Army Reserve Center
Newport, Rhode Island

Final Thesis Report

Alexander Hosko
Mechanical Option
Advisor: Dr. Treado
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ALEXANDER HOSKO - MECHANICAL OPTION

ARMY RESERVE CENTER - NEWPORT, RHODE ISLAND

Owner: U.S. Government - Department of Defense
Owner Representative: U.S. Army Corps of Engineers - Louisville District
General Contractor: J&J Contractors, Inc.
Architect, MEP Engineer, Structural Engineer, Civil Engineer, Project Manager: Michael Baker Associates

Project Information

Location: Newport, Rhode Island
Size: 59000 ft_2
Levels: 2 levels
Cost: $17 million
Construction Time (estimate): January 2009 – September 2011
Delivery Method: Design-Bid-Build

Architecture

The building will consist mostly of white range field brick on the exterior. Bands of tan ground face block will be present with period fields of matching tan split face block to break up the long mass of the elevations. A tower is used to highlight the main entrance. This tower is clad in a metal panel, colored to match the field brick. The wall system is a non-load bearing, insulated masonry cavity wall with decorative concrete masonry unit (CMU) or brick masonry veneer. The roofing system is a hipped, standing seam metal roof with a 3:12 pitch.

Electrical

13.8 kv electricity shall be brought in and then stepped down to 480/277V, 3PH, 4 wire by a 750 KVA transformer. Lighting will be accomplished with fluorescent lights with electronic ballasts and energy efficient T8 lamps.

Structural

The substructure consists of concrete spread footings and 5" slab on grade. The structural framing system is comprised of steel wide flange columns and beams supporting a 2" galvanized composite steel deck and a 4 ½" concrete slab at the second floor and a pre-engineered light gage metal truss system at the roof. The roofing system is supported by 1 ½" galvanized metal deck spanning between the steel joists.

Mechanical

Serving the building are three AHUs supplying 19,000 CFM, 24% of which is outside air. There are two boilers and two air-cooled rotary screw packaged water chillers piped in parallel. The chillers have capacities of 40 and 52 tons.

http://www.engr.psu.edu/ae/thesis/portfolios/2011/awh5035/index.html

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Credits / Acknowledgements

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Thesis Advisor: Dr. Stephen Treado

Michael Baker Corporation: Specifically Duncan Penney and Doug Barker

U.S. Army Corps of Engineers

Family and Friends for their support

Executive Summary

The main goal in designing the Army Reserve Center was to achieve a LEED Silver or Gold certification while maintaining good design practices such as following the applicable codes and following the requests of the United States Army Corps of Engineers. The codes that were followed were the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 62.1 and 90.1, the United Facilities Criteria (UFC) 4-171-05 and 3-400-02, and all applicable National Fire Protection Association (NFPA) codes and standards. To achieve this goal, a constant volume air handling unit was used for the auditorium, two variable air volume air handling units were used for the entire second floor and the core of the first floor, and smaller unit ventilators met the loads and ventilation requirements for the classrooms on the first floor and several other smaller zones on the first floor.

In order to make the Army Reserve Center more energy efficient, a variable refrigerant flow (VRF) system was used to take care of the heating and sensible cooling loads. The outside air required by ASHRAE and the latent cooling load were taken care of using a dedicated outdoor air system (DOAS). Another option that was explored was the use of a DOAS to handle the latent loads and the outside air requirements and a ground source heat pump (GSHP) to handle the remaining loads.

The systems were designed based on ASHRAE Standards using Microsoft Excel for the majority of calculations with some calculations done by hand. The Army Reserve Center was modeled with these systems in place using Trane Trace 700.

It was found that the best alternative for the Army Reserve Center was the combination of a DOAS system and a VRF system. This combination had the lowest first cost, saved mechanical space, and saved energy when compared to the existing VAV system. However, the combination of a GSHP and DOAS used the least amount of energy.

An acoustical study and a structural study were also performed. The acoustical study involved analyzing the sound created by the rooftop condensing units for VRF system. The structural study determined the roof deck, joists, and girders that are needed to support the additional weight of the rooftop condensing units for the VRF system.

General Building Data

The Army Reserve Center Training Center is located in Newport, Rhode Island and is occupied by the U.S. Army Reserve. It is 59,000 square feet of primarily offices, classrooms, and storage. There are two total stories. The project was awarded on January 15, 2009 and is estimated to be completed in September of 2011. The total cost of the project is $17 million and it is being built using the design-bid-built construction method.

The owner of the Army Reserve Center is the United States Government, specifically the Department of Defense represented by the U.S. Army Corps of Engineers – Louisville District. The contractor is J&J Contractors and the design team is Michael Baker.

Architecture

The building will consist mostly of white range field brick on the exterior. Bands of tan ground face block will be present with period fields of matching tan split face block to break up the long mass of the elevations. To emphasize certain transitions, light tan cast stone accents are used.

The massing of the building is meant to be simple, with a main two-story mass, and an attached 1-1/2 story mass which contains the assembly hall. This simple, proportional massing lends the design to be simply structured, providing maximum value for the given area program.

Zoning

The building is classified as Business Group B in the International Building Code as its primary occupancy. Its secondary occupancy consists of Assembly Group A-3 and Storage Group S-1 according to the International Building Code.

Building Enclosure

Primary Wall System

As shown in Figure 1 below, the primary wall system is a non-load bearing, insulated masonry cavity wall with decorative concrete masonry unit (CMU) or brick masonry veneer.

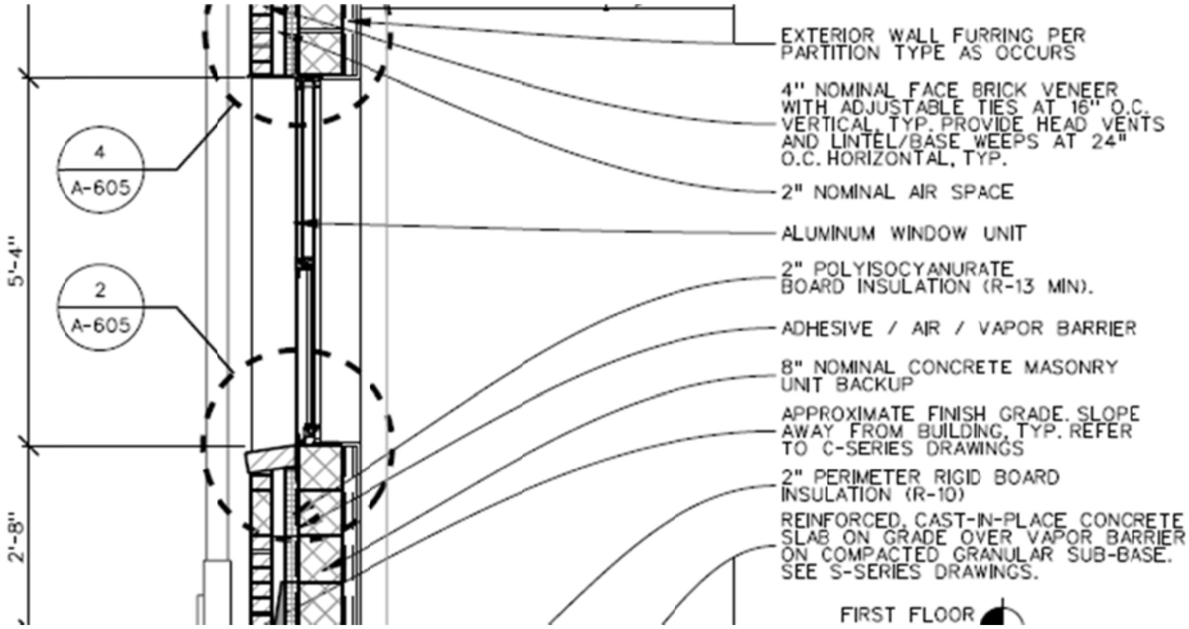


Figure 1

Second Floor and Up

The second floor consists of masonry veneer on metal studs to provide a lighter, more cost effective solution.

Roofing

As shown in Figure 2 below, the roofing system is a hipped, standing seam metal roof with a 3:12 pitch.

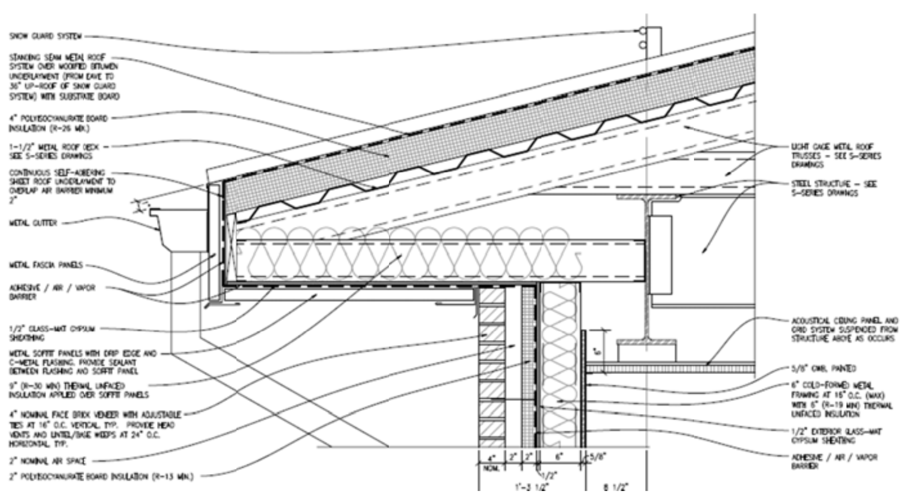


Figure 2

Windows/Doors

The windows are anodized aluminum fixed or operable, with aluminum storefront assemblies for large expanses of glazing, and at the major entry. Other doors will be insulated, painted metal doors in hollow metal frames.

Sustainability Features

The project is going to follow LEED Version 2.2 in an attempt to be sustainable. The Army Reserve Center is projected to obtain 36 to 42 LEED points which will thus achieve LEED Silver and or Gold. To achieve this, alternative transportation, water use reduction, optimizing energy performance, and using low emitting materials are all strategies that will be employed.

Construction

The construction of the Army Reserve Center training building will be completed in the fall of 2011. An organizational maintenance shop and an unheated storage building will also be built. The general contractor for the job is J&J Contractors, Inc. A design-bid-build method was used for the project delivery method.

Electrical

13.8 kV electricity shall be brought in from an existing manhole and then stepped down to 480/277V, three phase, four wires by a 750 KVA transformer. A 200 amp load break switch, current limiting fuse, and bayonet overload fuse shall be provided. Motors and other large electrical loads will operate at 480 volts and lighting will operate at 277 volts.

Lighting

Most of the Army Reserve Center will consist of fluorescent fixtures with electronic ballasts and energy efficient T8 lamps with an illumination level of 50 foot-candles. The storage spaces and mechanical/electrical rooms will have lighting levels of 20 and 30 foot-candles respectively. In order to save energy, occupancy sensors will be provided in accordance with ASHRAE 90.1.

Structural

The Army Reserve Center consists of two different types of structural systems. The first system is for the two story portion of the Army Reserve Center. It is made up of steel wide flange columns and beams that support a composite steel deck at the second floor and a pre-engineered light gage metal truss system at the roof. The second floor of the Army Reserve Center is composed of a steel beam floor framing which supports 2" galvanized composite steel deck and reinforced normal weight concrete, with an overall slab thickness of 4 ½”. To support the roofing system, 1 ½” galvanized metal deck spans between framing members consisting of light gage pre-engineered trusses that are spaced 48” apart and span to steel girders framing into steel columns. The exterior walls, supported by the foundation system, are composed of 4” masonry veneer with 8” concrete masonry backup and 6” light gage metal stud backup at the first and second floors respectively.

The second structural system of the Army Reserve Center is for the attached auditorium. It consists of steel joists that are supported by steel girders and columns. A 1 ½” galvanized metal deck spanning between steel joists is implemented to support the roofing system. The exterior walls, consisting of 4” masonry veneer with 8” concrete masonry backup, cantilever past the steel roof to form a low parapet around the roof’s perimeter. They are supported by the foundation system.

Fire Protection

The Army Reserve Center shall be provided with an automatic wet pipe sprinkler system in accordance with NFPA 13 and UFC 3-600-01. The water for the sprinkler system shall be obtained from a different water line then the domestic water line. Each sprinkler system shall be provided with a OS&Y gate valve, backflow preventer, tamper switch, flow switch, test and drain valve assembly and drain line. Access shall be available to components of the sprinkler system that require access.

Transportation

The Army Reserve Center has a vestibule at the main entrance located in the northeast corner of the building. Two other vestibules along the western wall also allow entry. There are two stairwells in the Army Reserve Center – one in the northeastern corner and another in the southeastern corner. There is one elevator in the northeastern part of the Army Reserve Center.

Telecommunications

Telecommunications in the Army Reserve Center will be from Verizon. Category 6 horizontal cabling shall be routed throughout the building in cable tray as open cabling. The assembly hall will contain a public address system. Cable television outlets are to be provided in break rooms, classrooms, the assembly hall and other spaces defined by UFC 4-171-05. An intercom/buzzer system will be provided at the entry vestibule with door release buttons provided in full-time offices adjacent to the entry.

Existing Variable Air Volume (VAV) System

The Army Reserve Center uses a Direct Digital Control (DDC) system with electronic actuation for control of all HVAC systems and equipment. The DDC system includes controllers for all air handling units, hydronic pumping systems, VAV terminal units and lighting. It monitors electricity, natural gas, water usage, is Johnson Control, Inc. (JCI) based, and is compatible with JCI N2 and LonWorks.

Airside

The Army Reserve Center uses three air handling units in order to heat, cool, and supply outside air to the building. All three air handling units are located in mechanical rooms on the second floor. AHU-1 is of the variable air volume type, provides 3700 CFM of supply air of which 24% is outside air, and serves the first floor offices along with several other spaces on the first floor. The load and required outside air for the rest of the spaces on the first floor is met with unit ventilators. AHU-2, also of the variable air volume type, handles the load and outside air required for the second floor. It provides 13,200 CFM of supply air which is 18% outside air. AHU-1 and AHU-2 have enthalpy based economizers and variable frequency drives on both the supply and return fans. Both AHU-1 and AHU-2 have a minimum and maximum amount of air. The maximum is determined by the maximum load that has to be met and the size of the system required to meet this load. The minimum, in this case, is determined by the required outside air for the zone. However, if the heating coil was electric instead of hot water, the minimum outside air across it could be the amount required for the coil to not overheat. Both AHU-1 and AHU-2 have chilled water cooling coils, hot water heating coils, and variable air volume boxes with hot water re-heat coils in each separate zone. The re-heat coils for each box contain 2-way modulating hot water control valves, are designed for an entering water temperature of 130°F with a 30°F temperature drop across the coil, and a pressure differential of 0.6 inches of water across the box. After the air reaches each zone, it is returned through a plenum until it eventually reaches the return fan of AHU-1 or AHU-2 and is sent outside.

AHU-3, a constant volume air handling unit, serves the assembly area. It provides 2100 CFM of supply air of which 64% is outside air. The assembly area contains occupancy sensors which provide information to the air handling unit in order to determine the amount of supply air required to meet the heating loads, cooling loads, and required outside air. After a constant volume of air is supplied to the auditorium, it is returned to the outside by one of two rooftop ventilators that are ducted to the auditorium from above.

Unit Ventilators one through eight (UV-1 through UV-8) are used throughout the first floor to handle the loads and outside air requirements of several smaller spaces. They each contain a chilled water cooling coil, a hot water heating coil, and motorized dampers in order to have economizer mode operation. They return air through the plenum until it reaches a relief ventilator. The spaces they serve have occupancy sensors to determine the amount of supply air required to meet the outside air and load requirements.

Waterside

In the Army Reserve Center, two boilers are present to heat the building. The heating accounts for 198 MMBtu/year which is 10.3% of the total energy used in the building. Both boilers have 959 MBH of capacity. Each boiler, B-1 and B-2, has inline primary boiler circulation pumps and secondary pumps with variable frequency drives to send hot water throughout the building. Hot water is supplied at 130°F and returned at 100°F with automatic reset based on outdoor air temperature. Hot water minimum flows are sent through coils when the outside air temperature is below 40°F in order to prevent freezing.

In the Army Reserve Center, two air-cooled rotary screw packaged water chillers which are piped in parallel are used to cool the building. The cooling accounts for 250 MMBtu/year which is 13% of the total energy used in the Army Reserve Center. The chillers have capacities of 40 and 52 tons. A variable flow primary pump with a variable frequency drive is used, with secondary pumps to send chilled water to the coils. The chilled water supply temperature is 42°F and the chilled water return temperature is 58°F.

