Technology and Engineering Development (TED) Building

Thomas Jefferson National Accelerator Facility

Newport News, VA

Final Report

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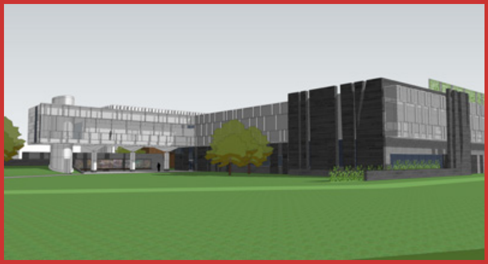

Renderings courtesy of EwingCole

Jefferson Lab Site Plan

General Information

Size: 70,000 SF, Two Stories

Cost: $16 Million

Construction Dates: 8/2010—9/2011

Design Team

Owner: Jefferson Lab

A/E: EwingCole

CM/GC: Mortenson Construction

Front Entrance

Architecture and Construction

The Technology and Engineering Development (TED) building is one phase of a four-phase project designed to upgrade and expand Jefferson Lab's current technical development and support space for the Continuous Electron Beam Accelerator Facility (CEBAF).

The 1st floor contains workshop space for scientists and engineers while the 2nd floor contains their offices. A two story high bay assembly area is located adjacent to the labs and offices. Collaboration between scientists and engineers is encouraged through an open office plan on the second floor and a courtyard between the TED and the existing test lab building.

Courtyard Between TED and Test Lab

Mechanical System

A hybrid geothermal heat pump system utilizing 192 vertical wells, as well as a cooling tower and boiler to offset peak loads, serve 12 water to water heat pumps that provide chilled water and hot water for the entire building.

Two 32,000 CFM air handlers serve the building. Each air handler is connected to an outside air preconditioning unit, which exchanges energy between exhaust air and incoming outside air. Outdoor air quantities are determined by exhaust make-up, pressurization requirements, and occupant ventilation as determined by ASHRAE Std. 62.1—2007.

West Façade

Electrical/Lighting System

A 2500 kVA pad mounted liquid-filled transformer steps voltage down from 12.47 kV (primary) to 480/277V (secondary) before connecting to the main TED switchboard. A 100 kW/125 kVA generator provides back-up power to a life-safety automatic transfer switch and a mission critical automatic transfer switch.

Lighting is primarily achieved through T-5 fluorescent fixtures with LEDs for task lighting. In the open office, photocells detect the amount of natural light and help control perimeter fixtures.

North Façade and Front Entrance

Structural System

The foundation is rooted to the ground using 35′ ft deep, 16″ diameter piles. Shallow spread and continuous footings support the interior while a continuous foundation wall supports exterior walls. Foundation concrete has a compressive strength of 4000 psi.

The second floor office is framed by steel wide flange beams. Steel wide flange columns provide vertical support for the office floor, office roof, and high bay roof. The office roof is framed by K-series joists while the high bay roof is framed by DLH joists, allowing greater span.

Visit: http://www.engr.psu.edu/ae/thesis/portfolios/2011/dhb5014/index.html

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Acknowledgments

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Mentors on the Thesis Class Discussion Board

Executive Summary

The TED is a 67,000 ft^2 building designed to provide technical support to the Continuous Electron Beam Accelerator Facility at the Thomas Jefferson National Accelerator Facility located in Newport News, VA. It is a two story building with technical workspaces on the first floor, open office and administrative spaces on the second floor, and an adjacent two story high bay assembly area. This report analyzes the existing mechanical system design and proposes two alternative mechanical system designs for the TED. Additionally, two breadth analyses are performed on the project construction of these systems and their effects on the currently designed electrical system.

The existing mechanical system consists of a variable air volume system that provides conditioned air to zones throughout the TED. Two air handling units, located on the roof, split the building into two air systems. One serves the first floor and high bay area, while the other serves the second floor. Hot and chilled water are produced by twelve central water to water heat pumps that are staged appropriately to meet the demand of heating or cooling. Additionally, a boiler is used as backup heat or in case of heat pump failure. The condenser system serving the heat pumps is comprised of a vertical bore geothermal well field along with a closed circuit cooler designed for 28% of the cooling load. Variable frequency drives are used to operate hot water, chilled water, and condenser distribution pumps as well as the air handling units' supply and return fans. The building automation system uses DDC to control the components of the system. The total first cost of the mechanical system is \$2.45 million. This equates to approximately \$35/ft^2 and accounts for close to 16% of the total building cost. The projected annual operational cost, based on a block energy model produced in Technical Report 2, is \$115,175 and equates to approximately \$1.68/ft^2.

One proposed alternative includes the implementation of a geothermal well field using Horizontal Direction Drilling (HDD) to meet the load currently met by the closed circuit cooler. HDD is used to install this field under a group of trees the owner would like to keep. The total annual energy savings from this replacement are estimated to be 89,430 kWh, equating to an annual cost savings of approximately \$6,000. After completing a construction

management breadth analysis, the addition of the geothermal well field is expected to cost an additional $178,000 and take approximately 3 weeks to install. The simple payback period is calculated as 30 years.

The second proposed alternative involves the implementation of a radiant concrete floor slab. An analysis was performed to examine not only the cooling capacity of the slab, but also its thermal storage capabilities. A number of excel spreadsheets were created using Microsoft Excel that, together, attempt to model the effectiveness of the radiant slab through a cooling design day. The slab was found to not have enough cooling capacity to meet the entire sensible load; preventing the use of a DOAS system. For supplemental cooling, a VAV system was modeled in parallel with the cooling slab. By pre-cooling the slab in the morning, the peak cooling electricity demand was decreased by 27.5% and the total cooling energy use for the day was decreased by 13%. Additionally, an electrical system breadth analysis showed that the motors, feeders, breakers, and the distributional panel associated with the cooling equipment could be downsized.

Section 1 Existing Design Conditions

1.1 Introduction

The Technology and Engineering Development (TED) Building is the new construction phase of a Technology and Engineering Development Facility project (TEDF) for the Thomas Jefferson National Accelerator Facility (Jefferson Lab). The TEDF is designed to upgrade and improve the technical support space for the Continuous Electron Beam Accelerator Facility (CEBAF). Jefferson Lab performs research in the areas of nuclear physics and is funded by the United States Department of Energy. The TED is two stories and comprises 68,000 ft^2. The first floor contains workspace and storage areas for physicists and electrical engineers while the second floor contains their offices and administration areas. In addition, a two-story high bay area for more extensive manufacturing is located adjacent to the first floor.

1.2 Design Objectives and Requirements

Besides adding new and improved technical space to Jefferson Lab, the TED, as part of the TEDF project, is designed to contribute to the upgrade of the workflow and functionality of the adjacent existing Test Lab Building 58 (also to be renovated and expanded as part of the TEDF project). Specifically for the heating, ventilation, and air-conditioning system, this upgrade represents an improvement in operational flexibility, service and maintenance of the mechanical equipment, and energy efficiency.

The project program set forth by Jefferson Lab requires the design of the TED to achieve LEED-NC Version 2.2 GOLD certification. Part of this requirement entails compliance with both ASHRAE Standard 62.1-2007 for adequate ventilation and ASHRAE Standard 90.1-2007 for energy efficiency. As was discussed in Technical Report 1, the TED meets or exceeds each of these standards.

1.3 Site and Budget

The TED is currently under construction on the Jefferson Lab campus located in Newport News, VA. At the heart of the campus is the CEBAF, which houses the particle accelerator and is the primary instrument used for research into the structure of atoms and their nuclei. The existing Test Lab building has been used as the technical support center for the CEBAF. It was originally built for NASA in 1965 and was converted by Jefferson Lab for CEBAF support use in the 1980s. Since then, the building's use has outgrown its functionality, resulting in the need for an additional building.

The TED will sit adjacent to the Test Lab building and be connected by two corridors which will enclose a courtyard between the two buildings. As one of the first buildings that will be visible from the main driveway into the campus, the TED is designed to provide an aesthetically pleasing view, while also giving a profound implication of the technical work that goes on inside. In addition, the specific construction site on the Jefferson Lab campus is in close proximity with a large portion of the campus's forest and wetland areas. The TED is designed to disturb only the minimum amount of natural vegetation. Figure 1-3-1 below illustrates the TED and its surrounding site.

Figure 1-3-1: TED Site Plan

An estimate for the total cost of the TED is \$15 million, or \$219/ft^2. This value does not include overhead, taxes, fees, or insurance. The heating, ventilation, and air-conditioning system is estimated to cost \$2.45 million, making up 16.3% of the total cost. This HVAC first cost equates to approximately \$35/ft^2.

1.4 Energy Sources and Rates

The following information on available utilities and rates was obtained from Technical Report II, where it was used to determine the annual energy use by the TED.

Electricity is provided to the TED via a Dominion Virginia Power substation. Dominion Power has various rate schedules and each depend on the type and amount of service provided to the customer. The designer's basis of design report mentions that the peak electricity demand is expected to be less than 500 kW. In addition, the TED is assumed to be a commercial business. These two parameters qualify the TED to be considered under the GS-2 Intermediate General Service (30 - 500 kW) Schedule.

Natural gas is available on the Jefferson Lab site, however, no information about the specific source and cost could be located. Instead, the average cost of natural gas (\$/ft^3 converted to \$/therm) in Virginia for the first six months in 2010 as reported by the U.S. Energy Information Administration was used. Table 1-4-1 below summarizes the utility rates for the TED.

Table 1-4-1: Utility Rates

Electricity	**Consumption (\$/kWh)**	**Demand (\$/kW)**	**Min Charge (\$/Month)**
June - September	0.06689	5.506	21.17
October - May	0.05969	4.068	21.17
Natural Gas	**Consumption (\$/therm)**		
Virginia 2010 Ave.	0.977		

1.5 Design Conditions

Environmental design conditions for Norfolk, VA were used in the HVAC design process because Newport News is located approximately 20 miles NWW of Norfolk, VA. To account for worst-case conditions, 0.4% summer design day and 99.6% winter design day values were used. Indoor design conditions correlate with the Jefferson Lab Energy Conservation Policy. Table 1-5-1 below shows specific environmental and indoor design conditions used.

Table 1-5-1: Environmental and Indoor Design Conditions

Condition	Summer	Winter
OA DB (°F)	91.9	22.0
OA WB (°F)	77.1	NA
IA DB (°F)	75.0	68.0
IA RH (%)	50.0	50.0
Mech/Elec DB (°F)	80.0	60.0
Mech Elec RH (%)	50.0	50.0
Clearness #	0.85	0.85
Ground Reflectance	0.20	0.20
OA CO2 (ppm)	400	400

1.6 Equipment Summary

The spaces of the TED are served by two air handlers as part of a VAV system. AHU-1 serves the first floor and high bay areas and AHU-2 serves the second floor office spaces. The terminal boxes for exterior spaces are series powered fan units while boxes serving all other zones are damper modulated VAV boxes. Coupled with each AHU is an outdoor air pre-conditioning unit that uses a total energy wheel to precondition incoming outdoor air using building exhaust air. Table 1-6-1 below summarizes the specifications for each AHU and OAU.

Table 1-6-1: AHU and OAU Summary

Name	Service	Total CFM
AHU-1	First Floor / High Bay	32000
AHU-2	Second Floor	32000
OAU-1	AHU-1	7500
OAU-2	AHU-2	6800

In addition to the main air handlers, cabinet unit heaters are used to heat two exit stairwells and wall mounted water cooled air-conditioning units are used to cool three data centers. Table 1-6-2 and Table 1-6-3 below summarizes this equipment while Table 1-6-4 on the following page summarizes all of the fans used in the TED.

Table 1-6-2: Cabinet Unit Heater Summary

Name	Service	Total CFM	Capacity (MBH)
CUH-1	Vesitbule	222	60
CUH-2	Vestibule	222	60

Table 1-6-3: Wall Mounted Water Cooled Air-conditioning Unit Summary

Name	Service	Total CFM	Capacity (Btu/h)
TD-CRU 1-1	Data Closet 1543	750	17400
TD-CRU 1-2	IDF Room 1534	750	17400
TD-CRU 2-1	TD 2532	750	17400

Table 1-6-4: TED Fan Summary

Fan	Type	CFM	Power (hp)
AHU 1 Supply	VAV	32000	50.00
AHU 1 Return	VAV	32000	30.00
AHU 2 Supply	VAV	32000	50.00
AHU 2 Return	VAV	32000	30.00
OAU 1 Supply	VAV	7500	7.50
OAU 1 Exhaust	VAV	6000	5.00
OAU 2 Supply	VAV	6800	5.00
OAU 2 Exhaust	VAV	6000	5.00
Computer Room AC Unit 1-1	VAV	750	0.16
Computer Room AC Unit 1-2	VAV	750	0.16
Computer Room AC Unit 2-1	VAV	750	0.16
Exhaust Fan 1-1	VAV	270	0.25
Exhaust Fan 1-2	VAV	800	0.75
Exhaust Fan 2-1	VAV	465	0.25
Cabinet Unit Heater-1	CAV	222	0.08
Cabinet Unit Heater-2	CAV	222	0.08
TD-FPB 1-01	VAV	880	0.33
TD-FPB 1-02	VAV	1440	0.50
TD-FPB 1-03	VAV	465	0.33
TD-FPB 1-04	VAV	1610	0.75
TD-FPB 1-05	VAV	830	0.33
TD-FPB 1-06	VAV	1525	0.50
TD-FPB 1-07	VAV	1250	0.50
TD-FPB 1-08	VAV	1250	0.50
TD-FPB 1-09	VAV	1525	0.50
TD-FPB 1-10	VAV	1125	0.50
TD-FPB 1-11	VAV	1125	0.50
TD-FPB 1-12	VAV	1125	0.50
TD-FPB 2-01	VAV	1510	0.50
TD-FPB 2-02	VAV	440	0.33
TD-FPB 2-03	VAV	440	0.33
TD-FPB 2-04	VAV	440	0.33
TD-FPB 2-05	VAV	1350	0.50
TD-FPB 2-06	VAV	1750	0.50
TD-FPB 2-07	VAV	960	0.30
TD-FPB 2-08	VAV	1075	0.50
TD-FPB 2-09	VAV	1000	0.50
TD-FPB 2-10	VAV	800	0.30
TD-FPB 2-11	VAV	1425	0.50
TD-FPB 2-12	VAV	1425	0.50
TD-FPB 2-13	VAV	895	0.30
TD-FPB 2-14	VAV	1000	0.50
TD-FPB 2-15	VAV	1250	0.50
TD-FPB 2-16	VAV	930	0.30
TD-FPB 2-17	VAV	650	0.30

Hot water and chilled water serving cooling and heating coils in the AHUs, terminal boxes, room air conditioning units, and cabinet unit heaters is made from a combination of twelve water source heat pumps. The condenser water serving these units runs through a hybrid geothermal vertical loop system that also contains a closed circuit cooler designed to meet 28% of the cooling load. In addition, a boiler is included inline with the hot water system to provide backup hot water incase of heat pump failure and to prevent condenser water freezing. Table 1-6-5 below summarizes the water source heat pumps while Table 1-6-6 and Table 1-6-7 summarize the closed circuit cooler and boiler. In addition, a summary of all the system pumps is located in Table 1-6-8 on the following page. Note that the geothermal condenser water pumps, chilled water pumps, and hot water pumps operate at n+1 redundancy.

Table 1-6-5: Water Source Heat Pump Summary

				Cooling				Heating			
Name	**Service**	**GPM**	**Cond GPM**	**EWT (F)**	**LWT (F)**	**Cond EWT (F)**	**Cond LWT (F)**	**EWT (F)**	**LWT (F)**	**Cond EWT (F)**	**Cond LWT (F)**
TD-WWHP-1	CHW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-2	CHW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-3	CHW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-4	CHW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-5	CHW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-6	CHW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-7	CHW/HW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-8	CHW/HW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-9	CHW/HW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-10	CHW/HW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-11	HW	62.5	75	50	42.2	85	95	110	120	55	45
TD-WWHP-12	HW	62.5	75	50	42.2	85	95	110	120	55	45

Table 1-6-6: Closed Circuit Cooler Summary

Name	Fan Type	Design gpm	EWT (F)	LWT (F)	Ambient Air WB (F)	Design Fan hp
TD-CCC-1	Centrifugal	270	95	85	80	30

Table 1-6-7: Gas Fired Condensing Boiler Summary

Name	Input (MBH)	Gross Output (MBH)	Efficiency
TD-B-1	1400	1200	0.86

Table 1-6-8: Pump Summary

Name	Service	GPM	Power (hp)	Speed (RPM)	Design Efficiency (%)
TD-GCWP-1	GCW	1100	50	1750	80
TD-GCWP-2	GCW	1100	50	1750	80
TD-GCWP-3	TD-CCC-1	270	10	1750	76.23
TD-CHWP-1	CHW	625	20	1750	80.5
TD-CHWP-2	CHW	625	20	1750	80.5
TD-HWP-1	HW	315	10	1750	76.7
TD-HWP-2	HW	315	10	1750	76.7
TD-HWP-3	TD-B-1	80	1.5	1750	63.06
TD-FZP-1	TD-AHU-1	60	1	1750	63.3
TD-FZP-2	TD-AHU-2	60	1	1750	63.3

In an effort to save additional energy and make the mechanical system as efficient as possible, variable frequency drives are used extensively for various fans and pumps throughout the system. Table 1-6-9 below summarizes the use of variable frequency drives throughout the TED.

Table 1-6-9: VFD Use Summary

Equipment Served	Description	HP
AHU-1	1st Floor AHU Supply Fan	50
AHU-1	1st Floor AHU Return Fan	30
AHU-2	2nd Floor AHU Supply Fan	50
AHU-2	2nd Floor AHU Return Fan	30
TD-CCC-1	Closed Circuit Cooler Fan	30
TD-HWP-1	Hot Water Distr. Pump	10
TD-HWP-2	Hot Water Distr. Pump (standby)	10
TD-CHWP-1	Chilled Water Distr Pump	20
TD-CHWP-2	Chilled Water Distr Pump (standby)	20
TD-GCWP-1	Geoth Cond Water Distr Pump	50
TD-GCWP-2	Geoth Cond Water Distr Pump (standby)	50

1.7 Lost Usable Space

Any space taken up by the mechanical equipment is space lost to be used by the building occupants. Therefore, it is important to minimize the square footage of mechanical rooms and shafts. Table 1-7-1 on the following page shows the amount of usable floor area lost to the TED mechanical rooms and shafts.

Table 1-7-1: Lost Usable Space

Floor	Mechanical Room (ft^2)	Shafts (ft^2)	Total Lost (ft^2)	% Floor Area
1	650	0	650	1.83
2	1690	0	1690	5.37

The first floor contains only a pump room that houses the two geothermal condenser water distribution pumps. From these pumps, the condenser water is piped through the ceiling to the main mechanical room located on the second floor. This mechanical room is where the twelve water source heat pumps and four chilled and hot water distribution pumps reside. From the second floor, the hot and chilled water can be distributed to the AHUs on the roof or to the locations of the terminal boxes, cabinet unit heaters, and room air-conditioning units throughout the building without the need of mechanical shafts. Instead, piping and ductwork use the mechanical room to go between floors, saving usable space for occupants.

1.8 Ventilation Requirements

Required ventilation rates were calculated for both systems, AHU-1 and AHU-2, using the ventilation rate procedure as described in Section 6 of ASHRAE Standard 62.1-2007. Zone areas were obtained from the contract documents, actual populations for each zone were obtained from the designer, and necessary cfm/ft^2 and cfm/person values were obtained from Table 6-1 of Standard 62.1-2007. For a more detailed description of the ventilation rate procedure, as well as full spreadsheets detailing the specific values for each zone in the two systems, please refer to Technical Report I. Table 1-8-1 below describes the conclusions of the analysis that was preformed in that report.

Table 1-8-1: Required Ventilation Compared to Designed Ventilation

System	Required OA (cfm)	Design OA (cfm)	Compliance
AHU 1	6369	7500	Yes
AHU 2	3748	6800	Yes

The designs of both systems meet and exceed the required ventilation according to Standard 62.1-2007. Meeting this requirement contributes to the effort of attaining LEED GOLD certification. Moreover, and most importantly, this significantly improves the indoor air quality throughout the TED.

1.9 Heating and Cooling Loads

A block model of the TED was constructed in Trane Trace 700 v6.2 in order to calculate the design air-conditioning loads on the building. The following information and conclusions about the heating and cooling loads were obtained from Technical Report II. Please refer to that report for a detailed description of the assumptions and procedures.

A block load model is used to get an approximation of mechanical system loads and overall energy use. It does not have as good accuracy as a room-by-room model, however, can be completed in less time, with less specific information, and with a smaller program file size. For the TED block load model, rooms with similar occupancy types were grouped together into zones which were, then, each assigned to appropriate systems. Figure 1-9-1 and 1-9-2 below illustrate how zones were modeled in the TRACE model.

Figure 1-9-1: First Floor Zones (AHU-1)

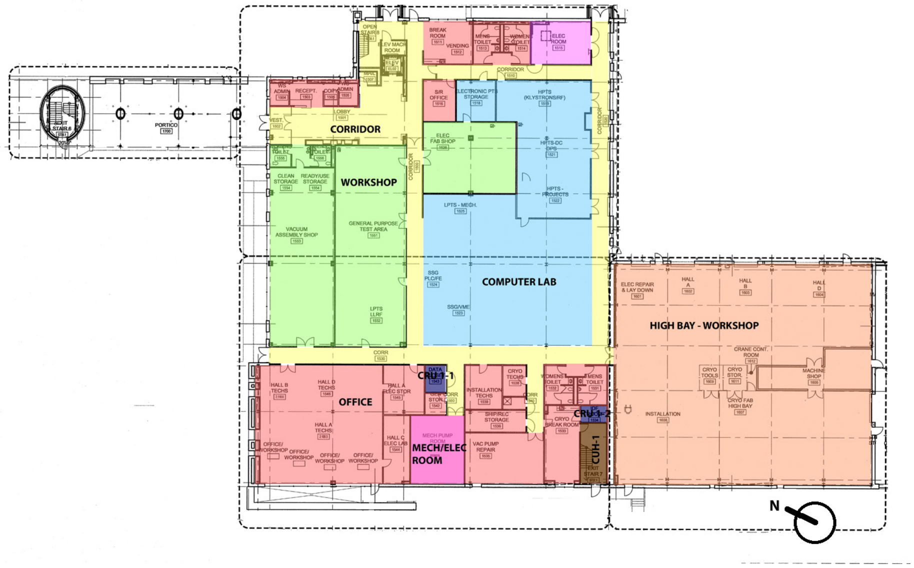


Figure 1-9-2: Second Floor Zones (AHU-2)

The design conditions descried in Section 1.5 of this report were used for the simulation. Table 1-9-3 below summarizes the results of the block load analysis.

Table 1-9-3: Modeled vs. Design Loads

		Cooling ft^2/ton		Heating Btuh/ft^2		Supply Air cfm/ft^2		% OA	
System	**Area (ft^2)**	**Modeled**	**Designed**	**Modeled**	**Designed**	**Modeled**	**Designed**	**Modeled**	**Designed**
AHU-1	36893	322.3	422.53	29.11	32.98	1.01	0.79	30.7	21
AHU-2	31398	332.5	310.78	27.23	34.01	0.9	0.93	37.8	52.6
Wall Mounted AC	277	61.61	60.45	0	0	8.66	8.66	0	0

The largest difference between the modeled and designed values can be seen in the Cooling ft^2/ton for system AHU-1. A lower modeled value is indicative of the fact that the block cooling load calculated for AHU-1 was 34% higher than that of the room by room cooling load calculated by the designer. Another significant difference is the heating load for the entire building being lower in the block results than in the designer's results. A possible source for these occurrences may be the over-estimation of plug loads in the block model. Plug loads are sources of heat generated inside the building due to (mainly) electronics plugged into receptacles. An over-estimation of this internal heat gain can increase cooling loads and decrease heating loads.

In summary, the loads resulting from the block model simulation are in relative agreement with the results calculated by the designer in the more specific room by room model. This analysis has shown that block models can make a good approximation of loads on the building without sacrificing time and money. This realization can be useful to engineers and building designers in determining the effectiveness of different solutions early in the design process.

Section 2 Existing Design Operation

2.1 Description of System Operation

Air System

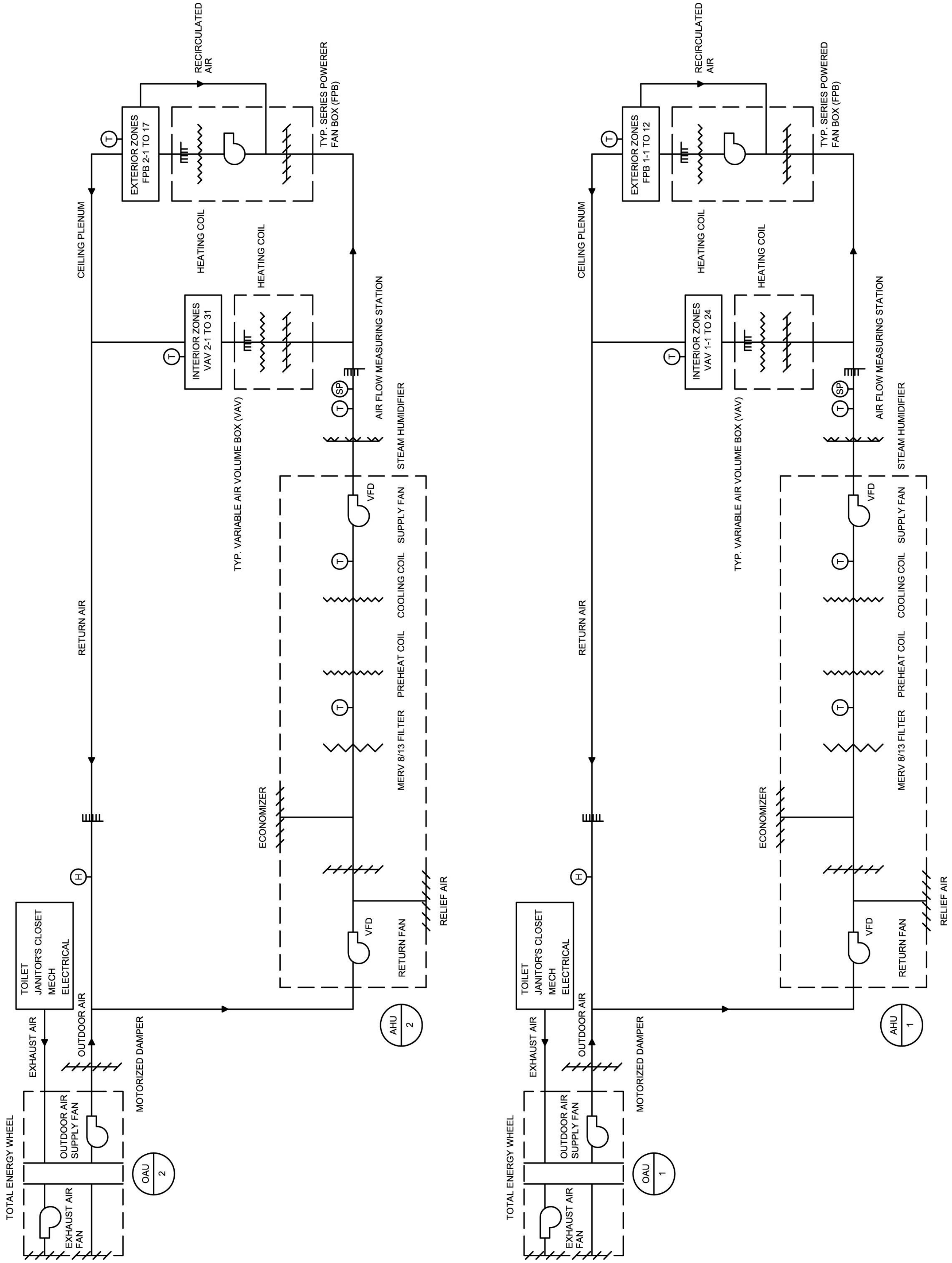
Refer to Figure 2-1-1 on the following page for the air system schematic diagram.

Conditioned air is delivered throughout the TED by a variable air volume with terminal box reheat system consisting of two 32,000 CFM air handling units, variable air volume boxes (VAV) for interior zones, and series powered fan boxes (FPB) for exterior zones. The first air handler, AHU-1, serves the first floor and the high bay area while the second air handler, AHU-2, serves the second floor. In addition, outdoor air pre-conditioning units utilize a total energy wheel to exchange sensible and latent heat between building exhaust air and incoming outdoor air.

The AHUs contain a return fan with VFD, economizer section, MERV 8/13 filter, preheat coil, cooling coil, and supply fan with VFD. The supply air discharge temperature is maintained between 51 F and 65 F and is set based on the highest temperature required to meet the space loads. An economizer cycle is enabled if the outdoor air dry bulb temperature is between 45 F and 65 F and the dew point is between 45 F and 50 F. If the return air dew point rises above 53 F, the supply air discharge temperature is lowered to 51 F to dehumidify the conditioned air. This is until the return air dew point drops below 50 F, at which point the discharge temperature is once again allowed to fluctuate. A static pressure sensor 2/3 down the supply duct modulates the supply fan VFD to maintain a set point of 1 in wg. In addition, based on measured supply and return air duct flows, the BAS modulates the return fan VFD to maintain a flow differential equal to 30% of the unit's required outdoor air. During unoccupied hours, the AHU systems are shutdown unless called upon to maintain space night setback temperatures.

Each air handler is coupled to its own outdoor air pre-conditioning unit (OAU), which uses building exhaust air to pre-condition incoming outdoor before it enters the air handling unit. By using a total energy wheel between

Figure 2-1-1: Air System Schematic



the two air streams, the OAU is able to cool and dehumidify outdoor air in the summer time and heat and humidify outdoor air in the winter time. During an economizer cycle, the OAU supply fan is de-energized while the exhaust fan continues to operate. During unoccupied hours, the entire OAU system is shut down.

Each terminal box unit is maintained by its own integral controls in conjunction with a zone thermostat. The load is met by first modulating a damper to adjust the amount of primary air entering the zone. The heating coil will not modulate open until the damper is set to a minimum position for outdoor air delivery. The fan runs continuously in FPBs during occupied hours. During unoccupied hours, the zone temperature set point is set back.

The humidifiers in each AHU main supply duct are enabled when the outdoor air dry bulb temperature is below 65 F. Once enabled, the output is modulated to maintain a return air humidity of 40%.

Hydronic System

Refer to Figure 2-1-2, Figure 2-1-3, and Figure 2-1-4 on page 28 and 29 for the hydronic system schematic diagrams.

Hot and chilled water is produced by twelve water to water heat pumps with intermittent hot water additions from a gas fired condensing boiler to prevent geothermal condenser water freezing or backup heat if a heat pump fails. The condenser water system serving these heat pumps is composed of a geothermal system containing 192 vertical bore wells and a closed circuit cooler for peak loads. There are two hot water distribution pumps, two chilled water distribution pumps, and two geothermal loop distribution pumps. Each of these pumps contains a VFD and is arranged such that as one pump is not able to meet the load, the second pump is energized and the two maintain equal VFD set points; also called a lead-spare arrangement. A specified system (hot water, chilled water, or condenser water) differential pressure determines the set point for the VFDs.

At the heart of the hydronic system is the twelve water to water heat pumps. These heat pumps supply hot water to AHU preheat coils, terminal box heating coils, and cabinet unit heater coils and supply chilled water to AHU cooling coils. Each heat pump is capable of producing hot or chilled water with nominal capacities of 260 MBH and 336 MBH respectively. However, seven are dedicated to chilled water production, two are dedicated to hot water production, and three have the ability to be switched between producing hot or chilled water. This arrangement maintains reliability and allows full load heating or cooling to be met without sacrificing the ability to simultaneously provide the other.

The heat pumps are piped such that four two-way modulating valves not only separate the changeover heat pumps from each other, but separate the dedicated producers of chilled water from the dedicated producers of hot water. If the outdoor air temperature is above 60 F, all three changeover heat pumps are assigned to produce chilled water. If the outdoor air temperature falls to between 30 F and 60 F, two of the three heat pumps are assigned to produce chilled water while the third is assigned to produce hot water. If the outdoor air temperature falls below 30 F, all three heat pumps are assigned to produce hot water.

Discharge hot water temperature is maintained at 120 F while discharge chilled water is maintained at 42 F. In each mode, the heat pumps are staged such that one begins to operate at small loads. If the system bypass modulating valve stays closed for ten minutes, indicating a full load on the one heat pump, a second heat pump for that mode is energized. The process is repeated over again until all heat pumps are online.

In a case where the hot water discharge temperature drops below 105 F or the entering condenser water temperature drops below 48 F, each indicating a high heating load, the boiler turns on and produces 140 F discharge primary loop water to be mixed with the secondary water loop serving the load. During boiler operation, the heating heat humps de-energize. Upon a rise in hot water supply temperature above 122 F and a rise in condenser supply temperature above 54 F, the boiler disengages and the heating heat pumps are re-energized.

The condenser water system is considered a hybrid geothermal system due to the combination of a geothermal well system and a closed circuit cooler. Condenser water temperatures are maintained between 55 F (peak heating load) and 85 F (peak cooling load). Upon a rise in temperature above 85 F, the closed circuit cooler spray pump and the third condenser water pump that serves the cooler are energized. The discharge water temperature is maintained at a set point that is a function of the outdoor air wet bulb temperature and is limited to between 65 F and 90 F.

Figure 2-1-2: Hot and Chilled Water Distribution System Schematic

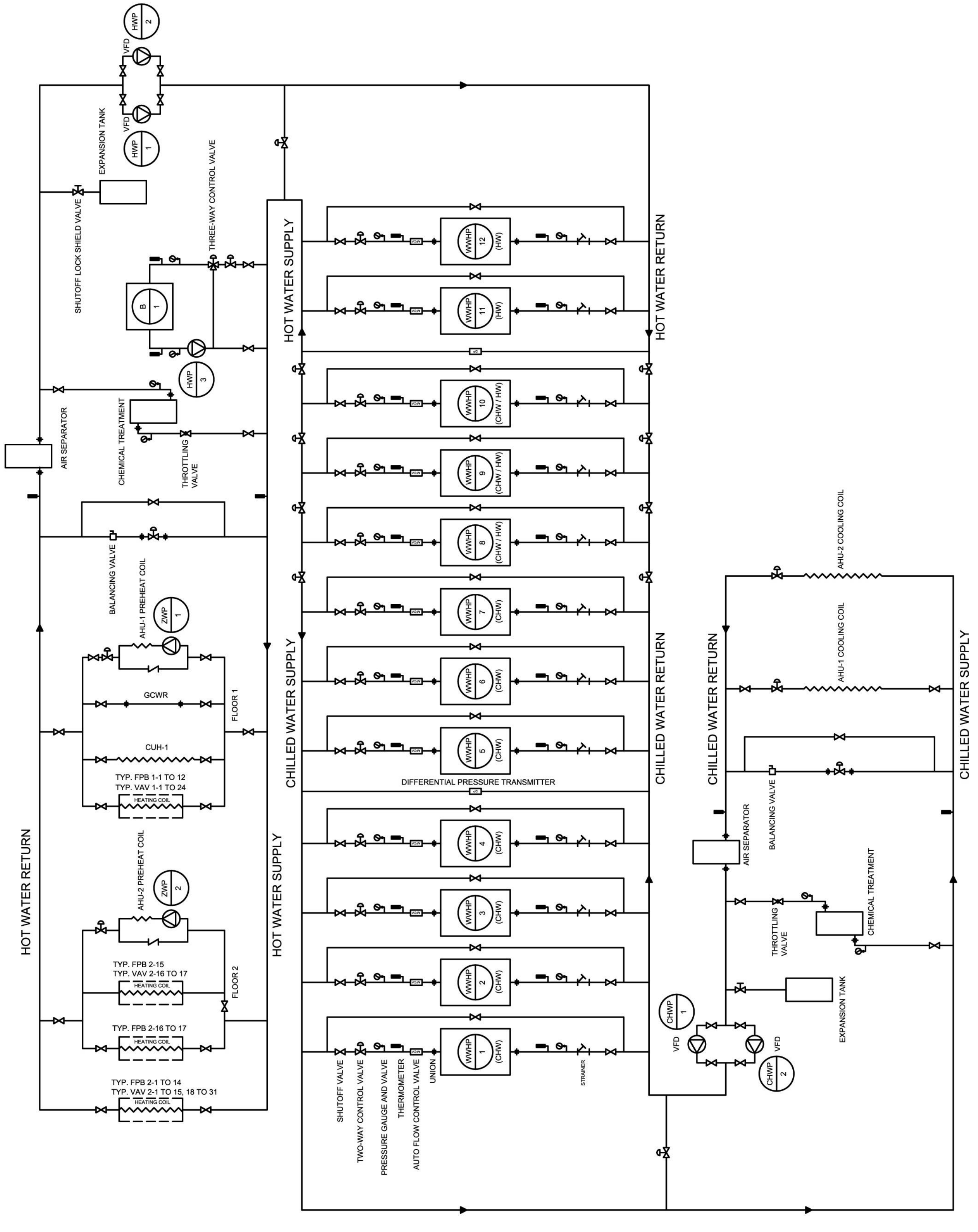


Figure 2-1-3: Condenser Water System Schematic

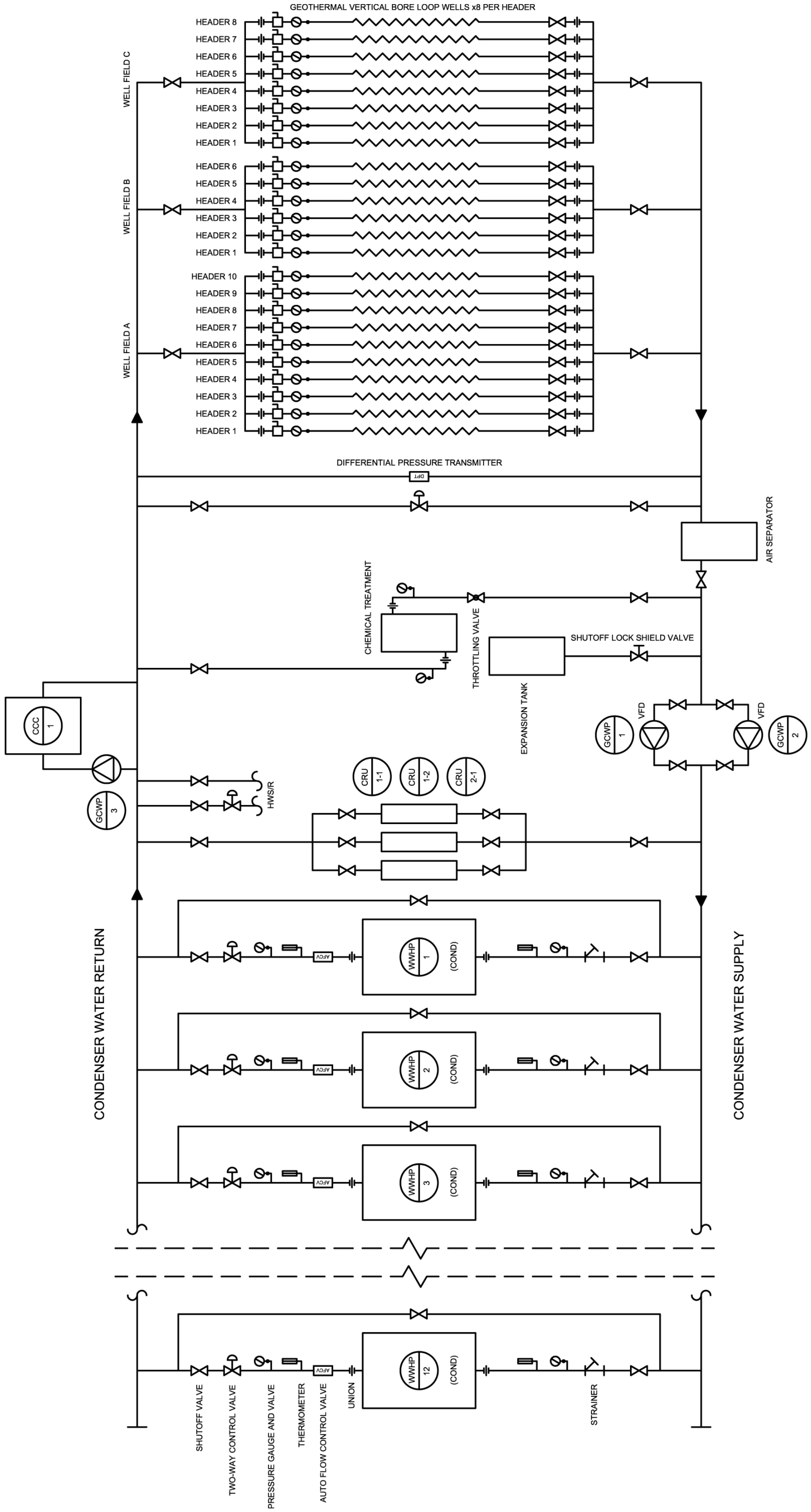
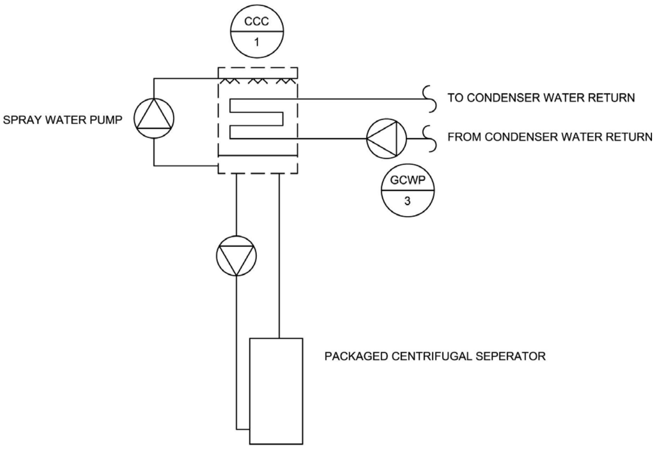


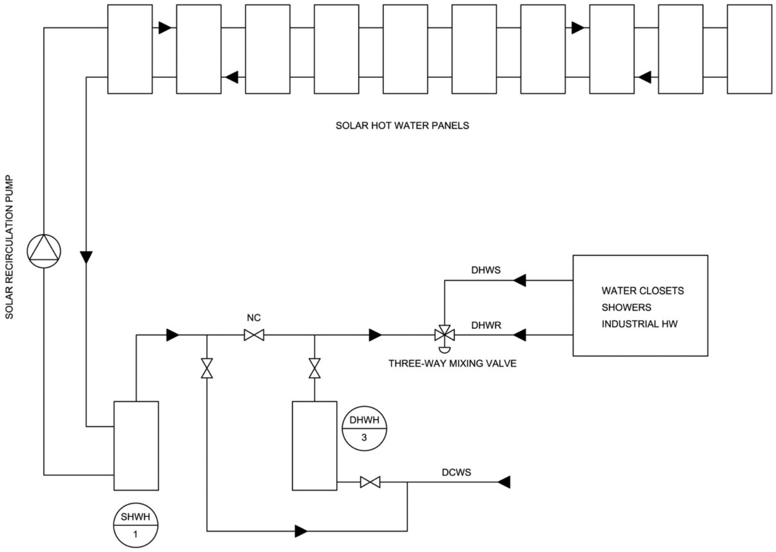
Figure 2-1-4: Closed Circuit Cooler Operation Schematic



Domestic Hot Water

The domestic water system includes water that serves potable systems, such as sinks and showers, as well as water that serves industrial processes. Hot water at 140 F is created primarily by a gas fired water heater and is mixed with recirculated water to produce 120 F domestic hot water. Additionally, solar thermal water panels are used to store heated water in a separate solar hot water tank. The water from this tank is mixed with incoming domestic cold water to be heated by the water heater. The addition of solar heated water decreases the amount of heat needed to be produced by the gas fired water heater. Figure 2-1-5 below shows a schematic of the solar hot water integration with the domestic hot water system.

Figure 2-1-5: Solar Hot Water System Schematic



2.2 Annual Energy Use and Cost

The following information on annual energy use can also be obtained in Technical Report II. In that report, the same block model that was used to calculate the heating and cooling loads was used to determine the annual energy use of the TED. The utility rates referenced in Section 1.4 of this report were used in the simulation.

The total energy consumption calculated by the block load model was broken down by building system and compared to the energy analysis that was prepared by the designer using a room by room model. Table 2-2-1 below and Figure 2-2-1 on the following page summarize this breakdown. Note that the largest differences in predicted consumption appear in the heating system and in the receptacle loads.

