Carl R. Darnall Army Medical Center

Architectural Engineering Senior Thesis
Final Report
April 8, 2014

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CARL R. DARNALL ARMY MEDICAL CENTER

PROJECT TEAM

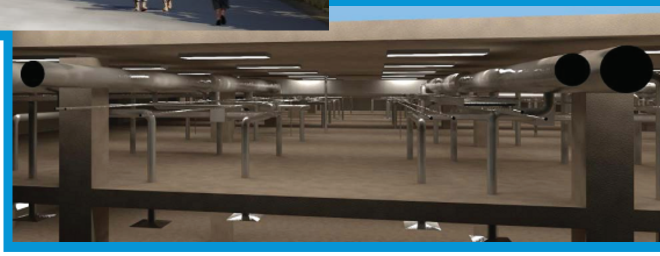
Owner ● Army Corps of Engineers
General Contractor ● Balfour Beatty and McCarthy
Architect ● HKS Architects and Wingler & Sharp
Structural Engineer ● Cagley & Associates
Mechanical Engineer ● Southland Industries
Electrical Engineer ● M.C. Dean

BUILDING STATS

Location ● Fort Hood, Texas
Total Size ● 900,000 sq. ft.
Number of Stories ● 6
Rough Project Cost ● $500 million
Projected Completion Date ● November 2014
Project Delivery Method ● Design-Build

Rendering of the main entrance and the patient bed tower. Courtesy of HKS Architects

Rendering of the healing garden. Courtesy of HKS Architects



Rendering of the intersititial building systems floor. Courtesy of HKS Architects

ARCHITECTURE

The façade of the medical center consists of Texas stone, and masonry recycled panels for easy maintenance and constructability.

Glazing provides daylighting into the transitional areas such as lobbies, waiting rooms, and public spaces like the cafeteria.

The medical center is broken into four parts, three clinics, a patient bed tower, and it also has a healing garden. Three story clinics have the potential to be expanded in the future, and the bed tower has a administrative floor that can be converted into more medical rooms.

MECHANICAL

A central utility plant located off site houses four 1,250 ton centrifugal chillers and four 11,600 MBH steam boilers.

The base loaded 200 ton heat recovery chiller provides chilled water during the winter and it preheats the returning heating hot water.

Twenty five air handlers provide 100% outside air for the hospital with enthalpy wheels that recover heat from the general exhaust air.

Above each floor is an IBS floor which allows for easy maintenance of the equipment for building services.

STRUCTURAL

Concrete beams were designed for redundancy in order to protect the medical center from progressive collapsing.

Steel braced frames on exterior or interior are the main component of the lateral system.

The floors designed for high activity for medical procedures are designed as a 10" two way slab, and the 6th floor is designed as an 8" two way. The IBS floors are designed as composite deck with concrete topping.

ELECTRICAL

Emergency power is provided to the building by two 480 V, 3 phase emergency power class generators.

The CUP receives 12.47kV from primary feeders which then steps down to 480/277, 3 phase with transformers.

The medical center has recessed lighting with more luminous lighting in the medical rooms.

MARISSA CALDWELL ● MECHANICAL ● DR. BAHNFLETH
www.engr.psu.edu/ae/thesis/portfolios/2015/mac5738/

Table of Contents

List of Figures

List of Tables

Acknowledgements

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Michael Morder	Mechanical Design Engineer, Southland Industries
Ashley Hayes	Project Manager, Southland Industries
Shawn Manley	Senior Mechanical Engineer, Southland Industries
Dr. W. Bahnfleth	Thesis Advisor, Professor at Penn State

Penn State Architectural Engineering Faculty

AE Class of 2015

AE Powerplayers

The Employees of Dunkin Donuts

Building Overview

The Carl R. Darnall Army Medical Center provides a vast range of medical services for the soldiers and families of Fort Hood. This medical center is replacing the current medical center across the street. The medical center comprises of the Woman's Clinic in the north east, the patient and visitor entrance in the north, the outpatient entrance on the west side, the emergency entrance on the east side, and the service entrance on the south side. The east side has the patient bed tower and the sixth floor is home to the administrative offices. The building allows for easy communication and navigation through the vast number of departments.

The entire building is designed with interstitial floors between the occupied levels that house the building services such as the mechanical, electrical, medical gas, and pneumatic tube systems. The building is served by an off-site central utility plant which consists of its chilled water plant and heating hot water plant. The medical center receives the services from an underground tunnel. The two heat recovery chillers help provide chilled water during colder weather, and they preheat the heating hot water return. It is base loaded, so during the winter, the centrifugal chillers and cooling towers do not need to run. Each of the four centrifugal chillers has a capacity of 1,250 tons, and the heat recovery chiller provides a capacity of 150 tons. Overall, the system provides enough capacity for future air handlers. The chilled water system provides a supply temperature of 44°F to the air handlers, fan coil units for electrical and telecom rooms. The building uses hot water produced by four gas fired steam boilers. The heated hot water system provides a supply temperature of 140°F.

Floors 5 and 6 of the east bed tower are conditioned by two dedicated outdoor air system (DOAS) air handlers in the penthouse on the roof. Both air handlers have an enthalpy recovery wheel which recovers energy from the exhaust air. AHU-2 serves constant air volume terminal units on floor 5 which consists of the pediatric department, as well as, a general medical / surgical department. AHU-3 serves constant air volume terminal units on floor 6 which consists of offices for the departments, officers, and the medical library.

Executive Summary

The Carl R. Darnall Army Medical Center Replacement is topic of this senior thesis report. Various systems were explored in order to determine ways to save energy consumption, initial and life cycle costs, and building space. The alterations will be made to the top two floors of the patient bed tower because of the massiveness of the entire building.

The designed system comprises of a chilled water and hot water systems from a central utility plant located off site. The proposed plan for this thesis topic is to eliminate the need for the central utility plant for the system. Besides using the central utility plant for space for the new equipment, this new system will be its own loop.

The new systems will be modeled based on ventilation requirements from ASHRAE 170-2013 and ASHRAE 62.1-2013 instead of UFC 4-510 which require stringent minimum ventilation airflow rates. By reducing the minimum ventilation air, the two DOAS units were reduced by two thirds the air flow. The chilled water coil was changed to a DX coil to provide cold air, and a gas fired heat exchanger was added to provide heat.

The first proposed system is a variable refrigerant flow system paired with a dedicated outdoor air system. The VRF system comprises of 16 outdoor units and over 200 VRF indoor units. The floors were arranged into 16 zones in order to create small systems with safe amounts of refrigerant in the loop. The VRF system saves over 37% in energy costs compared to the baseline design, but it has higher initial costs.

The second proposed system is a water source heat pump system paired with a dedicated outdoor air system. The WSHP system comprises of one loop with 200 indoor units, a 510 MBH gas fired water boiler, and a 230 ton cooling tower connected to it to maintain a water loop temperature between 60°F and 90°F. The WSHP system saves over 19% in energy costs and it has a shorter payback period than the VRF system.