Schematic Drawings of Existing Mechanical Systems

Shown below in Figure 3 is the chilled water flow diagram and shown below in Figure 4 is the heating hot water flow diagram.

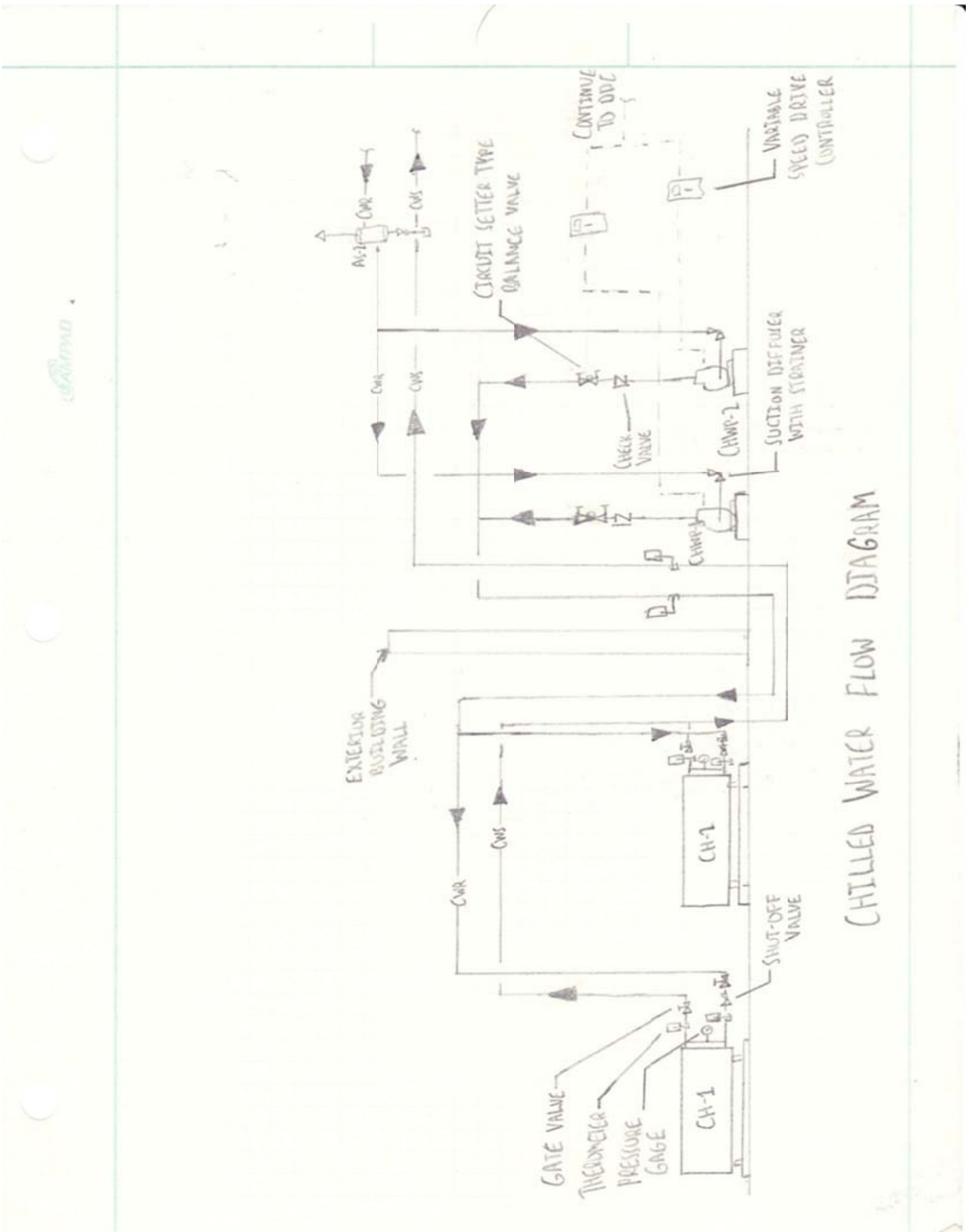
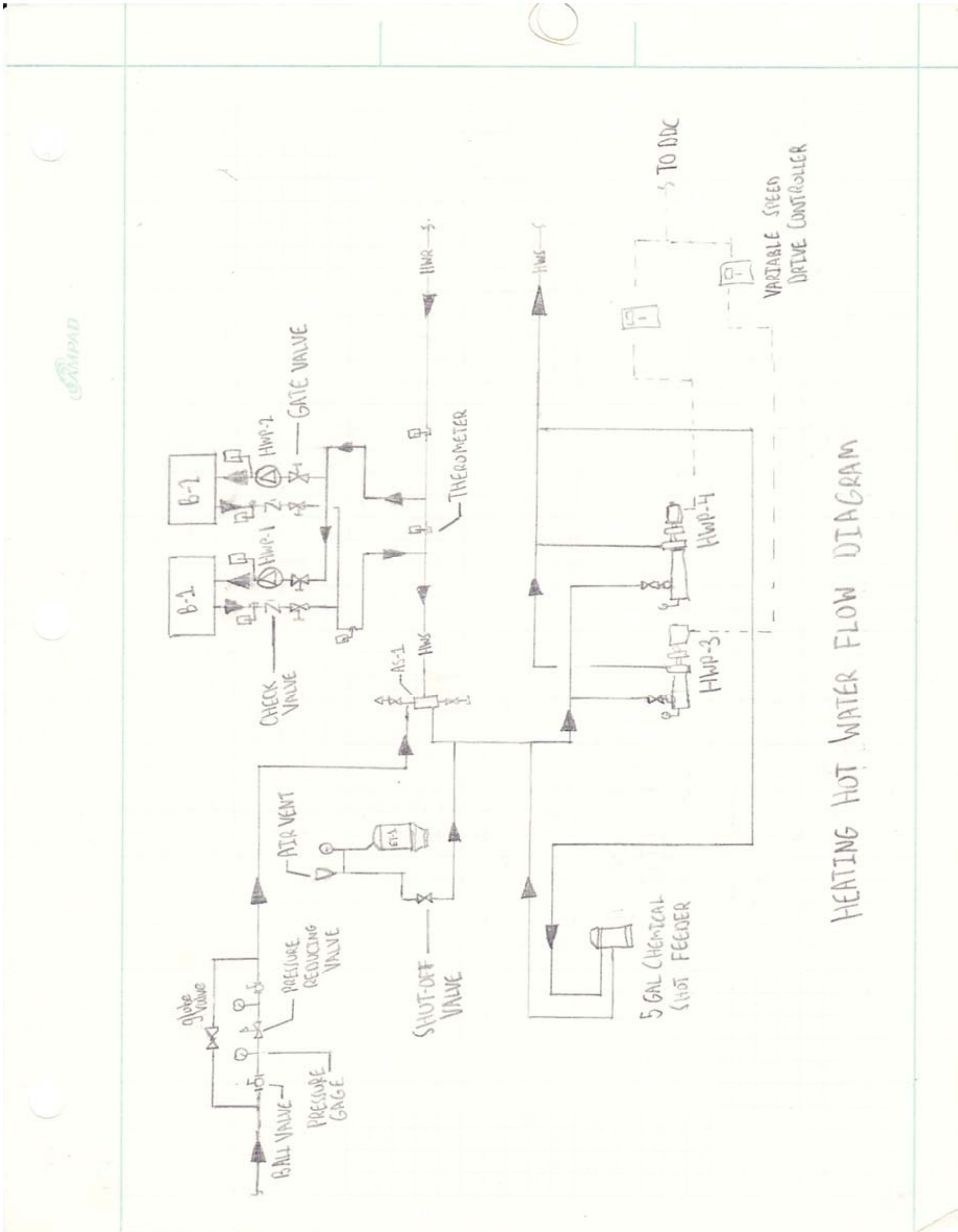


Figure 3



HEATING HOT WATER FLOW DIAGRAM
TO DDC
VARIABLE SPEED DRIVE CONTROLLER
B-1
B-2
HWP-1
HWP-2
HWP-3
HWP-4
GATE VALVE
CHECK VALVE
THEROMETER
HWR
HWS
AS-1
AIR VENT
SHUT-OFF VALVE
globe Valve
PRESSURE REDUCING VALVE
BALL VALVE
PRESSURE GAGE
5 GAL CHEMICAL SHOT FEEDER

Figure 4

Summary of Major Equipment

The Army Reserve Center contains three air handling units which are summarized in Table 1 below.

AIR HANDLING UNIT SCHEDULE					
TAG	UNIT TYPE	AREA SERVED	MAX SA (CFM)	MIN SA (CFM)	MIN OA (CFM)
AHU-1	VAV	FIRST FLOOR OFFICE	3700	1915	900
AHU-2	VAV	SECOND FLOOR	13200	8175	2375
AHU-3	CV	ASSEMBLY AREA	2100	2100	1345

Table 1

The rest of the ventilation for several other spaces on the first floor is done using small unit ventilators. The unit ventilators are summarized in Table 2 below.

FOUR PIPE UNIT VENTILATOR SCHEDULE					
TAG	AREA SERVED	SUPPLY CFM	MIN OA CFM	CHILLED WATER COOLING COIL CAPACITY (MBH) TOT/SENS	HOT WATER HEATING COIL CAPACITY (MBH)
UV-1	127-CLASSROOM	625	155	12.9 / 12.1	27
UV-2	128-CLASSROOM	440	150	20.4 / 13.3	14.4
UV-3	129-CLASSROOM	440	150	20.4 / 13.3	14.4
UV-4	SOUTH SUPPLY OFFICES	606	95	17.8 / 17.01	19.9
UV-5	WEST SUPPLY OFFICES	650	95	25.1 / 23.4	21.2
UV-6	WEAPONS SIMULATOR	975	205	26.2 / 26.2	25.5
UV-7	SIPRNET CAFÉ	1575	85	25.5 / 24.9	58.1
UV-8	MAILROOM SUITE	375	50	12.9 / 9.4	10

Table 2

To heat the Army Reserve Center, two boilers are present. They are summarized in Table 3 below.

HOT WATER BOILER SCHEDULE				
TAG	TYPE	MAX INPUT (MBH)	MAX OUTPUT (MBH)	MIN GAS INPUT (MBH)
B - 1,2	MODULATING VERTICAL	999	959	50

Table 3

To cool the Army Reserve Center, two air-cooled rotary screw packaged water chillers piped in parallel are used in the building. The chillers are manufactured by Trane, and they are summarized in Table 4 below.

AIR COOLED CHILLER SCHEDULE								
TAG	NOMINAL CAPACITY (TONS)	EFFICIENCY		COMPRESSOR		ELECTRICAL DATA		
		FULL LOAD EER	FULL LOAD COP	TYPE	REFRIG. TYPE	VOLTS/PHASE/HERTZ	MCA	MOCP
CH-1	40	9.9	2.9	SCROLL	R-410A	460 / 3 / 60	91.8	110.00
CH-2	52	9.9	2.9	SCROLL	R-410A	460 / 3 /60	108.2	125.00

Table 4

Pumps are used in the Army Reserve Center to send chilled and hot water throughout the building. They are summarized in Table 5 below.

PUMP SCHEDULE								
TAG	PUMP TYPE	FLUID TYPE	FLUID TEMP (°F)	GPM	HEAT (FT H2O)	ELECTRICAL DATA		
						MOTOR HP	NOMINAL MOTOR RPM	VOLTS/PHASE/HERTZ
CHWP - 1,2	BASE MTD, END SUCTION	WATER	42	130	50	5	1750	480 / 3 /60
HWP - 1,2	INLINE BOOSTER	WATER	130	100	10	3 / 4	1150	460 / 3 /60
HWP - 3,4	BASE MTD, END SUCTION	WATER	130	100	55	5	1750	460 / 3 /60

Table 5

Lost Space Due to Mechanical System

There are three mechanical rooms in the Army Reserve Center. The mechanical room on the first floor contains the boilers, one mechanical room on the second floor contains AHU-3, and the other mechanical room on the second floor contains AHU-1 and AHU-2. Shown below in Table 6 is the total area taken up by the mechanical rooms and the mechanical shaft area and the percentage of area compared to that of the total building area (the total building area is approximately 59,000 square feet).

Floor	Area	Percentage of Total Building Area
1st	1288	2.18%
2nd	1085	1.84%
Total	2373	**4.02%**

Table 6

Annual Energy Use

	Electric Consumption (kWh)	Gas Consumption (kBTU)	% of Total Building Energy	Total Building Energy (mmBtu/yr)
Heating				
Primary Heating		262,196	21.36%	262
Other Htg. Accessories	2,513		0.70%	8.6
Cooling				
Cooling Compessor	28,299		7.87%	96.6
Tower/Cond Fans	3,998		1.11%	13.6
Other Clg Accessories	340		0.10%	1.2
Auxiliary				
Supply Fans	110,180		30.65%	376
Pumps	18,383		5.11%	62.7
Lighting	75,159		20.91%	256.5
Receptacles	43,839		12.19%	149.6
Total	**282,711**	**262,196**	**100%**	**1,226.80**

Table 7

As shown in Table 7 above, the majority of the energy consumption of the Army Reserve Center is due to the supply fans, lighting, and primary heating, representing 30.65%, 20.91%, and 21.36% of the total energy used respectively. The supply fans were modeled in Trace based on the design documents. The motor horsepower was given in the design documents. However, in Trane Trace, the full load horsepower was asked for. While this number should be close, the actual horsepower at full load will have to be slightly less than that in the design documents since motors come in standard horsepower sizes. Thus, the supply fans may use slightly less energy than that calculated.

Figures 5 and 6 below show the monthly usage of natural gas and electricity, respectively. As one may predict, natural gas usage is negligible (if at all) in the summer because there is hardly any heating from the boilers. However, it increases in the winter month and is a maximum at 621 therms in January.

Electricity usage is at a maximum in August at 28,502 kilowatt hours because many of the air conditioning applications need a lot of electricity to meet their capacities. It is higher also in June and July.

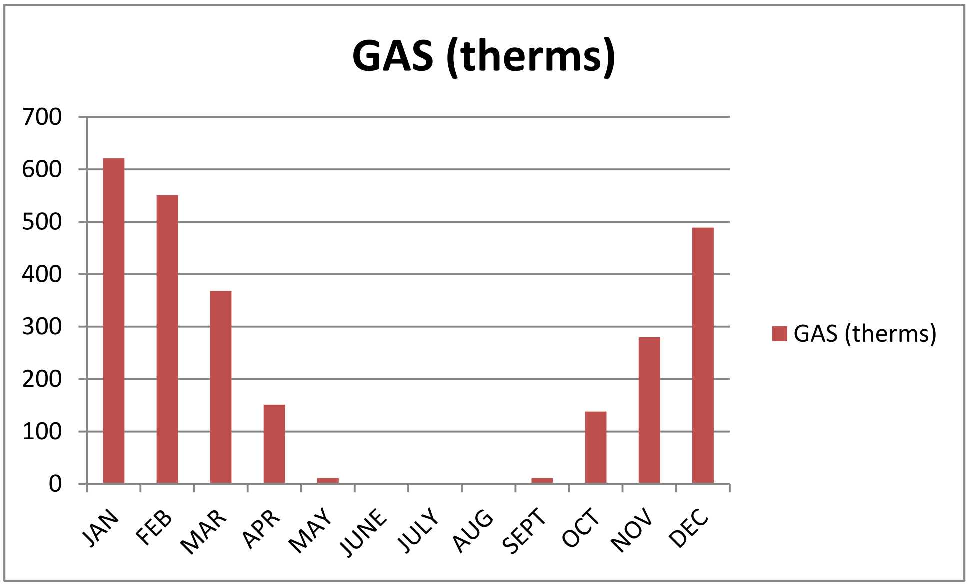


Figure 5 (above)

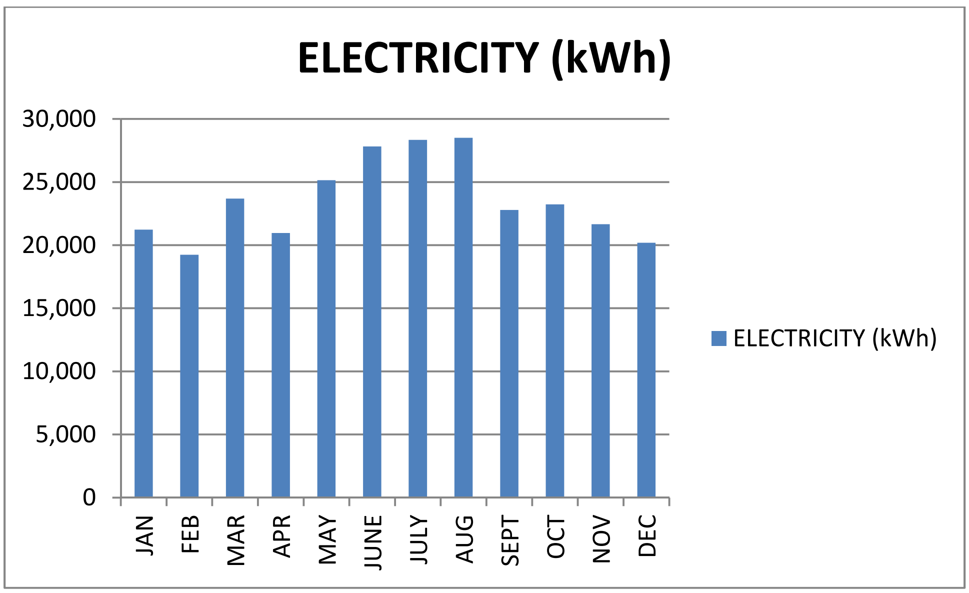


Figure 6

Fuel Costs

According to the specifications, the cost for electricity is $93.15/MWH or $0.09315/Kwh. The cost of natural gas is approximately $4.00/MMBtu. As shown in Table 8 below, the total cost to operate the building per year is $27,384. Since the area of the building is approximately 59,000 square feet, the cost per square foot be operate the Army Reserve Center is $0.46 / square foot.

