Technology and Engineering Development (TED) Building

Thomas Jefferson National Accelerator Facility

Newport News, VA

Tech Report III

Mechanical Systems Existing Conditions Report

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Executive Summary

This report examines the design and planned operation of the TED mechanical system as well as gives an overall evaluation of the system.

The TED is designed to upgrade the existing facilities currently utilized by The Thomas Jefferson National Accelerator Facility (Jefferson Lab). In order to help meet this program requirement, the mechanical system's design is intended to improve operational flexibility, maintenance, and energy efficiency. In addition, the project is aiming to be LEED v2 for New Construction GOLD certified. This adds additional incentive for an efficient, sustainable design.

A variable air volume system 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 serving the second floor. Hot and chilled water are produced by twelve 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 used to offset peak loads. 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.

Overall, the design effectively combines energy efficient technologies with energy efficient operational strategies and produces a mechanical system that uses energy very responsibly. However, such a dynamic system may sacrifice ease of maintenance and long term reliability. Careful and continual commissioning over the lifetime of the building will play an important role in maintaining the superior design efficiency.

Section 1 Design

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 (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 [2]. 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.

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 [3].

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.

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 [7].

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 [4]. 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 (ºF)	91.9	22.0
OA WB (ºF)	77.1	NA
IA DB (ºF)	75.0	68.0
IA RH (%)	50.0	50.0
Mech/Elec DB (ºF)	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 to offset peak design loads. 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 below. 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 below 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. The design conditions descried in section 1.5 of this report were used for the simulation. Table 1-9-1 below summarizes the results of the block load analysis.

Table 1-9-1: 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 Operation

2.1 Description of System Operation

Air System

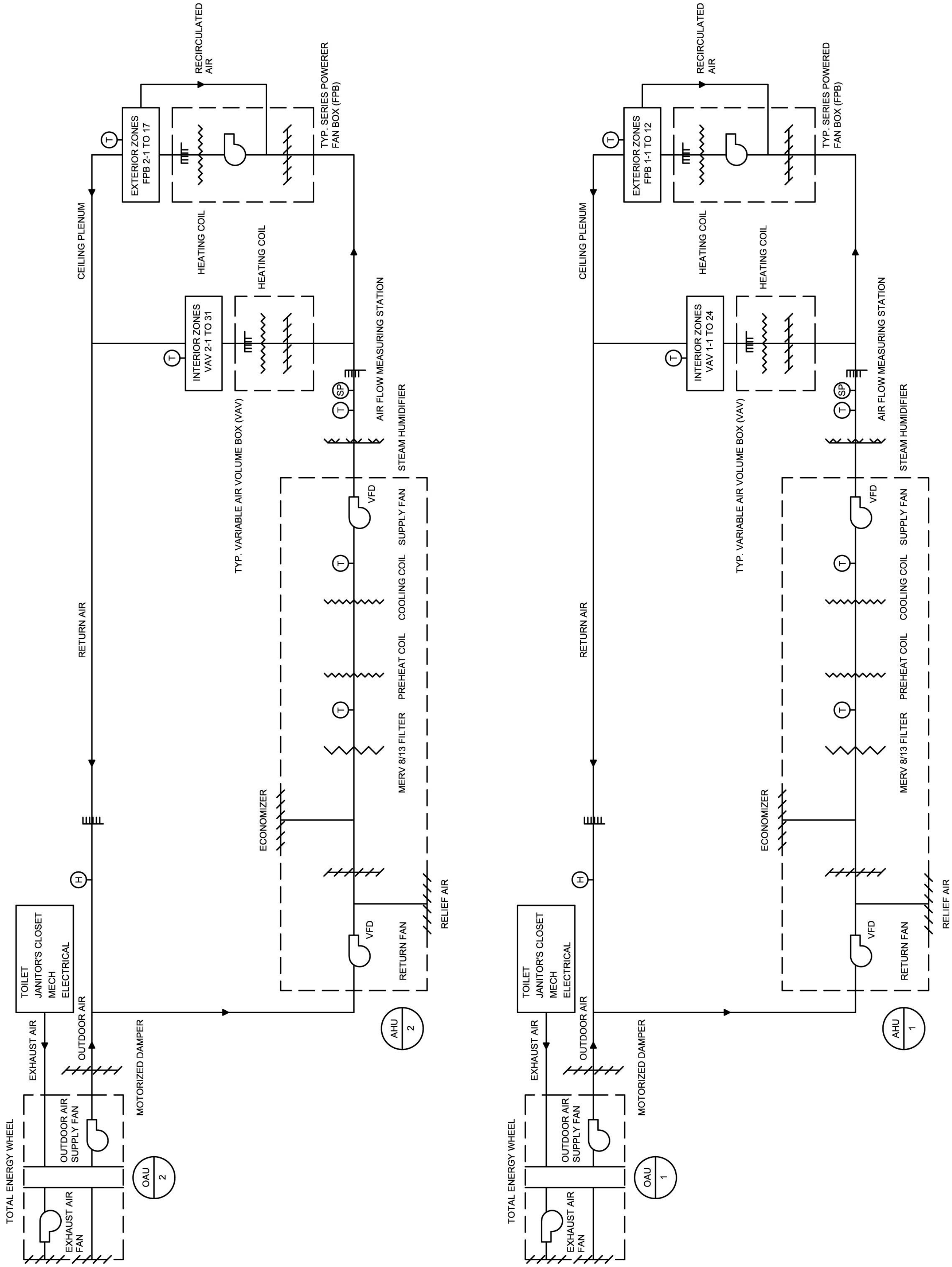
Refer to Figure 2-1-1 on the following page for the air system schematic diagram.

