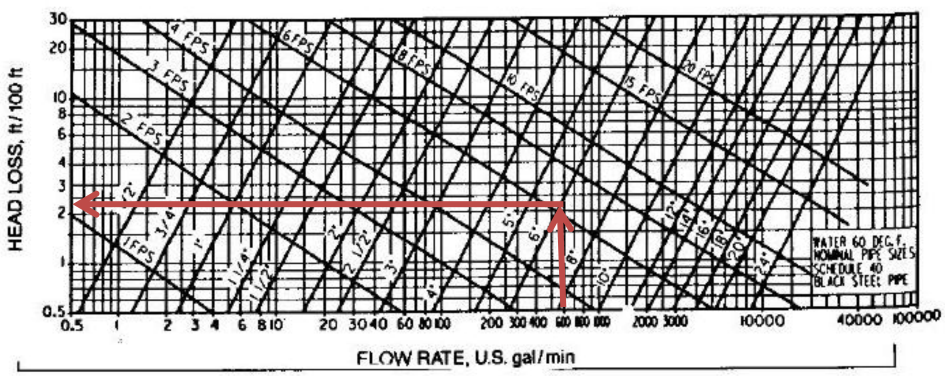
## *Full Storage*

The loop for the full storage system would require a flow rate of 600 gpm.

Loop Head Pressure:

$\dot{Q}_{,gpm} = 600\ gpm$

$D_{pipe}$ = 6”




Head loss through pipe = 2.1 ft / 100 ft

For Nominal Size 6”, $ft$= 0.015

90° elbow: K = 30 $ft$, $ft$=0.015
K = 30(0.015) = 0.45
L= 15 ft

Gate valve: $K_1$ = 8 $ft$ $ft$=0.015
$K_1$ = 8(0.015) = 0.12
L= 3.5 ft

Total Equivalent Length On-Peak Pump:

| | |
|---|---|
| Actual pipe length | 1135 ft |
| (12) 90° elbows | 180 ft |
| (2) Gate Valves | 7 ft |
| Total | 1322 ft |

$$\frac{2.1\,ft}{100\,ft} * 1322\,ft$$ = 28 ft + 45 ft (to top of tank) = **73 ft Head**

Total Equivalent Length Off-Peak Pump:

| | |
|---|---|
| Actual pipe length | 623 ft |
| (10) 90° elbows | 150 ft |
| (2) Gate Valves | 7 ft |
| Total | 780 ft |

$$\frac{2.1\,ft}{100\,ft} * 780\,ft$$ = 16 ft + 45 ft (to top of tank) = **61 ft Head**

The full storage system would require pumps that can handle a flow rate of 600 gpm with heads of 73 and 61 ft.

Pump:

**Table 45- Full Storage Pump Schedule**

| FULL STORAGE PUMP SCHEDULE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID TAG | MANUFACTURER/ SERIES | MODEL | SERVICE | FLUID TYPE | FLOW (gpm) | HEAD (ft wc) | PUMP EFFICIENCY (%) | RPM | PUMP MOTOR | | | EMER. POWER |
| | | | | | | | | | SHAFT POWER (Bhp) | MOTOR SIZE (Hp) | Volt/Hz/Ph | |
| CHW-1 | BELL & GOSSETT | SERIES 1510 4BC | GROUND LOOP WATER | CHW | 600 | 73 | 82.5% | 1,750 | 13.4 | 11.1 | 460/60/3 | NO |
| CHW-2 | BELL & GOSSETT | SERIES 1510 4BC | GROUND LOOP WATER | CHW | 600 | 73 | 82.5% | 1,750 | 13.4 | 11.1 | 460/60/3 | NO |
| CHW-3 | BELL & GOSSETT | SERIES 1510 4BC | GROUND LOOP WATER | CHW | 600 | 61 | 82.5% | 1,750 | 11.2 | 9.2 | 460/60/4 | NO |
| CHW-4 | BELL & GOSSETT | SERIES 1510 4BC | GROUND LOOP WATER | CHW | 600 | 61 | 82.5% | 1,750 | 11.2 | 9.2 | 460/60/4 | NO |

(Pump curves can be found in *Appendix D*)

## 6.8 Schematics

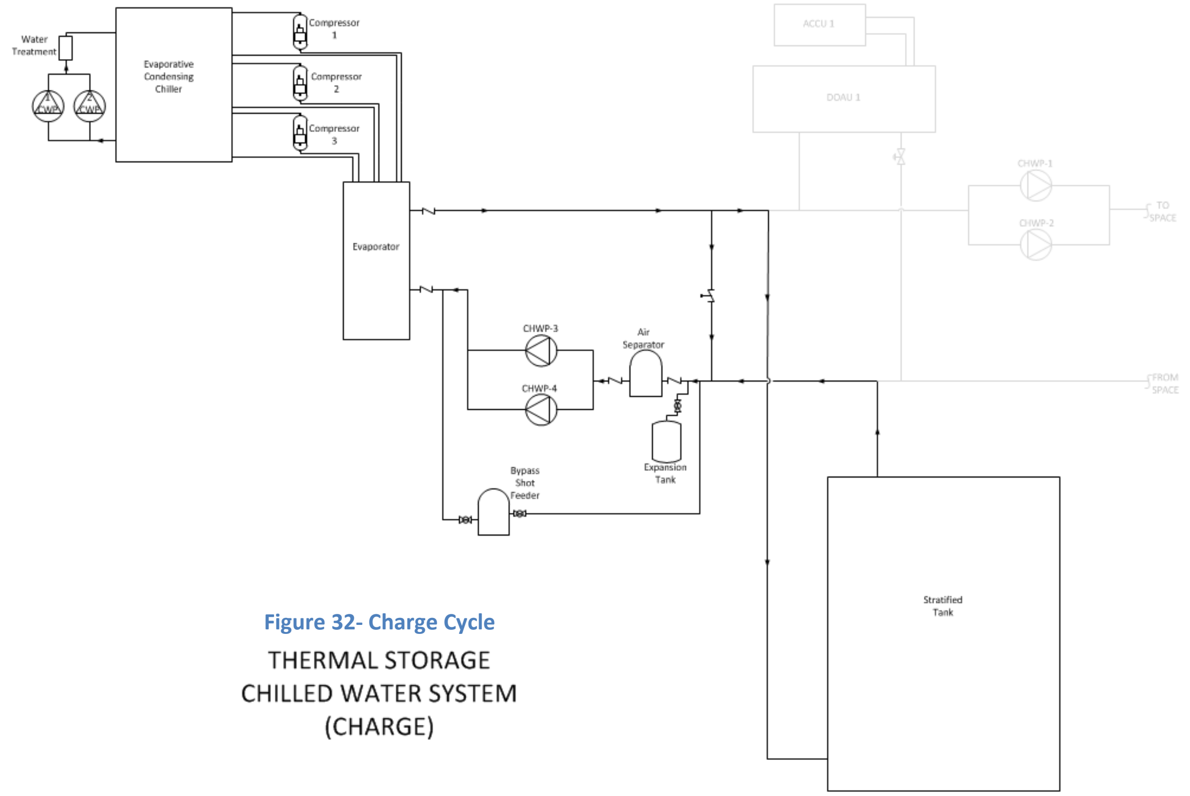



**Figure 32- Charge Cycle**

THERMAL STORAGE
CHILLED WATER SYSTEM
(CHARGE)

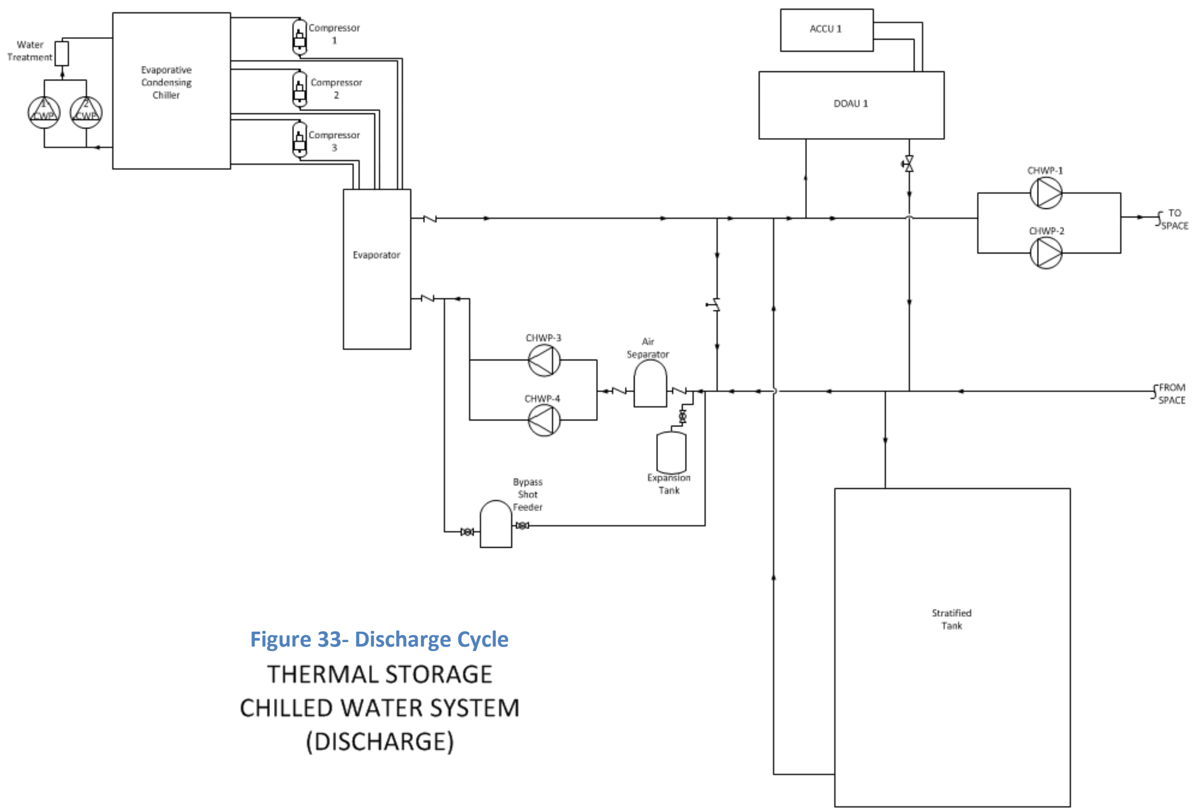



**Figure 33- Discharge Cycle**

THERMAL STORAGE
CHILLED WATER SYSTEM
(DISCHARGE)

## 6.9 Energy and Cost Analysis

An analysis of the proposed chilled water thermal storage annual energy consumption and operating costs was conducted.

### *Total Energy Consumption*

The TRACE model produced results shown below. *Table 46* shows the results for the partial storage system and *Table 47* shows the results for the full storage system. Both the energy consumption of the existing system and the thermal storage system are shown as a measure for comparison. Since the thermal storage system is only used for cooling, the heating systems are equal and thus gas usage is equal since only the heating system uses natural gas in this facility.

For the partial storage system, as can be seen, the thermal storage system **saves 196,911 kWh** of electricity. This is because the chillers in the thermal storage system have smaller capacities, requiring less energy and consequently, less pumping energy. The receptacle loads require the most energy (45% of the total building energy) and the smallest energy consumer in this system are the auxiliary loads.

Overall, the partial storage system saves 196,911 kWh of electricity and thus 672,055 kBtu/yr of total energy over the existing system.

**Table 46- Partial Storage Annual Energy Consumption**

| Thermal Storage (Partial Storage) vs. Existing System | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Electric kWh | | Gas kBtu | | Total Building Energy kBtu/yr | | % of Total Building Energy | |
| **System** | **Existing** | **Thermal Storage** | **Existing** | **Thermal Storage** | **Existing** | **Thermal Storage** | **Existing** | **Thermal Storage** |
| **Primary Heating** | | | | | | | | |
| Primary Heating | | | 666,654 | 666,654 | 666,654 | 666,654 | 12.5% | 14.3% |
| Heating Accessories | 17,520 | 17,520 | | | 59,796 | 59,796 | 1.1% | 1.3% |
| Heating Subtotal | **17,520** | **17,520** | **666,654** | **666,654** | **726,450** | **726,450** | 13.6% | **15.6%** |
| **Primary Cooling** | | | | | | | | |
| Cooling Compressor | 275,490 | 212,209 | | | 940,247 | 724,270 | 17.6% | 15.5% |
| Tower/Cond Fans | 36,017 | 27,509 | | | 122,926 | 93,888 | 2.3% | 2.0% |
| Condenser Pump | 31,071 | 11,442 | | | 106,045 | 39,052 | 2.0% | 0.8% |
| Cooling Accessories | 876 | 876 | | | 2,990 | 2,990 | 0.1% | 0.1% |
| Cooling Subtotal | **343,454** | **252,036** | **0** | **0** | **1,172,209** | **860,199** | 22.0% | **18.5%** |
| **Auxiliary** | | | | | | | | |
| Supply Fans | 6,644 | 6,644 | | | 22,676 | 22,676 | 0.4% | 0.5% |
| Pumps | 148,529 | 43,036 | | | 506,929 | 146,882 | 9.5% | 3.2% |
| Aux Subtotal | **155,173** | **49,680** | **0** | **0** | **529,605** | **169,558** | 9.9% | **3.6%** |
| **Lighting** | | | | | | | | |
| Lighting | **232,479** | **232,479** | **0** | **0** | **793,451** | **793,451** | **0** | **17.0%** |
| **Receptacles** | | | | | | | | |
| Receptacles | **618,652** | **618,652** | **0** | **0** | **2,111,459** | **2,111,461** | **0** | **45.3%** |
| **Total** | **1,367,278** | **1,170,367** | **666,654** | **666,654** | **5,333,174** | **4,661,119** | **100.0%** | **100.0%** |
| **Thermal Storage Savings** | **196,911** | | **0** | | **672,055** | | **-** | **-** |

For full storage, the thermal storage system **saves 76,026 kWh** of electricity. This is because the chillers in the thermal storage system have smaller capacities than the existing, requiring less energy and consequently, less pumping energy. The savings are not as great as the partial storage system, however, because the chiller is larger in the full storage system and the operating costs outweigh the costs saved by not running the chiller during the day. The receptacle loads require the most energy (42% of the total building energy) and the smallest energy consumer in this system is still the auxiliary loads.

**Table 47- Full Storage Annual Energy Consumption**

| Thermal Storage (Full Storage) vs. Existing System | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Electric kWh | | Gas kBtu | | Total Building Energy kBtu/yr | | % of Total Building Energy | |
| System | Existing | Thermal Storage | Existing | Thermal Storage | Existing | Thermal Storage | Existing | Thermal Storage |
| **Primary Heating** | | | | | | | | |
| Primary Heating | | | 666,654 | 666,654 | 666,654 | 666,654 | 12.5% | 13.1% |
| Heating Accessories | 17,520 | 17,520 | | | 59,796 | 59,796 | 1.1% | 1.2% |
| Heating Subtotal | **17,520** | **17,520** | **666,654** | **666,654** | **726,450** | **726,450** | 13.6% | **14.3%** |
| **Primary Cooling** | | | | | | | | |
| Cooling Compressor | 275,490 | 267,356 | | | 940,247 | 912,487 | 17.6% | 18.0% |
| Tower/Cond Fans | 36,017 | 34,055 | | | 122,926 | 116,230 | 2.3% | 2.3% |
| Condenser Pump | 31,071 | 21,434 | | | 106,045 | 73,154 | 2.0% | 1.4% |
| Cooling Accessories | 876 | 876 | | | 2,990 | 2,990 | 0.1% | 0.1% |
| Cooling Subtotal | **343,454** | **323,721** | **0** | **0** | **1,172,209** | **1,104,860** | 22.0% | **21.8%** |
| **Auxiliary** | | | | | | | | |
| Supply Fans | 6,644 | 6,644 | | | 22,676 | 22,676 | 0.4% | 0.4% |
| Pumps | 148,529 | 92,236 | | | 506,929 | 314,802 | 9.5% | 6.2% |
| Aux Subtotal | **155,173** | **98,880** | **0** | **0** | **529,605** | **337,478** | 9.9% | **6.7%** |
| **Lighting** | | | | | | | | |
| Lighting | **232,479** | **232,479** | **0** | **0** | **793,451** | **793,451** | **0** | **15.6%** |
| **Receptacles** | | | | | | | | |
| Receptacles | **618,652** | **618,652** | **0** | **0** | **2,111,459** | **2,111,461** | **0** | **41.6%** |
| **Total** | **1,367,278** | **1,291,252** | **666,654** | **666,654** | **5,333,174** | **5,073,700** | **100.0%** | **100.0%** |
| **Thermal Storage Savings** | **76,026** | | **0** | | **259,474** | | **-** | **-** |

Overall, the partial storage system saves 76,026 kWh of electricity and thus 259,474 kBtu/yr of total energy over the existing system.

The partial storage consumes the least amount of energy when compared to the existing and full storage systems. It saves 672,055 kBtu/yr over the existing system and 412,581 kBtu/yr over the full storage system.

## *Monthly Energy Consumption Breakdown*

A monthly breakdown of the energy consumption for electric and gas are below. *Table 48* represents the partial storage system and *Table 49* represents the full storage system. As can be seen by the tables and *Figures 35 and 36*, the electricity loads reach their peaks in the summer months, while the gas loads reach their peaks in the winter months. This same trend is followed by both systems but thermal storage uses less electricity than the existing system each month, especially in the winter.

**Table 48- Partial Storage Monthly Energy Consumption**

| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric [kWh] | Existing System | 95,367 | 86,851 | 108,507 | 100,962 | 127,664 | 138,070 | 140,425 | 147,252 | 118,424 | 109,410 | 101,721 | 92,626 | 1,367,279 |
| | Thermal Storage | 86,972 | 79,067 | 98,222 | 90,622 | 109,220 | 111,308 | 105,055 | 115,718 | 99,894 | 98,838 | 91,536 | 83,914 | 1,170,366 |
| | Storage Savings | 8,395 | 7,784 | 10,285 | 10,340 | 18,444 | 26,762 | 35,370 | 31,534 | 18,530 | 10,572 | 10,185 | 8,712 | 196,913 |
| Gas [therms] | Existing System | 1,465 | 1,252 | 653 | 320 | 252 | 252 | 229 | 270 | 242 | 375 | 471 | 886 | 6,667 |
| | Thermal Storage | 1,465 | 1,252 | 653 | 320 | 252 | 252 | 229 | 270 | 242 | 375 | 471 | 886 | 6,667 |
| | Storage Savings | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

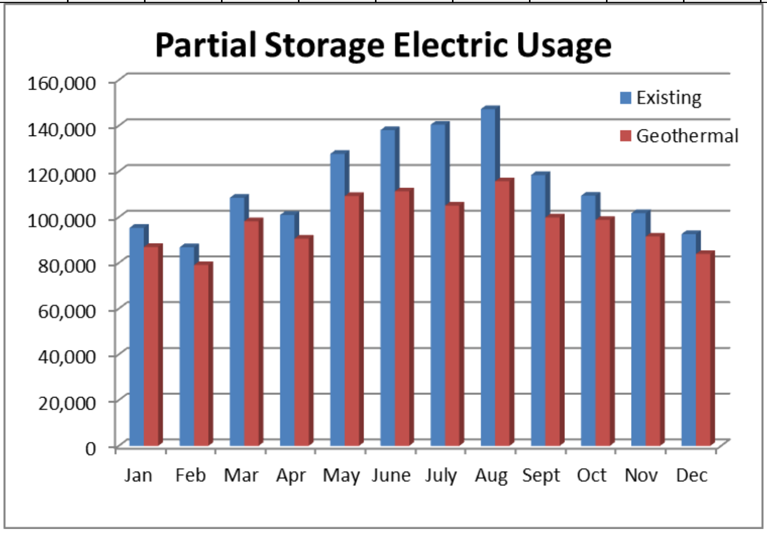



Figure 34- Partial Storage Monthly Electricity Consumption

The largest energy difference occurs in July. This could be due to the fact that for the partial storage system, the chiller runs overnight for 12 hours of its cycle, when the ambient air temperature is much cooler than during the daytime. Cooler ambient air temperatures make heat rejection from the chiller's condensing equipment more efficient.

**Table 49- Full Storage Monthly Energy Consumption**

| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric [kWh] | Existing System | 95,367 | 86,851 | 108,507 | 100,962 | 127,664 | 138,070 | 140,425 | 147,252 | 118,424 | 109,410 | 101,721 | 92,626 | 1,367,279 |
| | Thermal Storage | 82,013 | 74,701 | 103,379 | 95,526 | 121,897 | 133,437 | 135,469 | 142,434 | 113,000 | 103,929 | 96,500 | 88,969 | 1,291,254 |
| | Storage Savings | 13,354 | 12,150 | 5,128 | 5,436 | 5,767 | 4,633 | 4,956 | 4,818 | 5,424 | 5,481 | 5,221 | 3,657 | 76,025 |
| Gas [therms] | Existing System | 1,465 | 1,252 | 653 | 320 | 252 | 252 | 229 | 270 | 242 | 375 | 471 | 886 | 6,667 |
| | Thermal Storage | 1,465 | 1,252 | 653 | 320 | 252 | 252 | 229 | 270 | 242 | 375 | 471 | 886 | 6,667 |
| | Storage Savings | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

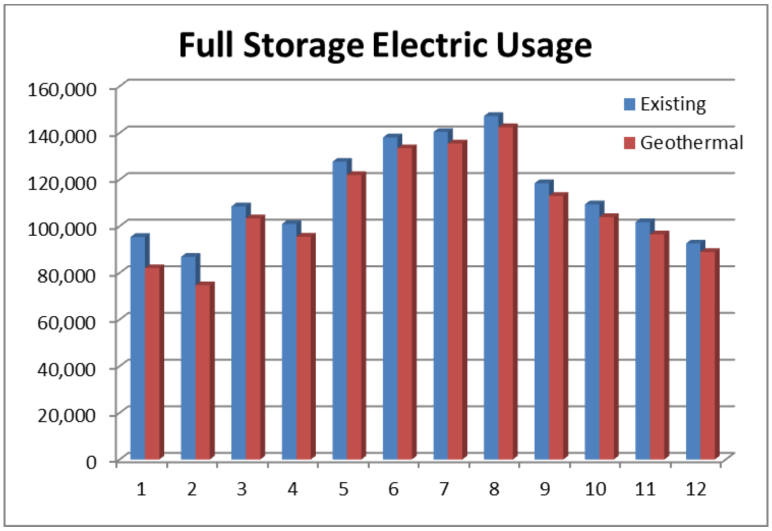



Figure 35- Full Storage Monthly Electricity Consumption

The largest difference for the full storage system occurs in January. This could be due to the fact that in the winter, the cooling load is much less. Therefore, if there is a call for cooling from a few heat pumps, the storage most likely will be able to handle the full load without using the full stored capacity and some chilled water can be saved for the next day.

### *Electrical Energy Breakdown*

Since the gas loads are equal for both systems, a comparison is unnecessary. *Tables 50* and *51* and *Figure 37* and *38* show a breakdown of solely the electrical power consumption by component. Primary heating is the smallest consumer of electric power in this building even though the geothermal system now handles the heating load completely. Receptacles, as can be anticipated, require a large portion of the electric supply for both partial and full storage. This is most likely due to the miscellaneous loads added to each room in the TRACE model. Large receptacle loads can result from equipment such as computers, projectors, and other general office equipment that can give off heat.