Total Cost of Energy				
	Electric Cost	**Gas Cost**	**% of Total Building Cost**	**Total Building Cost**
Heating				
Primary Heating		$1,048.78	3.83%	$1,048.78
Other Htg. Accessories	$234.09		0.85%	$234.09
Cooling				
Cooling Compessor	$2,636.05		9.63%	$2,636.05
Tower/Cond Fans	$372.41		1.36%	$372.41
Other Clg Accessories	$31.67		0.12%	$31.67
Auxiliary				
Supply Fans	$10,263.27		37.48%	$10,263.27
Pumps	$1,712.38		6.25%	$1,712.38
Lighting	$7,001.06		25.57%	$7,001.06
Receptacles	$4,083.60		14.91%	$4,083.60
Total	**$26,334.53**	**$1,048.78**	**100%**	**$27,383.31**

Table 8

Total Cost

As shown in Table 9 below, the total cost to obtain and install the air handling units, ductwork, unit ventilators, boilers, and chillers for the existing variable air volume system is $301,410. This was estimated using RS Means Cost Estimator.

VAV	AREA SERVED	CFM (MAX)	HEATING CAPACITY (MBH)	COOLING CAPACITY (Total / Sensible) (MBH)	MANUFACTURER	MODEL	COST
AHU-1	FIRST FLOOR OFFICES	3700	59.8	180 / 124	TRANE	MCC	$7,950.00
AHU-2	SECOND FLOOR	13200	144	530 / 380	TRANE	MCC	$21,775.00
AHU-3	ASSEMBLY	2100	125	148 / 81	TRANE	MCC	$5,055.00
UV-1	CLASSROOM	625	27	12.9 / 12.1	TRANE	BCHC	$2,125.00
UV-2	CLASSROOM	440	14.4	20.4 / 13.3	TRANE	BCHC	$2,335.00
UV-3	CLASSROOM	440	14.4	20.4 / 13.3	TRANE	BCHC	$2,335.00
UV-4	SOUTH SUPPLY OFFICES	606	19.9	17.8 / 17.0	TRANE	BCHC	$2,125.00
UV-5	WEST SUPPLY OFFICES	650	21.2	25.1 / 23.4	TRANE	BCHC	$2,705.00
UV-6	WEAPONS SIMULATOR	975	25.5	26.2 / 26.2	TRANE	BCHC	$2,705.00
B-1	WHOLE BUILDING	-	999	-	AERCO	KC-1000	$18,434.00
B-2	WHOLE BUILDING	-	999	-	AERCO	KC-1000	$18,434.00
CH-1	WHOLE BUILDING	-	-	480	TRANE	CGAM040	$39,100.00
CH-2	WHOLE BUILDING	-	-	624	TRANE	CGAM052	$44,625.00
DUCTWORK	WHOLE BUILDING	-	-	-	-	-	$131,707.00
TOTAL COST							**$301,410.00**

Table 9

ASHRAE Standard 62.1 Analysis

ASHRAE STANDARD 62.1 ANALYSIS	
SECTION	**COMPLIES?**
5.1 - NATURAL VENTILATION	YES
5.2 - VENTILATION AIR DISTRIBUTION	YES
5.3 - EXHAUST DUCT LOCATION	YES
5.4 - VENTILATION SYSTEM CONTROLS	YES
5.5 - AIRSTREAM SURFACES	YES
5.6 - OUTDOOR AIR INTAKES	NO
5.7 - LOCAL CAPTURE OF CONTAMINANTS	YES
5.8 - COMBUSTION AIR	YES
5.9 - PARITCULATE MATTER REMOVAL	YES
5.10 - DEHUMIDFICATION SYSTEMS	YES
5.11 - DRAIN PANS	YES
5.12 - FINNED-TUBE COILS AND HEAT EXCHANGERS	YES
5.13 - HUMIDFIERS AND WATER-SPRAY SYSTEMS	YES
5.14 - ACCESS FOR INSPECTION, CLEANING, AND MAINTENANCE	YES
5.15 - BUILDING ENVELOPE AND INTERIOR SURFACES	YES
5.16 - BUILDINGS WITH ATTACHED PARKING GARAGES	YES
5.17 - AIR CLASSIFICATION AND RECIRCULATION	YES
5.18 - REQUIREMENTS FOR BUILDINGS CONTAINING ETS AREAS AND ETS FREE AREAS	YES
6 - VENTILATION RATE PROCEDURE	YES

Table 10

As shown in Table 10 above, the Army Reserve Center is compliant with almost all of Section 5 and all of Section 6 of ASHRAE 62.1. Each occupant should receive enough ventilation air. The Army Reserve Center should not experience problems with mold or water leakage and the air quality also seems to be okay. The only exception occurs in Section 5.6 – Outdoor Air Intakes. It requires that outdoor air intakes are at least 15 feet from significantly contaminated exhaust. Several windows are about five to ten feet below an exhaust louver that runs out of room 123, a mechanical room. The exhaust comes from the janitor's closet and toilet rooms and thus probably has an offensive odor, making it significantly contaminated. The rest of the outdoor air intakes meet the required separation distances.

ASHRAE Standard 90.1 Analysis

ASHRAE STANDARD 90.1 ANALYSIS	
SECTION	**COMPLIES?**
5.1.4 - CLIMATE	YES
5.2 - COMPLIANCE PATHS	YES
5.4 - MANDATORY PROVISIONS	YES
5.4.3.5 - VESTIBULES	YES
5.5 - PERSPECTIVE BUILDING ENVELOPE OPTION	YES
6.3 - SIMPLIFIED APPROACH OPTIONS FOR HVAC SYSTEMS	YES
6.4 - MANDATORY PROVISIONS	YES
6.5 - PRESCRIPTIVE PATH	NO
7 - SERVICE WATER HEATING	NO
8 - POWER	NO
9 - LIGHTING	YES

Table 11

As shown in Table 11 above, the Army Reserve Center is compliant with much of ASHRAE 90.1. The Army Reserve Center is entirely compliant and has even exceeded the requirements for Section 5.5, Perspective Building Envelope Option. This is due to caulking and sealing the joints of windows, doors, and louvers in order to limit infiltration. Also, the R-values of the building materials exceed those required. However, the Army Reserve Center does not comply with Section 6, Heating, Ventilation, and Air Conditioning. It exceeds the maximum horsepower required for fans in Section 6.5. The Army Reserve Center does not follow Sections 7, Service Water Heating, and Section 8, Power, either. The water supplied to fixtures is ten degrees hotter than that required in Section 7 and the maximum voltage drop in branch circuits required is 10% versus the 2% allowed in Section 8. However, the Army Reserve Center not only meets, but exceeds all the requirements of Section 9, Lighting.

Although the Army Reserve Center fell short in meeting several requirements of ASHRAE 90.1, it still met most all of the requirements. The several that were not met may still be met after construction. For example, the maximum voltage drop in branch circuits may be less than 2% even though less than 10% was specified

Existing Mechanical Systems Conclusion

The mechanical systems for the Army Reserve Center seem to suit the building well. The Army Reserve Center is architecturally designed with three core spaces which are the auditorium, the western area of the first floor, and the second floor. Storage areas and smaller spaces, conditioned by unit ventilators, compose the rest of the building. Although there are several distinct HVAC systems, the Army Reserve Center seems to be conditioned well.

One problem with the current design of the Army Reserve Center is the small ceiling to floor height between the first and second floor. This leads to ducts with aspect ratios that are higher than recommended. To fix this, a variable refrigerant flow system could have been installed to handle the heating and cooling loads, with smaller ducts in place to supply the required outside air to each space. This would lead to either smaller ducts with lower aspect ratios or a smaller height of the building, which may reduce the total cost.

The total cost to operate the Army Reserve Center is $27,384 per year or $0.46 / square foot. This was based on an estimate performed using Trane Trace 700.

The systems, although there are several, should be maintainable by a maintenance staff. They offer good environmental control and comply with ASHRAE's requirements for indoor air quality. As mentioned above, the Army Reserve Center does a good job using several systems in a cost effective way.

Mechanical System Redesign

After analyzing the Army Reserve Center's current mechanical systems and talking to the design engineer, several options were considered in the redesign. The design engineer specifically mentioned that a variable refrigerant flow (VRF) system should be considered as an alternative to the current variable air volume (VAV) system.

Variable Refrigerant Flow

A variable refrigerant flow (VRF) system contains multiple indoor evaporators connected to a single condensing unit allowing heat to be transferred directly to the space by pipes containing the refrigerant located throughout the building. The pipes will be smaller than the ducts of a variable air volume (VAV) system because the heat capacity of the refrigerant is larger than that of air. This handles all of the sensible loads for the building. However, either operable windows or a separate air handler must be used for ventilation and to meet the latent load.

A variable refrigerant flow system has several benefits. VRF systems are lightweight, easily transported, and can fit into an elevator. To maintain the same load, the pipes of a VRF system take up less space than ductwork.

Variable refrigerant flow systems save energy when compared to conventional variable air volume systems. They have multiple compressors in each condensing unit which allows for wide capacity modulation and thus high part-load efficiency. Heat recovery VRF systems, which transfer heat from interior spaces that require cooling to exterior spaces that require heating, can be used for buildings that have simultaneous heating and cooling.

Ground Source Heat Pump

A heat pump either extracts heat from the outside during the winter to warm a space or sinks heat to the outside in the summer to cool a space. A ground source heat pump will be used to take advantage of the relatively constant 50°F – 60°F temperature of the Earth below the frost line. Although the life of a ground source heat pump is longer than other, ground source heat pumps are more expensive because wells must be dug for piping.

Dedicated Outdoor Air System

A dedicated outdoor air system (DOAS) brings in excess outside air to meet the ventilation requirements as well as the space latent load. The outside latent load is taken care of by the presence of desiccants and/or cooling coils. It also meets some of the sensible load. Chilled beams (active or passive), a variable refrigerant flow system, or several other options could be used to meet the rest of the sensible load. Thus, for the Army Reserve Center, DOAS accompanied with both a VRF System and a GSHP will be explored.

Breadth Topics

Acoustical Breadth

If a variable refrigerant flow system is used, the condensing units will be placed on the roof. The condensing units will make noise and an acoustical study will be done to determine if material is required to surround each of them to minimize the noise to an acceptable level.

Structural Breadth

If a variable refrigerant flow system is used, the condensing units will be placed on the roof. This may change the roof's structural requirements. A study will be done to determine the new roof deck, joists, and girders required to support the increased load.

Integration and Coordination

The Army Reserve Center should become far more energy efficient by decoupling the loads and ventilation. This will be done through the installation of a variable refrigerant flow (VRF) system to handle the sensible load requirements with a dedicated outdoor air system (DOAS) to handle the ventilation requirements and latent load. A ground source heat pump is another possible idea which would improve the building's energy efficiency with DOAS to handle the ventilation requirements and latent load.

The three systems (VAV, VRF/DOAS, and GSHP/DOAS) will be compared in order to determine the best system for the Army Reserve Center. There will probably be structural changes due to the addition of condensing units on the roof for the VRF system. Acoustically, there will be changes as well due to the addition of condensing units. There should be no other changes in the lighting, electrical, or architectural aspects of the building.

Variable Refrigerant Flow (VRF) with Dedicated Outdoor Air (DOAS)

A variable refrigerant flow (VRF) system was selected to replace the existing variable air volume system and the smaller unit ventilators scattered throughout the Army Reserve Center. To meet the ventilation air requirements and the latent load, a separate dedicated outside air system (DOAS) will be used. Although this type of system has many benefits as mentioned above, it is especially beneficial for the Army Reserve Center.

The aspect ratio of a duct is equivalent to its width divided by its height. The aspect ratio should be as close as one as possible because, as the aspect ratio increases, the pressure required to move air through the duct also increases. As the pressure loss increases, the size of the supply and return fans must also increase. Not only does this increase the initial cost of the fans, but the cost of the energy required to operate the fans also increases. Another disadvantage of a high aspect ratio is that ducts with higher aspect ratios are noisier than their square counterparts.

The Army Reserve Center contains ducts on the first floor that have dimensions of 20x8, 30x6, and 60x8. This leads to aspect ratios of 2.5, 5, and 7.5, each of which is far too high. With a variable refrigerant flow system in place, the total amount of air supplied to each zone will decrease dramatically, and thus the duct size can be reduced.

Although several duct sizes on the first floor should be reduced, the ducts on the second floor have aspect ratios that are far more reasonable. Thus, by using a variable refrigerant flow system their sizes can be reduced and it would be possible to shrink the plenum reducing the overall size of the building. This would thus reduce the total project cost and construction time.

Another benefit of using a variable refrigerant flow system is that the boilers can be removed from the building and smaller chillers can be used for the dedicated outdoor air system. This reduces cost for several reasons. It eliminates the cost of the boilers and larger chillers themselves, but also reduces cost for associated equipment, such as pumps and piping for each boiler and chiller. The Army Reserve Center would also not have to connect to a natural gas line. However, the U.S. Army Corps of Engineers would probably still want to have the ability for natural gas if necessary.

A variable refrigerant flow system has a much higher efficiency than the conventional variable air volume system with chillers. The COP of the chillers used in the Army Reserve Center is 2.90 at full load. Shown in Figure 7 below is the COP for the Multi V Sync developed by Life's Good Electronics. The Multi V Sync is a variable refrigerant flow system capable of simultaneous heating and cooling to different zones. Heat recovery, done by taking energy from a zone requiring cooling and transferring it to a zone requiring heating and vice versa, is also employed to save energy. A diagram of this system is shown in Figure 8 below.