Conditioned air is delivered throughout the TED by a variable air volume 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 18 and 19 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.

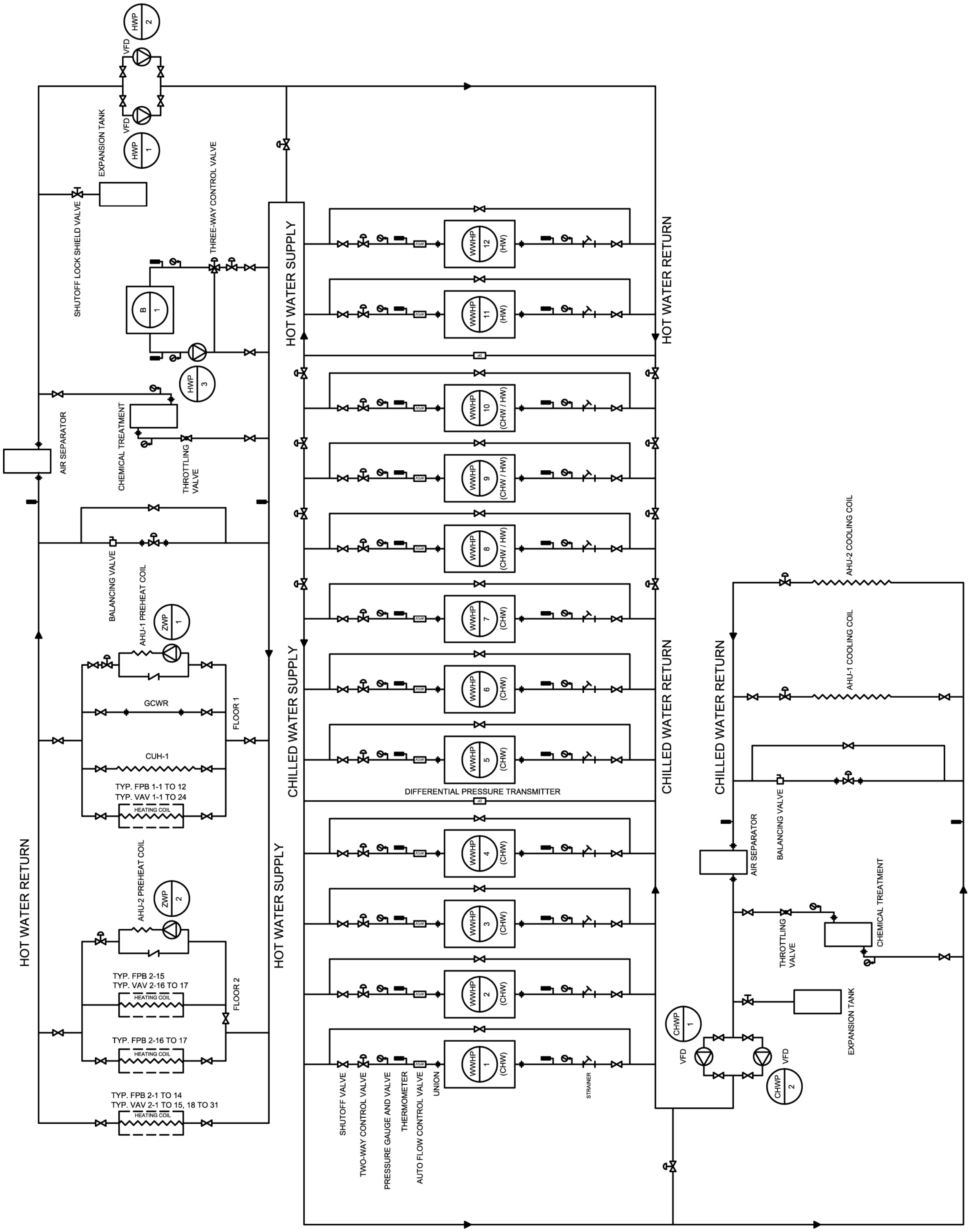


Figure 2-1-3: Condenser Water System Schematic.