Table 50- Partial Storage Electric Consumption

| | Electrical Consumption kWh | |
|---|---|---|
| | Existing System | Thermal Storage System |
| Primary Heating | 17,520 | 17,520 |
| Primary Cooling | 343,454 | 252,036 |
| Auxilary | 155,173 | 49,680 |
| Lighting | 232,479 | 232,479 |
| Receptacles | 618,652 | 618,652 |
| **Total** | **1,367,278** | **1,170,367** |

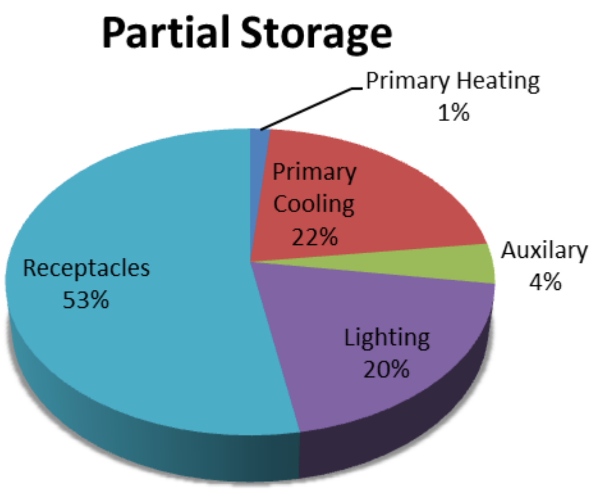



Figure 36- Partial Storage Electricity Consumption

Table 51- Full Storage Electric Consumption

| | Electrical Consumption kWh | |
|---|---|---|
| | Existing System | Thermal Storage System |
| Primary Heating | 17,520 | 17,520 |
| Primary Cooling | 343,454 | 323,721 |
| Auxilary | 155,173 | 98,880 |
| Lighting | 232,479 | 232,479 |
| Receptacles | 618,652 | 618,652 |
| **Total** | **1,367,278** | **1,291,252** |

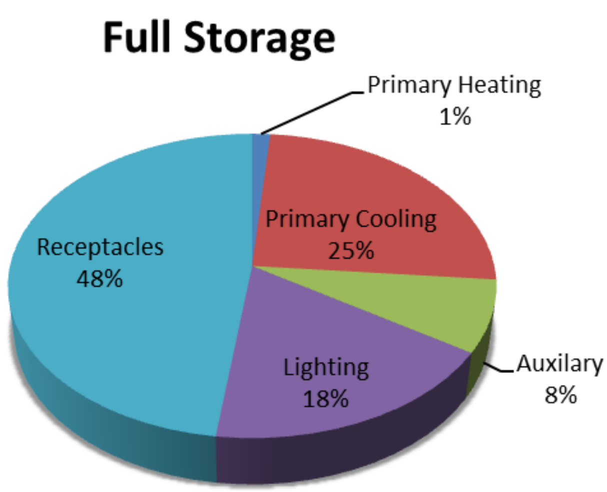



Figure 37- Full Storage Electricity Consumption

## *Initial Costs*

### Partial Storage

The total cost of installation for the partial storage system would be around $466,100 as shown in *Table 52*. When considering the cost of the existing chiller that is not necessary since the smaller chiller is taken into account in the thermal storage costs, $180,475 is saved as seen in *Table 53*. Therefore the cost of the partial storage system over the existing system is roughly $285,620.

**Table 52- Partial Storage Initial Investment**

| System Components | MAT. COST PER UNIT | INST. COST PER UNIT | QUANTITY | UNIT | COST MAT. | COST INST. | COST TOTAL |
|---|---|---|---|---|---|---|---|
| **Partial Storage Chilled Water Thermal Storage Components** | | | | | | | |
| Centrifugal, end suction, vertical split case, single stage 500 GPM pump | 17000.00 | 5400.00 | 4 | Ea. | 68,000.00 | 21,600.00 | 89,600.00 |
| Prestressed conc. aboveground water storage tank , 250,000 gallons | - | - | 1 | Ea. | - | - | 267500 |
| Water Chiller, integral air cooled condenser, 130 ton | 91000.00 | 7150.00 | 1 | Ea. | 91,000.00 | 7,150.00 | 98,150.00 |
| Polyvinyl chloride class 160, S.D.R. 26, 6" diameter tubing | 6.30 | 6.55 | 620 | L.F. | 3,906.00 | 4,061.00 | 7,967.00 |
| Piping insulation protective jacket, PVC | 0.73 | 3.91 | 620 | L.F. | 452.60 | 2,424.20 | 2,876.80 |
| Total | | | | | 163,358.60 | 35,235.20 | **466,093.80** |

**Table 53- Existing System Chiller Cost**

| System Components | MAT. COST PER UNIT | INST. COST PER UNIT | QUANTITY | UNIT | COST MAT. | COST INST. | COST TOTAL |
|---|---|---|---|---|---|---|---|
| **Existing System Components** | | | | | | | |
| Water Chiller, integral air cooled condenser, 300 ton | 172000.00 | 8475.00 | 1 | Ea. | 172,000.00 | 8,475.00 | 180,475.00 |

### Full Storage

The total cost of installation for the full storage system would be around $527,700 as shown in *Table 54*. When considering the cost of the existing chiller that is not necessary since the smaller chiller is taken into account in the thermals storage costs, $180,475 is saved as seen in *Table 53*. Therefore the cost of the partial storage system over the existing system is roughly $347,220.

**Table 54- Full Storage Initial Investment**

| System Components | MAT. COST PER UNIT | INST. COST PER UNIT | QUANTITY | UNIT | COST MAT. | COST INST. | COST TOTAL |
|---|---|---|---|---|---|---|---|
| **Full Storage Chilled Water Thermal Storage Components** | | | | | | | |
| Centrifugal, end suction, vertical split case, single stage 600 GPM pump | 17500.00 | 5700.00 | 4 | Ea. | 70,000.00 | 22,800.00 | 92,800.00 |
| Prestressed conc. aboveground water storage tank , 250,000 gallons | - | - | 1 | Ea. | - | - | 267,500.00 |
| Water Chiller, integral air cooled condenser, 250 ton | 148500.00 | 8050.00 | 1 | Ea. | 148,500.00 | 8,050.00 | 156,550.00 |
| Polyvinyl chloride class 160, S.D.R. 26, 6" diameter tubing | 6.30 | 6.55 | 620 | L.F. | 3,906.00 | 4,061.00 | 7,967.00 |
| Piping insulation protective jacket, PVC | 0.73 | 3.91 | 620 | L.F. | 452.60 | 2,424.20 | 2,876.80 |
| Total | | | | | 222,858.60 | 37,335.20 | **527,693.80** |

The partial storage system would save $61,600 over a full storage system in an initial investment.

## *Cost Breakdown*

One of the largest benefits of thermal storage is the shift from on-peak to off-peak electrical usage hours. Electricity is much cheaper at night and since the chiller can run at night and store the chilled water in the storage tank, great costs can be saved. *Table 55* shows the on-peak and off-peak electricity costs, provided by the facility's local power company, Dominion Power.

**Table 55- Electric Utility Rates**

| | On-Peak | Off-Peak |
|---|---|---|
| Electricity Cost $/kW | 13.45 | 2.75 |

### Partial Storage

Using the electricity and natural gas rates from Dominion Power for the local (undisclosed) area, it can be concluded that the Army Administration facility with a partial storage chilled water thermal storage system should expect to spend roughly $66,741 per year on utilities. This is roughly $47,948 less per year than the existing system, which translates to about $0.55 per square foot less each year than the existing system. These conclusions are summarized below in *Table 56*.

Table 56- Partial Storage Annual Cost Comparison

| Partial Storage Cost Comparison | | | | | | |
|---|---|---|---|---|---|---|
| | Consumption [kBtu/yr] | | Cost Per Year [$] | | Cost Per SF [$] | |
| System | Existing System | Thermal Storage | Existing System | Thermal Storage | Existing System | Thermal Storage |
| Electric Subtotal [kBtu] | 4,666,520 | 3,994,463 | 109,110 | 61,162 | 1.254 | 0.703 |
| Gas Subtotal [kBtu] | 666,654 | 666,654 | 5,579 | 5,579 | 0.064 | 0.064 |
| **Energy Total** | **5,333,174** | **4,661,117** | **114,689** | **66,741** | **1.32** | **0.77** |
| **Partial TES Savings** | **672,057** | | **47,948** | | **0.551** | |

### Full Storage

It can also be concluded that with a full storage chilled water thermal storage system, the building should expect to spend roughly $75,426 per year on utilities. This is roughly $39,263 less per year than the existing system, which translates to about $0.45 per square foot less each year than the existing system. These conclusions are summarized below in *Table 57*.

Table 57- Full Storage Annual Cost Comparison

| Full Storage Cost Comparison | | | | | | |
|---|---|---|---|---|---|---|
| | Consumption [kBtu/yr] | | Cost Per Year [$] | | Cost Per SF [$] | |
| System | Existing System | Thermal Storage | Existing System | Thermal Storage | Existing System | Thermal Storage |
| Electric Subtotal [kBtu] | 4,666,520 | 4,407,043 | 109,110 | 69,847 | 1.254 | 0.803 |
| Gas Subtotal [kBtu] | 666,654 | 666,654 | 5,579 | 5,579 | 0.064 | 0.064 |
| **Energy Total** | **5,333,174** | **5,073,697** | **114,689** | **75,426** | **1.32** | **0.87** |
| **Partial TES Savings** | **259,477** | | **39,263** | | **0.451** | |

The partial storage system saves roughly $8,685 more than the full storage system per year.

A monthly breakdown of the energy costs for electric and gas used by the partial storage system are shown in *Table 58* below. As can be seen by the table and *Figure 39*, the electricity costs reach their peaks in the summer months when the load is higher, while the gas loads reach their peaks in the winter months. These trends follow those summarized earlier in the monthly energy consumption section of this report.

Table 58- Partial Storage Monthly Costs

| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric $ | Existing System | 7,610 | 6,931 | 8,659 | 8,057 | 10,188 | 11,018 | 11,206 | 11,751 | 9,450 | 8,731 | 8,117 | 7,392 | 109,110 |
| | Thermal Storage | 4,403 | 4,510 | 4,903 | 5,143 | 5,425 | 5,519 | 5,590 | 5,554 | 5,510 | 5,152 | 4,953 | 4,500 | 61,162 |
| | Storage Savings | 3,207 | 2,421 | 3,756 | 2,914 | 4,763 | 5,499 | 5,616 | 6,197 | 3,940 | 3,579 | 3,164 | 2,892 | 47,948 |
| Gas $ | Existing System | 1,226 | 1,048 | 546 | 267 | 211 | 211 | 191 | 226 | 203 | 314 | 394 | 742 | 5,579 |
| | Thermal Storage | 1,226 | 1,048 | 546 | 267 | 211 | 211 | 191 | 226 | 203 | 314 | 394 | 742 | 5,579 |
| | Storage Savings | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

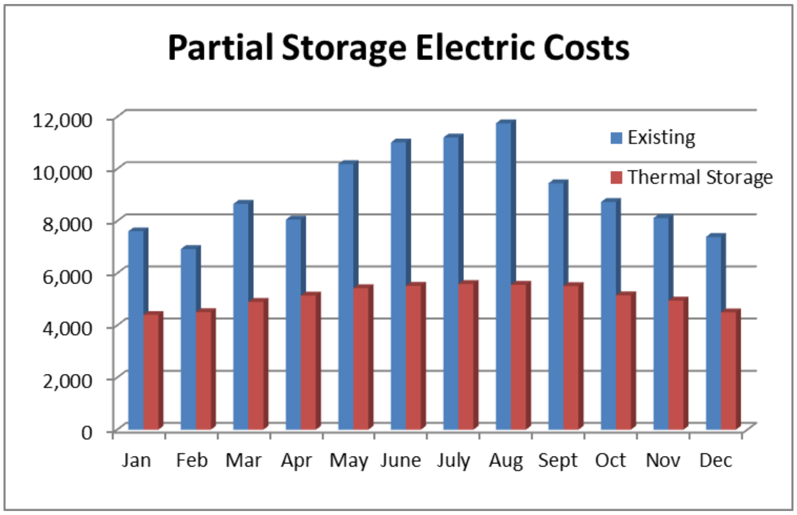



**Figure 38- Partial Storage Electricity Costs**

The partial storage costs each month are much lower than those of the existing system and are fairly stable. The full storage monthly cost breakdown, shown in *Table 59* and *Figure 40*, illustrates similar savings over the existing system, but shows a larger difference between summer and winter energy costs.

**Table 59- Full Storage Monthly Costs**

| | | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric $ | Existing System | 7,610 | 6,931 | 8,659 | 8,057 | 10,188 | 11,018 | 11,206 | 11,751 | 9,450 | 8,731 | 8,117 | 7,392 | 109,110 |
| | Thermal Storage | 3,828 | 4,013 | 5,010 | 5,393 | 6,979 | 7,348 | 7,502 | 7,431 | 7,344 | 5,328 | 5,063 | 4,608 | 69,847 |
| | Storage Savings | 3,782 | 2,918 | 3,649 | 2,664 | 3,209 | 3,670 | 3,704 | 4,320 | 2,106 | 3,403 | 3,054 | 2,784 | 39,263 |
| Gas $ | Existing System | 1,226 | 1,048 | 546 | 267 | 211 | 211 | 191 | 226 | 203 | 314 | 394 | 742 | 5,579 |
| | Thermal Storage | 1,226 | 1,048 | 546 | 267 | 211 | 211 | 191 | 226 | 203 | 314 | 394 | 742 | 5,579 |
| | Storage Savings | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

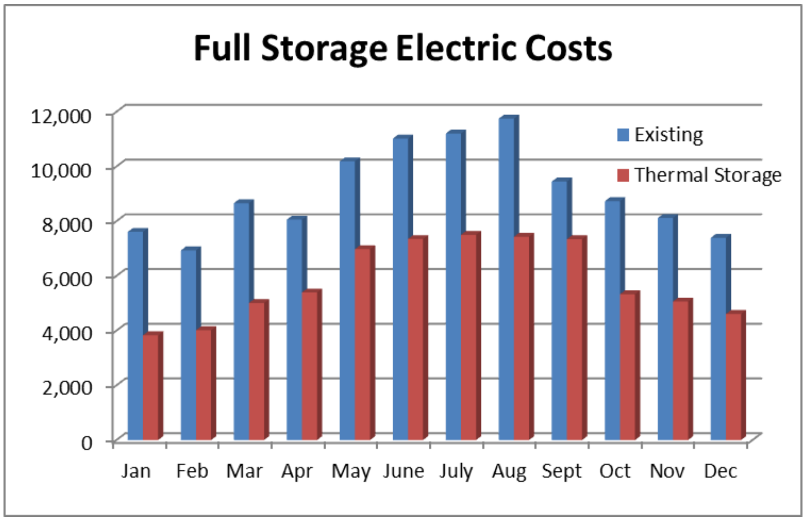



**Figure 39- Full Storage Electricity Costs**

## *Simple Payback*

### Partial Storage

With the initial cost of the partial storage system around $466,000 minus the savings of the $180,475 chiller not needed from the existing system, a simple payback period was determined. With a $47,950 utility savings per year and an assumed yearly maintenance cost of $2,500, the partial storage chilled water thermal storage system would have a return on its initial investment in 7 years as portrayed in *Table 60*. Since this is a government building with a longer life expectancy than most commercial buildings, 7 years is a very reasonable payback period.

**Table 60- Partial Storage Simple Payback Period**

| Partial Storage Simple Payback | | | | | | |
|---|---|---|---|---|---|---|
| Date | Year | Initial Cost [$] | Maint [$/yr] | Utility Savings [$/yr] | Savings per Year [$/yr] | Total Savings [$] |
| 2011 | 0 | $ 285,618.80 | | | | |
| 2012 | 1 | | $ 2,500.00 | $ 47,948.00 | $ 45,448.00 | |
| 2013 | 2 | | $ 2,500.00 | $ 47,948.00 | $ 45,448.00 | $ 90,896.00 |
| 2014 | 3 | | $ 2,500.00 | $ 47,948.00 | $ 45,448.00 | $136,344.00 |
| 2015 | 4 | | $ 2,500.00 | $ 47,948.00 | $ 45,448.00 | $181,792.00 |
| 2016 | 5 | | $ 2,500.00 | $ 47,948.00 | $ 45,448.00 | $227,240.00 |
| 2017 | 6 | | $ 2,500.00 | $ 47,948.00 | $ 45,448.00 | $272,688.00 |
| 2018 | 7 | | $ 2,500.00 | $ 47,948.00 | $ 45,448.00 | **$318,136.00** |

### Full Storage

With the initial cost of the full storage system around $528,000 minus the savings of the $180,475 chiller not needed from the existing system, a simple payback period was determined. With a $39,263 utility savings per year and an assumed yearly maintenance cost of $2,500, the full storage chilled water thermal storage system would have a return on its initial investment in 10 years as depicted in *Table 61*. Ten years, depending on the owner, can seem reasonable or not, however since this is a government building, 10 years could be deemed as a decent payback period.

**Table 61- Full Storage Simple Payback Period**

| Full Storage Simple Payback | | | | | | |
|---|---|---|---|---|---|---|
| Date | Year | Initial Cost [$] | Maint [$/yr] | Utility Savings [$/yr] | Savings per Year [$/yr] | Total Savings [$] |
| 2011 | 0 | $ 347,218.80 | | | | |
| 2012 | 1 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | |
| 2013 | 2 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | $ 73,526.00 |
| 2014 | 3 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | $110,289.00 |
| 2015 | 4 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | $147,052.00 |
| 2016 | 5 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | $183,815.00 |
| 2017 | 6 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | $220,578.00 |
| 2018 | 7 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | $257,341.00 |
| 2019 | 8 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | $294,104.00 |
| 2020 | 9 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | $330,867.00 |
| 2021 | 10 | | $ 2,500.00 | $ 39,263.00 | $ 36,763.00 | **$367,630.00** |

Partial storage has a smaller initial investment and a shorter payback period; therefore, partial storage would be preferred over full storage.

## 6.10 Emissions

With lower electricity usage and equal gas usage as the existing system, it can be expected that the thermal storage system would produce less emissions. As was anticipated, the partial storage system produces 261,891 lbs/yr $CO_2$, 526 lbs/yr $NO_X$, 1,583 lbs/yr $SO_X$, and 14 lbs/yr PM10 *less* than the existing system as shown in *Table 62*.

**Table 62- Partial Storage Pollution Emission Rates**

| | Delivered Electricity by Local State | | | On-Site Combustion in a Commercial Boiler | | | |
|---|---|---|---|---|---|---|---|
| Pollutant | Emission Factor lb/kWh | Electric Consumption kWh/year | Electric Total lbs/year | Emission Factor lbs/1000 $ft^3$ | Gas Consumption 1000 $ft^3$/year | Gas Total lbs/year | **Total Pollutants lbs/year** |
| $CO_{2e}$ | 1.40E+00 | 1,170,367 | 1,638,514 | 1.23E+02 | 667 | 81,998 | 1,720,512 |
| **$CO_2$** | **1.33E+00** | 1,170,367 | **1,556,588** | **1.22E+02** | **667** | **81,332** | **1,637,920** |
| $CH_4$ | 2.52E-03 | 1,170,367 | 2,949 | 2.50E-03 | 667 | 2 | 2,951 |
| $N_2O$ | 2.81E-05 | 1,170,367 | 33 | 2.50E-03 | 667 | 2 | 35 |
| **$NO_x$** | **2.67E-03** | 1,170,367 | **3,125** | **1.11E-01** | **667** | **74** | **3,199** |
| **$SO_x$** | **8.04E-03** | 1,170,367 | **9,410** | **6.32E-04** | **667** | **0** | **9,410** |
| CO | 9.74E-04 | 1,170,367 | 1,140 | 9.33E-02 | 667 | 62 | 1,202 |
| TNMOC | 8.77E-05 | 1,170,367 | 103 | - | - | - | 103 |
| VOC | - | - | - | 6.13E-03 | 667 | 4 | 4 |
| Lead | 1.02E-07 | 1,170,367 | 0 | 5.00E-07 | 667 | 0 | 0 |
| Mercury | 3.24E-08 | 1,170,367 | 0 | 2.60E-07 | 667 | 0 | 0 |
| **PM10** | **7.25E-05** | 1,170,367 | **85** | **8.40E-03** | **667** | **6** | **90** |
| Solid Waste | 1.47E-01 | 1,170,367 | 172,044 | - | - | - | 172,044 |

The full storage system produces 101,114 lbs/yr $CO_2$, 203 lbs/yr $NO_X$, 611 lbs/yr $SO_X$, and 6 lbs/yr PM10 *less* than the existing system as shown in *Table 63*.

**Table 63- Full Storage Pollution Emission Rates**

| | Delivered Electricity by Local State | | | On-Site Combustion in a Commercial Boiler | | | |
|---|---|---|---|---|---|---|---|
| Pollutant | Emission Factor lb/kWh | Electric Consumption kWh/year | Electric Total lbs/year | Emission Factor lbs/1000 $ft^3$ | Gas Consumption 1000 $ft^3$/year | Gas Total lbs/year | **Total Pollutants lbs/year** |
| $CO_{2e}$ | 1.40E+00 | 1,291,252 | 1,807,753 | 1.23E+02 | 667 | 81,998 | 1,889,751 |
| **$CO_2$** | **1.33E+00** | 1,291,252 | **1,717,365** | **1.22E+02** | **667** | **81,332** | **1,798,697** |
| $CH_4$ | 2.52E-03 | 1,291,252 | 3,254 | 2.50E-03 | 667 | 2 | 3,256 |
| $N_2O$ | 2.81E-05 | 1,291,252 | 36 | 2.50E-03 | 667 | 2 | 38 |
| **$NO_x$** | **2.67E-03** | 1,291,252 | **3,448** | **1.11E-01** | **667** | **74** | **3,522** |
| **$SO_x$** | **8.04E-03** | 1,291,252 | **10,382** | **6.32E-04** | **667** | **0** | **10,382** |
| CO | 9.74E-04 | 1,291,252 | 1,258 | 9.33E-02 | 667 | 62 | 1,320 |
| TNMOC | 8.77E-05 | 1,291,252 | 113 | - | - | - | 113 |
| VOC | - | - | - | 6.13E-03 | 667 | 4 | 4 |
| Lead | 1.02E-07 | 1,291,252 | 0 | 5.00E-07 | 667 | 0 | 0 |
| Mercury | 3.24E-08 | 1,291,252 | 0 | 2.60E-07 | 667 | 0 | 0 |
| **PM10** | **7.25E-05** | 1,291,252 | **94** | **8.40E-03** | **667** | **6** | **99** |
| Solid Waste | 1.47E-01 | 1,291,252 | 189,814 | - | - | - | 189,814 |

## 6.11 Depth 2 Analysis Conclusion

A redesign utilizing a chilled water thermal storage tank would be beneficial for this facility. Particularly a partial storage system would save the most energy and money. It was concluded that partial storage would provide the most benefits saving 672,055 kBtu/yr and thus roughly $50,000 annually over the existing system. With an initial investment of $466,093, the partial storage system can expect to see a payback after 7 years. The full storage system saved 259,474 kBtu/yr and $39,263 annually over the existing system. With an initial investment of $527,693, the full storage system would expect to see a payback after 10 years.

# 7.0 Acoustical Breadth

The penthouse is located on the fourth floor and is separated only by a wall from active office spaces. An acoustical analysis of the sound attenuation through the wall from the penthouse to the offices will be performed. An analysis of the sound reduction caused by downsizing the equipment to the implementation of thermal storage and geothermal systems will also be conducted. Possible investigations into sound solutions could include altering the material properties of the separating wall or moving the penthouse to the fourth floor roof. Since the building's height restriction was removed, moving the penthouse to the fourth floor roof and enclosing the rest of the fourth floor where the penthouse was located should decrease acoustical problems.

## 7.1 Acoustical Analysis Procedure

Using the manufacturer specs, sound power levels were determined for the existing penthouse equipment including DOAU fans, pumps, the two boilers and the chiller. The levels provided are sound power levels ($L_W$), so these sound power levels first need to be converted to sound pressure levels ($L_P$) with the equation:

$$L_P = L_W + 10\log(\frac{4}{R})$$

R is the room constant ($m^2$ Sabin): $R = A + 4mV$

*where,*
A is the total room sound absorption: $A = S_1 \propto_1 + S_2 \propto_2 + \cdots + S_n \propto_n$,
m is the decay rate of sound energy in the air, and
V is the volume of the room.

The 4mV term accounts for sound absorption in the air and is typically used when the space is very large. However, since the penthouse is fairly small, this term can be neglected. Therefore,

$$R = A = S_1 \propto_1 + S_2 \propto_2 + \cdots + S_n \propto_n,$$

*where,*
$S_n$ is the area of each surface in the room, and
$\alpha_n$ is the absorption coefficient of each surface.

The walls, floor, and ceiling inside the penthouse are composed of 20 gauge galvanized steel. Experimental sound data for galvanized steel could not be found, so metal decking was used to compare absorption coefficients since it is the closest material to the actual wall type found. According to the SAE Institute, metal deck with 1" batts, as found in the source room, has the absorption coefficients shown in *Table 64*. Also, gypsum board, as found in the receiving room, has the absorption coefficients shown in the table.