Construction Breadth

Since the mechanical system is reducing in size, the IBS floors were changed to large plenums, so the cost savings was analyzed to justify changing the systems. Removing the IBS floors also saved time by eliminating the assembly of the floor, but it lost time in the ease of installing mechanical equipment.

Structural Breadth

By reducing the size of the DOAS units, the load on the roof decreases, so the roof was analyzed in order to prove it can withstand the decrease. The reinforcement was reduced in size because the new design does not account for anti-terrorism force protection or progressive collapse resistance.

ASHRAE Standard 62.1-2013 Compliance

Ventilation Air Distribution

Section 5.1 requires the ventilation air distribution system be completely adjustable in order to maintain the minimum ventilation airflow requirement. The constant air volume boxes, along with the diffusers in the rooms have adjustable dampers and control boxes to maintain the minimum. Although the medical center does not have a plenum return, it would require a device to maintain the minimum ventilation rate.

The drawing documentation states air balance testing should be made in accordance with Associated Air Balance Council (AABC), the National Environmental Balancing Bureau (NEBB), and the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA).

Exhaust Duct Location

Since the patient rooms, operating rooms, and general medical rooms are exhausting possible hazardous contaminants, the exhaust ducts are negatively pressurized in accordance with section 5.2 of ASHRAE 62.1 in an event of a leak, the ducts would take in air instead of releasing it.

Ventilation System Controls

In order to meet the minimum outdoor ventilation load, all constant air volume terminal units have a control box, as well as dampers. The army medical center is controlled by open protocol DDC building automation system (BAS). The BAS program monitors all control points of the AHU's down to the thermostats in each patient room.

Airstream Surfaces

Since the ducts are susceptible to condensation, all ducts are constructed of sheet metal and are connected with metal fasteners and metal hangers. This complies with section 5.4 on airstream surfaces in relation to mold growth and corrosion.

Outdoor Air Intakes

ASHRAE 170 calls for at least a 10ft vertical distance from the roof to the exhaust outlet, and they should be located in order to minimize the recirculation of exhausted air. Although the exhaust fans are located in their own section of the roof far from the intake louvers, they do not comply with the 10ft vertical distance ASHRAE 170 calls for. The distance of the outlet to the roof level is just shy of 10 ft. By having a separate section for the exhaust fans, they all meet the minimum separation distances as seen in Table 1.

Proper applications were made in order to manage rain entrainment. There is a draining system in order to protect the outdoor air handling units from rain. The intake louvers are designed to angle properly to take in air without taking in rain, all of the air handlers also have insect screens.

Table 1 Air Intake Minimum Separation Distance ASHRAE 62.1 Table 5.5.1

TABLE 5.5.1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Class 2 air exhaust/relief outlet (Note 1)	10 (3)
Class 3 air exhaust/relief outlet (Note 1)	15 (5)
Class 4 air exhaust/relief outlet (Note 2)	30 (10)
Plumbing vents terminating less than 3 ft (1 m) above the level of the outdoor air intake	10 (3)
Plumbing vents terminating at least 3 ft (1 m) above the level of the outdoor air intake	3 (1)
Vents, chimneys, and flues from combustion appliances and equipment (Note 3)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 4)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 4)	25 (7.5)
Driveway, street, or parking place (Note 4)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 5 and 6)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: This requirement applies to the distance from the outdoor air intakes for one ventilation system to the exhaust/relief outlets for any other ventilation system.
Note 2: Minimum distance listed does not apply to laboratory fume hood exhaust air outlets. Separation criteria for fume hood exhaust shall be in compliance with NFPA 45[5] and ANSI/AIHA Z9.5.[6] Information on separation criteria for industrial environments can be found in the *ACGIH Industrial Ventilation Manual*[7] and in *ASHRAE Handbook—HVAC Applications*.[8]
Note 3: Shorter separation distances shall be permitted when determined in accordance with (a) ANSI Z223.1/NFPA 54[9] for fuel gas burning appliances and equipment, (b) NFPA 31[10] for oil burning appliances and equipment, or (c) NFPA 211[11] for other combustion appliances and equipment.
Note 4: Distance measured to closest place that vehicle exhaust is likely to be located
Note 5: Shorter separation distance shall be permitted where outdoor surfaces are sloped more than 45 degrees from horizontal or that are less than 1 in. (30 mm) wide.
Note 6: Where snow accumulation is expected, the surface of the snow at the expected average snow depth constitutes the "other surface directly below intake."

Local Capture of Contaminants

Any noncombustion equipment discharging potentially hazardous contaminants are ducted and exhausted directly outdoors.

Combustion Air

Since the central utility plant is not located in the building, and is in its own building off site, section 6.7 on combustion air does not apply for the army medical center.

Particulate Matter Removal

Section 5.8 states the minimum MERV rating used for the filters must be 8. However, ASHRAE 170 states air must pass through two filtration banks, the effective MERV rating should be at least MERV 12. The system abides by note C, that states, a MERV rating of 14 can be used for the second filter bank as long as there is a MERV 7 filter down stream of the terminal unit. Figure 1 shows the schematic of the two penthouse air handlers which shows one of the two filter banks.

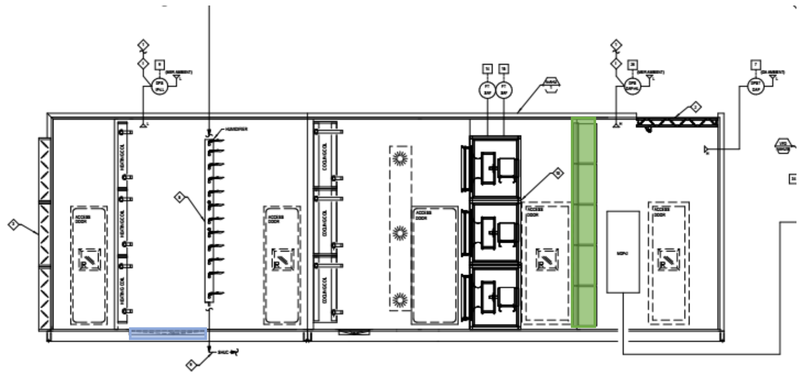

Figure 1 Air Handler Schematic

Dehumidification Systems

5.9 requires all air handlers must be designed to a relative humidity of 65%, the air handlers for the bed tower are designed to 59.3%. The building must intake outdoor air equal or more than the maximum exhaust airflow. This ensures a positive pressure in the building that limits the infiltration of untreated outdoor air.

Drain Pans

All air handlers must have a condensate drain pan for the cooling coils, with a slope of at least 0.125 in/ft., the medical center have air handlers that exceed this slope. The drain outlets are located at the lowest point of the pan in order to properly drain. A drain seal such as a P-trap is required if there is a negative pressure at the drain pan, however, the air handlers are blow through, so it is positively pressured at the drain pan. These drain pans are located under the water-condensing equipment, as well as they comply with the size mentioned in section 5.10.

Finned-Tube Coils and Heat Exchangers

As mentioned in section 5.10, drain pans are located under water producing equipment, they also have an access space of 18 inches in order to clean and maintain them. Figure 1 above shows the drain pans highlighted in blue. Below, Figure 2, is the layout of the bed tower penthouse with the access space highlighted.