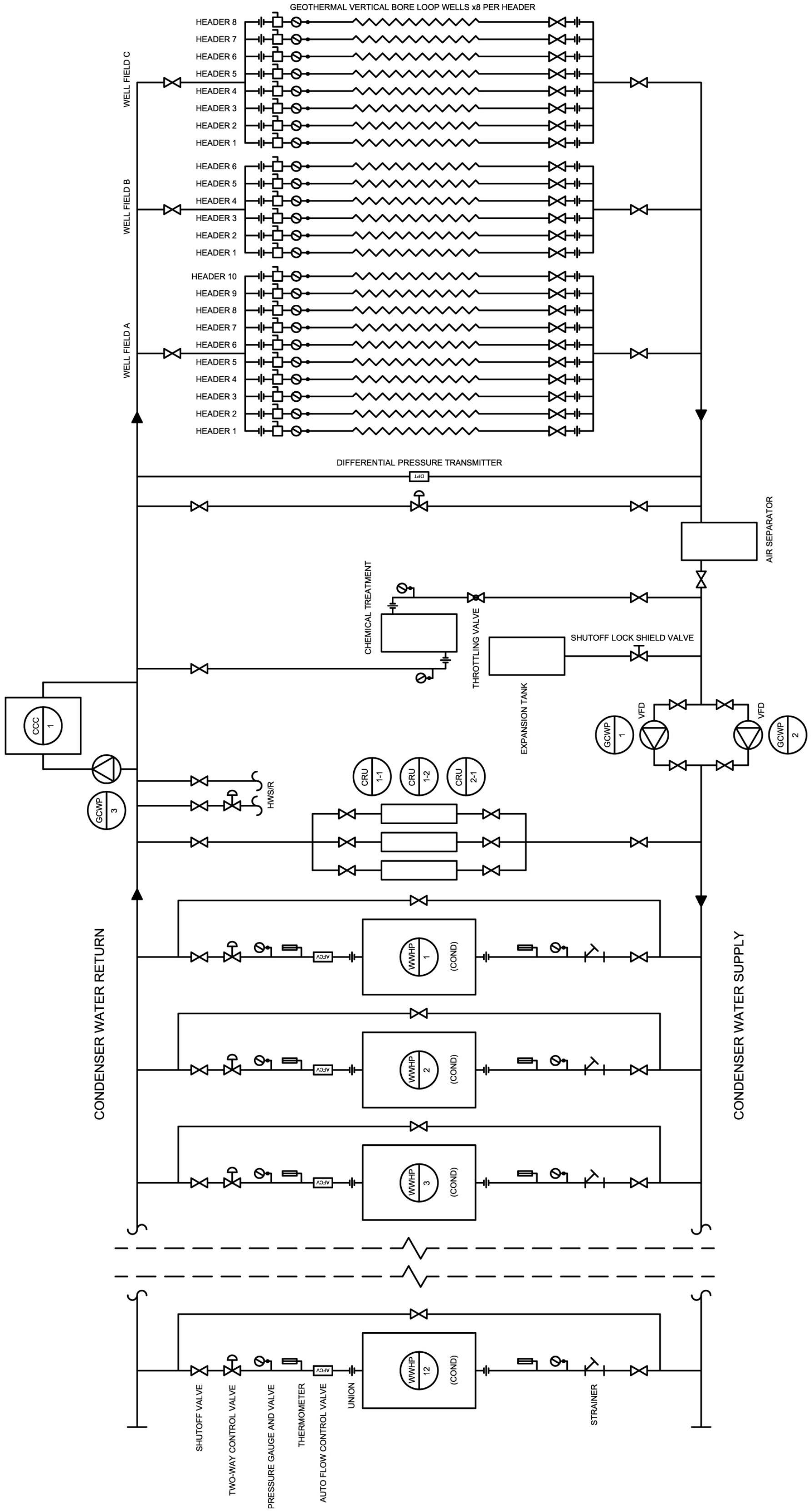
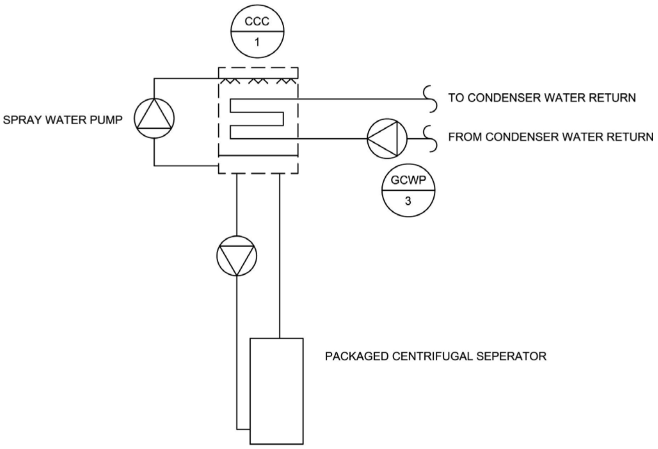