Table 2-2-1: Annual Energy Consumption by Building System (Modeled)

	Electricity (kWh)		Gas (kBtu)	
System	**Modeled**	**Designed**	**Modeled**	**Designed**
Primary Heating	31,407	11,949	163,785	95,857
Primary Cooling	235,745	200,169	-	-
Supply Fans	323,354	205,143	-	-
Pumps	31,792	39,011	-	-
Lighting	203,843	193,442	-	-
Receptacles	993,946	418,511	-	-
Building Total	**1,820,087**	**1,068,225**	**163,785**	**95,857**

The energy consumed by the modeled primary heating system is significantly more than the predicted energy consumption by the designed primary heating system. The likely source of error may be contributed to inaccuracies in creating the heating plant in the Trace block model due to a combination of user unfamiliarity with the program and the untraditional nature of the central heating and cooling plant.

The modeled receptacle load is more than double the designed receptacle load. This could be attributed to the nature of the block load. Areas with smaller power densities (W/ft^2), such as corridors or storage rooms, may be included in areas with larger power densities. For instance, the zone called

1_Computer Labs has a specified receptacle power density of 15 W/ft^2. Any extra area included in this zone that would not necessarily be included in a room by room analysis would have a large effect on the load contributed by that zone.

Figure 2-2-1: Annual Energy Consumption by Building System (Modeled)

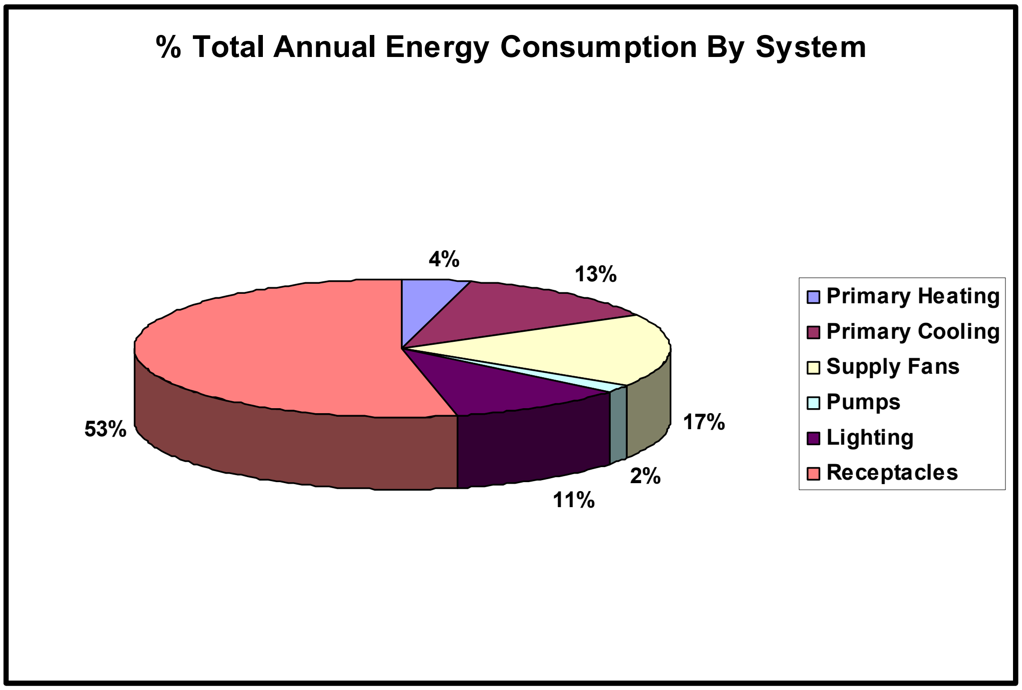
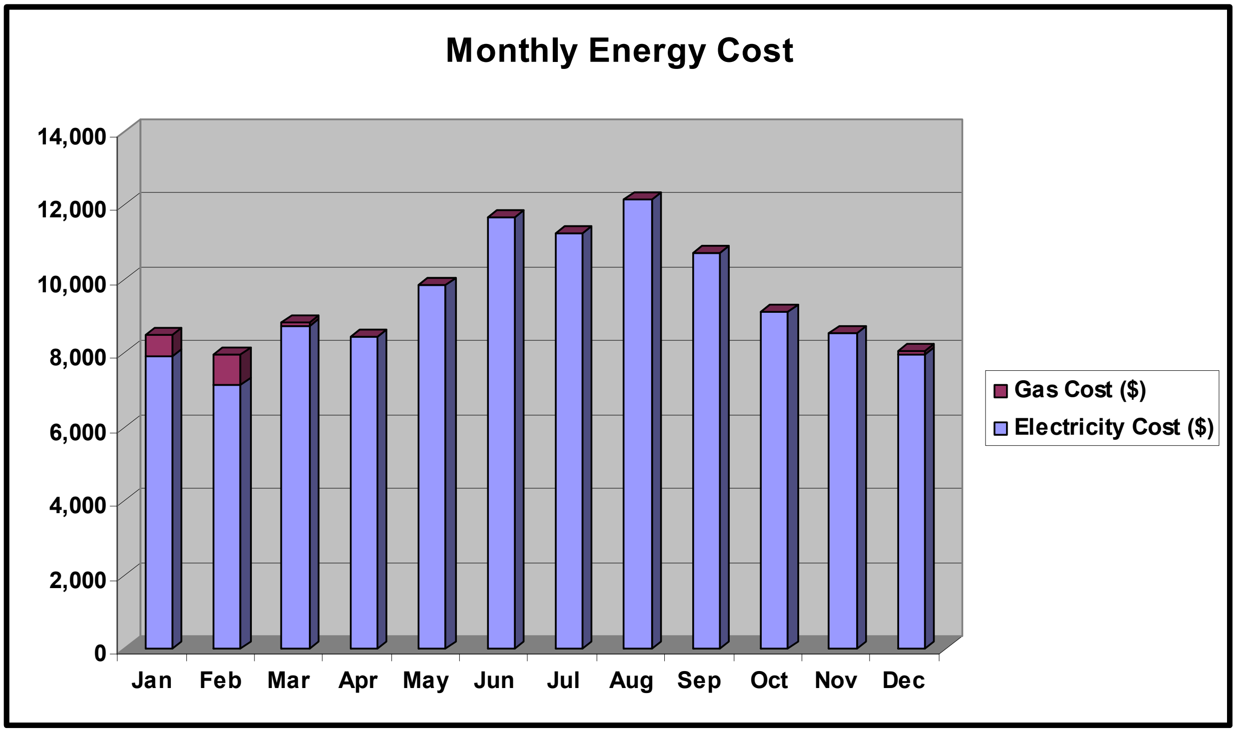


Table 2-2-2 below and Figure 2-2-2 on the following page show the monthly energy consumption, monthly energy cost, total energy cost, and total cost per square foot of floor area.

Table 2-2-2: Monthly Energy Consumption and Cost (Modeled)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Electricity (kWh)	132,364	119,691	146,685	141,865	164,948	174,656	168,286	181,867	160,140	152,959	142,844	133,783	1,820,088
Electricity Cost ($)	7,901	7,144	8,756	8,468	9,846	11,683	11,257	12,165	10,712	9,130	8,526	7,986	113,574
Gas (therms)	611	838	91	0	0	0	0	0	0	0	4	94	1,638
Gas Cost ($)	597	819	89	0	0	0	0	0	0	0	4	92	1,601
Total Cost ($)	8,498	7,963	8,845	8,468	9,846	11,683	11,257	12,165	10,712	9,130	8,530	8,078	115,175
Building Area (ft^2)	**68,568**												
Total Utility Cost ($)	**115,175**												
Cost Density ($/ft^2)	**1.68**												

Figure 2-2-2: Monthly Energy Cost By Utility (Modeled)



From Figure 2-2-2, it can be seen that electricity consumption dominates the cost of energy in the TED. This is because the primary source of both hot water and chilled water is the twelve water source heat pumps connected to a vertical bore geothermal loop. Electricity is used in the heat pump compressors as well as the condenser water, chilled water, and hot water pumps, and all of the fans in the building. The gas fired boiler is only used in the cases of close to peak heating design load.

An energy density for the TED was calculated in order to establish a comparison of energy efficiency to other buildings in the United States. The total annual energy consumption was summed and divided by the building floor area, resulting in an energy density of 90.6 kBtu/ft^2. According to a United States Department of Energy's Energy Information Administration report that surveyed energy consumption in commercial buildings in 2003, typical buildings ranging in size from 50,001 ft^2 to 100,000 ft^2 in the East North Atlantic part of the US have an average energy density of 91.5 kBtu/ft^2. Typical office buildings in the same location have an energy density of 120 kBtu/ft^2. Though the TED is not fully considered an office building, it is the most similar building type surveyed. When compared to buildings of similar size and type, the TED uses below average amounts of energy per square foot of floor area.

2.3 LEED Assessment

With the TED striving for a rating of LEED GOLD, there are many characteristics of the building that can be considered for LEED credit. This section will only focus on those credits pertaining most to the mechanical system. The assessment will be based on LEED 2009 for New Construction and Major Renovations and determine which credits are obtainable.

Energy and Atmosphere

Prerequisite 1 requires commissioning on HVAC systems, lighting systems, domestic hot water, and renewable energy systems along with appropriate documentation. The TED is specified for commissioning on these systems in addition to many others, including fire protection, life safety, and security systems. Also, the required documentation is specified to be completed including a basis of design report, commissioning plan, and a commissioning report.

Prerequisite 2 for energy performance, option one, requires the completion of an energy simulation model that shows improved performance of at least 10% over a baseline building as outline in ASHRAE Standard 90.1-2007, Appendix G. The energy simulation run by the designer shows an energy use that is 65% better than the baseline outlined in Appendix G.

Prerequisite 3 prohibits the use of chlorofluorocarbons (CFC) as refrigerants in air-conditioners. The only refrigerant used in the TED is R-410a, which has a chemical composition of 50% CH_2F_2 and 50% CHF_2CF_3. It does not contain any chlorine and therefore is not a CFC.

Credit 1 requires the comparison of annual energy costs between an energy simulation run for the new building and an energy simulation run for the ASHRAE Standard 90.1-2007 baseline building as described in Appendix G. The annual energy savings mentioned for prerequisite 2 lead to an annual energy cost savings of approximately 53%. This qualifies the TED for all 19 points.

Credit 2 rewards the production and use of on-site renewable energy. The TED mechanical system does not produce on-site renewable energy and does not obtain this credit.

Credit 3 requires enhanced commissioning that represents the involvement of a third party commissioning agent prior to the start of the construction document phase. The design team for the TED determined through their basis of design report that a third party commissioning agent would be included no later than the design development phase. This agent would be involved in developing a commissioning plan as well as overseeing the contractor and sub-contractors as they commission the building. The TED qualifies for these 2 points.

Credit 4 requires the calculation of the overall environmental impact of the refrigerants. Table 2-3-1 below summarizes the calculation for the refrigerant used in the heat pumps and determines qualification for the points associated with this credit. Values were obtained from the designer.

Table 2-3-1: Environmental Impact of R-410a

LCODP	0.00
LCGWP	32.89
GWPr	1890.00
ODPr	0.00
Lr	0.02
Mr	0.10
Rc	0.58
Life	10.00

LCGWP + LCODP x 10^5 =	32.9 < or =? 100

Where LCODP = [ODPr x (Lr x Life +Mr) x Rc]/Life
LCGWP = [GWPr x (Lr x Life +Mr) x Rc]/Life
LCODP: Lifecycle Ozone Depletion Potential (lb CFC 11/Ton-Year)
LCGWP: Lifecycle Direct Global Warming Potential (lb CO2/Ton-Year)
GWPr: Global Warming Potential of Refrigerant (0 to 12,000 lb CO2/lbr)
ODPr: Ozone Depletion Potential of Refrigerant (0 to 0.2 lb CFC 11/lbr)
Lr: Refrigerant Leakage Rate
Mr: End-of-life Refrigerant Loss
Rc: Refrigerant Charge
Life: Equipment Life

Credit 5 requires a measurement and verification plan to be implemented. The TED is specified to undergo a measurement and verification process by an organization who is a member of Associated Air Balance Council or the National Environmental Balancing Bureau. This qualifies the TED to receive 3 points associated with this credit.

Credit 6 requires the purchase of a green power generation contract that purchases electricity from renewable energy sources for at least 35% of the total electricity use. It is unknown whether or not such a contract has been purchased for the TED at this time. The designers plan on a green power contract to be used, however, it is ultimately up to the owner to follow through with it. Assuming the owner follows through with purchasing a green power contract, the point for this credit can be added.

Indoor Environmental Quality

Prerequisite 1 requires the ventilation system to meet the requirements of ASHRAE Standard 62.1-2007 as described by the ventilation rate procedure. In Technical Report 1, it was determined that the TED meets the requirements of Std. 62.1 as well as the required ventilation as determined by the ventilation rate procedure.

Prerequisite 2 requires smoking to be prohibited inside the building and within 25 ft of entries, intakes, and windows. The TED meets this prerequisite.

Credit 1 requires CO_2 monitors be installed in densely occupied spaces (25 ppl/1000 ft^2) to maintain and verify proper ventilation of those paces. The only spaces in the TED with a occupancy density greater than this specification are the conference rooms. The conference rooms include CO_2 sensors that interact with the ventilation system to maintain proper concentrations. One point is awarded for this credit.

Credit 2 requires the increase of outdoor air ventilation rates to 30% above the rates required by ASHRAE 62.1-2007. For AHU-1, the required outdoor air rate is 6369 CFM and the designed outdoor air rate is 7500 CFM. This increase in only 18% does not qualify the TED for points for this credit.

Credits 3 through 6.1 do not apply to the mechanical systems. Instead, they apply to construction materials and lighting controls. For more information regarding these systems, please refer to Technical Report 1.

Credit 6.2 requires that at least half of the occupants in the building be able to control their own environment through controls or operable windows. Due to the largely open plans, BAS determined temperature set points, and inoperable windows, it can be assumed that less than 50% of the occupants have direct control over their own environment. Therefore, the point for this credit is not obtained.

Credit 7.1 requires the design of HVAC systems to provide thermal environments within the conditions set by ASHRAE Standard 55-2004. The indoor temperature and relative humidity set points are 75 F (summer) or 68 F (winter) and 50% RH which are within the range of desired conditions as described by Std. 55. This achieves the TED 1 point.

Credit 7.2 requires the monitoring and confirmation of the design parameters set forth for credit 7.1 by taking surveys of occupants within 6 to 18 months after occupancy. The mechanical design engineer has written a survey to be used for occupants to evaluate their environmental conditions; however, since TED construction is not yet complete, it is unknown if this survey will be used. Assuming the survey is used, the point associated with this credit can be gained.

Credits 8.1 and 8.2 do not apply to the mechanical systems. Instead, they apply to the architectural systems.

Section 3 Existing Systems Evaluation

To successfully evaluate the mechanical system, the design requirements and objectives must be revisited. Four different requirements or objectives were determined in the opening section of this report: operational flexibility, easier maintenance, efficiency, and LEED GOLD attainable.

Operational Flexibility

The mechanical system provides a large amount of operational flexibility. In the air system, the combination of terminal boxes and the use of a VFD on the supply fan allows for large variations in air quantities to be delivered to separate zones without wasting unneeded fan energy. With each terminal box having its own air damper, heating coil, and thermostat, the zone temperatures can be controlled with acceptable accuracy. In addition, the ability to humidify and dehumidify the supply air leads to further thermal comfort acceptances. Lastly, the inclusion of both an economizer section in the AHUs as well as the coupling of an OAU to each AHU allows for greater flexibility in the use of outdoor air for heating, cooling, and ventilation over a more traditional system. One caution in the use of VAV systems, however, is the accountability of proper ventilation delivery rates for each zone. If certain terminal boxes are operating at minimum flow, slightly askew outdoor air fractions can lead to improper ventilation air amounts to those zones.

The hydronic system also exhibits large amounts of operational flexibility. The primary example is the arrangement of the twelve water to water heat pumps. The three heat pumps that are piped to operate in either cooling or heating mode replace the otherwise required six “unimode” heat pumps to provide enough cooling or heating for peak loads. This flexibility comes from the realization that peak heating and peak cooling loads will not occur at the same time. At $28,400 each, not purchasing three extra heat pumps saves a significant amount of first cost. Additionally, the ability for the boiler to run instead of hot water heat pumps when freeze protection of the condenser lines is needed saves on energy cost. This is due to the price of natural gas being cheaper per unit energy than that of electricity, which would be used if one of the heat pumps remained operating for the same function.

Ease of Maintenance

The mechanical system is largely centralized into one mechanical room that is located on the second floor. Though this location makes installation and removal of equipment more difficult, it is the optimum place when considering lost useable space. From the second floor, the mechanical system has access to both the first floor ceiling and the roof; eliminating the need for mechanical shafts and opening the floor plan for more useable space.

Though it was exemplified in the previous section, this flexible, yet highly dynamic, system can prove to be more difficult to maintain and operate. With so many moving parts comes the increased possibility of malfunction. Though safeties and alarms are implemented to deter damage or safety risks, improper sequencing or actuations can lead to a constant stream of problems that can frustrate any building operator. This may be especially true as longevity becomes a factor and parts begin to need replacement at various time intervals.

The designers of the TED have a commissioning plan that can ensure proper operation. Commissioning helps certify that all sensors, actuators, and controllers are calibrated and working properly so that the system can operate more closely to how it was designed.

Efficiency

The overall system is designed to operate with a large amount of energy efficiency. The use of VFDs, energy recovery units (OAUs), economizers, heat pump/boiler staging, geothermal well fields, etc. all contribute significantly to energy use and cost savings. It is modeled to use as much as 65% less energy than a baseline ASHRAE Standard 90.1 building as well as save 50% on energy costs. Also, the TED is projected to operate at a lower energy density for a building of similar size, location, and occupancy.

LEED GOLD Attainability

The assessment performed in this report revealed many opportunities for the TED to gain LEED points for the mechanical system alone. Additionally, through the research performed for all three technical reports, many opportunities for LEED points have presented themselves throughout other building systems. The TED should be able to attain LEED GOLD certification.

Section 4 Proposed Alternative Systems

4.1 Full Load Geothermal Design

Geothermal systems use the ground as a heat exchanger to reject or add heat to the building. Because of its large thermal capacitance, the ground a few feet below the surface is maintained at relatively constant moderate temperatures throughout the year. These generally range from 45 F to 75 F throughout the country. During the summer, the ground temperature is cooler than the air temperature, which allows for more heat from the building to be dissipated to the ground than to the air. The reverse is true during the winter, when the ground temperature is warmer than the air temperature and heat can be added to the building. This duality works very well in coordination with heat pumps, air-conditioning equipment that can be run to produce a heating or cooling effect.

The TED, located just a few miles from Norfolk, VA, utilizes a hybrid geothermal system that does not utilize the geothermal aspect to the fullest extent. The condensing water running through this system serves all twelve water source heat pumps in the TED as well as heat pumps located in the adjacent Building 58 renovation. Jefferson Lab was in favor of using a geothermal system, however, was not willing to yield the appropriate amount of space to size the system for full cooling load capacity. The reason for resisting allocation of the appropriate amount of land was to preserve a group of trees located to the northwest of the TED. Therefore, the design team elected to design the geothermal system as large as possible and add a closed circuit cooler sized with a capacity 28% of design cooling load.

The focus of this alternative is to resize the geothermal system to full load capacity, utilizing the land occupied by a group of trees previously determined off limits. The benefit associated with this resize is the elimination of the closed circuit cooler, which includes its associated fan and pump energy. Additionally, educational value is obtained by researching various geothermal design methods and sizing a geothermal field.

The goal of this design alternative is to compare the energy use and costs of the currently designed hybrid geothermal system with the energy use and costs of the proposed full-load geothermal system.

4.2 Radiant Cooling Floor Slabs

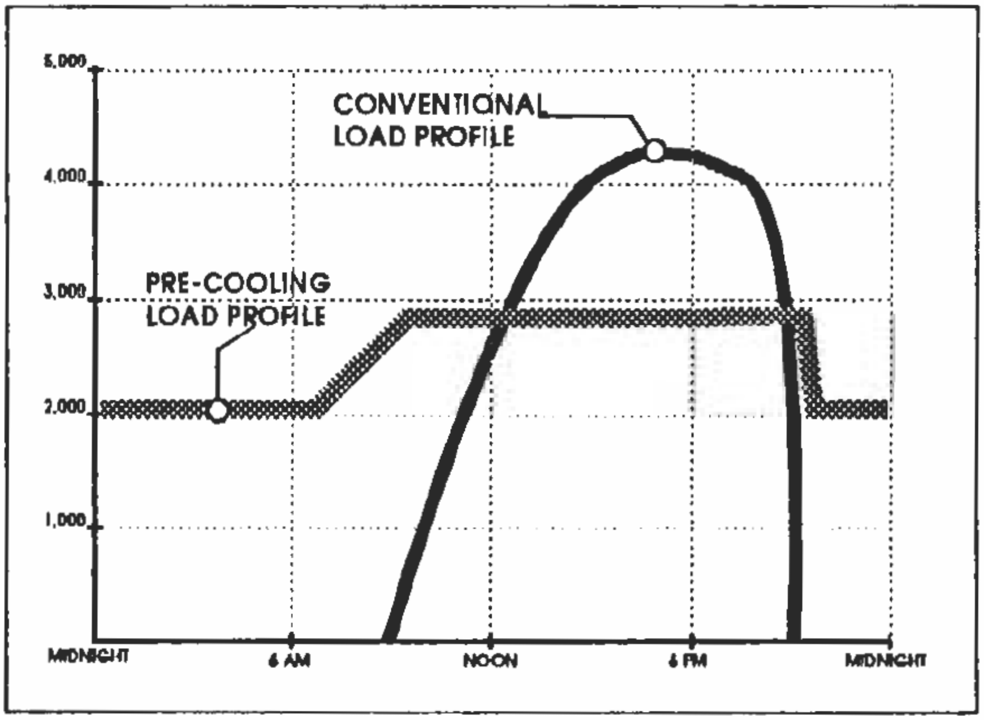
In general, radiant systems use cooled or heated water running through building elements in an attempt to meet the space sensible loads while the air system is used to meet the latent loads and remaining sensible loads. If the air system can meet these loads while introducing only the minimum required outdoor air as determined by ASHRAE Std. 62.1, it is called a Dedicated Outdoor Air System (DOAS). There are multiple solutions for radiant systems, each of which can be used for cooling and/or heating. These include passive or active chilled beams, radiant ceiling panels, and radiant floors. For this system alternative, the use of radiant cooling by the concrete floor slabs will be explored for the following reasons.

A larger use of radiant surface area available from the floor can result in the use of higher surface temperatures during cooling. This can decrease the required energy needed to cool the radiant surface and aid in the prevention of condensation.

Radiant floor slabs also present an interesting opportunity for the examination of slab thermal storage; where the thermal capacitance of the concrete floor slab can be used to shift and shave central plant cooling and heating loads. Ongoing research at the Massachusetts Institute of Technology suggests that a slab that is optimally primed during the night and early morning hours can save as much as 25% on energy during a typical summer week in Atlanta, GA. This research incorporates 24-hour load forecasts into a program that predicts the performance of the slab for the following 24 hours. With this information, a compressor schedule is established that can optimize its associated power function with constraints on personal comfort and chiller freezing.

Additionally, a case study on the Pennsylvania Convention Center in Philadelphia, PA, shows that a radiant slab thermal storage system was implemented to flatten and reduce cooling loads. Figure 4-2-2 on the following page illustrates the effect of the radiant slab on the daily cooling load profile.

Figure 4-2-1: The Pennsylvania Convention Center Load Profile Comparison



Lastly, educational value is obtained by the requirement of analyzing a radiant slab's capabilities and performance throughout a cooling day and its effect on the overall HVAC system.

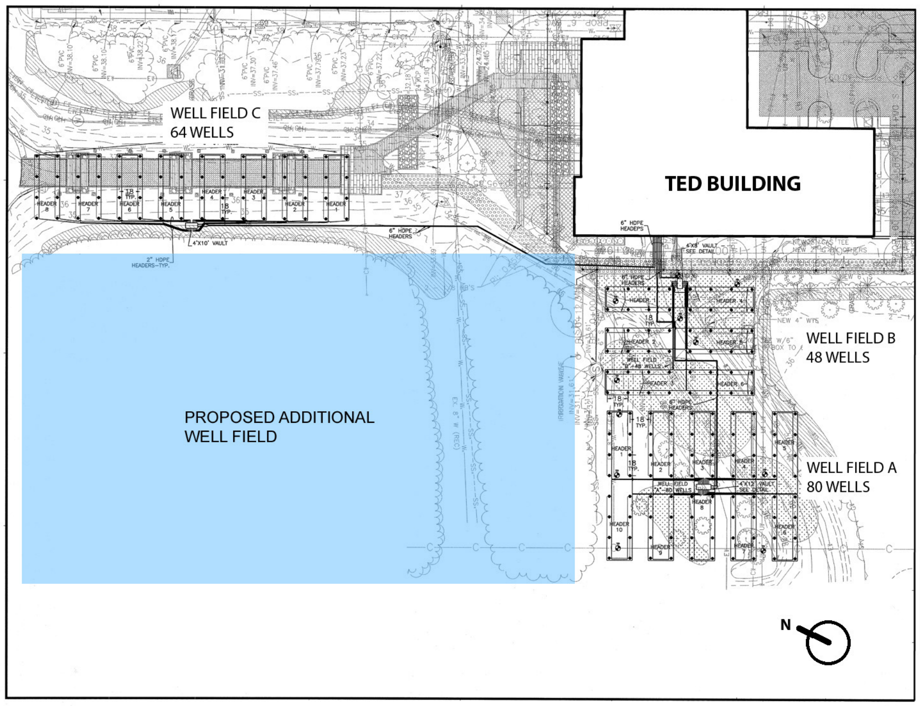
The goal of this design alternative is to examine the effectiveness of a radiant floor slab in reducing and shifting the daily peak required cooling energy for the TED. This analysis must be completed within the context of the thermal comfort, ventilation, and environmental parameters of the TED.

Section 5 Full Load Geothermal Design

5.1 Determining a Field Type: Horizontal Excavation, Vertical Bore, or Horizontal Directional Drilling

The current condenser water system for the twelve heat pumps that provide chilled and hot water throughout the TED utilizes a hybrid geothermal system. Please refer to Section 2 of this report for a detailed description of the condenser system operation and schematic. This geothermal system serves water to air heat pumps located in the neighboring Building 58 as well as central water to water heat pumps in the TED. The current vertical bore geothermal well field is sized to meet 72% of the design cooling load, 267 tons, while the remaining 28% of the design cooling load, 67 tons, is met by a closed circuit cooler placed in series with the well field. The size of the well field also meets the required heating load of 213 tons. Figure 5-1-1 below shows the current layout of the geothermal wells as well as the highlighted area proposed to be used for additional well placement. This area is approximately 550 ft by 320 ft.

Figure 5-1-1: Existing Geothermal Layout with Proposed Area for Addition



Three different geothermal field types were researched in order to determine the best layout to pursue for the TED. The first type is a horizontal field created by excavation. For this type, a large area of land is excavated to a depth below the frost line and the heat exchanger tubing is laid parallel to the ground surface inside the resulting trench. According to McQuay's Geothermal Heat Pump Design Manual, this type of field layout is generally the easiest and cheapest to install at $600 to $800 per ton, however, require a large amount of space of approximately 2500 ft^2/ton. This space requirement limits the applicability of this type of field to commercial projects. At 2500 ft^2/ton, approximately 167,500 ft^2 would need to be available to satisfy the additional 67 tons of cooling for the TED. With approximately 150,000 ft^2 of land to available, this field type was not chosen.

The second type of field layout is the vertical bore, where heat exchanger pipes are placed perpendicular to the ground surface with depths ranging from 200' to 400' deep. Though this layout is generally more expensive to install, between $900 and $1300 per ton, it requires less land area than a horizontal layout; approximately 250 ft^2/ton, according to McQuay's Geothermal Heat Pump Design Manual. With this land requirement, an additional vertical bore field to meet the extra tonnage is possible because they would need only 16,750 ft^2 of land. However, this would disturb trees the owner determined off limits. Due to this request, the possibility of a third field layout was explored.

The third type is a horizontal field bored by horizontal directional drilling (HDD). HDD drilling has been used by utility and telecommunication installers for a number of years. However, it is a technology that has begun to be used by the building industry over the last few years. This type of drilling allows installment of a horizontal bore field with minimal land disturbance. HDD utilizes a directional drill bit that can change the direction of the drill during the drilling process while under ground. This allows installers to begin drilling at an angle into the ground to a prescribed depth and then continue parallel to the ground surface until the bore length is met. The drill is then directed to the surface where the heat exchanger pipe is attached and pulled back through the bore hole. With this type of drilling, a geothermal field can be installed under obstacles such as roads, ponds, or trees. Installers, such as A-One Geothermal, Inc, are capable of placing loops up to 600 ft in length and 45 ft deep. It is also possible to stack loops at depth intervals of 15 ft. Additionally, the cost of HDD can be approximately 20% to 30% lower than vertical bore drilling. Figure 5-1-2 shows basic utilization of HDD drilling.

Due to the flexibility of HDD and its ability to install a geothermal field under obstacles, such as trees, it was the chosen installation method for the additional TED geothermal field. Therefore, a field may be installed that meets the design cooling load as well as limits the disturbance to the existing trees, per the owner's request.

5.2 Field Sizing

The size and layout of the HDD field was determined from the total length of bore required to obtain the proper heat transfer from the condenser water to the ground. No formal bore length calculation procedure could be found for HDD geothermal fields. However, because the loops are installed between 15 ft and 45 ft below the ground surface, it is assumed that the heat exchange will be similar to that of vertical bore wells. Therefore, the required loop length was calculated using the procedure outlined by the 2007 ASHRAE Handbook: HVAC Applications Chapter 32 for vertical bore wells.

Equation 5-2-1 forms the basis of the bore length calculation.

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41\ W_c)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \qquad (5\text{-}2\text{-}1)$$

Where

L_c = *required bore length for cooling (ft)*

F_{sc} = *short circuit heat loss factor*

PLF_m = *part load factor during design month*

q_a = *net annual average heat transfer to the ground (Btu/h)*

q_{lc} = *building design cooling block load (Btu/h)*

R_{ga} = *effective thermal resistance of ground, annual pulse (h-ft-F/Btu)*

R_{gd} = *effective thermal resistance of ground, daily pulse (h-ft-F/Btu)*

R_{gm} = *effective thermal resistance of ground, monthly pulse (h-ft-F/Btu)*

R_b = *thermal resistance of bores (h-ft-F/Btu)*

t_g = *undisturbed ground temperature (F)*

t_p = *temperature penalty for interference of adjacent bores (F)*

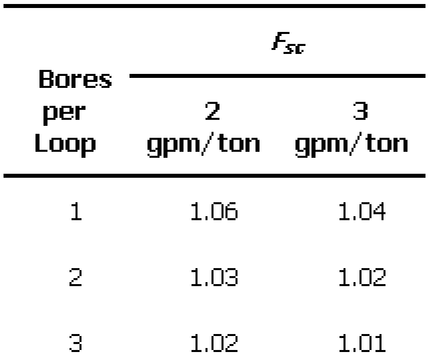
t_{wi} = *liquid temperature at heat pump inlet (F)*

t_{wo} = *liquid temperature at heat pump outlet (F)*

W_c = *power input at design cooling load (W)*

The short circuit heat loss factor, F_{sc}, takes into account heat transfer occurring between the supply and return legs of the pipe loop within the bore. This factor is determined from Table 5-2-1, which can be found in the ASHRAE Handbook and is shown below. For the TED, all loops will be piped in parallel (1 Bore per Loop) and 3 gpm/ton is used.

Table 5-2-1: Short Circuit Heat Loss Factor



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

The net annual average heat transfer to the ground, q_a, is the difference between the design cooling and heating loads, where cooling is negative. Because the existing geothermal field meets the design heating load, q_a is equivalent to the excess cooling load this well field is being designed for, 67 tons.

The effective thermal resistances of the ground, R_{ga}, R_{gm}, R_{gd}, consider three different pulses of heat exchanges seen in the ground. These three pulses are considered through long-term, q_a, monthly, PLF_m, and daily, F_{sc}, heat exchanges. Equations 5-2-2a, b, and c are used to find R_{ga}, R_{gm}, and R_{gd}.

$$R_{ga} = \frac{(G_f - G_1)}{k_g} \tag{5-2-2a}$$

$$R_{gm} = \frac{(G_1 - G_2)}{k_g} \tag{5-2-2b}$$

$$R_{gd} = \frac{G_2}{k_g} \tag{5-2-2c}$$

Where

G_i = *G-factor*

k_g = *thermal conductivity of the ground (Btu/hr-ft-F)*

The ground thermal conductivity varies based on the ground type at the site. A geological survey performed for the site revealed that the ground is composed of mainly gravel, sand, and silt and that its conductivity is 1.01 Btu/hr-ft-F. Each G-factor is a function of thermal diffusivity of the ground, the time of operation (i.e. heat pulse), and outside pipe diameter. These terms and the G-factor are related through the dimensionless Fourier number, defined by Equation 5-2-3 below.

$$Fo = \frac{4\alpha_g \tau}{d_b{}^2} \tag{5-2-3}$$

Where

α_g = *ground thermal diffusivity (ft²/day)*

τ = *time of operation*

d_b = *outside diameter of the pipe*

For each G-factor, a different Fourier number must be calculated depending on the heat pulse time mentioned above. The time of operation term is determined for a year (3650 days), a month (30 days), and 6 hours (0.25 days). Equations 5-2-3a, b, and c below describe this.

$$Fo_f = \frac{4\alpha_g \tau_f}{{d_b}^2} \qquad (5\text{-}2\text{-}3a)$$

$$Fo_1 = \frac{4\alpha_g (\tau_f - \tau_1)}{{d_b}^2} \qquad (5\text{-}2\text{-}3b)$$

$$Fo_1 = \frac{4\alpha_g (\tau_f - \tau_2)}{{d_b}^2} \qquad (5\text{-}2\text{-}3b)$$

Where

τ_1 = *3650 days*

τ_2 = *3650 + 30 = 3680 days*

τ_f = *3650 + 30 + 0.25 = 3680.25 days*

Once the Fourier number corresponding to each heat pulse time is calculated, the G-factors can be graphically determined by using Figure 15 from the ASHRAE handbook, and finally, the three effective thermal resistances of the ground can be calculated as described in equation 5-2-2a, b, and c.

The thermal resistance of the bores, R_b, is found using Table 6 from the ASHRAE Handbook and is a function of the bore fill conductivity, diameter of the bore, and the diameter of the pipe. For the TED, bentonite grout with thermal conductivity of 1.0 h-ft-F/Btu, 1 in DR 11 HDPE, and a 5 in bore hole will be used. These properties are the same as those used for the existing vertical bore design. Therefore, the thermal resistance of the bores equals 0.09 hr-ft-F/Btu.

The ground temperature, t_g, for the TED was determined from the building drawings as 62 F. However, if this information were not so readily available,

Figure 17 from the ASHRAE Handbook, showing an approximate groundwater temperature map of the continental United States, can be used.

The temperature penalty, t_p, represents the long term effect on the ground temperature from the geothermal heat exchanger. The design engineers for the TED estimated a ground temperature rise of 9.1 F over a period of 20 years, which was the value used in this calculation.

The condenser water temperature at the heat pump inlets and outlets, t_i and t_o, are designed to be 90 F and 99 F respectively. The power input at the design cooling load was assumed to be 0 W.

With all of the variables of equation 5-2-1 accounted for, the total required length of bore to meet the design cooling load was calculated as 21442 ft. Table 5-2-3 below summarizes the variables used and the result.

Table 5-2-2: Bore Length Summary

F_{sc}	PLF_m	q_a	q_{lc}	R_{ga}	R_{gm}	R_{gd}	R_b	t_g	t_p	t_{wi}	t_{wo}	W_c
1.04	1.00	-804000.00	-804000.00	0.46	0.32	0.24	0.09	62.00	9.10	90.00	99.00	0.00

t_f	t_2	t_1	Fo_f	Fo_1	Fo_2	G_f	G_1	G_2
7330.25	7330.00	7300.00	119911.16	494.84	4.09	1.02	0.56	0.24

L_c
21441.40

5.3 Field Layout

According to information provided on the website of A-One Geothermal, Inc, there must be extra space provided at either end of the bore to drill down to and up from the desired depth. The example given was 300 ft of land is required for a 200 ft bore length at the specified depth. Additionally, where the drill comes to the surface must be free of obstacles so that workers can attach the piping that will be pulled back through the bore. It was found that if the 320 ft length of the proposed area were used for the bore length, the additional 100 ft would not be available. The drill would surface inside a large patch of trees, restricting access for pipe attachment. It is determined that along the 550 ft axis, the drill bit can surface in a clearing beside a road just beyond the edge of the trees. Thus, a bore length of 450 ft is determined feasible.

Using the total bore length calculated in the previous section, a 450 ft bore length equates to the requirement of 48 bores. In order to fit the number of bores within the 320 ft dimension, three layers of horizontal bores will be stacked at depths of 15 ft, 30 ft, and 45 ft, and separated 15 ft horizontally. This results in 16 bores in each layer. The total dimensions of the bore field grid under the trees are 450 ft by 240 ft, which is within the allotted area. Figure 5-3-1 and Figure 5-3-2 on the following page show schematics of the HDD geothermal field.

Figure 5-3-1: HDD Geothermal Field Layout

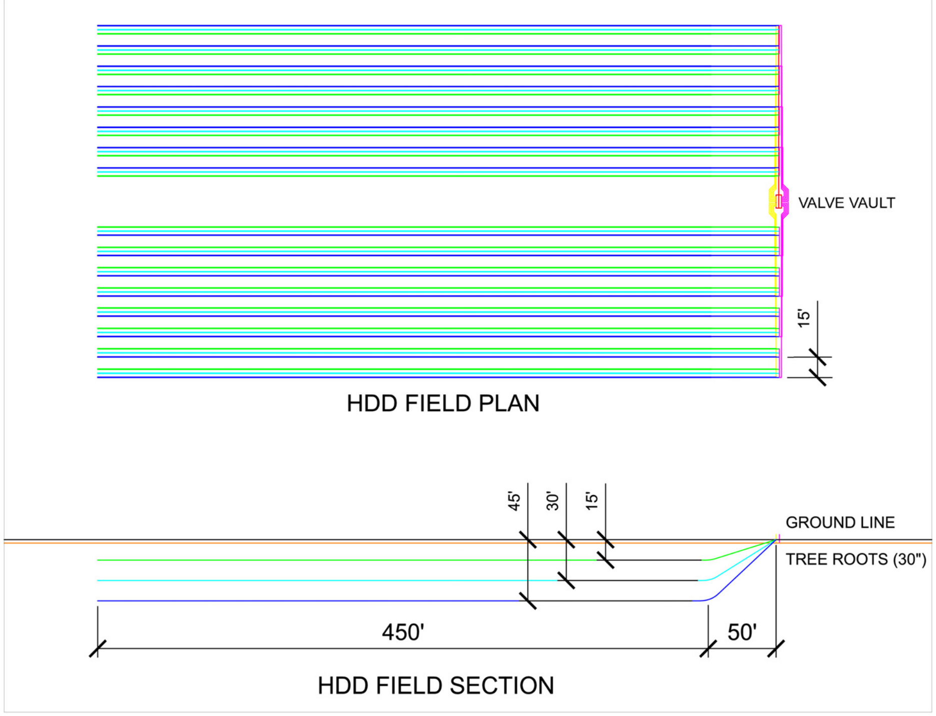
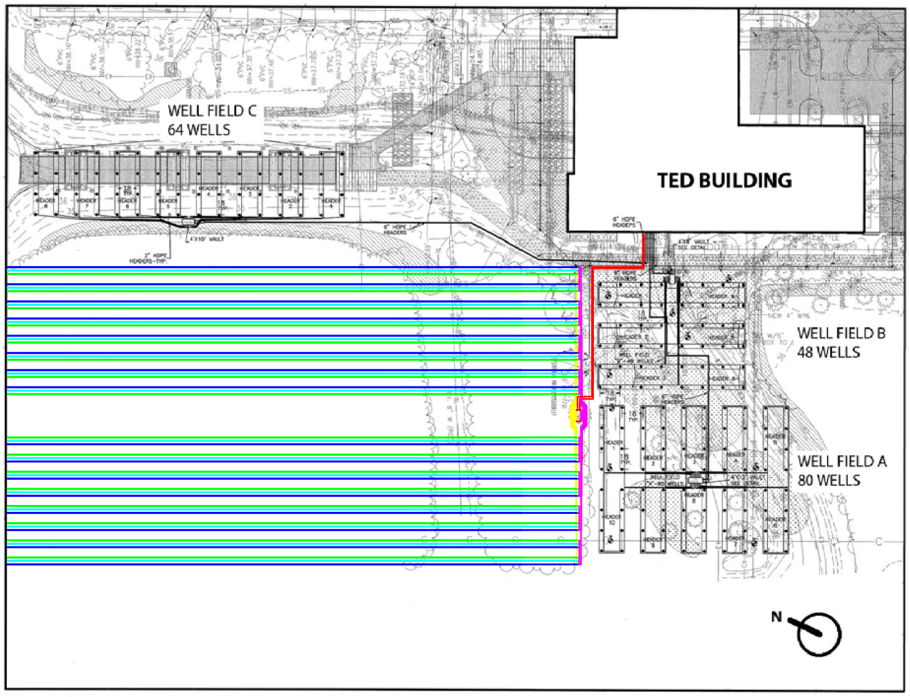


Figure 5-3-2: HDD Geothermal Field Plan



The condenser water flow is delivered to a valve vault from the building through 6” HDPE piping. The valve vault distributes the water to (8) 2” headers. Each of these headers distributes flow to (6) 1” loops. The loops are piped to the header in a reverse-return fashion. The pipe size was reduced in the valve vault as well as through the header runs as flow was directed to each branch. A ball valve in the supply and return mains inside the building allow the entire HDD portion of the field to be controlled when required to meet the condenser load or isolated for maintenance. Additionally, each header is equipped with a ball valve for loop controllability or isolation. This introduces the same control mechanisms to the HDD field as the three vertical bore fields currently designed for the TED.

5.4 Pump Sizing

The proposed condenser system does not change the number of heat pumps because the design cooling load for either building has not been changed. Therefore, it also does not change the required condenser water flow through the geothermal system. However, an analysis must be done to determine if the HDD field adds head loss to the system. The system head loss is calculated using the branch of the system with the largest head loss. The engineering drawings indicate that the maximum head loss through the geothermal system occurs through the last loop in well field C (35.8 ft wg). The head loss table used for DR 11 HDPE pipe as well as the two figures from Heating, Ventilating, and Air Conditioning used to determine the equivalent lengths for fittings can be found in Appendix A. Table 5-4-1 on the following page shows a summary and results of the head loss calculation from the building through the last bore of the HDD field.

Since the total head loss is not greater than the total head loss through well field C, the HDD field does not add total head loss to the system. Therefore, because the design flow and head loss through the system do not change, the condenser water distribution pumps do not need to be resized.

Table 5-4-1: HDD Field Head Loss Summary

	Component	Size (in)	Flow (gpm)	Length (ft)	Velocity (fps)	Head Loss (ft wg) / 100'	Head Loss (ft wg)
Main	Ball Valve	6	201	1.5	2.86	0.51	0.01
	Run	6	201	28.5	2.86	0.51	0.15
	90 Bend	6	201	15.0	2.86	0.51	0.08
	Run	6	201	44.5	2.86	0.51	0.23
	90 Bend	6	201	15.0	2.86	0.51	0.08
	Run	6	201	113.5	2.86	0.51	0.58
	90 Bend	6	201	15.0	2.86	0.51	0.08
	Run	6	201	12.5	2.86	0.51	0.06
	90 Bend	6	201	15.0	2.86	0.51	0.08
	Run	6	201	11.5	2.86	0.51	0.06
Vault Manifold	Tee Run	6	201	10.0	2.86	0.51	0.05
	Tee Run	6	176	10.0	2.50	0.41	0.04
	Tee Run	6	151	10.0	2.14	0.30	0.03
	Tee Run	4	126	7.0	3.87	1.41	0.10
	Tee Run	4	101	7.0	3.10	0.93	0.07
	Tee Run	4	75	7.0	2.32	0.55	0.04
	Tee Run	4	50	7.0	1.55	0.26	0.02
Header	Ball Valve	2	25	0.5	2.78	1.66	0.01
	Run	2	25	2.0	2.78	1.66	0.03
	90 Bend	2	25	5.0	2.78	1.66	0.08
	Run	2	25	4.0	2.78	1.66	0.07
	45 Bend	2	25	3.0	2.78	1.66	0.05
	Run	2	25	2.8	2.78	1.66	0.05
	45 Bend	2	25	3.0	2.78	1.66	0.05
	Run	2	25	114.5	2.78	1.66	1.89
	Tee Run	2	25	3.5	2.78	1.66	0.06
	Tee Run	2	20.9	3.5	2.22	1.06	0.04
	Tee Run	2	16.8	3.5	1.70	0.75	0.03
	Tee Run	1 1/2	12.56	2.8	2.17	1.36	0.04
	Tee Run	1 1/4	8.375	2.5	1.71	1.08	0.03
Loop	Run	1	4.1875	450.0	1.47	0.96	4.32
	Sum						**8.46**
	Return						8.46
	Total						**16.93**

5.5 Energy Use and Costs

The components of the current condenser water system are the twelve central heat pumps of the TED, the air to water heat pumps serving Building 58, the closed circuit cooler system, and the central condenser water pumps. The closed circuit cooler system is comprised of two tower fans, one condenser water pump, one tower spray pump, and a spray pan electric heater. For a more detailed description of the operation of the designed condenser system, along with a schematic, please refer to Section 2.1 of this report.