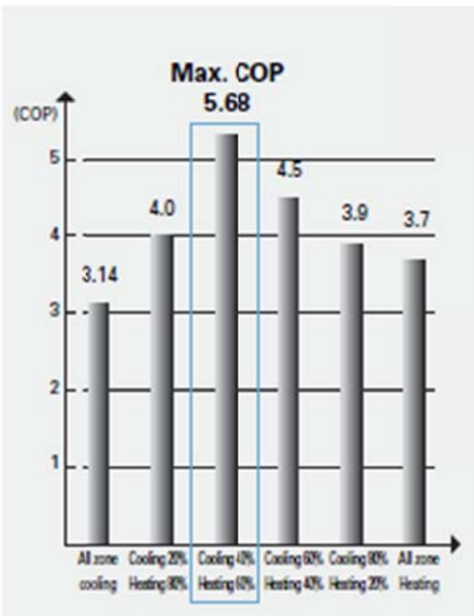


Figure 7

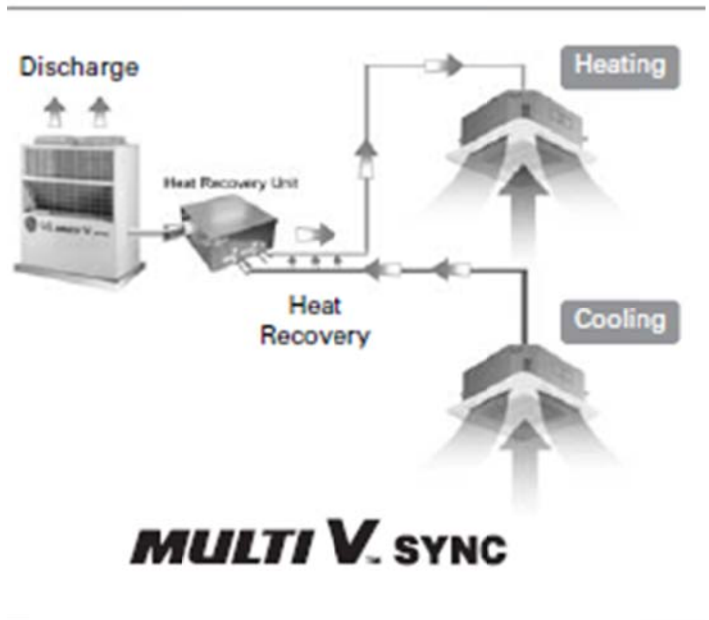


Figure 8

Load Analysis

Trane Trace 700 was used to model the Army Reserve Center in order to determine the total energy required as well as the heating and cooling loads. The outside air required to meet the latent loads was determined using a hand calculation.

In the Trace model, a Variable Refrigerant Volume System was selected. Dedicated ventilation was also used. The dedicated ventilation system was configured so that it would be dehumidified to the low dew point required in the design documents without being reheated. The air was not reheated because latent load is a problem in cooling and not heating. Thus, this cool air will help to take care of some of the sensible load.

Airflow

Airflow was determined by the design engineer using ASHRAE 62.1. The infiltration for the building was assumed to be pressurized tight construction thus allowing 0.3 air changes per hour.

Lighting

The average lighting of the Army Reserve Center is 0.71 Watts / square foot. Since the design load is estimated based on the block load method, this is used for each of the blocks.

Schedules

The Army Reserve Center is primarily a low rise office building. Thus, the schedules that were used for the lighting, people, and ventilation were the low rise office schedules. They are shown for the typical weekday below in Tables 12, 13, 14, and 15 below.

Vent - Low Rise Office		
Start Time	**End Time**	**Percentage**
Midnight	7 a.m.	0
7 a.m.	Midnight	100

Table 12

People - Low Rise Office		
Start Time	**End Time**	**Percentage**
Midnight	7 a.m.	0
7 a.m.	8 a.m.	30
8 a.m.	11 a.m.	100
11 a.m.	Noon	80
Noon	1 p.m.	40
1 p.m.	2 p.m.	80
2 p.m.	5 p.m.	100
5 p.m.	6 p.m.	30
6 p.m.	9 p.m.	10
9 p.m.	Midnight	5

Table 13

Misc - Low Rise Office		
Start Time	End Time	Percentage
Midnight	7 a.m.	5
7 a.m.	8 a.m.	80
8 a.m.	10 a.m.	90
10 a.m.	Noon	95
Noon	2 p.m.	80
2 p.m.	4 p.m.	90
4 p.m.	5 p.m.	95
5 p.m.	6 p.m.	80
6 p.m.	7 p.m.	70
7 p.m.	8 p.m.	60
8 p.m.	9 p.m.	40
9 p.m.	10 p.m.	30
10 p.m.	Midnight	20

Table14

Lights - Low Rise Office		
Start Time	End Time	Percentage
Midnight	7 a.m.	5
7 a.m.	8 a.m.	80
8 a.m.	10 a.m.	90
10 a.m.	Noon	95
Noon	2 p.m.	80
2 p.m.	4 p.m.	90
4 p.m.	5 p.m.	95
5 p.m.	6 p.m.	80
6 p.m.	7 p.m.	70
7 p.m.	8 p.m.	60
8 p.m.	9 p.m.	40
9 p.m.	10 p.m.	30
10 p.m.	Midnight	20

Table 15

Occupancy

The number of people each space is to be designed for is given in the design documents. Those values are used to determine the occupancy. For the offices, each occupant is assumed to have a personal computer that gives off 150 watts. For the library and the copy center, an appropriate amount of watts for each computer, copier, and printer are assumed. Each person is assumed for most spaces to have a sensible load of 250 Btu/h and a latent load of 200 Btu/h because most of the spaces are classrooms or general office space. However, each person is assumed to have a sensible load of 225 Btu/h and a latent load of 105 Btu/h for the auditorium.

Indoor / Outdoor Air Conditions

The design conditions of Providence, Rhode Island were used for the Army Reserve Center because they were the closet available to Newport, Rhode Island. These are:

Heating: 10.8°F (99.0% Occurrence)
Cooling: 89.7°F DB / 73.2°F WB (0.4% Occurrence)

However, because it was requested by the US Army Corps of Engineers, 0°F was used for heating. Also, as requested, indoor cooling design conditions shall be 74°F with 50% relative humidity and indoor heating shall be 72°F for occupied spaces and 55°F for unoccupied spaces.

Results

Shown in Table 16 below are the cubic feet per minute for each space and the air handler that is needed to meet the latent load. The formula Q = 4840 * CFM * ΔW was used where ΔW is the change in the humidity ratio of the air. The new CFM vary slightly from the initial CFM for AHU-1, AHU-2, and AHU-3. AHU-1 is a lot larger due to the removal of all unit ventilators. Those spaces were placed on AHU-1 for the handling of the latent loads, and a variable refrigerant flow system for the sensible loads. AHU-3 is also slightly larger. However, AHU-2 is a lot smaller because it will also only handle the latent loads and ventilation requirements.

Unit	Space	Latent Load (BTU)	ΔW (lb moisture/lb DA)	CFM to Meet Latent Load
AHU-1	Office	1200	0.0005	526
AHU-1	Lobby	100	0.0005	40
AHU-1	Corridor	2500	0.0012	441
AHU-1	Breakroom	12917	0.0038	705
AHU-1	Armory	200	0.0009	46
AHU-1	Restroom	900	0.0020	94
AHU-1	Storage	250	0.0007	75
AHU-1	Library	12000	0.0025	1009
AHU-1	Fam Readiness	100	0.0008	27
AHU-1	Classrooms (moved from UV)	7300	0.0011	1427
AHU-1	Offices (moved from UV)	2200	0.0004	1136
AHU-1	Offices (moved from UV)	3000	0.0002	3338
AHU-1	Interior Control Rooms (moved from UV)	900	0.0008	237
AHU-1	**Total**	**43567**	**-**	**9101**
AHU-2	Office Area	20800	0.0020	2149
AHU-2	Unit Common	19330	0.0028	1419
AHU-2	Corridor	2400	0.0022	223
AHU-2	Restroom	300	0.0033	19
AHU-2	Classroom	2600	0.0015	365
AHU-2	Copy Room	200	0.0001	362
AHU-2	Pub Storage	700	0.0029	49
AHU-2	**Total**	**46330**		**4585**
AHU-3	Assembly	18,900	0.0013	2936
AHU-3	**Total**	**18,900**	**-**	**2936**

Table 16

The total CFM in the table above meets the latent load, but will also handle some of the sensible load when cooling occurs. To meet the latent load at peak conditions, the temperature of the air remains at the dew point of 57°F. This air is not reheated and supplied directly to the space. The equation Q_S = 1.08 * CFM * ΔT is used to determine the sensible heat transfer rate that can be met with the CFM used to handle the latent load. This is shown for each space in Table 17 below when the space is in cooling mode.

Sensible Load Met by CFM from Latent Load for Cooling						
Unit	Space	CFM from latent load	ΔT (°F)	Sensible Load Met by CFM (Btu/hr)	Total Cooling Sensible Load (Btu/hr)	Remaining Cooling Sensible Load (Btu/hr)
AHU-1	Office	526	17	9665	22200	12535
AHU-1	Lobby	40	17	738	3300	2562
AHU-1	Corridor	441	17	8096	9300	1204
AHU-1	Breakroom	705	17	12943	22200	9257
AHU-1	Armory	46	17	843	1500	657
AHU-1	Restroom	94	17	1732	3300	1568
AHU-1	Storage	75	17	1383	3700	2317
AHU-1	Library	1009	17	18526	27700	9174
AHU-1	Fam Readiness	27	17	492	2300	1808
AHU-1	Classrooms (moved from UV)	1427	17	26195	47800	21605
AHU-1	Offices (moved from UV)	1136	17	20864	24900	4036
AHU-1	Offices (moved from UV)	3338	17	61278	23900	0
AHU-1	Interior Control Rooms (moved from UV)	237	17	4345	12500	8155
AHU-1	Total	9101	-	167098	204600	74880
AHU-2	Office Area	2149	17	39451	271900	232449
AHU-2	Unit Common	1419	17	26055	126600	100545
AHU-2	Corridor	223	17	4085	29200	25115
AHU-2	Restroom	19	17	348	3900	3552
AHU-2	Classroom	365	17	6703	14500	7797
AHU-2	Copy Room	362	17	6638	2800	0
AHU-2	Pub Storage	49	17	907	13500	12593
AHU-2	Total	4585	-	84187	462400	382051
AHU-3	Assembly	2936	17	53906	95500	41594
AHU-3	Total	2936	-	53906	95500	41594

Table 17

In heating mode, the CFM of air supplied will only be heated up to room temperature. Thus, the remaining loads must be met through the variable refrigerant flow system. When modeling in Trace, these loads will include everything except for the ventilation loads. The total heating loads are shown in the Table 18 below.

TOTAL HEATING LOAD		
Unit	**Space**	**Total Heating Sensible Load (Btu/hr)**
AHU-1	Office	15379
AHU-1	Lobby	7564
AHU-1	Corridor	16155
AHU-1	Breakroom	19995
AHU-1	Armory	1259
AHU-1	Restroom	3670
AHU-1	Storage	6549
AHU-1	Library	26808
AHU-1	Fam Readiness	2535
AHU-1	Classrooms (moved from UV)	51797
AHU-1	Offices (moved from UV)	14150
AHU-1	Offices (moved from UV)	14741
AHU-1	Interior Control Rooms (moved from UV)	15945
AHU-1	**Total**	**196547**
AHU-2	Office Area	187950
AHU-2	Unit Common	112210
AHU-2	Corridor	25036
AHU-2	Restroom	2110
AHU-2	Classroom	15221
AHU-2	Copy Room	1532
AHU-2	Pub Storage	14609
AHU-2	**Total**	**358668**
AHU-3	Assembly	97187
AHU-3	**Total**	**97187**

Table 18

The units selected for the existing VAV system and the new VRF system are shown in Table 19 below.

UNITS FOR VAV	AREA SERVED	CFM (MAX)	HEATING CAPACITY (MBH)	COOLING CAPACITY (Total / Sensible) (MBH)	MANUFACTURER	MODEL
AHU-1	FIRST FLOOR OFFICES	3700	59.8	180 / 124	TRANE	MCC
AHU-2	SECOND FLOOR	13200	144	530 / 380	TRANE	MCC
AHU-3	ASSEMBLY	2100	125	148 / 81	TRANE	MCC
UV-1	CLASSROOM	625	27	12.9 / 12.1	TRANE	BCHC
UV-2	CLASSROOM	440	14.4	20.4 / 13.3	TRANE	BCHC
UV-3	CLASSROOM	440	14.4	20.4 / 13.3	TRANE	BCHC
UV-4	SOUTH SUPPLY OFFICES	606	19.9	17.8 / 17.0	TRANE	BCHC
UV-5	WEST SUPPLY OFFICES	650	21.2	25.1 / 23.4	TRANE	BCHC
UV-6	WEAPONS SIMULATOR	975	25.5	26.2 / 26.2	TRANE	BCHC
UNITS FOR VRF						
AHU-1	1ST FLOOR AND SPACES PREVIOUSLY ON UVS	9200	-	211 / 167	TRANE	MCC
AHU-2	SECOND FLOOR	4600	-	130.5 / 84.2	TRANE	MCC
AHU-3	ASSEMBLY	3000	-	72.8 / 53.9	TRANE	MCC
VRV-1	FIRST FLOOR SPACES	-	108	96	DAIKIN	REYQ96PYDN
VRV-2	SPACES PREVIOUSLY ON UVS	-	135	120	DAIKIN	REYQ120PYDN
VRV-3	2ND FLOOR OFFICE AREA	-	189	168	DAIKIN	REYQ168PYDN
VRV-4	2ND FLOOR OFFICE AREA	-	189	168	DAIKIN	REYQ168PYDN
VRV-5	2ND FLOOR MISCELLANEOUS	-	81	72	DAIKIN	REYQ72PYDN
VRV-6	ASSEMBLY	-	108	96	DAIKIN	REYQ96PYDN

Table 19

Annual Energy Use

	Electric Consumption (kWh)	Gas Consumption (kBTU)	% of Total Building Energy	Total Building Energy (mmBtu/yr)
Heating				
Primary Heating	90,935		30.49%	310.4
Other Htg. Accessories			0.00%	
Cooling				
Cooling Compessor	35,409		11.88%	120.9
Tower/Cond Fans	4,693		1.57%	16
Other Clg Accessories	296		0.10%	1
Auxiliary				
Supply Fans	45,602		15.28%	155.6
Pumps	2,029		0.68%	6.9
Lighting	74,484		24.97%	254.2
Receptacles	44,821		15.03%	153
Total	**298,269**	-	**100%**	**1,018.00**

Table 20

As shown in the Table 20 above, the total building energy consumed by the Army Reserve Center is 1,018 mmBtu/yr. All of the energy used by the building is electricity which would thus allow the natural gas connections to the building to be eliminated. However, in case of power failure or if the army wants a backup natural gas boiler, they should probably still be left in. The main sources of energy use are primary heating and lighting. They use 30.49% and 24.97% of the electricity respectively.

Figure below shows the monthly use of electricity. The total electricity usage for the Army Reserve Center is 298,269 kWh for a whole year. The electricity is a maximum in January at 34,078 kWh. This is because, unlike the existing VAV system, electricity is used for both heating and cooling and no natural gas is present. As shown in figure below, the electricity usage is maximum in the winter and summer, when mostly heating or cooling is required. This is because, as shown in Figure 7, the COP of a VRF system is maximum whenever the load requires about half heating and half cooling because of heat recovery.

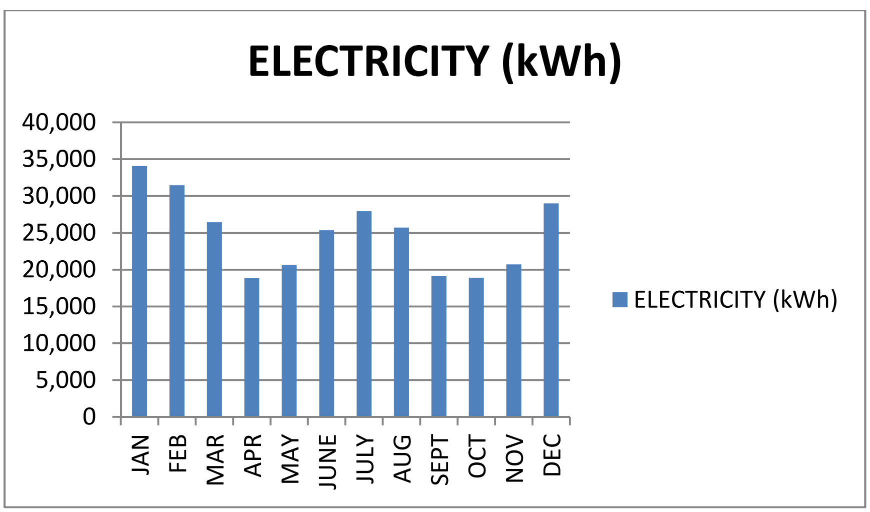


Figure 9

Fuel Costs

According to the specifications, the cost for electricity is $93.15/MWH or $0.09315/Kwh. The cost of natural gas is approximately $4.00/MMBtu. However, using a VRF system, there is no natural gas used in the Army Reserve Center. As shown in the Table 21 below, the total annual energy cost to operate the building is $27,783.76.