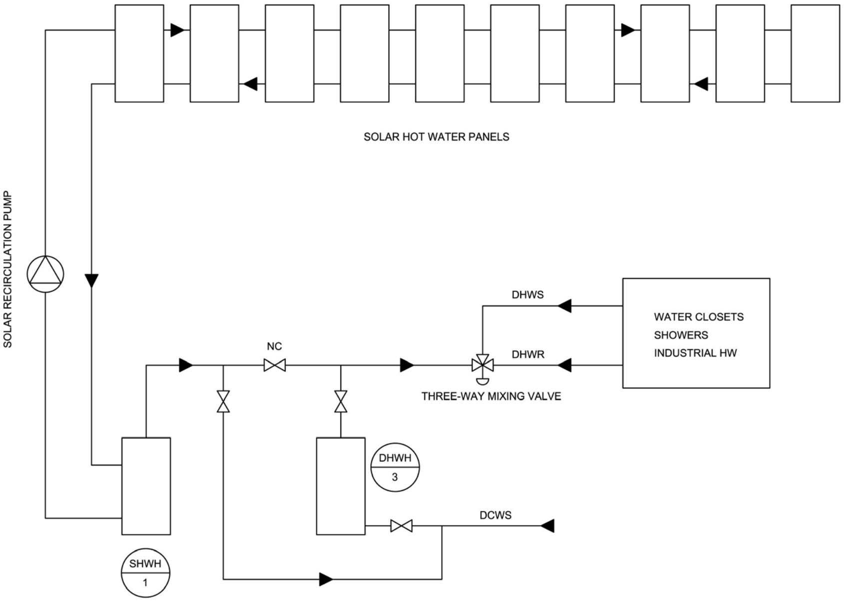
Figure 2-1-4: Closed Circuit Cooler Operation Schematic.



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 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).