To determine the impact of the elimination of the closed circuit cooler system and the expansion of the geothermal field, an estimate of the annual energy use, annual energy cost, and first costs were calculated for both the current and proposed condenser system designs. The associated first costs will be noted briefly in this section to help determine a payback period for the new system. However, a more detailed first cost analysis is presented in the construction breadth.

According to the design drawings, the closed circuit cooler is anticipated to run for 1599 hours per year. Table 5-5-1 below estimates the annual energy use and cost for running the closed circuit cooler system.

Table 5-5-1: Annual Energy Use and Cost of Closed Circuit Cooler System

Component	**hp**	**kW**	**Hours**	**kWh**	**$/kWh**	**Cost**	**Total kWh/yr**	**Total Cost/yr**
Fan (2)	60	44.74	1599	71543.62	0.06689	$4,785.55	89429.53	**$5,981.94**
CWP-3	10	7.46	1599	11923.94	0.06689	$797.59		
Spray Pump	5	3.73	1599	5961.97	0.06689	$398.80		
Spray Pan Heater	-	9.00	79.95	719.55	0.06689	$48.13		

In the energy model that was produced using Trane TRACE 700, a variable frequency geothermal pump was used to model the main condenser water distribution pump. Table 5-5-2 below summarizes the annual energy use and cost for running the distribution pump.

Table 5-5-2: Annual Energy Use and Cost of Condenser Water Distribution Pump

Component	**hp**	**ftwg**	**kW**	**kWh**	**$/kWh**	**Cost**	**Total kWh/yr**	**Total Cost/yr**
CWP-1	50	110	37.29	32164.60	0.06689	$2,151.49	32164.60	**$2,151.49**

After adding the HDD geothermal field, a head loss calculation was performed to determine whether or not the distribution pump was to be resized. The current 110 ft wg was determined by the engineer by adding the largest system head of the Building 58 distribution to the largest head of the geothermal system, which was found to be to and from well field C. The calculation for the HDD field resulted in a head loss less than the head loss of well field C. Therefore, with the maximum head loss as well as the total flow unchanged, the distribution pump does not need to be changed. Without the closed circuit cooler system, the energy used for the proposed geothermal design is equal to the distribution pump energy as seen in Table 5-5-2 above. Table 5-5-3 below summarizes the energy use and first costs of the current and proposed systems.

Table 5-5-3: Annual Energy Use and Cost Comparison of Current Condenser System with the Proposed Condenser System

	Current	**Proposed**	**Difference**
Total Energy Use (Annual), kWh	121594.13	32164.60	-89429.53
Total Operational Cost (Annual), $	$8,133.43	$2,151.49	-$5,981.94
Total First Cost, $	$756,073.90	$934,170.19	$178,096.29

Dividing the additional first cost by the savings in annual operating costs gives a simple payback period of approximately 30 years.

5.5 Conclusion

An HDD geothermal field was analyzed as a possible solution to the geothermal design problem presented for the TED. In terms of energy use, this solution showed to save a significant amount of annual energy compared to the use of a cooling tower for a number of hours during the year. With the total annual energy estimated for the HVAC system to be 646,138 kWh with the cooling tower, an 89,430 kWh savings equates to an approximate 13.8% reduction. The additional $178,000 to install the field, 7.3% of the current HVAC budget of $2.45 million, would be reason for most owners to decline the proposal, particularly with a payback period of 30 years. However, the owner of the TED seemed willing to pay for a full size geothermal field, if the land were available. Therefore, it is possible that the owner would consider the HDD solution.

Section 6 Radiant Cooling Floor Slabs

6.1 Determining a Modeling Technique

Research about the modeling of radiant floor slabs suggested that readily available load and energy modeling programs, such as Trane TRACE, Carrier HAP, or Equest, were not capable of such a task. Two modeling programs that have the capability of modeling such a system are IES and Energy Plus. However, because no direct access to either program is available, nor has previous training with either been had, neither program was considered for model development.

In one case, radiant floors were approximated in Equest by fan coil units without the associated fan energy. However, this approximation does not take into account any transient factors associated with the concrete's thermal capacitance. If modeled by a fan coil unit, radiant ceiling panel, or passive chilled beam, the thermal storage effect the radiant slab can have on shifting the central plant load is not considered. Additionally, a significant portion of cooling loads that appear later in the day occur due to radiant heat transferred from space surfaces, equipment, occupants, lights, and direct solar gain to construction elements, including the floor, within the space. This radiant energy is absorbed by these elements, their temperature rises over time, and the heat is transferred back to the space as cooling load by convection later in the day. A cooled slab can absorb the radiation earlier in the day, particularly direct solar gain, without rising its temperature to a point that would cause the convection of heat back into the space; effectively lessening the cooling load later in the day.

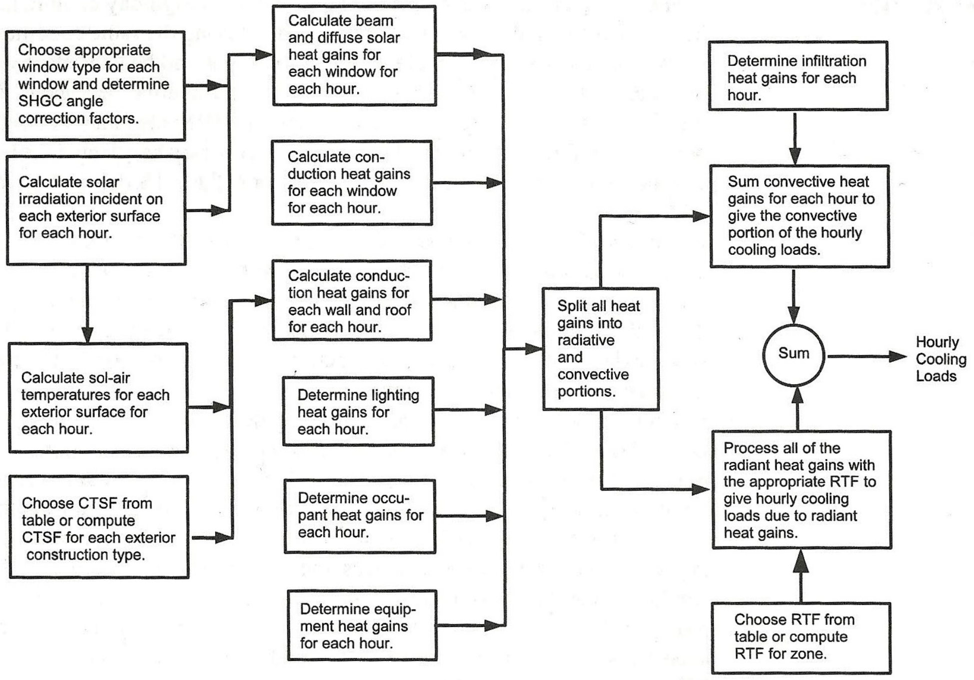
Because programs other than IES or Energy Plus do not have the capability of approximating the two above mentioned transient effects of a cooled slab, a load and energy model of the proposed radiant floor system was developed using Microsoft Excel. This model attempts to analyze some thermal storage effects of the slab for a design cooling day. Additionally, great educational value is obtained by attempting to create an accurate model of the building's cooling load and associated HVAC energy use.

6.2 Load Model Development

Adapting the RSTM Method

The algorithm that was used to model the proposed radiant slab system was adapted from the Radiant Time Series Method (RSTM) as described by Jeffrey Spitler in the Load Calculation Applications Manual published by ASHRAE. This method was formulated to convert heat gains into building cooling loads on an hourly basis without the need of iteration, as the more formal Heat Balance Method (HBM) would require. In this way, the RSTM method is suitable for spreadsheet calculations and is more easily understood than the heat balance method. Refer to Figure 6-2-1 below for a general sequence diagram that describes the RSTM method. For more information regarding the details of the RSTM method, please reference the Load Calculation Applications Manual. For example heat gain spreadsheet calculations performed for the TED, refer to Appendix B.

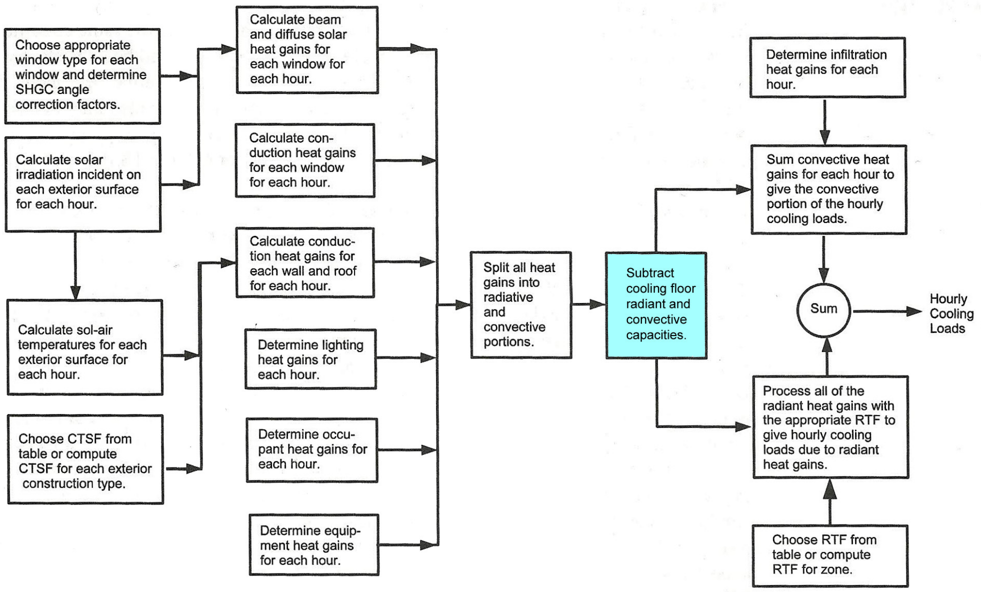
Figure 6-2-1: RSTM Method Sequence Diagram From the ASHRAE Load Calculation Applications Manual



As shown by the figure above, the RSTM method is sequential. That is, once individual heat gains are determined, they are each split into appropriate radiative and convective portions. Then, Radiant Time Factors (RTF) are applied hourly to the total radiative gain. These RTFs are developed based on the construction properties of the space and split each hourly radiative heat gain into associated time-lagged convective cooling loads for each hour. These convective cooling loads that result from the application of RTFs to the radiative heat gains are added to the convective gains determined for each individual heat gain in the previous step. Thus, an hourly cooling load is calculated.

If the cooling capacity of the radiant floor slab can be calculated for each hour and split into its radiative and convective components, then the radiative capacity for each hour can be subtracted from the summed radiative heat gains before RTFs are applied to convert them into hourly convective cooling loads. Additionally, the convective capacity can be subtracted from the hourly convective heat gains before they are summed with the RTF-modified radiative gains. In this way, the effect of the radiant floor on reducing the cooling load can be approximated. Please refer to Figure 6-2-2 below for the radiant floor adapted RSTM method flow diagram.

Figure 6-2-2: Radiant Floor Adapted RSTM Method Sequence Diagram



Modeling the Floor Slab

As described in the sub-section above, the floor slab's cooling capacity is to be split into its radiative and convective portion to be added back into the RSTM method load calculation. In Possibilities and Limitations of Radiant Floor Cooling, Bjarne Olesen describes that the typical heat transfer coefficient between a cooled floor and the room is 1.23 Btu/hr-ft^2-F where the radiative component is 0.97 BTU/hr-ft^2-F. Using these coefficients, the cooling capacity of the slab can be split into radiative and convective components as shown by Equations 6-2-1a and 6-2-1b below.

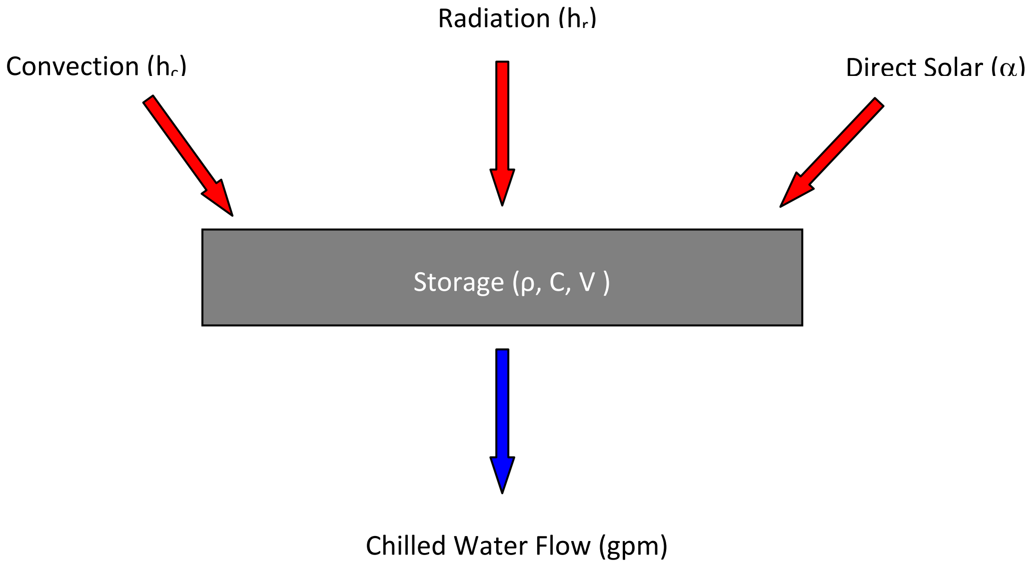
$$q_r = 0.97 A_s (T_s - T_a) \qquad \text{(6-2-1a)}$$

$$q_c = 0.26 A_s (T_s - T_a) \qquad \text{(6-2-1b)}$$

The air temperature can be set to the indoor air temperature set point, however, more discussion is required to determine the floor surface temperature for each hour.

A simplified heat balance approach was used to approximate the transient effect the radiative heat gain, convective heat gain, solar radiation gain, and chilled water flow have on the floor slab temperature. This temperature was assumed to represent the surface temperature of the slab. The procedure described below does not solve for the exact temperature distribution through the slab, however, provides an approximation of slab performance to be used in the space load calculation as described in the previous sub-section. A heat balance performed on the slab as a control volume is shown in Figure 6-2-3 and Equation 6-2-2 on the following page. The heat balance includes the heat gained by radiation, convection, and direct solar gain, and the heat lost represented by the flow of chilled water through the slab. The heat storage term is included in order to account for the slab's thermal capacitance. Solar radiation not absorbed by the slab is added back into the general load calculation as a direct solar radiant load. Additionally, it is assumed that all of the direct solar gain that comes through the windows will hit the floor.

Figure 6-2-3: Floor Slab Heat Balance



$$\dot{E}_{st} = \dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} \qquad (6\text{-}2\text{-}2)$$

Substituting values for the slab control volume yields:

$$\rho CV \frac{dT_s}{dt} = h_r A_s (T_a - T_s) + h_c A_s (T_a - T_s) + \alpha I_{dsg} A_{dsg} - 500GPM(T_{chwr} - T_{chws}) \qquad (6\text{-}2\text{-}3)$$

Where

ρ = *floor slab concrete density* (lb_m/ft^3)

C = *floor slab concrete thermal capacitance* (Btu/lb_m-F)

V = *floor slab concrete volume* (ft^3)

h_r = *radiative portion of floor slab heat transfer coefficient* (Btu/hr-ft^2-F)

h_c = *convective portion of floor slab heat transfer coefficient* (Btu/hr-ft^2-F)

A_s = *floor slab area* (ft^2)

T_s = *slab temperature* (F)

T_a = indoor air temperature (F)

α = slab surface absorbance

I_{dsg} = direct solar radiation through window (Btu/hr-ft^2)

A_{dsg} = direct solar radiation area (ft^2)

GPM = chilled water flow through the slab (gpm)

T_{chwr} = return chilled water temperature (F)

T_{chws} = supply chilled water temperature (F)

Simplifying yields:

$$\frac{dT_s}{dt} + aT_s = b \qquad (6\text{-}2\text{-}4)$$

Where

$$a = \frac{(h_r + h_c)A_s}{\rho CV}$$

$$b = \frac{aT_a + \alpha I_{dsg} A_{dsg} - 500GPM(T_{chwr} - T_{chws})}{\rho CV}$$

Using the discrete form of Equation 6-2-4, where $\frac{dT_s}{dt} = \frac{T_{s_t} - T_{s_{t-1}}}{\Delta t}$, the temperature of the slab at the end of the current time step can be calculated based on the parameters of constants a and b for the current time step and the temperature of the slab at the end of the last time step. This yields Equation 6-2-5 below.

$$T_{s_t} = (b - aT_{s_{t-1}})\Delta t + T_{s_{t-1}} \qquad (6\text{-}2\text{-}5)$$

The radiative and convective components of the slab cooling capacity can be found by using the resultant slab temperature of Equation 6-2-5 and applying it to Equations 6-2-1a and 6-2-1b for each hour during the day. Using this model, chilled water flow rates can be entered for each hour that drive the floor temperature to the desired value. For an example floor slab spreadsheet calculation, refer to Appendix B.

6.3 Environmental Design Conditions

The TRACE model used to analyze the existing HVAC design predicted that the cooling design day would occur in July. A spreadsheet provided with ASHRAE's Load Calculation Applications Manual was used to obtain outdoor air temperatures, solar intensities, and sol-air temperatures for each hour of July 21st using the 0.4% design condition of Newport News, VA. These values show an outdoor air design temperature of 95.2 F. Sol-air temperatures calculated for vertical surfaces were used for the walls and a horizontal surface for the roof.

Solar gains from windows were also calculated using a spreadsheet provided by ASHRAE's Load Calculation Applications Manual. This spreadsheet calculated the direct and diffuse solar gain through a given window for each hour of the day based on the sun's movement throughout the day as well as specified window parameters.

Design drawings indicate a design wet bulb temperature of 78 F, corresponding to a water content of 0.0168 lb_w/lb_a. This water content was kept constant through the entire day.

6.4 Indoor Design Conditions

The indoor design conditions with a radiant floor system are governed by a number of factors that are not usually closely examined with traditional VAV systems.

Thermal Comfort

Thermal comfort conditions as defined by ASHRAE Standard 55 are based on the operative temperature and the relative humidity in the space. The operative temperature is approximated by taking the average of the indoor air dry bulb temperature and the mean radiant temperature. Generally, an operative temperature of 75 F and a RH of 50% is considered comfortable for summer conditions. The addition of a radiant cooling floor, however, lowers the mean radiant temperature. This allows for a rise in air dry bulb temperature to create the same operative temperature of 75 F. Olesen's paper showed that a difference in floor surface temperature and air temperature of 9 F has the equivalent thermal comfort cooling effect as lowering the air temperature by 3.6 F. Therefore, if the indoor air dry bulb temperature set point is increased to 78 F, a floor surface temperature of 68 F can be used to provide adequate thermal comfort.

Another thermal comfort parameter that needs to be taken into account with radiant floors is the vertical air temperature distribution. ASHRAE Standard 55 recommends that the vertical air temperature gradient between the ankles and the head be no more than 4 F. Olesen's paper also shows that a temperature difference between the floor surface and the room air of 10.8 F results in a vertical air temperature gradient of 3 F for sitting occupants and 3.42 F for standing occupants. Therefore, an air temperature of 78 F and a floor surface temperature of 68 F will provide adequate thermal comfort to occupants.

Humidity

With any radiant cooling system, humidity control is of great importance. If the radiant surface is cooled below the dew point temperature of the space, condensation will form on the cooled surface. Prolonged existence of condensation can lead to finish deterioration, mold growth, and eventual indoor air quality problems. Space conditions of 78 F and 50% RH correspond to a dew point temperature of 57 F. This temperature is well below the design floor slab surface temperature of 68 F. Additionally, infiltration of humid outdoor air is minimized by positively pressurizing the building. For the first floor, the design outdoor air flow is 7500 CFM even though the necessary outdoor air flow for ventilation is 6340 CFM. For the second floor, actual and necessary ventilation rates are 6800 CFM and 6000 CFM respectively. Meanwhile, exhaust air flows for both systems are 6000 CFM. The excess outdoor air flow to pressurize the building was determined by the designer and takes into consideration air leakage through doors and a first floor fume hood. Humidity sensors will also be used to help maintain a

50% relative humidity in the space. Though humidity sensors tend to be relatively inaccurate, the high radiant surface temperature helps mitigate this characteristic of the sensors.

6.5 Radiant Floor Slab System Design

The radiant slab is installed in the first floor and the second floor areas as shown in Figures 6-5-1 and 6-5-2 below. The high bay area is not modeled as having a radiant slab due to the greater chance of uncontrolled infiltration of humid air while loading doors are kept open. Additionally, the latent load in the health club is determined to be too high if maximum occupancy capacity occurs. Therefore, the slab under the health club will not be cooled to prevent condensation from sudden rises in the humidity level.

Figure 6-5-1: First Floor Radiant Slab (Blue)

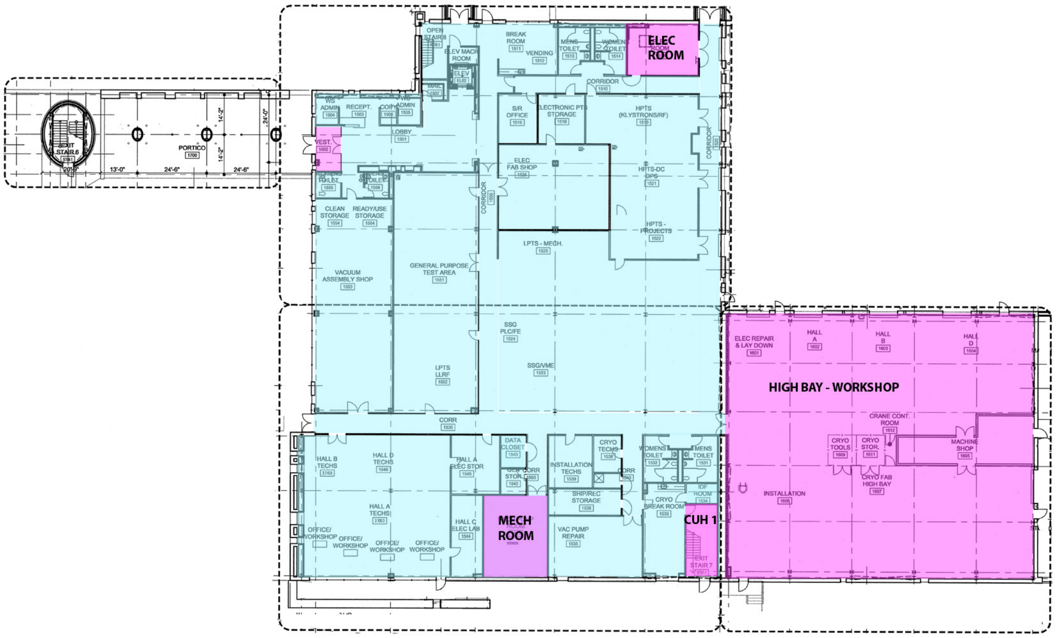
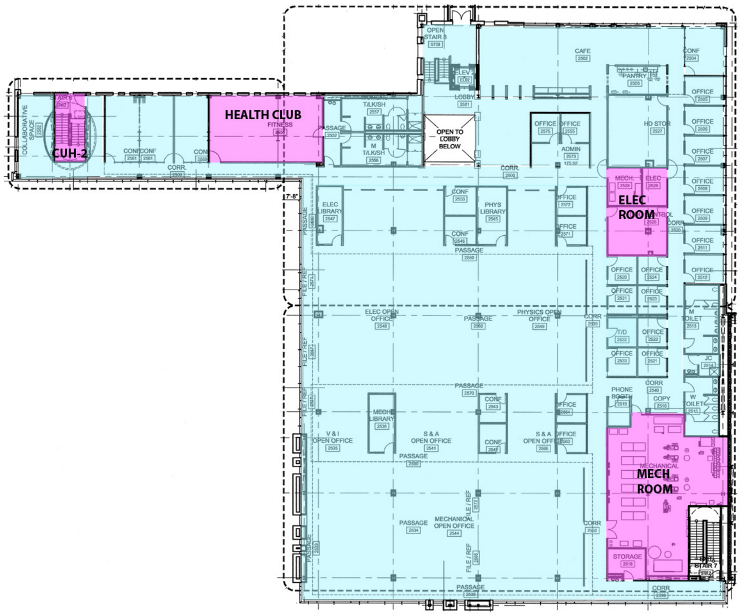


Figure 6-5-2: Second Floor Radiant Slab (Blue)



For each floor slab, 3/8” cross linked polyethylene tubing (PEX) will run through the concrete at a spacing of 6 inches. This is a recommended spacing that will create a relatively constant slab temperature at the tube level. The first floor slab on grade will be insulated on the bottom by 2” Rigid Extruded Polyurethane insulation and the second floor suspended slab will be insulated on the bottom of the metal decking by 3” spray foam insulation. Additionally, the tubing must sit at least 1 ½” from the slab surfaces. Figures 6-5-3 and 6-5-4 illustrate the construction of the radiant floor slabs.

Figure 6-5-3: First Floor Radiant Slab Construction

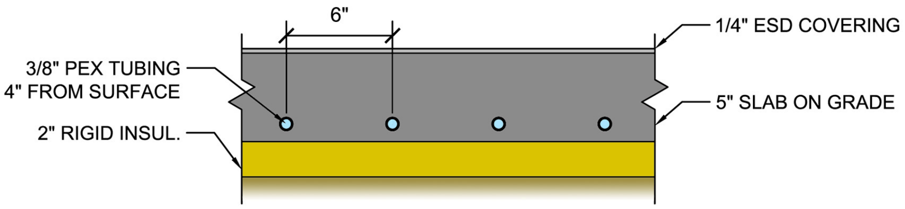
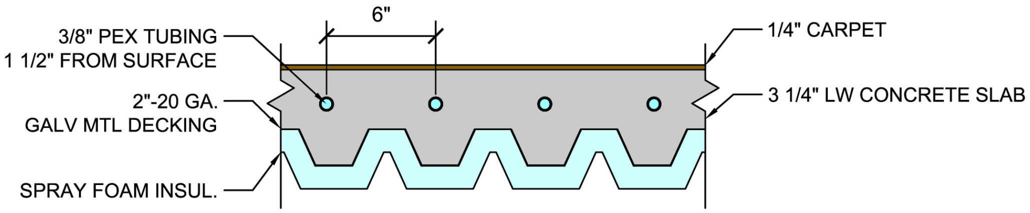


Figure 6-5-4: Second Floor Radiant Slab Construction



The floor slab construction greatly impacts the required chilled water temperature supplied to the slab to maintain its capacity. A steady-state, one dimensional conduction heat flow analysis through the cross section of the slab construction can determine the required chilled water temperature as described by Equation 6-5-1a and 6-5-1b.

$$\dot{q}'' = \frac{T_s - T_w}{\sum R_n} \tag{6-5-1a}$$

$$T_w = T_s - \dot{q}'' \sum R_n \tag{6-5-1b}$$

Where

$\dot{q}''$ = Heat Flow (Btu/hr-ft^2)

T_s = Slab Surface Temperature (F)

T_w = Chilled Water Temperature (F)

$R = \frac{L}{k}$ = Thermal Resistance of Layer (hr-ft^2-F/Btu)

Using Olesen's heat transfer coefficient for a cooled slab as 1.23 Btu/hr-ft^2-F, the indoor air temperature set point as 78 F, and the floor surface temperature as 68 F, the steady state heat transfer to the slab is 12.3 Btu/hr. Additionally, an ASHRAE Journal Article describing the design of a radiant floor slab implemented in a retail store states that a generally accepted temperature difference between the supply and return water is 5 F. To approximate the effect of this temperature gradient, the chilled water temperature included in Equation 6-5-1b is assumed to be the average of the supply and return temperatures. Table 6-5-3 and Table 6-5-4 below summarize the calculation for each floor slab that determines the required chilled water supply temperature.

Table 6-5-3: First Floor Slab Water Temperature

Material	L (in)	k (Btu-in/hr-ft2-F)	R (hr-ft^2-F/Btu)	q (Btu/hr-ft^2-F)	T (F)	T_{chws} (F)	T_{chwr} (F)
Paint-Epoxy (Gray)	NA	-	-	12.30	68.00	-	-
ESD Concrete	0.25	Very Conductive	-	12.30	68.00	-	-
5" Slab NW Concrete (150)	4.00	15.00	0.27	12.30	68.00	-	-
PEX Tubing (3/8" Diam)	0.07	2.63	0.03	12.30	64.39	61.89	66.89

Table 6-5-4: Second Floor Slab Water Temperature

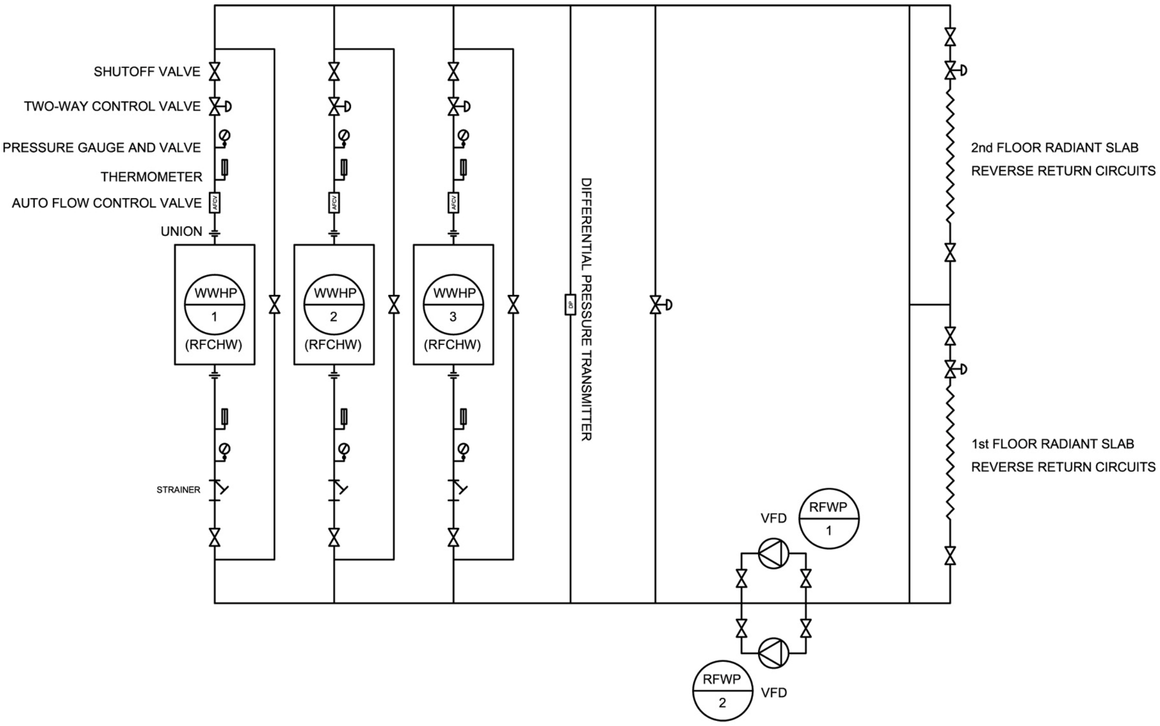
Material	L (in)	k (Btu-in/hr-ft^2-F)	R (hr-ft^2-F/Btu)	q (Btu/hr-ft^2-F)	T (F)	T_{chws} (F)	T_{chwr} (F)
Carpet Tile (Gray)	0.25	0.48	0.52	12.30	68.00	-	-
3.25" Slab LW Concrete (100)	1.50	5.45	0.28	12.30	61.59	-	-
PEX Tubing (3/8" Diam)	0.07	2.63	0.03	12.30	57.88	55.38	60.38

It is recommended that the PEX tubing sit at least 1 ½” to 2” below that slab surface level. The second floor slab requires a lower water temperature because of the presence of the carpet floor covering. Usually, this case is undesirable for radiant floor slabs due to its requirement of colder chilled water. However, in the case of two slabs, this point may be beneficial. Notice that if the first floor tubing sits 4” below the slab surface and if the second floor tubing sits 1 ½” from the slab surface, that the water supply and return temperatures of each slab are approximately 5 F apart. Water leaving the second floor slab can be supplied to the first floor slab for cooling. With the ability to pipe the radiant slabs in series, the water flow rate can be decreased to the maximum requirement of the two slabs instead of equaling the sum requirement of both slabs. Modulating bypasses valves parallel to each slab can be used to control the required flow rate through each slab.

Because of the presence of a geothermal loop and the high energy efficiency ratings (EER) of central heat pumps, the floor slabs are served by similar central heat pumps as currently designed. The heat pumps are staged on as the required flow rate increases above the available capacity. The efficiency of the heat pump is increased, however, due to the raising of the evaporating temperature. Instead of chilled water being cooled from 50 F to 42.2 F, as for an AHU cooling coil, the chilled water for the radiant slab system must be cooled from 66 F to 55 F. Data provided by the manufacturer of the heat pumps suggests an approximate resulting EER of 16 Btu/hr/W. An increase of 2 Btu/hr/W from the heat pumps serving the AHU cooling coil. A central distribution pump with n+1 redundancy as well as a variable frequency drive pumps the required amount of water through the slab system.

Figure 6-5-5 below illustrates a schematic of the proposed radiant floor slab system.

Figure 6-5-5: Radiant Floor Slab System Operation Schematic



The head loss through the slab was calculated using an estimation of the amount of pipe required. This amount was divided by 300 ft, the recommended length of one PEX tubing circuit in a slab by the ASHRAE Journal Article mentioned before. The total required maximum flow through the slabs was then divided by this amount to give the flow through each 300 ft circuit. The derivation of the maximum flow required is determined in Section 6.7 to come. This flow was applied to a pressure loss chart for PEX Tubing at 60 F and the head loss per 100 ft of tubing was calculated. This value was multiplied by 3 to give the head loss for one circuit. Since the slabs are designed to be in series, this head was multiplied by two. The resulting head was comparable to the head calculated for a hot water coil in the VAV terminal boxes. Therefore, an approximation was made for the distribution tubing that the head loss was comparable to the distribution of hot or cold water, yet higher due to the need to be transported from one slab to the other. Table 6-5-5 below summarizes this calculation. The PEX head loss chart can be found in Appendix A.

Table 6-5-5: Head Loss Through Radiant Floor Slab Circuit

Pipe Type	Pipe Size (in)	Pipe Length (ft)	Max Flow (GPM)	Flow (GPM)	Length (ft)	ftH20 / 100 ft	ftH20
PEX	3/8"	106015	170	0.481064	300	2.25	6.75

Determining the water flow through each circuit also allowed for the calculation of the water velocity through the PEX tubing. Using the velocity, 1.6 ft/s, and the PEX inside wall diameter, 0.235”, the Reynolds number was calculated to be approximately 10427. The typically accepted Reynolds number for turbulent flow in a round pipe is 4000. Therefore, turbulent flow is present in the pipe to enhance heat transfer.

6.6 Air System Design

A more detailed description of the results of the load simulation will be discussed in the following sections; however, they reveal that the radiant slabs as designed do not have the capacity to meet enough of the sensible load to require only the ventilation amount of supply air. Because a sizeable portion of the sensible load is not met by the radiant slab, using a DOAS system that delivers less humid and warmer air (due to desiccant dehumidification) requires more air to keep the dry bulb temperature in the space from rising above the set point of 78 F than a VAV system with 55 F supply air. Even with the radiant slab, each space, with the exception of the first floor corridor space, requires more air than is required for ventilation purposes only to meet the design sensible cooling load. Therefore, the radiant slab systems on each floor will work in parallel with downsized VAV systems to meet the cooling load. The outdoor and exhaust air requirements for each floor remain the same; therefore, the outdoor air total energy preconditioning units supplying outdoor air to each air handling unit are unchanged from the current design.

Equation 6-6-1 below was used to determine the required CFM to the space to meet the cooling load.

$$q_s = 1.08 CFM_s (T_{ia} - T_{sa}) \tag{6-6-1}$$

Where

q_s = sensible cooling load (Btu/hr)

T_{ia} = Indoor Air Dry Bulb Temperature Set point (F)

T_{sa} = Supply Air Dry Bulb Temperature Set point (F)

CFM_s = Required Airflow for Sensible Load (CFM)

Generally the sensible load (temperature set point) is used to determine the airflow for the space. The low limit of supply air is equal to the required amount of outdoor air which is driven by the ventilation or pressurization rate. Additionally, humidity sensors will be used to be sure that space humidity on the first floor does not rise above a dew point of 68 F (78 F, 71% RH) and on the second floor does not rise above an allowable dew point of 60 F (78 F DB, 55% RH). This dew point temperature will keep air that may get under the carpet on the second floor from condensing due to the cooled concrete. However, with the space dew point design temperature of 57 F (75 F, 50% RH), the cooling coil in the air handling units is sized accordingly to meet latent loads on the system and prevent a buildup of space humidity.

After the total required air flow was calculated for each space, they were summed by floor to determine the total required supply air for each system.

The coil loads for each air handler was determined by an analysis of the mixing of the return and outdoor air to produce the required supply air. The required outdoor air for each space, determined by a combination of ASHRAE Standard 62.1 and building pressurization requirements, was subtracted from the required total supply air flow to give the return air flow for each system. Outdoor air is brought in through total energy precondition units that exchange sensible and latent energy between the building exhaust and the incoming outdoor air. The effects of the outdoor air units' pre-conditioning was approximated by the procedure outlined by Berner Energy Recovery using a base efficiency of 0.78 as specified by the manufacturer of the unit. As described by Equations 6-6-3 and 6-6-3a below, the dry bulb temperature and humidity ratio of the air entering the cooling coil were determined from an energy and mass balance performed on the adiabatic mixing of the pre-conditioned outdoor air and the return air (assumes constant density). A detailed model of the air stratification that occurs within each space with the presence of a radiant cooling floor was not constructed. Therefore, perfect mixing was assumed within the space such that return air conditions are equivalent to space air conditions.

$$(\dot{m}T)_{oa} + (\dot{m}T)_{ra} = (\dot{m}T)_{ea} \tag{6-6-3}$$

$$(\dot{m}w)_{oa} + (\dot{m}w)_{ra} = (\dot{m}w)_{ea} \tag{6-6-3a}$$

Where

$\dot{m}$ = Airflow (CFM)

T = Dry Bulb Temperature (F)

w = Humidity Ratio (lb_w/lb_a)

The sensible and latent loads on the coil are determined by Equations 6-6-4 and 6-6-4a shown on the following page. The total cooling load on the coil is equal to the sum of the sensible and latent loads.

$$q_s = 1.08CFM_r(T_{ea} - T_{sa}) \qquad (6\text{-}6\text{-}1)$$

$$q_l = 4840CFM_r(w_{ea} - w_{sa}) \qquad (6\text{-}6\text{-}1a)$$

Where

q_s = sensible cooling load (Btu/hr)

q_l = latent cooling load (Btu/hr)

T_{ea} = Coil Entering Air Dry Bulb Temperature (F)

T_{sa} = Supply Air Dry Bulb Temperature Set point (F)

w_{ea} = Coil Entering Air Humidity Ratio (lb_w/lb_a)

w_{sa} = Supply Air Humidity Ratio Set point (lb_w/lb_a)

CFM_r = Required Supply Airflow for Sensible Load (CFM)

6.7 Loads

Current Design Loads and Model Accuracy

The load modeling of the current design as described in Section 1 and Section 2 were performed using Trane TRACE 700 building modeling software. In order to more accurately compare the relative value of implementing the radiant floor system instead of the current all VAV system, the current design was modeled using the Excel model as described at the beginning of this section. In this way, the differences or irregularities between the excel model and TRACE are normalized. Modeling the current system also allowed for a check of the relative validity of the excel model on predicting building loads in general.

The current system was modeled in Excel by setting all water flow through the radiant floor slabs to 0 gpm and setting the indoor design temperatures to those described in Section 1 of this thesis (75 F, 50% RH). Without being cooled, the floors heat up over time and contribute convective loads to the space. Zone areas, construction, glazing, occupancy, lighting, infiltration, and miscellaneous loads were entered into the Excel model just as they had been entered into the TRACE block model. However, neither plenum heat gain to the return air nor heat gain from fans was included in the Excel model. The TRACE block model was altered slightly to correct issues found in the model since Tech Report 2 was developed. These revisions include corrections made for over estimating the miscellaneous load and required ventilation air quantities. Table 6-7-1 below shows a summary and comparison of loads and airflows calculated by each model.

Table 6-7-1: Current Design Loads and Airflows

		Peak Sensible (Btu/hr)			Peak Latent (Btu/hr)			Air Flow Required (CFM)		
Zone	**Area (ft^2)**	**Excel Model**	**TRACE Model**	**% Diff**	**Excel Model**	**TRACE Model**	**% Diff**	**Excel Model**	**TRACE Model**	**% Diff**
1_Workshop	6081.0	105374	115740	91.04%	14250	13769	103.49%	4879	5172	94.33%
1_Office	7233.0	134125	156078	85.93%	15000	15000	100.00%	6209	7003	88.66%
1_Computer Lab	6485.0	135921	148933	91.26%	11400	11400	100.00%	6292	6682	94.16%
1_Mech/Elec	1101.0	7321	7264	100.78%	0	0	-	271	261	103.83%
1_Corridor	5488.0	45718	47409	96.43%	2400	1920	125.00%	2117	2127	99.53%
1_High Bay	10225.0	148605	156331	95.06%	9625	12767	75.39%	6880	6956	98.91%
CUH-1	280.0	2437	2517	96.82%	0	0	-	113	113	100.00%
CRU 1-1	101.0	16456	17770	92.61%	0	0	-	762	797	95.61%
CRU 1-2	73.0	16598	17921	92.62%	0	0	-	768	804	95.52%
2_Office	18507.0	403890	384354	105.08%	36800	36800	100.00%	18698	17246	108.42%
2_Conference	1103.0	45045	44338	101.59%	11780	11756	100.20%	2085	1988	104.88%
2_Health Club	955.0	26196	26358	99.39%	21800	21800	100.00%	1213	1183	102.54%
2_Mech/Elec	2627.0	23494	15517	151.41%	0	0	-	870	557	156.19%
2_Corridor	7941.0	156939	169007	92.86%	0	0	-	7266	7583	95.82%
CUH-2	265.0	3880	3505	110.70%	0	0	-	179	157	114.01%
CRU 2-1	103.0	16840	17784	94.69%	0	0	-	780	798	97.74%

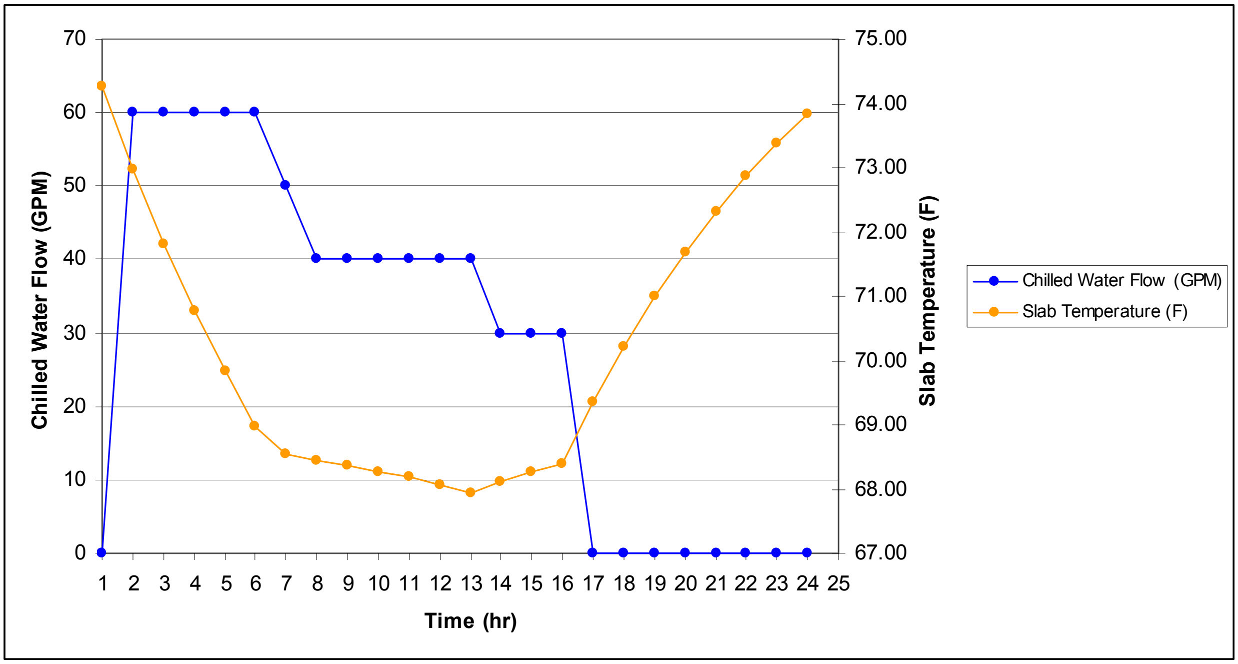
	Excel Model	**TRACE Model**	**% Diff**
AHU 1 Air Flow (CFM)	26648	28201	94.49%
AHU 2 Air Flow (CFM)	30132	28557	105.52%
Coil Load 1 (Tons)	80.6	84.4	95.50%
Coil Load 2 (Tons)	82.0	82.7	99.15%

The Excel model demonstrated to be relatively accurate compared to the TRACE model in calculating design cooling loads for each space, required air flows for each system, and the total coil cooling load.