**Table 64- Absorption Coefficients**

| Metal Deck (perforated channels, 25mm(1") batts) | | | | | | | |
|---|---|---|---|---|---|---|---|
| f [Hz] | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| α | - | 0.19 | 0.69 | 0.99 | 0.88 | 0.52 | 0.27 |

| Plasterboard (12mm (1/2") paneling on studs) | | | | | | | |
|---|---|---|---|---|---|---|---|
| f [Hz] | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| α | - | 0.29 | 0.1 | 0.06 | 0.05 | 0.04 | 0.04 |

$L_p$ is designated as $L_S$ in the source room and $L_R$ in the receiving room. The $L_R$ is the value that will determine the Noise Criteria (NC), which is a numerical index used to define design goals for the maximum allowable noise in a given space. In an office space like the one sharing a wall with the DOAU, a max NC of 35 is acceptable and in a conference room like the one sharing a wall with the rest of the penthouse, a max NC of 30 is acceptable according to the Facility Guidelines Institute. To arrive at an NC value, first an $L_S$ was calculated by the procedure above. From the $L_S$, transmission loss values through the separating wall are subtracted to get a sound level entering the receiving room. The separating wall is composed of 2 layers of 20 gauge galvanized steel sheeting, 3 lb/cu.ft. of foam insulation, 6" batt insulation, and 5/8" gypsum wall board. The transmission loss through 20 Ga steel sheets was found through collected experimental data. Transmission loss through the other materials was calculated using the materials' densities and thicknesses using the equation:

$$TL = 20 \log(fm_s) - 47.3$$

*where,*

f is the respective frequency, and

$m_s$ is the material's density multiplied by its thickness.

After subtracting the transmission loss through each material from the source room sound power level, the absorption of the receiving room must be considered.

$$L_R = L_S - TL + 10 \log (S/R_R)$$

*where,*

S is the surface area of the shared wall.

Using the calculated $L_R$ values, the noise criteria can then be found using the chart below.

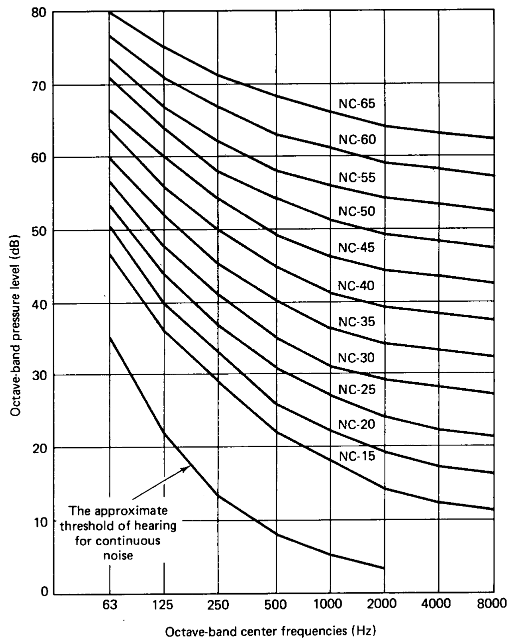



Figure 40- NC Curves

The highest NC curve reached by a sound pressure level is the NC in the space.

## 7.2 Existing Sound Levels

The current penthouse includes two boilers, eight pumps, and the DOAU unit, which houses six fans. Since the DOAU unit is an enclosed box within the penthouse and shares its own wall with the occupied spaces, it was treated as a second separate space than the penthouse, as diagrammed in *Figure 42*.

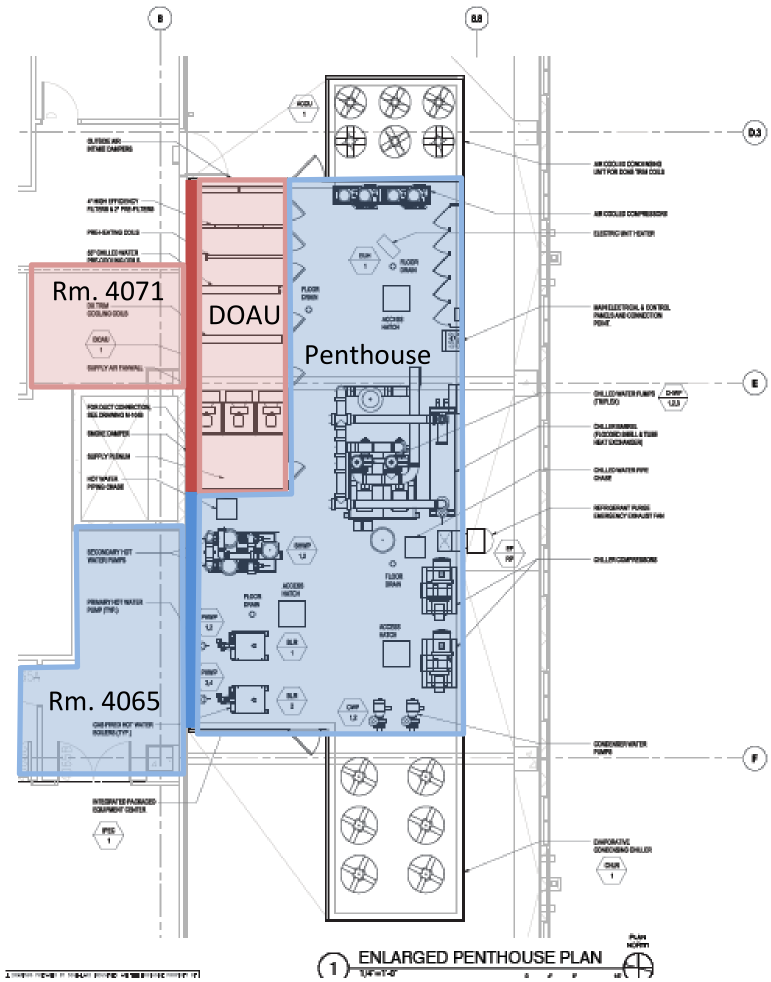



Figure 41- DOAU & Penthouse Layout

Sound transmission loss calculations were performed between the DOAU and Room 4071 and the rest of the penthouse with Room 4065. *Tables 65 and 66* show the NC calculations for the existing DOAU and penthouse. It is concluded that Room 4071 has an NC of 30, which is acceptable for an office space. This means that mechanical noise can still be heard in this space, but it will be at a level that is not disturbing to the occupant. Room 4071 is a storage room, a smart decision by the architect to minimize noise pollution, so an acceptable NC would actually be greater than the prescribed 35. The low frequencies tend to dominate during propagation, as is evident by the 125 Hz frequency having the highest sound pressure level, reaching the highest NC curve.

Room 4065 has a noise criterion of 14. This is well below the acceptable NC of 30 for a conference room. The 125 Hz frequency again dominates.

### Table 65- DOAU NC Calculations

| DOAU Sound Power (dB re: 10E-12 watts) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | | |
| Inlet (one fan) | | 98 | 92 | 89 | 92 | 83 | 80 | 80 | | |
| Inlet (six fans) | | 106 | 100 | 97 | 100 | 91 | 88 | 88 | | |
| Penthouse $\alpha_n$ | | - | 0.19 | 0.69 | 0.99 | 0.88 | 0.52 | 0.27 | | |
| Penthouse R | | - | 157 | 569 | 816 | 725 | 428 | 222 | $S_{DOAU}$= | 824 |
| $L_s$ [dB] | | - | 84 | 75 | 77 | 68 | 67 | 70 | $m_s$ [kg/m$^2$] | |
| TL | (2) 20 Ga steel | - | 19 | 22 | 28 | 30 | 35 | 42 | - | |
| | 3 lb/cu.ft. insulation | - | 0 | 2 | 8 | 14 | 20 | 26 | 1.22 | |
| | 6" batt insulation | - | 0 | 0 | 0 | 0 | 2 | 8 | 0.15 | |
| | 5/8" GWB | - | 14 | 20 | 26 | 32 | 38 | 44 | 9.53 | |
| $L_s$-TL [dB] | | - | 51 | 31 | 14 | 0 | 0 | 0 | | |
| | | | | | | | | | | |
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | | |
| Receiving $\alpha_n$ | | - | 0.29 | 0.1 | 0.06 | 0.05 | 0.04 | 0.04 | | |
| Receiving R | | - | 160 | 55 | 33 | 28 | 22 | 22 | $S_{ROOM\ 4071}$= | 552 |
| $L_R$ [dB] | | - | 47 | 32 | 18 | 4 | 5 | 5 | | |
| NC | | - | 30 | 18 | 12 | 0 | 0 | 0 | | |

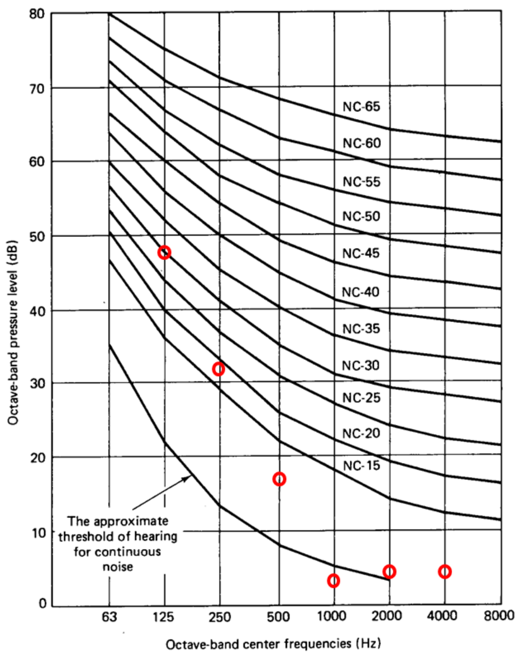
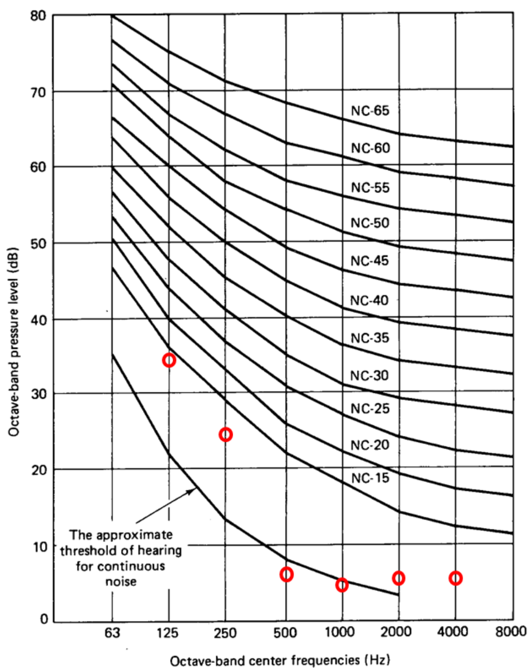


**Table 66- Penthouse NC Calculations**

| Penthouse Sound Power (dB re: 10E-12 watts) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | | |
| Inlet (1 boiler) | | 75 | 72 | 72 | 75 | 76 | 63 | 55 | | |
| Inlet (2 boilers) | | 78 | 75 | 75 | 78 | 79 | 66 | 58 | | |
| Inlet (1 compressor) | | 66 | 69 | 68 | 67 | 65 | 64 | 54 | | |
| Inlet (4 compressors) | | 72 | 75 | 74 | 73 | 71 | 70 | 60 | | |
| Inlet (1 pump) | | 85 | 80 | 82 | 82 | 80 | 77 | 74 | | |
| Inlet (8 pumps) | | 94 | 89 | 91 | 91 | 89 | 86 | 83 | | |
| Total Inlet dB | | 94 | 89 | 91 | 91 | 89 | 86 | 83 | | |
| Penthouse $\alpha_n$ | | - | 0.19 | 0.69 | 0.99 | 0.88 | 0.52 | 0.27 | | |
| Penthouse R | | - | 393 | 1428 | 2049 | 1822 | 1076 | 559 | $S_{PENT}$= | 2070 |
| $L_s$ [dB] | | - | 69 | 66 | 64 | 62 | 62 | 62 | $m_s$ [kg/m$^2$] | |
| TL | (2) 20 Ga steel | - | 19 | 22 | 28 | 30 | 35 | 42 | - | |
| | 3 lb/cu.ft. insulation | - | 0 | 2 | 8 | 14 | 20 | 26 | 1.22 | |
| | 6" batt insulation | - | 0 | 0 | 0 | 0 | 2 | 8 | 0.15 | |
| | 5/8" GWB | - | 14 | 20 | 26 | 32 | 38 | 44 | 9.53 | |
| $L_s$-TL [dB] | | - | 36 | 22 | 2 | 0 | 0 | 0 | | |
| | | | | | | | | | | |
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | | |
| Receiving $\alpha_n$ | | - | 0.29 | 0.1 | 0.06 | 0.05 | 0.04 | 0.04 | | |
| Receiving R | | - | 245 | 85 | 51 | 42 | 34 | 34 | $S_{ROOM\ 4065}$= | 846 |
| $L_R$ [dB] | | - | 34 | 24 | 6 | 5 | 6 | 6 | | |
| NC | | - | 14 | 13 | 0 | 0 | 1 | 2 | | |

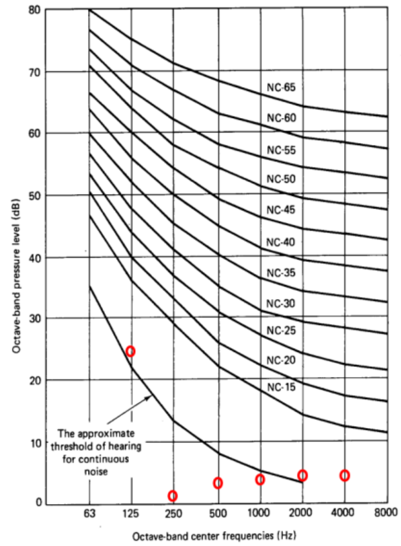



## 7.3 Proposed Sound Solutions

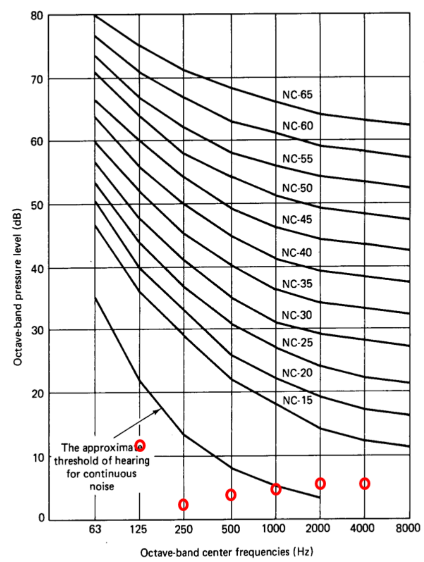
**Alternative Materials**

A company called Green Glue was created as a cheap and easy solution to sound damping. Green Glue is simply glue used between two layers of gypsum wall board that will act to provide soundproofing. The Green Glue company provides transmission loss data on their website that was used in the following noise criteria calculations:

| DOAU Sound Power (dB re: 10E-12 watts) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| Inlet (one fan) | | 98 | 92 | 89 | 92 | 83 | 80 | 80 |
| Inlet (six fans) | | 106 | 100 | 97 | 100 | 91 | 88 | 88 |
| Penthouse $\alpha_n$ | | - | 0.19 | 0.69 | 0.99 | 0.88 | 0.52 | 0.27 |
| Penthouse R | | - | 157 | 569 | 816 | 725 | 428 | 222 |
| $L_s$ [dB] | | - | 84 | 75 | 77 | 68 | 67 | 70 |
| TL | (2) 20 Ga steel | - | 19 | 22 | 28 | 30 | 35 | 42 |
| | 3 lb/cu.ft. insulation | - | 0 | 2 | 8 | 14 | 20 | 26 |
| | 6" batt insulation | - | 0 | 0 | 0 | 0 | 2 | 8 |
| | Green Glue | | 23 | 40 | 45 | 55 | 53 | 60 |
| | 5/8" GWB | - | 14 | 20 | 26 | 32 | 38 | 44 |
| $L_s$-TL [dB] | | - | 28 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | |
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| Receiving $\alpha_n$ | | - | 0.29 | 0.1 | 0.06 | 0.05 | 0.04 | 0.04 |
| Receiving R | | - | 160 | 55 | 33 | 28 | 22 | 22 |
| $L_R$ [dB] | | - | 24 | 1 | 3 | 4 | 5 | 5 |
| NC | | - | 1 | 0 | 0 | 0 | 1 | 2 |




| Penthouse Sound Power (dB re: 10E-12 watts) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| Inlet (1 boiler) | | 75 | 72 | 72 | 75 | 76 | 63 | 55 |
| Inlet (2 boilers) | | 78 | 75 | 75 | 78 | 79 | 66 | 58 |
| Inlet (1 compressor) | | 66 | 69 | 68 | 67 | 65 | 64 | 54 |
| Inlet (4 compressors) | | 72 | 75 | 74 | 73 | 71 | 70 | 60 |
| Inlet (1 pump) | | 85 | 80 | 82 | 82 | 80 | 77 | 74 |
| Inlet (8 pumps) | | 94 | 89 | 91 | 91 | 89 | 86 | 83 |
| Total Inlet dB | | 94 | 89 | 91 | 91 | 89 | 86 | 83 |
| Penthouse $\alpha_n$ | | - | 0.19 | 0.69 | 0.99 | 0.88 | 0.52 | 0.27 |
| Penthouse R | | - | 393 | 1428 | 2049 | 1822 | 1076 | 559 |
| $L_s$ [dB] | | - | 69 | 66 | 64 | 62 | 62 | 62 |
| TL | (2) 20 Ga steel | - | 19 | 22 | 28 | 30 | 35 | 42 |
| | 3 lb/cu.ft. insulation | - | 0 | 2 | 8 | 14 | 20 | 26 |
| | 6" batt insulation | - | 0 | 0 | 0 | 0 | 2 | 8 |
| | Green Glue | - | 23 | 40 | 45 | 55 | 53 | 60 |
| | 5/8" GWB | - | 14 | 20 | 26 | 32 | 38 | 44 |
| $L_s$-TL [dB] | | - | 13 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | |
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| Receiving $\alpha_n$ | | - | 0.29 | 0.1 | 0.06 | 0.05 | 0.04 | 0.04 |
| Receiving R | | - | 245 | 85 | 51 | 42 | 34 | 34 |
| $L_R$ [dB] | | - | 11 | 2 | 4 | 5 | 6 | 6 |
| NC | | - | 0 | 0 | 0 | 0 | 1 | 2 |



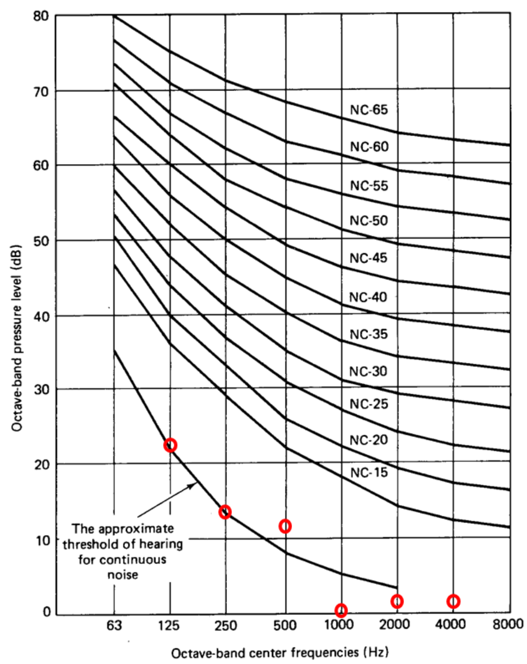

The addition of the Green Glue drastically decreased the sound levels traveling through the wall of the occupied zone. Through both the DOAU and Penthouse regions, only an NC of 2 would be detected in the receiving rooms. Green Glue is a cheap sound solution because it only costs $1.99/SF. This means that only an additional investment of $415 for raw materials would be needed to install the Green Glue.

**Penthouse Relocation**

As part of the architectural breadth, the penthouse will be moved to the roof. The roof is composed of 9” batt insulation over a 9 ½” concrete slab. The penthouse was treated as one space, so the DOAU noise was added to the boiler and pump noise. The receiving room below was also treated as one open space with the same footprint as the penthouse. It is concluded that if the penthouse were moved to the roof, there would be little to no sound propagating through the concrete slab to disturb the rooms below. Also, the penthouse would be centered over the core of the building, so if sound were to travel into the building, the receiving rooms would be restrooms and an elevator lobby. As is evident by *Table 67,* the noise criterion in the receiving space is barely above the threshold of human hearing. In this case, the 500 Hz frequency hit the highest NC curve. These calculations did not take into account the sound attenuation caused by the air in the plenum space. This will further aid in sound reduction.

**Table 67- Roof Penthouse NC Calculations**

| Roof Penthouse Sound Power (dB re: 10E-12 watts) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | | |
| Inlet (six fans) | | 106 | 100 | 97 | 100 | 91 | 88 | 88 | | |
| Inlet (2 boilers) | | 78 | 75 | 75 | 78 | 79 | 66 | 58 | | |
| Inlet (8 pumps) | | 94 | 89 | 91 | 91 | 89 | 86 | 83 | | |
| Total Inlet dB | | 106 | 100 | 98 | 101 | 93 | 90 | 89 | | |
| Penthouse $\alpha_n$ | | - | 0.19 | 0.69 | 0.99 | 0.88 | 0.52 | 0.27 | | |
| Penthouse R | | - | 454 | 1649 | 2366 | 2103 | 1243 | 645 | $S_{PENT}$= | 2390 |
| $L_S$ [dB] | | - | 79 | 72 | 73 | 66 | 65 | 67 | $m_s$ [kg/m$^2$] | |
| TL | 9" R-30 Insulation | - | 0 | 0 | 0 | 1 | 7 | 14 | 0.27 | |
| | 9.5" Concrete Slab | - | 50 | 56 | 62 | 68 | 74 | 80 | 554.99 | |
| $L_S$-TL [dB] | | - | 30 | 16 | 12 | 0 | 0 | 0 | | |
| | | | | | | | | | | |
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | | |
| Receiving $\alpha_n$ | | - | 0.29 | 0.1 | 0.06 | 0.05 | 0.04 | 0.04 | | |
| Receiving R | | - | 853 | 294 | 176 | 147 | 118 | 118 | $S_{ROOM}$= | 2940 |
| $L_R$ [dB] | | - | 22 | 13 | 11 | 0 | 1 | 1 | | |
| NC | | - | 1 | 0 | 2 | 0 | 0 | 0 | | |



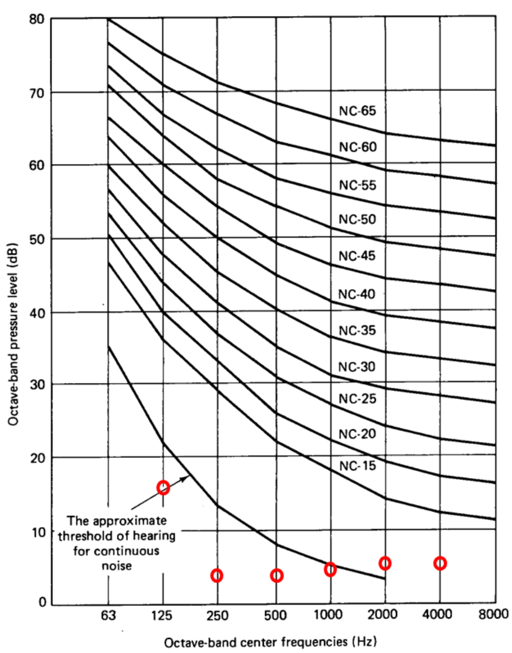

## 7.4 New Equipment Sound Levels

Since the pumps are the most contributing factor to the high noise levels in the penthouse, nothing would change with the addition of thermal storage. The chiller and pumps will be made smaller, but they will still put off similar sound levels. The hot water pumps, also, would not change and continue to contribute to higher levels. Therefore, an acoustical analysis of the new thermal storage equipment was not done because they would be the same as the existing system.

If the ground-source heat pumps were implemented, however, there would be no need for the boilers and chiller in the penthouse. This also eliminates the need for the 8 pumps, which are the sources of the largest sound levels found in the penthouse. The DOAS will remain untouched, so its sound propagation into room 4071 will be the same. In the rest of the penthouse, however, the only components left will be (2) air cooled compressors for the DOAS air cooled condensing unit that serves the DX trim coils. The pumps for the ground loop will be moved to the basement, so they won't be adding to the noise levels in the penthouse. *Table 68* shows the NC calculations for the penthouse if a geothermal system were installed.