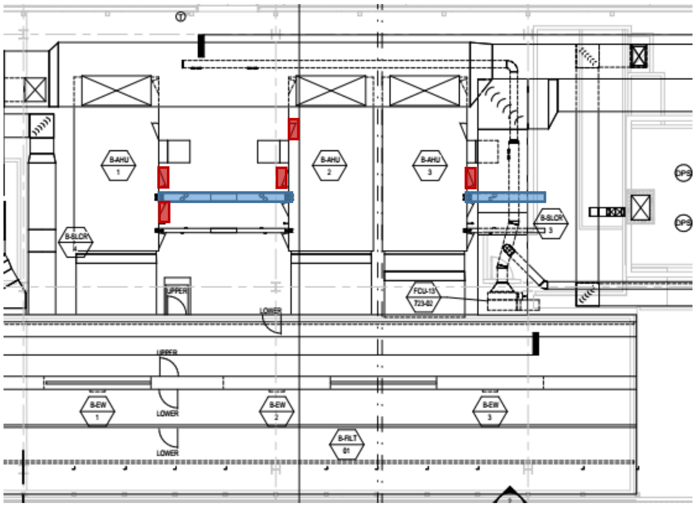

Figure 2 Bed Tower Penthouse Layout

Humidifiers and water-spray systems

The steam humidifiers use potable water as specified in 5.12.1, and contain no chemical additives other than the standard ones in the potable water system. There are no obstructions greater than 15 degrees downstream of the humidifiers.

Access for inspection, cleaning, and maintenance

All equipment has a clearance big enough for routine inspection and maintenance as specified in 5.13.1. The IBS floors allow terminal units to be easily accessible for regular maintenance by a person with a wheeled cart by means of aisles highlighted in Figure 3 below. Controllers and sensors are easily accessible to both the occupants of the medical center as well as for maintenance. Every air handler has multiple access doors in order to maintain different components of the air handler. Some air handlers share access space with another air handler shown in Figure 2 above.

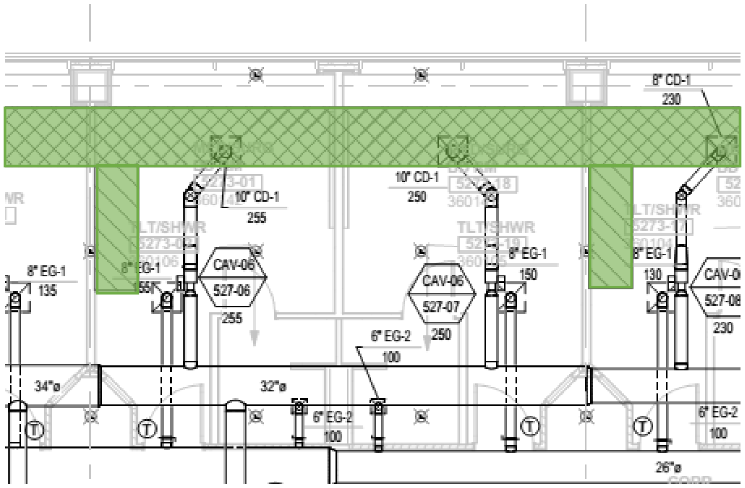

Figure 3 Level 5 IBS Floor Accessible Aisles

Building Envelope

The building envelope has a weather barrier in the roof construction with the liquid applied water barrier, as well as a water barrier layer in the wall construction. All joints within the construction of the envelope are treated in order to break the pathway for air leakage. All pipes and ducts expected to reach low temperatures are insulated in order to prevent condensation from forming as mentioned in 5.14.2.

Buildings with Attached Parking Garages

The army medical center does not have a parking garage attached to it, so section 5.15 does not apply to the building.

Air Classification and Recirculation

The bed tower of the medical center has mainly patient rooms as well as office space. The offices on the 6th floor can be classified as either Class 1 or 2. This air can be recirculated within the office space it originally circulated in. The patient rooms are class 3, can be recirculated within the space of origin, but it cannot be transferred to other spaces. Accidental recirculation from exhaust leaking into the supply side of the enthalpy wheel is allowed.

Requirements for Buildings Containing ETS Areas and ETS-Free Areas

There are no Environmental tobacco smoke areas in the army medical center, so section 5.17 does not apply to the building.

ASHRAE 62.1 Section 6: Procedures

Ventilation Rate Procedure

The breathing zone air flows are calculated using ventilation rate procedure using equation 6.2.2.1:

$$V_{bz} = R_p \times P_z + R_a \times A_z$$

The values for people outdoor air rate per person (R_p), area outdoor air rate per square foot (R_a) are found in table 6.2.2.1. Both R_p and R_a are multiplied by the number of people in the ventilation zone (P_z) and the area of the zone (A_z) respectively. The equation calculates V_{bz} which is the breathing zone outdoor airflow. The minimum outdoor air changes for medical rooms are found in table 7.1 of ASHRAE 170. The outdoor air flow is found by multiplying the air change per hour by the volume of the room divided by 60 to convert to cfm. Appendix B has the ventilation air flow calculations for all spaces in levels 5 and 6.

The outdoor air flow that must be provided to the zone by the air distribution system (Voz) is determined by the equation 6.2.2.3:

$$V_{oz} = V_{bz}/E_z$$

Ez is the zone air distribution effectiveness that is determined by table 6.2.2.2. Since the air distribution is ceiling supply of cold air and a ceiling exhaust, since it is 100% outside air, the Ez for both air handlers is 1.0. The required breathing zone air flow is the same as the zone outside air flow.

According to 6.2.4, 100% outdoor air systems have a outdoor air intake flow (Vot) using the equation 6.2.4:

$$V_{ot} = \sum_{all\ zones} V_{oz}$$

System	Breathing Zone Air Flow (Vbz)	Zone Air Distribution Effectiveness (Ez)	Outdoor Air Intake Flow (Vot)
AHU-2: Floor 5 Surgery	7160	1.0	7160
AHU-3: Floor 6 Admin	13894	1.0	13894

Table 2 Breathing Zone Air Flows

Section 6.2.5 multiple-zone recirculating systems does not apply to the army medical center because it is a 100% outside air system, thus has no return air. Critical Z values or primary outdoor air fraction values do not apply to the building.

Exhaust Ventilation

The exhaust airflows were calculated using Table 6-4 which include the required exhaust air rates to maintain clean air and proper ventilation. ASHRAE 170 table 7.1 states whether or not a space must be exhausted. If it has to be exhausted, then the entire supply outside air cfm must be exhausted. Most of the spaces on level 5 are exhausted, but only the storage rooms and restrooms must be exhausted on level 6. The exhaust calculations are found in Appendix B, along with the ventilation calculations.