Radiant Slab Load and Comparison

Excel was then used to model the performance of the radiant slab system and its effects on the loads for three design days in a row (72 hours). This was done to allow for the incorporation of heat gained or lost by building elements as a result of the previous day. Chilled water flow through the slabs of each zone was set manually for each hour for each space. An iterative process was used to find the optimum flow values that cool the slabs in the morning and maintain the slab temperature at approximately 68 F throughout the day. Figure 6-7-1 below shows the schedule for the first floor office space as an example.

Figure 6-7-1: Example Slab Water Flow and Temperature for Design Day of First Floor Office Space



The exception to this general was in the workshop and corridor spaces. During the morning, when sensible loads are relatively low, the required air fell below the minimum outdoor ventilation air. To prevent a large amount of air reheat during these times, the capacity of the slab was lowered by delaying cooling of the slab temperature. Examples of the spreadsheets used to model the radiant floor can be found in Appendix B. Table 6-7-2 shows the resulting effect of the radiant slab on the air system.

Table 6-7-2: Radiant Slab Loads and Airflows

		Air Flow Required (CFM)			
Zone	**Area (ft^2)**	**With Slab**	**No slab**	**% Diff**	**Req OA**
1_Workshop	6081.0	1704	4879	34.93%	1215
1_Office	7233.0	1961	6209	31.58%	809
1_Computer Lab	6485.0	2533	6292	40.26%	1737
1_Mech/Elec	1101.0	271	271	100.00%	0
1_Corridor	5488.0	742	2117	35.05%	389
1_High Bay	10225.0	6880	6880	100.00%	2190
CUH-1	280.0	113	113	100.00%	0
CRU 1-1	101.0	615	762	80.71%	0
CRU 1-2	73.0	637	768	82.94%	0
2_Office	18507.0	7343	18698	39.27%	2030
2_Conference	1103.0	1229	2085	58.94%	446
2_Health Club	955.0	1213	1213	100.00%	457
2_Mech/Elec	2627.0	870	870	100.00%	0
2_Corridor	7941.0	2925	7266	40.26%	476
CUH-2	265.0	179	179	100.00%	0
CRU 2-1	103.0	629	780	80.64%	0

	With Slab	**No Slab**	**% Diff**
AHU 1 Air Flow (CFM)	16825	26648	63.14%
AHU 2 Air Flow (CFM)	15446	30132	51.26%
Coil Load 1 (Tons)	62.0	84.1	73.72%
Coil Load 2 (Tons)	52.0	83.9	61.98%

From the table above, it can be seen that there is still significant peak sensible load to be met by the air system and that the required amount of air to cool the space exceeds the required outdoor air significantly. Thus, the limiting factor in supply air is not the ventilation air, as in DOAS systems, but in the required air to meet the rest of the sensible load. For this reason, a downsized VAV system working in parallel with the radiant slab was modeled.

Because the slabs are designed in series, the total flow required through the slabs is the maximum of either the first or second floor slab. Figure 6-7-1 on the following page shows the flow through each slab and the maximum of the two.

In summary, the radiant slab had a significant effect on the required air flow for each space. Thus, the air handling units, supply fans, and chilled water pumps supplying the cooling coils could be downsized. Additionally, the maximum heat pumps required to be staged on for the air system was lessened. Table 6-7-3 summarizes a comparison of the new radiant floor and air systems to the currently designed systems for the TED. When sizing the fans, the same static pressure was assumed through the unit as the current design. Additionally, the new AHU cooling coil chilled water pumps were sized using the same head as the current design.

Figure 6-7-2: Total Radiant Slab Required Chilled Water Flow

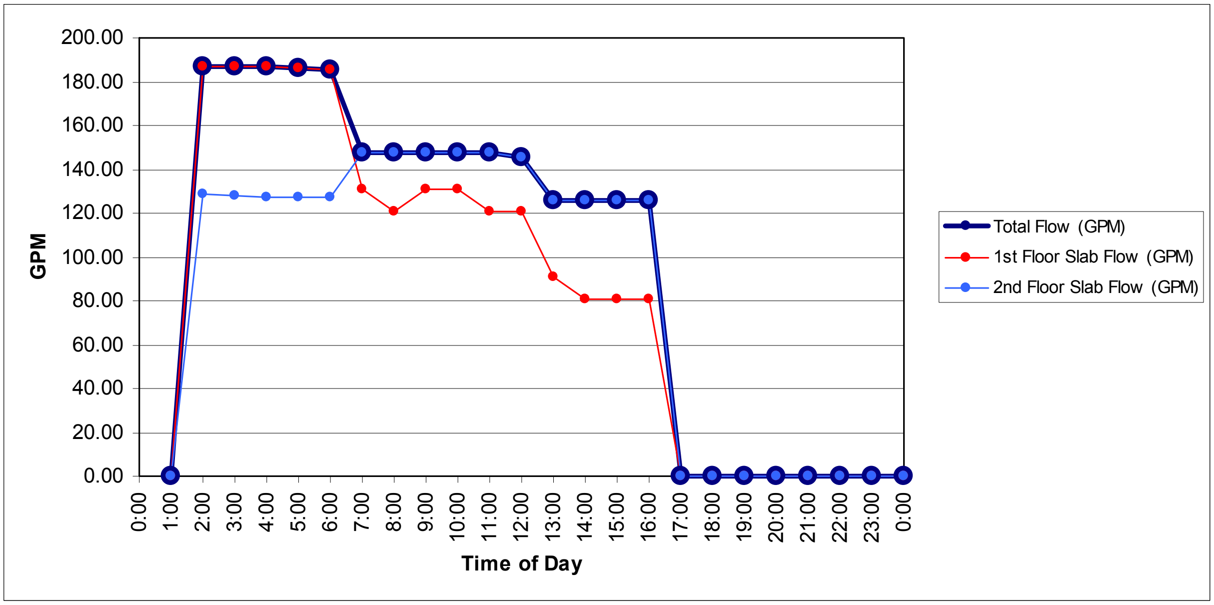


Table 6-7-3: Radiant Slab System Compared to Currently Designed System

Fans	**Power (HP)**		**Capacity (CFM)**	
	With Slab	**No slab**	**With Slab**	**No slab**
AHU 1 Supply Fan	20	50	17528	32000
AHU 1 Return Fan	10	30	17528	32000
AHU 2 Supply Fan	20	50	17528	32000
AHU 2 Return Fan	10	30	17528	32000
Pumps	**Power (HP)**		**Capacity (GPM)**	
	With Slab	**No slab**	**With Slab**	**No slab**
CHWP-1	15	20	350	625
CHWP-2	15	20	350	625
RFWP-1	7.5	-	187	-
RFWP-2	7.5	-	187	-
Air Side Heatpumps	**# Req**		**EER**	
	With Slab	**No slab**	**With Slab**	**No slab**
	6	9	14	14
Floor Side Heatpumps	**# Req**		**EER**	
	With Slab	**No slab**	**With Slab**	**No slab**
	3	-	16	-

6.8 Energy

The main goal of this report was to analyze how a radiant cooling slab can shift and shave the peak cooling power load. Once loads and airflows were found, an energy model used actual equipment selections to model the required energy for each hour during the design day. The energy of fans and pumps were found using the fan affinity laws since each fan and pump contains a VFD. Equations 6-8-1a and 6-8-1b below describes how power can be obtained from the maximum capacity and power of the fan or pump.

$$\frac{Q_1}{Q_2} = \left(\frac{RPM_1}{RPM_2}\right) \tag{6-8-1a}$$

$$\frac{P_1}{P_2} = \left(\frac{RPM_1}{RPM_2}\right)^3 \tag{6-8-1b}$$

Heat pumps were staged on based on the required chilled water flow from them. Using manufacturer data, the heat pump flow capacity was used such that if the required flow exceeded the peak capacity of a heat pump, the next heat pump was staged on. Even if working at part load, the maximum energy produced by any heat pump in operation was assumed. Figure 6-8-1 on the following page shows the power required for a cooling design day for the TED using the currently designed system and the radiant floor system developed in this report.

Notice that the slab had a significant effect on decreasing the peak load for the day from 283 kW to 205 kW, a savings of 27.5%. It successfully shifted load to the morning, where it was used to pre-cool the slabs. Additionally, the radiant floor slab placed more load on the water pumps and heat pumps while reducing the demand of fans. Figure 6-8-2 on the following page compares the relative daily heat pump, fan, and pump power for each design.

Figure 6-8-1: Hourly Cooling Demand for Radiant Slab System Compared to Currently Designed System

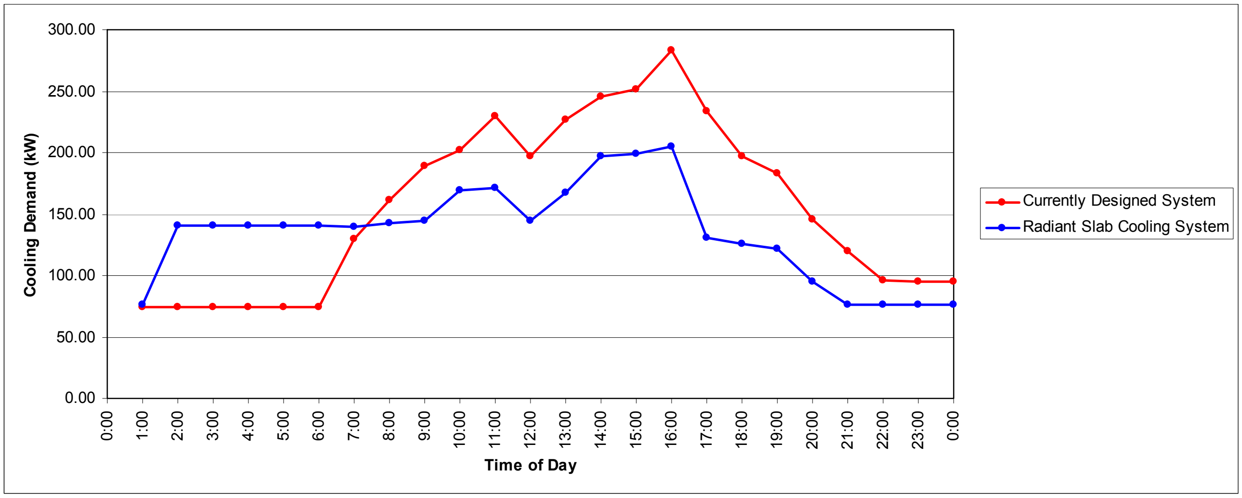
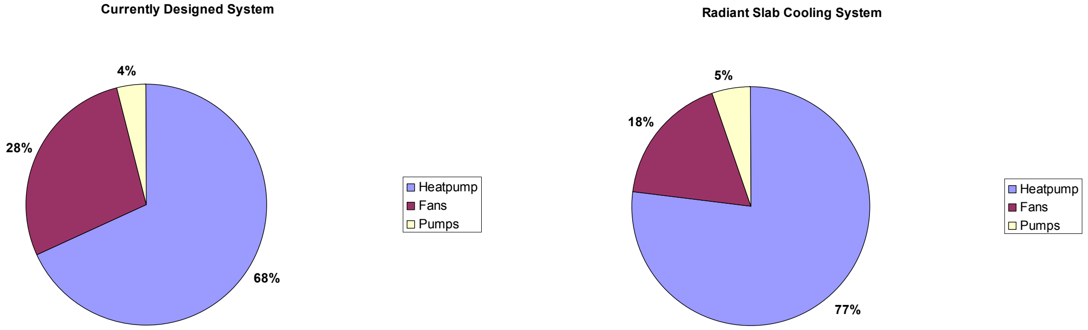


Figure 6-8-2: System Cooling Daily kWh Percentage by Equipment



Additionally, the radiant slab system saves on total cooling energy required during a design day by 13%. Though the electricity rate for the TED does not change from morning to afternoon, the savings in total energy equates to a savings of $32.65. Table 6-8-1 below summarizes these savings.

Table 6-8-1: Daily Energy and Cost Savings

	Peak Demand (kW)	Daily Usage (kWh)	Cost
Currently Designed System	283.18	3725.71	$249.21
Radiant Slab Cooling System	205.33	3237.55	$216.56
Savings	27.49%	13.10%	13.10%

The analysis performed did not have the capability of performing a year long energy study, and so, a total pay back period can not be determined. However, a comparison of estimated cost between the radiant floor system and current system can be found in the construction breadth portion of this report.

6.10 Conclusion

The main goal of this analysis was to determine the effectiveness of a radiant concrete floor slab. This included both the load capacity and thermal storage ability. Because the TED has a significantly higher cooling load than heating load, due to its location and internal loads, the design cooling case was analyzed. As modeled, the radiant slab was not found to have the capacity to implement a DOAS system, in which only the minimum amount of air required for ventilation would need to be provided. However, because the radiant slab can be used to store cooling capacity by pre-cooling it during the morning, it was still capable of reducing peak cooling electricity demand by 27.5%. Additionally, the arrangement of the slabs in series, allowing for the re-use of chilled water flow, and the higher than normal required chilled water temperature, which increased the efficiency of the heat pumps, showed a total cooling energy usage savings of 13% during a design day. This showed that a radiant floor slab can be effective in reducing the required cooling energy. However, there are challenges to the use of a radiant slab which offer opportunities of further research and improvement.

Capacity

There are several limiting factors on a radiant floor cooling capacity. For thermal comfort reasons described in Section 6.4 of this report, the radiant floor temperature should not be below about 66 F for sedentary activity. Additionally, the radiant floor does not induce significant convective cooling because of cooled air staying close to the floor. These factors are not present for chilled beams, which induce high convective cooling, or chilled ceiling panels, which can be maintained at a lower surface temperature and induces a convective mixing current due to buoyancy forces. If these factors limit the radiant floor to the extent of not meeting the sensible load, as in the case of the TED, an additional cooling method must be implemented, either in the form of an air system or other radiant systems. In either case, with the presence of an additional cooling system, an issue of controllability becomes more evident.

Controllability

The radiant slab does not respond as quickly to a demand for cooling as other radiant systems or air systems do. To effectively control the slab, particularly in coordination with other HVAC systems, it would be most beneficial to be able to anticipate the cooling loads for the day, and prime the slab accordingly. For instance, if morning cooling loads are low, and the minimum amount of ventilation air must be supplied to the space, the slab should be only cooled to a point that meets the portion of the sensible load not met by the ventilation air. If the slab is overcooled during this time, either the space will be overcooled or the ventilation air would need to be reheated. These two alternatives sacrifice thermal comfort and/or energy usage.

The required anticipation of cooling loads makes a good case for the development and use of predictive control schemes. These schemes would include predictions of the thermal loads on the space as well as predictions of how effective the slab, in coordination with other HVAC systems, will be on meeting those loads. This effectiveness is dependent on the dynamic response of the slab to space loads as well as chilled water flow and/or temperature. The research being performed at MIT on the optimization of radiant slab pre-cooling control as well as the research underway at Penn State regarding the accuracy of whole building thermal simulations each contributes to the realization of this type of control scheme.

The analysis performed in this report served as an attempt to model these dynamic responses and optimize the control of the slab accordingly. However, the model used did not account for temperature distributions in the slab; both vertically and horizontally, and only performed an energy balance on the slab. This most likely over predicted the responsiveness of the slab to changes in space loads or chilled water flow. Additionally, the model performed the analysis on a zone by zone basis. It may prove difficult to control the temperature of a slab in such a way, considering the diffusion of heat throughout the floor slab as well as different zones contributing different loads to the slab at different times.

Section 7 Construction Breadth

7.1 Full Load Geothermal Design

Despite their proven ability to save energy, owners dismiss geothermal fields because they require too much initial investment or not enough land is available. For the TED, the owner was committed to installing a geothermal field to save energy consumption, however, did not allow the engineers to implement a full load field due to insufficient land area. The alternative studied in Section 5 not only analyzed the energy savings that were missed out on as a consequence of partial field sizing, but introduced a new way of geothermal installation that is not commonly used or considered; Horizontal Directional Drilling. Because this type of field installation is relatively new, a breadth analysis was completed to describe how HDD fields are installed, the associated installation costs, and the impact on the building construction schedule.

HDD Field Installation

The process of horizontal directional drilling involves the drilling of a pilot hole into the ground to the required depth, drilling horizontally for the required length underground, and then surfacing the drill bit. At this point, a reamer is attached to the drill line that was passed through with the pilot drill hole. This reamer is pulled back through the pilot hole with the process pipe attached. The reamer is also used to enlarge the hole to the desired diameter as it is pulled back through. Because of this process, there must be space at the far end of the bore for the drill to come up through the ground surface for the process pipe and reamer to be attached and pulled back through. The location of the drill bit can be monitored via a GPS tracker or hard wired through the drill line. Either of these methods allows the drill operator to steer the drill bit in the desired direction and at the desired angle. Figure 7-1-1 below illustrates the planned entrance and exit locations of the directional drill for the TED.

Figure 7-1-1: HDD Geothermal Field Construction Layout

HDD Field Installation Cost

Large first costs are one of the reasons geothermal fields are not as widely used. Vertical bore and horizontal trench geothermal systems are widely enough used such that there exits general cost per ton, cost per bore, or cost per square foot of land required. Because HDD is not used often in for geothermal applications, RS Means 2011 Mechanical Cost Data and Site Work and Landscape Cost Data were used to estimate the cost of the HDD field for the TED. Additionally, city cost index multipliers obtained for Newport News, VA from RS Means were applied. For mechanical equipment, these include 100.3 for material, 64.2 for installation (labor and equipment), 85.3 for the total including overhead and profit. For site work (bore drilling), these include 114 for material, 87.2 for installation (labor and equipment), 95.5 for the total including overhead and profit. Table 7-1-1 summarizes the breakdown of costs estimated for the HDD field.

Table 7-1-1: HDD Geothermal Field Installation Costs

Source	Horizontal (HDD) Field First Cost	Qty	Material	Labor	Equipment	Total Incl O&P	Total Cost
33.05.23.0202	Mobilization of Equipment (ea)	1	-	$392.40	$531.92	$1,289.25	$1,289.25
33.05.23.0210	Bores (ft)	21441	$0.07	$2.24	$3.03	$7.45	$159,717.01
22.11.13.0054	Piping HDPE 1" (ft)	42883	$0.72	-	-	$0.66	$28,257.63
22.11.13.0062	Piping HDPE 2" (ft)	247	$1.50	-	-	$1.38	$342.03
22.11.13.0082	Piping HDPE 6" (ft)	422	$7.52	-	-	$6.97	$2,941.97
07.17.13.0300	Grouting (cuft)	1053	$17.88	-	-	$16.50	$17,368.82
31.43.13.0200	Grouting (crew, days)	4	-	$1,286.20	$279.04	$2,459.13	$10,352.94
22.11.13.4030	Pipe Joint Welds 1" (1 every 40 ft)	1072	-	$4.53	-	$7.64	$8,190.62
22.11.13.4050	Pipe Joint Welds 2" (1 every 40 ft)	6	-	$9.68	-	$16.28	$100.55
22.11.13.4080	Pipe Joint Welds 6" (1 every 40 ft)	11	-	$24.42	-	$41.07	$433.24
22.11.13.4350	Welding Equipment 1" and 2" (ea)	1	-	-	$35.32	$48.23	$48.23
22.11.13.4370	Welding Equipment 6" (ea)	1	-	-	$89.82	$107.92	$107.92
	HDD Total						$229,150.19
Estimate	Condenser Water Pump (2)						$17,084.00
Estimate	Current Vertical Bore Field						$687,936.00
	Total						**$934,170.19**

The estimate received from the geothermal contractor on the project for the currently designed vertical bore field is approximately $687,936. Per foot of bore length this equates to $11.94/ft. Converting the HDD field into a similar metric, the cost is $10.69/ft. This shows that the HDD field is of similar cost per foot of bore length to a vertical bore.

The cost estimate consultant on the project estimated the cost of the closed circuit cooler system (tower, pumps, and piping) to be $51,053 and the condenser water distribution pumps to be $17,084. Adding these components to the vertical bore field estimate yields a total current geothermal system design estimate of $756,073.90. Adding the cost of the pumps as determined by the cost consultant on the project to the estimated HDD field costs and the current vertical bore field costs yields a total proposed geothermal cost of $934,170.19, as was seen in Section 5.

HDD Field Schedule

RS Means 2011 Cost data was also used to estimate the amount of time it will take to install the field. Figure 7-1-2 on the following page summarizes time necessary to install the field. It is assumed that after the mobilization of equipment and the beginning of boring takes place, all other materials and trades can go on behind the drilling.

Table 7-1-2: HDD Geothermal Field Installation Time

Source	Horizontal (HDD) Field Schedule	Daily Output	Days
33.05.23.0202	Mobilization of Equipment (ea)	2.00	0.50
33.05.23.0210	Bores (ft)	350.00	61.26
22.11.13.0054	Piping HDPE 1" (ft)	-	-
22.11.13.0062	Piping HDPE 2" (ft)	-	-
22.11.13.0082	Piping HDPE 6" (ft)	-	-
07.17.13.0300	Grouting (cuft)	-	-
31.43.13.0200	Grouting (crew, days)	1.00	4
22.11.13.4030	Pipe Joint Welds 1" (1 every 40 ft)	273.00	3.93
22.11.13.4050	Pipe Joint Welds 2" (1 every 40 ft)	128.00	0.05
22.11.13.4080	Pipe Joint Welds 6" (1 every 40 ft)	63.00	0.17
22.11.13.4350	Welding Equipment 1" and 2" (ea)	-	-
22.11.13.4370	Welding Equipment 6" (ea)	-	-
	HDD Total		61.76

Unfortunately, a construction schedule could not be obtained from the designer or from the CMGC. However, because the geothermal field is installed outside of the building footprint, the extended schedule of approximately 13 weeks is not expected to impact the critical path of the construction timeline. Additionally, it is possible to drill the HDD field while the drilling of field C (north of the TED) is under way.

7.2 Radiant Slab

Due to the modeling technique used for the radiant slab, a payback period could not be calculated. However, because the air system was able to be downsized, it is important to analyze the affects on first cost. Additionally, the floor slabs of the building can not be poured until the radiant tubing has been installed. Therefore, an analysis was done to estimate the schedule impact of the radiant floor. An estimate to determine the required length of 3/8” tubing was done by taking the square root of the radiant slab area to find an estimated total slab width, dividing this width by the spacing of the tubing, 6”, to determine how many lengths would be needed to fill up the width, and then multiplying again by the square root of the radiant slab area, which determines the length of each segment 6” apart. By this algorithm, the total length of tubing required was calculated to be 106,015 ft for 53115 ft^2 of radiant slab area.

Radiant Cooling Floor Slab Cost

An estimate was made for the first costs of both the currently designed system and newly designed radiant floor system so that a comparison can be made between the two. Information regarding the currently designed system was obtained from a cost estimate performed by the cost consultant on the project. Because the total number of heat pumps (3 for the radiant floor, 6 for the air system) and the outdoor air units did not change, they were left out of the estimate. The estimates include fans, pumps, radiant floor piping, VFDs for the pump and fan motors, spray foam insulation that would have to be installed on the underside of the second story steel deck, and rigid insulation that would be installed under the slab on grade. Duct sizes would certainly be changed due to a less quantity of air required. This change would cheapen the cost of ducting for a system with a radiant floor than without a radiant floor. However, a detailed duct layout redesign was not performed, and therefore, was left out of the calculation. In this cost estimate, the same city cost indexes were used as for the geothermal cost estimate with the addition of Light Commercial Cost Data multipliers of 100.0 for material, 67.6 for installation, and 85.5 for total costs. These multipliers were used for the insulation estimates. Figure 7-2-1 below summarizes and compares the cost estimate for both the current design and the radiant floor design. The radiant floor slab system will cost approximately $163,000 more to install.

Table 7-2-1: Cost of Radiant Floor Design Compared to Current Design

Source	Radiant Floor System	Qty	Material	Labor	Equipment	Total Incl O&P	Total Cost
23.83.16.0130	PEX w/ Oxygen Barrier 3/8"	106015	$1.02	$0.62	-	$2.17	$229,693.75
07.21.23.0330	Spray Foam Insulation (SF)	27654	$1.23	$0.20	$0.20	$1.90	$52,490.06
07.21.13.1940	2" Rigid Insulation (SF)	25461	$1.00	$0.25	-	$1.47	$37,442.95
23.21.23.4420	RFWP (187 GPM, 7.5 HP)	2	$3,862.50	$311.37	-	$4,137.05	$8,274.10
23.21.23.4530	CHWP (350 GPM, 15 HP)	2	$4,429.00	$452.61	-	$4,926.08	$9,852.15
Estimate / CFM	AHU 1 (17000 CFM)	1	$92,990.00	$5,780.00	-	$98,770.00	$98,770.00
Estimate / CFM	AHU 2 (15000 CFM)	1	$82,050.00	$5,100.00	-	$87,150.00	$87,150.00
Estimate	RFWP VFD	2	$9,900.82	$2,099.18	-	$12,000.00	$24,000.00
Estimate	CHWP VFD	2	$9,900.82	$2,099.18	-	$12,000.00	$24,000.00
Estimate	AHU 1 VFD	2	$9,900.82	$2,099.18	-	$12,000.00	$24,000.00
Estimate	AHU 2 VFD	2	$9,900.82	$2,099.18	-	$12,000.00	$24,000.00
	Total						$619,673.00

Source	Original VAV System	Qty	Material	Labor	Equipment	Total Incl O&P	Total Cost
Estimate	CHWP (625 GPM, 20 HP)	2	$5,483.28	$684.72	-	$6,168.00	$12,336.00
Estimate	AHU 1 (32000 CFM)	1	$175,040.00	$11,105.22	-	$186,145.22	$186,145.22
Estimate	AHU 2 (32000 CFM)	1	$175,040.00	$11,105.22	-	$186,145.22	$186,145.22
Estimate	CHWP VFD	2	$9,900.82	$2,099.18	-	$12,000.00	$24,000.00
Estimate	AHU 1 VFD	2	$9,900.82	$2,099.18	-	$12,000.00	$24,000.00
Estimate	AHU 2 VFD	2	$9,900.82	$2,099.18	-	$12,000.00	$24,000.00
	Total						$456,626.44

Radiant Cooling Floor Slab Schedule

The scheduling of the radiant slab is dominated by the time it takes to tie the tubing and lay it down to be poured over. Using RS Means 2011 data, it was determined that to lay down the estimated length of tubing would take 26 weeks at 800 ft per day if it was performed by one crew. This crew consists of only one steamfitter and a steamfitter apprentice. Because the laying of the radiant floor will impact the critical schedule of the TED, a half year is too long. Two options available to decrease this installment time is the use of more crews or the use of a modular system called the Climate Mat.

The Climate Mat is a product of Viega that makes the installment of radiant tubing modular. Viega manufactures the Climate Mat to specifications determined by the engineer and is made to hold the tubing at the desired spacing. The preassembled tubing mat is brought to the site ready to be rolled out in the floor, instead of individually tying and laying tubing at the site. Figure 7-2-2 and 7-2-3 on the following page displays an image of the Climate Mat.

Figure 7-2-2 and 7-2-3: Climate Mat by Viega

In a case study where a radiant cooling slab was installed in a Wal-Mart, the Climate Mat was estimated to save approximately 188 hours per 10,000 ft^2 of radiant floor area. For the TED, which has a radiant floor area of 51945 ft^2, this would equate to saving 976 installment hours, or 122 days. This brings the installment time of 26 weeks down to 2 weeks. This would be the equivalent of having approximately 13 crews work on laying the pipe for two weeks. Though the TED is not as perfectly square and large as a Wal-Mart super store, the installment time savings would still be significant.

Section 8 Electrical Breadth

The two mechanical alternatives analyzed in this report were able to either remove or significantly downsize cooling equipment. It is important to understand the effect this has on the electrical system associated with this equipment, including motor sizes, feeder sizes, circuit protection, and panel sizes. Additionally, if the changes are large enough, the sizes of larger equipment like switchgear and transformers could be affected as well.

The electrical system sizing begins with determining the motor sizes required to drive each piece of equipment. For fans, the required capacity and static pressure were used to determine the required fan break horse powers by performance tables provided by a manufacturer. The required break horse power was rounded up to attain the standard motor size found in Table 430.250 of the NEC 2008. Pump motors were sized using pump curves provided by the manufacturer. The fan performance tables and pump curves, along with the selections, can be found in Appendix D. Additionally, Table 430.250 of the NEC 2008 was used to determine the full load amps (FLA) associated with each motor.

Generally, motor circuits are made up of the motor, disconnect, motor circuit protector (breaker), and a feeder that connects the components into a circuit. This feeder is connected to a distribution panel, bus bar, or motor control center where it is combined with other loads and taken back to a higher point in the system; such as another distribution panel, switchgear, or switchboard. The disconnect is used for manual shutoff or startup and must be within plain view of the motor. Standard disconnect sizes range from 30 A, 60 A, and 100 A. The feeder line conductors are sized based on Table 310.16 in the NEC 2008 and are determined from a load capacity of 1.25 x FLA. The motors used for pumps and fans in the TED are 460V 3ϕ, therefore, three lines travel to the motor (one for each phase). Additionally, a fourth conductor is included in the conduit that serves as a grounding conductor for the motor encasement. Table 250.122 of the NEC 2008 is used to size the grounding conductor based on the capacity of the overcurrent device ahead of the equipment. This overcurrent device includes the motor circuit protector. This is sized based on the maximum ampere capacity of the line conductors. Standard sizes of overcurrent devices are found in Section 240.6 in the NEC 2008. Lastly, the conduit holding the line and grounding conductors is sized using Table C.1 in the NEC 2008, where the maximum allowable number of conductors is given for a range of conduit sizes.

Figure 8-1-1 below shows a diagram of the motor circuit used for fans and pumps. Because the air handling unit fans are located on the roof, water proof enclosed disconnects will be located in plain view of the motor on the roof. Additionally, the VFDs, along with the pumps they serve, are located in the same mechanical room. Since the VFDs can act as a disconnect, an additional disconnect in the circuit is not required. In summary, the AHU fans on the roof require a separate disconnect and the water distribution pumps do not. Table 8-1-1 on the following page summarizes the changes made to the electrical system as a result of the elimination of the closed circuit cooler and addition of the radiant slab. Refer to Figure 8-1-1 for circuit component locations.

Figure 8-1-1: Motor Circuit Diagram

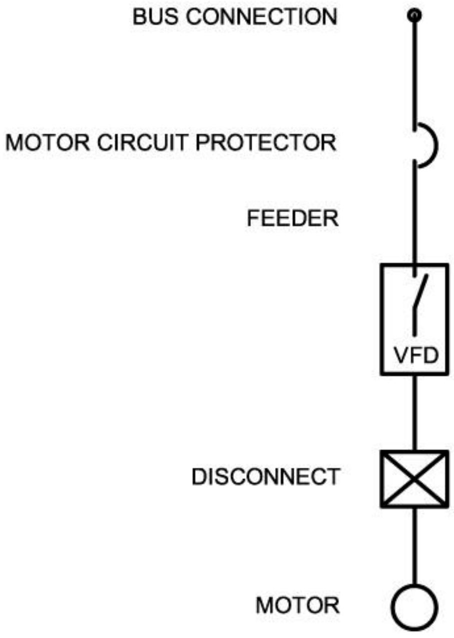


Table 8-1-1: Motor Circuit Modification Summary

Currently Designed System	**HP**	**Voltage**	**Phase**	**FLA**	**Conductor (Cu) and Conduit**	**Disconnect**	**MCP Trip**	**MCP Frame**	**Bus**
AHU 1 Supply Fan	50	460	3	65	3#2 & #8G, 1-1/2" C	100	100	250	DP_HVAC-2-1
AHU 1 Return Fan	30	460	3	40	3#6 & #10G, 1" C	100	60	100	DP_HVAC-2-1
AHU 2 Supply Fan	50	460	3	65	3#2 & #8G, 1-1/2" C	100	100	250	DP_HVAC-2-1
AHU 2 Return Fan	30	460	3	40	3#6 & #10G, 1" C	100	60	100	DP_HVAC-2-1
CHWP-1	20	460	3	27	3#10 & #10G, 3/4" C	-	30	100	DP_HVAC-2-1
CHWP-2	20	460	3	27	3#10 & #10G, 3/4" C	-	30	100	DP_HVAC-2-1
CCC-1 Fan 1	30	460	3	40	3#6 & #10G, 1" C	60	60	100	DP_HVAC-2-1
CCC-1 Fan 2	30	460	3	40	3#6 & #10G, 1" C	60	60	100	DP_HVAC-2-1
CWP-3	10	460	3	14	3#10 & #10G, 3/4" C	30	30	100	DP_HVAC-2-1
CCC-1 Circ Pump	2	460	3	3.4	3#12 & #12G, 3/4" C	30	15	100	DP_HVAC-2-1

Proposed System	**HP**	**Voltage**	**Phase**	**FLA**	**Conductor (Cu) and Conduit**	**Disconnect**	**MCP Trip**	**MCP Frame**	**Bus**
AHU 1 Supply Fan	20	460	3	27	3#10 & #10 G, 3/4" C	60	35	67.5	DP_HVAC-2-1
AHU 1 Return Fan	10	460	3	14	3#14 & #12 G, 1/2" C	30	20	35	DP_HVAC-2-1
AHU 2 Supply Fan	20	460	3	27	3#10 & #10 G, 3/4" C	60	35	67.5	DP_HVAC-2-1
AHU 2 Return Fan	10	460	3	14	3#14 & #12 G, 1/2" C	30	20	35	DP_HVAC-2-1
CHWP-1	15	460	3	21	3#10 & #10 G, 3/4" C	-	35	52.5	DP_HVAC-2-1
CHWP-2	15	460	3	21	3#10 & #10 G, 3/4" C	-	35	52.5	DP_HVAC-2-1
RFWP-1	7.5	460	3	11	3#14 & #12 G, 1/2" C	-	20	27.5	DP_HVAC-2-1
RFWP-2	7.5	460	3	11	3#14 & #12 G, 1/2" C	-	20	27.5	DP_HVAC-2-1
(CCC-1 Fan 1)	-	-	-	-	-	-	-	-	-
(CCC-1 Fan 2)	-	-	-	-	-	-	-	-	-
(CWP-3)	-	-	-	-	-	-	-	-	-
(CCC-1 Circ Pump)	-	-	-	-	-	-	-	-	-

With the changes in place, the associated distribution bus DP_HVAC-2-1, which distributes power to other HVAC loads as well, sees 215 FLA less. This allows the bus size to reduce from an 800 A bus to a 600 A bus. Table 8-1-2 below summarizes the changes to the distribution bus. Bus DP_HVAC-2-1 is brought back to a 4000 A switchgear. The 215 FLA less on this piece of equipment does not affect the size. Therefore, the switchgear, nor the transformer the switchgear comes from, can be changed.

Table 8-1-2: Distribution Bus Modification Summary

Currently Designed System - Associated Bus	**Voltage**	**FL Amps**	**Breaker**	**Conductor (Cu) and Conduit**
DP_HVAC-2-1 800A Bus	480/277	800	800	2-[(4)500kCMIL & #1/0 G, 4" C]
Currently Designed System - Associated Switchboard	**Voltage**	**FL Amps**	**Breaker**	**Conductor (Cu) and Conduit**
SWBD TED-1 4000A	480/277	4000	4000	10-[(4)600kCMIL & 500kCMIL G, 4" C]
Currently Designed System - Associated Transformer	**Pr. Voltage**	**Sec. Voltage**	**kVA**	
T-SUB TED, 3Φ, 60 Hz	12.47 kV	480/278	2500	

Proposed System - Associated Bus	**Voltage**	**FL Amps**	**Breaker**	**Conductor (Cu) and Conduit**
DP_HVAC-2-1 600A Bus	480/277	600	600	2-[(4)350kCMIL & #1 G, 3" C]
Proposed System - Associated Switchboard	**Voltage**	**FL Amps**	**Breaker**	**Conductor (Cu) and Conduit**
SWBD TED-1 4000A	480/277	4000	4000	10-[(4)600kCMIL & 500kCMIL G, 4" C]
Proposed System - Associated Transformer	**Pr. Voltage**	**Sec. Voltage**	**kVA**	
T-SUB TED, 3Φ, 60 Hz	12.47 kV	480/278	2500	

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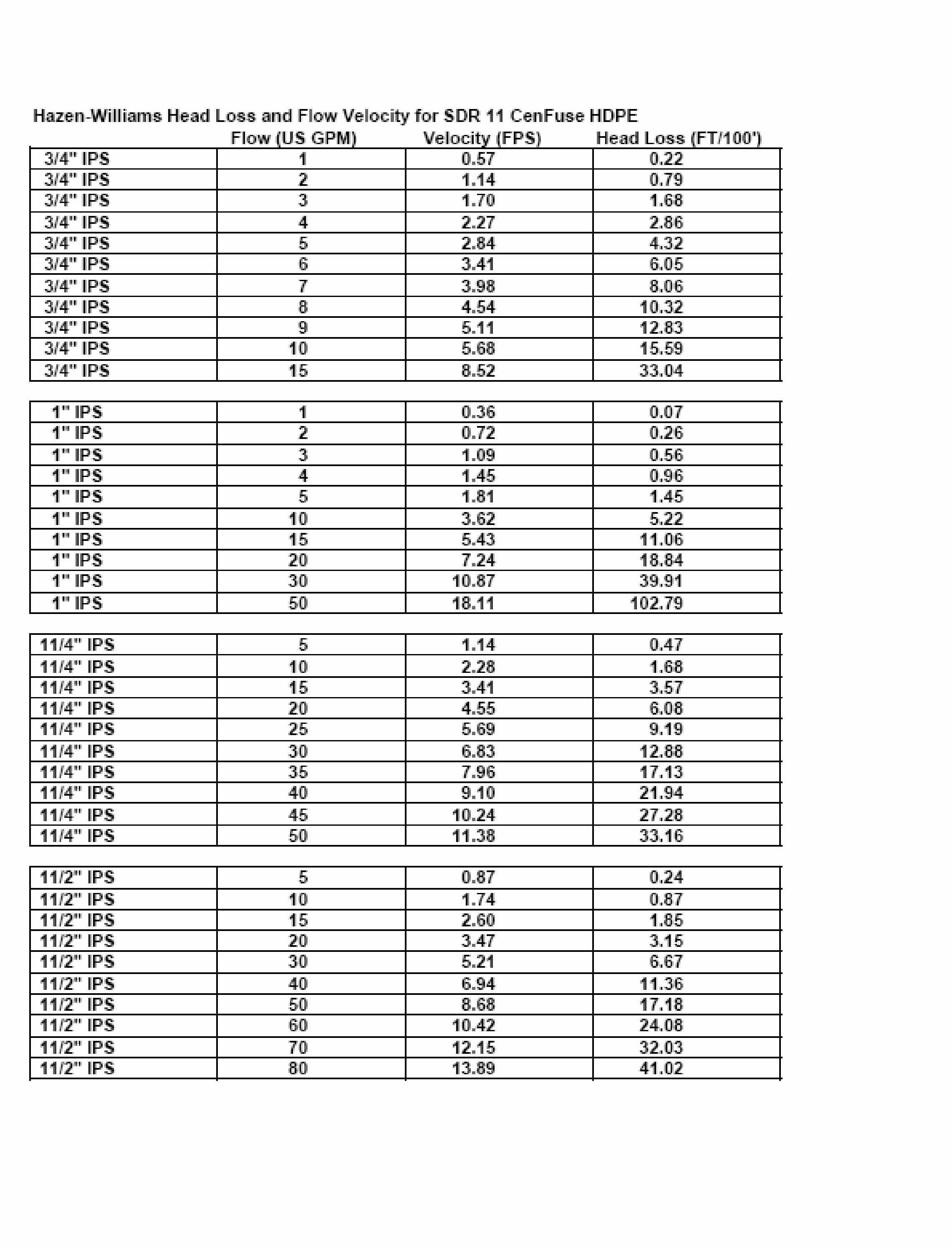
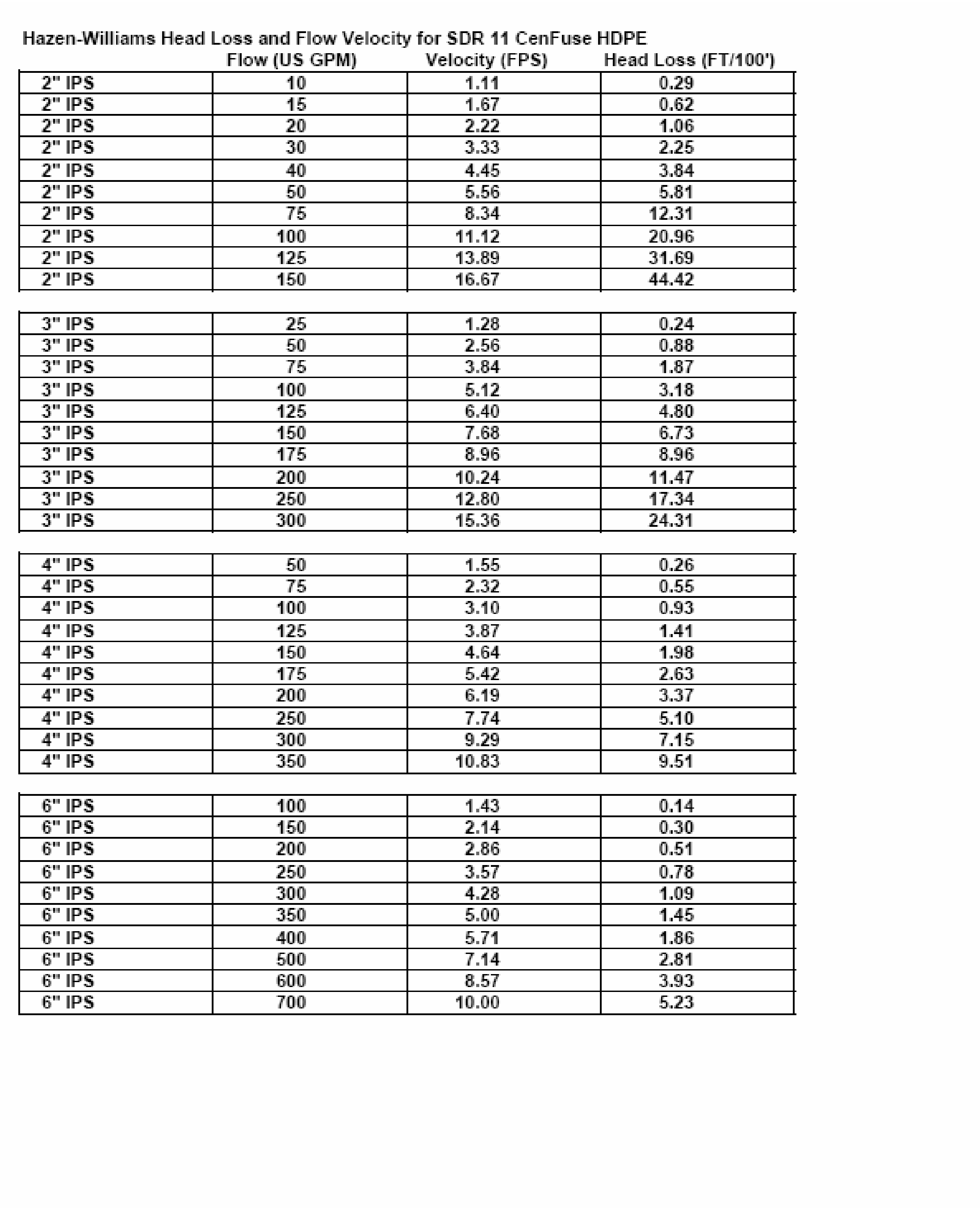
Appendix A – Pipe Loss Tables and Charts