**Table 68- Geothermal Penthouse NC Calculations**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Penthouse Sound Power (dB re: 10E-12 watts) | | | | | | | | | | |
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | | |
| Inlet (1 compressor) | | 66 | 69 | 68 | 67 | 65 | 64 | 54 | | |
| Inlet (2 compressors) | | 69 | 72 | 71 | 70 | 68 | 67 | 57 | | |
| Total Inlet dB | | 69 | 72 | 71 | 70 | 68 | 67 | 57 | | |
| Penthouse $\alpha_n$ | | - | 0.19 | 0.69 | 0.99 | 0.88 | 0.52 | 0.27 | | |
| Penthouse R | | - | 393 | 1428 | 2049 | 1822 | 1076 | 559 | $S_{PENT}$= | 2070 |
| $L_s$ [dB] | | - | 52 | 45 | 43 | 41 | 43 | 36 | $m_s$ [kg/m$^2$] | |
| TL | (2) 20 Ga steel | - | 19 | 22 | 28 | 30 | 35 | 42 | - | |
| | 3 lb/cu.ft. insulation | - | 0 | 2 | 8 | 14 | 20 | 26 | 1.22 | |
| | 6" batt insulation | - | 0 | 0 | 0 | 0 | 2 | 8 | 0.15 | |
| | 5/8" GWB | - | 14 | 20 | 26 | 32 | 38 | 44 | 9.53 | |
| $L_s$-TL [dB] | | - | 19 | 1 | 0 | 0 | 0 | 0 | | |
| | | | | | | | | | | |
| f [Hz] | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | | |
| Receiving $\alpha_n$ | | - | 0.29 | 0.1 | 0.06 | 0.05 | 0.04 | 0.04 | | |
| Receiving R | | - | 245 | 85 | 51 | 42 | 34 | 34 | $S_{ROOM\ 4065}$= | 846 |
| $L_R$ [dB] | | - | 16 | 4 | 4 | 5 | 6 | 6 | | |
| NC | | - | 0 | 0 | 0 | 0 | 1 | 2 | | |




With only two compressors in the penthouse, the sound levels in Room 4065 are around an NC level of 2. This is virtually undetectable by human hearing. Therefore, if a geothermal system was installed, even though it would not be economically beneficial, acoustically it would cause lower mechanical sound levels in occupied spaces.

## 7.5 Acoustical Breadth Conclusion

The existing sound levels in spaces adjacent to the penthouse are within the acceptable recommended NC ranges. However, the levels specified mean that some mechanical noise can still be heard by the occupied spaces, they just won't be at high enough levels to bother occupants. If sound isolation equipment were to fail or the adjacent rooms were sound sensitive for some particular reason, then steps to reduce sound propagation can be taken. This analysis concluded that if the penthouse were moved to the roof, the sound reaching the occupied spaces would be almost non-existent, pending the proper sound and vibration-isolating equipment. Also, if a geothermal system were installed, the need for 8 pumps in the penthouse would be eliminated and the sound levels would drop to virtually undetectable. The most practical solution, however, would be to invest in Green Glue. This would avoid the inconvenience of having to move any equipment and it would be a cheap solution.

Overall, the existing sound propagation through the shared penthouse wall is acceptable per industry standards. However, if the building owner called for lower sound levels, it would be recommended to add soundproofing Green Glue to the gypsum wallboard.

# 8.0 Architectural Breadth

## 8.1 Objective

An overall building height restriction of fifty feet was originally issued.  In accordance with this height restriction, the penthouse was placed in a "well" on the fourth floor of the building. This left less usable space for the penthouse, so the design team needed to design a compact, efficient penthouse. Also, since the architect still wanted the building to maintain four levels, the height restriction resulted in lower ceiling heights and subsequently smaller plenum sizes, causing coordination issues for the mechanical design team. Therefore, the mechanical engineers needed to design a system that utilized smaller duct sizes and terminal units, taking up less room in the plenum.

After the design was submitted, the height restriction was lifted. Therefore, this architectural study moved the penthouse from the fourth floor to the roof. The penthouse had to be specially designed to be compact to fit in its current position, but on the roof, there will be more room for equipment. A screening system was also chosen to shade the penthouse from the street view. Since the design team was having coordination problems with the small plenum spaces, the floor to floor heights were also raised to allow for more plenum space.

## 8.2 Penthouse Relocation

With almost the whole roof area to work with, the penthouse could be as large as the engineers needed it to be (with the approval of the architect). For the purpose of this analysis, the penthouse was increased 700 SF over the existing penthouse. It was kept close to the southern end of the building for direct access to the existing mechanical shaft without having to create new penetrations as pictured in *Figure 42*.

Figure 42- Aerial View of Army Administration Facility

With the penthouse now moved to the roof, an additional 2,700 SF is now available for occupancy. With this extra square footage, there is space for 8 more rooms, each with their own window(s) as pictured in *Figure 43.* With this addition of zones however, especially at the southern end of the building, the cooling loads would need to be reconsidered because the heat gains are sure to increase.

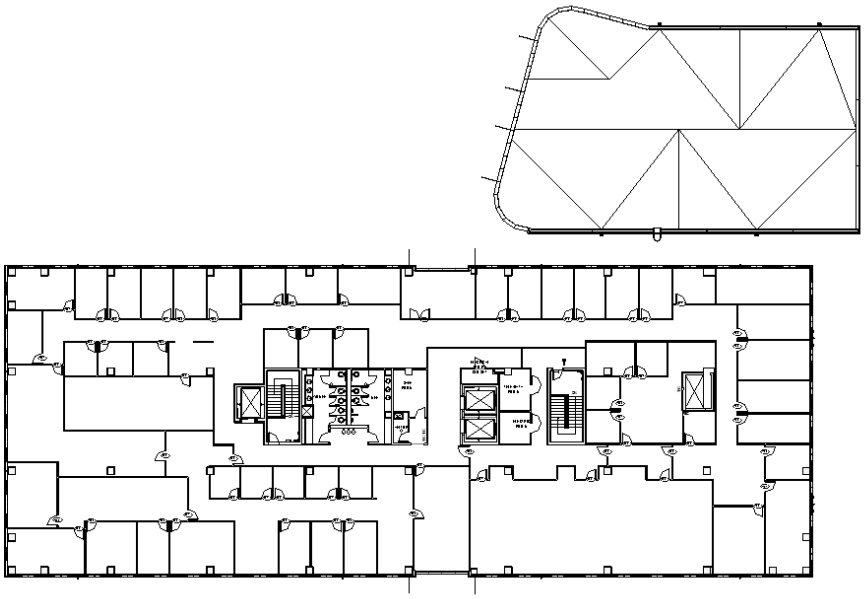


Figure 43- 4th Floor Redesigned Floor Plan3

## 8.3 Penthouse Screening

For the screening device, a simple louvered device like the one pictured in *Figure 44* will be implemented. This will allow the necessary volume of air to reach the condenser fans in the chiller and the air cooled condensing unit, but at the angle of the street level, the louvers would look like a solid wall, masking the mechanical equipment. By carrying the louvers up and over the equipment, it can also act as a shade for both the equipment and the maintenance staff.

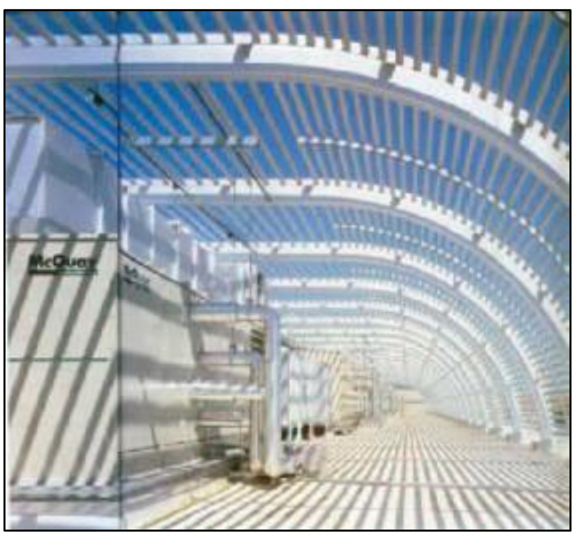


Figure 44- Example Screening System

As an additional measure to hide the penthouse, the parapet, which is currently about 2 ft. above the roof floor, was raised another 3 ft. Therefore the penthouse, which is 9 ft. tall, will only have 4 ft. sticking over the parapet as seen in *Figure 45*. Since the penthouse is set back from the exterior façade at least 20 ft., at ground level the parapet should be high enough to completely cover the penthouse.

A 6 ft. tall person would have to stand 310 ft. away from the building to see any of the penthouse.

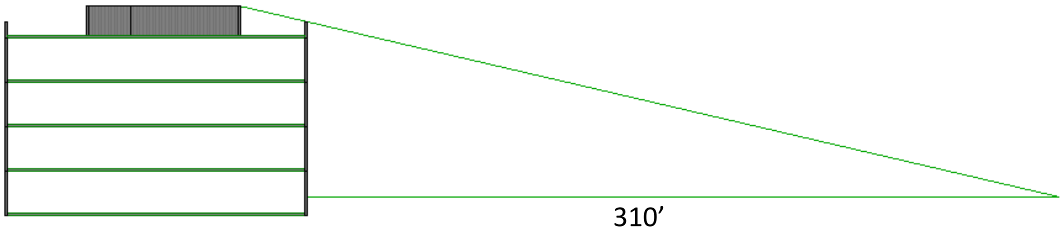



Figure 45- Penthouse Visualization Distance

## 8.4 Raised Floor Heights

The first floor is 14 feet high, floor to floor. This allows for a 4’-1 ½” plenum with a 10 ½ inch floor slab. The second, third and fourth floor, however, are only 12 ft. floor to floor with 9 ft. ceilings. A 2’-1 ½” plenum is very tight, especially to coordinate mechanical ducts with electrical buses and sprinklers, not to mention the building structure. The FPIUs, for one thing, are 22 inches tall leaving only 3 ½ inches above for any passing equipment as shown in *Figure 46*.

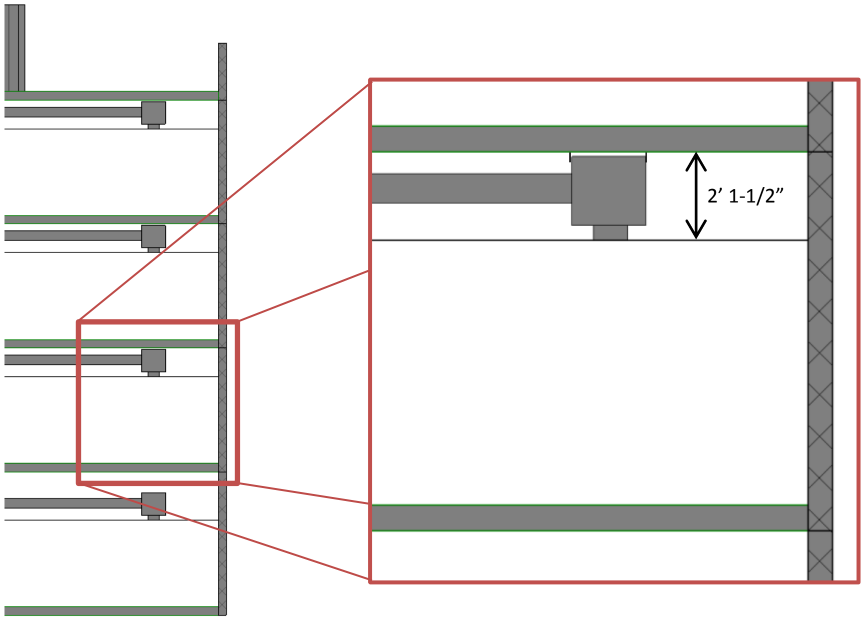



Figure 46- Existing Plenum Section

After speaking with some of the mechanical contractors on the job, they emphasized the point that it was a challenge to install the terminal units flush against the floor above. They had to actually change the size of the FPIUs, which are mass produced 28 inches tall, to 22 inches tall. *Figure 47* is a photo taken from on-site showing the lack of space in the plenum area. The FPIU is flush against the above floor.

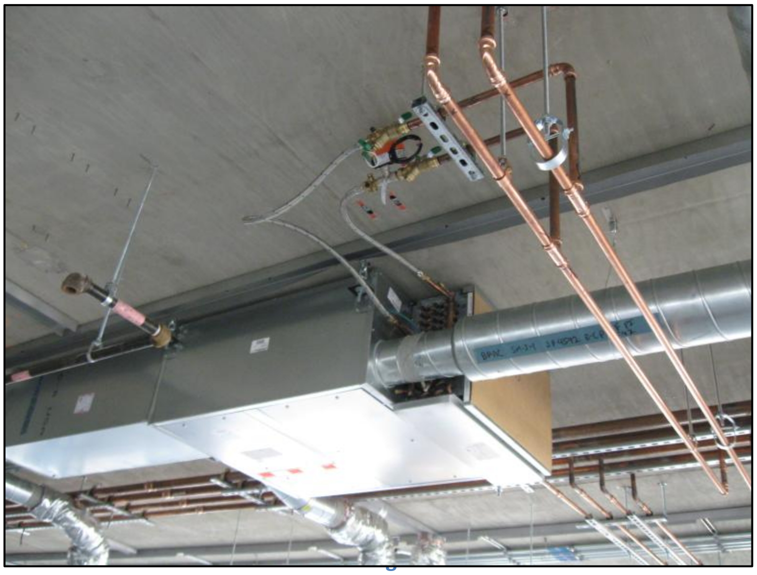


**Figure 47- FPIU in Plenum Space**

For this analysis, the floor to floor heights for the second through fourth floor were moved to 14 ft. as shown in *Figure 48.* With 4' 1 ½" of plenum space, there is 27.5 inches above, give or take, which makes coordination and installation much easier.

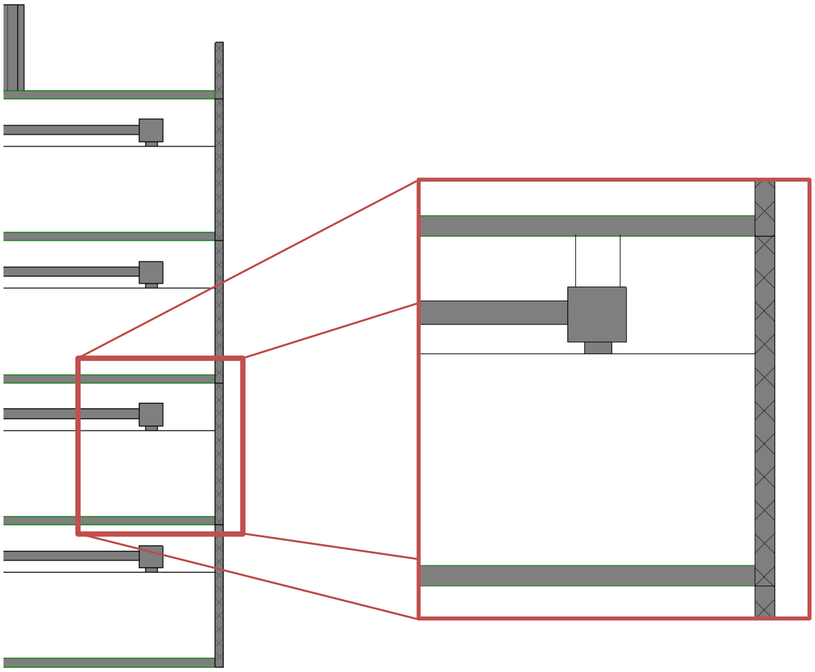


**Figure 48- Redesigned Plenum Section**

With the newly raised floor to floor heights and parapet, the building facade gained an additional 11 ft. *Figure 49* shows an eastern elevation of the existing building next to an elevation of the redesign. Notice the obvious height change and subtle addition of the penthouse on the roof.

Existing East Elevation Redesign East Elevation

Figure 49- Elevation Comparison

## 8.5 Thermal Storage Tank

With the proposed redesign of a chilled water thermal storage system, one of the issues was disguising the tank so it was not an eyesore. The idea is to disguise the tank by the parking garage. The tank was designed to be 50 ft. tall so as not to exceed the height of the building and garage. It was placed in the southwest corner of the garage, closest to the building, and a vehicular exit ramp was built around it as seen in *Figure 50*. This way, the tank looks like it is part of the structural system of the parking garage.

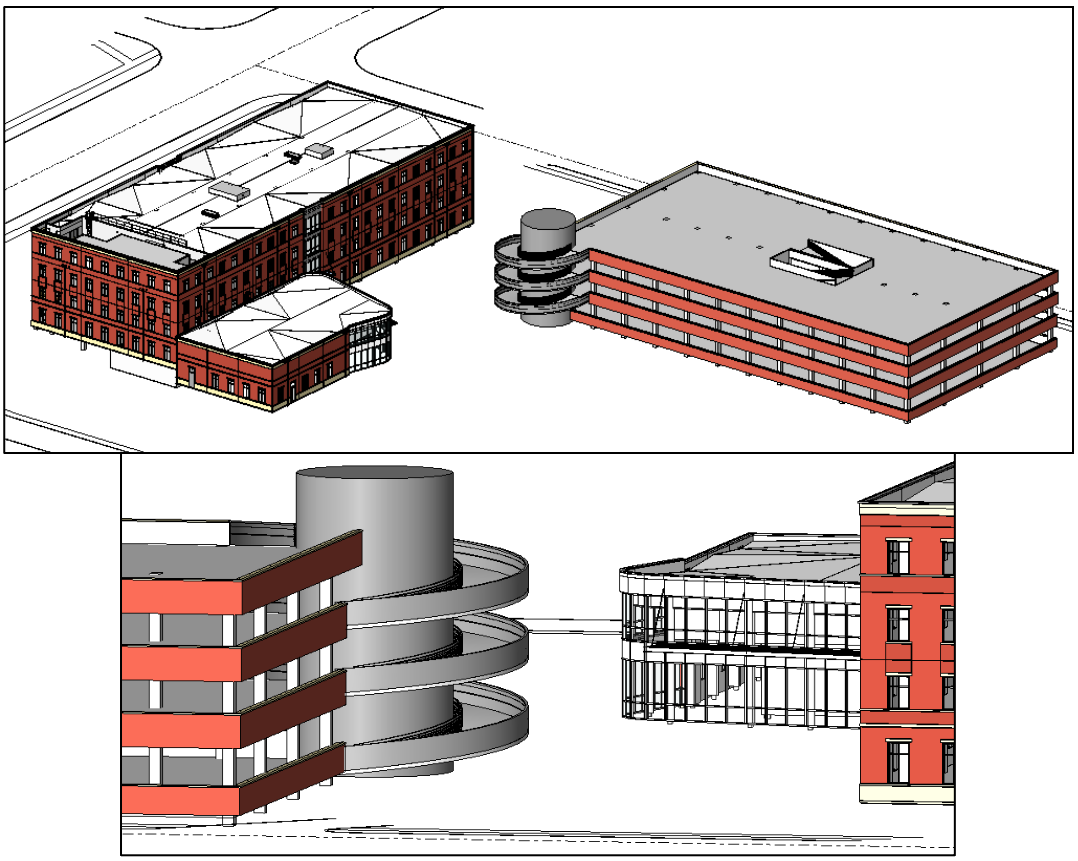


Figure 50- Thermal Storage Tank Integration

## 8.6 Architectural Breadth Conclusion

If the penthouse were moved to the roof, this would allow for more occupiable space on the fourth floor. Some possible options to help camouflage it would be a louvered screening system as well as a heightened parapet. With the removal of the 50 ft. height restriction, the floor to floor heights were raised and granted two additional feet of plenum space on the second, third, and fourth floor. This would greatly ease coordination issues and allow space for possible future additions to the plenum equipment. The thermal storage depth was assimilated into this breadth by the creative incorporation of the storage tank into the parking garage ramp structure.

## 9.0 Conclusions and Recommendation

Based on the analyses presented in this report, it can be concluded that a geothermal system would not be an economical alternative for this facility in its current location. The size of the load and the conductivity of the local soil require a large 251,700 ft. loop that would require an initial investment of $653,372. Due to the additional pumping power required for this length of pipe, the system would require 139,377 kWh of electricity 10% more electricity each year but saves 666,654 kBtu/yr of gas. Even though the system overall uses 4% less energy than the existing system, with the local prices of electricity versus gas, the geothermal system overall would cost $5,542 more on utilities than the existing system. Since the system would never pay for itself and for the reasons mentioned above, it would be ill-advised to install a ground-source heat pump system in this facility.

The thermal storage system, on the other hand, proved to have great energy and economic savings. The thermal storage system could be implemented to utilize a chiller that creates and stores chilled water in a storage tank during cheaper off-peak hours to be used during peak loads. Both partial and full storage cycles were analyzed and concluded that partial storage would provide the most benefits saving 672,055 kBtu/yr and thus roughly $50,000 annually over the existing system. With an initial investment of $466,093, the partial storage system can expect to see a payback after 7 years. The full storage system saved 259,474 kBtu/yr and $39,263 annually over the existing system. With an initial investment of $527,693, the full storage system would expect to see a payback after 10 years.

For the acoustical breadth, sound attenuation calculations through the wall between the penthouse and the adjacent offices concluded that the noise criterions in the occupied spaces are acceptable per industry standards. However, if there was a desire for lower sound levels, the use of Green Glue or moving the penthouse to the roof are viable options. For the architectural breadth, the penthouse was moved to the fourth floor roof and the area where the penthouse was located was enclosed, gaining 2,700 SF of occupiable space. The raised ceiling heights allow for more plenum space and an attractive screening device will hide the now visible penthouse and shade the roof. By building the stratified thermal storage tank in the parking garage, it can be used as an architectural feature rather than an eyesore.

Of the three alternatives proposed, it can be concluded that geothermal would not be a practical system to implement. Full or partial thermal storage would both provide some savings, but partial storage would be the most economically advantageous.

## 10.0 MAE Course Implementation

Much of the information and methods in this report were gleaned from Masters Coursework. As an MAE student, it is a requirement to apply some of the knowledge learned during these classes to this AE Senior Capstone Thesis Project. The following Masters Class content was utilized during the conception of this paper:

**AE 557**, Centralized Cooling Production and Distribution Systems, focuses on central chiller plants and includes discussions on thermal storage systems. Information learned from this course was used in the implementation of a chilled water storage system in the Army Administration Facility, as well as the chiller and pump sizing procedures. The comparisons between chilled water and ice storage and among the sensible storage devices were taken directly from the AE 557 notes.

**AE 558**, Centralized Heating and Distribution Systems, includes an economic analysis that will be used to calculate the payback period of implementing a geothermal heat pump or a thermal storage system. Also, the ability to pick an appropriate piping configuration and then compute the head loss through those pipes was attained during this course.