Section 6 Summary

The table of ventilation calculations for each room is found in Appendix B. ASHRAE 170-2013 and ASHRAE 62.1-2013 were used for minimum outside air rates for various spaces. The two air handlers for floors 5 and 6 were analyzed, AHU-2 for level 5 and AHU-3 for level 6. AHU-2 ventilation calculations were made using mainly ASHRAE 170 because of the strict medical program of surgical and isolation rooms. AHU-3 calculations were made using strictly ASHRAE 62.1 because of the attention on office spaces and lack of procedure rooms.

All of the design values for both systems exceed the calculated values significantly. The design values were calculated using UFC-4-510 the design guide for Unified Facilities Criteria for Military Medical Facilities by the Department of Defense. The UFC guidelines are more stringent than both ASHRAE 62.1 and ASHRAE 170 ventilation rates. For AHU-2, some values were taken from ASHRAE 62.1 for offices and break rooms, however, UFC has more specific ventilation rates than ASHRAE.

Compliance with ASHRAE 90.1

Climate

Carl R. Darnall medical center is located in Fort Hood, Texas. Fort Hood falls in Bell County in Texas, it is in Zone 2A as shown in Figure 4.

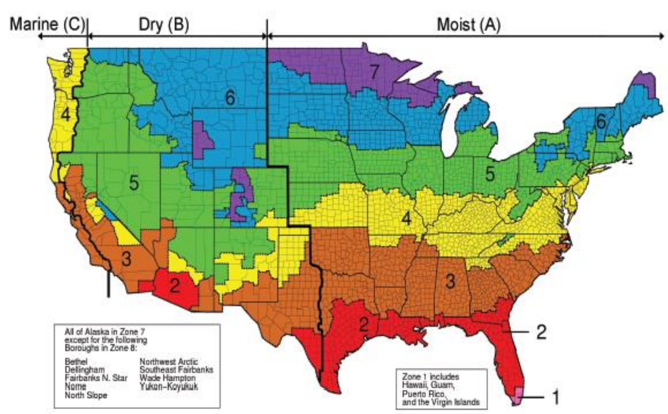

Figure B1-1 U.S. climate zone map (*ASHRAE Transactions*, Briggs et al., 2003).

Figure 4 B1-1 U.S. Climate Zone Map

Compliance Paths

Section 5.2 states according to each zone, the building must comply with certain insulation values as well as fenestration percentage less than 40%. Overall, the medical center has a fenestration percentage of 23.9% which passes the standard significantly. The bed tower, more specifically, floors 5-6 have a fenestration percentage of 28.9% which also complies with the standard.

Prescriptive Building Envelope Option

ASHRAE 90.1 section 5.5 states a non-residential building must comply with the set building construction standards for each climate zone. Below, in Table 3, the medical center's building construction U-values are compared with Table 5.5-2 which can be seen in Appendix A. The building construction of floors 5-6 of the medical center complies with ASHRAE 90.1 Building Envelope.

Building Construction Comparison			
	Actual U-Value (Btu/h*ft2*F)	ASHRAE U-Value (Btu/h*ft2*F)	Does it Comply?
Wall	0.0526	0.151	Yes
Roof	0.0321	0.039	Yes
Window	0.42	0.57	Yes

Table 3 Building Construction Comparison

Section 6: Heating, Ventilating, and Air Conditioning

Mandatory Provisions

All of the mechanical equipment in the army medical center meet the minimum equipment efficiencies presented in tables' 6.8.1-1 through 6.8.1-13 of ASHRAE 90.1. Load calculations were performed in accordance with ANSI/ASHRAE/ACCA Standard 183 in order to size the systems and equipment.

Prescriptive Path

The army medical center is designed as a 100% dedicated outdoor air system, therefore, under favorable conditions, the building will receive free cooling through this air side economizer. Simultaneous heating and cooling may not occur in zones, zone controls will limit terminal units from wasting energy through re-cooling or reheating the air. The some of the CAV terminal units in the medical center can heat the incoming cold supply air down to the proper temperature for that zone.

Section 7: Service Water Heating

All water heating equipment in the medical center have an efficiency that surpasses the minimum performance requirements presented in table 7.8. The piping insulation for the heated hot water system meets the insulation conductivity listed in Table 6.8.3-1 for the operating temperature range of 105°F-140°F. There are temperature maintenance controls on the heated hot water equipment in order to regulate temperature.

Section 8: Power

The army medical center uses both the Unified Facilities Criteria and the National Electrical Code 2008 for its power standards. Level 6 consists of mainly receptacles for office equipment and lights, however, level 5 has patient bed interfaces, nurse call cable, as well as equipment power.

Section 9: Lighting

The army medical center must comply with section 9 which includes the lighting power density. Since the building is healthcare, each space varies by activity the type of medical attention being performed in each room. More light is need for a surgery room than an office. Therefore, lighting power density was calculated separately for level 5 and 6, using both the building area method, and the space by space method. The lighting power density according to building area method for level 5 would be 1.05 W/sf2 because the building is a hospital. The space by space method was applied to level 6 because of the focus of offices using table 9.6.1. The lighting power density calculations for level 6 are shown in Appendix C. The lighting controls and fixtures for both floors vary as well. Both levels have recessed lighting, but the fixtures on level 5 have a higher luminous flux in the procedure rooms. Occupancy sensors are used on level 6 in the offices to save energy, but not on level 5 due to high activity.

Design Load Estimation

Design Conditions

Location

Carl R. Darnall Army Medical Center is located on the base of Fort Hood, Texas, so the climate data for Fort Hood, Texas was used for the energy model. Using Trace 700, a energy model was created using design conditions from the design documents as well as climate data from ASHRAE 2009 Fundamentals. As shown in Figure 1, Fort Hood experiences harsh summers with temperatures in the high 90s. All of the climate data can be found in Appendix A.

Table 4 Climate Data for Coldest & Hottest Months

Coldest Month	Heating DB (99.6%)	Humidification DP/MCDB and HR (99.6%)		
		DP	HR	MCDB
January	23.7	9.8	9.4	33.5

Hottest Month	Cooling DB/MCWB (0.4%)	
	DB	MCWB
August	99.9	73.4

Building Construction

The army medical center was modeled in Trace 700 using the building construction listed in Table 5. The building construction meets the required building construction U-values set by ASHRAE 90.1 section 5.5 as mentioned previously in Tech Report 1. The hospital was modeled as tight construction with a pressurization of 0.06 cfm/SF of wall. This prevents dirty unconditioned outdoor air from coming in.

Building Construction			
Construction	Description	U-Value (Btu/h*ft^2*F)	SC
Slab	8" HW Concrete	0.491	-
Roof	12" HW Conc. 8" Insul	0.0345	-
Wall	4 in. Brick, 6 in ins, 8 in HW Conc. Block	0.0432	-
Partition	0.75" Gyp Frame	0.3879	-
Glass	3mm Dbl Low-E	0.295	0.5

Table 5 Building Construction U-Values

The average wall heights of a patient medical room is listed in Table 6 below. Table 6 displays the effect of the interstitial building services floors between each level of medical space. The IBS floors are floors specifically for building services such as chilled water, hot water, plumbing, conduit, medical gas, and other services. It is over 7 feet tall thus providing access for maintenance to each of the building systems. With the height of the IBS, the floor to floor heights for each floor is about 19 ft.