HDPE Pipe Losses



Hazen-Williams Head Loss and Flow Velocity for SDR 11 CenFuse HDPE

	Flow (US GPM)	Velocity (FPS)	Head Loss (FT/100')
3/4" IPS	1	0.57	0.22
3/4" IPS	2	1.14	0.79
3/4" IPS	3	1.70	1.68
3/4" IPS	4	2.27	2.86
3/4" IPS	5	2.84	4.32
3/4" IPS	6	3.41	6.05
3/4" IPS	7	3.98	8.06
3/4" IPS	8	4.54	10.32
3/4" IPS	9	5.11	12.83
3/4" IPS	10	5.68	15.59
3/4" IPS	15	8.52	33.04
1" IPS	1	0.36	0.07
1" IPS	2	0.72	0.26
1" IPS	3	1.09	0.56
1" IPS	4	1.45	0.96
1" IPS	5	1.81	1.45
1" IPS	10	3.62	5.22
1" IPS	15	5.43	11.06
1" IPS	20	7.24	18.84
1" IPS	30	10.87	39.91
1" IPS	50	18.11	102.79
11/4" IPS	5	1.14	0.47
11/4" IPS	10	2.28	1.68
11/4" IPS	15	3.41	3.57
11/4" IPS	20	4.55	6.08
11/4" IPS	25	5.69	9.19
11/4" IPS	30	6.83	12.88
11/4" IPS	35	7.96	17.13
11/4" IPS	40	9.10	21.94
11/4" IPS	45	10.24	27.28
11/4" IPS	50	11.38	33.16
11/2" IPS	5	0.87	0.24
11/2" IPS	10	1.74	0.87
11/2" IPS	15	2.60	1.85
11/2" IPS	20	3.47	3.15
11/2" IPS	30	5.21	6.67
11/2" IPS	40	6.94	11.36
11/2" IPS	50	8.68	17.18
11/2" IPS	60	10.42	24.08
11/2" IPS	70	12.15	32.03
11/2" IPS	80	13.89	41.02



Hazen-Williams Head Loss and Flow Velocity for SDR 11 CenFuse HDPE

	Flow (US GPM)	Velocity (FPS)	Head Loss (FT/100')
2" IPS	10	1.11	0.29
2" IPS	15	1.67	0.62
2" IPS	20	2.22	1.06
2" IPS	30	3.33	2.25
2" IPS	40	4.45	3.84
2" IPS	50	5.56	5.81
2" IPS	75	8.34	12.31
2" IPS	100	11.12	20.96
2" IPS	125	13.89	31.69
2" IPS	150	16.67	44.42
3" IPS	25	1.28	0.24
3" IPS	50	2.56	0.88
3" IPS	75	3.84	1.87
3" IPS	100	5.12	3.18
3" IPS	125	6.40	4.80
3" IPS	150	7.68	6.73
3" IPS	175	8.96	8.96
3" IPS	200	10.24	11.47
3" IPS	250	12.80	17.34
3" IPS	300	15.36	24.31
4" IPS	50	1.55	0.26
4" IPS	75	2.32	0.55
4" IPS	100	3.10	0.93
4" IPS	125	3.87	1.41
4" IPS	150	4.64	1.98
4" IPS	175	5.42	2.63
4" IPS	200	6.19	3.37
4" IPS	250	7.74	5.10
4" IPS	300	9.29	7.15
4" IPS	350	10.83	9.51
6" IPS	100	1.43	0.14
6" IPS	150	2.14	0.30
6" IPS	200	2.86	0.51
6" IPS	250	3.57	0.78
6" IPS	300	4.28	1.09
6" IPS	350	5.00	1.45
6" IPS	400	5.71	1.86
6" IPS	500	7.14	2.81
6" IPS	600	8.57	3.93
6" IPS	700	10.00	5.23

3/8” PEX Pipe Losses

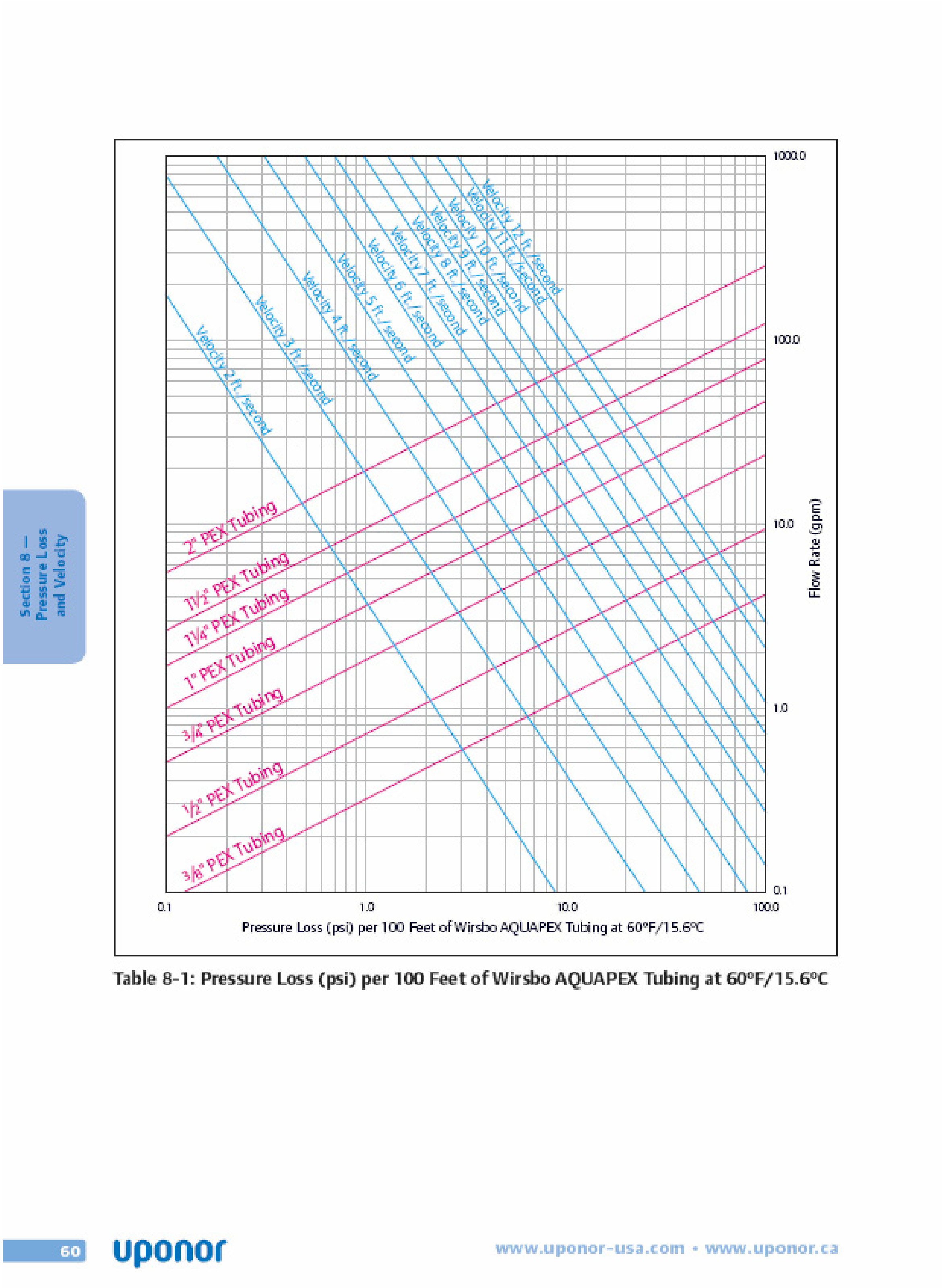


Table 8-1: Pressure Loss (psi) per 100 Feet of Wirsbo AQUAPEX Tubing at 60°F/15.6°C

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Appendix B – Example Calculation Spreadsheets

Zone Properties: 1_Office

	Name		1_Office
	Floor Area (SF)	7233	
	Zone Height (ft)	15.3	
	Occ. # (People)	75	
	Min OA Occ (CFM)	809	
	Min OA Unocc (CFM)	434	
		DB (F)	w (lb_a/lb_w)
	Occ Setpoint	78	0.0102
	Unocc Setpoint	80	
	Supply Air Setpoint (F)	55	0.008
		Sensible	**Latent**
	Occ. Load (BTU/hr/per)	250	200
	Lighting Load (Btu/hr)	27353	0
	Misc. 1 Load (Btu/hr)	86326	0
	ACH/h	0	
	Infiltration CFM	0.00	
	Design w(lb_a/lb_w)	0.0168	
	Floor		
ρ	**Density (lb/ft^3)**	150	
k	**Conductivity (Btu/hr-ft-F)**	1.25	
α	**Absorbtivity**	0.6	
Cp	**Heat Capacity**	0.2	
T_{CHWS}	**CHWS Temp (F)**	55	
T_{CHWR}	**CHWR Temp (F)**	60	
T_{CHWM}	**CHWM Temp (F)**	57.5	
h_{rad}	**Rad Coeff. (Btu/hr-ft^2-F)**	0.97	
h_{conv}	**Conv Coeff. (Btu/hr-ft2-F)**	0.27	
δ	**Thickness (ft)**	0.4166667	
V	**Volume (ft^3)**	3013.75	

	N Brick Ven Stud		W Brick Ven Stud		E Brick Ven Stud		N Curtain Wall System	W Alum Storefront	E Curtain Wall System	E Alum Storefront		
	Ext Wall 1		**Ext Wall 2**		**Ext Wall 3**		**Window 1**	**Window 2**	**Window 3**	**Window 4**	**Roof**	
	Constr.	**CTSF**	**Constr.**	**CTSF**	**Constr.**	**CTSF**	**Constr.**	**Constr.**	**Constr.**	**Constr.**	**Constr.**	**CTSF**
Layer 1	F01	0.002	F01	0.002	F01	0.002					NA	NA
Layer 2	A7	0.053	A7	0.053	A7	0.053						
Layer 3	F04	0.151	F04	0.151	F04	0.151						
Layer 4	I03	0.172	I03	0.172	I03	0.172						
Layer 5	G01	0.147	G01	0.147	G01	0.147						
Layer 6	F02	0.115	F02	0.115	F02	0.115						
Area	770	0.088	1540	0.088	975	0.088	172	364.5	115	44		
Direction	0	0.067	270	0.067	90	0.067	0	270	90	90		
U-Value	0.0667	0.051	0.0667	0.051	0.0667	0.051	0.4	0.4	0.4	0.4		
SHGC	-	0.038	-	0.038	-	0.038	0.38	0.28	0.38	0.28		
		0.029		0.029		0.029						
		0.022		0.022		0.022						
		0.017		0.017		0.017						
		0.013		0.013		0.013						
		0.009		0.009		0.009						
		0.007		0.007		0.007						
		0.005		0.005		0.005						
		0.004		0.004		0.004						
		0.003		0.003		0.003						
		0.002		0.002		0.002						
		0.002		0.002		0.002						
		0.001		0.001		0.001						
		0.001		0.001		0.001						
		0.001		0.001		0.001						

External Wall Conduction: 1_Office

Convection	0.54
Radiation	0.46

		N Brick Ven Stud					**W Brick Ven Stud**					**E Brick Ven Stud**						
Time	**Time**	**I_{direct} (BTU/hr·ft^2)**	**OA Temp (F)**	**Sol-Air (F)**	**UA(Tsola - Ta)**	**q_{cond} (Btu/hr)**	**I_{direct} (BTU/hr·ft^2)**	**OA Temp (F)**	**Sol-Air (F)**	**UA(Tsola - Ta)**	**q_{cond} (Btu/hr)**	**I_{direct} (BTU/hr·ft^2)**	**OA Temp (F)**	**Sol-Air (F)**	**UA(Tsola - Ta)**	**q_{cond} (Btu/hr)**	**q_{conv} (Btu/hr)**	**q_{rad} (Btu/hr)**
1:00		0.0	80.5	80.5	130.48		0.0	80.5	80.5	260.96		0.0	80.5	80.5	165.22		2624.24	2537.83
2:00		0.0	79.6	79.6	82.59		0.0	79.6	79.6	165.18		0.0	79.6	79.6	104.58		2105.33	2538.83
3:00		0.0	78.7	78.7	36.48		0.0	78.7	78.7	72.96		0.0	78.7	78.7	46.19		1675.77	2539.83
4:00		0.0	77.9	77.9	-3.49		0.0	77.9	77.9	-6.99		0.0	77.9	77.9	-4.42		1320.92	2540.83
5:00		0.0	77.4	77.4	-32.43		0.0	77.4	77.4	-64.86		0.0	77.4	77.4	-41.06		1026.29	2541.83
6:00		0.0	77.1	77.1	-46.91		0.0	77.1	77.1	-93.83		0.0	77.1	77.1	-59.40		781.02	2542.83
7:00		52.9	77.4	93.2	782.86		11.3	77.4	80.8	282.76		137.2	77.4	118.5	2635.59		581.97	2543.83
8:00		63.0	78.2	97.0	977.84		23.7	78.2	85.3	746.94		237.8	78.2	149.5	4648.68		531.76	2544.83
9:00		42.3	79.6	92.3	736.75		32.6	79.6	89.4	1172.70		262.0	79.6	158.2	5217.84		798.51	2545.83
10:00		41.6	81.9	94.4	841.28		39.4	81.9	93.7	1613.47		244.7	81.9	155.3	5027.60		1302.94	2546.83
11:00		45.5	84.6	98.2	1038.24		44.5	84.6	97.9	2043.47		200.3	84.6	144.6	4334.11		1858.20	2547.83
12:00		47.7	87.6	101.9	1226.79		47.7	87.6	101.9	2453.59		138.1	87.6	129.0	3316.99		2353.53	2548.83
13:00		49.1	90.6	105.3	1401.33		52.3	90.6	106.2	2901.44		66.3	90.6	110.5	2111.77		2737.89	2549.83
14:00		48.4	92.9	107.4	1509.78		113.0	92.9	126.8	5009.62		49.4	92.9	107.7	1931.12		2993.66	2550.83
15:00		45.9	94.5	108.2	1551.60		179.5	94.5	148.3	7223.14		45.9	94.5	108.2	1964.69		3198.13	2551.83
16:00		43.2	95.2	108.1	1548.06		231.4	95.2	164.6	8894.42		41.4	95.2	107.6	1925.70		3517.52	2552.83
17:00		38.4	94.8	106.4	1456.07		259.6	94.8	172.7	9727.75		35.2	94.8	105.4	1781.17		3999.41	2553.83
18:00		57.2	93.7	110.8	1685.28		252.6	93.7	169.5	9393.75		27.2	93.7	101.8	1549.28		4566.35	2554.83
19:00		63.3	91.8	110.8	1684.18		186.5	91.8	147.8	7165.29		16.4	91.8	96.7	1217.75		5095.31	2555.83
20:00		5.2	89.5	91.0	668.91		10.8	89.5	92.7	1510.59		0.8	89.5	89.7	761.73		5437.86	2556.83
21:00		0.0	87.1	87.1	467.30		0.0	87.1	87.1	934.61		0.0	87.1	87.1	591.72		5345.57	2557.83
22:00		0.0	85.0	85.0	361.30		0.0	85.0	85.0	722.60		0.0	85.0	85.0	457.49		4741.20	2558.83
23:00		0.0	83.2	83.2	267.41		0.0	83.2	83.2	534.81		0.0	83.2	83.2	338.60		3967.70	2559.83
0:00		0.0	81.7	81.7	188.24		0.0	81.7	81.7	376.49		0.0	81.7	81.7	238.36		3244.46	2560.83
1:00	1	0.0	80.5	80.5	130.48	794.75	0.0	80.5	80.5	260.96	3065.45	0.0	80.5	80.5	165.22	999.50	2624.24	2235.46
2:00	2	0.0	79.6	79.6	82.59	653.24	0.0	79.6	79.6	165.18	2423.85	0.0	79.6	79.6	104.58	821.66	2105.33	1793.43
3:00	3	0.0	78.7	78.7	36.48	530.28	0.0	78.7	78.7	72.96	1905.75	0.0	78.7	78.7	46.19	667.24	1675.77	1427.51
4:00	4	0.0	77.9	77.9	-3.49	424.32	0.0	77.9	77.9	-6.99	1487.76	0.0	77.9	77.9	-4.42	534.07	1320.92	1125.23
5:00	5	0.0	77.4	77.4	-32.43	332.78	0.0	77.4	77.4	-64.86	1148.82	0.0	77.4	77.4	-41.06	418.94	1026.29	874.25
6:00	6	0.0	77.1	77.1	-46.91	253.80	0.0	77.1	77.1	-93.83	873.01	0.0	77.1	77.1	-59.40	319.53	781.02	665.32
7:00	7	52.9	77.4	93.2	782.86	188.05	11.3	77.4	80.8	282.76	650.39	137.2	77.4	118.5	2635.59	239.28	581.97	495.75
8:00	8	63.0	78.2	97.0	977.84	176.87	23.7	78.2	85.3	746.94	493.64	237.8	78.2	149.5	4648.68	314.24	531.76	452.98
9:00	9	42.3	79.6	92.3	736.75	268.57	32.6	79.6	89.4	1172.70	438.21	262.0	79.6	158.2	5217.84	771.95	798.51	680.22
10:00	10	41.6	81.9	94.4	841.28	395.17	39.4	81.9	93.7	1613.47	491.35	244.7	81.9	155.3	5027.60	1526.34	1302.94	1109.91
11:00	11	45.5	84.6	98.2	1038.24	494.93	44.5	84.6	97.9	2043.47	635.08	200.3	84.6	144.6	4334.11	2311.11	1858.20	1582.91
12:00	12	47.7	87.6	101.9	1226.79	584.95	47.7	87.6	101.9	2453.59	849.32	138.1	87.6	129.0	3316.99	2924.13	2353.53	2004.86
13:00	13	49.1	90.6	105.3	1401.33	688.42	52.3	90.6	106.2	2901.44	1115.70	66.3	90.6	110.5	2111.77	3266.04	2737.89	2332.27
14:00	14	48.4	92.9	107.4	1509.78	809.25	113.0	92.9	126.8	5009.62	1423.45	49.4	92.9	107.7	1931.12	3311.11	2993.66	2550.15
15:00	15	45.9	94.5	108.2	1551.60	940.14	179.5	94.5	148.3	7223.14	1850.49	45.9	94.5	108.2	1964.69	3131.84	3198.13	2724.34
16:00	16	43.2	95.2	108.1	1548.06	1067.44	231.4	95.2	164.6	8894.42	2558.40	41.4	95.2	107.6	1925.70	2888.08	3517.52	2996.40
17:00	17	38.4	94.8	106.4	1456.07	1178.22	259.6	94.8	172.7	9727.75	3558.32	35.2	94.8	105.4	1781.17	2669.77	3999.41	3406.91
18:00	18	57.2	93.7	110.8	1685.28	1262.43	252.6	93.7	169.5	9393.75	4708.28	27.2	93.7	101.8	1549.28	2485.50	4566.35	3889.85
19:00	19	63.3	91.8	110.8	1684.18	1328.76	186.5	91.8	147.8	7165.29	5793.09	16.4	91.8	96.7	1217.75	2313.91	5095.31	4340.45
20:00	20	5.2	89.5	91.0	668.91	1397.65	10.8	89.5	92.7	1510.59	6541.11	0.8	89.5	89.7	761.73	2131.34	5437.86	4632.25
21:00	21	0.0	87.1	87.1	467.30	1409.21	0.0	87.1	87.1	934.61	6573.21	0.0	87.1	87.1	591.72	1916.78	5345.57	4553.63
22:00	22	0.0	85.0	85.0	361.30	1298.20	0.0	85.0	85.0	722.60	5810.57	0.0	85.0	85.0	457.49	1671.23	4741.20	4038.80
23:00	23	0.0	83.2	83.2	267.41	1128.16	0.0	83.2	83.2	534.81	4792.93	0.0	83.2	83.2	338.60	1426.50	3967.70	3379.89
0:00	24	0.0	81.7	81.7	188.24	954.37	0.0	81.7	81.7	376.49	3852.70	0.0	81.7	81.7	238.36	1201.18	3244.46	2763.80
1:00	25	0.0	80.5	80.5	130.48	794.75	0.0	80.5	80.5	260.96	3065.45	0.0	80.5	80.5	165.22	999.50	2624.24	2235.46
2:00	26	0.0	79.6	79.6	82.59	653.24	0.0	79.6	79.6	165.18	2423.85	0.0	79.6	79.6	104.58	821.66	2105.33	1793.43
3:00	27	0.0	78.7	78.7	36.48	530.28	0.0	78.7	78.7	72.96	1905.75	0.0	78.7	78.7	46.19	667.24	1675.77	1427.51
4:00	28	0.0	77.9	77.9	-3.49	424.32	0.0	77.9	77.9	-6.99	1487.76	0.0	77.9	77.9	-4.42	534.07	1320.92	1125.23
5:00	29	0.0	77.4	77.4	-32.43	332.78	0.0	77.4	77.4	-64.86	1148.82	0.0	77.4	77.4	-41.06	418.94	1026.29	874.25
6:00	30	0.0	77.1	77.1	-46.91	253.80	0.0	77.1	77.1	-93.83	873.01	0.0	77.1	77.1	-59.40	319.53	781.02	665.32
7:00	31	52.9	77.4	93.2	782.86	188.05	11.3	77.4	80.8	282.76	650.39	137.2	77.4	118.5	2635.59	239.28	581.97	495.75
8:00	32	63.0	78.2	97.0	977.84	176.87	23.7	78.2	85.3	746.94	493.64	237.8	78.2	149.5	4648.68	314.24	531.76	452.98
9:00	33	42.3	79.6	92.3	736.75	268.57	32.6	79.6	89.4	1172.70	438.21	262.0	79.6	158.2	5217.84	771.95	798.51	680.22
10:00	34	41.6	81.9	94.4	841.28	395.17	39.4	81.9	93.7	1613.47	491.35	244.7	81.9	155.3	5027.60	1526.34	1302.94	1109.91
11:00	35	45.5	84.6	98.2	1038.24	494.93	44.5	84.6	97.9	2043.47	635.08	200.3	84.6	144.6	4334.11	2311.11	1858.20	1582.91
12:00	36	47.7	87.6	101.9	1226.79	584.95	47.7	87.6	101.9	2453.59	849.32	138.1	87.6	129.0	3316.99	2924.13	2353.53	2004.86
13:00	37	49.1	90.6	105.3	1401.33	688.42	52.3	90.6	106.2	2901.44	1115.70	66.3	90.6	110.5	2111.77	3266.04	2737.89	2332.27
14:00	38	48.4	92.9	107.4	1509.78	809.25	113.0	92.9	126.8	5009.62	1423.45	49.4	92.9	107.7	1931.12	3311.11	2993.66	2550.15
15:00	39	45.9	94.5	108.2	1551.60	940.14	179.5	94.5	148.3	7223.14	1850.49	45.9	94.5	108.2	1964.69	3131.84	3198.13	2724.34
16:00	40	43.2	95.2	108.1	1548.06	1067.44	231.4	95.2	164.6	8894.42	2558.40	41.4	95.2	107.6	1925.70	2888.08	3517.52	2996.40
17:00	41	38.4	94.8	106.4	1456.07	1178.22	259.6	94.8	172.7	9727.75	3558.32	35.2	94.8	105.4	1781.17	2669.77	3999.41	3406.91
18:00	42	57.2	93.7	110.8	1685.28	1262.43	252.6	93.7	169.5	9393.75	4708.28	27.2	93.7	101.8	1549.28	2485.50	4566.35	3889.85
19:00	43	63.3	91.8	110.8	1684.18	1328.76	186.5	91.8	147.8	7165.29	5793.09	16.4	91.8	96.7	1217.75	2313.91	5095.31	4340.45
20:00	44	5.2	89.5	91.0	668.91	1397.65	10.8	89.5	92.7	1510.59	6541.11	0.8	89.5	89.7	761.73	2131.34	5437.86	4632.25
21:00	45	0.0	87.1	87.1	467.30	1409.21	0.0	87.1	87.1	934.61	6573.21	0.0	87.1	87.1	591.72	1916.78	5345.57	4553.63
22:00	46	0.0	85.0	85.0	361.30	1298.20	0.0	85.0	85.0	722.60	5810.57	0.0	85.0	85.0	457.49	1671.23	4741.20	4038.80
23:00	47	0.0	83.2	83.2	267.41	1128.16	0.0	83.2	83.2	534.81	4792.93	0.0	83.2	83.2	338.60	1426.50	3967.70	3379.89
0:00	48	0.0	81.7	81.7	188.24	954.37	0.0	81.7	81.7	376.49	3852.70	0.0	81.7	81.7	238.36	1201.18	3244.46	2763.80

Roof Conduction: 1_Office

Convection	0.4
Radiation	0.6

Time	**Time**	**Ceiling I_{direct} (BTU/hr·ft^2)**	**OA Temp (F)**	**Sol-Air (F)**	**q_{cond} (Btu/hr)**	**q_{conv} (Btu/hr)**	**q_{rad} (Btu/hr)**
1:00		0.0	83.6	76.6			
2:00		0.0	82.6	75.6			
3:00		0.0	81.7	74.7			
4:00		0.0	80.9	73.9			
5:00		0.0	80.4	73.4			
6:00		0.0	80.1	73.1			
7:00		52.3	80.4	84.4			
8:00		62.9	81.1	105.8			
9:00		42.3	82.6	126.8			
10:00		41.5	84.8	145.9			
11:00		45.4	87.5	161.8			
12:00		47.6	90.5	173.6			
13:00		49.0	93.5	180.3			
14:00		48.4	95.8	181.1			
15:00		45.9	97.4	175.9			
16:00		43.2	98.2	165.1			
17:00		38.5	97.8	149.1			
18:00		56.3	96.7	129.5			
19:00		63.6	94.8	107.2			
20:00		7.3	92.5	86.3			
21:00		0.0	90.1	83.1			
22:00		0.0	88.1	81.1			
23:00		0.0	86.2	79.2			
0:00		0.0	84.7	77.7			
1:00	**1**	0.0	83.6	76.6	0	0	0
2:00	**2**	0.0	82.6	75.6	0	0	0
3:00	**3**	0.0	81.7	74.7	0	0	0
4:00	**4**	0.0	80.9	73.9	0	0	0
5:00	**5**	0.0	80.4	73.4	0	0	0
6:00	**6**	0.0	80.1	73.1	0	0	0
7:00	**7**	52.3	80.4	84.4	0	0	0
8:00	**8**	62.9	81.1	105.8	0	0	0
9:00	**9**	42.3	82.6	126.8	0	0	0
10:00	**10**	41.5	84.8	145.9	0	0	0
11:00	**11**	45.4	87.5	161.8	0	0	0
12:00	**12**	47.6	90.5	173.6	0	0	0
13:00	**13**	49.0	93.5	180.3	0	0	0
14:00	**14**	48.4	95.8	181.1	0	0	0
15:00	**15**	45.9	97.4	175.9	0	0	0
16:00	**16**	43.2	98.2	165.1	0	0	0
17:00	**17**	38.5	97.8	149.1	0	0	0
18:00	**18**	56.3	96.7	129.5	0	0	0
19:00	**19**	63.6	94.8	107.2	0	0	0
20:00	**20**	7.3	92.5	86.3	0	0	0
21:00	**21**	0.0	90.1	83.1	0	0	0
22:00	**22**	0.0	88.1	81.1	0	0	0
23:00	**23**	0.0	86.2	79.2	0	0	0
0:00	**24**	0.0	84.7	77.7	0	0	0
1:00	**25**	0.0	83.6	76.6	0	0	0
2:00	**26**	0.0	82.6	75.6	0	0	0
3:00	**27**	0.0	81.7	74.7	0	0	0
4:00	**28**	0.0	80.9	73.9	0	0	0
5:00	**29**	0.0	80.4	73.4	0	0	0
6:00	**30**	0.0	80.1	73.1	0	0	0
7:00	**31**	52.3	80.4	84.4	0	0	0
8:00	**32**	62.9	81.1	105.8	0	0	0
9:00	**33**	42.3	82.6	126.8	0	0	0
10:00	**34**	41.5	84.8	145.9	0	0	0
11:00	**35**	45.4	87.5	161.8	0	0	0
12:00	**36**	47.6	90.5	173.6	0	0	0
13:00	**37**	49.0	93.5	180.3	0	0	0
14:00	**38**	48.4	95.8	181.1	0	0	0
15:00	**39**	45.9	97.4	175.9	0	0	0
16:00	**40**	43.2	98.2	165.1	0	0	0
17:00	**41**	38.5	97.8	149.1	0	0	0
18:00	**42**	56.3	96.7	129.5	0	0	0
19:00	**43**	63.6	94.8	107.2	0	0	0
20:00	**44**	7.3	92.5	86.3	0	0	0
21:00	**45**	0.0	90.1	83.1	0	0	0
22:00	**46**	0.0	88.1	81.1	0	0	0
23:00	**47**	0.0	86.2	79.2	0	0	0
0:00	**48**	0.0	84.7	77.7	0	0	0

Window Gain: 1_Office – Part 1

Convection	0.54
Radiation	0.46

		N Curtain Wall System							**W Alum Storefront**						
Time	**Time**	**I_{Beam} (BTU/hr-ft^2)**	**I_{Diff} (BTU/hr-ft^2)**	**OA Temp (F)**	**q_{cond} (Btu/hr)**	**q_{diff} (Btu/hr)**	**q_{beam} (Btu/hr)**	**$q_{cond+diff}$ (Btu/hr)**	**I_{Beam} (BTU/hr-ft^2)**	**I_{Diff} (BTU/hr-ft^2)**	**OA Temp (F)**	**q_{cond} (Btu/hr)**	**q_{diff} (Btu/hr)**	**q_{beam} (Btu/hr)**	**$q_{cond+diff}$ (Btu/hr)**
1:00		0.0	0.0	80.5	174.79	0.0	0.0	174.79	0.0	0.0	80.5	370.41	0.0	0.0	370.41
2:00		0.0	0.0	79.6	110.63	0.0	0.0	110.63	0.0	0.0	79.6	234.45	0.0	0.0	234.45
3:00		0.0	0.0	78.7	48.87	0.0	0.0	48.87	0.0	0.0	78.7	103.57	0.0	0.0	103.57
4:00		0.0	0.0	77.9	-4.68	0.0	0.0	-4.68	0.0	0.0	77.9	-9.92	0.0	0.0	-9.92
5:00		0.0	0.0	77.4	-43.44	0.0	0.0	-43.44	0.0	0.0	77.4	-92.06	0.0	0.0	-92.06
6:00		0.0	0.0	77.1	-62.85	0.0	0.0	-62.85	0.0	0.0	77.1	-133.18	0.0	0.0	-133.18
7:00		37.1	15.6	77.4	-43.75	892.2	1474.8	848.50	0.0	11.2	77.4	-92.72	1001.5	0.0	908.75
8:00		34.1	28.9	78.2	10.56	1650.2	795.2	1660.77	0.0	23.7	78.2	22.37	2113.4	0.0	2135.74
9:00		6.1	36.3	79.6	113.23	2076.4	49.8	2189.61	0.0	32.5	79.6	239.96	2903.6	0.0	3143.52
10:00		0.0	41.6	81.9	267.49	2378.9	0.0	2646.35	0.0	39.3	81.9	566.86	3513.9	0.0	4080.74
11:00		0.0	45.5	84.6	450.87	2602.0	0.0	3052.92	0.0	44.4	84.6	955.49	3967.1	0.0	4922.55
12:00		0.0	47.7	87.6	658.48	2726.8	0.0	3385.32	0.0	47.7	87.6	1395.44	4258.0	0.0	5653.42
13:00		0.0	49.0	90.6	864.73	2803.7	0.0	3668.40	0.0	52.2	90.6	1832.53	4662.4	0.0	6494.90
14:00		0.0	48.4	92.9	1023.03	2768.2	0.0	3791.21	56.4	56.2	92.9	2167.99	5019.8	0.0	7187.78
15:00		0.0	45.8	94.5	1132.13	2621.7	0.0	3753.86	120.0	59.2	94.5	2399.19	5283.6	0.0	7682.75
16:00		0.0	43.2	95.2	1182.24	2470.0	0.0	3652.19	170.9	60.1	95.2	2505.39	5369.3	0.0	7874.74
17:00		0.0	38.4	94.8	1157.18	2198.5	0.0	3355.68	201.6	57.8	94.8	2452.29	5160.9	0.0	7613.22
18:00		25.1	32.0	93.7	1077.90	1828.8	438.9	2906.68	202.3	50.3	93.7	2284.27	4494.8	0.0	6779.11
19:00		41.6	21.7	91.8	949.62	1240.3	1398.8	2189.93	152.8	34.1	91.8	2012.43	3045.7	0.0	5058.17
20:00		4.2	1.3	89.5	789.48	75.0	198.3	864.53	9.5	1.9	89.5	1673.05	173.1	0.0	1846.15
21:00		0.0	0.0	87.1	626.00	0.0	0.0	626.00	0.0	0.0	87.1	1326.60	0.0	0.0	1326.60
22:00		0.0	0.0	85.0	483.99	0.0	0.0	483.99	0.0	0.0	85.0	1025.67	0.0	0.0	1025.67
23:00		0.0	0.0	83.2	358.21	0.0	0.0	358.21	0.0	0.0	83.2	759.12	0.0	0.0	759.12
0:00		0.0	0.0	81.7	252.17	0.0	0.0	252.17	0.0	0.0	81.7	534.39	0.0	0.0	534.39
1:00	**1**	0.0	0.0	80.5	174.79	0.0	0.0	174.79	0.0	0.0	80.5	370.41	0.0	0.0	370.41
2:00	**2**	0.0	0.0	79.6	110.63	0.0	0.0	110.63	0.0	0.0	79.6	234.45	0.0	0.0	234.45
3:00	**3**	0.0	0.0	78.7	48.87	0.0	0.0	48.87	0.0	0.0	78.7	103.57	0.0	0.0	103.57
4:00	**4**	0.0	0.0	77.9	-4.68	0.0	0.0	-4.68	0.0	0.0	77.9	-9.92	0.0	0.0	-9.92
5:00	**5**	0.0	0.0	77.4	-43.44	0.0	0.0	-43.44	0.0	0.0	77.4	-92.06	0.0	0.0	-92.06
6:00	**6**	0.0	0.0	77.1	-62.85	0.0	0.0	-62.85	0.0	0.0	77.1	-133.18	0.0	0.0	-133.18
7:00	**7**	37.1	15.6	77.4	-43.75	892.2	1474.8	848.50	0.0	11.2	77.4	-92.72	1001.5	0.0	908.75
8:00	**8**	34.1	28.9	78.2	10.56	1650.2	795.2	1660.77	0.0	23.7	78.2	22.37	2113.4	0.0	2135.74
9:00	**9**	6.1	36.3	79.6	113.23	2076.4	49.8	2189.61	0.0	32.5	79.6	239.96	2903.6	0.0	3143.52
10:00	**10**	0.0	41.6	81.9	267.49	2378.9	0.0	2646.35	0.0	39.3	81.9	566.86	3513.9	0.0	4080.74
11:00	**11**	0.0	45.5	84.6	450.87	2602.0	0.0	3052.92	0.0	44.4	84.6	955.49	3967.1	0.0	4922.55
12:00	**12**	0.0	47.7	87.6	658.48	2726.8	0.0	3385.32	0.0	47.7	87.6	1395.44	4258.0	0.0	5653.42
13:00	**13**	0.0	49.0	90.6	864.73	2803.7	0.0	3668.40	0.0	52.2	90.6	1832.53	4662.4	0.0	6494.90
14:00	**14**	0.0	48.4	92.9	1023.03	2768.2	0.0	3791.21	56.4	56.2	92.9	2167.99	5019.8	0.0	7187.78
15:00	**15**	0.0	45.8	94.5	1132.13	2621.7	0.0	3753.86	120.0	59.2	94.5	2399.19	5283.6	0.0	7682.75
16:00	**16**	0.0	43.2	95.2	1182.24	2470.0	0.0	3652.19	170.9	60.1	95.2	2505.39	5369.3	0.0	7874.74
17:00	**17**	0.0	38.4	94.8	1157.18	2198.5	0.0	3355.68	201.6	57.8	94.8	2452.29	5160.9	0.0	7613.22
18:00	**18**	25.1	32.0	93.7	1077.90	1828.8	438.9	2906.68	202.3	50.3	93.7	2284.27	4494.8	0.0	6779.11
19:00	**19**	41.6	21.7	91.8	949.62	1240.3	1398.8	2189.93	152.8	34.1	91.8	2012.43	3045.7	0.0	5058.17
20:00	**20**	4.2	1.3	89.5	789.48	75.0	198.3	864.53	9.5	1.9	89.5	1673.05	173.1	0.0	1846.15
21:00	**21**	0.0	0.0	87.1	626.00	0.0	0.0	626.00	0.0	0.0	87.1	1326.60	0.0	0.0	1326.60
22:00	**22**	0.0	0.0	85.0	483.99	0.0	0.0	483.99	0.0	0.0	85.0	1025.67	0.0	0.0	1025.67
23:00	**23**	0.0	0.0	83.2	358.21	0.0	0.0	358.21	0.0	0.0	83.2	759.12	0.0	0.0	759.12
0:00	**24**	0.0	0.0	81.7	252.17	0.0	0.0	252.17	0.0	0.0	81.7	534.39	0.0	0.0	534.39
1:00	**25**	0.0	0.0	80.5	174.79	0.0	0.0	174.79	0.0	0.0	80.5	370.41	0.0	0.0	370.41
2:00	**26**	0.0	0.0	79.6	110.63	0.0	0.0	110.63	0.0	0.0	79.6	234.45	0.0	0.0	234.45
3:00	**27**	0.0	0.0	78.7	48.87	0.0	0.0	48.87	0.0	0.0	78.7	103.57	0.0	0.0	103.57
4:00	**28**	0.0	0.0	77.9	-4.68	0.0	0.0	-4.68	0.0	0.0	77.9	-9.92	0.0	0.0	-9.92
5:00	**29**	0.0	0.0	77.4	-43.44	0.0	0.0	-43.44	0.0	0.0	77.4	-92.06	0.0	0.0	-92.06
6:00	**30**	0.0	0.0	77.1	-62.85	0.0	0.0	-62.85	0.0	0.0	77.1	-133.18	0.0	0.0	-133.18
7:00	**31**	37.1	15.6	77.4	-43.75	892.2	1474.8	848.50	0.0	11.2	77.4	-92.72	1001.5	0.0	908.75
8:00	**32**	34.1	28.9	78.2	10.56	1650.2	795.2	1660.77	0.0	23.7	78.2	22.37	2113.4	0.0	2135.74
9:00	**33**	6.1	36.3	79.6	113.23	2076.4	49.8	2189.61	0.0	32.5	79.6	239.96	2903.6	0.0	3143.52
10:00	**34**	0.0	41.6	81.9	267.49	2378.9	0.0	2646.35	0.0	39.3	81.9	566.86	3513.9	0.0	4080.74
11:00	**35**	0.0	45.5	84.6	450.87	2602.0	0.0	3052.92	0.0	44.4	84.6	955.49	3967.1	0.0	4922.55
12:00	**36**	0.0	47.7	87.6	658.48	2726.8	0.0	3385.32	0.0	47.7	87.6	1395.44	4258.0	0.0	5653.42
13:00	**37**	0.0	49.0	90.6	864.73	2803.7	0.0	3668.40	0.0	52.2	90.6	1832.53	4662.4	0.0	6494.90
14:00	**38**	0.0	48.4	92.9	1023.03	2768.2	0.0	3791.21	56.4	56.2	92.9	2167.99	5019.8	0.0	7187.78
15:00	**39**	0.0	45.8	94.5	1132.13	2621.7	0.0	3753.86	120.0	59.2	94.5	2399.19	5283.6	0.0	7682.75
16:00	**40**	0.0	43.2	95.2	1182.24	2470.0	0.0	3652.19	170.9	60.1	95.2	2505.39	5369.3	0.0	7874.74
17:00	**41**	0.0	38.4	94.8	1157.18	2198.5	0.0	3355.68	201.6	57.8	94.8	2452.29	5160.9	0.0	7613.22
18:00	**42**	25.1	32.0	93.7	1077.90	1828.8	438.9	2906.68	202.3	50.3	93.7	2284.27	4494.8	0.0	6779.11
19:00	**43**	41.6	21.7	91.8	949.62	1240.3	1398.8	2189.93	152.8	34.1	91.8	2012.43	3045.7	0.0	5058.17
20:00	**44**	4.2	1.3	89.5	789.48	75.0	198.3	864.53	9.5	1.9	89.5	1673.05	173.1	0.0	1846.15
21:00	**45**	0.0	0.0	87.1	626.00	0.0	0.0	626.00	0.0	0.0	87.1	1326.60	0.0	0.0	1326.60
22:00	**46**	0.0	0.0	85.0	483.99	0.0	0.0	483.99	0.0	0.0	85.0	1025.67	0.0	0.0	1025.67
23:00	**47**	0.0	0.0	83.2	358.21	0.0	0.0	358.21	0.0	0.0	83.2	759.12	0.0	0.0	759.12
0:00	**48**	0.0	0.0	81.7	252.17	0.0	0.0	252.17	0.0	0.0	81.7	534.39	0.0	0.0	534.39