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# Appendix A- Ventilation Rate Analysis

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-1-D1-1 | | | | | | | | | | 50 | |
| | Perim Office | Office | 232 | 1 | 1060 | 1.2 | 5 | 0.06 | 20 | 50 | Y |
| FPIU-1-D3-1 | | | | | | | | | | 80 | |
| | Office | Office | 150 | 1 | 1061c | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| | Office | Office | 150 | 1 | 1062c | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| | Office | Office | 150 | 1 | 1063c | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| | Office | Office | 150 | 1 | 1064c | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| FPIU-1-D3-2 | | | | | | | | | | 60 | |
| | Office | Office | 150 | 1 | 1065c | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| | Office | Office | 150 | 1 | 1066c | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| | Office | Office | 150 | 1 | 1067c | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| FPIU-1-D4-1 | | | | | | | | | | 180 | |
| | Mens Shower | Toilet | 405 | 1 | 1007 | 0 | 0 | 0 | 0 | 99 | Y |
| | Womens Shower | Toilet | 298 | 1 | 1009 | 0 | 0 | 0 | 0 | 81 | Y |
| FPIU-1-E2-1 | | | | | | | | | | 120 | |
| | Waiting | Reception | 337 | 1 | 1058 | 10.1 | 5 | 0.06 | 71 | 79 | Y |
| | Office | Office | 155 | 1 | 1059c | 0.8 | 5 | 0.06 | 13 | 41 | Y |
| VAV-1-E2-1 | | | | | | | | | | 450 | |
| | VTC Suite | Conference | 421 | 1 | 1056 | 21.1 | 5 | 0.06 | 131 | 135 | Y |
| FPIU-1-E3-1 | | | | | | | | | | 120 | |
| | Hall | Corridor | 400 | 1 | 1055a | 0 | 0 | 0.06 | 24 | 37 | Y |
| | Hall | Corridor | 837 | 1 | 1068 | 0 | 0 | 0.06 | 50 | 53 | Y |
| | Safe room | Storage | 315 | 1 | 1069 | 0 | 0 | 0.12 | 38 | 16 | N |
| | Elevator Machine Room | Elevator | 39 | 1 | 1070 | 0 | 0 | 0.12 | 5 | 13 | Y |
| FPIU-1-F2-1 | | | | | | | | | | 60 | |
| | Mailroom | Office | 195 | 1 | 1057 | 1.0 | 5 | 0.06 | 17 | 35 | Y |
| | Hall | Corridor | 220 | 1 | 1072 | 0 | 0 | 0.06 | 13 | 13 | Y |
| | Hall | Corridor | 240 | 1 | 1075 | 0 | 0 | 0.06 | 14 | 15 | Y |
| FPIU-1-G1-2 | | | | | | | | | | 160 | |
| | Exterior Hall (with door) | Corridor | 221 | 1 | 1054 | 0 | 0 | 0.06 | 13 | 37 | Y |
| FPIU-1-G2-2 | | | | | | | | | | 200 | |
| | Vending | Break | 100 | 1 | 1077 | 4.0 | 5 | 0.06 | 26 | 28 | Y |
| FPIU-1-F3-1 | | | | | | | | | | 60 | |
| | File & Equip | Storage | 135 | 1 | 1053 | 0 | 0 | 0.12 | 16 | 9 | N |
| FPIU-1-G1-2 | | | | | | | | | | 160 | |
| FPIU-1-G1-1 | | | | | | | | | | 180 | |
| FPIU-1-G2-1 | | | | | | | | | | 280 | |
| FPIU-1-G2-2 | | | | | | | | | | 200 | |
| FPIU-1-F3-1 | | | | | | | | | | 60 | |
| FPIU-1-G3-1 | | | | | | | | | | 80 | |
| FPIU-1-G4-1 | | | | | | | | | | 60 | |
| | Open Office | Office | 3,259 | 1 | 1052 | 18.0 | 5 | 0.06 | 286 | 906 | Y |
| FPIU-1-G4-1 | | | | | | | | | | 60 | |
| | Office | Office | 150 | 1 | 1047 | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| | Office | Office | 150 | 1 | 1048 | 0.8 | 5 | 0.06 | 13 | 20 | Y |
| FPIU-1-F4-1 | | | | | | | | | | 60 | |
| | Office | Office | 100 | 1 | 1049 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 1 | 1050 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 1 | 1051 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-1-F4-2 | | | | | | | | | | 160 | |
| | Hall | Corridor | 37 | 1 | 1003 | 0 | 0 | 0.06 | 2 | 28 | Y |
| | Waiting Reception | Reception | 272 | 1 | 1046 | 8.2 | 5 | 0.06 | 57 | 132 | Y |
| FPIU-1-F5-1 | | | | | | | | | | 400 | |
| | Lobby | Lobby | 1,013 | 1 | 1001 | 30 | 7.5 | 0.06 | 289 | 380 | Y |
| | Elevator Machine Room | Elevator | 135 | 1 | 1005 | 0 | 0 | 0.12 | 16 | 20 | Y |
| FPIU-1-D6-1 | | | | | | | | | | 160 | |
| | Waiting | Reception | 460 | 1 | 1015 | 13.8 | 5 | 0.06 | 97 | 160 | Y |

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-1-E7-1 | | | | | | | | | | 50 | |
| | Exhibit Room | Office | 48 | 1 | 1017 | 0.2 | 5 | 0.06 | 4 | 9 | Y |
| | Office | Office | 155 | 1 | 1016C | 0.8 | 5 | 0.06 | 13 | 29 | Y |
| | Office | Office | 101 | 1 | 1040E | 0.5 | 5 | 0.06 | 9 | 13 | Y |
| FPIU-1-E7-3 | | | | | | | | | | 180 | |
| | Open Office | Office | 577 | 1 | 1018 | 2.9 | 5 | 0.06 | 49 | 180 | Y |
| FPIU-1-E7-2 | | | | | | | | | | 80 | |
| | IP Office | Office | 112 | 1 | 1022E | 0.6 | 5 | 0.06 | 10 | 24 | Y |
| | IP Office | Office | 118 | 1 | 1023E | 0.6 | 5 | 0.06 | 10 | 20 | Y |
| | File Cabinets | Storage | 140 | 1 | 1041 | 0.0 | 0 | 0.12 | 17 | 17 | Y |
| | Office | Office | 101 | 1 | 1042E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-1-D8-1 | | | | | | | | | | 260 | |
| | Library/Conference | Conference | 201 | 1 | 1019 | 10.1 | 5 | 0.06 | 62 | 169 | Y |
| FPIU-1-D8-2 | | | | | | | | | | 50 | |
| | Judge Advocate | Office | 274 | 1 | 1021 | 1.4 | 5 | 0.06 | 23 | 50 | Y |
| FPIU-1-E8-1 | | | | | | | | | | 160 | |
| | Safe room | Storage | 108 | 1 | 1011B | 0 | 0 | 0.12 | 13 | 15 | Y |
| | Telecom | Telecom | 167 | 1 | 1012 | 0 | 0 | 0 | 0 | 15 | Y |
| | Hall | Corridor | 43 | 1 | 1012a | 0 | 0 | 0.06 | 3 | 24 | Y |
| | Electric | Electrical | 146 | 1 | 1013 | 0 | 0 | 0.06 | 9 | 15 | Y |
| | Hall | Corridor | 411 | 1 | 1037 | 0 | 0 | 0.06 | 25 | 30 | Y |
| | Rolling Files | Storage | 480 | 1 | 1038 | 0 | 0 | 0.12 | 58 | 30 | N |
| | Cart Storage | Storage | 85 | 1 | 1039 | 0 | 0 | 0.12 | 10 | 30 | Y |
| FPIU-1-E8-1 | | | | | | | | | | 110 | |
| | Hall | Corridor | 422 | 1 | 1024 | 0 | 0 | 0.06 | 25 | 53 | Y |
| | Perim Office | Office | 152 | 1 | 1025C | 0.8 | 5 | 0.06 | 13 | 30 | Y |
| | Perim Office | Office | 152 | 1 | 1026C | 0.8 | 5 | 0.06 | 13 | 30 | Y |
| | Office | Office | 197 | 1 | 1027C | 1.0 | 5 | 0.06 | 17 | 36 | Y |
| FPIU-1-F7-1 | | | | | | | | | | 300 | |
| | Secure Network Room 2-part 1 | Classroom | 301 | 1 | 1045a | 10.5 | 10 | 0.12 | 141 | 300 | Y |
| FPIU-1-F7-2 | | | | | | | | | | 300 | |
| | Secure Network Room 2-part2 | Classroom | 301 | 1 | 1045b | 10.5 | 10 | 0.12 | 141 | 300 | Y |
| FPIU-1-G6-1 | | | | | | | | | | 160 | |
| | Computer Assembly | Office | 443 | 1 | 1043 | 5.0 | 5 | 0.06 | 52 | 124 | Y |
| | Secure Network Room 1 | Electrical | 400 | 1 | 1044 | 0 | 0 | 0.06 | 24 | 16 | N |
| | Hall | Corridor | 186 | 1 | 1071 | 0 | 0 | 0.06 | 11 | 8 | N |
| | Hall | Corridor | 122 | 1 | 1076 | 0 | 0 | 0.06 | 7 | 12 | Y |
| FPIU-1-G7-1 | | | | | | | | | | 230 | |
| | IP Office | Office | 112 | 1 | 1028E | 0.6 | 5 | 0.06 | 10 | 50 | Y |
| | Break | Break | 365 | 1 | 1036 | 9.1 | 5 | 0.06 | 67 | 130 | Y |
| | Hall | Corridor | 511 | 1 | 1073 | 0 | 0 | 0.06 | 31 | 50 | Y |
| FPIU-1-G8-1 | | | | | | | | | | 90 | |
| | Office | Office | 166 | 1 | 1033C | 0.8 | 5 | 0.06 | 14 | 29 | Y |
| | Office | Office | 166 | 1 | 1034C | 0.8 | 5 | 0.06 | 14 | 29 | Y |
| | Office | Office | 188 | 1 | 1035C | 0.9 | 5 | 0.06 | 16 | 33 | Y |
| FPIU-1-G8-2 | | | | | | | | | | 50 | |
| | Senior Judge | Office | 290 | 1 | 1032B | 1.5 | 5 | 0.06 | 25 | 50 | Y |
| FPIU-1-G8-3 | | | | | | | | | | 80 | |
| | Office | Office | 197 | 1 | 1029B | 1.0 | 5 | 0.06 | 17 | 29 | Y |
| | Perim Office | Office | 152 | 1 | 1030C | 0.8 | 5 | 0.06 | 13 | 26 | Y |
| | Perim Office | Office | 152 | 1 | 1031C | 0.8 | 5 | 0.06 | 13 | 26 | Y |
| FPIU-1-C8-1/2 | | | | | | | | | | 300 | |
| VAV-1-C8-1/2 | | | | | | | | | | 1300 | |
| | Court Room | Courtroom | 1,780 | 1 | c1009 | 124.6 | 5 | 0.06 | 730 | 820 | Y |
| FPIU-1-C6-1 | | | | | | | | | | 150 | |
| | Security Screening | Lobby | 374 | 1 | c1002 | 9.8 | 7.5 | 0.06 | 96 | 150 | Y |
| FPIU-1-C6-2 | | | | | | | | | | 240 | |
| | Waiting Area | Reception | 367 | 1 | c1004 | 11.0 | 5 | 0.06 | 77 | 104 | Y |
| | Witness | Conference | 230 | 1 | c1005 | 11.5 | 5 | 0.06 | 71 | 136 | Y |

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-1-B6-1 | | | | | | | | | | 220 | |
| FPIU-1-B6-2 | | | | | | | | | | 220 | |
| | Deliberation Room | Conference | 425 | 1 | c1006 | 20.0 | 5 | 0.06 | 126 | 440 | Y |
| FPIU-1-B7-1 | | | | | | | | | | 120 | |
| | Robe Dress | Office | 272 | 1 | c1007 | 1.4 | 5 | 0.06 | 23 | 70 | Y |
| | Hall | Corridor | 410 | 1 | c1008 | 0 | 0 | 0.06 | 25 | 26 | Y |
| | Office | Office | 206 | 1 | c1010 | 1.0 | 5 | 0.06 | 18 | 32 | Y |
| FPIU-1-B8-1 | | | | | | | | | | 90 | |
| | Break | Break | 105 | 1 | c1017 | 2.6 | 7.5 | 0.18 | 39 | 61 | Y |
| | Hall | Corridor | 105 | 1 | c1018 | 0 | 0 | 0.06 | 6 | 8 | Y |
| FPIU-1-B10-1 | | | | | | | | | | 50 | |
| | Office | Office | 145 | 1 | C1011C | 0.7 | 5 | 0.06 | 12 | 50 | Y |
| FPIU-1-B10-2 | | | | | | | | | | 80 | |
| | Office | Office | 110 | 1 | C1014e | 0.6 | 5 | 0.06 | 9 | 23 | Y |
| | Office | Office | 110 | 1 | c1015e | 0.6 | 5 | 0.06 | 9 | 23 | Y |
| | Office | Office | 110 | 1 | c1016e | 0.6 | 5 | 0.06 | 9 | 23 | Y |
| | Water Service | Mechanical | 330 | 1 | c1019 | 0 | 0 | 0.12 | 40 | 11 | N |
| FPIU-2-D1-1 | | | | | | | | | | 30 | |
| | Office | Office | 188 | 2 | 2029 | 0.9 | 5 | 0.06 | 16 | 30 | Y |
| FPIU-2-D2-1 | | | | | | | | | | 40 | |
| | Open Office | Office | 384 | 2 | 2028 | 1.9 | 5 | 0.06 | 33 | 40 | Y |
| FPIU-2-D3-1 | | | | | | | | | | 60 | |
| | Office | Office | 144 | 2 | 2024C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 144 | 2 | 2025C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 144 | 2 | 2026C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| FPIU-2-D3-2 | | | | | | | | | | 60 | |
| | Office | Office | 100 | 2 | 2020E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2021E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2022E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-2-D4-1 | | | | | | | | | | 60 | |
| | Office | Office | 100 | 2 | 2017E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2018E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2019E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-2-D6-1 | | | | | | | | | | 160 | |
| | Waiting | Reception | 361 | 2 | 2013 | 10.8 | 5 | 0.06 | 76 | 160 | Y |
| FPIU-2-E5-1 | | | | | | | | | | 190 | |
| | Hall | Corridor | 176 | 2 | 2014 | 0 | 0 | 0.06 | 11 | 14 | Y |
| | CTA file | Storage | 133 | 2 | 2015 | 0 | 0 | 0.12 | 16 | 9 | N |
| | Litigation Support | Office | 292 | 2 | 2016 | 1.5 | 5 | 0.06 | 25 | 167 | Y |
| FPIU-2-D6-2 | | | | | | | | | | 400 | |
| | Deposition room | Conference | 556 | 2 | 2012 | 27.8 | 5 | 0.06 | 172 | 400 | Y |
| FPIU-2-D7-1 | | | | | | | | | | 60 | |
| | Office | Office | 100 | 2 | 2103E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2104E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2105E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-2-D8-1 | | | | | | | | | | 70 | |
| | Office | Office | 100 | 2 | 2095E | 0.5 | 5 | 0.06 | 9 | 24 | Y |
| | Hall | Corridor | 561 | 2 | 2096 | 0 | 0 | 0.06 | 34 | 43 | Y |
| | Office | Office | 100 | 2 | 2102E | 0.5 | 5 | 0.06 | 9 | 24 | Y |
| FPIU-2-D9-1 | | | | | | | | | | 20 | |
| | Office | Office | 131 | 2 | 2094 | 0.7 | 5 | 0.06 | 11 | 20 | Y |
| FPIU-2-E7-1 | | | | | | | | | | 90 | |
| | Office | Office | 100 | 2 | 2099E | 0.5 | 5 | 0.06 | 9 | 23 | Y |
| | Office | Office | 100 | 2 | 2100E | 0.5 | 5 | 0.06 | 9 | 23 | Y |
| | Office | Office | 100 | 2 | 2101E | 0.5 | 5 | 0.06 | 9 | 23 | Y |
| FPIU-2-E9-1 | | | | | | | | | | 80 | |
| | Office | Office | 110 | 2 | 2086E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 2 | 2090E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 2 | 2091E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 2 | 2093E | 0.6 | 5 | 0.06 | 9 | 20 | Y |

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-2-E8-2 | | | | | | | | | | 90 | |
| | Office | Office | 115 | 2 | 2089E | 0.6 | 5 | 0.06 | 10 | 20 | Y |
| | Office | Office | 100 | 2 | 2097E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 100 | 2 | 2098E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Hall | Corridor | 417 | 2 | 2092 | 0 | 0 | 0.06 | 25 | 34 | Y |
| FPIU-8-E8-1 | | | | | | | | | | 160 | |
| | Rolling Files | Office | 944 | 2 | 2088 | 4.7 | 5 | 0.06 | 80 | 160 | Y |
| FPIU2-F5-1 | | | | | | | | | | 190 | |
| | Lobby | Lobby | 227 | 2 | 2001 | 6.8 | 7.5 | 0.06 | 65 | 68 | Y |
| | Hall | Corridor | 497 | 2 | 2002 | 0 | 0 | 0.06 | 30 | 64 | Y |
| | Safe | Storage | 135 | 2 | 2005 | 0 | 0 | 0.12 | 16 | 18 | Y |
| | Telecom | Telecom | 91 | 2 | 2009 | 0 | 0 | 0 | 0 | 18 | Y |
| | Electric | Electrical | 147 | 2 | 2010 | 0 | 0 | 0.06 | 9 | 18 | Y |
| | Hall | Corridor | 358 | 2 | 2011 | 0 | 0 | 0.06 | 21 | 29 | Y |
| FPIU-2-E3-1 | | | | | | | | | | 350 | |
| | Litigation Support Work Area | Office | 657 | 2 | 2023 | 3.3 | 5 | 0.06 | 56 | 255 | Y |
| | Files | Storage | 754 | 2 | 2052 | 0 | 0 | 0.12 | 90 | 95 | Y |
| FPIU-2-E2-1 | | | | | | | | | | 130 | |
| | Open Office | Office | 413 | 2 | 2027 | 2.1 | 5 | 0.06 | 35 | 60 | Y |
| | Office | Office | 100 | 2 | 2033E | 0.5 | 5 | 0.06 | 9 | 14 | Y |
| | Open Office | Office | 381 | 2 | 2037 | 1.9 | 5 | 0.06 | 32 | 56 | Y |
| FPIU-2-E1-1 | | | | | | | | | | 80 | |
| | Office | Office | 145 | 2 | 2030C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 145 | 2 | 2031C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 145 | 2 | 2034C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 145 | 2 | 2035C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| FPIU-2-F7-1 | | | | | | | | | | 60 | |
| | Office | Office | 145 | 2 | 2036C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 145 | 2 | 2039C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 145 | 2 | 2040C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| FPIU-2-F2-1 | | | | | | | | | | 100 | |
| | Office | Office | 100 | 2 | 2038E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2047E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2048E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2050E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2051E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-2-G2-1 | | | | | | | | | | 80 | |
| | Office | Office | 100 | 2 | 2042E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 144 | 2 | 2043C | 0.7 | 5 | 0.06 | 12 | 21 | Y |
| | Office | Office | 144 | 2 | 2044C | 0.7 | 5 | 0.06 | 12 | 21 | Y |
| | Office | Office | 144 | 2 | 2045C | 0.7 | 5 | 0.06 | 12 | 21 | Y |
| FPIU-2-G1-1 | | | | | | | | | | 40 | |
| | Office | Office | 210 | 2 | 2041 | 1.1 | 5 | 0.06 | 18 | 40 | Y |
| FPIU-2-F3-1 | | | | | | | | | | 140 | |
| | Hall | Corridor | 406 | 2 | 2046 | 0 | 0 | 0.06 | 24 | 28 | Y |
| | Hall | Corridor | 127 | 2 | 2049 | 0 | 0 | 0.06 | 8 | 11 | Y |
| | Break | Break | 147 | 2 | 2053 | 3.7 | 7.5 | 0.18 | 54 | 67 | Y |
| FPIU-2-G3-1 | | | | | | | | | | 120 | |
| | Open Office | Office | 194 | 2 | 2054 | 1.0 | 5 | 0.06 | 16 | 25 | Y |
| | Open Office | Office | 497 | 2 | 2055 | 2.5 | 5 | 0.06 | 42 | 95 | Y |
| FPIU-2-F4-1 | | | | | | | | | | 100 | |
| | Office | Office | 100 | 2 | 2061E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2062E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2063E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2064E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 2 | 2065E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-2-G4-1 | | | | | | | | | | 60 | |
| | Office | Office | 145 | 2 | 2056C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 145 | 2 | 2057C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 145 | 2 | 2058C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| FPIU-2-G6-1 | | | | | | | | | | 80 | |
| | Office | Office | 145 | 2 | 2059C | 0.7 | 5 | 0.06 | 12 | 15 | Y |
| | Office | Office | 219 | 2 | 2067 | 1.1 | 5 | 0.06 | 19 | 48 | Y |
| | Office | Office | 153 | 2 | 2068C | 0.8 | 5 | 0.06 | 13 | 17 | Y |

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-2-F7-1 | | | | | | | | | | 110 | |
| | Office | Office | 100 | 2 | 2071E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 100 | 2 | 2072E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Hall | Office | 327 | 2 | 2073 | 1.6 | 5 | 0.06 | 28 | 49 | Y |
| FPIU-2-F7-2 | | | | | | | | | | 80 | |
| | Hall | Corridor | 333 | 2 | 2060 | 0 | 0 | 0.06 | 20 | 10 | N |
| | Copy Area | Office | 205 | 2 | 2066 | 1.0 | 5 | 0.06 | 17 | 34 | Y |
| | Open Office | Office | 212 | 2 | 2070 | 1.1 | 5 | 0.06 | 18 | 36 | Y |
| FPIU-2-G7-1 | | | | | | | | | | 60 | |
| | Office | Office | 150 | 2 | 2069C | 0.8 | 5 | 0.06 | 13 | 26 | Y |
| | Office | Office | 110 | 2 | 2074E | 0.6 | 5 | 0.06 | 9 | 17 | Y |
| | Office | Office | 110 | 2 | 2075E | 0.6 | 5 | 0.06 | 9 | 17 | Y |
| FPIU-2-F8-1 | | | | | | | | | | 520 | |
| | Mock Court | Conference | 510 | 2 | 2081 | 25.5 | 5 | 0.06 | 158 | 520 | Y |
| FPIU-2-F8-2 | | | | | | | | | | 90 | |
| | Hall | Corridor | 294 | 2 | 2080 | 0 | 0 | 0.06 | 18 | 9 | N |
| | Open Office | Office | 368 | 2 | 2082 | 1.8 | 5 | 0.06 | 31 | 63 | Y |
| | Office | Office | 100 | 2 | 2087E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| FPIU-2-F9-1 | | | | | | | | | | 60 | |
| | Office | Office | 110 | 2 | 2083E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 2 | 2084E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 2 | 2085E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-2-G8-1 | | | | | | | | | | 60 | |
| | Office | Office | 110 | 2 | 2076E | 0.6 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 110 | 2 | 2077E | 0.6 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 169 | 2 | 2078C | 0.8 | 5 | 0.06 | 14 | 24 | Y |
| FPIU-2-G9-1 | | | | | | | | | | 40 | |
| | Office | Office | 210 | 2 | 2079 | 1.1 | 5 | 0.06 | 18 | 40 | Y |
| FPIU-3-D1-1 | | | | | | | | | | 50 | |
| | Office | Office | 228 | 3 | 3030 | 1.1 | 5 | 0.06 | 19 | 50 | Y |
| FPIU-3-D1-2 | | | | | | | | | | 50 | |
| | Office | Office | 154 | 3 | 3028C | 0.8 | 5 | 0.06 | 13 | 25 | Y |
| | Office | Office | 154 | 3 | 3029C | 0.8 | 5 | 0.06 | 13 | 25 | Y |
| FPIU-3-D3-1 | | | | | | | | | | 50 | |
| | Office | Office | 154 | 3 | 3022C | 0.8 | 5 | 0.06 | 13 | 25 | Y |
| | Office | Office | 154 | 3 | 3023C | 0.8 | 5 | 0.06 | 13 | 25 | Y |
| FPIU-3-D3-2 | | | | | | | | | | 60 | |
| | Office | Office | 110 | 3 | 3016E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 3 | 3020E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 3 | 3021E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-3-D4-1 | | | | | | | | | | 60 | |
| | Office | Office | 110 | 3 | 3013E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 3 | 3014E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 110 | 3 | 3015E | 0.6 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-3-E1-1 | | | | | | | | | | 100 | |
| | Open Office | Office | 330 | 3 | 3031 | 1.7 | 5 | 0.06 | 28 | 57 | Y |
| | Office | Office | 116 | 3 | 3032D | 0.6 | 5 | 0.06 | 10 | 22 | Y |
| | Office | Office | 116 | 3 | 3033E | 0.6 | 5 | 0.06 | 10 | 22 | Y |
| FPIU-3-E2-1 | | | | | | | | | | 80 | |
| | Office | Office | 102 | 3 | 3024E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 102 | 3 | 3025E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 102 | 3 | 3026E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 102 | 3 | 3027E | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| FPIU-3-D3-3 | | | | | | | | | | 220 | |
| | Waiting | Reception | 215 | 3 | 3012 | 6.5 | 5 | 0.06 | 45 | 116 | Y |
| | Hall | Corridor | 712 | 3 | 3017 | 0 | 0 | 0.06 | 43 | 35 | N |
| | Break Area | Break | 183 | 3 | 3019 | 4.6 | 7.5 | 0.18 | 67 | 69 | Y |
| FPIU-3-E4-1 | | | | | | | | | | 320 | |
| | Conference | Conference | 312 | 3 | 3018 | 15.6 | 5 | 0.06 | 97 | 320 | Y |
| FPIU-3-E2-2 | | | | | | | | | | 170 | |
| | Hall | Corridor | 373 | 3 | 3038 | 0 | 0 | 0.06 | 22 | 32 | Y |
| | Open Office | Office | 234 | 3 | 3039 | 1.2 | 5 | 0.06 | 20 | 68 | Y |
| | Archive | Storage | 428 | 3 | 3040 | 0 | 0 | 0.12 | 51 | 51 | Y |