Total Cost of Energy				
	Electric Cost	**Gas Cost**	**% of Total Building Cost**	**Total Building Cost**
Heating				
Primary Heating				
Other Htg. Accessories	$8,470.60		30.49%	$8,470.60
Cooling				
Cooling Compessor	$3,298.35		11.87%	$3,298.35
Tower/Cond Fans	$437.15		1.57%	$437.15
Other Clg Accessories	$27.57		0.10%	$27.57
Auxiliary				
Supply Fans	$4,247.83		15.29%	$4,247.83
Pumps	$189.00		0.68%	$189.00
Lighting	$6,938.18		24.97%	$6,938.18
Receptacles	$4,175.08		15.03%	$4,175.08
Total	**$27,783.76**	**-**	**100%**	**$27,783.76**

Table 21

Total Cost

As shown in Table 22 below, the total cost to obtain and install the variable refrigerant volume units and the air handling units for the variable volume system is $283,105. This was found online from manufacturer catalogs (where available) and using RS Means Costworks.

VRF	AREA SERVED	CFM (MAX)	HEATING CAPACITY (MBH)	COOLING CAPACITY (Total / Sensible) (MBH)	MANUFACTURER	MODEL	COST
AHU-1	1ST FLOOR AND SPACES PREVIOUSLY ON UVS	9200	-	211 / 167	TRANE	MCC	$17,250.00
AHU-2	SECOND FLOOR	4600	-	130.5 / 84.2	TRANE	MCC	$9,725.00
AHU-3	ASSEMBLY	3000	-	72.8 / 53.9	TRANE	MCC	$6,200.00
CH-1	AHUs FOR DEHUMIDFICATION	-	-	96	TTRANE	CGAM040	$10,900.00
VRV-1	FIRST FLOOR SPACES	-	108	96	DAIKIN	EYQ96PYDI	$15,459.84
VRV-2	SPACES PREVIOUSLY ON UVS	-	135	120	DAIKIN	EYQ120PYD	$21,642.24
VRV-3	2ND FLOOR OFFICE AREA	-	189	168	DAIKIN	EYQ168PYD	$29,372.16
VRV-4	2ND FLOOR OFFICE AREA	-	189	168	DAIKIN	EYQ168PYD	$29,372.16
VRV-5	2ND FLOOR MISCELLANEOUS	-	81	72	DAIKIN	EYQ72PYDI	$12,480.00
VRV-6	ASSEMBLY	-	108	96	DAIKIN	EYQ96PYDI	$15,459.84
DUCTWORK	WHOLE BUILDING	-	-	-	-	-	$115,243.00
TOTAL COST							**$283,104.24**

Table 22

Lost Space due to Mechanical Systems

One of the main reasons for the use of a variable refrigerant flow system was that the space lost due to mechanical systems would be smaller. However, this does not appear to be the case. Because of the removal of the unit ventilators, the size of AHU-1 increased. However, the size of AHU-2 decreased. Overall, the air handlers will probably take up close to the same amount of space. However, there is no need for boilers due to the use of condensing units which will be located on the roof. Thus, the mechanical room on the first floor can be reduced in size. It currently takes up 1288 square feet, or 2.18% of the building's total area. It can be reduced to approximately 500 feet, because there is still space for outside air intake louvers, or 0.85% of the building's total area.

LEED

The energy use for the ASHRAE 90.1 Baseline Building is 1,759.2 mmBtu/year. As shown in table above, the building uses 1,018 mmBtu/year with a variable refrigerant flow system in place. This saves 42% of total energy when compared to the ASHRAE Baseline. This gives the building 16 of a possible 19 LEED points in the under EA Credit 1: Optimize Energy Performance. The Army Reserve Center will thus be project to have 43-49 LEED points total and will thus receive a LEED Gold rating.

Greenhouse Gases

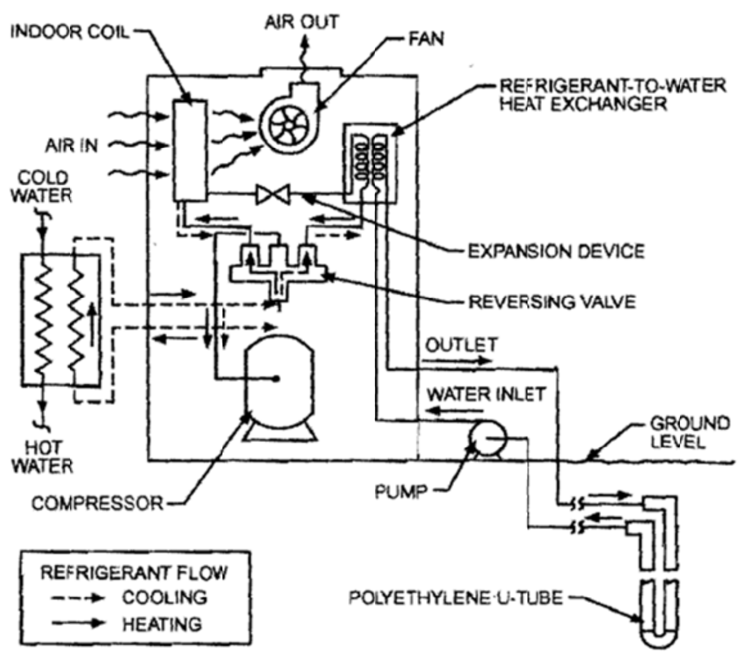
As explained in Tech Report 2, Rhode Island is part of the Eastern Interconnection which uses primarily coal (53.9%), nuclear (23.0%) , and natural gas (12.7%) for electricity generation. Shown below in Table 23 is the total electrical usage of the Army Reserve Center with a VRF system, and the emissions that are created when this system is implemented.

TOTAL EMISSIONS FOR VRF SYSTEM			
	TOTAL ELECTRICAL USAGE (kWh)	TOAL EMISSION FRACTION (LB / kWh)	TOTAL POLLUTION (LB)
CO_2	298,269	1.64	489,161
NO_X		3.00 * 10^-3	895
SO_X		8.57 * 10^-3	2,556
PM		9.26 * 10^-5	2,762

Table 23

Ground Source Heat Pump (GSHP) with Dedicated Outdoor Air (DOAS)

A ground source heat pump (GSHP) and a dedicated outdoor air system (DOAS) could be used to help to reduce energy consumption. A ground source heat pump uses the Earth as a heat source or sink, depending on whether heating or cooling is required. This works well because the earth has a relatively constant temperature of 50°F – 60°F. A GSHP does this by sending a refrigerant through pipes in the ground and then passing it through a heat exchanger. This is shown in Figure 10.

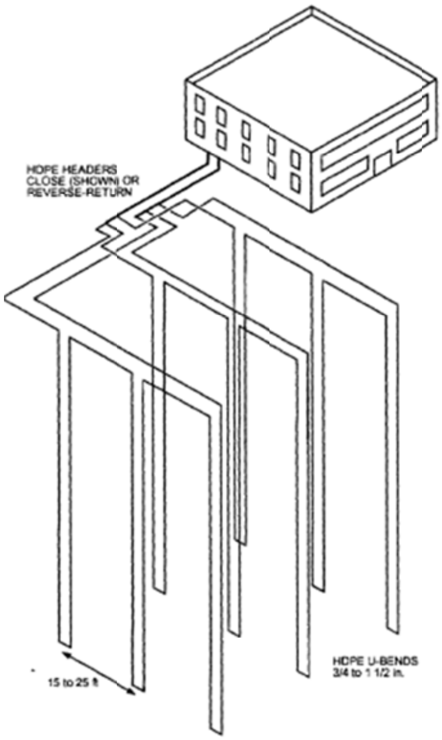


Vertical Closed-Loop Ground-Coupled Heat Pump System

Figure 10

The advantages of using a GSHP are similar to those of the variable refrigerant flow system described above. Using a GSHP will save energy and will also allow for smaller dedicated outdoor air handlers to replace the existing larger variable air volume and constant air volume air handlers.

There are two types of GSHPs: vertical and horizontal. Vertical GSHPs, shown in Figure 11, are those in which the pipes are placed downward in to the ground and horizontal GSHPs, shown in Figure 12, are those in which pipes are laid across the ground.



Vertical Ground-Coupled Heat Pump Piping

Figure 11

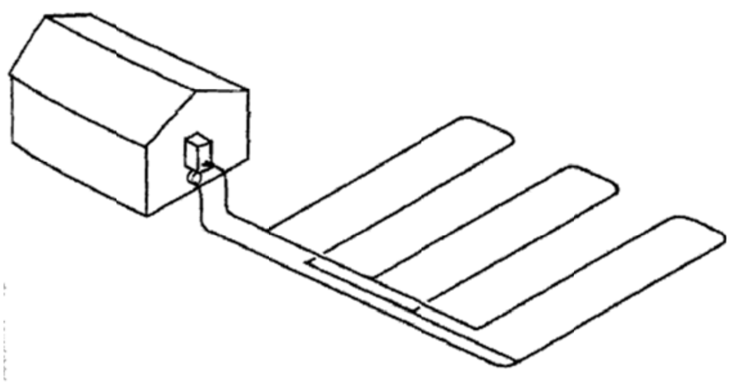


Figure 12

Vertical GSHPs have several advantages and disadvantages according to the 2007 ASHRAE Handbook – HVAC Applications. Because the pipes are drilled vertically downward, they require much smaller plots of land and are deeper in the ground, thus the soil is more consistent in temperature and thermal properties than the soil the pipes come in contact with in a horizontal GSHP. Other advantages are that they require the smallest amount of piping and pumping energy and yield the most efficient GSHP system performance. Disadvantages include that it is difficult to find contractors able to install a vertical loop GSHP and the higher cost of installing a vertical loop GSHP.

Horizontal GSHPs also have several advantages and disadvantages according to the 2007 ASHRAE Handbook – HVAC Applications. The advantages are that they cost less than vertical GSHPs and trained equipment operators are more widely available. The disadvantages are that ground properties fluctuate because the pipes are not deep enough to be unaffected by season and rainfall, pumps need to use more energy, and the system is less efficient.

Load Analysis

Trane Trace 700 was used to model the Army Reserve Center in order to determine the total energy required as well as the heating and cooling loads. The outside air required to meet the latent loads was determined using a hand calculation.

In the Trace model, a water source heat pump (WSHP) is initially selected as the system type. However, when defining the cooling plant, a ground source heat pump can be selected under the equipment type tab. As in the variable refrigerant volume system, dedicated ventilation is once again selected.

Assumptions

Airflow, lighting, schedules, occupancy, indoor conditions, and outdoor conditions are all the same as those used for designing the variable refrigerant flow system.

Sizing the GSHP

HEAT PUMP	NO. OF UNITS	MANUFACTURER	MODEL	CAPACITY (TONS)
GSHP 1-17	17	TRANE	4TWB3060A	5

Table 24

The heat pumps shown in Table 24 above will be used in order to meet the heating and cooling capacity of the building.

Vertical

To size a vertical ground source heat pump, the method of Ingersoll and Zobel can be used. It treats the design as heat transfer from a cylinder buried within the earth. The following equation is used:

$$q = \frac{L(t_g - t_w)}{R}$$

where

q = heat transfer rate, Btu/h
L = required bore length, ft
t_g = ground temperature, °F
t_w = liquid temperature, °F
R = effective thermal resistance of the ground, h·ft·°F/Btu

However, this equation must be modified to account for the variable heat rate of a ground heat exchanger by using a series of constant heat-rate pulses and also the resistance of the pipe wall and interfaces between the pipe and fluid and the pipe and the ground. The following equation must thus be used:

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

The required length for heating is

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

where

F_{sc} = short circuit heat loss factor
L_c = required bore length for cooling, ft
L_h = required bore length for heating, ft
PLF_m = part load factor during design month
q_a = net annual average heat transfer to the ground, Btu/h
q_{lc} = building design cooling block load, Btu/h
q_{lh} = building design heating block load, Btu/h
R_{ga} = effective thermal resistance of ground (annual pulse), h·ft·°F/Btu
R_{gd} = effective thermal resistance of ground (daily pulse), h·ft·°F/Btu
R_{gm} = effective thermal resistance of ground (monthly pulse), h·ft·°F/Btu
R_b = thermal resistance of pipe, 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
W_h = power input at design heating load, W

Fsc: Fsc is found using Table 25 below which is found in Chapter 32 in the ASHRAE Handbook – HVAC Applications. Three Bores per Loop will be selected at 3 gpm/ton thus a value of 1.01 will be used.

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

Table 25

PLF_m: The part load factor for the design month is found by dividing the load of the building by the total capacity available. This is equal to 0.98 for the Army Reserve Center.

q_a: To determine the net annual average heat transfer to the ground, the following equation is used:

$$q_a = \frac{C_{fc} q_{lc} EFLhours_c + C_{fh} q_{lh} EFLhours_h}{8760}$$

C_{fc} and C_{fh} are heat pump correction factors based on the cooling EER and heating COP of the heat pump shown in Table 26 below, and $EFLhours_c$ and $EFLhours_h$ are the equivalent full-load hours which are provided in the 2007 ASHRAE Handbook – HVAC Applications and shown in Table 27 below. For the Army Reserve Center, the equivalent full load hours for cooling and heating are 970 and 1000, respectively, because Boston was used since it is the closest city to Newport, Rhode Island. The heat pump correction factors are 1.302 for cooling and 0.82 for heating because an EER of 11.3 is used for cooling and for heating, a COP of 8.50 is present. Since 8.50 is not in the Table 26 (and this is a maximum COP which is probably not achieved much), the heating COP of 4.5 will be assumed. With a building design cooling block load of 999,600 Btu/hr and a building design heating block load of 905,700 Btu/hr, q_a was found to be 228,894 Btu/hr.

Cooling EER	C_{fc}	Heating COP	C_{fh}
11	1.31	3	0.75
13	1.26	3.5	0.77
15	1.23	4	0.8
17	1.2	4.5	0.82

Table 26 (left)

Table 8 Equivalent Full-Load Hours (EFLH) for Typical Occupancy with Constant-Temperature Set Points

	EFLH Occupancy							
	School		Office		Retail		Hospital	
Location	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Atlanta, GA	290-200	690-830	690-480	1080-1360	600-380	1380-1860	430-160	2010-2850
Baltimore, MD	460-320	500-610	890-720	690-1080	770-570	880-1480	590-300	1340-2340
Bismarck, ND	500-460	150-250	990-950	250-540	900-810	340-780	730-530	540-1290
Boston, MA	520-450	300-510	1000-960	450-970	870-760	610-1380	680-420	1020-2330
Charleston, WV	440-310	430-570	840-770	620-1140	730-620	820-1600	550-320	1260-2560
Charlotte, NC	320-200	650-730	780-530	1060-1340	670-420	1350-1830	490-180	1990-2820
Chicago, IL	470-390	280-410	920-820	420-780	810-670	550-1090	640-400	870-1780
Dallas, TX	200-120	830-890	520-340	1350-1580	440-280	1660-2090	310-100	2320-3100
Detroit, MI	480-400	230-360	1020-970	390-820	900-790	530-1170	710-460	870-1950
Fairbanks, AK	630-560	26-54	1170-1050	64-200	1090-930	110-320	930-690	210-600
Great Falls, MT	430-360	130-220	890-820	210-490	800-680	290-710	640-420	500-1210
Hilo, HI	1-0	1360-1390	23-13	2440-2580	14-8	2990-3370	0-0	4060-4910
Houston, TX	130-90	940-1000	350-250	1550-1770	300-190	1870-2290	200-70	2540-3320
Indianapolis, IN	480-400	380-560	920-840	560-1000	820-690	730-1410	640-390	1120-2250
Los Angeles, CA	160-80	780-910	580-370	1280-1670	440-250	1740-2350	180-20	2740-3770
Louisville, KY	430-290	550-670	830-710	770-1250	720-570	1000-1720	550-300	1480-2690
Madison, WI	470-390	210-310	900-840	320-640	800-700	420-900	640-440	680-1490
Memphis, TN	240-170	700-830	600-420	1090-1350	510-330	1350-1780	370-140	1910-2680
Miami, FL	12-6	1260-1300	46-34	1980-2150	37-25	2350-2740	12-1	3110-3890
Minneapolis, MN	500-420	200-300	950-860	320-610	860-720	430-870	700-470	680-1420
Montgomery, AL	180-120	840-910	470-330	1260-1510	400-250	1550-1990	260-90	2170-2950
Nashville, TN	320-250	570-740	680-590	830-1280	590-470	1030-1710	450-240	1490-2620
New Orleans, LA	110-67	920-990	320-230	1500-1720	260-160	1820-2240	160-46	2500-3280
New York, NY	440-350	360-550	870-790	540-1040	760-630	720-1480	590-330	1160-2440
Omaha, NE	400-330	310-440	800-720	480-820	720-600	610-1130	570-360	920-1780
Phoenix, AZ	110-65	950-1020	290-210	1340-1610	250-170	1630-2090	140-34	2220-3040
Pittsburgh, PA	500-470	300-530	950-910	440-920	840-750	600-1310	650-420	960-2160
Portland, ME	480-400	190-300	980-880	310-630	870-710	410-900	690-420	700-1520
Richmond, VA	410-270	630-730	820-660	880-1310	710-520	1110-1770	530-250	1650-2760
Sacramento, CA	360-220	680-850	990-640	1080-1430	830-480	1460-2020	540-120	2250-3180
Salt Lake City, UT	540-520	410-710	1060-1040	510-1090	930-830	660-1520	720-440	1060-2470
Seattle, WA	650-460	260-460	1370-1270	440-1200	1170-960	710-1860	850-360	1340-3270
St. Louis, MO	400-280	460-550	800-710	680-1100	700-570	850-1500	550-320	1260-2330
Tampa, FL	58-35	1050-1110	190-140	1800-2000	160-100	2170-2580	90-22	2910-3710
Tulsa, OK	300-240	580-770	620-560	830-1300	540-450	1030-1730	410-220	1470-2630

Table 27 (left)

<u>q_{lc} and q_{lh}</u>: The building design cooling and heating lock loads were found to be 999,600 Btu/hr and 905,700 Btu/hr using a model created in Trane Trace 700.