Table 6 Patient Room Wall Heights

Patient Room Wall Construction	
Floor-to-Floor	19
Floor-to-Ceiling	9
Plenum	10

Block Layout

Due to the monstrosity of the hospital, it was analyzed using the block layouts in Figure 5 and Figure 6 below. Two air handlers located in the penthouse feed both levels 5 and 6 respectively. The two floors were broken down into exterior, exterior corner, and interior rooms. Then they were broken down according to design conditions. As seen in figure 1, the zones were created according to exposure and activity of the occupants. Since level 6 has a large number of offices, the zones were split according to exposure and design conditions as well.

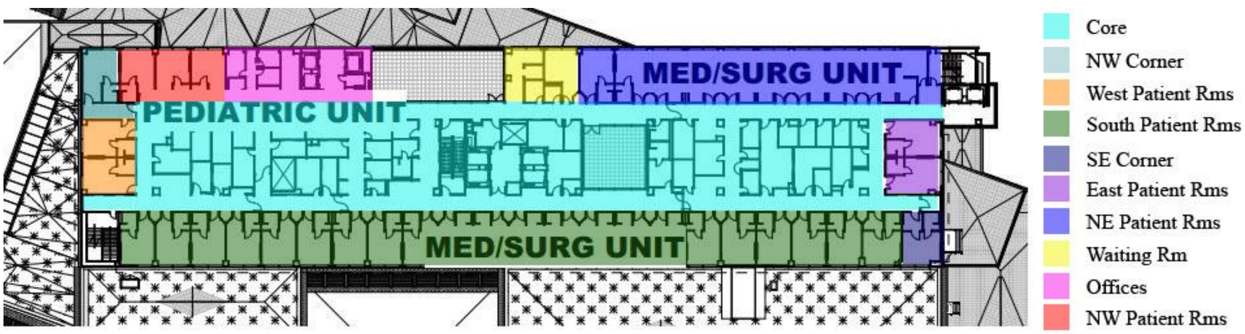

Figure 5 Level 5 Block Layout

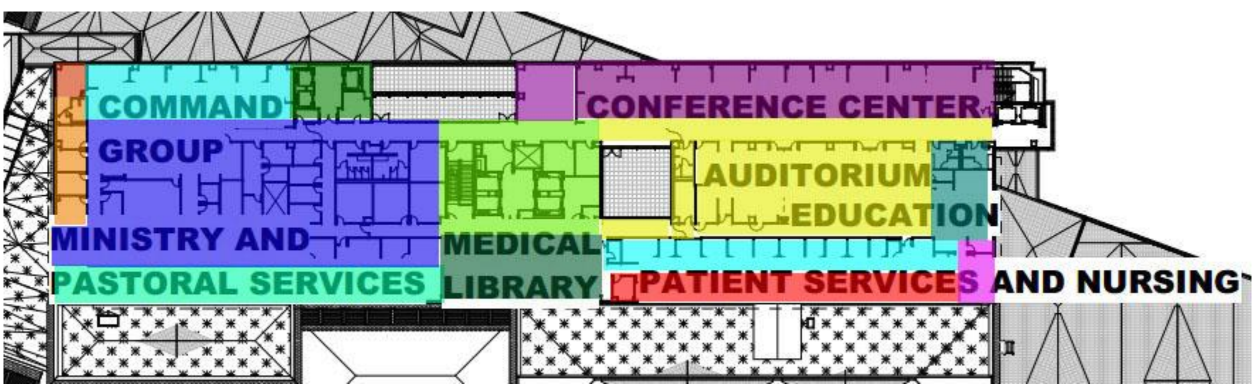

Figure 6 Level 6 Block Layout

Load Assumptions

Occupancy

The occupancy for the building were found using mainly the design documents for the medical spaces. The ASHRAE 62.1 standard was also used to find the occupant densities for the office spaces on level 6.

Lighting

The lighting power densities were referenced from the design documents, specifically the electrical plans. The lighting power densities varied for each space type. The LPD for the patient rooms were slightly lower than the medical support rooms, and the LPD for the office spaces were higher than some of the patient medical rooms. A few of the major templates used for the building spaces are included in Appendix B.

Miscellaneous Equipment Loads

The sixth level is mainly patient medical rooms, so the miscellaneous is on the lower side even though it is a hospital. The rooms for medical support such as the treatment rooms, equipment storage and labs have a higher miscellaneous equipment load of 15 W/sq. ft., these miscellaneous equipment loads can be found in the templates in Appendix B.

Thermostat Settings

The set points for the thermostats vary depending on the building space. The relative humidity for all building spaces is 55%, however the cooling dry bulb and drift point vary according to Table 7 below.

Thermostat Settings		
Space	Cooling DB/DP	Heating DB/DP
Conference/Office	78/81	70/64
Medical Room	75/81	75/64
Medical Support	78/81	68/64

Table 7 Thermostat Settings

Schedule

The demand for a hospital is high, and not always consistent through a 24-hour period. Therefore, a 100% diversity factor was taken into account for the occupant, miscellaneous equipment, and lighting loads. The greatest load for lighting, occupancy, and equipment will be during typical work hours of 7 a.m. to 5 p.m., however, the medical center is designed to condition the space for no less than 80% of the occupancy. Although schedules were taken into account, the medical center is designed for close to maximum capacity.

System Equipment

Heating & Cooling

Although the central utility plant consists of four centrifugal chillers and four gas fired steam boilers, the Trace model for this analysis used only one centrifugal chiller and one gas fired steam boiler. The proposed CUP is designed for the entire building, so a smaller CUP should be modeled for the building to obtain reasonable energy consumption. Future analysis of the central utility plant is required to measure an accurate capacity for the two levels being analyzed.

Air Side Equipment

Two rooftop air handlers were modeled for the two levels. Each air handler was modeled with air to air energy recovery in the form of an energy recovery wheel recovering energy from the general exhaust air. Both air handlers supply to Constant Air Volume Terminal Units on the IBS floors for the building spaces.

Conclusion

Table 8 displays the comparisons in cooling loads and heating loads with both the design engineers proposed system and the modeled system. There are slight differences in total supply CFM which may be due to overcompensating in equipment and lighting loads for the building spaces. There are significant differences in the heating and cooling loads, this error may be due to the central utility plant being over designed. The CUP for the hospital was designed to serve the entire building, so for this model, only one gas fired steam boiler and one centrifugal chiller was modeled. In order to keep the models consistent, the same capacity for both pieces of equipment were used. By modeling equipment with a high capacity for the spaces' needs, the system is producing extra energy. The central utility plant may be of interest to analyze further later, however, it is beyond the scope of this project.