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-3-E5-2 | | | | | | | | | | 130 | |
| | Lobby | Lobby | 225 | 3 | 3001 | 6.8 | 7.5 | 0.06 | 64 | 67 | Y |
| | Hall | Corridor | 562 | 3 | 3002 | 0 | 0 | 0.06 | 34 | 45 | Y |
| | Safe room | Storage | 136 | 3 | 3005 | 0 | 0 | 0.12 | 16 | 10 | N |
| | Mens Restroom | Toilet | 246 | 3 | 3006 | 0 | 0 | 0 | 0 | 15 | Y |
| | Telecom | Telecom | 117 | 3 | 3009 | 0 | 0 | 0 | 0 | 10 | Y |
| | Electric | Electrical | 154 | 3 | 3010 | 0 | 0 | 0.06 | 9 | 10 | Y |
| FPIU-3-F2-1 | | | | | | | | | | 80 | |
| | Office | Office | 103 | 3 | 3041E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 103 | 3 | 3042E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 103 | 3 | 3043E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Copy Area | Corridor | 189 | 3 | 3045 | 0 | 0 | 0.06 | 11 | 20 | Y |
| FPIU-3-F2-2 | | | | | | | | | | 80 | |
| | Office | Office | 103 | 3 | 3046E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 103 | 3 | 3047E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 103 | 3 | 3048E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 103 | 3 | 3049E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU3-G1-2 | | | | | | | | | | 60 | |
| | Office | Office | 116 | 3 | 3034E | 0.6 | 5 | 0.06 | 10 | 18 | Y |
| | Office | Office | 116 | 3 | 3035E | 0.6 | 5 | 0.06 | 10 | 18 | Y |
| | Office | Office | 116 | 3 | 3036E | 0.6 | 5 | 0.06 | 10 | 18 | Y |
| FPIU-3-G3-2 | | | | | | | | | | 80 | |
| | Hall | Corridor | 500 | 3 | 3050 | 0 | 0 | 0.06 | 30 | 56 | Y |
| | Open Office | Office | 206 | 3 | 3064 | 1.0 | 5 | 0.06 | 18 | 30 | Y |
| | Office | Office | 97 | 3 | 3065E | 0.5 | 5 | 0.06 | 8 | 20 | Y |
| | Office | Office | 97 | 3 | 3066E | 0.5 | 5 | 0.06 | 8 | 20 | Y |
| FPIU-3-F5-1 | | | | | | | | | | 110 | |
| | Supply Storage | Storage | 143 | 3 | 3062 | 0 | 0 | 0.12 | 17 | 14 | N |
| | Doc Prep Work | Office | 215 | 3 | 3063 | 1.1 | 5 | 0.06 | 18 | 55 | Y |
| FPIU-3-G1-1 | | | | | | | | | | 50 | |
| | Office | Office | 218 | 3 | 3037 | 1.1 | 5 | 0.06 | 19 | 50 | Y |
| FPIU-3-G2-1 | | | | | | | | | | 80 | |
| | Office | Office | 154 | 3 | 3051C | 0.8 | 5 | 0.06 | 13 | 23 | Y |
| | Office | Office | 102 | 3 | 3052E | 0.5 | 5 | 0.06 | 9 | 17 | Y |
| | Office | Office | 102 | 3 | 3053D | 0.5 | 5 | 0.06 | 9 | 17 | Y |
| | Office | Office | 102 | 3 | 3054E | 0.5 | 5 | 0.06 | 9 | 17 | Y |
| FPIU-3-G3-1 | | | | | | | | | | 60 | |
| | Office | Office | 102 | 3 | 3055E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 102 | 3 | 3056E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 102 | 3 | 3057E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-3-G4-1 | | | | | | | | | | 60 | |
| | Office | Office | 102 | 3 | 3058 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 102 | 3 | 3059 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 102 | 3 | 3060 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-3-G5-1 | | | | | | | | | | 80 | |
| | Waiting | Reception | 170 | 3 | 3061 | 5.1 | 5 | 0.06 | 36 | 80 | Y |
| FPIU-3-D6-1 | | | | | | | | | | 60 | |
| | Office | Office | 181 | 3 | 3069B | 0.9 | 5 | 0.06 | 15 | 46 | Y |
| | Office | Office | 152 | 3 | 3070 | 0.8 | 5 | 0.06 | 13 | 14 | Y |
| FPIU-3-D7-2 | | | | | | | | | | 60 | |
| | Office | Office | 152 | 3 | 3071C | 0.8 | 5 | 0.06 | 13 | 22 | Y |
| | Office | Office | 101 | 3 | 3072E | 0.5 | 5 | 0.06 | 9 | 19 | Y |
| | Office | Office | 101 | 3 | 3073E | 0.5 | 5 | 0.06 | 9 | 19 | Y |
| FPIU-3-D7-3 | | | | | | | | | | 60 | |
| | Office | Office | 101 | 3 | 3074E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 101 | 3 | 3077E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 101 | 3 | 3078E | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-3-E10-1 | | | | | | | | | | 50 | |
| | Office | Office | 166 | 3 | 3080C | 0.8 | 5 | 0.06 | 14 | 50 | Y |
| FPIU-3-E5-1 | | | | | | | | | | 100 | |
| | Hall | Corridor | 335 | 3 | 3011 | 0 | 0 | 0.06 | 20 | 15 | N |
| | Open Office | Office | 200 | 3 | 3068 | 1.0 | 5 | 0.06 | 17 | 28 | Y |
| | Hall | Corridor | 627 | 3 | 3075 | 0 | 0 | 0.06 | 38 | 62 | Y |

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-3-D7-1 | | | | | | | | | | 400 | |
| | Deposition room | Conference | 544 | 3 | 3076 | 27.2 | 5 | 0.06 | 169 | 400 | Y |
| FPIU-3-E8-1 | | | | | | | | | | 40 | |
| | Print | Office | 122 | 3 | 3079 | 0.6 | 5 | 0.06 | 10 | 18 | Y |
| | Open Office | Office | 197 | 3 | 3082 | 1.0 | 5 | 0.06 | 17 | 18 | Y |
| FPIU-3-E10-2 | | | | | | | | | | 50 | |
| | Office | Office | 160 | 3 | 3081C | 0.8 | 5 | 0.06 | 14 | 25 | Y |
| | Office | Office | 160 | 3 | 3083C | 0.8 | 5 | 0.06 | 14 | 25 | Y |
| FPIU-3-F7-1 | | | | | | | | | | 150 | |
| | Doc Production | Office | 1,026 | 3 | 3106 | 5.1 | 5 | 0.06 | 87 | 150 | Y |
| FPIU-3-F8-1 | | | | | | | | | | 70 | |
| | Office | Office | 100 | 3 | 3084 | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 105 | 3 | 3086 | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 105 | 3 | 3088 | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Hall | Corridor | 197 | 3 | 3090 | 0 | 0 | 0.06 | 12 | 18 | Y |
| FPIU-3-F8-2 | | | | | | | | | | 50 | |
| | Office | Office | 160 | 3 | 3085 | 0.8 | 5 | 0.06 | 14 | 25 | Y |
| | Office | Office | 160 | 3 | 3087 | 0.8 | 5 | 0.06 | 14 | 25 | Y |
| FPIU-3-F6-1 | | | | | | | | | | 400 | |
| | Deposition room | Conference | 570 | 3 | 3067 | 28.5 | 5 | 0.06 | 177 | 400 | Y |
| FPIU-3-F6-2 | | | | | | | | | | 150 | |
| | Hall | Corridor | 351 | 3 | 3097 | 0 | 0 | 0.06 | 21 | 38 | Y |
| | Break area | Break | 223 | 3 | 3103 | 5.6 | 7.5 | 0.18 | 82 | 94 | Y |
| | Storage | Storage | 40 | 3 | 3104 | 0 | 0 | 0.12 | 5 | 19 | Y |
| FPIU-3-G7-2 | | | | | | | | | | 110 | |
| | Open Office | Office | 287 | 3 | 3091 | 1.4 | 5 | 0.06 | 24 | 41 | Y |
| | War Room | Office | 207 | 3 | 3096 | 1.0 | 5 | 0.06 | 18 | 30 | Y |
| | Open Office | Office | 262 | 3 | 3105 | 1.3 | 5 | 0.06 | 22 | 39 | Y |
| FPIU-3-G9-2 | | | | | | | | | | 70 | |
| | Office | Office | 160 | 3 | 3089C | 0.8 | 5 | 0.06 | 14 | 23 | Y |
| | Office | Office | 160 | 3 | 3092C | 0.8 | 5 | 0.06 | 14 | 23 | Y |
| | Office | Office | 160 | 3 | 3093C | 0.8 | 5 | 0.06 | 14 | 23 | Y |
| FPIU-3-G7-1 | | | | | | | | | | 60 | |
| | Office | Office | 104 | 3 | 3100E | 0.5 | 5 | 0.06 | 9 | 19 | Y |
| | Office | Office | 104 | 3 | 3101E | 0.5 | 5 | 0.06 | 9 | 19 | Y |
| | Office | Office | 147 | 3 | 3102C | 0.7 | 5 | 0.06 | 12 | 22 | Y |
| FPIU-3-G8-1 | | | | | | | | | | 60 | |
| | Office | Office | 105 | 3 | 3095 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 104 | 3 | 3098 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 104 | 3 | 3099 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-3-G9-1 | | | | | | | | | | 50 | |
| | Office | Office | 221 | 3 | 3094 | 1.1 | 5 | 0.06 | 19 | 50 | Y |
| FPIU-4-D2-1 | | | | | | | | | | 50 | |
| | Office | Office | 200 | 4 | 4026 | 1.0 | 5 | 0.06 | 17 | 50 | Y |
| FPIU-4-D2-2 | | | | | | | | | | 60 | |
| | Office | Office | 147 | 4 | 4024C | 0.7 | 5 | 0.06 | 12 | 30 | Y |
| | Office | Office | 147 | 4 | 4025C | 0.7 | 5 | 0.06 | 12 | 30 | Y |
| FPIU-4-D2-3 | | | | | | | | | | 60 | |
| | Office | Office | 147 | 4 | 4021C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 147 | 4 | 4022C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 147 | 4 | 4023C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| FPIU-4-D3-1 | | | | | | | | | | 80 | |
| | Office | Office | 193 | 4 | 4014C | 1.0 | 5 | 0.06 | 16 | 27 | Y |
| | Office | Office | 147 | 4 | 4016C | 0.7 | 5 | 0.06 | 12 | 27 | Y |
| | Office | Office | 147 | 4 | 4018C | 0.7 | 5 | 0.06 | 12 | 27 | Y |
| FPIU-4-D5-1 | | | | | | | | | | 320 | |
| | Deposition room | Conference | 338 | 4 | 4034 | 16.9 | 5 | 0.06 | 105 | 320 | Y |
| FPIU-4-E1-1 | | | | | | | | | | 50 | |
| | Office | Office | 153 | 4 | 4027C | 0.8 | 5 | 0.06 | 13 | 28 | Y |
| | Office | Office | 177 | 4 | 4028C | 0.9 | 5 | 0.06 | 15 | 23 | Y |

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-4-E2-1 | | | | | | | | | | 80 | |
| | Hall | Corridor | 419 | 4 | 4013 | 0 | 0 | 0.06 | 25 | 25 | Y |
| | Office | Office | 100 | 4 | 4029 | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 100 | 4 | 4030 | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| | Office | Office | 100 | 4 | 4031 | 0.5 | 5 | 0.06 | 9 | 18 | Y |
| FPIU-4-E3-1 | | | | | | | | | | 180 | |
| | Break | Break | 139 | 4 | 4032 | 3.5 | 7.5 | 0.18 | 51 | 64 | Y |
| | Files | Storage | 691 | 4 | 4033 | 0 | 0 | 0.12 | 83 | 80 | N |
| FPIU-4-E3-1 | | | | | | | | | | 60 | |
| | Office | Office | 293 | 4 | 4020 | 1.5 | 5 | 0.06 | 25 | 60 | Y |
| FPIU-4-E3-2 | | | | | | | | | | 80 | |
| | Hall | Corridor | 269 | 4 | 4012a | 0 | 0 | 0.06 | 16 | 20 | Y |
| | Office | Office | 100 | 4 | 4015 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 4 | 4017 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 4 | 4019 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-4-E5-1 | | | | | | | | | | 170 | |
| | Waiting | Reception | 298 | 4 | 4012 | 8.9 | 5 | 0.06 | 63 | 108 | Y |
| | Hall | Corridor | 526 | 4 | 4042 | 0 | 0 | 0.06 | 32 | 62 | Y |
| FPIU-4-E5-2 | | | | | | | | | | 180 | |
| | Lobby | Lobby | 230 | 4 | 4001 | 6.9 | 7.5 | 0.06 | 66 | 66 | Y |
| | Hall | Corridor | 500 | 4 | 4002 | 0 | 0 | 0.06 | 30 | 54 | Y |
| | Safe | Storage | 125 | 4 | 4005 | 0 | 0 | 0.12 | 15 | 15 | Y |
| | Telecom | Telecom | 90 | 4 | 4009 | 0 | 0 | 0 | 0 | 15 | Y |
| | Electric | Electrical | 146 | 4 | 4010 | 0 | 0 | 0.06 | 9 | 15 | Y |
| | Hall | Corridor | 165 | 4 | 4011 | 0 | 0 | 0.06 | 10 | 12 | Y |
| | Hall | Corridor | 248 | 4 | 4073 | 0 | 0 | 0.06 | 15 | 21 | Y |
| | Hall | Corridor | 113 | 4 | 4075 | 0 | 0 | 0.06 | 7 | 18 | Y |
| FPIU-4-G1-2 | | | | | | | | | | 90 | |
| | Office | Office | 293 | 4 | 4060 | 1.5 | 5 | 0.06 | 25 | 45 | Y |
| | Agency supply | Office | 315 | 4 | 4061a | 1.6 | 5 | 0.06 | 27 | 45 | Y |
| FPIU-4-F3-1 | | | | | | | | | | 150 | |
| | Agency supply | Office | 485 | 4 | 4061b | 2.4 | 5 | 0.06 | 41 | 90 | Y |
| | Break Area | Break | 222 | 4 | 4062 | 9.1 | 5 | 0.06 | 59 | 60 | Y |
| FPIU-4-F3-2 | | | | | | | | | | 130 | |
| | Waiting | Reception | 271 | 4 | 4056 | 8.1 | 5 | 0.06 | 57 | 81 | Y |
| | Hall | Corridor | 249 | 4 | 4056a | 0 | 0 | 0.06 | 15 | 49 | Y |
| FPIU-4-F3-3 | | | | | | | | | | 100 | |
| | Office | Office | 100 | 4 | 4045 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 4 | 4047 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 4 | 4049 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | Office | Office | 100 | 4 | 4051 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| | SIPR | Office | 100 | 4 | 4054 | 0.5 | 5 | 0.06 | 9 | 20 | Y |
| FPIU-4-G8-1 | | | | | | | | | | 160 | |
| VAV-4-G8-1 | | | | | | | | | | 400 | |
| | Commanders Conf | Conference | 558 | 4 | 4044 | 27.9 | 5 | 0.06 | 173 | 280 | Y |
| FPIU-4-G1-1 | | | | | | | | | | 50 | |
| | Office | Office | 315 | 4 | 4059 | 1.6 | 5 | 0.06 | 27 | 50 | Y |
| FPIU-4-G2-1 | | | | | | | | | | 100 | |
| | Office | Office | 293 | 4 | 4055 | 1.5 | 5 | 0.06 | 25 | 44 | Y |
| | Office | Office | 147 | 4 | 4057 | 0.7 | 5 | 0.06 | 12 | 21 | Y |
| | Office | Office | 234 | 4 | 4058 | 1.2 | 5 | 0.06 | 20 | 35 | Y |
| FPIU-4-G4-1 | | | | | | | | | | 50 | |
| | Office | Office | 210 | 4 | 4052 | 1.1 | 5 | 0.06 | 18 | 28 | Y |
| | Hall | Corridor | 290 | 4 | 4053a | 0 | 0 | 0.06 | 17 | 23 | Y |
| FPIU-4-G4-2 | | | | | | | | | | 80 | |
| | Office | Office | 147 | 4 | 4046 | 0.7 | 5 | 0.06 | 12 | 24 | Y |
| | Office | Office | 147 | 4 | 4048 | 0.7 | 5 | 0.06 | 12 | 24 | Y |
| | Office | Office | 147 | 4 | 4050 | 0.7 | 5 | 0.06 | 12 | 24 | Y |
| | Hall | Corridor | 290 | 4 | 4053b | 0 | 0 | 0.06 | 17 | 27 | Y |
| FPIU-4-G5-1 | | | | | | | | | | 80 | |
| | Waiting | Reception | 173 | 4 | 4043 | 5.2 | 5 | 0.06 | 36 | 60 | Y |
| FPIU-4-D6-1 | | | | | | | | | | 60 | |
| | Office | Office | 147 | 4 | 4035C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 147 | 4 | 4036C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 147 | 4 | 4037C | 0.7 | 5 | 0.06 | 12 | 20 | Y |

| Terminal Unit | Space | Occupancy Type (by Code) | Area | Floor | Room Number | ASHRAE 62.1 2007 OCCUPANCY PEOPLE | OSA CFM/ PERSON | OSA CFM / SF | TOTAL OSA | OSA CFM Design | Standard 62.1 Compliant? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FPIU-4-D6-2 | | | | | | | | | | 60 | |
| | Office | Office | 147 | 4 | 4038C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 147 | 4 | 4039C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| | Office | Office | 147 | 4 | 4040C | 0.7 | 5 | 0.06 | 12 | 20 | Y |
| FPIU-4-D8-1 | | | | | | | | | | 50 | |
| | Office | Office | 117 | 4 | 4041D | 0.6 | 5 | 0.06 | 10 | 33 | Y |
| | Hall | Corridor | 133 | 4 | 4042a | 0 | 0 | 0.06 | 8 | 17 | Y |
| FPIU-4-F7-1 | | | | | | | | | | 70 | |
| | Hall | Corridor | 144 | 4 | 4064 | 0 | 0 | 0.06 | 9 | 8 | N |
| | Office | Office | 100 | 4 | 4067E | 0.5 | 5 | 0.06 | 9 | 14 | Y |
| | Office | Office | 100 | 4 | 4068E | 0.5 | 5 | 0.06 | 9 | 14 | Y |
| | Office | Office | 148 | 4 | 4069C | 0.7 | 5 | 0.06 | 13 | 19 | Y |
| | Office | Office | 100 | 4 | 4070E | 0.5 | 5 | 0.06 | 9 | 14 | Y |
| FPIU-4-F7-2 | | | | | | | | | | 160 | |
| | IMCen Support | Office | 195 | 4 | 4065 | 1.0 | 5 | 0.06 | 17 | 60 | Y |
| | Judge Advocate Recruiting | Office | 386 | 4 | 4066 | 1.9 | 5 | 0.06 | 33 | 76 | Y |
| | Files | Office | 123 | 4 | 4071 | 0.6 | 5 | 0.06 | 10 | 24 | Y |
| FPIU-4-F7-1 | | | | | | | | | | 200 | |
| VAV-4-F6-1 | | | | | | | | | | 1400 | |
| | Training1 | Lecture | 900 | 4 | 4063a | 90.0 | 7.5 | 0.06 | 729 | 760 | Y |
| FPIU-4-F7-2 | | | | | | | | | | 100 | |
| VAV-4-F7-1 | | | | | | | | | | 1060 | |
| | Training2 | Lecture | 700 | 4 | 4063b | 70.0 | 7.5 | 0.06 | 567 | 577 | Y |
| FPIU-4-G8-1 | | | | | | | | | | 200 | |
| VAV-4-G8-1 | | | | | | | | | | 1140 | |
| | Training3 | Lecture | 650 | 4 | 4063c | 65.0 | 7.5 | 0.06 | 527 | 656 | Y |
| | | | | | | | | | | | |
| | | **TOTALS:** | **80,031** | | | | | | | **23,750** | |