Window Gain: 1_Office – Part 2

E Curtain Wall System							E Alum Storefront									
I_{Beam} (BTU/hr-ft^2)	I_{Diff} (BTU/hr-ft^2)	OA Temp (F)	q_{cond} (Btu/hr)	q_{diff} (Btu/hr)	q_{beam} (Btu/hr)	$q_{cond+diff}$ (Btu/hr)	I_{Beam} (BTU/hr-ft^2)	I_{Diff} (BTU/hr-ft^2)	OA Temp (F)	q_{cond} (Btu/hr)	q_{diff} (Btu/hr)	q_{beam} (Btu/hr)	$q_{cond+diff}$ (Btu/hr)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{beam} (Btu/hr)
0.0	0.0	80.5	116.86	0.0	0.0	116.86	0.0	0.0	80.5	44.71	0.0	0.0	44.71	381.65	325.11	0.00
0.0	0.0	79.6	73.97	0.0	0.0	73.97	0.0	0.0	79.6	28.30	0.0	0.0	28.30	241.57	205.79	0.00
0.0	0.0	78.7	32.68	0.0	0.0	32.68	0.0	0.0	78.7	12.50	0.0	0.0	12.50	106.71	90.90	0.00
0.0	0.0	77.9	-3.13	0.0	0.0	-3.13	0.0	0.0	77.9	-1.20	0.0	0.0	-1.20	-10.22	-8.70	0.00
0.0	0.0	77.4	-29.04	0.0	0.0	-29.04	0.0	0.0	77.4	-11.11	0.0	0.0	-11.11	-94.86	-80.80	0.00
0.0	0.0	77.1	-42.02	0.0	0.0	-42.02	0.0	0.0	77.1	-16.08	0.0	0.0	-16.08	-137.23	-116.90	0.00
112.2	24.2	77.4	-29.25	924.0	4795.0	894.74	112.2	24.2	77.4	-11.19	260.5	1351.8	249.30	1566.69	1334.59	7621.62
191.7	45.7	78.2	7.06	1747.0	8166.7	1754.10	191.7	45.7	78.2	2.70	492.5	2302.4	495.23	3264.76	2781.09	11264.27
206.0	55.8	79.6	75.71	2132.2	8685.8	2207.92	206.0	55.8	79.6	28.97	601.1	2448.7	630.09	4412.42	3758.72	11184.23
185.0	59.7	81.9	178.85	2283.9	7542.4	2462.72	185.0	59.7	81.9	68.43	643.9	2126.4	712.30	5347.15	4554.98	9668.82
140.6	59.8	84.6	301.46	2287.1	5141.9	2588.55	140.6	59.8	84.6	115.34	644.8	1449.6	760.12	6115.04	5209.10	6591.51
80.9	57.5	87.6	440.26	2197.3	2006.4	2637.61	80.9	57.5	87.6	168.45	619.5	565.6	787.93	6730.71	5733.57	2572.01
12.9	53.8	90.6	578.16	2055.8	89.4	2633.98	12.9	53.8	90.6	221.21	579.6	25.2	800.79	7342.96	6255.11	114.63
0.0	49.4	92.9	684.00	1889.3	0.0	2573.33	0.0	49.4	92.9	261.71	532.6	0.0	794.35	7747.21	6599.47	0.00
0.0	45.8	94.5	756.95	1752.9	0.0	2509.85	0.0	45.8	94.5	289.61	494.2	0.0	783.80	7954.34	6775.92	0.00
0.0	41.4	95.2	790.45	1584.1	0.0	2374.51	0.0	41.4	95.2	302.43	446.6	0.0	749.01	7911.24	6739.21	0.00
0.0	35.2	94.8	773.70	1347.7	0.0	2121.38	0.0	35.2	94.8	296.02	379.9	0.0	675.97	7433.77	6332.47	0.00
0.0	27.2	93.7	720.69	1040.6	0.0	1761.32	0.0	27.2	93.7	275.74	293.4	0.0	569.12	6488.76	5527.47	438.85
0.0	16.5	91.8	634.92	629.4	0.0	1264.37	0.0	16.5	91.8	242.93	177.5	0.0	420.38	4823.74	4109.11	1398.75
0.0	0.8	89.5	527.85	32.3	0.0	560.16	0.0	0.8	89.5	201.96	9.1	0.0	211.07	1880.22	1601.67	198.28
0.0	0.0	87.1	418.54	0.0	0.0	418.54	0.0	0.0	87.1	160.14	0.0	0.0	160.14	1366.89	1164.39	0.00
0.0	0.0	85.0	323.60	0.0	0.0	323.60	0.0	0.0	85.0	123.81	0.0	0.0	123.81	1056.82	900.26	0.00
0.0	0.0	83.2	239.50	0.0	0.0	239.50	0.0	0.0	83.2	91.64	0.0	0.0	91.64	782.18	666.30	0.00
0.0	0.0	81.7	168.60	0.0	0.0	168.60	0.0	0.0	81.7	64.51	0.0	0.0	64.51	550.62	469.05	0.00
0.0	0.0	80.5	116.86	0.0	0.0	116.86	0.0	0.0	80.5	44.71	0.0	0.0	44.71	381.65	325.11	0.00
0.0	0.0	79.6	73.97	0.0	0.0	73.97	0.0	0.0	79.6	28.30	0.0	0.0	28.30	241.57	205.79	0.00
0.0	0.0	78.7	32.68	0.0	0.0	32.68	0.0	0.0	78.7	12.50	0.0	0.0	12.50	106.71	90.90	0.00
0.0	0.0	77.9	-3.13	0.0	0.0	-3.13	0.0	0.0	77.9	-1.20	0.0	0.0	-1.20	-10.22	-8.70	0.00
0.0	0.0	77.4	-29.04	0.0	0.0	-29.04	0.0	0.0	77.4	-11.11	0.0	0.0	-11.11	-94.86	-80.80	0.00
0.0	0.0	77.1	-42.02	0.0	0.0	-42.02	0.0	0.0	77.1	-16.08	0.0	0.0	-16.08	-137.23	-116.90	0.00
112.2	24.2	77.4	-29.25	924.0	4795.0	894.74	112.2	24.2	77.4	-11.19	260.5	1351.8	249.30	1566.69	1334.59	7621.62
191.7	45.7	78.2	7.06	1747.0	8166.7	1754.10	191.7	45.7	78.2	2.70	492.5	2302.4	495.23	3264.76	2781.09	11264.27
206.0	55.8	79.6	75.71	2132.2	8685.8	2207.92	206.0	55.8	79.6	28.97	601.1	2448.7	630.09	4412.42	3758.72	11184.23
185.0	59.7	81.9	178.85	2283.9	7542.4	2462.72	185.0	59.7	81.9	68.43	643.9	2126.4	712.30	5347.15	4554.98	9668.82
140.6	59.8	84.6	301.46	2287.1	5141.9	2588.55	140.6	59.8	84.6	115.34	644.8	1449.6	760.12	6115.04	5209.10	6591.51
80.9	57.5	87.6	440.26	2197.3	2006.4	2637.61	80.9	57.5	87.6	168.45	619.5	565.6	787.93	6730.71	5733.57	2572.01
12.9	53.8	90.6	578.16	2055.8	89.4	2633.98	12.9	53.8	90.6	221.21	579.6	25.2	800.79	7342.96	6255.11	114.63
0.0	49.4	92.9	684.00	1889.3	0.0	2573.33	0.0	49.4	92.9	261.71	532.6	0.0	794.35	7747.21	6599.47	0.00
0.0	45.8	94.5	756.95	1752.9	0.0	2509.85	0.0	45.8	94.5	289.61	494.2	0.0	783.80	7954.34	6775.92	0.00
0.0	41.4	95.2	790.45	1584.1	0.0	2374.51	0.0	41.4	95.2	302.43	446.6	0.0	749.01	7911.24	6739.21	0.00
0.0	35.2	94.8	773.70	1347.7	0.0	2121.38	0.0	35.2	94.8	296.02	379.9	0.0	675.97	7433.77	6332.47	0.00
0.0	27.2	93.7	720.69	1040.6	0.0	1761.32	0.0	27.2	93.7	275.74	293.4	0.0	569.12	6488.76	5527.47	438.85
0.0	16.5	91.8	634.92	629.4	0.0	1264.37	0.0	16.5	91.8	242.93	177.5	0.0	420.38	4823.74	4109.11	1398.75
0.0	0.8	89.5	527.85	32.3	0.0	560.16	0.0	0.8	89.5	201.96	9.1	0.0	211.07	1880.22	1601.67	198.28
0.0	0.0	87.1	418.54	0.0	0.0	418.54	0.0	0.0	87.1	160.14	0.0	0.0	160.14	1366.89	1164.39	0.00
0.0	0.0	85.0	323.60	0.0	0.0	323.60	0.0	0.0	85.0	123.81	0.0	0.0	123.81	1056.82	900.26	0.00
0.0	0.0	83.2	239.50	0.0	0.0	239.50	0.0	0.0	83.2	91.64	0.0	0.0	91.64	782.18	666.30	0.00
0.0	0.0	81.7	168.60	0.0	0.0	168.60	0.0	0.0	81.7	64.51	0.0	0.0	64.51	550.62	469.05	0.00
0.0	0.0	80.5	116.86	0.0	0.0	116.86	0.0	0.0	80.5	44.71	0.0	0.0	44.71	381.65	325.11	0.00
0.0	0.0	79.6	73.97	0.0	0.0	73.97	0.0	0.0	79.6	28.30	0.0	0.0	28.30	241.57	205.79	0.00
0.0	0.0	78.7	32.68	0.0	0.0	32.68	0.0	0.0	78.7	12.50	0.0	0.0	12.50	106.71	90.90	0.00
0.0	0.0	77.9	-3.13	0.0	0.0	-3.13	0.0	0.0	77.9	-1.20	0.0	0.0	-1.20	-10.22	-8.70	0.00
0.0	0.0	77.4	-29.04	0.0	0.0	-29.04	0.0	0.0	77.4	-11.11	0.0	0.0	-11.11	-94.86	-80.80	0.00
0.0	0.0	77.1	-42.02	0.0	0.0	-42.02	0.0	0.0	77.1	-16.08	0.0	0.0	-16.08	-137.23	-116.90	0.00
112.2	24.2	77.4	-29.25	924.0	4795.0	894.74	112.2	24.2	77.4	-11.19	260.5	1351.8	249.30	1566.69	1334.59	7621.62
191.7	45.7	78.2	7.06	1747.0	8166.7	1754.10	191.7	45.7	78.2	2.70	492.5	2302.4	495.23	3264.76	2781.09	11264.27
206.0	55.8	79.6	75.71	2132.2	8685.8	2207.92	206.0	55.8	79.6	28.97	601.1	2448.7	630.09	4412.42	3758.72	11184.23
185.0	59.7	81.9	178.85	2283.9	7542.4	2462.72	185.0	59.7	81.9	68.43	643.9	2126.4	712.30	5347.15	4554.98	9668.82
140.6	59.8	84.6	301.46	2287.1	5141.9	2588.55	140.6	59.8	84.6	115.34	644.8	1449.6	760.12	6115.04	5209.10	6591.51
80.9	57.5	87.6	440.26	2197.3	2006.4	2637.61	80.9	57.5	87.6	168.45	619.5	565.6	787.93	6730.71	5733.57	2572.01
12.9	53.8	90.6	578.16	2055.8	89.4	2633.98	12.9	53.8	90.6	221.21	579.6	25.2	800.79	7342.96	6255.11	114.63
0.0	49.4	92.9	684.00	1889.3	0.0	2573.33	0.0	49.4	92.9	261.71	532.6	0.0	794.35	7747.21	6599.47	0.00
0.0	45.8	94.5	756.95	1752.9	0.0	2509.85	0.0	45.8	94.5	289.61	494.2	0.0	783.80	7954.34	6775.92	0.00
0.0	41.4	95.2	790.45	1584.1	0.0	2374.51	0.0	41.4	95.2	302.43	446.6	0.0	749.01	7911.24	6739.21	0.00
0.0	35.2	94.8	773.70	1347.7	0.0	2121.38	0.0	35.2	94.8	296.02	379.9	0.0	675.97	7433.77	6332.47	0.00
0.0	27.2	93.7	720.69	1040.6	0.0	1761.32	0.0	27.2	93.7	275.74	293.4	0.0	569.12	6488.76	5527.47	438.85
0.0	16.5	91.8	634.92	629.4	0.0	1264.37	0.0	16.5	91.8	242.93	177.5	0.0	420.38	4823.74	4109.11	1398.75
0.0	0.8	89.5	527.85	32.3	0.0	560.16	0.0	0.8	89.5	201.96	9.1	0.0	211.07	1880.22	1601.67	198.28
0.0	0.0	87.1	418.54	0.0	0.0	418.54	0.0	0.0	87.1	160.14	0.0	0.0	160.14	1366.89	1164.39	0.00
0.0	0.0	85.0	323.60	0.0	0.0	323.60	0.0	0.0	85.0	123.81	0.0	0.0	123.81	1056.82	900.26	0.00
0.0	0.0	83.2	239.50	0.0	0.0	239.50	0.0	0.0	83.2	91.64	0.0	0.0	91.64	782.18	666.30	0.00
0.0	0.0	81.7	168.60	0.0	0.0	168.60	0.0	0.0	81.7	64.51	0.0	0.0	64.51	550.62	469.05	0.00

Infiltration: 1_Office

Convection	1
Radiation	0

		N Brick Ven Stud				
Time	**Time**	**OA DB Temp (F)**	**q_{sens} (Btu/hr)**	**q_{latent} (Btu/hr)**	**q_{conv} (Btu/hr)**	**q_{rad} (Btu/hr)**
1:00		83.6	0	0	0.00	0.00
2:00		82.6	0	0	0.00	0.00
3:00		81.7	0	0	0.00	0.00
4:00		80.9	0	0	0.00	0.00
5:00		80.4	0	0	0.00	0.00
6:00		80.1	0	0	0.00	0.00
7:00		80.4	0	0	0.00	0.00
8:00		81.1	0	0	0.00	0.00
9:00		82.6	0	0	0.00	0.00
10:00		84.8	0	0	0.00	0.00
11:00		87.5	0	0	0.00	0.00
12:00		90.5	0	0	0.00	0.00
13:00		93.5	0	0	0.00	0.00
14:00		95.8	0	0	0.00	0.00
15:00		97.4	0	0	0.00	0.00
16:00		98.2	0	0	0.00	0.00
17:00		97.8	0	0	0.00	0.00
18:00		96.7	0	0	0.00	0.00
19:00		94.8	0	0	0.00	0.00
20:00		92.5	0	0	0.00	0.00
21:00		90.1	0	0	0.00	0.00
22:00		88.1	0	0	0.00	0.00
23:00		86.2	0	0	0.00	0.00
0:00		84.7	0	0	0.00	0.00
1:00	**1**	83.6	0	0	0.00	0.00
2:00	**2**	82.6	0	0	0.00	0.00
3:00	**3**	81.7	0	0	0.00	0.00
4:00	**4**	80.9	0	0	0.00	0.00
5:00	**5**	80.4	0	0	0.00	0.00
6:00	**6**	80.1	0	0	0.00	0.00
7:00	**7**	80.4	0	0	0.00	0.00
8:00	**8**	81.1	0	0	0.00	0.00
9:00	**9**	82.6	0	0	0.00	0.00
10:00	**10**	84.8	0	0	0.00	0.00
11:00	**11**	87.5	0	0	0.00	0.00
12:00	**12**	90.5	0	0	0.00	0.00
13:00	**13**	93.5	0	0	0.00	0.00
14:00	**14**	95.8	0	0	0.00	0.00
15:00	**15**	97.4	0	0	0.00	0.00
16:00	**16**	98.2	0	0	0.00	0.00
17:00	**17**	97.8	0	0	0.00	0.00
18:00	**18**	96.7	0	0	0.00	0.00
19:00	**19**	94.8	0	0	0.00	0.00
20:00	**20**	92.5	0	0	0.00	0.00
21:00	**21**	90.1	0	0	0.00	0.00
22:00	**22**	88.1	0	0	0.00	0.00
23:00	**23**	86.2	0	0	0.00	0.00
0:00	**24**	84.7	0	0	0.00	0.00
1:00	**25**	83.6	0	0	0.00	0.00
2:00	**26**	82.6	0	0	0.00	0.00
3:00	**27**	81.7	0	0	0.00	0.00
4:00	**28**	80.9	0	0	0.00	0.00
5:00	**29**	80.4	0	0	0.00	0.00
6:00	**30**	80.1	0	0	0.00	0.00
7:00	**31**	80.4	0	0	0.00	0.00
8:00	**32**	81.1	0	0	0.00	0.00
9:00	**33**	82.6	0	0	0.00	0.00
10:00	**34**	84.8	0	0	0.00	0.00
11:00	**35**	87.5	0	0	0.00	0.00
12:00	**36**	90.5	0	0	0.00	0.00
13:00	**37**	93.5	0	0	0.00	0.00
14:00	**38**	95.8	0	0	0.00	0.00
15:00	**39**	97.4	0	0	0.00	0.00
16:00	**40**	98.2	0	0	0.00	0.00
17:00	**41**	97.8	0	0	0.00	0.00
18:00	**42**	96.7	0	0	0.00	0.00
19:00	**43**	94.8	0	0	0.00	0.00
20:00	**44**	92.5	0	0	0.00	0.00
21:00	**45**	90.1	0	0	0.00	0.00
22:00	**46**	88.1	0	0	0.00	0.00
23:00	**47**	86.2	0	0	0.00	0.00
0:00	**48**	84.7	0	0	0.00	0.00

Internal Gain: 1_Office

Convection	0.4	**Convection**	0.46	**Convection**	0.75
Radiation	0.6	**Radiation**	0.54	**Radiation**	0.25

		Occupancy					**Lighting**				**Misc. 1**			
Time	**Time**	**Schedule**	**q (Btu/hr)**	**q_{conv} (Btu/hr)**	**q_{rad} (Btu/hr)**	**q_{latent} (Btu/hr)**	**Schedule**	**q (Btu/hr)**	**q_{conv} (Btu/hr)**	**q_{rad} (Btu/hr)**	**Schedule**	**q (Btu/hr)**	**q_{conv} (Btu/hr)**	**q_{rad} (Btu/hr)**
1:00		0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
2:00		0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
3:00		0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
4:00		0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
5:00		0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
6:00		0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
7:00		1	18750	7500	11250	15000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
8:00		1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
9:00		1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
10:00		1	18750	7500	11250	15000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
11:00		0.8	15000	6000	9000	12000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
12:00		0.4	7500	3000	4500	6000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
13:00		0.8	15000	6000	9000	12000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
14:00		1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
15:00		1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
16:00		1	18750	7500	11250	15000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
17:00		0.3	5625	2250	3375	4500	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
18:00		0.1	1875	750	1125	1500	0.7	15317.7	7046.12	8271.54	0.7	60428.1	45321.1	15107
19:00		0.1	1875	750	1125	1500	0.6	13129.4	6039.53	7089.89	0.6	51795.5	38846.6	12948.9
20:00		0.1	1875	750	1125	1500	0.4	8752.95	4026.36	4726.59	0.4	34530.3	25897.8	8632.59
21:00		0.1	1875	750	1125	1500	0.3	6564.71	3019.77	3544.94	0.3	25897.8	19423.3	6474.44
22:00		0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29
23:00		0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29
0:00		0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29
1:00	**1**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
2:00	**2**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
3:00	**3**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
4:00	**4**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
5:00	**5**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
6:00	**6**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
7:00	**7**	1	18750	7500	11250	15000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
8:00	**8**	1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
9:00	**9**	1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
10:00	**10**	1	18750	7500	11250	15000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
11:00	**11**	0.8	15000	6000	9000	12000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
12:00	**12**	0.4	7500	3000	4500	6000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
13:00	**13**	0.8	15000	6000	9000	12000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
14:00	**14**	1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
15:00	**15**	1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
16:00	**16**	1	18750	7500	11250	15000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
17:00	**17**	0.3	5625	2250	3375	4500	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
18:00	**18**	0.1	1875	750	1125	1500	0.7	15317.7	7046.12	8271.54	0.7	60428.1	45321.1	15107
19:00	**19**	0.1	1875	750	1125	1500	0.6	13129.4	6039.53	7089.89	0.6	51795.5	38846.6	12948.9
20:00	**20**	0.1	1875	750	1125	1500	0.4	8752.95	4026.36	4726.59	0.4	34530.3	25897.8	8632.59
21:00	**21**	0.1	1875	750	1125	1500	0.3	6564.71	3019.77	3544.94	0.3	25897.8	19423.3	6474.44
22:00	**22**	0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29
23:00	**23**	0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29
0:00	**24**	0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29
1:00	**25**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
2:00	**26**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
3:00	**27**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
4:00	**28**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
5:00	**29**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
6:00	**30**	0	0	0	0	0	0.05	1094.12	503.295	590.824	0.05	4316.29	3237.22	1079.07
7:00	**31**	1	18750	7500	11250	15000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
8:00	**32**	1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
9:00	**33**	1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
10:00	**34**	1	18750	7500	11250	15000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
11:00	**35**	0.8	15000	6000	9000	12000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
12:00	**36**	0.4	7500	3000	4500	6000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
13:00	**37**	0.8	15000	6000	9000	12000	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
14:00	**38**	1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
15:00	**39**	1	18750	7500	11250	15000	0.9	19694.1	9059.3	10634.8	0.9	77693.3	58270	19423.3
16:00	**40**	1	18750	7500	11250	15000	0.95	20788.3	9562.6	11225.7	0.95	82009.6	61507.2	20502.4
17:00	**41**	0.3	5625	2250	3375	4500	0.8	17505.9	8052.71	9453.18	0.8	69060.7	51795.5	17265.2
18:00	**42**	0.1	1875	750	1125	1500	0.7	15317.7	7046.12	8271.54	0.7	60428.1	45321.1	15107
19:00	**43**	0.1	1875	750	1125	1500	0.6	13129.4	6039.53	7089.89	0.6	51795.5	38846.6	12948.9
20:00	**44**	0.1	1875	750	1125	1500	0.4	8752.95	4026.36	4726.59	0.4	34530.3	25897.8	8632.59
21:00	**45**	0.1	1875	750	1125	1500	0.3	6564.71	3019.77	3544.94	0.3	25897.8	19423.3	6474.44
22:00	**46**	0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29
23:00	**47**	0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29
0:00	**48**	0.05	937.5	375	562.5	750	0.2	4376.47	2013.18	2363.3	0.2	17265.2	12948.9	4316.29

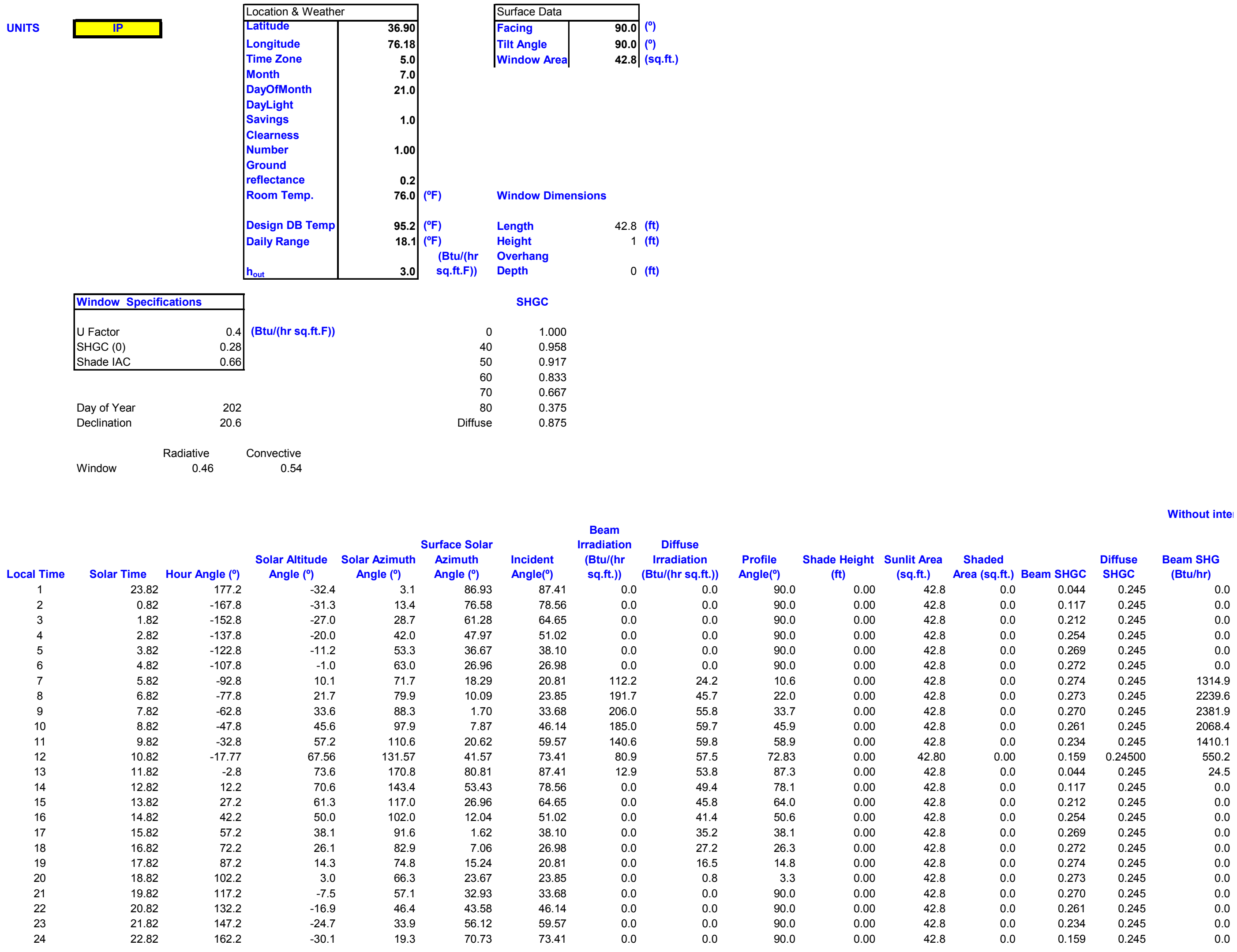
Radiant Floor Slab Performance: 1_Office

a 0.0992

Time	Time	Floor q_{Beam} (BTU/hr)	αq_{Beam} (BTU/hr)	IA Temp (F)	GPM	b	Slab Surface (F)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{water} (Btu/hr)
1:00		0.00	0.00	78	0	7.74	75.00	-5859	-21048	0
2:00		0.00	0.00	78	60	6.08	73.64	-8518	-30600	150000
3:00		0.00	0.00	78	60	6.08	72.41	-10913	-39205	150000
4:00		0.00	0.00	78	60	6.08	71.31	-13070	-46955	150000
5:00		0.00	0.00	78	60	6.08	70.31	-15014	-53937	150000
6:00		0.00	0.00	78	60	6.08	69.42	-16764	-60227	150000
7:00		7621.62	4572.97	78	50	6.41	68.94	-17702	-63598	125000
8:00		11264.27	6758.56	78	50	6.43	68.53	-18500	-66464	125000
9:00		11184.23	6710.54	78	40	6.71	68.43	-18680	-67110	100000
10:00		9668.82	5801.29	78	40	6.70	68.34	-18862	-67763	100000
11:00		6591.51	3954.91	78	40	6.68	68.24	-19065	-68494	100000
12:00		2572.01	1543.21	78	40	6.65	68.12	-19301	-69339	100000
13:00		114.63	68.78	78	40	6.63	67.99	-19545	-70216	100000
14:00		0.00	0.00	78	30	6.91	68.16	-19226	-69070	75000
15:00		0.00	0.00	78	30	6.91	68.30	-18939	-68038	75000
16:00		0.00	0.00	78	30	6.91	68.43	-18680	-67109	75000
17:00		0.00	0.00	78	0	7.74	69.38	-16827	-60452	0
18:00		438.85	263.31	78	0	7.74	70.24	-15152	-54435	0
19:00		1398.75	839.25	78	0	7.75	71.02	-13631	-48970	0
20:00		198.28	118.97	78	0	7.74	71.71	-12276	-44103	0
21:00		0.00	0.00	78	0	7.74	72.34	-11058	-39728	0
22:00		0.00	0.00	78	0	7.74	72.90	-9961	-35787	0
23:00		0.00	0.00	78	0	7.74	73.41	-8973	-32237	0
0:00		0.00	0.00	78	0	7.74	73.86	-8083	-29039	0
1:00	1	0.00	0.00	78	0	7.74	74.27	-7281	-26158	0
2:00	2	0.00	0.00	78	60	6.08	72.98	-9799	-35203	150000
3:00	3	0.00	0.00	78	60	6.08	71.82	-12067	-43351	150000
4:00	4	0.00	0.00	78	60	6.08	70.78	-14110	-50691	150000
5:00	5	0.00	0.00	78	60	6.08	69.83	-15950	-57302	150000
6:00	6	0.00	0.00	78	60	6.08	68.98	-17608	-63258	150000
7:00	7	7621.62	4572.97	78	50	6.41	68.55	-18462	-66328	125000
8:00	8	11264.27	6758.56	78	40	6.71	68.45	-18645	-66984	100000
9:00	9	11184.23	6710.54	78	40	6.71	68.37	-18810	-67578	100000
10:00	10	9668.82	5801.29	78	40	6.70	68.28	-18979	-68184	100000
11:00	11	6591.51	3954.91	78	40	6.68	68.18	-19171	-68873	100000
12:00	12	2572.01	1543.21	78	40	6.65	68.07	-19396	-69681	100000
13:00	13	114.63	68.78	78	40	6.63	67.95	-19630	-70524	100000
14:00	14	0.00	0.00	78	30	6.91	68.12	-19303	-69348	75000
15:00	15	0.00	0.00	78	30	6.91	68.27	-19008	-68288	75000
16:00	16	0.00	0.00	78	30	6.91	68.40	-18743	-67334	75000
17:00	17	0.00	0.00	78	0	7.74	69.35	-16883	-60655	0
18:00	18	438.85	263.31	78	0	7.74	70.22	-15203	-54617	0
19:00	19	1398.75	839.25	78	0	7.75	71.00	-13677	-49134	0
20:00	20	198.28	118.97	78	0	7.74	71.69	-12317	-44251	0
21:00	21	0.00	0.00	78	0	7.74	72.32	-11095	-39861	0
22:00	22	0.00	0.00	78	0	7.74	72.88	-9995	-35907	0
23:00	23	0.00	0.00	78	0	7.74	73.39	-9003	-32345	0
0:00	24	0.00	0.00	78	0	7.74	73.85	-8110	-29136	0
1:00	25	0.00	0.00	78	0	7.74	74.26	-7306	-26246	0
2:00	26	0.00	0.00	78	60	6.08	72.97	-9821	-35282	150000
3:00	27	0.00	0.00	78	60	6.08	71.81	-12087	-43422	150000
4:00	28	0.00	0.00	78	60	6.08	70.77	-14128	-50755	150000
5:00	29	0.00	0.00	78	60	6.08	69.82	-15966	-57360	150000
6:00	30	0.00	0.00	78	60	6.08	68.98	-17622	-63310	150000
7:00	31	7621.62	4572.97	78	50	6.41	68.54	-18475	-66375	125000
8:00	32	11264.27	6758.56	78	40	6.71	68.45	-18657	-67026	100000
9:00	33	11184.23	6710.54	78	40	6.71	68.36	-18821	-67616	100000
10:00	34	9668.82	5801.29	78	40	6.70	68.28	-18989	-68218	100000
11:00	35	6591.51	3954.91	78	40	6.68	68.18	-19180	-68904	100000
12:00	36	2572.01	1543.21	78	40	6.65	68.06	-19404	-69709	100000
13:00	37	114.63	68.78	78	40	6.63	67.94	-19637	-70549	100000
14:00	38	0.00	0.00	78	30	6.91	68.11	-19309	-69370	75000
15:00	39	0.00	0.00	78	30	6.91	68.26	-19014	-68309	75000
16:00	40	0.00	0.00	78	30	6.91	68.40	-18748	-67353	75000
17:00	41	0.00	0.00	78	0	7.74	69.35	-16888	-60671	0
18:00	42	438.85	263.31	78	0	7.74	70.21	-15207	-54632	0
19:00	43	1398.75	839.25	78	0	7.75	70.99	-13680	-49148	0
20:00	44	198.28	118.97	78	0	7.74	71.69	-12321	-44263	0
21:00	45	0.00	0.00	78	0	7.74	72.32	-11098	-39872	0
22:00	46	0.00	0.00	78	0	7.74	72.88	-9997	-35917	0
23:00	47	0.00	0.00	78	0	7.74	73.39	-9006	-32354	0
0:00	48	0.00	0.00	78	0	7.74	73.85	-8112	-29144	0

Example ASHRAE Load Calculation Applications Manual Spreadsheet:

- Window Gain



UNITS IP

Location & Weather		
Latitude	**36.90**	
Longitude	**76.18**	
Time Zone	**5.0**	
Month	**7.0**	
DayOfMonth	**21.0**	
DayLight Savings	**1.0**	
Clearness Number	**1.00**	
Ground reflectance	**0.2**	
Room Temp.	**76.0**	**(ºF)**
Design DB Temp	**95.2**	**(ºF)**
Daily Range	**18.1**	**(ºF)**
h$_{out}$	**3.0**	**(Btu/(hr sq.ft.F))**

Surface Data		
Facing	**90.0**	**(º)**
Tilt Angle	**90.0**	**(º)**
Window Area	**42.8**	**(sq.ft.)**

Window Dimensions

Length	42.8	**(ft)**
Height	1	**(ft)**
Overhang Depth	0	**(ft)**

Window Specifications		
U Factor	0.4	**(Btu/(hr sq.ft.F))**
SHGC (0)	0.28	
Shade IAC	0.66	

	SHGC
0	1.000
40	0.958
50	0.917
60	0.833
70	0.667
80	0.375
Diffuse	0.875

Day of Year	202
Declination	20.6

	Radiative	Convective
Window	0.46	0.54

Without inte

Local Time	**Solar Time**	**Hour Angle (º)**	**Solar Altitude Angle (º)**	**Solar Azimuth Angle (º)**	**Surface Solar Azimuth Angle (º)**	**Incident Angle(º)**	**Beam Irradiation (Btu/(hr sq.ft.))**	**Diffuse Irradiation (Btu/(hr sq.ft.))**	**Profile Angle(º)**	**Shade Height (ft)**	**Sunlit Area (sq.ft.)**	**Shaded Area (sq.ft.)**	**Beam SHGC**	**Diffuse SHGC**	**Beam SHG (Btu/hr)**
1	23.82	177.2	-32.4	3.1	86.93	87.41	0.0	0.0	90.0	0.00	42.8	0.0	0.044	0.245	0.0
2	0.82	-167.8	-31.3	13.4	76.58	78.56	0.0	0.0	90.0	0.00	42.8	0.0	0.117	0.245	0.0
3	1.82	-152.8	-27.0	28.7	61.28	64.65	0.0	0.0	90.0	0.00	42.8	0.0	0.212	0.245	0.0
4	2.82	-137.8	-20.0	42.0	47.97	51.02	0.0	0.0	90.0	0.00	42.8	0.0	0.254	0.245	0.0
5	3.82	-122.8	-11.2	53.3	36.67	38.10	0.0	0.0	90.0	0.00	42.8	0.0	0.269	0.245	0.0
6	4.82	-107.8	-1.0	63.0	26.96	26.98	0.0	0.0	90.0	0.00	42.8	0.0	0.272	0.245	0.0
7	5.82	-92.8	10.1	71.7	18.29	20.81	112.2	24.2	10.6	0.00	42.8	0.0	0.274	0.245	1314.9
8	6.82	-77.8	21.7	79.9	10.09	23.85	191.7	45.7	22.0	0.00	42.8	0.0	0.273	0.245	2239.6
9	7.82	-62.8	33.6	88.3	1.70	33.68	206.0	55.8	33.7	0.00	42.8	0.0	0.270	0.245	2381.9
10	8.82	-47.8	45.6	97.9	7.87	46.14	185.0	59.7	45.9	0.00	42.8	0.0	0.261	0.245	2068.4
11	9.82	-32.8	57.2	110.6	20.62	59.57	140.6	59.8	58.9	0.00	42.8	0.0	0.234	0.245	1410.1
12	10.82	-17.77	67.56	131.57	41.57	73.41	80.9	57.5	72.83	0.00	42.80	0.00	0.159	0.24500	550.2
13	11.82	-2.8	73.6	170.8	80.81	87.41	12.9	53.8	87.3	0.00	42.8	0.0	0.044	0.245	24.5
14	12.82	12.2	70.6	143.4	53.43	78.56	0.0	49.4	78.1	0.00	42.8	0.0	0.117	0.245	0.0
15	13.82	27.2	61.3	117.0	26.96	64.65	0.0	45.8	64.0	0.00	42.8	0.0	0.212	0.245	0.0
16	14.82	42.2	50.0	102.0	12.04	51.02	0.0	41.4	50.6	0.00	42.8	0.0	0.254	0.245	0.0
17	15.82	57.2	38.1	91.6	1.62	38.10	0.0	35.2	38.1	0.00	42.8	0.0	0.269	0.245	0.0
18	16.82	72.2	26.1	82.9	7.06	26.98	0.0	27.2	26.3	0.00	42.8	0.0	0.272	0.245	0.0
19	17.82	87.2	14.3	74.8	15.24	20.81	0.0	16.5	14.8	0.00	42.8	0.0	0.274	0.245	0.0
20	18.82	102.2	3.0	66.3	23.67	23.85	0.0	0.8	3.3	0.00	42.8	0.0	0.273	0.245	0.0
21	19.82	117.2	-7.5	57.1	32.93	33.68	0.0	0.0	90.0	0.00	42.8	0.0	0.270	0.245	0.0
22	20.82	132.2	-16.9	46.4	43.58	46.14	0.0	0.0	90.0	0.00	42.8	0.0	0.261	0.245	0.0
23	21.82	147.2	-24.7	33.9	56.12	59.57	0.0	0.0	90.0	0.00	42.8	0.0	0.234	0.245	0.0
24	22.82	162.2	-30.1	19.3	70.73	73.41	0.0	0.0	90.0	0.00	42.8	0.0	0.159	0.245	0.0

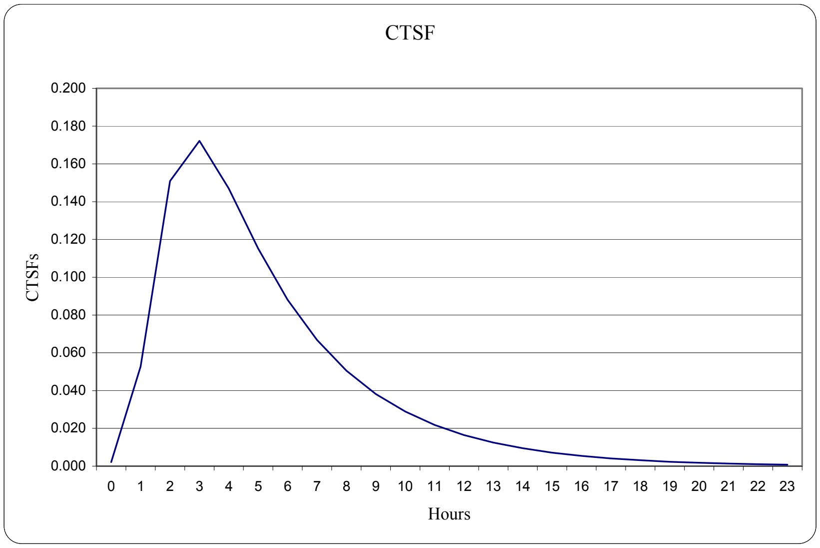
Example ASHRAE Load Calculation Applications Manual Spreadsheet:

- Conduction Transfer Series Factor (CTSF) Generation
- Veneer Wall with Stud Backup

UNITS	**IP**
	Layer Code
	F01
	A7
	F04
	I03
	G01
	F02

Enter layer codes from outside to inside.

Overall U	0.05646
0	0.002
1	0.053
2	0.151
3	0.172
4	0.147
5	0.115
6	0.088
7	0.067
8	0.051
9	0.038
10	0.029
11	0.022
12	0.017
13	0.013
14	0.009
15	0.007
16	0.005
17	0.004
18	0.003
19	0.002
20	0.002
21	0.001
22	0.001
23	0.001



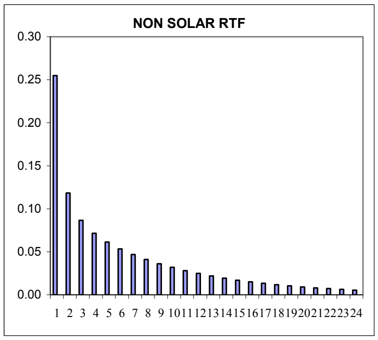
sum	1.000000
R	17.710

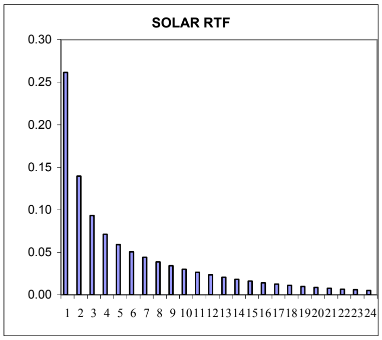
Example ASHRAE Load Calculation Applications Manual Spreadsheet:

- Radiant Time Series Factor (RTF) Generation
- 1_Office

	Units	**IP**															
1	**Surface ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
2	**Surface Name**	ick Veneer	ick Veneer	ick Veneer	Window 1	Window 2	Window 3	Window 4	Roof	Floor	Furniture	Parition 1	Partition 2	Parition 3	Partition 4	Parition 5	Partition 6
3	**Facing**	0.0	270.0	90.0	0.0	270.0	90.0	90.0	0.0	0.0	0.0	0.0	90.0	270.0	0.0	0.0	0.0
4	**Tilt Angle**	90.0	90.0	90.0	90.0	90.0	90.0	90.0	0.0	180.0	180.0	90.0	90.0	90.0	0.0	180.0	180.0
5	**Area**	770.0	1540.00	975.0	172.0	364.5	115.0	44.0	7233.0	7233.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0
6	**LW Emissivity In**	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
7	**Boundary Cond**	TA	TA	TA	TA	TA	TA	TA	TA	TA	TA	TA	TA	TA	TA	TA	TA
8	**Number of Layers**	6	6	6	5	5	5	5	6	3	3	5	5	5	5	5	5
	Layer1	F01	F01	F01	E0	E0	E0	E0	E0	E0	E0	E0	E0	E0	E0	E0	E0
	Layer2	A7	A7	A7	W1	W1	W1	W1	M11	M14	B7	E1	E1	E1	E1	E1	E1
	Layer3	F04	F04	F04	B1	B1	B1	B1	F08	E0	E0	B1	B1	B1	B1	B1	B1
	Layer4	I03	I03	I03	W1	W1	W1	W1	E4			E1	E1	E1	E1	E1	E1
	Layer5	G01	G01	G01	E0	E0	E0	E0	E5			E0	E0	E0	E0	E0	E0
	Layer6	F02	F02	F02					E0								
	Layer7																
	Layer8																
	Layer9																
	Layer10																

RTF coefficients	**NSolar**	**Solar**
	0.25	0.26
	0.12	0.14
	0.09	0.09
	0.07	0.07
	0.06	0.06
	0.05	0.05
	0.05	0.04
	0.04	0.04
	0.04	0.03
	0.03	0.03
	0.03	0.03
	0.02	0.02
	0.02	0.02
	0.02	0.02
	0.02	0.02
	0.02	0.01
	0.01	0.01
	0.01	0.01
	0.01	0.01
	0.01	0.01
	0.01	0.01
	0.01	0.01
	0.01	0.01
	0.01	0.01
	1.00	1.01





Note:
The purpose of this spreadsheet is to generate Radiant Time Factors for building zones. The user can add more surfaces to the zone in columns M, N, etc. by following the format in columns C:L. Currently only 20 surfaces per zone are allowed, though that limit could be changed in the VBA code.

1. Surface ID numbers should be assigned sequentially.
2. Surface Name is at the discretion of the user.
3. Facing Angle is degrees clockwise from north.
4. Tilt angle is degrees above horizontal.
5. Surface area is in square feet (IP) or square meters (SI)
6. Long wave emissivities are used to estimate radiation distributions.
7. All boundary conditions should be set to "TA"
8. The number of layers, including surface conductances, should be set, then in the following rows, layers are specified from the outside to the inside. Additional layers can be added into the LAYERS IP or LAYERS SI worksheets; then using the unit conversion button, the layers for the other worksheet will be synchronized.