Table 8 Load Comparison for Design and Calculation

System	Total Supply / OA (CFM)		Cooling (SF/ton)		Heating (Btuh/ft^2)	
	Design	Calculated	Design	Calculated	Design	Calculated
BAHU-2	25,751	28,583	280.37	220.64	22.7	26.05
BAHU-3	24,188	30,633	280.37	177.18	22.7	28.88

Annual Energy Consumption

Fuel Consumption

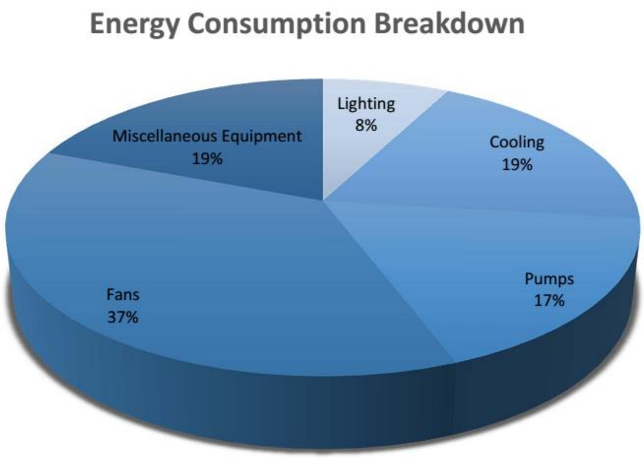

Figure 7 Energy Consumption Breakdown

The Trace 700 Model was analyzed to break out the energy consumption for each of the building components: lighting, miscellaneous equipment, cooling plant, pumps, and fans. As shown in Figure 7 to the left, most of the electrical energy usage comes from the fans, however, the heating plant is not modeled in this because it uses mainly natural gas to operate. Overall, the building uses a total of 3550 MWh of electricity.

Figure 8 displays the monthly energy consumption broken down into building loads. The cooling plant load increases during the summer as expected, however the fan does not increase significantly. Since Fort Hood has hot weather year round, it may be the cause of the skewed results.

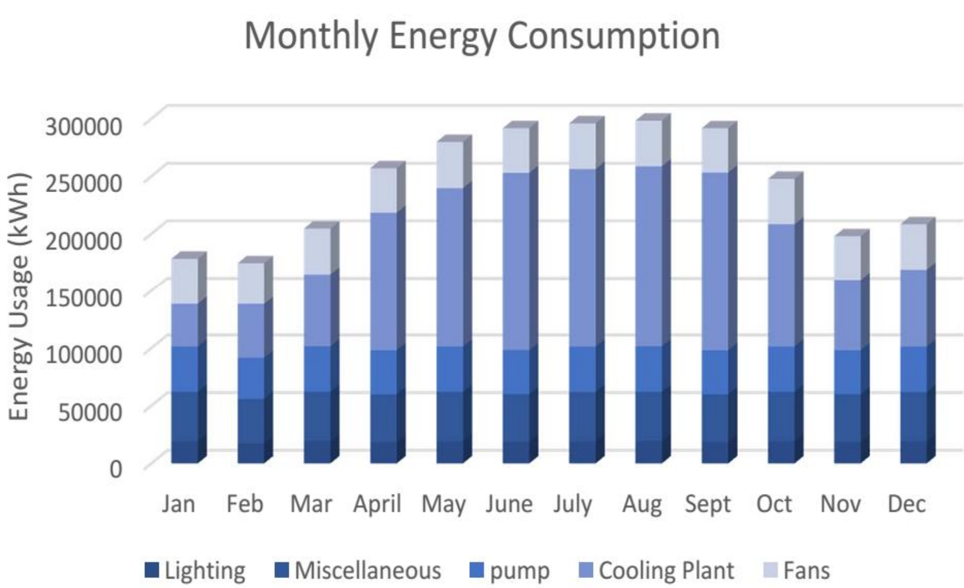

Figure 8 Monthly Energy Consumption

Water Consumption

Figure 9 Monthly Water Consumption, shown below, displays the water consumption in kgal per month with an average increase during the summer months of May through September. Since Fort Hood has higher average temperatures, there is a spike in water usage during the summer because of the demand to cool outdoor air. During the months of June through September, which have the extreme temperature spikes in weather, the water consumption oscillates between 450, and 500 kgal per month. The highest consumption occurs in June with an average of 490 kgal of water.

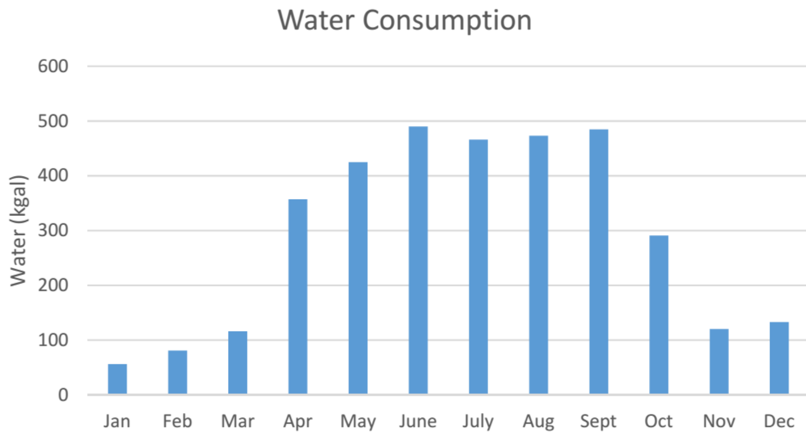

Figure 9 Monthly Water Consumption

Annual Consumption Results

The analysis for the medical center shows most energy is consumed by the cooling process. Since the weather is harsh in Texas, this was expected. However, the fan energy does not equally reflect the spike in cooling demands during the summer. The monthly water consumption is parallel with cooling demand spikes during the summer. The energy breakdown for the modeled building shows most energy being consumed by the fans. The design engineer also had an energy analysis performed. Their energy breakdown according to use showed the miscellaneous equipment load consuming the most energy. The difference in energy consumption may be because of the over design of the CUP which means more energy is going towards the heating and cooling plants in the modeled building in this analysis. The design engineer's energy analysis results showed the designed medical center outperformed the baseline model by 44.5% in energy savings.

Annual Operating Cost

Energy consumption was determined using the average utility costs of Fort Hood, Texas. The average electricity cost is $0.094/kWh, and the average natural gas cost is $0.642/therm. The energy consumption was broken down into the major building components that consume the most energy. The average annual operating cost for the two floors of the medical center is $368,148 which is $5.49/SF per year.

The monthly utility costs are displayed in Figure 10: monthly energy costs. This figure shows the energy costs between the two largest energies in demand: natural gas and electricity. Since the weather is extremely hot in Fort Hood, not a lot of heat is needed year round. Therefore, the cost in natural gas stays consistent. The boilers create enough heating hot water for the equipment, and exterior zones, but the bulk of the monthly energy costs go to electricity because of the lighting, miscellaneous equipment loads, and fan energy.