# Appendix B- Fenestration Calculations

| Space | Occupancy Type (by Code) | Area | Floor | Room Number | Slab to Slab to Height | East Wall Length | West Wall Length | South Wall Length | North Wall Length | East Window % | West Window % | South Window % | North Window % | East Wall Area | West Wall Area | South Wall Area | North Wall Area | Window Area [SF] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vestibule | Vestibule | 172 | 1 | 1000 | 14 | 18 | | | | 80 | | | | 252 | 0 | 0 | 0 | 201.6 |
| Vestibule | Vestibule | 166 | 1 | 1002 | 14 | 18 | | | | 80 | | | | 252 | 0 | 0 | 0 | 201.6 |
| Mens Shower | Toilet | 405 | 1 | 1007 | 14 | 14 | | | | 16 | | | | 196 | 0 | 0 | 0 | 31.36 |
| Womens Shower | Toilet | 298 | 1 | 1009 | 14 | 7 | | | | 33 | | | | 98 | 0 | 0 | 0 | 32.34 |
| Demark | Telecom | 75 | 1 | 1010 | 14 | 8 | | | | | | | | 112 | 0 | 0 | 0 | 0 |
| Judge Advocate | Office | 274 | 1 | 1021 | 14 | | | 18 | | | | 25 | | 0 | 0 | 252 | 0 | 63 |
| Perim Office | Office | 152 | 1 | 1025 | 14 | | | 10 | | | | 23 | | 0 | 0 | 140 | 0 | 32.2 |
| Perim Office | Office | 152 | 1 | 1026 | 14 | | | 10 | | | | 23 | | 0 | 0 | 140 | 0 | 32.2 |
| Office | Office | 197 | 1 | 1027 | 14 | | | 10 | | | | 23 | | 0 | 0 | 140 | 0 | 32.2 |
| Office | Office | 197 | 1 | 1029 | 14 | | | 10 | | | | 23 | | 0 | 0 | 140 | 0 | 32.2 |
| Perim Office | Office | 152 | 1 | 1030 | 14 | | | 10 | | | | 23 | | 0 | 0 | 140 | 0 | 32.2 |
| Perim Office | Office | 152 | 1 | 1031 | 14 | | | 10 | | | | 23 | | 0 | 0 | 140 | 0 | 32.2 |
| Senior Judge | Office | 290 | 1 | 1032 | 14 | | 22 | 14 | | | 21 | 19 | | 0 | 308 | 196 | 0 | 101.92 |
| Office | Office | 166 | 1 | 1033 | 14 | | 10 | | | | 23 | | | 0 | 140 | 0 | 0 | 32.2 |
| Office | Office | 166 | 1 | 1034 | 14 | | 10 | | | | 23 | | | 0 | 140 | 0 | 0 | 32.2 |
| Office | Office | 188 | 1 | 1035 | 14 | | 10 | | | | 23 | | | 0 | 140 | 0 | 0 | 32.2 |
| Exit Corridor | Corridor | 248 | 1 | 1036a | 14 | | 5 | | | | 80 | | | 0 | 70 | 0 | 0 | 56 |
| Computer Assembly | Office | 443 | 1 | 1043 | 14 | | 42 | | | | 21 | | | 0 | 588 | 0 | 0 | 123.48 |
| Office | Office | 150 | 1 | 1047 | 14 | | 10 | | | | 23 | | | 0 | 140 | 0 | 0 | 32.2 |
| Office | Office | 150 | 1 | 1048 | 14 | | 10 | | | | 23 | | | 0 | 140 | 0 | 0 | 32.2 |
| Open Office | Office | 285 | 1 | 1052a | 14 | | 40 | | | | 23 | | | 0 | 560 | 0 | 0 | 128.8 |
| Open Office | Office | 910 | 1 | 1052b | 14 | | 50 | | | | 23 | | | 0 | 700 | 0 | 0 | 161 |
| Open Office | Office | 452 | 1 | 1052e | 14 | | 23 | | 20 | | 20 | | 23 | 0 | 322 | 0 | 280 | 128.8 |
| Open Office | Office | 452 | 1 | 1052f | 14 | | 23 | | 20 | | 20 | | 23 | 0 | 322 | 0 | 280 | 128.8 |
| Exterior Hall (with door) | Corridor | 221 | 1 | 1054 | 14 | | | | 9 | | | | 23 | 0 | 0 | 0 | 126 | 28.98 |
| Mailroom | Office | 195 | 1 | 1057 | 14 | | | | 10 | | | | 23 | 0 | 0 | 0 | 140 | 32.2 |
| Waiting | Reception | 337 | 1 | 1058 | 14 | | | | 12 | | | | 19 | 0 | 0 | 0 | 168 | 31.92 |
| Perim Office | Office | 155 | 1 | 1059 | 14 | | | | 10 | | | | 23 | 0 | 0 | 0 | 140 | 32.2 |
| Perim Office | Office | 232 | 1 | 1060 | 14 | 22 | | | 11 | 21 | | | 23 | 308 | 0 | 0 | 154 | 100.1 |
| Office | Office | 150 | 1 | 1061 | 14 | 10 | | | | 23 | | | | 140 | 0 | 0 | 0 | 32.2 |
| Office | Office | 150 | 1 | 1062 | 14 | 10 | | | | 23 | | | | 140 | 0 | 0 | 0 | 32.2 |
| Office | Office | 150 | 1 | 1063 | 14 | 10 | | | | 23 | | | | 140 | 0 | 0 | 0 | 32.2 |
| Office | Office | 150 | 1 | 1064 | 14 | 10 | | | | 23 | | | | 140 | 0 | 0 | 0 | 32.2 |
| Office | Office | 150 | 1 | 1065 | 14 | 10 | | | | 23 | | | | 140 | 0 | 0 | 0 | 32.2 |
| Office | Office | 150 | 1 | 1066 | 14 | 10 | | | | 23 | | | | 140 | 0 | 0 | 0 | 32.2 |
| Office | Office | 150 | 1 | 1067 | 14 | 10 | | | | 23 | | | | 140 | 0 | 0 | 0 | 32.2 |
| Hall | Corridor | 186 | 1 | 1071 | 14 | | | | 10 | | | | | 0 | 0 | 0 | 140 | 0 |
| Vestibule | Mechanical | 162 | 1 | c1001 | 20 | | | | 11 | | | | 80 | 0 | 0 | 0 | 220 | 176 |
| Security Screening | Lobby | 327 | 1 | c1002a | 20 | | | | 28 | | | | 90 | 0 | 0 | 0 | 560 | 504 |
| Waiting Area | Reception | 367 | 1 | c1004 | 20 | | | | 12 | | | | 90 | 0 | 0 | 0 | 240 | 216 |
| Witness | Conference | 230 | 1 | c1005 | 20 | | | | 16 | | | | 90 | 0 | 0 | 0 | 320 | 288 |
| Deliberation Room-part a | Conference | 213 | 1 | c1006a | 20 | 8 | | | 11 | 90 | | | 90 | 160 | 0 | 0 | 220 | 342 |
| Deliberation Room-part b | Conference | 212 | 1 | c1006b | 20 | 8 | | | 11 | 90 | | | 90 | 160 | 0 | 0 | 220 | 342 |
| Robe Dress | Office | 272 | 1 | c1007 | 20 | 20 | | | | 70 | | | | 400 | 0 | 0 | 0 | 280 |
| Office | Office | 206 | 1 | c1010 | 20 | 15 | | | | 10 | | | | 300 | 0 | 0 | 0 | 30 |
| Office | Office | 145 | 1 | c1011 | 20 | 17 | | | | 16 | | | | 340 | 0 | 0 | 0 | 54.4 |
| Hall | Corridor | 362 | 1 | c1012 | 20 | 7 | | | | 50 | | | | 140 | 0 | 0 | 0 | 70 |
| Office | Office | 110 | 1 | c1014 | 20 | 12 | | 10 | | 11 | | 13 | | 240 | 0 | 200 | 0 | 52.4 |
| Office | Office | 110 | 1 | c1015 | 20 | | | 10 | | | | 13 | | 0 | 0 | 200 | 0 | 26 |
| Office | Office | 110 | 1 | c1016 | 20 | | | 10 | | | | 13 | | 0 | 0 | 200 | 0 | 26 |
| Break | Break | 105 | 1 | c1017 | 20 | | | 13 | | | | 10 | | 0 | 0 | 260 | 0 | 26 |
| Water Service | Mechanical | 330 | 1 | c1019 | 20 | | 18 | 18 | | | 0 | 0 | | 0 | 360 | 360 | 0 | 0 |
| Vestibule | Vestibule | 164 | 1 | c1020 | 20 | | | 10 | | | | 18 | | 0 | 0 | 200 | 0 | 36 |
| Deposition room | Conference | 556 | 2 | 2012 | 12 | 30 | | | | 20 | | | | 360 | 0 | 0 | 0 | 72 |
| Waiting | Reception | 361 | 2 | 2013 | 12 | 18 | | | | 75 | | | | 216 | 0 | 0 | 0 | 162 |
| Office | Office | 100 | 2 | 2017 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2018 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2019 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2020 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2021 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2022 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 144 | 2 | 2024 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 144 | 2 | 2025 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 144 | 2 | 2026 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Open Office | Office | 384 | 2 | 2028 | 12 | 15 | | | | 27 | | | | 180 | 0 | 0 | 0 | 48.6 |
| Office | Office | 188 | 2 | 2029 | 12 | 15 | | | 12 | 18 | | | 17 | 180 | 0 | 0 | 144 | 56.88 |
| Office | Office | 145 | 2 | 2030 | 12 | | | | 10 | 20 | | | | 0 | 0 | 0 | 120 | 0 |
| Office | Office | 145 | 2 | 2031 | 12 | | | | 10 | 20 | | | | 0 | 0 | 0 | 120 | 0 |
| Office | Office | 145 | 2 | 2034 | 12 | | | | 10 | 20 | | | | 0 | 0 | 0 | 120 | 0 |
| Office | Office | 145 | 2 | 2035 | 12 | | | | 10 | 20 | | | | 0 | 0 | 0 | 120 | 0 |
| Office | Office | 145 | 2 | 2036 | 12 | | | | 10 | 20 | | | | 0 | 0 | 0 | 120 | 0 |
| Office | Office | 145 | 2 | 2039 | 12 | | | | 10 | 20 | | | | 0 | 0 | 0 | 120 | 0 |
| Office | Office | 145 | 2 | 2040 | 12 | | | | 10 | 20 | | | | 0 | 0 | 0 | 120 | 0 |
| Office | Office | 210 | 2 | 2041 | 12 | | 21 | | 10 | | 16 | | 20 | 0 | 252 | 0 | 120 | 64.32 |
| Office | Office | 100 | 2 | 2042 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 144 | 2 | 2043 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 144 | 2 | 2044 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 144 | 2 | 2045 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Open Office | Office | 497 | 2 | 2055 | 12 | | 21 | | | | 19 | | | 0 | 252 | 0 | 0 | 47.88 |
| Office | Office | 145 | 2 | 2056 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 145 | 2 | 2057 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 145 | 2 | 2058 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 145 | 2 | 2059 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 219 | 2 | 2067 | 12 | | 18 | | | | 75 | | | 0 | 216 | 0 | 0 | 162 |
| Office | Office | 153 | 2 | 2068 | 12 | | 12 | | | | 17 | | | 0 | 144 | 0 | 0 | 24.48 |
| Office | Office | 150 | 2 | 2069 | 12 | | 15 | | | | 25 | | | 0 | 180 | 0 | 0 | 45 |
| Office | Office | 110 | 2 | 2074 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 110 | 2 | 2075 | 12 | | 15 | | | | 20 | | | 0 | 180 | 0 | 0 | 36 |
| Office | Office | 110 | 2 | 2076 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 110 | 2 | 2077 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 169 | 2 | 2078 | 12 | | 15 | | | | 13 | | | 0 | 180 | 0 | 0 | 23.4 |
| Office | Office | 210 | 2 | 2079 | 12 | | 18 | 12 | | | 22 | 17 | | 0 | 216 | 144 | 0 | 72 |
| Office | Office | 110 | 2 | 2083 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 110 | 2 | 2084 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 110 | 2 | 2085 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 110 | 2 | 2086 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 110 | 2 | 2090 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 110 | 2 | 2091 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Hall | Corridor | 417 | 2 | 2092 | 12 | 7 | | | | 39 | | | | 84 | 0 | 0 | 0 | 32.76 |
| Office | Office | 110 | 2 | 2093 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 131 | 2 | 2094 | 12 | 12 | | 10 | | 17 | | 20 | | 144 | 0 | 120 | 0 | 48.48 |
| Office | Office | 100 | 2 | 2095 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2102 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2103 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2104 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 100 | 2 | 2105 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Office | Office | 110 | 3 | 3013 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 110 | 3 | 3014 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 110 | 3 | 3015 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 110 | 3 | 3016 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 110 | 3 | 3020 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 110 | 3 | 3021 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 154 | 3 | 3022 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 154 | 3 | 3023 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 154 | 3 | 3028 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 154 | 3 | 3029 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 228 | 3 | 3030 | 12 | 20 | | | 12 | 20 | | | 17 | 240 | 0 | 0 | 144 | 72.48 |
| Open Office | Office | 330 | 3 | 3031 | 12 | | | | 17 | | | | 24 | 0 | 0 | 0 | 204 | 48.96 |
| Office | Office | 116 | 3 | 3032 | 12 | | | | 10 | | | | 20 | 0 | 0 | 0 | 120 | 24 |
| Office | Office | 116 | 3 | 3033 | 12 | | | | 10 | | | | 20 | 0 | 0 | 0 | 120 | 24 |
| Office | Office | 116 | 3 | 3034 | 12 | | | | 10 | | | | 20 | 0 | 0 | 0 | 120 | 24 |
| Office | Office | 116 | 3 | 3035 | 12 | | | | 10 | | | | 20 | 0 | 0 | 0 | 120 | 24 |
| Office | Office | 116 | 3 | 3036 | 12 | | | | 10 | | | | 20 | 0 | 0 | 0 | 120 | 24 |
| Office | Office | 218 | 3 | 3037 | 12 | | 20 | | 12 | | 20 | | 17 | 0 | 240 | 0 | 144 | 72.48 |
| Office | Office | 154 | 3 | 3051 | 12 | | 14 | | | | 15 | | | 0 | 168 | 0 | 0 | 25.2 |
| Office | Office | 102 | 3 | 3052 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 102 | 3 | 3053 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 102 | 3 | 3054 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 102 | 3 | 3055 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 102 | 3 | 3056 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 102 | 3 | 3057 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 102 | 3 | 3058 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 102 | 3 | 3059 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 102 | 3 | 3060 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Waiting | Reception | 170 | 3 | 3061 | 12 | | 17 | | | | 80 | | | 0 | 204 | 0 | 0 | 163.2 |
| Deposition room | Conference | 570 | 3 | 3067 | 12 | | 18 | | | | 23 | | | 0 | 216 | 0 | 0 | 49.68 |
| Office | Office | 181 | 3 | 3069 | 12 | 17 | | | | 80 | | | | 204 | 0 | 0 | 0 | 163.2 |
| Office | Office | 152 | 3 | 3070 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 152 | 3 | 3071 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 101 | 3 | 3072 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 101 | 3 | 3073 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 101 | 3 | 3074 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 101 | 3 | 3077 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 101 | 3 | 3078 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Print | Office | 122 | 3 | 3079 | 12 | 13 | | | | 20 | | | | 156 | 0 | 0 | 0 | 31.2 |
| Office | Office | 166 | 3 | 3080 | 12 | 18 | | 10 | | 23 | | 20 | | 216 | 0 | 120 | 0 | 73.68 |
| Office | Office | 160 | 3 | 3081 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 160 | 3 | 3083 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 160 | 3 | 3085 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 160 | 3 | 3087 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 160 | 3 | 3089 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 160 | 3 | 3092 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 160 | 3 | 3093 | 12 | | | 10 | | | | 20 | | 0 | 0 | 120 | 0 | 24 |
| Office | Office | 221 | 3 | 3094 | 12 | | 21 | 10 | | | 20 | 20 | | 0 | 252 | 120 | 0 | 74.4 |
| Office | Office | 105 | 3 | 3095 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 104 | 3 | 3098 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 104 | 3 | 3099 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 104 | 3 | 3100 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 104 | 3 | 3101 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 147 | 3 | 3102 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 315 | 3 | 4000 | 12 | | 23 | | 14 | | 18 | | 15 | 0 | 276 | 0 | 168 | 74.88 |
| Office | Office | 193 | 4 | 4014 | 12 | 18 | | | | 23 | | | | 216 | 0 | 0 | 0 | 49.68 |
| Office | Office | 147 | 4 | 4016 | 12 | 15 | | | | 27 | | | | 180 | 0 | 0 | 0 | 48.6 |
| Office | Office | 147 | 4 | 4018 | 12 | 15 | | | | 27 | | | | 180 | 0 | 0 | 0 | 48.6 |
| Office | Office | 147 | 4 | 4021 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4022 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4023 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4024 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4025 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 200 | 4 | 4026 | 12 | 20 | | | 10 | 20 | | | 20 | 240 | 0 | 0 | 120 | 72 |
| Office | Office | 153 | 4 | 4027 | 12 | | | | 15 | | | | 27 | 0 | 0 | 0 | 180 | 48.6 |
| Office | Office | 177 | 4 | 4028 | 12 | | | | 10 | | | | 20 | 0 | 0 | 0 | 120 | 24 |
| Deposition room | Conference | 338 | 4 | 4034 | 12 | 22 | | | | 75 | | | | 264 | 0 | 0 | 0 | 198 |
| Office | Office | 147 | 4 | 4035 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4036 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4037 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4038 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4039 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4040 | 12 | 10 | | | | 20 | | | | 120 | 0 | 0 | 0 | 24 |
| Office | Office | 117 | 4 | 4041 | 12 | 12 | | 10 | | 17 | | 0 | | 144 | 0 | 120 | 0 | 24.48 |
| Hall | Corridor | 526 | 4 | 4042 | 12 | | | 11 | | | | 0 | | 0 | 0 | 132 | 0 | 0 |
| Hall | Corridor | 133 | 4 | 4042a | 12 | | | 11 | | | | 0 | | 0 | 0 | 132 | 0 | 0 |
| Waiting | Reception | 173 | 4 | 4043 | 12 | | 11 | | | | 18 | | | 0 | 132 | 0 | 0 | 23.76 |
| Commanders Conf | Conference | 558 | 4 | 4044 | 12 | | 18 | | | | 75 | | | 0 | 216 | 0 | 0 | 162 |
| Office | Office | 147 | 4 | 4046 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4048 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 147 | 4 | 4050 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 210 | 4 | 4052 | 12 | | 13 | | | | 15 | | | 0 | 156 | 0 | 0 | 23.4 |
| Office | Office | 293 | 4 | 4055 | 12 | | 19 | | | | 21 | | | 0 | 228 | 0 | 0 | 47.88 |
| Office | Office | 147 | 4 | 4057 | 12 | | 10 | | | | 20 | | | 0 | 120 | 0 | 0 | 24 |
| Office | Office | 234 | 4 | 4058 | 12 | | 15 | | | | 27 | | | 0 | 180 | 0 | 0 | 48.6 |
| Office | Office | 315 | 4 | 4059 | 12 | | 23 | | 14 | | 17 | | 14 | 0 | 276 | 0 | 168 | 70.44 |
| Office | Office | 293 | 4 | 4060 | 12 | | | | 20 | | | | 20 | 0 | 0 | 0 | 240 | 48 |
| Agency supply | Files | 315 | 4 | 4061a | 12 | | | | 20 | | | | 20 | 0 | 0 | 0 | 240 | 48 |
| Training1 | Training Room | 900 | 4 | 4063a | 12 | | 28 | | | | 21 | | | 0 | 336 | 0 | 0 | 70.56 |
| Training2 | Training Room | 700 | 4 | 4063b | 12 | | 22 | | | | 18 | | | 0 | 264 | 0 | 0 | 47.52 |
| Training3 | Training Room | 650 | 4 | 4063c | 12 | | 22 | | | | 18 | | | 0 | 264 | 0 | 0 | 47.52 |
| IMCen Support | Office | 195 | 4 | 4065 | 12 | | | 20 | | | | | | 0 | 0 | 240 | 0 | 0 |
| Files | Files | 123 | 4 | 4071 | 12 | | | 10 | | | | | | 0 | 0 | 120 | 0 | 0 |
| Main Switchgear | Main Electrical | 300 | 4 | B001 | 12 | | 15 | | | | | | | 0 | 180 | 0 | 0 | 0 |
| UPS | UPS | 300 | 4 | B002 | 12 | | 15 | | | | | | | 0 | 180 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | | | | | |
| | **TOTALS:** | **38,548** | | | | | | | | | | | | 12182 | 12918 | 5636 | 6640 | **9713.3** |

# Appendix C- Geothermal Depth Calculations

## Pump Sizing

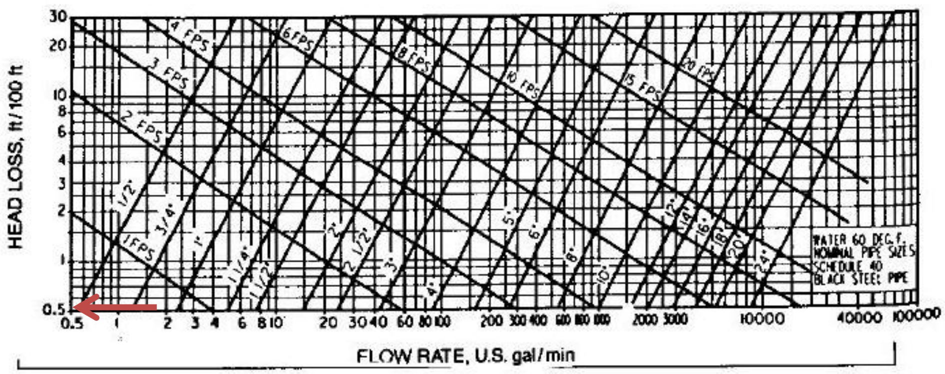
**Loop Head Pressure**

$$\dot{Q}_{,gpm} = \frac{292[tons]}{500[bores]} = 0.58\left[\frac{tons}{bore}\right] * 3\left[\frac{gpm}{ton}\right] = 1.75\ \left[\frac{gpm}{bore}\right]$$

$d_{branch}$ = 1-1/4”

$d_{header}$ = 6”

***Branch***




(The chart above is for commercial steel pipe. It was used for these calculations because the friction factors of high density polyethylene pipes are very similar.)

Head loss through branch = 0.5 ft / 100 ft

For Nominal Size 1-1/4”, $ft$= 0.022

90° elbow: K = 30 $ft$, $ft$ =0.022

K = 30(0.022) = 0.66

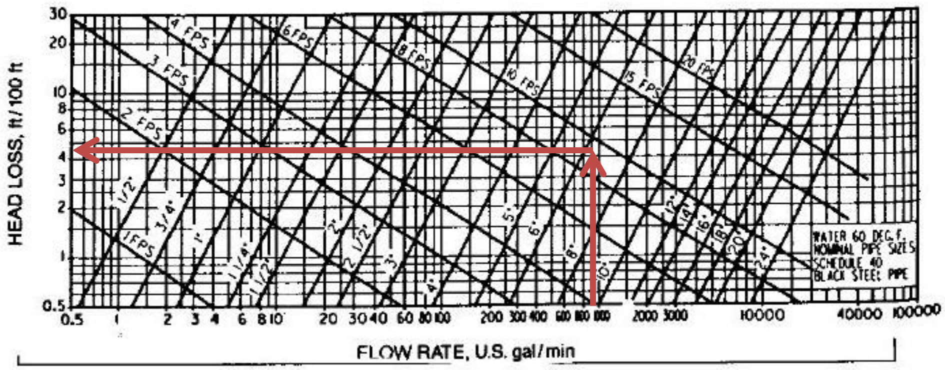
L= 3.5 ft

Total Equivalent Branch Length:

| | |
|---|---|
| Actual pipe length | 1235 ft |
| (4) 90° elbows | 14 ft |
| Total | 1249 ft |

$\frac{0.5\ ft}{100\ ft} * 1249\ ft$ = 6 ft Head

***Header***




*Head loss example, 876 gpm flow rate

Since the flow rate through the header decreases with every branch that splits off, the head loss will also decrease. The table below is a spreadsheet of the header head loss as it flows to the last branch.

| Flow Rate [gpm] | Actual Length | Branch # | Head Loss [ft/100ft] | # Fittings L= 15 90° Elbows | L= 10 Tee, through | L= 30 Tee,branch | L= 3.5 Gate Valve | Total Head Loss [ft] |
|---|---|---|---|---|---|---|---|---|
| 876 | 1740 | 0 | 4.5 | 12 | | | 2 | 86.72 |
| 848 | 40 | 1 | 4.3 | | 2 | 2 | | 2.58 |
| 819 | 40 | 2 | 4.1 | | 2 | 2 | | 1.64 |
| 791 | 40 | 3 | 4 | | 2 | 2 | | 1.60 |
| 763 | 40 | 4 | 3.8 | | 2 | 2 | | 1.52 |
| 735 | 40 | 5 | 3.7 | | 2 | 2 | | 1.48 |
| 706 | 40 | 6 | 3.6 | | 2 | 2 | | 1.44 |
| 678 | 40 | 7 | 3.1 | | 2 | 2 | | 1.24 |
| 650 | 40 | 8 | 3 | | 2 | 2 | | 1.20 |
| 622 | 40 | 9 | 2.7 | | 2 | 2 | | 1.08 |
| 593 | 40 | 10 | 2.4 | | 2 | 2 | | 0.96 |
| 565 | 40 | 11 | 2.2 | | 2 | 2 | | 0.88 |
| 537 | 40 | 12 | 2 | | 2 | 2 | | 0.80 |
| 509 | 40 | 13 | 1.7 | | 2 | 2 | | 0.68 |
| 480 | 40 | 14 | 1.5 | | 2 | 2 | | 0.60 |
| 452 | 40 | 15 | 1.4 | | 2 | 2 | | 0.56 |
| 424 | 40 | 16 | 1.3 | | 2 | 2 | | 0.52 |
| 396 | 40 | 17 | 1.1 | | 2 | 2 | | 0.44 |
| 367 | 40 | 18 | 1 | | 2 | 2 | | 0.40 |
| 339 | 40 | 19 | 0.9 | | 2 | 2 | | 0.36 |
| 311 | 40 | 20 | 0.75 | | 2 | 2 | | 0.30 |
| 283 | 40 | 21 | 0.55 | | 2 | 2 | | 0.22 |
| 254 | 40 | 22 | 0.5 | | 2 | 2 | | 0.20 |
| 226 | 40 | 23 | 0 | | 2 | 2 | | 0.00 |
| 198 | 40 | 24 | 0 | | 2 | 2 | | 0 |
| 170 | 40 | 25 | 0 | | 2 | 2 | | 0 |
| 141 | 40 | 26 | 0 | | 2 | 2 | | 0 |
| 113 | 40 | 27 | 0 | | 2 | 2 | | 0 |
| 85 | 40 | 28 | 0 | | 2 | 2 | | 0 |
| 57 | 40 | 29 | 0 | | 2 | 2 | | 0 |
| 28 | 40 | 30 | 0 | | | 2 | | 0 |
| | | | | | | | Total | 107 |