Zone Load Summary: 1_Office – Part 1

		Ext Wall		Window		Beam	Roof		Infiltration			Occ.			Lighting		Misc.		Floor		
Time	Time	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{rad} (Btu/hr)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{lat} (Btu/hr)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{lat} (Btu/hr)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	$1-\alpha q_{Beam}$ (BTU/hr)
1:00		2624.24	2537.83	381.65	325.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-5858.73	-21048.03	0.00
2:00		2105.33	2538.83	241.57	205.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-8517.54	-30600.07	0.00
3:00		1675.77	2539.83	106.71	90.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-10912.60	-39204.54	0.00
4:00		1320.92	2540.83	-10.22	-8.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-13070.07	-46955.45	0.00
5:00		1026.29	2541.83	-94.86	-80.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-15013.52	-53937.47	0.00
6:00		781.02	2542.83	-137.23	-116.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-16764.18	-60226.87	0.00
7:00		581.97	2543.83	1566.69	1334.59	7621.62	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	8052.71	9453.18	51795.51	17265.17	-17702.40	-63597.50	3048.65
8:00		531.76	2544.83	3264.76	2781.09	11264.27	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-18500.34	-66464.17	4505.71
9:00		798.51	2545.83	4412.42	3758.72	11184.23	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-18680.15	-67110.18	4473.69
10:00		1302.94	2546.83	5347.15	4554.98	9668.82	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9562.60	11225.66	61507.17	20502.39	-18861.77	-67762.67	3867.53
11:00		1858.20	2547.83	6115.04	5209.10	6591.51	0.00	0.00	0.00	0.00	0.00	6000.00	9000.00	12000.00	9562.60	11225.66	61507.17	20502.39	-19065.26	-68493.72	2636.60
12:00		2353.53	2548.83	6730.71	5733.57	2572.01	0.00	0.00	0.00	0.00	0.00	3000.00	4500.00	6000.00	8052.71	9453.18	51795.51	17265.17	-19300.65	-69339.39	1028.81
13:00		2737.89	2549.83	7342.96	6255.11	114.63	0.00	0.00	0.00	0.00	0.00	6000.00	9000.00	12000.00	8052.71	9453.18	51795.51	17265.17	-19544.54	-70215.58	45.85
14:00		2993.66	2550.83	7747.21	6599.47	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-19225.72	-69070.20	0.00
15:00		3198.13	2551.83	7954.34	6775.92	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-18938.53	-68038.43	0.00
16:00		3517.52	2552.83	7911.24	6739.21	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9562.60	11225.66	61507.17	20502.39	-18679.83	-67109.02	0.00
17:00		3999.41	2553.83	7433.77	6332.47	0.00	0.00	0.00	0.00	0.00	0.00	2250.00	3375.00	4500.00	8052.71	9453.18	51795.51	17265.17	-16826.79	-60451.81	0.00
18:00		4566.35	2554.83	6488.76	5527.47	438.85	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	7046.12	8271.54	45321.07	15107.02	-15151.89	-54434.55	175.54
19:00		5095.31	2555.83	4823.74	4109.11	1398.75	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	6039.53	7089.89	38846.63	12948.88	-13630.69	-48969.52	559.50
20:00		5437.86	2556.83	1880.22	1601.67	198.28	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	4026.36	4726.59	25897.76	8632.59	-12275.96	-44102.51	79.31
21:00		5345.57	2557.83	1366.89	1164.39	0.00	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	3019.77	3544.94	19423.32	6474.44	-11058.18	-39727.54	0.00
22:00		4741.20	2558.83	1056.82	900.26	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-9961.21	-35786.57	0.00
23:00		3967.70	2559.83	782.18	666.30	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-8973.06	-32236.54	0.00
0:00		3244.46	2560.83	550.62	469.05	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-8082.93	-29038.68	0.00
1:00	**1**	2624.24	2235.46	381.65	325.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-7281.10	-26158.04	0.00
2:00	**2**	2105.33	1793.43	241.57	205.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-9798.82	-35203.16	0.00
3:00	**3**	1675.77	1427.51	106.71	90.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-12066.78	-43351.01	0.00
4:00	**4**	1320.92	1125.23	-10.22	-8.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-14109.75	-50690.59	0.00
5:00	**5**	1026.29	874.25	-94.86	-80.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-15950.06	-57302.08	0.00
6:00	**6**	781.02	665.32	-137.23	-116.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-17607.82	-63257.72	0.00
7:00	**7**	581.97	495.75	1566.69	1334.59	7621.62	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	8052.71	9453.18	51795.51	17265.17	-18462.35	-66327.69	3048.65
8:00	**8**	531.76	452.98	3264.76	2781.09	11264.27	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-18644.90	-66983.52	4505.71
9:00	**9**	798.51	680.22	4412.42	3758.72	11184.23	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-18810.38	-67578.01	4473.69
10:00	**10**	1302.94	1109.91	5347.15	4554.98	9668.82	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9562.60	11225.66	61507.17	20502.39	-18979.08	-68184.10	3867.53
11:00	**11**	1858.20	1582.91	6115.04	5209.10	6591.51	0.00	0.00	0.00	0.00	0.00	6000.00	9000.00	12000.00	9562.60	11225.66	61507.17	20502.39	-19170.93	-68873.33	2636.60
12:00	**12**	2353.53	2004.86	6730.71	5733.57	2572.01	0.00	0.00	0.00	0.00	0.00	3000.00	4500.00	6000.00	8052.71	9453.18	51795.51	17265.17	-19395.84	-69681.34	1028.81
13:00	**13**	2737.89	2332.27	7342.96	6255.11	114.63	0.00	0.00	0.00	0.00	0.00	6000.00	9000.00	12000.00	8052.71	9453.18	51795.51	17265.17	-19630.29	-70523.62	45.85
14:00	**14**	2993.66	2550.15	7747.21	6599.47	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-19302.96	-69347.68	0.00
15:00	**15**	3198.13	2724.34	7954.34	6775.92	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-19008.11	-68288.39	0.00
16:00	**16**	3517.52	2996.40	7911.24	6739.21	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9562.60	11225.66	61507.17	20502.39	-18742.50	-67334.18	0.00
17:00	**17**	3999.41	3406.91	7433.77	6332.47	0.00	0.00	0.00	0.00	0.00	0.00	2250.00	3375.00	4500.00	8052.71	9453.18	51795.51	17265.17	-16883.25	-60654.63	0.00
18:00	**18**	4566.35	3889.85	6488.76	5527.47	438.85	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	7046.12	8271.54	45321.07	15107.02	-15202.74	-54617.26	175.54
19:00	**19**	5095.31	4340.45	4823.74	4109.11	1398.75	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	6039.53	7089.89	38846.63	12948.88	-13676.50	-49134.10	559.50
20:00	**20**	5437.86	4632.25	1880.22	1601.67	198.28	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	4026.36	4726.59	25897.76	8632.59	-12317.22	-44250.76	79.31
21:00	**21**	5345.57	4553.63	1366.89	1164.39	0.00	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	3019.77	3544.94	19423.32	6474.44	-11095.35	-39861.09	0.00
22:00	**22**	4741.20	4038.80	1056.82	900.26	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-9994.70	-35906.87	0.00
23:00	**23**	3967.70	3379.89	782.18	666.30	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-9003.22	-32344.91	0.00
0:00	**24**	3244.46	2763.80	550.62	469.05	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-8110.10	-29136.29	0.00
1:00	**25**	2624.24	2235.46	381.65	325.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-7305.58	-26245.97	0.00
2:00	**26**	2105.33	1793.43	241.57	205.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-9820.87	-35282.37	0.00
3:00	**27**	1675.77	1427.51	106.71	90.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-12086.64	-43422.36	0.00
4:00	**28**	1320.92	1125.23	-10.22	-8.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-14127.64	-50754.86	0.00
5:00	**29**	1026.29	874.25	-94.86	-80.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-15966.18	-57359.98	0.00
6:00	**30**	781.02	665.32	-137.23	-116.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	503.29	590.82	3237.22	1079.07	-17622.33	-63309.87	0.00
7:00	**31**	581.97	495.75	1566.69	1334.59	7621.62	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	8052.71	9453.18	51795.51	17265.17	-18475.42	-66374.67	3048.65
8:00	**32**	531.76	452.98	3264.76	2781.09	11264.27	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-18656.68	-67025.84	4505.71
9:00	**33**	798.51	680.22	4412.42	3758.72	11184.23	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-18820.99	-67616.14	4473.69
10:00	**34**	1302.94	1109.91	5347.15	4554.98	9668.82	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9562.60	11225.66	61507.17	20502.39	-18988.64	-68218.44	3867.53
11:00	**35**	1858.20	1582.91	6115.04	5209.10	6591.51	0.00	0.00	0.00	0.00	0.00	6000.00	9000.00	12000.00	9562.60	11225.66	61507.17	20502.39	-19179.54	-68904.27	2636.60
12:00	**36**	2353.53	2004.86	6730.71	5733.57	2572.01	0.00	0.00	0.00	0.00	0.00	3000.00	4500.00	6000.00	8052.71	9453.18	51795.51	17265.17	-19403.59	-69709.21	1028.81
13:00	**37**	2737.89	2332.27	7342.96	6255.11	114.63	0.00	0.00	0.00	0.00	0.00	6000.00	9000.00	12000.00	8052.71	9453.18	51795.51	17265.17	-19637.27	-70548.72	45.85
14:00	**38**	2993.66	2550.15	7747.21	6599.47	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-19309.25	-69370.29	0.00
15:00	**39**	3198.13	2724.34	7954.34	6775.92	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9059.30	10634.83	58269.95	19423.32	-19013.78	-68308.75	0.00
16:00	**40**	3517.52	2996.40	7911.24	6739.21	0.00	0.00	0.00	0.00	0.00	0.00	7500.00	11250.00	15000.00	9562.60	11225.66	61507.17	20502.39	-18747.61	-67352.53	0.00
17:00	**41**	3999.41	3406.91	7433.77	6332.47	0.00	0.00	0.00	0.00	0.00	0.00	2250.00	3375.00	4500.00	8052.71	9453.18	51795.51	17265.17	-16887.85	-60671.15	0.00
18:00	**42**	4566.35	3889.85	6488.76	5527.47	438.85	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	7046.12	8271.54	45321.07	15107.02	-15206.89	-54632.14	175.54
19:00	**43**	5095.31	4340.45	4823.74	4109.11	1398.75	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	6039.53	7089.89	38846.63	12948.88	-13680.23	-49147.51	559.50
20:00	**44**	5437.86	4632.25	1880.22	1601.67	198.28	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	4026.36	4726.59	25897.76	8632.59	-12320.59	-44262.84	79.31
21:00	**45**	5345.57	4553.63	1366.89	1164.39	0.00	0.00	0.00	0.00	0.00	0.00	750.00	1125.00	1500.00	3019.77	3544.94	19423.32	6474.44	-11098.38	-39871.97	0.00
22:00	**46**	4741.20	4038.80	1056.82	900.26	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-9997.42	-35916.67	0.00
23:00	**47**	3967.70	3379.89	782.18	666.30	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-9005.68	-32353.74	0.00
0:00	**48**	3244.46	2763.80	550.62	469.05	0.00	0.00	0.00	0.00	0.00	0.00	375.00	562.50	750.00	2013.18	2363.30	12948.88	4316.29	-8112.32	-29144.25	0.00

Zone Load Summary: 1_Office – Part 2

Total	Total	RTF	RTF	Air_{lat}	Air_{sens}	Air_{tot}	CFM_{lat}	CFM_{sense}	Slab GPM	Slab Surface Temp	Required CFM 62.1
q_{conv} (Btu/hr)	q_{rad} (Btu/hr)	q_{Beam} (BTU/hr)	q_{rad} (Btu/hr)	q_{lat} (Btu/hr)	q_{sens} (Btu/hr)	q_{tot} (Btu/hr)					
887.68	-16515.19								0	75.00	434
-2430.13	-26185.55								60	73.64	434
-5389.61	-34903.91								60	72.41	434
-8018.86	-42753.42								60	71.31	434
-10341.57	-49806.54								60	70.31	434
-12379.87	-56131.04								60	69.42	434
51794.49	-21750.73								50	68.94	809
60125.44	-19830.10								50	68.53	809
61360.03	-19497.48								40	68.43	809
66358.08	-17682.82								40	68.34	809
65977.74	-20008.73								40	68.24	809
52631.81	-29838.63								40	68.12	809
56384.53	-25692.28								40	67.99	809
66344.39	-18611.74								30	68.16	809
67043.19	-17402.53								30	68.30	809
71318.70	-14838.93								30	68.43	809
56704.61	-21472.15								0	69.38	434
49020.43	-21848.70								0	70.24	434
41924.53	-21140.81								0	71.02	434
25716.24	-25459.83								0	71.71	434
18847.36	-24860.94								0	72.34	434
11173.87	-25085.39								0	72.90	434
11113.87	-21768.32								0	73.41	434
11049.21	-18766.71								0	73.86	434
-534.70	-21927.57	297.72	-22575.80	0.00	-22812.78	-22812.78	0.00	0.00	0	74.27	434
-3711.40	-31534.05	263.58	-24910.31	0.00	-28358.13	-28358.13	0.00	0.00	60	72.98	434
-6543.78	-40162.70	233.44	-28011.87	0.00	-34322.21	-34322.21	0.00	0.00	60	71.82	434
-9058.54	-47904.17	206.78	-31557.81	0.00	-40409.56	-40409.56	0.00	0.00	60	70.78	434
-11278.11	-54838.74	183.17	-35379.39	0.00	-46474.33	-46474.33	0.00	0.00	60	69.83	434
-13223.51	-61039.40	162.26	-39360.43	0.00	-52421.68	-52421.68	0.00	0.00	60	68.98	434
51034.54	-26528.99	921.04	-33678.20	15000.00	18277.38	33277.38	1408.72	735.80	50	68.55	809
59980.87	-22441.30	1682.64	-31196.48	15000.00	30467.04	45467.04	1408.72	1226.53	40	68.45	809
61229.81	-21830.92	2122.38	-29789.42	15000.00	33562.76	48562.76	1408.72	1351.16	40	68.37	809
66240.78	-19541.16	2283.18	-28234.69	15000.00	40289.26	55289.26	1408.72	1621.95	40	68.28	809
65872.08	-21353.27	2140.93	-27602.92	12000.00	40410.09	52410.09	1126.97	1626.82	40	68.18	809
52536.63	-30724.56	1727.40	-29181.30	6000.00	25082.72	31082.72	563.49	1009.77	40	68.07	809
56298.78	-26217.88	1299.41	-28466.66	12000.00	29131.53	41131.53	1126.97	1172.77	40	67.95	809
66267.15	-18889.90	1062.56	-26385.96	15000.00	40943.76	55943.76	1408.72	1648.30	30	68.12	809
66973.62	-17479.98	909.42	-25019.01	15000.00	42864.02	57864.02	1408.72	1725.60	30	68.27	809
71256.03	-14620.52	794.09	-23384.48	15000.00	48665.64	63665.64	1408.72	1959.16	30	68.40	809
56648.16	-20821.90	699.29	-23800.68	4500.00	33546.77	38046.77	422.61	1350.51	0	69.35	434
48969.57	-20696.38	662.73	-23531.84	1500.00	26100.46	27600.46	140.87	1050.74	0	70.22	434
41878.72	-19520.77	712.96	-22937.89	1500.00	19653.79	21153.79	140.87	791.22	0	71.00	434
25674.97	-23532.66	594.55	-23494.76	1500.00	2774.76	4274.76	140.87	111.71	0	71.69	434
18810.19	-22998.68	500.50	-23442.48	1500.00	-4131.80	-2631.80	140.87	0.00	0	72.32	434
11140.38	-23725.72	434.17	-23572.77	750.00	-11998.22	-11248.22	70.44	0.00	0	72.88	434
11083.71	-21056.63	381.29	-22958.48	750.00	-11493.48	-10743.48	70.44	0.00	0	73.39	434
11022.04	-18661.36	336.56	-22107.23	750.00	-10748.63	-9998.63	70.44	0.00	0	73.85	434
-559.17	-22015.50	297.72	-22464.19	0.00	-22725.65	-22725.65	0.00	0.00	0	74.26	434
-3733.45	-31613.26	263.58	-24800.80	0.00	-28270.67	-28270.67	0.00	0.00	60	72.97	434
-6563.64	-40234.05	233.44	-27897.32	0.00	-34227.52	-34227.52	0.00	0.00	60	71.81	434
-9076.43	-47968.44	206.78	-31436.72	0.00	-40306.37	-40306.37	0.00	0.00	60	70.77	434
-11294.23	-54896.64	183.17	-35251.80	0.00	-46362.85	-46362.85	0.00	0.00	60	69.82	434
-13238.02	-61091.55	162.26	-39226.86	0.00	-52302.62	-52302.62	0.00	0.00	60	68.98	434
51021.47	-26575.97	921.04	-33539.34	15000.00	18403.16	33403.16	1408.72	740.87	50	68.54	809
59969.09	-22483.62	1682.64	-31063.94	15000.00	30587.79	45587.79	1408.72	1231.39	40	68.45	809
61219.20	-21869.05	2122.38	-29663.50	15000.00	33678.07	48678.07	1408.72	1355.80	40	68.36	809
66231.22	-19575.50	2283.18	-28116.75	15000.00	40397.64	55397.64	1408.72	1626.31	40	68.28	809
65863.47	-21384.20	2140.93	-27494.42	12000.00	40509.97	52509.97	1126.97	1630.84	40	68.18	809
52528.87	-30752.43	1727.40	-29083.30	6000.00	25172.96	31172.96	563.49	1013.40	40	68.06	809
56291.80	-26242.98	1299.41	-28379.60	12000.00	29211.61	41211.61	1126.97	1175.99	40	67.94	809
66260.86	-18912.51	1062.56	-26309.64	15000.00	41013.79	56013.79	1408.72	1651.12	30	68.11	809
66967.95	-17500.35	909.42	-24953.06	15000.00	42924.31	57924.31	1408.72	1728.03	30	68.26	809
71250.92	-14638.87	794.09	-23329.07	15000.00	48715.94	63715.94	1408.72	1961.19	30	68.40	809
56643.56	-20838.42	699.29	-23756.74	4500.00	33586.11	38086.11	422.61	1352.10	0	69.35	434
48965.43	-20711.26	662.73	-23500.57	1500.00	26127.59	27627.59	140.87	1051.84	0	70.21	434
41874.98	-19534.18	712.96	-22920.19	1500.00	19667.76	21167.76	140.87	791.78	0	70.99	434
25671.61	-23544.75	594.55	-23490.58	1500.00	2775.59	4275.59	140.87	111.74	0	71.69	434
18807.16	-23009.56	500.50	-23449.81	1500.00	-4142.15	-2642.15	140.87	0.00	0	72.32	434
11137.65	-23735.53	434.17	-23587.50	750.00	-12015.68	-11265.68	70.44	0.00	0	72.88	434
11081.25	-21065.46	381.29	-22976.22	750.00	-11513.68	-10763.68	70.44	0.00	0	73.39	434
11019.82	-18669.31	336.56	-22124.31	750.00	-10767.92	-10017.92	70.44	0.00	0	73.85	434

Floor 1 Summary – Part 1

		1_Workshop			1_Office			1_Computer Lab			1_Mech/Elec			1_Corridor		
		Total $CFM_{cooling}$	**Req OA CFM**	**Floor GPM**	**Total $CFM_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total $CFM_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total $CFM_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total $CFM_{cooling}$**	**Req OA CFM**	**Floor GPM**
Time	**Time**															
1:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
2:00			1095.00	50.00		434.00	60.00		778.20	55.00		0.00	0.00		329.00	20.00
3:00			1095.00	50.00		434.00	60.00		778.20	55.00		0.00	0.00		329.00	20.00
4:00			1095.00	50.00		434.00	60.00		778.20	55.00		0.00	0.00		329.00	20.00
5:00			1095.00	50.00		434.00	60.00		778.20	55.00		0.00	0.00		329.00	20.00
6:00			1095.00	50.00		434.00	60.00		778.20	55.00		0.00	0.00		329.00	20.00
7:00			1215.00	30.00		809.00	50.00		1737.00	30.00		0.00	0.00		389.00	20.00
8:00			1215.00	30.00		809.00	50.00		1737.00	30.00		0.00	0.00		389.00	20.00
9:00			1215.00	30.00		809.00	40.00		1737.00	40.00		0.00	0.00		389.00	20.00
10:00			1215.00	30.00		809.00	40.00		1737.00	40.00		0.00	0.00		389.00	20.00
11:00			1215.00	30.00		809.00	40.00		1737.00	30.00		0.00	0.00		389.00	20.00
12:00			1215.00	30.00		809.00	40.00		1737.00	30.00		0.00	0.00		389.00	20.00
13:00			1215.00	20.00		809.00	40.00		1737.00	30.00		0.00	0.00		389.00	0.00
14:00			1215.00	20.00		809.00	30.00		1737.00	30.00		0.00	0.00		389.00	0.00
15:00			1215.00	20.00		809.00	30.00		1737.00	30.00		0.00	0.00		389.00	0.00
16:00			1215.00	20.00		809.00	30.00		1737.00	30.00		0.00	0.00		389.00	0.00
17:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
18:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
19:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
20:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
21:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
22:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
23:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
0:00			1095.00	0.00		434.00	0.00		778.20	0.00		0.00	0.00		329.00	0.00
1:00	**1**	0.00	1095.00	0.00	0.00	434.00	0.00	0.00	778.20	0.00	77.79	0.00	0.00	0.00	329.00	0.00
2:00	**2**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	67.85	0.00	0.00	0.00	329.00	20.00
3:00	**3**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	59.42	0.00	0.00	0.00	329.00	20.00
4:00	**4**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	52.16	0.00	0.00	0.00	329.00	20.00
5:00	**5**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	45.86	0.00	0.00	0.00	329.00	20.00
6:00	**6**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	40.35	0.00	0.00	0.00	329.00	20.00
7:00	**7**	715.71	1215.00	30.00	735.80	809.00	50.00	1548.86	1737.00	30.00	178.12	0.00	0.00	211.44	389.00	20.00
8:00	**8**	1123.14	1215.00	30.00	1226.53	809.00	40.00	2076.13	1737.00	30.00	201.89	0.00	0.00	353.17	389.00	20.00
9:00	**9**	1195.14	1215.00	30.00	1351.16	809.00	40.00	2124.25	1737.00	40.00	209.80	0.00	0.00	374.44	389.00	20.00
10:00	**10**	1402.50	1215.00	30.00	1621.95	809.00	40.00	2357.81	1737.00	40.00	229.70	0.00	0.00	458.25	389.00	20.00
11:00	**11**	1415.99	1215.00	30.00	1626.82	809.00	40.00	2351.67	1737.00	30.00	241.32	0.00	0.00	474.54	389.00	20.00
12:00	**12**	912.70	1215.00	30.00	1009.77	809.00	40.00	1632.30	1737.00	30.00	223.22	0.00	0.00	307.35	389.00	20.00
13:00	**13**	1018.36	1215.00	20.00	1172.77	809.00	40.00	1742.97	1737.00	30.00	229.88	0.00	0.00	400.16	389.00	0.00
14:00	**14**	1415.87	1215.00	20.00	1648.30	809.00	30.00	2243.19	1737.00	30.00	253.31	0.00	0.00	580.11	389.00	0.00
15:00	**15**	1487.73	1215.00	20.00	1725.60	809.00	30.00	2285.53	1737.00	30.00	257.24	0.00	0.00	635.16	389.00	0.00
16:00	**16**	1704.58	1215.00	20.00	1959.16	809.00	30.00	2532.75	1737.00	30.00	271.20	0.00	0.00	726.36	389.00	0.00
17:00	**17**	1253.48	1095.00	0.00	1350.51	434.00	0.00	1838.05	778.20	0.00	249.36	0.00	0.00	550.54	329.00	0.00
18:00	**18**	1004.04	1095.00	0.00	1050.74	434.00	0.00	1458.36	778.20	0.00	236.59	0.00	0.00	453.47	329.00	0.00
19:00	**19**	775.08	1095.00	0.00	791.22	434.00	0.00	1128.81	778.20	0.00	223.05	0.00	0.00	357.96	329.00	0.00
20:00	**20**	193.56	1095.00	0.00	111.71	434.00	0.00	368.41	778.20	0.00	187.94	0.00	0.00	121.44	329.00	0.00
21:00	**21**	0.00	1095.00	0.00	0.00	434.00	0.00	4.29	778.20	0.00	165.72	0.00	0.00	26.26	329.00	0.00
22:00	**22**	0.00	1095.00	0.00	0.00	434.00	0.00	0.00	778.20	0.00	137.89	0.00	0.00	0.00	329.00	0.00
23:00	**23**	0.00	1095.00	0.00	0.00	434.00	0.00	0.00	778.20	0.00	126.54	0.00	0.00	0.00	329.00	0.00
0:00	**24**	0.00	1095.00	0.00	0.00	434.00	0.00	0.00	778.20	0.00	115.86	0.00	0.00	0.00	329.00	0.00
1:00	**25**	0.00	1095.00	0.00	0.00	434.00	0.00	0.00	778.20	0.00	77.79	0.00	0.00	0.00	329.00	0.00
2:00	**26**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	67.85	0.00	0.00	0.00	329.00	20.00
3:00	**27**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	59.42	0.00	0.00	0.00	329.00	20.00
4:00	**28**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	52.16	0.00	0.00	0.00	329.00	20.00
5:00	**29**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	45.86	0.00	0.00	0.00	329.00	20.00
6:00	**30**	0.00	1095.00	50.00	0.00	434.00	60.00	0.00	778.20	55.00	40.35	0.00	0.00	0.00	329.00	20.00
7:00	**31**	710.32	1215.00	30.00	740.87	809.00	50.00	1530.45	1737.00	30.00	178.12	0.00	0.00	248.84	389.00	20.00
8:00	**32**	1118.28	1215.00	30.00	1231.39	809.00	40.00	2059.54	1737.00	30.00	201.89	0.00	0.00	386.86	389.00	20.00
9:00	**33**	1190.76	1215.00	30.00	1355.80	809.00	40.00	2109.30	1737.00	40.00	209.80	0.00	0.00	404.78	389.00	20.00
10:00	**34**	1398.55	1215.00	30.00	1626.31	809.00	40.00	2344.35	1737.00	40.00	229.70	0.00	0.00	485.58	389.00	20.00
11:00	**35**	1412.44	1215.00	30.00	1630.84	809.00	40.00	2339.54	1737.00	30.00	241.32	0.00	0.00	499.16	389.00	20.00
12:00	**36**	909.50	1215.00	30.00	1013.40	809.00	40.00	1621.37	1737.00	30.00	223.22	0.00	0.00	329.53	389.00	20.00
13:00	**37**	1015.47	1215.00	20.00	1175.99	809.00	40.00	1733.14	1737.00	30.00	229.88	0.00	0.00	420.14	389.00	0.00
14:00	**38**	1413.27	1215.00	20.00	1651.12	809.00	30.00	2234.33	1737.00	30.00	253.31	0.00	0.00	598.11	389.00	0.00
15:00	**39**	1485.39	1215.00	20.00	1728.03	809.00	30.00	2277.55	1737.00	30.00	257.24	0.00	0.00	651.38	389.00	0.00
16:00	**40**	1702.47	1215.00	20.00	1961.19	809.00	30.00	2525.56	1737.00	30.00	271.20	0.00	0.00	740.96	389.00	0.00
17:00	**41**	1251.58	1095.00	0.00	1352.10	434.00	0.00	1831.57	778.20	0.00	249.36	0.00	0.00	563.69	329.00	0.00
18:00	**42**	1002.33	1095.00	0.00	1051.84	434.00	0.00	1452.52	778.20	0.00	236.59	0.00	0.00	465.32	329.00	0.00
19:00	**43**	773.54	1095.00	0.00	791.78	434.00	0.00	1123.55	778.20	0.00	223.05	0.00	0.00	368.64	329.00	0.00
20:00	**44**	192.17	1095.00	0.00	111.74	434.00	0.00	363.68	778.20	0.00	187.94	0.00	0.00	131.06	329.00	0.00
21:00	**45**	0.00	1095.00	0.00	0.00	434.00	0.00	0.03	778.20	0.00	165.72	0.00	0.00	34.92	329.00	0.00
22:00	**46**	0.00	1095.00	0.00	0.00	434.00	0.00	0.00	778.20	0.00	137.89	0.00	0.00	0.00	329.00	0.00
23:00	**47**	0.00	1095.00	0.00	0.00	434.00	0.00	0.00	778.20	0.00	126.54	0.00	0.00	0.00	329.00	0.00
0:00	**48**	0.00	1095.00	0.00	0.00	434.00	0.00	0.00	778.20	0.00	115.86	0.00	0.00	0.00	329.00	0.00

Floor 1 Summary – Part 2

1_High Bay			CUH-1			CRU 1-1			CRU 1-2			**Floor 1**		
Total CFM$_{cooling}$	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
	1840.50	0.00		0.00	0.00		0.00	1.00		0.00	1.00			
	1840.50	0.00		0.00	0.00		0.00	1.00		0.00	1.00			
	1840.50	0.00		0.00	0.00		0.00	1.00		0.00	1.00			
	1840.50	0.00		0.00	0.00		0.00	1.00		0.00	0.30			
	1840.50	0.00		0.00	0.00		0.00	1.00		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	2190.50	0.00		0.00	0.00		0.00	0.50		0.00	0.30			
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
	1840.50	0.00		0.00	0.00		0.00	0.00		0.00	0.00			
2036.46	1840.50	0.00	34.60	0.00	0.00	39.75	0.00	0.00	48.71	0.00	0.00	**2237.30**	**4476.70**	**0.00**
1848.29	1840.50	0.00	29.91	0.00	0.00	28.03	0.00	1.00	36.12	0.00	1.00	**2010.20**	**4476.70**	**187.00**
1690.93	1840.50	0.00	26.00	0.00	0.00	18.16	0.00	1.00	25.48	0.00	1.00	**1820.00**	**4476.70**	**187.00**
1553.87	1840.50	0.00	22.71	0.00	0.00	9.67	0.00	1.00	16.30	0.00	1.00	**1654.72**	**4476.70**	**187.00**
1433.30	1840.50	0.00	19.94	0.00	0.00	2.25	0.00	1.00	11.73	0.00	0.30	**1513.07**	**4476.70**	**186.30**
1328.54	1840.50	0.00	17.63	0.00	0.00	-1.83	0.00	0.50	8.94	0.00	0.30	**1393.63**	**4476.70**	**185.80**
3820.24	2190.50	0.00	64.35	0.00	0.00	443.73	0.00	0.50	459.42	0.00	0.30	**8177.69**	**6340.50**	**130.80**
4572.80	2190.50	0.00	73.41	0.00	0.00	531.31	0.00	0.50	548.65	0.00	0.30	**10707.04**	**6340.50**	**120.80**
5037.29	2190.50	0.00	75.94	0.00	0.00	552.50	0.00	0.50	570.79	0.00	0.30	**11491.29**	**6340.50**	**130.80**
5594.71	2190.50	0.00	81.56	0.00	0.00	595.61	0.00	0.50	614.93	0.00	0.30	**12957.02**	**6340.50**	**130.80**
5910.32	2190.50	0.00	84.29	0.00	0.00	605.87	0.00	0.50	625.87	0.00	0.30	**13336.68**	**6340.50**	**120.80**
5676.07	2190.50	0.00	77.52	0.00	0.00	522.65	0.00	0.50	542.44	0.00	0.30	**10904.02**	**6340.50**	**120.80**
5950.93	2190.50	0.00	79.91	0.00	0.00	520.77	0.00	0.50	541.01	0.00	0.30	**11656.77**	**6340.50**	**90.80**
6456.18	2190.50	0.00	92.94	0.00	0.00	579.42	0.00	0.50	600.59	0.00	0.30	**13869.92**	**6340.50**	**80.80**
6627.57	2190.50	0.00	101.27	0.00	0.00	582.72	0.00	0.50	604.30	0.00	0.30	**14307.13**	**6340.50**	**80.80**
6876.42	2190.50	0.00	112.83	0.00	0.00	614.72	0.00	0.50	636.91	0.00	0.30	**15434.95**	**6340.50**	**80.80**
6316.68	1840.50	0.00	111.16	0.00	0.00	530.92	0.00	0.00	551.67	0.00	0.00	**12752.37**	**4476.70**	**0.00**
5885.00	1840.50	0.00	109.85	0.00	0.00	470.46	0.00	0.00	489.71	0.00	0.00	**11158.22**	**4476.70**	**0.00**
5383.46	1840.50	0.00	103.42	0.00	0.00	407.74	0.00	0.00	425.35	0.00	0.00	**9596.07**	**4476.70**	**0.00**
4430.59	1840.50	0.00	80.49	0.00	0.00	283.66	0.00	0.00	299.08	0.00	0.00	**6076.88**	**4476.70**	**0.00**
3813.75	1840.50	0.00	71.31	0.00	0.00	214.26	0.00	0.00	227.98	0.00	0.00	**4523.57**	**4476.70**	**0.00**
3192.18	1840.50	0.00	60.20	0.00	0.00	145.50	0.00	0.00	157.57	0.00	0.00	**3693.34**	**4476.70**	**0.00**
2900.09	1840.50	0.00	54.32	0.00	0.00	136.78	0.00	0.00	147.80	0.00	0.00	**3365.52**	**4476.70**	**0.00**
2664.27	1840.50	0.00	48.88	0.00	0.00	132.08	0.00	0.00	142.15	0.00	0.00	**3103.23**	**4476.70**	**0.00**
2042.20	1840.50	0.00	34.60	0.00	0.00	40.12	0.00	0.00	48.57	0.00	0.00	**2243.27**	**4476.70**	**0.00**
1853.74	1840.50	0.00	29.91	0.00	0.00	28.37	0.00	1.00	36.00	0.00	1.00	**2015.87**	**4476.70**	**187.00**
1696.12	1840.50	0.00	26.00	0.00	0.00	18.47	0.00	1.00	25.37	0.00	1.00	**1825.38**	**4476.70**	**187.00**
1558.80	1840.50	0.00	22.71	0.00	0.00	9.95	0.00	1.00	16.20	0.00	1.00	**1659.82**	**4476.70**	**187.00**
1437.98	1840.50	0.00	19.94	0.00	0.00	2.50	0.00	1.00	11.64	0.00	0.30	**1517.92**	**4476.70**	**186.30**
1332.99	1840.50	0.00	17.63	0.00	0.00	-1.60	0.00	0.50	8.85	0.00	0.30	**1398.23**	**4476.70**	**185.80**
3824.47	2190.50	0.00	64.35	0.00	0.00	443.93	0.00	0.50	459.35	0.00	0.30	**8200.69**	**6340.50**	**130.80**
4576.82	2190.50	0.00	73.41	0.00	0.00	531.50	0.00	0.50	548.59	0.00	0.30	**10728.27**	**6340.50**	**120.80**
5041.11	2190.50	0.00	75.94	0.00	0.00	552.67	0.00	0.50	570.73	0.00	0.30	**11510.88**	**6340.50**	**130.80**
5598.34	2190.50	0.00	81.56	0.00	0.00	595.76	0.00	0.50	614.88	0.00	0.30	**12975.03**	**6340.50**	**130.80**
5913.77	2190.50	0.00	84.29	0.00	0.00	606.01	0.00	0.50	625.82	0.00	0.30	**13353.18**	**6340.50**	**120.80**
5679.35	2190.50	0.00	77.52	0.00	0.00	522.77	0.00	0.50	542.40	0.00	0.30	**10919.06**	**6340.50**	**120.80**
5954.05	2190.50	0.00	79.91	0.00	0.00	520.88	0.00	0.50	540.97	0.00	0.30	**11670.43**	**6340.50**	**90.80**
6459.14	2190.50	0.00	92.94	0.00	0.00	579.52	0.00	0.50	600.55	0.00	0.30	**13882.30**	**6340.50**	**80.80**
6630.39	2190.50	0.00	101.27	0.00	0.00	582.81	0.00	0.50	604.26	0.00	0.30	**14318.32**	**6340.50**	**80.80**
6879.10	2190.50	0.00	112.83	0.00	0.00	614.80	0.00	0.50	636.89	0.00	0.30	**15445.00**	**6340.50**	**80.80**
6319.22	1840.50	0.00	111.16	0.00	0.00	530.99	0.00	0.00	551.65	0.00	0.00	**12761.32**	**4476.70**	**0.00**
5887.41	1840.50	0.00	109.85	0.00	0.00	470.52	0.00	0.00	489.69	0.00	0.00	**11166.08**	**4476.70**	**0.00**
5385.75	1840.50	0.00	103.42	0.00	0.00	407.80	0.00	0.00	425.33	0.00	0.00	**9602.85**	**4476.70**	**0.00**
4432.77	1840.50	0.00	80.49	0.00	0.00	283.72	0.00	0.00	299.06	0.00	0.00	**6082.62**	**4476.70**	**0.00**
3815.83	1840.50	0.00	71.31	0.00	0.00	214.31	0.00	0.00	227.96	0.00	0.00	**4530.07**	**4476.70**	**0.00**
3194.15	1840.50	0.00	60.20	0.00	0.00	145.54	0.00	0.00	157.56	0.00	0.00	**3695.34**	**4476.70**	**0.00**
2901.96	1840.50	0.00	54.32	0.00	0.00	136.82	0.00	0.00	147.79	0.00	0.00	**3367.42**	**4476.70**	**0.00**
2666.05	1840.50	0.00	48.88	0.00	0.00	132.11	0.00	0.00	142.14	0.00	0.00	**3105.03**	**4476.70**	**0.00**

Floor 2 Summary – Part 1

2_Office			2_Conference			2_Health Center			2_Mech/Elec		
Total CFM$_{cooling}$	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
	1111.00	110.00		67.00	8.00		58.00	0.00		0.00	0.00
	1111.00	110.00		67.00	7.00		58.00	0.00		0.00	0.00
	1111.00	110.00		67.00	7.00		58.00	0.00		0.00	0.00
	1111.00	110.00		67.00	7.00		58.00	0.00		0.00	0.00
	1111.00	110.00		67.00	7.00		58.00	0.00		0.00	0.00
	2030.00	90.00		446.00	7.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	7.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	7.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	7.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	7.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	5.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	5.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	5.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	5.00		457.00	0.00		0.00	0.00
	2030.00	90.00		446.00	5.00		457.00	0.00		0.00	0.00
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
	1111.00	0.00		67.00	0.00		58.00	0.00		0.00	0.00
0.00	1111.00	0.00	65.06	67.00	0.00	125.85	58.00	0.00	93.83	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	8.00	99.24	58.00	0.00	70.91	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	7.00	79.10	58.00	0.00	54.69	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	7.00	63.39	58.00	0.00	42.84	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	7.00	51.03	58.00	0.00	33.92	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	7.00	41.53	58.00	0.00	27.15	0.00	0.00
1615.96	2030.00	90.00	488.64	446.00	7.00	650.29	457.00	0.00	403.33	0.00	0.00
3130.50	2030.00	90.00	754.74	446.00	7.00	863.94	457.00	0.00	491.60	0.00	0.00
3800.46	2030.00	90.00	938.59	446.00	7.00	1032.82	457.00	0.00	539.58	0.00	0.00
4882.95	2030.00	90.00	1097.46	446.00	7.00	1167.23	457.00	0.00	619.55	0.00	0.00
5341.97	2030.00	90.00	1086.33	446.00	7.00	1162.12	457.00	0.00	679.23	0.00	0.00
4242.13	2030.00	90.00	857.96	446.00	5.00	983.54	457.00	0.00	660.74	0.00	0.00
5023.12	2030.00	90.00	1012.83	446.00	5.00	1099.76	457.00	0.00	706.25	0.00	0.00
6427.08	2030.00	90.00	1167.65	446.00	5.00	1191.45	457.00	0.00	795.64	0.00	0.00
6763.62	2030.00	90.00	1193.56	446.00	5.00	1200.03	457.00	0.00	827.75	0.00	0.00
7334.42	2030.00	90.00	1228.91	446.00	5.00	1212.79	457.00	0.00	870.14	0.00	0.00
6247.48	1111.00	0.00	873.15	67.00	0.00	891.64	58.00	0.00	797.18	0.00	0.00
5744.64	1111.00	0.00	691.73	67.00	0.00	712.06	58.00	0.00	726.39	0.00	0.00
5139.88	1111.00	0.00	586.69	67.00	0.00	603.21	58.00	0.00	638.13	0.00	0.00
3133.11	1111.00	0.00	423.44	67.00	0.00	476.08	58.00	0.00	484.78	0.00	0.00
2172.12	1111.00	0.00	326.92	67.00	0.00	383.78	58.00	0.00	369.75	0.00	0.00
1247.62	1111.00	0.00	218.65	67.00	0.00	286.03	58.00	0.00	262.84	0.00	0.00
1224.69	1111.00	0.00	191.04	67.00	0.00	239.04	58.00	0.00	219.40	0.00	0.00
1252.81	1111.00	0.00	174.23	67.00	0.00	204.24	58.00	0.00	189.34	0.00	0.00
23.13	1111.00	0.00	61.26	67.00	0.00	125.87	58.00	0.00	91.83	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	8.00	99.26	58.00	0.00	69.87	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	7.00	79.11	58.00	0.00	54.19	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	7.00	63.39	58.00	0.00	42.62	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	7.00	51.03	58.00	0.00	33.86	0.00	0.00
0.00	1111.00	110.00	0.00	67.00	7.00	41.53	58.00	0.00	27.17	0.00	0.00
1701.01	2030.00	90.00	488.18	446.00	7.00	650.30	457.00	0.00	403.38	0.00	0.00
3199.14	2030.00	90.00	754.40	446.00	7.00	863.95	457.00	0.00	491.67	0.00	0.00
3855.71	2030.00	90.00	938.34	446.00	7.00	1032.82	457.00	0.00	539.65	0.00	0.00
4927.16	2030.00	90.00	1097.27	446.00	7.00	1167.23	457.00	0.00	619.62	0.00	0.00
5377.02	2030.00	90.00	1086.19	446.00	7.00	1162.12	457.00	0.00	679.29	0.00	0.00
4269.55	2030.00	90.00	857.86	446.00	5.00	983.54	457.00	0.00	660.79	0.00	0.00
5044.18	2030.00	90.00	1012.75	446.00	5.00	1099.76	457.00	0.00	706.29	0.00	0.00
6442.84	2030.00	90.00	1167.59	446.00	5.00	1191.45	457.00	0.00	795.68	0.00	0.00
6775.04	2030.00	90.00	1193.52	446.00	5.00	1200.03	457.00	0.00	827.78	0.00	0.00
7342.31	2030.00	90.00	1228.88	446.00	5.00	1212.79	457.00	0.00	870.16	0.00	0.00
6252.62	1111.00	0.00	873.13	67.00	0.00	891.64	58.00	0.00	797.20	0.00	0.00
5747.70	1111.00	0.00	691.71	67.00	0.00	712.06	58.00	0.00	726.41	0.00	0.00
5141.48	1111.00	0.00	586.68	67.00	0.00	603.21	58.00	0.00	638.15	0.00	0.00
3133.80	1111.00	0.00	423.44	67.00	0.00	476.08	58.00	0.00	484.79	0.00	0.00
2172.35	1111.00	0.00	326.92	67.00	0.00	383.78	58.00	0.00	369.76	0.00	0.00
1247.68	1111.00	0.00	218.65	67.00	0.00	286.03	58.00	0.00	262.85	0.00	0.00
1224.71	1111.00	0.00	191.04	67.00	0.00	239.04	58.00	0.00	219.40	0.00	0.00
1252.86	1111.00	0.00	174.23	67.00	0.00	204.24	58.00	0.00	189.35	0.00	0.00