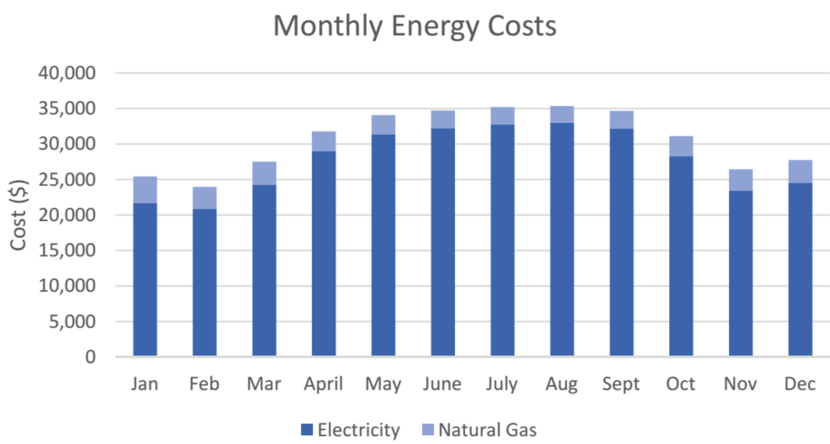

Figure 10 Monthly Energy Costs

Operating Costs per Equipment Use

The operating costs were broken down into monthly costs for the different equipment and space loads in Figure 11: monthly energy costs per use. The cooling plant cost the most according to this analysis by a significant amount. The other loads were roughly the same cost, with miscellaneous loads being the highest. The lighting costs did not change from month to month since they operate on a set schedule, the fan cost also stayed roughly the same.

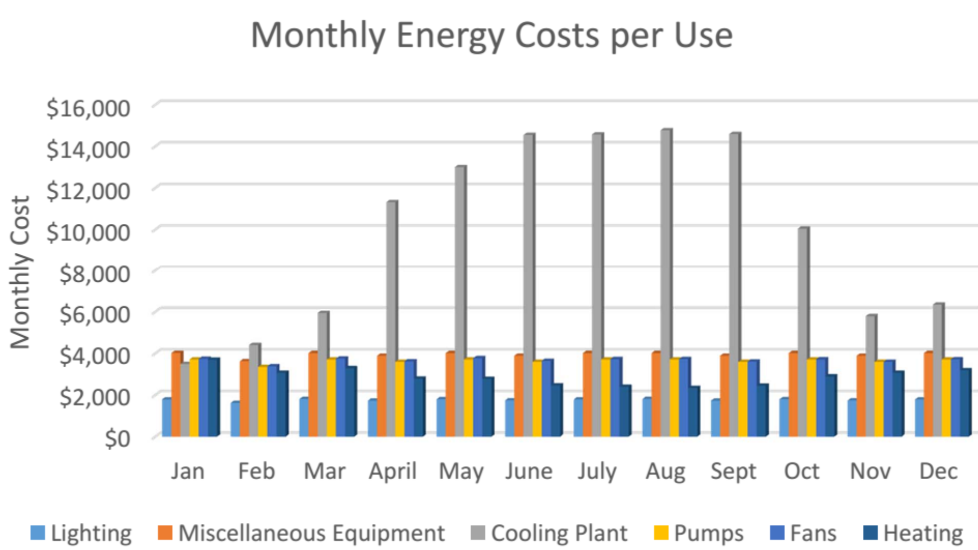

Figure 11 Energy Costs per Equipment

Using the monthly operating costs analyzed by the Trace 700 model, the annual costs for the different loads were found. The annual operating costs are displayed in Table 9. The highest annual operating cost is for the cooling plant which is $118,810, this is over double the second highest annual cost, the miscellaneous load.

Table 9 Annual Energy Cost per Load

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total Cost
Lighting	$1,795	$1,621	$1,809	$1,735	$1,802	$1,748	$1,788	$1,809	$1,735	$1,802	$1,742	$1,788	$21,171
Miscellaneous Equipment	$4,019	$3,628	$4,016	$3,887	$4,016	$3,887	$4,016	$4,016	$3,887	$4,016	$3,887	$4,017	$47,293
Cooling Plant	$3,495	$4,404	$5,941	$11,313	$12,998	$14,546	$14,574	$14,773	$14,590	$10,042	$5,789	$6,345	$118,810
Pumps	$3,713	$3,353	$3,713	$3,593	$3,713	$3,593	$3,713	$3,713	$3,593	$3,713	$3,593	$3,713	$43,714
Fans	$3,738	$3,388	$3,750	$3,623	$3,771	$3,642	$3,726	$3,727	$3,608	$3,714	$3,594	$3,720	$43,999
Heating	$3,700	$3,065	$3,290	$2,789	$2,779	$2,464	$2,400	$2,344	$2,452	$2,895	$3,066	$3,191	$34,438

Emissions

The location of the army medical center puts it on the Electric Reliability Council of Texas (ERCOT) Interconnection. Using the emission factors for the ERCOT electricity grid in Source Energy and Emission Factors for Energy Use in Buildings in Appendix C, the delivered energy to the building emits 6.07 million lbs of CO_2, 7810 lbs of NOx, and 34,435 lbs of SO_2. Although the CO_2 emission is significantly larger than the other greenhouse gases, the amount of CO_2 is not considered dangerous. The emissions are listed in Table 10 below.

Table 10 Emission Pollutants

Pollutant	Emission (lb/yr)
CO_2	6,070,500
SO_2	34,435
NO_x	7,810

Design Considerations

The function of the Medical Center is to replace the current hospital at Fort Hood, located in Killeen, Texas. The medical center consists of pediatric clinics, women's clinic, emergency services, a cafeteria, offices, and other various medical rooms. The medical center's central utility plant is located in a 25,000 sq. ft. building less than 100 feet from the medical center. The building houses the mechanical equipment for the waterside system: the chilled water, heating hot water, and steam systems. The rooftop air handling units are located in the penthouses located on each of the clinic's roofs. The air handlers are designed for 100% outdoor air and contribute to the LEED Gold Certification this building will be awarded upon completion.

Outdoor & Indoor Design Conditions

Carl R. Darnall Army Medical Center is located in a very hot and humid location identified by ASHRAE 90.1 section 5 as Zone 2A in Killeen, Texas. The outdoor air design conditions for both summer and winter are displayed in the table below, Table 11 Climate Data for Coldest & Hottest Months. This table displays the main concern is the cooling loads during the hot months.

Table 11 Climate Data for Coldest & Hottest Months

Coldest Month	Heating DB (99.6%)	Humidification DP/MCDB and HR (99.6%)		
		DP	HR	MCDB
January	23.7	9.8	9.4	33.5

Hottest Month	Cooling DB/MCWB (0.4%)	
	DB	MCWB
August	99.9	73.4

The indoor design conditions for the medical center vary according to occupancy types. The thermostats were placed at nursing stations as well as in the medical rooms, there is a thermostat for each individual medical room in order to meet the patient's needs. The thermostat settings for the three main room types are displayed in the table below, Table 12: Thermostat Settings. In all, most of the supporting rooms are designed for a 78F DB and 81 DP, but the medical rooms are designed at 75 F DB, and 81 driftpoint because of the stringent medical needs. All rooms, no matter the classification, were designed for a relative humidity of 55%.