<u>R_{ga}, R_{gd}, R_{gm}</u>: To find R_{ga}, R_{gd}, and R_{gm}, a Fourier number is first found for each effective thermal resistance of the ground. Figure 15 in the ASHRAE Handbook – HVAC Applications is used to determine the G-factor based on each Fourier number and then that value is used to determine the effective thermal resistances of the ground. To find these values, the ground was determined to be heavy sand with 15% water and the diameter of the pipes was determined to be 1 ¼”. This led to an R_{ga}, R_{gm}, and R_{gd} of 0.2045, 0.1682, and 0.2045, respectively.

<u>R_b:</u> R_b was determined by to be 0.06 using a formula in the ASHRAE Handbook – HVAC Applications.

<u>t_g:</u> The ground temperature was determined to be 55°F from Figure 13 below, taken from the ASHRAE Handbook – HVAC Applications.

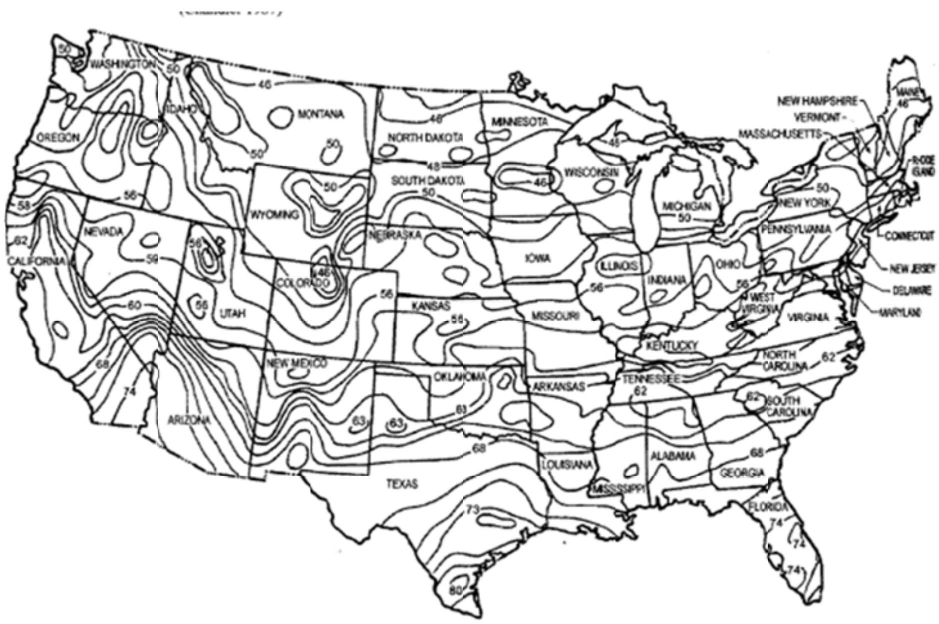


Figure 13

<u>t_p</u>: The temperature penalty for interference of adjacent bores was assumed to be 4.7°F based on Table 28 below, which was found in the ASHRAE Handbook – HVAC Applications.

Equivalent Full Load Hours Heating/Cooling	Bore Separation, ft	Temperature Penalty, °F	Base Bore Length, ft/ton (refrigeration)
1000/500	15	Negligible	180
1000/1000	15	4.7	225
	20	2.4	206
500/1000	15	7.6	260
	20	3.9	228
	15	12.8	345
500/1500	20	6.7	254
	25	3.5	224
	15	Not advisable	
0/2000	20	10.4	316
	25	5.5	252
Correction Factors for Other Grid Patterns			
1 × 10 grid $C_f = 0.36$	2 × 10 grid $C_f = 0.45$	5 × 5 grid $C_f = 0.75$	20 × 20 grid $C_f = 1.14$

Table 28

<u>t_{wi} and t_{wo}:</u> t_{wi} is assumed to be 20 to 30°F higher than the temperature of the ground in cooling and 10 to 20°F lower than t_g for heating. Thus, a t_{wi} will be 75°F in cooling and 35°F in

heating. T_{wo} will be assumed to be the same as t_{wi} because it will be assumed that the pump itself will not transfer that much excess heat to the fluid.

<u>W_c and W_h:</u> The power input at design cooling load was found to be 63.35 kW and the power input at design heating load was found to be 57.70 kW based on the model created using Trane Trace 700.

Using the values determined above, the total length of piping for cooling was found to be 15,424 feet, and the total length of piping for heating was found to be 23,048 feet. The length of piping needed is the greater of the two values, thus 23,048 feet was used. The piping is colored blue in in Figure 14 below and, as shown in Figure 14 below, there is plenty of extra space.

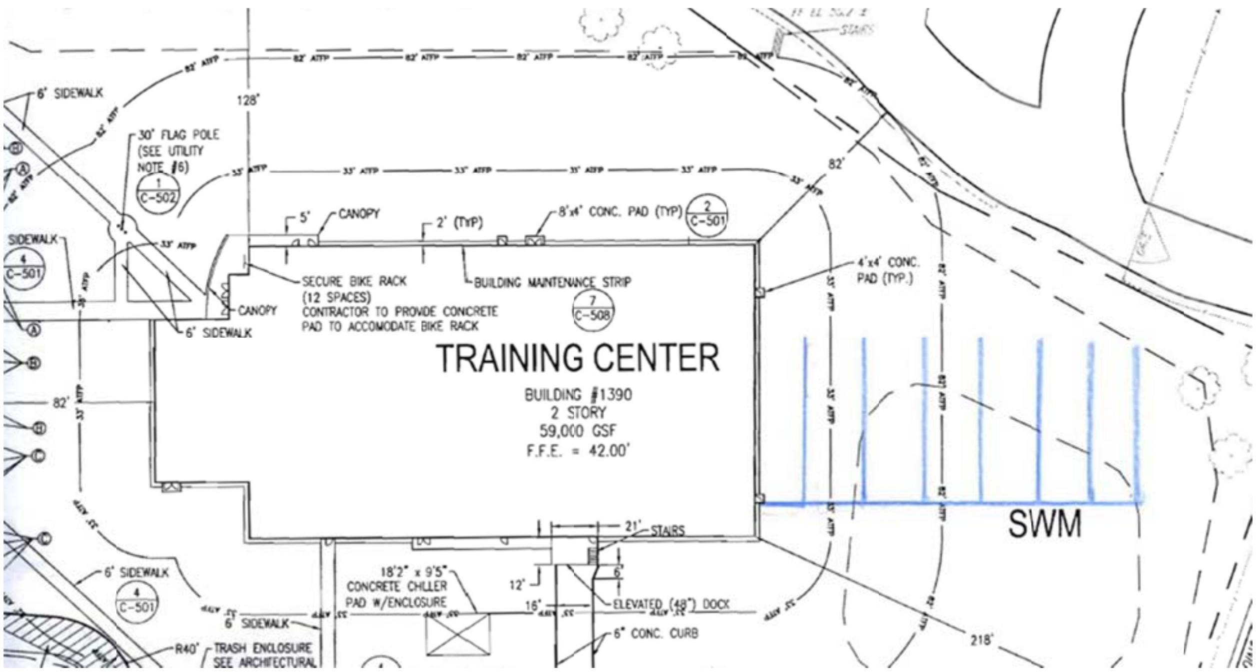


Figure 14

Horizontal

If a horizontal ground source heat pump is used, Table 11 in the Geothermal Energy section of the ASHRAE Handbook – HVAC Applications can be used in the design. Depending on the feet of pipe per feet of bore, 250, 170, or 150 feet of pipe per ton of cooling is required. This would lead to a total of 20285 feet, 14161 feet, or 12495 feet.

However, as mentioned above, a vertical GSHP has several advantages relative to a horizontal design. Thus, a vertical GSHP will be used in the Army Reserve Center.

Space Requirements: Horizontal or Vertical Use

According to the ASHRAE Handbook – HVAC Applications, a separation of 20 feet should be between each bore. Bore depths can be as deep as 600 feet. As shown in Figure 14 above, there are a total of seven rows, six of which contain three boreholes and one with two boreholes.

Annual Energy Use

	Electric Consumption (kWh)	Gas Consumption (kBTU)	% of Total Building Energy	Total Building Energy (mmBtu/yr)
Heating				
Primary Heating	14,320	9,208	6.62%	58.1
Other Htg. Accessories	118		0.05%	0.4
Cooling				
Cooling Compessor	22,932		8.92%	78.3
Tower/Cond Fans				
Other Clg Accessories	43		0.01%	0.1
Auxiliary				
Supply Fans	84,340		32.81%	287.9
Pumps	13,320		5.19%	45.5
Lighting	74,484		28.97%	254.2
Receptacles	44,821		17.44%	153
Total	**254,378**	**9,208**	**100%**	**877.50**

Table 29

As shown in Table 29 above, the total building energy consumed by the Army Reserve Center is 878 mmBtu/yr. The supply fans and lighting use the largest percentage of building energy at 32.81% and 28.97% respectively. Although most of the heating is done by the ground source heat pump and is thus electricity, a backup boiler uses natural gas to help meet the load if necessary.

The total amount of natural gas used per month is shown in Figure 15 below. It is a maximum of 64 therms in February. The total amount of electricity used per month is shown in Figure 16 below. Most of the electricity is used throughout the summer months due to the high cooling loads and the electricity is a maximum of 24,826 kWh in August.

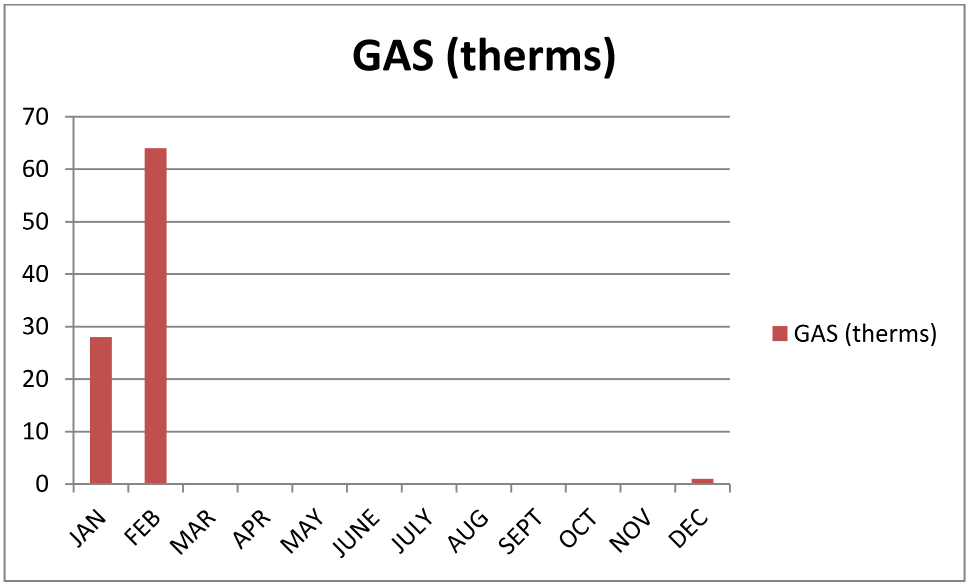


Figure 15

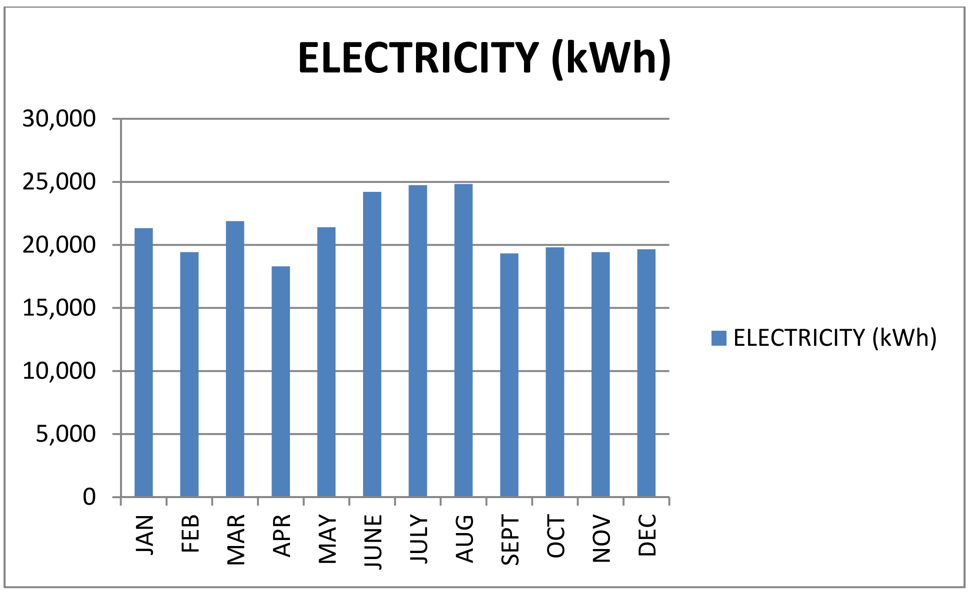


Figure 16

Fuel Costs

According to the specifications, the cost for electricity is $93.15/MWH or $0.09315/Kwh. The cost of natural gas is approximately $4.00/MMBtu. As shown in Table 29 below, the total cost of energy is $23,732 per year.

Total Cost of Energy				
	Electric Cost	**Gas Cost**	**% of Total Building Cost**	**Total Building Cost**
Heating				
Primary Heating	$1,333.91	$36.83	5.78%	$1,370.74
Other Htg. Accessories	$10.99		0.05%	$10.99
Cooling				
Cooling Compessor	$2,136.12		9.00%	$2,136.12
Tower/Cond Fans				$0.00
Other Clg Accessories	$4.01		0.02%	$4.01
Auxiliary				
Supply Fans	$7,856.27		33.10%	$7,856.27
Pumps	$1,240.76		5.23%	$1,240.76
Lighting	$6,938.18		29.24%	$6,938.18
Receptacles	$4,175.08		17.59%	$4,175.08
Total	**$23,695.31**	**$36.83**	**100%**	**$23,732.14**

Table 29

Total Cost

As shown in Table 30 below, the total cost to obtain and install the air handing units, boiler, ground source heat pumps, and to install the piping for the GSHP system is $502,085. This was found using RS Means Cost Estimator and the 2007 ASHRAE Handbook – HVAC Applications.

GSHP	AREA SERVED	CFM (MAX)	HEATING CAPACITY (MBH)	COOLING CAPACITY (Total / Sensible) (MBH)	MANUFACTURER	MODEL	COST
AHU-1	1ST FLOOR AND SPACES PREVIOUSLY ON UVS	9200	-	211 / 167	TRANE	MCC	$17,250.00
AHU-2	SECOND FLOOR	4600	-	130.5 / 84.2	TRANE	MCC	$9,725.00
AHU-3	ASSEMBLY	3000	-	72.8 / 53.9	TRANE	MCC	$6,200.00
CH-1	AHUs FOR DEHUMIDFICATION	-	-	96	TTRANE	CGAM040	$10,900.00
B-1	WHOLE BUILDING	-	655	-	-	-	$14,150.00
GSHP-1 TO GSHP-17	WHOLE BUILDING	-	60 (EACH)	60 (EACH)	TRANE	4TWB3060A	$85,000.00
VERTICAL LOOP PIPING	WHOLE BUILDING	-	-	-	-	-	$243,617.36
DUCTWORK	WHOLE BUILDING	-	-	-	-	-	$115,243.00
TOTAL COST							**$502,085.36**

Table 30

Lost Space due to Mechanical Systems

The geothermal system used allowed the air handling units to be sized as dedicated outdoor air handlers, the same size as those as for the variable refrigerant flow system. However, unlike the VRF system, there will still need to be boilers used in order to meet the remainder of the heating load. Thus, the mechanical space lost will be approximately the same as in the existing variable air volume system.