Floor 2 Summary – Part 2

2_Corridor			CUH 2			CRU 2-1			**Floor 2**		
Total CFM$_{cooling}$	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**	**Total CFM$_{cooling}$**	**Req OA CFM**	**Floor GPM**
	476.00	0.00		0.00	0.00		0.00	0.00			
	476.00	10.00		0.00	0.00		0.00	1.00			
	476.00	10.00		0.00	0.00		0.00	1.00			
	476.00	10.00		0.00	0.00		0.00	0.50			
	476.00	10.00		0.00	0.00		0.00	0.50			
	476.00	10.00		0.00	0.00		0.00	0.50			
	476.00	50.00		0.00	0.00		0.00	0.50			
	476.00	50.00		0.00	0.00		0.00	0.50			
	476.00	50.00		0.00	0.00		0.00	0.50			
	476.00	50.00		0.00	0.00		0.00	0.50			
	476.00	50.00		0.00	0.00		0.00	0.50			
	476.00	30.00		0.00	0.00		0.00	0.50			
	476.00	30.00		0.00	0.00		0.00	0.50			
	476.00	30.00		0.00	0.00		0.00	0.50			
	476.00	30.00		0.00	0.00		0.00	0.50			
	476.00	30.00		0.00	0.00		0.00	0.50			
	476.00	0.00		0.00	0.00		0.00	0.00			
	476.00	0.00		0.00	0.00		0.00	0.00			
	476.00	0.00		0.00	0.00		0.00	0.00			
	476.00	0.00		0.00	0.00		0.00	0.00			
	476.00	0.00		0.00	0.00		0.00	0.00			
	476.00	0.00		0.00	0.00		0.00	0.00			
	476.00	0.00		0.00	0.00		0.00	0.00			
	476.00	0.00		0.00	0.00		0.00	0.00			
43.91	476.00	0.00	26.50	0.00	0.00	53.31	0.00	0.00	**355.16**	**1712.00**	**0.00**
0.00	476.00	10.00	21.43	0.00	0.00	33.61	0.00	1.00	**191.59**	**1712.00**	**129.00**
0.00	476.00	10.00	17.56	0.00	0.00	15.88	0.00	1.00	**151.36**	**1712.00**	**128.00**
0.00	476.00	10.00	14.49	0.00	0.00	6.32	0.00	0.50	**120.72**	**1712.00**	**127.50**
0.00	476.00	10.00	12.04	0.00	0.00	-0.10	0.00	0.50	**97.00**	**1712.00**	**127.50**
0.00	476.00	10.00	10.13	0.00	0.00	-4.44	0.00	0.50	**78.81**	**1712.00**	**127.50**
570.88	476.00	50.00	75.21	0.00	0.00	442.67	0.00	0.50	**3804.30**	**3409.00**	**147.50**
808.25	476.00	50.00	109.94	0.00	0.00	531.91	0.00	0.50	**6158.97**	**3409.00**	**147.50**
922.93	476.00	50.00	139.15	0.00	0.00	555.06	0.00	0.50	**7373.53**	**3409.00**	**147.50**
1174.26	476.00	50.00	165.54	0.00	0.00	600.53	0.00	0.50	**9106.99**	**3409.00**	**147.50**
1359.33	476.00	50.00	179.64	0.00	0.00	613.19	0.00	0.50	**9808.62**	**3409.00**	**147.50**
1262.98	476.00	50.00	173.69	0.00	0.00	531.87	0.00	0.50	**8181.04**	**3409.00**	**145.50**
1629.45	476.00	30.00	171.61	0.00	0.00	531.71	0.00	0.50	**9643.01**	**3409.00**	**125.50**
2170.23	476.00	30.00	174.57	0.00	0.00	591.96	0.00	0.50	**11926.62**	**3409.00**	**125.50**
2507.66	476.00	30.00	172.09	0.00	0.00	596.32	0.00	0.50	**12664.72**	**3409.00**	**125.50**
2816.65	476.00	30.00	173.77	0.00	0.00	628.85	0.00	0.50	**13636.67**	**3409.00**	**125.50**
2923.74	476.00	0.00	159.28	0.00	0.00	547.83	0.00	0.00	**11892.48**	**1712.00**	**0.00**
2881.54	476.00	0.00	144.98	0.00	0.00	489.44	0.00	0.00	**10901.35**	**1712.00**	**0.00**
2524.35	476.00	0.00	127.51	0.00	0.00	427.62	0.00	0.00	**9619.77**	**1712.00**	**0.00**
1475.26	476.00	0.00	99.24	0.00	0.00	302.99	0.00	0.00	**6091.91**	**1712.00**	**0.00**
1005.09	476.00	0.00	78.01	0.00	0.00	232.16	0.00	0.00	**4335.68**	**1712.00**	**0.00**
670.61	476.00	0.00	58.90	0.00	0.00	161.80	0.00	0.00	**2744.65**	**1712.00**	**0.00**
562.41	476.00	0.00	49.75	0.00	0.00	151.84	0.00	0.00	**2486.32**	**1712.00**	**0.00**
489.71	476.00	0.00	42.98	0.00	0.00	146.12	0.00	0.00	**2353.30**	**1712.00**	**0.00**
178.75	476.00	0.00	26.51	0.00	0.00	52.94	0.00	0.00	**507.35**	**1712.00**	**0.00**
13.06	476.00	10.00	21.44	0.00	0.00	33.49	0.00	1.00	**203.63**	**1712.00**	**129.00**
0.00	476.00	10.00	17.56	0.00	0.00	15.80	0.00	1.00	**150.86**	**1712.00**	**128.00**
0.00	476.00	10.00	14.49	0.00	0.00	6.27	0.00	0.50	**120.51**	**1712.00**	**127.50**
0.00	476.00	10.00	12.04	0.00	0.00	-0.12	0.00	0.50	**96.94**	**1712.00**	**127.50**
0.00	476.00	10.00	10.14	0.00	0.00	-4.46	0.00	0.50	**78.84**	**1712.00**	**127.50**
602.69	476.00	50.00	75.21	0.00	0.00	442.66	0.00	0.50	**3920.77**	**3409.00**	**147.50**
833.29	476.00	50.00	109.94	0.00	0.00	531.91	0.00	0.50	**6252.39**	**3409.00**	**147.50**
942.55	476.00	50.00	139.15	0.00	0.00	555.06	0.00	0.50	**7448.23**	**3409.00**	**147.50**
1189.53	476.00	50.00	165.54	0.00	0.00	600.53	0.00	0.50	**9166.35**	**3409.00**	**147.50**
1371.08	476.00	50.00	179.64	0.00	0.00	613.19	0.00	0.50	**9855.35**	**3409.00**	**147.50**
1272.12	476.00	50.00	173.69	0.00	0.00	531.87	0.00	0.50	**8217.55**	**3409.00**	**145.50**
1636.41	476.00	30.00	171.61	0.00	0.00	531.71	0.00	0.50	**9671.00**	**3409.00**	**125.50**
2175.38	476.00	30.00	174.57	0.00	0.00	591.96	0.00	0.50	**11947.51**	**3409.00**	**125.50**
2511.29	476.00	30.00	172.09	0.00	0.00	596.32	0.00	0.50	**12679.76**	**3409.00**	**125.50**
2819.03	476.00	30.00	173.77	0.00	0.00	628.85	0.00	0.50	**13646.95**	**3409.00**	**125.50**
2925.10	476.00	0.00	159.28	0.00	0.00	547.83	0.00	0.00	**11898.98**	**1712.00**	**0.00**
2882.14	476.00	0.00	144.98	0.00	0.00	489.44	0.00	0.00	**10905.01**	**1712.00**	**0.00**
2524.42	476.00	0.00	127.51	0.00	0.00	427.62	0.00	0.00	**9621.45**	**1712.00**	**0.00**
1475.06	476.00	0.00	99.24	0.00	0.00	302.99	0.00	0.00	**6092.41**	**1712.00**	**0.00**
1004.81	476.00	0.00	78.01	0.00	0.00	232.16	0.00	0.00	**4335.63**	**1712.00**	**0.00**
670.33	476.00	0.00	58.90	0.00	0.00	161.80	0.00	0.00	**2744.44**	**1712.00**	**0.00**
562.18	476.00	0.00	49.75	0.00	0.00	151.84	0.00	0.00	**2486.13**	**1712.00**	**0.00**
489.54	476.00	0.00	42.98	0.00	0.00	146.12	0.00	0.00	**2353.20**	**1712.00**	**0.00**

Total Building Load and Radiant Floor Energy Summary

Total Total CFM$_{cooling}$	Req OA CFM	Floor GPM		Floor Pump Power (kW)	Floor Chiller # Required	Floor Chiller Power (kW)
2592.45	6188.70	0.00	2.00	0.00	0	0.00
2201.79	6188.70	187.00	1.00	5.59	3	56.95
1971.36	6188.70	187.00	1.00	5.59	3	56.95
1775.43	6188.70	187.00	1.00	5.59	3	56.95
1610.07	6188.70	186.30	1.00	5.53	3	56.95
1472.45	6188.70	185.80	1.00	5.49	3	56.95
11981.99	9749.50	147.50	2.00	2.74	2	37.97
16866.01	9749.50	147.50	2.00	2.74	2	37.97
18864.82	9749.50	147.50	2.00	2.74	2	37.97
22064.00	9749.50	147.50	2.00	2.74	2	37.97
23145.31	9749.50	147.50	2.00	2.74	2	37.97
19085.06	9749.50	145.50	2.00	2.63	2	37.97
21299.78	9749.50	125.50	2.00	1.69	2	37.97
25796.53	9749.50	125.50	2.00	1.69	2	37.97
26971.85	9749.50	125.50	2.00	1.69	2	37.97
29071.62	9749.50	125.50	2.00	1.69	2	37.97
24644.85	6188.70	0.00	2.00	0.00	0	0.00
22059.57	6188.70	0.00	2.00	0.00	0	0.00
19215.85	6188.70	0.00	2.00	0.00	0	0.00
12168.79	6188.70	0.00	2.00	0.00	0	0.00
8859.24	6188.70	0.00	2.00	0.00	0	0.00
6437.99	6188.70	0.00	2.00	0.00	0	0.00
5851.85	6188.70	0.00	2.00	0.00	0	0.00
5456.53	6188.70	0.00	2.00	0.00	0	0.00
2750.63	6188.70	0.00	2.00	0.00	0	0.00
2219.50	6188.70	187.00	1.00	5.59	3	56.95
1976.24	6188.70	187.00	1.00	5.59	3	56.95
1780.33	6188.70	187.00	1.00	5.59	3	56.95
1614.86	6188.70	186.30	1.00	5.53	3	56.95
1477.07	6188.70	185.80	1.00	5.49	3	56.95
12121.47	9749.50	147.50	2.00	2.74	2	37.97
16980.67	9749.50	147.50	2.00	2.74	2	37.97
18959.11	9749.50	147.50	2.00	2.74	2	37.97
22141.39	9749.50	147.50	2.00	2.74	2	37.97
23208.53	9749.50	147.50	2.00	2.74	2	37.97
19136.61	9749.50	145.50	2.00	2.63	2	37.97
21341.43	9749.50	125.50	2.00	1.69	2	37.97
25829.81	9749.50	125.50	2.00	1.69	2	37.97
26998.08	9749.50	125.50	2.00	1.69	2	37.97
29091.95	9749.50	125.50	2.00	1.69	2	37.97
24660.30	6188.70	0.00	2.00	0.00	0	0.00
22071.09	6188.70	0.00	2.00	0.00	0	0.00
19224.29	6188.70	0.00	2.00	0.00	0	0.00
12175.03	6188.70	0.00	2.00	0.00	0	0.00
8865.70	6188.70	0.00	2.00	0.00	0	0.00
6439.78	6188.70	0.00	2.00	0.00	0	0.00
5853.55	6188.70	0.00	2.00	0.00	0	0.00
5458.23	6188.70	0.00	2.00	0.00	0	0.00

AHU-1 Summary

OAU 1								Return Fan 1		Supply Fan 1		Cooling Coil 1					
OAE DB (F)	OAE w (lbw/lba)	OAE h (Btu/lba)	Actual OA CFM	Exh CFM	OAL DB	OAL h	OAL w	Ret CFM	Power (kW)	E Air CFM	Power (kW)	E Air h	E Air w	E Air DB	q_{sens} (Btu/hr)	q_{lat} (Btu/hr)	Req GPM
80.5	0.0168	37.7586	7500.00	6000.00	78.96	32.87	0.0127	0.00	**0.00**	7500.00	**1.17**	32.87	0.0127	78.96	194086.75	170575.06	93.50
79.6	0.0168	37.5279	7500.00	6000.00	78.61	32.78	0.0127	0.00	**0.00**	7500.00	**1.17**	32.78	0.0127	78.61	191228.73	170553.78	92.76
78.7	0.0168	37.3058	7500.00	6000.00	78.27	32.70	0.0127	0.00	**0.00**	7500.00	**1.17**	32.70	0.0127	78.27	188477.21	170533.29	92.05
77.9	0.0168	37.1131	7500.00	6000.00	77.97	32.63	0.0127	0.00	**0.00**	7500.00	**1.17**	32.63	0.0127	77.97	186091.51	170515.52	91.44
77.4	0.0168	36.9737	7500.00	6000.00	77.76	32.58	0.0127	0.00	**0.00**	7500.00	**1.17**	32.58	0.0127	77.76	184364.71	170502.65	90.99
77.1	0.0168	36.9039	7500.00	6000.00	77.65	32.55	0.0127	0.00	**0.00**	7500.00	**1.17**	32.55	0.0127	77.65	183500.25	170496.21	90.77
77.4	0.0168	36.9726	7500.00	6000.00	77.76	32.57	0.0127	2177.69	**0.01**	9677.69	**2.51**	31.97	0.0121	77.81	238442.66	193690.56	110.80
78.2	0.0168	37.1679	7500.00	6000.00	78.06	32.65	0.0127	4707.04	**0.14**	12207.04	**5.04**	31.59	0.0117	78.04	303693.97	220641.12	134.44
79.6	0.0168	37.5373	7500.00	6000.00	78.62	32.79	0.0127	5491.29	**0.23**	12991.29	**6.07**	31.57	0.0116	78.36	327757.83	229025.90	142.77
81.9	0.0168	38.0921	7500.00	6000.00	79.47	33.00	0.0127	6957.02	**0.47**	14457.02	**8.37**	31.51	0.0115	78.76	371054.94	244684.09	157.88
84.6	0.0168	38.7517	7500.00	6000.00	80.48	33.25	0.0127	7336.68	**0.55**	14836.68	**9.04**	31.59	0.0115	79.26	388674.70	248787.57	163.45
87.6	0.0168	39.4984	7500.00	6000.00	81.62	33.53	0.0127	4904.02	**0.16**	12404.02	**5.29**	32.09	0.0117	80.19	337503.65	222953.28	143.71
90.6	0.0168	40.2402	7500.00	6000.00	82.76	33.81	0.0127	5656.77	**0.25**	13156.77	**6.31**	32.13	0.0116	80.72	365413.00	231036.74	152.94
92.9	0.0168	40.8096	7500.00	6000.00	83.63	34.03	0.0127	7869.92	**0.67**	15369.92	**10.06**	31.91	0.0114	80.75	427470.71	254654.70	174.90
94.5	0.0168	41.2020	7500.00	6000.00	84.23	34.18	0.0127	8307.13	**0.79**	15807.13	**10.94**	31.93	0.0114	80.96	443205.86	259346.16	180.14
95.2	0.0168	41.3823	7500.00	6000.00	84.50	34.24	0.0127	9434.95	**1.16**	16934.95	**13.45**	31.82	0.0113	80.89	473466.40	271371.73	190.98
94.8	0.0168	41.2921	7500.00	6000.00	84.36	34.21	0.0127	6752.37	**0.43**	14252.37	**8.02**	32.17	0.0115	81.36	405692.24	242799.31	166.28
93.7	0.0168	41.0070	7500.00	6000.00	83.93	34.10	0.0127	5158.22	**0.19**	12658.22	**5.62**	32.39	0.0117	81.52	362539.55	225798.67	150.86
91.8	0.0168	40.5456	7500.00	6000.00	83.22	33.93	0.0127	3596.07	**0.06**	11096.07	**3.78**	32.62	0.0119	81.54	317994.34	209122.53	135.16
89.5	0.0168	39.9696	7500.00	6000.00	82.34	33.71	0.0127	76.88	**0.00**	7576.88	**1.20**	33.67	0.0127	82.30	223382.51	171597.21	101.28
87.1	0.0168	39.3816	7500.00	6000.00	81.44	33.49	0.0127	0.00	**0.00**	7500.00	**1.17**	33.49	0.0127	81.44	214188.13	170724.53	98.70
85.0	0.0168	38.8708	7500.00	6000.00	80.66	33.29	0.0127	0.00	**0.00**	7500.00	**1.17**	33.29	0.0127	80.66	207861.94	170677.52	97.06
83.2	0.0168	38.4184	7500.00	6000.00	79.97	33.12	0.0127	0.00	**0.00**	7500.00	**1.17**	33.12	0.0127	79.97	202258.41	170635.86	95.61
81.7	0.0168	38.0370	7500.00	6000.00	79.39	32.98	0.0127	0.00	**0.00**	7500.00	**1.17**	32.98	0.0127	79.39	197534.13	170600.71	94.39
80.5	0.0168	37.7586	7500.00	6000.00	78.96	32.87	0.0127	0.00	**0.00**	7500.00	**1.17**	32.87	0.0127	78.96	194086.75	170575.06	93.50
79.6	0.0168	37.5279	7500.00	6000.00	78.61	32.78	0.0127	0.00	**0.00**	7500.00	**1.17**	32.78	0.0127	78.61	191228.73	170553.78	92.76
78.7	0.0168	37.3058	7500.00	6000.00	78.27	32.70	0.0127	0.00	**0.00**	7500.00	**1.17**	32.70	0.0127	78.27	188477.21	170533.29	92.05
77.9	0.0168	37.1131	7500.00	6000.00	77.97	32.63	0.0127	0.00	**0.00**	7500.00	**1.17**	32.63	0.0127	77.97	186091.51	170515.52	91.44
77.4	0.0168	36.9737	7500.00	6000.00	77.76	32.58	0.0127	0.00	**0.00**	7500.00	**1.17**	32.58	0.0127	77.76	184364.71	170502.65	90.99
77.1	0.0168	36.9039	7500.00	6000.00	77.65	32.55	0.0127	0.00	**0.00**	7500.00	**1.17**	32.55	0.0127	77.65	183500.25	170496.21	90.77
77.4	0.0168	36.9726	7500.00	6000.00	77.76	32.57	0.0127	2200.69	**0.01**	9700.69	**2.53**	31.97	0.0121	77.81	239014.11	193935.53	111.01
78.2	0.0168	37.1679	7500.00	6000.00	78.06	32.65	0.0127	4728.27	**0.15**	12228.27	**5.06**	31.58	0.0117	78.04	304221.40	220867.21	134.64
79.6	0.0168	37.5373	7500.00	6000.00	78.62	32.79	0.0127	5510.88	**0.23**	13010.88	**6.10**	31.56	0.0116	78.36	328244.45	229234.48	142.94
81.9	0.0168	38.0921	7500.00	6000.00	79.47	33.00	0.0127	6975.03	**0.47**	14475.03	**8.40**	31.50	0.0115	78.76	371502.52	244875.93	158.05
84.6	0.0168	38.7517	7500.00	6000.00	80.48	33.25	0.0127	7353.18	**0.55**	14853.18	**9.08**	31.59	0.0115	79.25	389084.62	248963.26	163.60
87.6	0.0168	39.4984	7500.00	6000.00	81.62	33.53	0.0127	4919.06	**0.16**	12419.06	**5.30**	32.09	0.0117	80.19	337877.47	223113.48	143.84
90.6	0.0168	40.2402	7500.00	6000.00	82.76	33.81	0.0127	5670.43	**0.25**	13170.43	**6.33**	32.13	0.0116	80.71	365752.59	231182.27	153.06
92.9	0.0168	40.8096	7500.00	6000.00	83.63	34.03	0.0127	7882.30	**0.68**	15382.30	**10.08**	31.91	0.0114	80.75	427778.32	254786.53	175.02
94.5	0.0168	41.2020	7500.00	6000.00	84.23	34.18	0.0127	8318.32	**0.80**	15818.32	**10.96**	31.93	0.0114	80.96	443483.82	259465.28	180.24
95.2	0.0168	41.3823	7500.00	6000.00	84.50	34.24	0.0127	9445.00	**1.17**	16945.00	**13.47**	31.82	0.0113	80.89	473716.24	271478.80	191.08
94.8	0.0168	41.2921	7500.00	6000.00	84.36	34.21	0.0127	6761.32	**0.43**	14261.32	**8.03**	32.17	0.0115	81.35	405914.64	242894.62	166.36
93.7	0.0168	41.0070	7500.00	6000.00	83.93	34.10	0.0127	5166.08	**0.19**	12666.08	**5.63**	32.39	0.0117	81.52	362734.73	225882.30	150.93
91.8	0.0168	40.5456	7500.00	6000.00	83.22	33.93	0.0127	3602.85	**0.06**	11102.85	**3.79**	32.62	0.0119	81.53	318162.67	209194.66	135.22
89.5	0.0168	39.9696	7500.00	6000.00	82.34	33.71	0.0127	82.62	**0.00**	7582.62	**1.21**	33.67	0.0127	82.30	223525.26	171658.35	101.33
87.1	0.0168	39.3816	7500.00	6000.00	81.44	33.49	0.0127	0.00	**0.00**	7500.00	**1.17**	33.49	0.0127	81.44	214188.13	170724.53	98.70
85.0	0.0168	38.8708	7500.00	6000.00	80.66	33.29	0.0127	0.00	**0.00**	7500.00	**1.17**	33.29	0.0127	80.66	207861.94	170677.52	97.06
83.2	0.0168	38.4184	7500.00	6000.00	79.97	33.12	0.0127	0.00	**0.00**	7500.00	**1.17**	33.12	0.0127	79.97	202258.41	170635.86	95.61
81.7	0.0168	38.0370	7500.00	6000.00	79.39	32.98	0.0127	0.00	**0.00**	7500.00	**1.17**	32.98	0.0127	79.39	197534.13	170600.71	94.39

AHU-2 Summary

OAU 2									Return Fan 2		Supply Fan 2				Cooling Coil 2		
OAE DB (F)	OAE w (lbw/lba)	OAE h (Btu/lba)	Actual OA CFM	Exh CFM	OAL DB	OAL h	OAL w	Ret CFM	Power (kW)	E Air CFM	Power (kW)	E Air h	E Air w	E Air DB	q_{sens} (Btu/hr)	q_{lat} (Btu/hr)	Req GPM
80.5	0.0168	37.7586	6800.00	6000.00	78.80	32.37	0.0123	0.00	**0.00**	6800.00	**0.87**	32.37	0.0123	78.80	174778.13	140750.85	80.90
79.6	0.0168	37.5279	6800.00	6000.00	78.51	32.30	0.0123	0.00	**0.00**	6800.00	**0.87**	32.30	0.0123	78.51	172625.05	140733.17	80.35
78.7	0.0168	37.3058	6800.00	6000.00	78.22	32.23	0.0123	0.00	**0.00**	6800.00	**0.87**	32.23	0.0123	78.22	170552.19	140716.15	79.81
77.9	0.0168	37.1131	6800.00	6000.00	77.98	32.17	0.0123	0.00	**0.00**	6800.00	**0.87**	32.17	0.0123	77.98	168754.94	140701.38	79.35
77.4	0.0168	36.9737	6800.00	6000.00	77.80	32.12	0.0123	0.00	**0.00**	6800.00	**0.87**	32.12	0.0123	77.80	167454.05	140690.69	79.01
77.1	0.0168	36.9039	6800.00	6000.00	77.71	32.10	0.0123	0.00	**0.00**	6800.00	**0.87**	32.10	0.0123	77.71	166802.81	140685.34	78.84
77.4	0.0168	36.9726	6800.00	6000.00	77.80	32.12	0.0123	0.00	**0.00**	6800.00	**0.87**	32.12	0.0123	77.80	167443.65	140690.61	79.01
78.2	0.0168	37.1679	6800.00	6000.00	78.05	32.18	0.0123	158.97	**0.00**	6958.97	**0.93**	32.13	0.0122	78.05	173215.24	142398.33	80.93
79.6	0.0168	37.5373	6800.00	6000.00	78.52	32.30	0.0123	1373.53	**0.00**	8173.53	**1.51**	31.90	0.0119	78.43	206833.20	155359.25	92.87
81.9	0.0168	38.0921	6800.00	6000.00	79.22	32.47	0.0123	3106.99	**0.04**	9906.99	**2.69**	31.67	0.0116	78.84	255077.61	173859.61	109.98
84.6	0.0168	38.7517	6800.00	6000.00	80.06	32.68	0.0123	3808.62	**0.08**	10608.62	**3.31**	31.68	0.0115	79.32	278670.77	181381.13	117.96
87.6	0.0168	39.4984	6800.00	6000.00	81.01	32.92	0.0123	2181.04	**0.01**	8981.04	**2.01**	32.18	0.0118	80.28	245208.99	164107.79	104.95
90.6	0.0168	40.2402	6800.00	6000.00	81.95	33.15	0.0123	3643.01	**0.07**	10443.01	**3.15**	32.01	0.0116	80.58	288464.40	179731.53	120.05
92.9	0.0168	40.8096	6800.00	6000.00	82.68	33.33	0.0123	5926.62	**0.29**	12726.62	**5.71**	31.73	0.0113	80.50	350524.02	204090.84	142.21
94.5	0.0168	41.2020	6800.00	6000.00	83.17	33.45	0.0123	6664.72	**0.41**	13464.72	**6.76**	31.69	0.0113	80.62	372530.85	211980.18	149.87
95.2	0.0168	41.3823	6800.00	6000.00	83.40	33.51	0.0123	7636.67	**0.62**	14436.67	**8.33**	31.60	0.0112	80.55	398364.29	222343.27	159.16
94.8	0.0168	41.2921	6800.00	6000.00	83.29	33.48	0.0123	5892.48	**0.28**	12692.48	**5.66**	31.82	0.0113	80.84	354186.23	203764.19	143.06
93.7	0.0168	41.0070	6800.00	6000.00	82.93	33.39	0.0123	4901.35	**0.16**	11701.35	**4.44**	31.93	0.0114	80.87	326894.83	193188.87	133.35
91.8	0.0168	40.5456	6800.00	6000.00	82.34	33.25	0.0123	3619.77	**0.07**	10419.77	**3.13**	32.08	0.0116	80.84	290739.83	179507.41	120.58
89.5	0.0168	39.9696	6800.00	6000.00	81.61	33.06	0.0123	91.91	**0.00**	6891.91	**0.91**	33.02	0.0123	81.56	197692.61	141898.74	87.07
87.1	0.0168	39.3816	6800.00	6000.00	80.86	32.88	0.0123	0.00	**0.00**	6800.00	**0.87**	32.88	0.0123	80.86	189921.45	140875.09	84.82
85.0	0.0168	38.8708	6800.00	6000.00	80.21	32.72	0.0123	0.00	**0.00**	6800.00	**0.87**	32.72	0.0123	80.21	185155.63	140836.01	83.59
83.2	0.0168	38.4184	6800.00	6000.00	79.64	32.58	0.0123	0.00	**0.00**	6800.00	**0.87**	32.58	0.0123	79.64	180934.23	140801.38	82.50
81.7	0.0168	38.0370	6800.00	6000.00	79.15	32.46	0.0123	0.00	**0.00**	6800.00	**0.87**	32.46	0.0123	79.15	177375.20	140772.17	81.58
80.5	0.0168	37.7586	6800.00	6000.00	78.80	32.37	0.0123	0.00	**0.00**	6800.00	**0.87**	32.37	0.0123	78.80	174778.13	140750.85	80.90
79.6	0.0168	37.5279	6800.00	6000.00	78.51	32.30	0.0123	0.00	**0.00**	6800.00	**0.87**	32.30	0.0123	78.51	172625.05	140733.17	80.35
78.7	0.0168	37.3058	6800.00	6000.00	78.22	32.23	0.0123	0.00	**0.00**	6800.00	**0.87**	32.23	0.0123	78.22	170552.19	140716.15	79.81
77.9	0.0168	37.1131	6800.00	6000.00	77.98	32.17	0.0123	0.00	**0.00**	6800.00	**0.87**	32.17	0.0123	77.98	168754.94	140701.38	79.35
77.4	0.0168	36.9737	6800.00	6000.00	77.80	32.12	0.0123	0.00	**0.00**	6800.00	**0.87**	32.12	0.0123	77.80	167454.05	140690.69	79.01
77.1	0.0168	36.9039	6800.00	6000.00	77.71	32.10	0.0123	0.00	**0.00**	6800.00	**0.87**	32.10	0.0123	77.71	166802.81	140685.34	78.84
77.4	0.0168	36.9726	6800.00	6000.00	77.80	32.12	0.0123	0.00	**0.00**	6800.00	**0.87**	32.12	0.0123	77.80	167443.65	140690.61	79.01
78.2	0.0168	37.1679	6800.00	6000.00	78.05	32.18	0.0123	252.39	**0.00**	7052.39	**0.97**	32.10	0.0122	78.05	175535.82	143393.08	81.78
79.6	0.0168	37.5373	6800.00	6000.00	78.52	32.30	0.0123	1448.23	**0.00**	8248.23	**1.55**	31.88	0.0119	78.43	208688.87	156154.66	93.55
81.9	0.0168	38.0921	6800.00	6000.00	79.22	32.47	0.0123	3166.35	**0.04**	9966.35	**2.74**	31.66	0.0116	78.84	256552.40	174491.74	110.52
84.6	0.0168	38.7517	6800.00	6000.00	80.06	32.68	0.0123	3855.35	**0.08**	10655.35	**3.35**	31.67	0.0115	79.32	279831.53	181878.64	118.39
87.6	0.0168	39.4984	6800.00	6000.00	81.01	32.92	0.0123	2217.55	**0.02**	9017.55	**2.03**	32.17	0.0118	80.27	246116.01	164496.48	105.29
90.6	0.0168	40.2402	6800.00	6000.00	81.95	33.15	0.0123	3671.00	**0.07**	10471.00	**3.18**	32.01	0.0116	80.57	289159.69	180029.50	120.30
92.9	0.0168	40.8096	6800.00	6000.00	82.68	33.33	0.0123	5947.51	**0.29**	12747.51	**5.74**	31.73	0.0113	80.50	351043.14	204313.32	142.40
94.5	0.0168	41.2020	6800.00	6000.00	83.17	33.45	0.0123	6679.76	**0.41**	13479.76	**6.78**	31.69	0.0113	80.61	372904.40	212140.27	150.01
95.2	0.0168	41.3823	6800.00	6000.00	83.40	33.51	0.0123	7646.95	**0.62**	14446.95	**8.35**	31.60	0.0112	80.55	398619.46	222452.63	159.25
94.8	0.0168	41.2921	6800.00	6000.00	83.29	33.48	0.0123	5898.98	**0.28**	12698.98	**5.67**	31.82	0.0113	80.84	354347.85	203833.46	143.12
93.7	0.0168	41.0070	6800.00	6000.00	82.93	33.39	0.0123	4905.01	**0.16**	11705.01	**4.44**	31.93	0.0114	80.87	326985.82	193227.86	133.39
91.8	0.0168	40.5456	6800.00	6000.00	82.34	33.25	0.0123	3621.45	**0.07**	10421.45	**3.13**	32.08	0.0116	80.84	290781.48	179525.26	120.59
89.5	0.0168	39.9696	6800.00	6000.00	81.61	33.06	0.0123	92.41	**0.00**	6892.41	**0.91**	33.02	0.0123	81.56	197704.94	141904.02	87.08
87.1	0.0168	39.3816	6800.00	6000.00	80.86	32.88	0.0123	0.00	**0.00**	6800.00	**0.87**	32.88	0.0123	80.86	189921.45	140875.09	84.82
85.0	0.0168	38.8708	6800.00	6000.00	80.21	32.72	0.0123	0.00	**0.00**	6800.00	**0.87**	32.72	0.0123	80.21	185155.63	140836.01	83.59
83.2	0.0168	38.4184	6800.00	6000.00	79.64	32.58	0.0123	0.00	**0.00**	6800.00	**0.87**	32.58	0.0123	79.64	180934.23	140801.38	82.50
81.7	0.0168	38.0370	6800.00	6000.00	79.15	32.46	0.0123	0.00	**0.00**	6800.00	**0.87**	32.46	0.0123	79.15	177375.20	140772.17	81.58

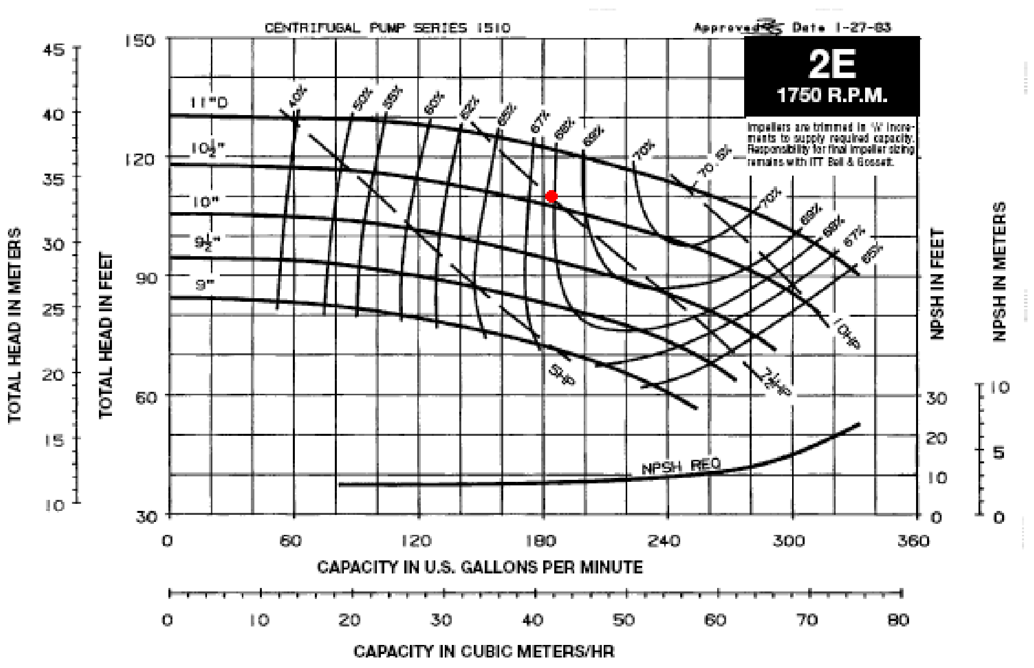
Air System and Total Building Energy Summary

# Heatpumps			Cond GPM	Heatpump Power (kW)	CHW Pump Power (kW)	Cond Pump Power (kW)	Total Power (kW)
3	0	3	225	55.89	0.92	0.32	75.94
3	0	3	450	55.89	0.90	2.55	140.70
3	0	3	450	55.89	0.88	2.55	140.68
3	0	3	450	55.89	0.87	2.55	140.66
3	0	3	450	55.89	0.85	2.55	140.59
3	0	3	450	55.89	0.85	2.55	140.54
4	0	4	450	74.51	1.19	2.55	139.14
4	0	4	450	74.51	1.74	2.55	142.41
4	0	4	450	74.51	2.28	2.55	144.65
5	0	5	525	93.14	3.34	4.05	169.60
5	0	5	525	93.14	3.88	4.05	171.54
4	0	4	450	74.51	2.67	2.55	144.59
5	0	5	525	93.14	3.54	4.05	166.95
6	0	6	600	111.77	5.55	6.05	196.53
6	0	6	600	111.77	6.25	6.05	199.41
6	0	6	600	111.77	7.46	6.05	205.28
5	0	5	375	93.14	5.15	1.48	130.94
5	0	5	375	93.14	3.99	1.48	125.80
5	0	5	375	93.14	2.91	1.48	121.35
4	0	4	300	74.51	1.16	0.76	95.32
3	0	3	225	55.89	1.07	0.32	76.10
3	0	3	225	55.89	1.03	0.32	76.05
3	0	3	225	55.89	0.98	0.32	76.00
3	0	3	225	55.89	0.95	0.32	75.97
3	0	3	225	55.89	0.92	0.32	75.94
3	0	3	450	55.89	0.90	2.55	140.70
3	0	3	450	55.89	0.88	2.55	140.68
3	0	3	450	55.89	0.87	2.55	140.66
3	0	3	450	55.89	0.85	2.55	140.59
3	0	3	450	55.89	0.85	2.55	140.54
4	0	4	450	74.51	1.19	2.55	139.16
4	0	4	450	74.51	1.76	2.55	142.50
4	0	4	450	74.51	2.30	2.55	144.75
5	0	5	525	93.14	3.37	4.05	169.71
5	0	5	525	93.14	3.90	4.05	171.64
4	0	4	450	74.51	2.69	2.55	144.65
5	0	5	525	93.14	3.55	4.05	167.01
6	0	6	600	111.77	5.56	6.05	196.61
6	0	6	600	111.77	6.26	6.05	199.48
6	0	6	600	111.77	7.46	6.05	205.33
5	0	5	375	93.14	5.16	1.48	130.97
5	0	5	375	93.14	4.00	1.48	125.82
5	0	5	375	93.14	2.91	1.48	121.37
4	0	4	300	74.51	1.16	0.76	95.33
3	0	3	225	55.89	1.07	0.32	76.10
3	0	3	225	55.89	1.03	0.32	76.05
3	0	3	225	55.89	0.98	0.32	76.00
3	0	3	225	55.89	0.95	0.32	75.97

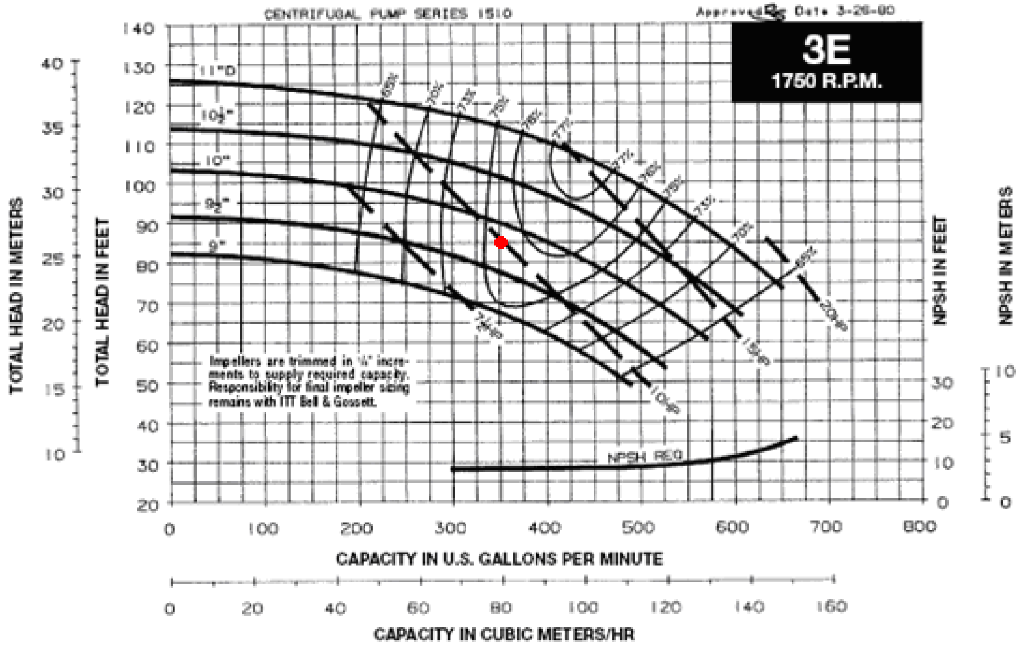
Daily Max kW	**205.33**
Daily Total kWh	**3237.55**
Total $	**$216.56**

Appendix C – Fan and Pump Performance

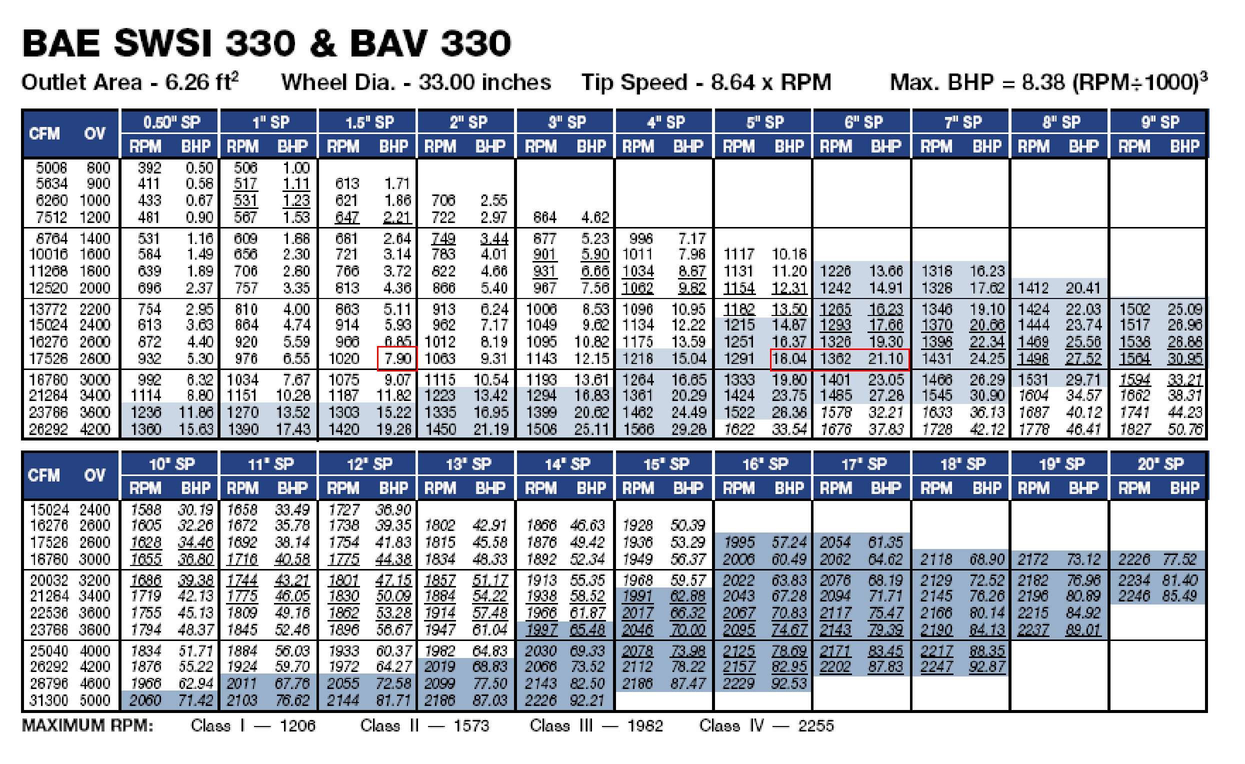
Radiant Floor Chilled Water Pumps: Bell and Gossett Series 1510 2E



AHU Cooling Coils Chilled Water Pumps: Bell and Gossett Series 1510 3E



AHU Supply (5.8” SP) and Return (1.5” SP) Fans: Twin City Fans



BAE SWSI 330 & BAV 330

Outlet Area - 6.26 ft^2 Wheel Dia. - 33.00 inches Tip Speed - 8.64 x RPM Max. BHP = 8.38 (RPM÷1000)^3

CFM	OV	0.50" SP		1" SP		1.5" SP		2" SP		3" SP		4" SP		5" SP		6" SP		7" SP		8" SP		9" SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
5008	800	392	0.50	506	1.00																		
5634	900	411	0.58	517	1.11	613	1.71																
6260	1000	433	0.67	531	1.23	621	1.86	706	2.55														
7512	1200	481	0.90	567	1.53	647	2.21	722	2.97	864	4.62												
8764	1400	531	1.16	609	1.88	681	2.64	749	3.44	877	5.23	996	7.17										
10016	1600	584	1.49	656	2.30	721	3.14	783	4.01	901	5.90	1011	7.98	1117	10.18								
11268	1800	639	1.89	706	2.80	766	3.72	822	4.66	931	6.66	1034	8.87	1131	11.20	1226	13.66	1316	16.23				
12520	2000	696	2.37	757	3.35	813	4.36	866	5.40	967	7.56	1062	9.82	1154	12.31	1242	14.91	1328	17.62	1412	20.41		
13772	2200	754	2.95	810	4.00	863	5.11	913	6.24	1006	8.53	1096	10.95	1182	13.50	1265	16.23	1346	19.10	1424	22.03	1502	25.09
15024	2400	813	3.63	864	4.74	914	5.93	962	7.17	1049	9.62	1134	12.22	1215	14.87	1293	17.66	1370	20.66	1444	23.74	1517	26.96
16276	2600	872	4.40	920	5.59	966	6.85	1012	8.19	1095	10.82	1175	13.59	1251	16.37	1326	19.30	1398	22.34	1469	25.56	1538	28.86
17528	2800	932	5.30	976	6.55	1020	7.90	1063	9.31	1143	12.15	1218	15.04	1291	18.04	1362	21.10	1431	24.25	1498	27.52	1564	30.95
18780	3000	992	6.32	1034	7.67	1075	9.07	1115	10.54	1193	13.61	1264	16.65	1333	19.80	1401	23.05	1468	26.29	1531	29.71	1594	33.21
21284	3400	1114	8.80	1151	10.28	1187	11.82	1223	13.42	1294	16.83	1361	20.29	1424	23.75	1485	27.28	1545	30.90	1604	34.57	1662	38.31
23788	3800	1236	11.86	1270	13.52	1303	15.22	1335	16.95	1399	20.62	1462	24.49	1522	28.38	1578	32.21	1633	36.13	1687	40.12	1741	44.23
26292	4200	1360	15.63	1390	17.43	1420	19.28	1450	21.19	1506	25.11	1566	29.28	1622	33.54	1676	37.83	1728	42.12	1778	46.41	1827	50.76

CFM	OV	10" SP		11" SP		12" SP		13" SP		14" SP		15" SP		16" SP		17" SP		18" SP		19" SP		20" SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
15024	2400	1588	30.19	1658	33.49	1727	36.90																
16276	2600	1605	32.26	1672	35.78	1738	39.35	1802	42.91	1866	46.63	1928	50.39										
17528	2800	1628	34.46	1692	38.14	1754	41.83	1815	45.58	1876	49.42	1936	53.29	1995	57.24	2054	61.35						
18780	3000	1655	36.80	1716	40.58	1775	44.38	1834	48.33	1892	52.34	1949	56.37	2006	60.49	2062	64.62	2118	68.90	2172	73.12	2226	77.52
20032	3200	1686	39.38	1744	43.21	1801	47.15	1857	51.17	1913	55.35	1968	59.57	2022	63.83	2076	68.19	2129	72.52	2182	76.96	2234	81.40
21284	3400	1719	42.13	1775	46.05	1830	50.09	1884	54.22	1938	58.52	1991	62.88	2043	67.28	2094	71.71	2145	76.26	2196	80.89	2246	85.49
22536	3600	1755	45.13	1809	49.16	1862	53.28	1914	57.48	1966	61.87	2017	66.32	2067	70.83	2117	75.47	2166	80.14	2215	84.92		
23788	3800	1794	48.37	1845	52.46	1896	56.67	1947	61.04	1997	65.48	2046	70.00	2095	74.67	2143	79.39	2190	84.13	2237	89.01		
25040	4000	1834	51.71	1884	56.03	1933	60.37	1982	64.83	2030	69.33	2078	73.98	2125	78.69	2171	83.45	2217	88.35				
26292	4200	1876	55.22	1924	59.70	1972	64.27	2019	68.83	2066	73.52	2112	78.22	2157	82.95	2202	87.83	2247	92.87				
28796	4600	1966	62.94	2011	67.76	2055	72.58	2099	77.50	2143	82.50	2186	87.47	2229	92.53								
31300	5000	2060	71.42	2103	76.62	2144	81.71	2186	87.03	2226	92.21												

MAXIMUM RPM: Class I — 1206 Class II — 1573 Class III — 1962 Class IV — 2255