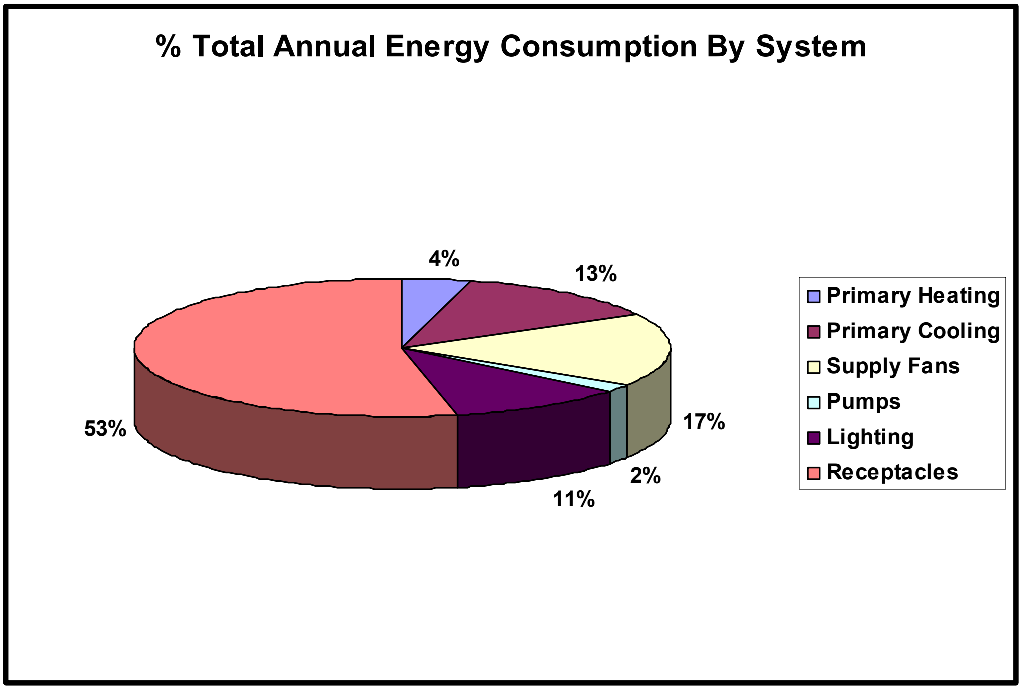
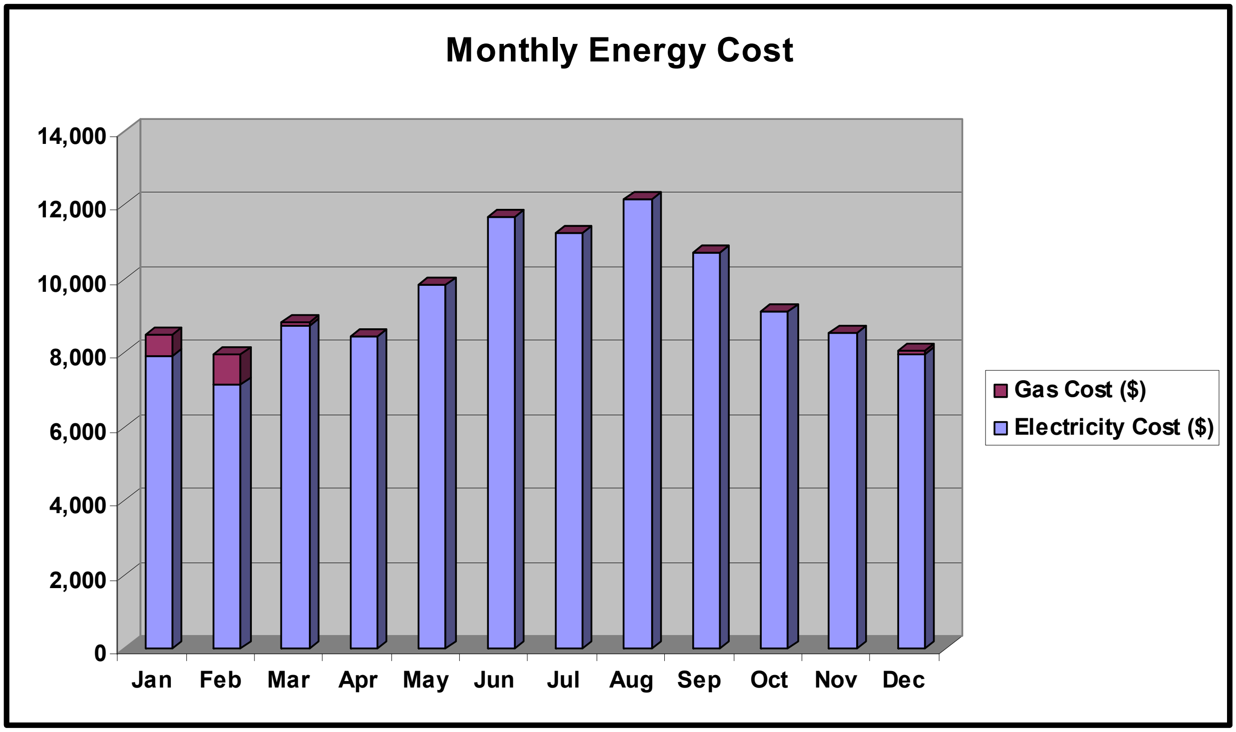


Table 2-2-2 below and Figure 2-2-2 on the following page show the monthly energy consumption, monthly energy cost, total energy cost, and total cost per square foot of floor area.

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 on the previous page, 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 [5]. 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 [6].

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 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 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 frustrates any building operator. This may be especially true as longevity becomes a factor and parts begin to need replacement at various time intervals.

The best guard against these possible operational problems is quality commissioning in the beginning of operation as well as throughout the life of the building. This 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 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. However, this is based on an energy simulation performed by a commercialized energy simulator that may be limited in modeling highly non-traditional systems such as this. It will be interesting to see how the building actually performs once it is fully constructed, commissioned, and occupied.

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.

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7. Virginia Power Company (2010). *Schedule GS-2 Intermediate General Service*. <http://www.dom.com/dominion-virginia-power/customer-service/rates-and-tariffs/pdf/vabgs2.pdf.> (accessed October, 2010).

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