LEED

The energy use for the ASHRAE 90.1 Baseline Building is 1,759.2 mmBtu/year. As shown in table above, the building uses 877.5 mmBtu/year. This saves 50% of total energy of the ASHRAE Baseline with the a variable refrigerant flow system in place. This gives the building 19 of a possible 19 LEED points in the under EA Credit 1: Optimize Energy Performance. The Army Reserve Center will thus receive 46-52 LEED points and obtain a gold or platinum rating.

Greenhouse Gases

As explained in Tech Report 2, Rhode Island is part of the Eastern Interconnection which uses primarily coal (53.9%), nuclear (23.0%) , and natural gas (12.7%) for electricity generation. Shown below in Table 31 and Table 32 is the total electrical and natural gas usage of the Army Reserve Center with a GSHP system, and the emissions that are created when this system is implemented.

TOTAL ELECTRICAL EMISSIONS FOR GSHP SYSTEM			
	TOTAL ELECTRICAL USAGE (kWh)	TOAL EMISSION FRACTION (LB / kWh)	TOTAL POLLUTION (LB)
CO_2	254,378	1.64	417,180
NO_x		3.00 * 10^-3	763
SO_x		8.57 * 10^-3	2,180
PM		9.26 * 10^-5	2,356

Table 31 (above)

TOTAL GAS EMISSIONS FOR GSHP SYSTEM			
	TOTAL GAS USAGE (*1000 FT^3)	TOAL EMISSION FRACTION (LB / 1000 FT3)	TOTAL POLLUTION (LB)
CO_2	9,208	11.6	106,813
NO_x		0.0164	151
SO_x		1.22	11,234
PM		0.002237	21

Table 32 (above)

Structural Breadth

As mentioned in the Variable Refrigerant Flow section, Daikin Variable Refrigerant Volume Units will be added. These units will be placed on the roof, thus changing the structural design of the roof. As shown in Figure 17 below, the roof is broken up into 30'x30' bays. The variable refrigerant volume units will be placed as shown in Figure 17 below.

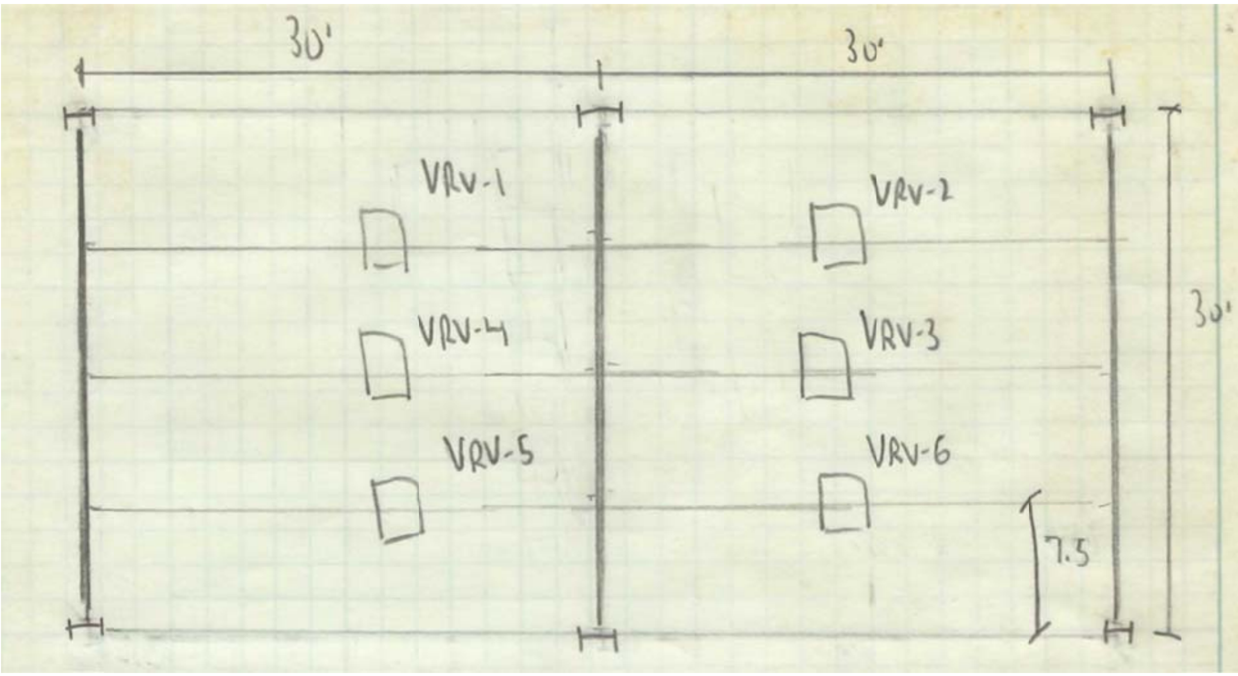


Figure 17

The mass of each VRV unit is given in the manufacturer's catalog and is shown in Table 33 below. They were treated as dead loads in determining the roof structure.

TAG	MANUFACTURER	MODEL	MASS (LB)
VRV-1	DAIKIN	REYQ96PYDN	732
VRV-2	DAIKIN	REYQ120PYDN	732
VRV-3	DAIKIN	REYQ168PYDN	1036
VRV-4	DAIKIN	REYQ168PYDN	1036
VRV-5	DAIKIN	REYQ72PYDN	732
VRV-6	DAIKIN	REYQ96PYDN	732

Table 33

The total dead load was first determined based on data shown in Table 34 below.

TOTAL DEAD LOAD (psf)	
VRV UNITS	3
STANDING SEAM METAL ROOF	2
INSULATION	3
APPROXIMATE DECK SELF WEIGHT	3
TOTAL	11

Table 34

Next, the total load on the roof deck was found. This included the dead load, but also assumed a 30 psf snow load and a 20 psf live load. The total load was found to be 61 psf. A Vulcraft 1.5B20 roof deck, highlighted in Table 35 below, will be used.

VERTICAL LOADS FOR TYPE 1.5B

No. of Spans	Deck Type	Max. SDI Const. Span	Allowable Total (Dead + Live) Uniform Load (PSF) Span (ft.-in.) C. to C. of Support										
			5'-0	5'-6	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0
1	B 24	4'-8	66	52	42	36	30	27	24	21	20		
	B 22	5'-7	91	71	57	47	40	34	30	27	24	22	20
	B 21	6'-0	104	81	64	53	44	38	33	29	26	24	22
	B 20	6'-5	115	89	71	58	48	41	36	31	28	25	23
	B 19	7'-1	139	107	85	69	57	48	41	36	32	29	26
	B 18	7'-8	162	124	98	79	65	55	47	41	36	32	29
	B 16	8'-8	206	157	123	99	81	68	58	50	44	39	34
2	B 24	5'-10	126	104	87	74	64	55	47	41	36	32	29
	B 22	6'-11	102	85	71	61	52	46	40	35	32	28	26
	B 21	7'-4	118	97	82	70	60	52	46	41	36	33	29
	B 20	7'-9	132	109	91	78	67	59	51	46	41	36	33
	B 19	8'-5	154	127	107	91	79	69	60	53	48	43	39
	B 18	9'-1	174	144	121	103	89	78	68	60	54	48	44
	B 16	10'-3	219	181	152	130	112	97	86	76	68	61	55
3	B 24	5'-10	130	100	79	65	54	45	39	34	31	27	25
	B 22	6'-11	128	106	89	76	65	57	50	44	39	34	31
	B 21	7'-4	147	122	102	87	75	65	56	49	42	38	34
	B 20	7'-9	165	136	114	97	84	72	61	53	46	41	36
	B 19	8'-5	193	159	134	114	98	84	71	61	53	47	41
	B 18	9'-1	218	180	151	129	111	96	81	69	60	52	46
	B 16	10'-3	274	226	190	162	140	119	100	85	73	64	56

Table 35

To size the joists and girders, the same loads were used except that the self-weight of the joists and girders were included. Using the Standard LRFD Load Table from the Steel Joist Institute, it was determined that 28K8 joists will be used as shown in Table 36 below.

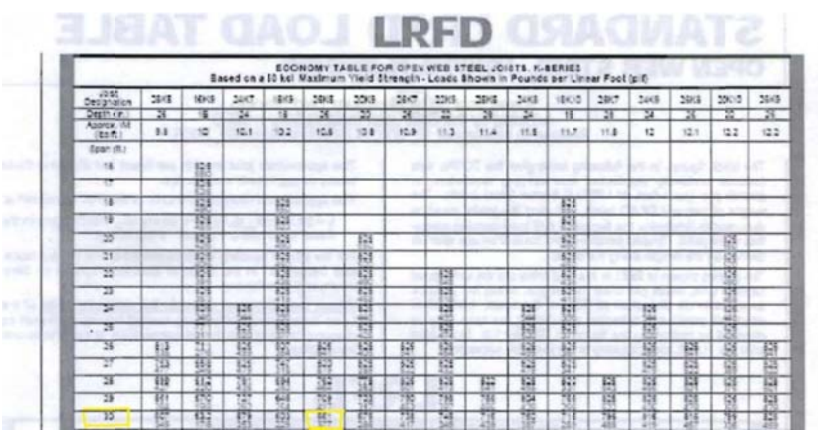


Table 36

Likewise, using the Flexural Design Tables provided by the American Institute of Steel Construction, it was determined that W10x54 girders will be used as shown in Table 37 below.

Table 3–2 (continued)
W Shapes
Selection by Z_x

F_y = 50 ksi

Z_x

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF		L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.^{3}	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.^{4}	ASD	LRFD
W21×55	126	314	473	192	289	10.8	16.3	6.11	17.4	1140	156	234
W14×74	126	314	473	196	294	5.34	8.03	8.76	31.0	795	128	191
W18×60	123	307	461	189	284	9.64	14.5	5.93	18.2	984	151	227
W12×79	119	297	446	187	281	3.77	5.67	10.8	39.9	662	116	175
W14×68	115	287	431	180	270	5.20	7.81	8.69	29.3	722	117	175
W10×88	113	282	424	172	259	2.63	3.95	9.29	51.1	534	131	197
W18×55	112	279	420	172	258	6.26	13.9	5.90	17.5	890	141	212
W21×50	110	274	413	165	248	12.2	18.3	4.59	13.6	984	158	237
W12×72	108	269	405	170	256	3.72	5.59	10.7	37.4	597	105	158
W21×48[f]	107	265	398	162	244	9.78	14.7	6.09	16.6	959	144	217
W16×57	105	262	394	161	242	7.98	12.0	5.65	18.3	758	141	212
W14×61	102	254	383	161	242	4.96	7.46	8.65	27.5	640	104	156
W18×50	101	252	379	155	233	8.69	13.1	5.83	17.0	800	128	192
W10×77	97.6	244	366	150	225	2.59	3.90	9.18	45.2	455	112	169
W12×65[f]	96.8	237	356	154	231	3.60	5.41	11.9	35.1	533	94.5	142
W21×44	95.4	238	358	143	214	11.2	16.8	4.45	13.0	843	145	217
W16×50	92.0	230	345	141	213	7.59	11.4	5.62	17.2	659	124	185
W18×46	90.7	226	340	138	207	9.71	14.6	4.56	13.7	712	130	195
W14×53	87.1	217	327	136	204	5.27	7.93	6.78	22.2	541	103	155
W12×58	86.4	216	324	136	205	3.76	5.66	8.87	29.9	475	87.8	132
W10×68	85.3	213	320	132	199	2.57	3.86	9.15	40.6	394	97.8	147
W16×45	82.3	205	309	127	191	7.16	10.8	5.55	16.5	586	111	167
W18×40	78.4	196	294	119	180	8.86	13.3	4.49	13.1	612	113	169
W14×48	78.4	196	294	123	184	5.10	7.66	6.75	21.1	484	93.8	141
W12×53	77.9	194	292	123	185	3.65	5.48	8.76	28.2	425	83.2	125
W10×60	74.6	186	280	116	175	2.53	3.80	9.08	36.6	341	85.8	129
W16×40	73.0	182	274	113	170	6.69	10.1	5.55	15.9	518	97.7	146
W12×50	71.9	179	270	112	169	3.97	5.97	6.92	23.9	391	90.2	135
W8×67	70.1	175	263	105	159	1.73	2.60	7.49	47.7	272	103	154
W14×43	69.6	174	261	109	164	4.82	7.24	6.68	20.0	428	83.3	125
W10×54	66.6	166	250	105	158	2.49	3.74	9.04	33.7	303	74.7	112

Table 37

A detailed calculation is located in Appendix A.

Acoustical Breadth

As mentioned in the Variable Refrigerant Flow section, Daikin Variable Refrigerant Volume Units will be added. They will be above small offices, which should have sound levels at a maximum of 40-45 dBA, as shown in Table 38 below.

Type of Room - Occupancy		Noise Criterion - NC -	Noise Rating - NR -	db(A)
Very quiet	Concert and opera halls, recording studios, theaters, etc.	10 - 20	20	25 - 30
	Private bedrooms, live theaters, television and radio studios, conference and lecture rooms, cathedrals and large churches, libraries, etc.	20 - 25	25	25 - 30
	Private living rooms, board rooms, conference and lecture rooms, hotel bedrooms	30 - 40	30	30 - 35
Quiet	Public rooms in hotels, small offices classrooms, courtrooms	30 - 40	35	40 - 45
Moderate noisy	Drawing offices, toilets, bathrooms, reception areas, lobbies, corridors, department stores, etc.	35 - 45	40	45 - 55
Noisy	Kitchens in hospitals and hotels, laundry rooms, computer rooms, canteens, supermarkets, office landscape, etc.	40 - 50	45	45 - 55

Table 38

These units will be placed on the roof, in the locations shown in Figure 18 below. At point X in Figure 18, a maximum decibel level may be achieved because of the combined sound produced by the VRV units. It may also occur at any one of the individual units because the distance from the units to point X may be enough to lower the sound to less than that of the sound next to the unit.

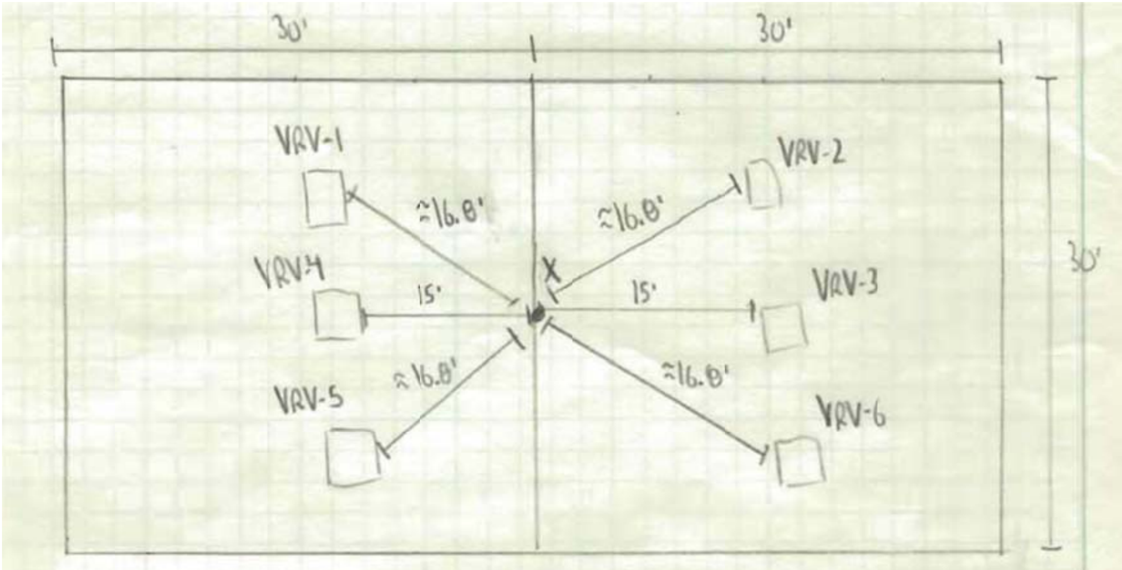


Figure 18

According to the specifications, the variable refrigerant volume units have the decibel levels shown in Table 39 below.