For Nominal Size 6", $ft$= 0.015

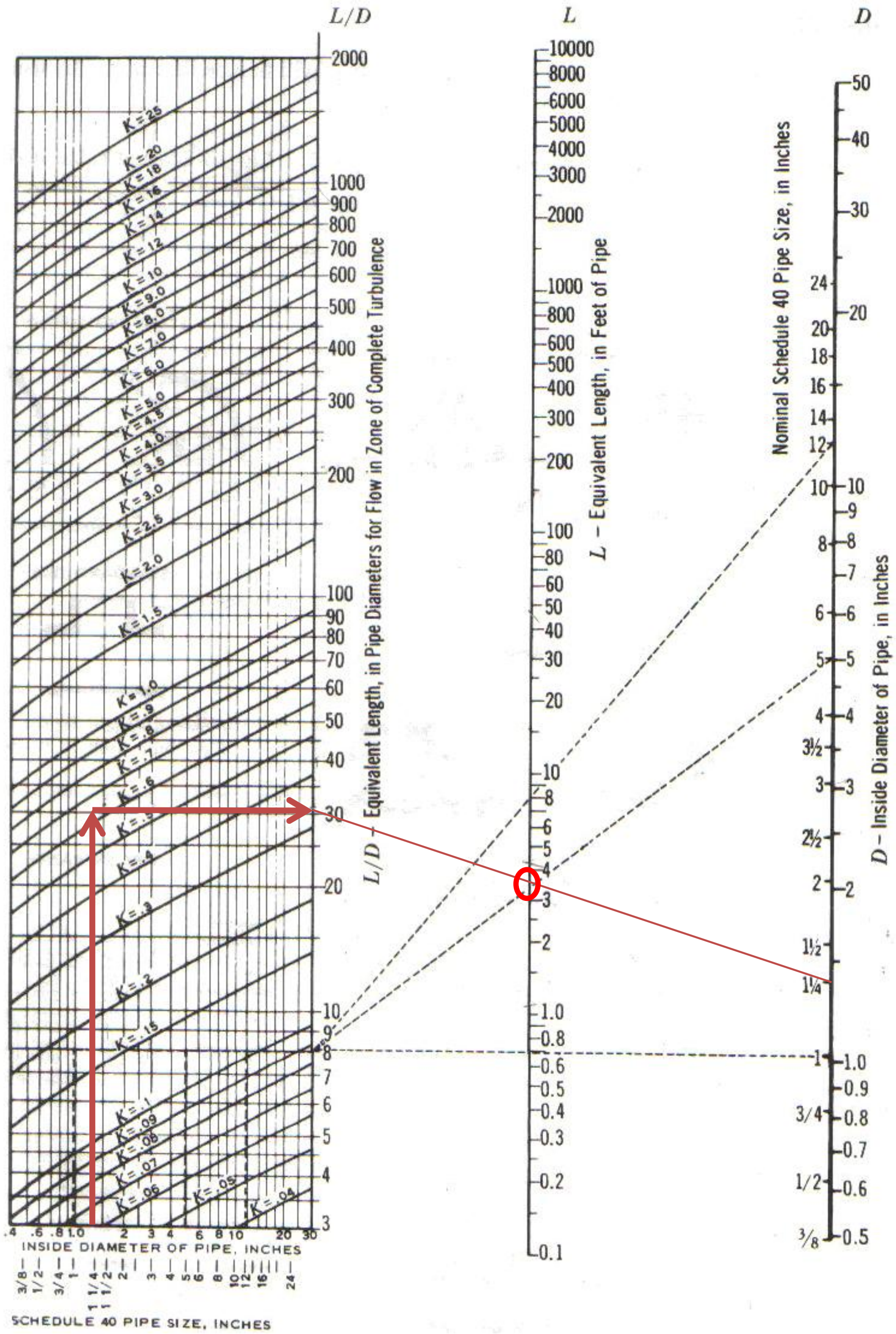
90° elbow: K = 30 $ft$, $ft$=0.015
K = 30(0.015) = 0.45
L= 15 ft

Tee, through: K = 20 $ft$, $ft$=0.015
K = 20(0.015) = 0.3
L= 10 ft

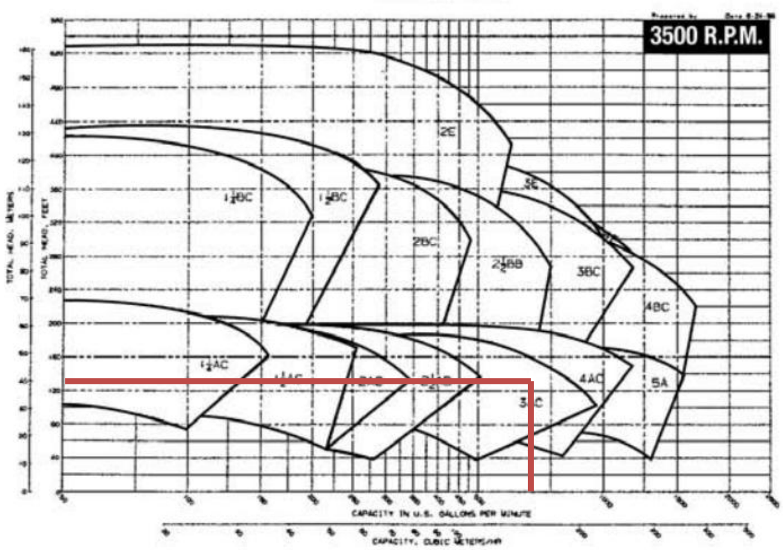
Tee, branch: K = 60 $ft$, $ft$=0.015
K = 60(0.015) = 0.9
L= 30 ft

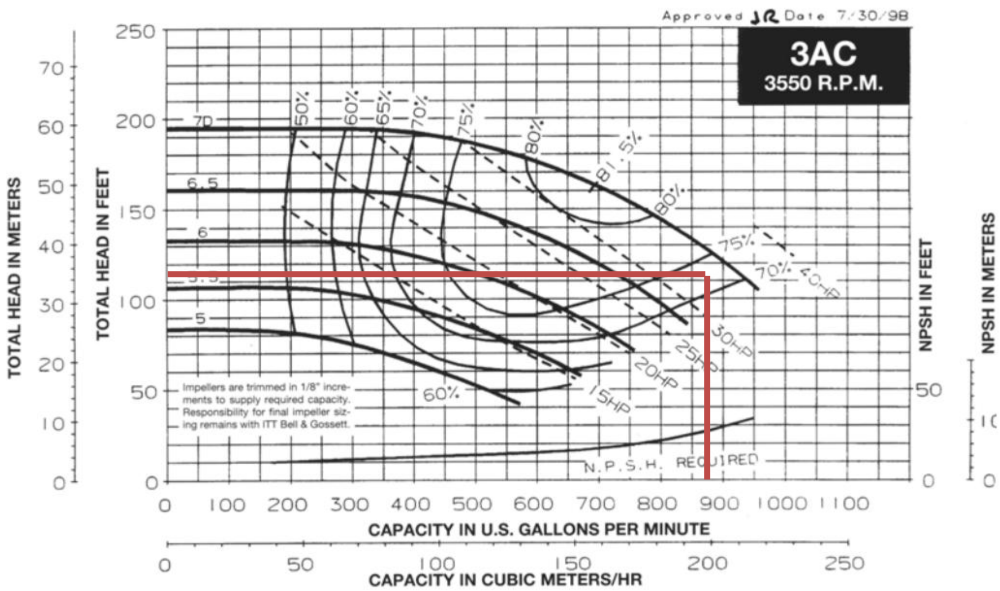
Gate valve: $K_1$ = 8 $ft$ $ft$=0.015
$K_1$ = 8(0.015) = 0.12
L= 3.5 ft

Total Head = 6 + 107 = **113 ft Head**




*equivalent length example, 90° elbow


3500 R.P.M.
1½BC
1¼BC
2E
3E
2BC
2½BB
3BC
4BC
1½AC
4AC
5A
3AC
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY, CUBIC METERS/HR

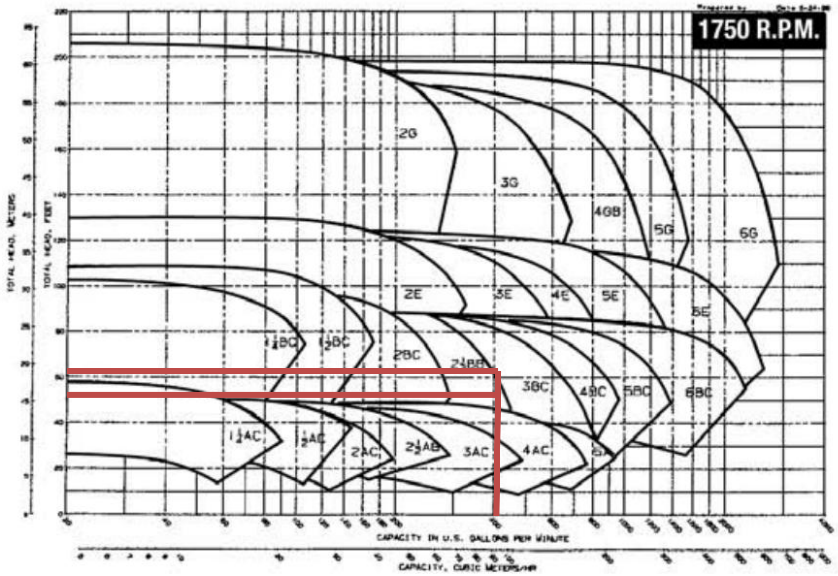

Approved JR Date 7/30/98
3AC
3550 R.P.M.
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
NPSH IN FEET
NPSH IN METERS
7D
6.5
6
5
50%
60%
65%
70%
75%
80%
81.5%
80%
75%
70%
60%
40HP
30HP
25HP
20HP
15HP
Impellers are trimmed in 1/8" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.
N.P.S.H. REQUIRED
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY IN CUBIC METERS/HR

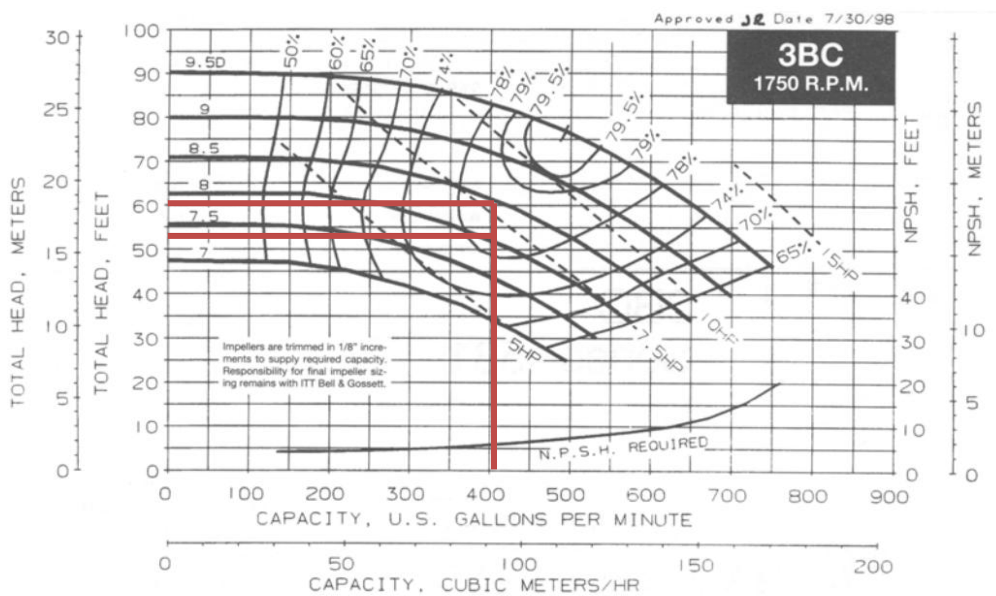
# Initial Cost Estimates

| System Components | MAT. COST PER UNIT | INST. COST PER UNIT | QUANTITY | UNIT | COST MAT. | COST INST. | COST TOTAL |
|---|---|---|---|---|---|---|---|
| **GEOTHERMAL HEAT PUMP SYSTEM 300 TON, VERTICAL LOOP, 200 LF PER TON** | | | | | | | |
| Mobilization excavator | | 246.00 | 2 | Ea. | | 492.00 | 492.00 |
| Mobilization support crew & equip. | | 172.00 | 2 | Ea. | | 344.00 | 344.00 |
| Mobilization drill rig | | 80.00 | 2 | Ea. | | 160.00 | 160.00 |
| Drill wells 6" diameter | | 6.45 | 251 | C.L.F. | | 1,618.95 | 1,618.95 |
| Pipe loops 1 1/4" diameter | 124.00 | 184.00 | 251 | C.L.F. | 31,124.00 | 46,184.00 | 77,308.00 |
| Pipe headers 6" diameter | 3.43 | 3.70 | 1385 | L.F. | 4,752.00 | 5,120.00 | 9,872.00 |
| U-fittings for loops | 5.15 | 16.25 | 500 | Ea. | 2,575.00 | 8,125.00 | 10,700.00 |
| Header tee fittings | 10.45 | 27.50 | 60 | Ea. | 627.00 | 1,650.00 | 2,277.00 |
| Header elbow fittings | 6.85 | 17.30 | 16 | Ea. | 109.60 | 276.80 | 386.40 |
| Excavate trench for pipe header | | 6.97 | 411 | B.C.Y. | | 2,865.87 | 2,865.87 |
| Backfill trench for pipe header | | 2.68 | 567 | L.C.Y. | | 1,519.52 | 1,519.52 |
| Compact trench for pipe header | | 2.34 | 411 | E.C.Y. | | 962.14 | 962.14 |
| Circulation pump 25 HP | 7000.00 | 1025.00 | 2 | Ea. | 14,000.00 | 2,050.00 | 16,050.00 |
| Variable frequency drive | 3125.00 | 1225.00 | 1 | Ea. | 3,125.00 | 1,225.00 | 4,350.00 |
| Pump control system | 1275.00 | 610.00 | 1 | Ea. | 1,275.00 | 610.00 | 1,885.00 |
| Pump gauges | 39.50 | 21.00 | 2 | Ea. | 79.00 | 42.00 | 121.00 |
| Pump gauge fittings | 94.00 | 21.00 | 2 | Ea. | 188.00 | 42.00 | 230.00 |
| Pipe insulation for pump connection | 2.82 | 6.45 | 12 | L.F. | 33.84 | 77.40 | 111.24 |
| Pipe for pump connection | 28.50 | 28.45 | 12 | L.F. | 342.00 | 341.40 | 683.40 |
| Pipe fittings for pump connection | 32.00 | 174.80 | 1 | Ea. | 32.00 | 174.80 | 206.80 |
| Install thermostat wells | 7.80 | 53.27 | 2 | Ea. | 15.60 | 106.54 | 122.14 |
| Install gauge wells | 7.80 | 55.85 | 2 | Ea. | 15.60 | 111.70 | 127.30 |
| Thermometers, stem type, 9" case, 8" stem, 3/4" NPT | 38.50 | 87.40 | 8 | Ea. | 308.00 | 699.20 | 1,007.20 |
| Gauges, pressure or vacuum, 3-1/2" diameter dial | 770.00 | 264.00 | 1 | Ea. | 770.00 | 264.00 | 1,034.00 |
| Pipe strainer for pump | 157.00 | 269.00 | 1 | Ea. | 157.00 | 269.00 | 426.00 |
| Shut valve for pump | 595.00 | 288.00 | 1 | Ea. | 595.00 | 288.00 | 883.00 |
| Expansion joints for pump | 330.00 | 106.00 | 2 | Ea. | 660.00 | 212.00 | 872.00 |
| Water-source heat pump, 1.5 ton, 17 MBH | 1775.00 | 445.00 | 150 | Ea. | 266,250.00 | 66,750.00 | 333,000.00 |
| Water-source heat pump, 1500 MBH | 156200.00 | 42450.00 | 1 | Ea. | 156,200.00 | 42,450.00 | 198,650.00 |
| Geothermal Heat Pump Incentive | 51.00 | | 292 | ton | | | (14,892.00) |
| Total | | | | | 483,233.64 | 185,031.32 | 653,372.96 |

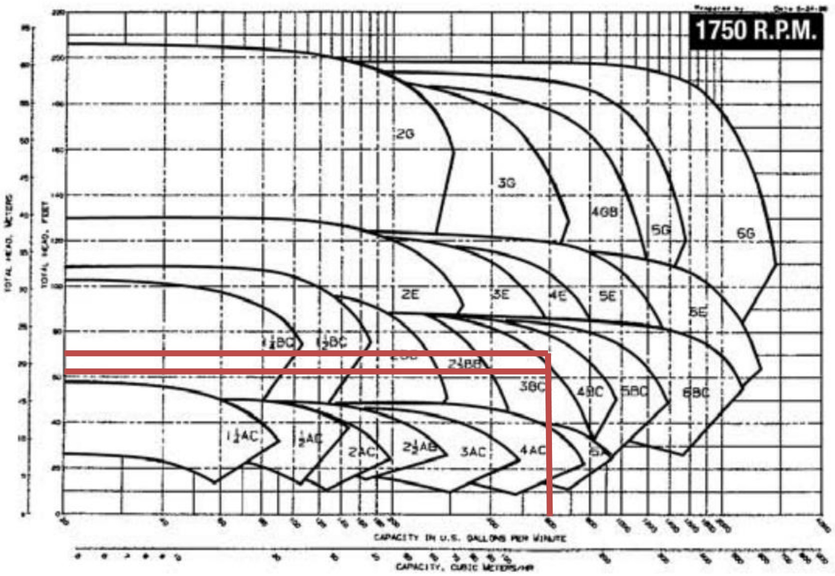
# Appendix D- Thermal Storage Pump Selection

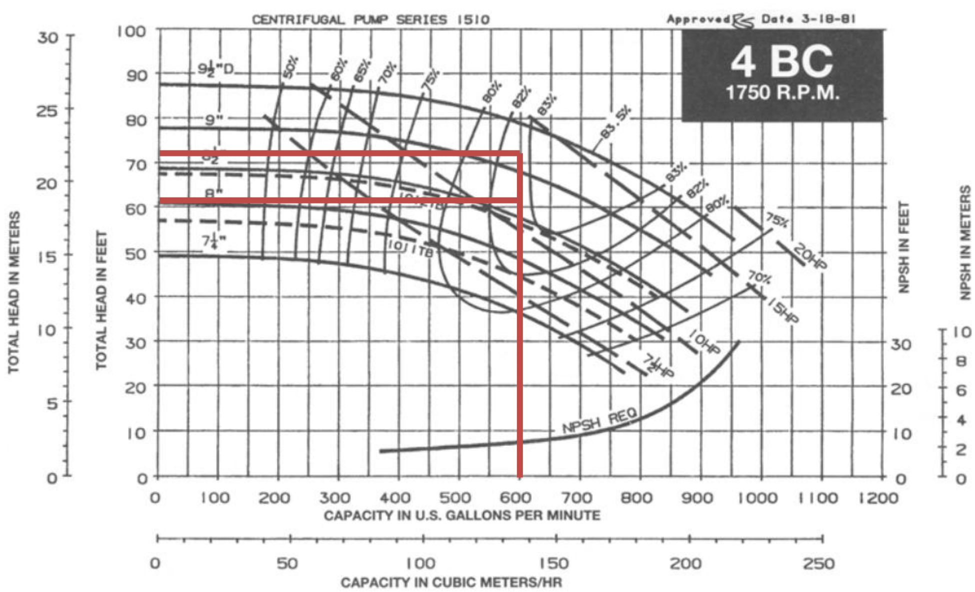
**Partial Storage**:



**Full Storage**:



# Appendix E- Emission Rates

**Table 8 Emission Factors for On-Site Combustion in a Commercial Boiler (lb of pollutant per unit of fuel)**

| Pollutant (lb) | Commercial Boiler | | | | | |
|---|---|---|---|---|---|---|
| | Bituminous Coal * | Lignite Coal ** | Natural Gas | Residual Fuel Oil | Distillate Fuel Oil | LPG |
| | 1000 lb | 1000 lb | 1000 ft$^3$ *** | 1000 gal | 1000 gal | 1000 gal |
| $CO_{2e}$ | 2.74E+03 | 2.30E+03 | 1.23E+02 | 2.56E+04 | 2.28E+04 | 1.35E+04 |
| $CO_2$ | 2.63E+03 | 2.30E+03 | 1.22E+02 | 2.55E+04 | 2.28E+04 | 1.32E+04 |
| $CH_4$ | 1.15E-01 | 2.00E-02 | 2.50E-03 | 2.31E-01 | 2.32E-01 | 2.17E-01 |
| $N_2O$ | 3.68E-01 | ND † | 2.50E-03 | 1.18E-01 | 1.19E-01 | 9.77E-01 |
| $NO_X$ | 5.75E+00 | 5.97E+00 | 1.11E-01 | 6.41E+00 | 2.15E+01 | 1.57E+01 |
| $SO_X$ | 1.66E+00 | 1.29E+01 | 6.32E-04 | 4.00E+01 | 3.41E+01 | 0.00E+00 |
| CO | 2.89E+00 | 4.05E-03 | 9.33E-02 | 5.34E+00 | 5.41E+00 | 2.17E+00 |
| VOC | ND † | ND † | 6.13E-03 | 3.63E-01 | 2.17E-01 | 3.80E-01 |
| Lead | 1.79E-03 | 6.86E-02 | 5.00E-07 | 1.51E-06 | ND † | ND † |
| Mercury | 6.54E-04 | 6.54E-04 | 2.60E-07 | 1.13E-07 | ND † | ND † |
| PM10 | 2.00E+00 | ND † | 8.40E-03 | 4.64E+00 | 1.88E+00 | 4.89E-01 |

* from the U.S. LCI data module: Bituminous Coal Combustion in an Industrial Boiler (NREL 2005)
** from the U.S. LCI data module: Lignite Coal Combustion in an Industrial Boiler (NREL 2005)
*** Gas volume at 60°F and 14.70 psia.
† no data available

**Table B-10 Total Emission Factors for Delivered Electricity by State (lb of pollutant per kWh of electricity)**

| Pollutant (lb) | RI | SC | SD | TN | TX | UT | VA | VT | WA | WI | WV | WY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_{2e}$ | 1.18E+00 | 1.00E+00 | 1.45E+00 | 1.46E+00 | 1.99E+00 | 2.62E+00 | 1.40E+00 | 1.88E-02 | 4.11E-01 | 2.03E+00 | 2.41E+00 | 2.67E+00 |
| $CO_2$ | 1.04E+00 | 9.57E-01 | 1.36E+00 | 1.40E+00 | 1.85E+00 | 2.51E+00 | 1.33E+00 | 1.78E-02 | 3.82E-01 | 1.92E+00 | 2.31E+00 | 2.52E+00 |
| $CH_4$ | 5.65E-03 | 1.72E-03 | 3.02E-03 | 2.43E-03 | 5.80E-03 | 4.21E-03 | 2.52E-03 | 2.25E-05 | 1.13E-03 | 4.13E-03 | 3.85E-03 | 5.42E-03 |
| $N_2O$ | 2.04E-05 | 2.12E-05 | 3.91E-05 | 3.28E-05 | 4.37E-05 | 5.53E-05 | 2.81E-05 | 1.70E-06 | 1.05E-05 | 5.32E-05 | 5.08E-05 | 7.30E-05 |
| $NO_X$ | 7.91E-04 | 1.90E-03 | 2.45E-03 | 2.77E-03 | 2.42E-03 | 5.00E-03 | 2.67E-03 | 1.38E-04 | 6.13E-04 | 3.51E-03 | 4.62E-03 | 4.58E-03 |
| $SO_X$ | 9.90E-03 | 5.73E-03 | 3.97E-03 | 7.32E-03 | 1.05E-02 | 1.47E-02 | 8.04E-03 | 1.13E-04 | 1.70E-03 | 6.60E-03 | 1.35E-02 | 7.05E-03 |
| CO | 8.52E-04 | 3.22E-04 | 5.26E-04 | 4.14E-04 | 9.77E-04 | 6.89E-04 | 9.74E-04 | 5.90E-05 | 1.80E-04 | 7.13E-04 | 6.50E-04 | 9.00E-04 |
| TNMOC | 9.92E-05 | 4.89E-05 | 4.12E-05 | 4.17E-05 | 8.22E-05 | 5.78E-05 | 8.77E-05 | 1.02E-04 | 3.74E-05 | 8.26E-05 | 5.26E-05 | 7.43E-05 |
| Lead | 6.87E-09 | 7.66E-08 | 1.47E-07 | 1.24E-07 | 1.49E-07 | 2.08E-07 | 1.02E-07 | 6.33E-10 | 3.21E-08 | 1.97E-07 | 1.92E-07 | 2.77E-07 |
| Mercury | 4.09E-09 | 1.62E-08 | 3.01E-08 | 2.50E-08 | 2.96E-08 | 4.15E-08 | 3.24E-08 | 1.03E-09 | 6.62E-09 | 4.01E-08 | 3.87E-08 | 5.54E-08 |
| PM10 | 7.02E-05 | 4.61E-05 | 8.12E-05 | 6.75E-05 | 1.37E-04 | 1.14E-04 | 7.25E-05 | 7.67E-06 | 2.46E-05 | 1.11E-04 | 1.05E-04 | 1.49E-04 |
| Solid Waste | 1.31E-02 | 1.17E-01 | 2.26E-01 | 1.91E-01 | 1.82E-01 | 3.20E-01 | 1.47E-01 | 2.83E-04 | 4.96E-02 | 3.03E-01 | 2.95E-01 | 4.26E-01 |