DIAKIN VRV UNITS		
TAG	**MODEL**	**dBA**
VRV-1	REYQ96PYDN	58
VRV-2	REYQ120PYDN	60
VRV-3	REYQ168PYDN	61
VRV-4	REYQ168PYDN	61
VRV-5	REYQ72PYDN	58
VRV-6	REYQ96PYDN	58

Table 39

From the specifications, the units operate at 460 volts and the sound is produced at a frequency of 60 hertz. The sound is measured at a point 3.3 feet in front of the unit.

The sound level of each individual unit at point X is found by using the following equations:

$dB = 10 \log (I / I_0)$

dB = sound level in decibels (adjusted so dBA will be used)
I = the intensity
I_0 = the reference intensity

$I_1 / I_2 = (d_2 / d_1)^2$

I_1 = intensity at point 1
I_2 = intensity at point 2
d_1 = distance from source to intensity 1
d_2 = distance from source to intensity 2

Using the above equations, the dBA level at point X was found for each VRV unit. It is shown in Table 40 below.

DIAKIN VRV UNITS		
TAG	**MODEL**	**dBA AT POINT X**
VRV-1	REYQ96PYDN	44
VRV-2	REYQ120PYDN	46
VRV-3	REYQ168PYDN	48
VRV-4	REYQ168PYDN	48
VRV-5	REYQ72PYDN	44
VRV-6	REYQ96PYDN	44

Table 40

The combined effect of the individual VRV units at point X was then determined using Table 41 below. It was found to be 53 dBA.

When Two dB Values Differ by	Add the Following dB to the Higher Value
0 or 1	3
2 or 3	2
4 to 8	1
9 or more	0

Table 41

At point X, the sound level (53 dBA) is less than that of the sound level at VRV-3 and VRV-4, which is 61 dBA. However, as shown in Table 42 below, the total transmission loss through the roof will be approximately 35 dBA. Thus, the total sound level in the office space is 26 dBA, which will not create a problem since offices have a maximum noise level of 40-45 dBA as shown in Table 38.

Building Construction	Transmission Loss (dB) 125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	STC Rating	IIC Rating†
31 Construction no. 30 with 5/8-in gypsum board screwed to resilient channels spaced 24 in oc perpendicular to joists	30	35	44	50	54	60	47	39
32 Construction no. 31 with 3-in glass-fiber insulation in cavity	36	40	45	52	58	64	49	46
33. 4-in reinforced concrete slab (54 lb/ft²)	48	42	45	56	57	66	44	25
34. 14-in precast concrete tees with 2-in concrete topping on 2-in slab (75 lb/ft²)	39	45	50	52	60	68	54	24
35. 6-in reinforced concrete slab (75 lb/ft²)	38	43	52	59	67	72	55	34
36. 6-in reinforced concrete slab with 3/4-in T&G wood flooring on 1 1/2 by 2 wooden battens floated on 1-in glass fiber (83 lb/ft²)	38	44	52	55	60	65	55	57
37. 18-in steel joists 16 in oc with 1 5/8-in concrete on 5/8-in plywood under heavy carpet laid on pad, and 5/8-in gypsum board attached to joists on ceiling side (20 lb/ft²)	27	37	45	54	60	65	47	62
Roofs²								
38. 3 by 8 wood beams 32 in oc with 2 by 6 T&G planks, asphalt felt built-up roofing, and gravel topping	29	33	37	44	55	63	43	
39 Construction no. 38 with 2 by 4s 16 in oc between beams, 1/2-in gypsum board supported by metal channels on ceiling side with 4-in glass-fiber insulation in cavity	35	42	49	62	67	79	53	

Table 42

A detailed calculation can be found in Appendix B.

System Comparison and Recommendation

SYSTEM COMPARISON				
	ANNUAL ENERGY USE (mmBtu/yr)	FIRST COST	ANNUAL ENERGY COST	MECHANICAL SPACE SAVED (FT)
VAV	1,227	$301,410.00	$27,384.00	-
VRF	1018	$283,105.00	$27,784.00	800
GSHP	878	$502,086.00	$23,733.00	-

Table 43

As shown in Table 43 above, there are advantages in cost, energy use, and saved mechanical space in replacing the existing variable air volume system with either a variable refrigerant flow system or a ground source heat pump system. The ground source heat pump system uses 86% of the total energy of the variable refrigerant flow system and only 72% of the energy of the variable air volume system. This saves $3651 per year compared to the VAV system and $4051 when compared to the VRF system. However, the first cost of the variable refrigerant flow system is only 56% of the cost of the ground source heat pump system.

Although the VRF system cost is the cheapest based on the equipment costs found, this number may be misleading. Variable refrigerant flow systems are used commonly in Europe. Thus, the numbers for the equipment was found in euros and then converted to US dollars. The equipment may be slightly more expensive if it was ordered for a job in the United States. Also, the cost of installation, estimated using RS Means, may be slightly higher because there are not many contractors with experience in VRF systems. Another disadvantage of a VRF system is that extra maintenance may have to be hired in order to operate a VRF system. If an extra employee needs to be hired, this would add an annual cost of at least $40,000 per year, thus making the energy savings and first cost savings not worth it for a VRF system.

One predicted advantage with using a VRF system or a GSHP that hopefully would have occurred was decreasing the size of ductwork due to it only providing outside air and handling the latent load. The first floor ductwork was relatively the same size as with the VAV; however, the second floor ductwork was able to be shrunk. This is because the latent load on the first floor is high relative to the sensible load whereas the second floor is dominated by the sensible load. Less ductwork is used which will provide cost savings and reduce the pressure in ducts (and thus noise); however, it was not as much as predicted.

Although the variable refrigerant flow system uses less energy, the annual cost of energy is the greatest. This is because electricity is used for heating and the price of electricity is currently high relative to the price of natural gas, which is used for heating in the variable air volume system and used for some heating in the ground source heat pump system. The annual energy cost would thus change in upcoming years based on the change in the price of natural gas relative to that of electricity.

The most logical system selected for the Army Reserve Center would be the ground source heat pump system, based on solely energy consumption and cost of energy per year. However, the payback for the system is 54 years which is certainly not worth the extra added cost. Based on information from the National Institute of Standards and Technology, energy is not supposed to escalate much relative to inflation. Thus, a drastic change in the cost of energy is not expected to occur, which makes the simple payback of 54 years to be an accurate estimate, and certainly not justifiable. Thus, based on a combination of energy consumption, first cost, and saved mechanical space, the variable refrigerant flow system should be selected, assuming that extra maintenance would not be required.

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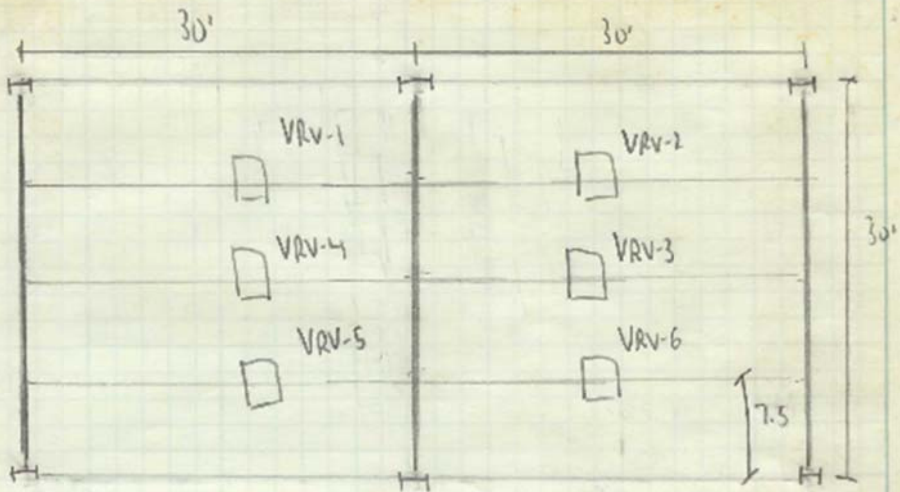
Appendix A

pg. 1



Daiken VRF Units:

Quantity	Model	Tag	Mass (lb)
1	REYQ72PYDN	VRV-5	732
2	REYQ96PYDN	VRV-1, VRV-6	732
1	REYQ120PYDN	VRV-2	732
2	REYQ168PYDN	VRV-3,4	1036

Roof Deck

Live Load: Assumed 20psf for roof.

Snow Load: 30psf

Dead Load: VRV Units: 732lb + 732lb + 1036lb = 2500lb

$$\frac{2500\text{lb}}{900\text{feet}} = 2.78\text{psf} \approx 3\text{psf}$$

Total DL:
3psf VRV units
2psf standing seam metal roof
3psf insulation
3psf appx. deck self weight
11psf

pg. 2

Total load supported by deck: 20 psf LL
30 psf SL
11 psf DL

61 psf

Use Vulcraft 1.5 B20.

Joists

Use load combinations
↳ ASCE 7-05 pg. 5
Use combination 3: 1.2D + 1.6S + L
Total load: 1.2(11) + 1.6(30) + 20 = 81.2 psf + joist self weight
joists are spaced at 7.5'
81.2 psf (7.5') = 609 plf + self weight
Using Standard LRFD Load Table:
18K8: 30' foot span so 661 plf > 609 + self weight
661 plf > 609 + 1.2(10.6)
661 plf > 622 plf (OK)

roof total load: 61(7.5) = 458 plf

$\Delta_{LL,max} = \frac{L}{240}$

for 18K8: 377 × 1.5 > 458
567 plf > 458 plf

Thus it handles deflection.

Use 18K8 joists for roof.

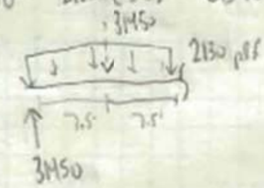
Pg. 3

Girders

Total load: 61 psf + 5 psf (joists) + 5 psf (assumed beam self weight) = 71 psf

$\frac{71 \text{ lb}}{1 \text{ ft}^2} \cdot 30' = 2130$ plf

$V_u = 2130(30) = 63900$ lb = 63.9 kips



$M_u = 31950(15) - 31950(7.5) = 239625$ lb·ft = 240 kip·ft

Using the American Institute of Steel Construction W-Shapes table...

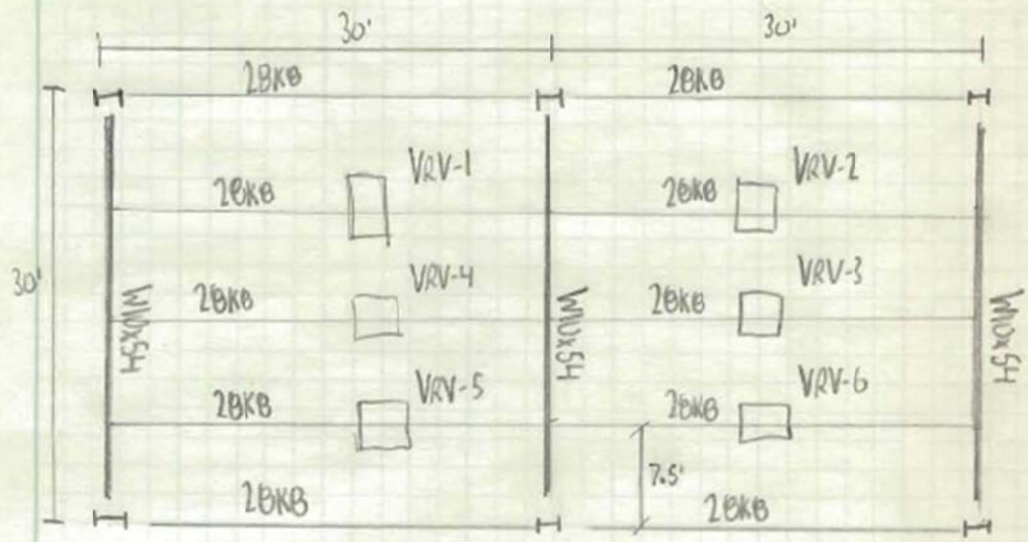
$V_u \leq \phi V_n$

$M_u \leq \phi M_n$

Select W10x54: $\phi V_n = 112$ kips > 64 kips

$\phi M_n = 250$ kip feet > 240 kip feet

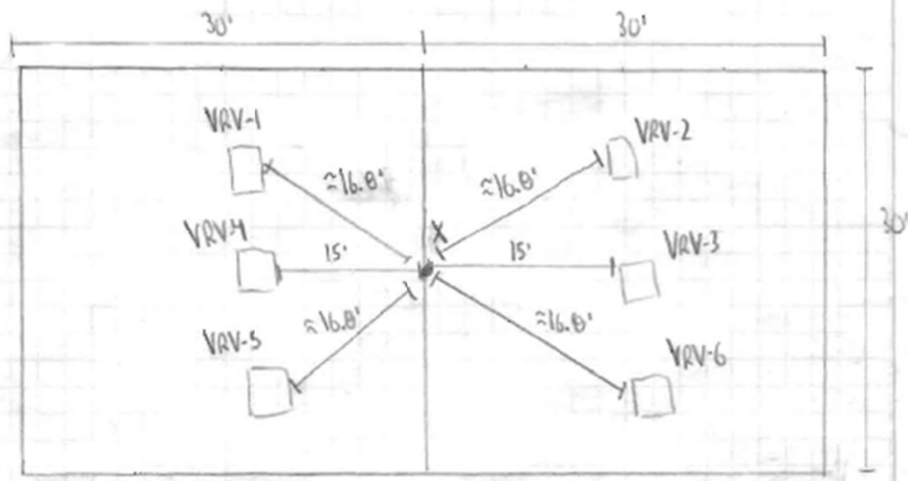
Use **W10x54**



Roof Deck: Vulcraft 1.5B20
Joists: 28K8
Girders: W10x54

Appendix B

Pg. 1



Daikin VRV Units: Quantity	Model	Tag	dBA
1	REYQ72PYDN	VRV-5	58
2	REYQ96PYDN	VRV-1,6	58
1	REYQ120PYDN	VRV-2	60
2	REYQ168PYDN	VRV-3,4	61

- Sound is produced at 60Hz/460V
- measured at point 3.3 feet in front of unit

Will take total noise at worst possible point - center of VRV Units. ↳ labeled X

$$dB = 10\log(I/I_0)$$

$$\frac{I_1}{I_2} = (d_2/d_1)^2$$

$$\Delta dB = 10\log(d_2/d_1)^2 = 20\log(d_2/d_1)$$

VRV-1: $\Delta dB = 20\log(16.8/3.3) = 14.1\,dBA$

$dB_{1x} = 58 - 14.1 = 43.9\,dBA$

pg 2

VRV-2: $\Delta dB = 20\log(16.8/3.3) = 14.1$ dBA
$dB_{2x} = 60 - 14.1$ dBA $= 45.9$ dBA

VRV-3: $\Delta dB = 20\log(15/3.3) = 13.2$ dBA
$dB_{3x} = 61 - 13.2 = 47.8$ dBA

VRV-4: $\Delta dB = 20\log((15)/3.3) = 13.2$
$dB_{4x} = 61 - 13.2 = 47.8$ dBA

VRV-5: $\Delta dB = 20\log(16.8/3.3) = 14.1$ dBA
$dB_{5x} = 58 - 14.1 = 43.9$ dBA

VRV-6: $\Delta dB = 20\log(16.8/3.3) = 14.1$ dBA
$dB_{6x} = 58 - 14.1 = 43.9$ dBA

at point x...

VRV-Unit	dBA
1	44
2	46
3	48
4	48
5	44
6	44

44, 46 → 48 → 48
48, 48 → 51
44, 44 → 47
51, 47 → 52
48, 52 → (53)

when added together... **53 dBA** at point x.

The type of space below the units is a small office. Thus, a dB level of 40-45 dBA should be present.

The worst points are at VRV-3,4 so 61 dBA is the worst. The increase in distance reduces sound more than effects of adding dBA from all units

pg. 3

Total transmission loss of roof of ARC's Construction : 35 dBA

61 dBA - 35 dBA = 26 dBA

Thus, the VRV Units will not cause a noise problem in the office area below.