Table 12 Thermostat Settings

Thermostat Settings			
Space	Cooling Drybulb Temp (F)	Heating Drybulb Temp (F)	Relative Humidity
Conference/Office	78	70	55
Medical Room	75	75	55
Medical Support	78	68	55

Ventilation Requirements

The design engineers proposed a 100% outdoor air system for Carl R. Darnall Army Medical Center. The first technical report was an evaluation of both ASHRAE 62.1 for the offices on level 6 and ASHRAE 170 for the medical rooms and supporting medical rooms for the minimum ventilation rates. The overall calculated outdoor airflows and the actual designed outdoor air flows are listed in Table 13 Ventilation Calculations.

Table 13 Ventilation Calculations

Air Handler	Space Type	Actual Design		Calculated
		Supply Airflow	Outdoor Airflow	Outdoor Airflow
AHU-2	Level 5 Medical Rooms	45,000	45,000	7,160
AHU-3	Level 6 Offices	45,000	45,000	13,894

Since the actual design for the medical center is 100% outdoor air, the actual design outdoor airflows are significantly more than the ASHRAE 62.1 calculated airflows. Since, the calculated outdoor airflow is 30% of the supply airflow, it is three times as small as the design dedicated outdoor airflow.

Heating & Cooling Loads

The results from the second technical reports were calculated using Trace 700 model to compare the heating and cooling loads with the actual design. Although, the calculated loads were similar between the design and calculated model, differences can be explained through overcompensation for equipment and lighting loads. The results shown in Table 14: Load Comparison, show the similarities between the two floors for the actual designed loads, however, the calculated loads in the model vary by floor. Level 5 calculations are based on ASHRAE 170 and Level 6 calculations are mainly based on ASHRAE 62.1, each air handlers was designed using a different standard which may explain discrepancies between the two. The Trace 700 model was also designed for occupants in the building at all times. The design engineers used UFC-4-510 as the basis for design which is more stringent than ASHRAE 62.1 and ASHRAE 170 for equipment, ventilation and lighting loads.

Table 14 Load Comparison

System	Total Supply / OA (CFM)		Cooling (SF/ton)		Heating (Btuh/ft^2)	
	Design	Calculated	Design	Calculated	Design	Calculated
BAHU-2	25,751	28,583	280.37	220.64	22.7	26.05
BAHU-3	24,188	30,633	280.37	177.18	22.7	28.88

Annual Energy Usage

The annual electrical energy consumption was broken down into monthly energy use and separated into the five top energy consuming loads. As seen in Figure 12 Base Monthly Energy Consumption, the cooling plant consumes the most energy, and the fans consume the least. For most of the systems, the energy usage remains constant, however, as expected, the energy usage for the cooling plant increases during the summer months.

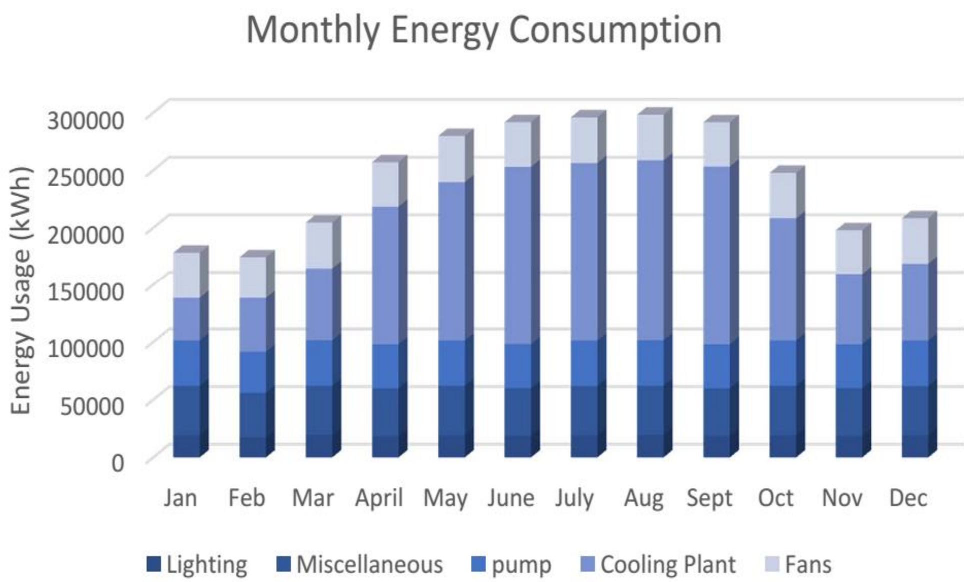

Figure 12 Base Monthly Energy Consumption

The monthly water consumption spikes during the summer because of the extreme outdoor temperatures, thus requiring a large cooling demand. During the hotter months when the cooling tower must run, the chiller will be require more make up water as seen in figure 13: water consumption.

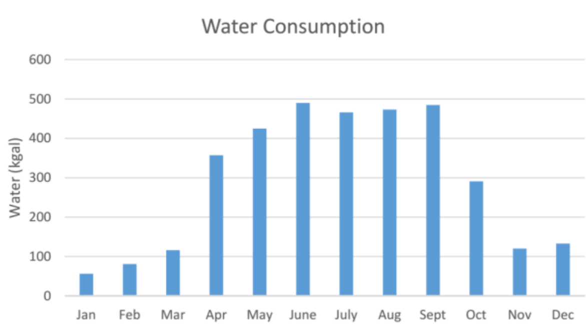

Figure 13 Water Consumption

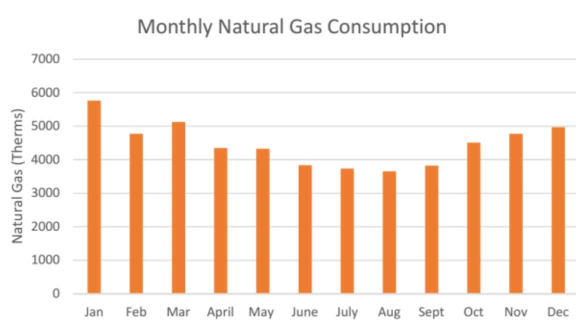

Figure 14 Monthly Natural Gas Consumption

The monthly natural gas consumption is relatively constant since the heating demand is not large during the winter, and only November thru March require more heat than the summer as displayed in Figure 14: monthly natural gas consumption.

Energy Sources & Rates

The design engineers provided average utility rates for the three main energy sources: natural gas, electricity, and domestic water. The utility rates were obtained by the U.S Energy Information Administration (EIA) and were used to calculate monthly and annual utility costs. The utility rates provided are displayed in Table 15 Utility Rates.

Table 15 Utility Rates

Utility Rates for Texas	
Electricity	$0.1176 per kWh
Natural Gas	$9.93 per mcf
Domestic Water	$2.26693 per kgal

Influencing Factors of the Design

The army medical center is not applicable for rebates or tax relief from energy utility companies. The design engineers focused on saving money through the design of the mechanical systems.

Mechanical First Cost

Overall, the project was awarded to Balfour Beatty and McCarthy with a bid of $534 million for the construction costs. The first mechanical cost of the project was a total of $38,913,000, this cost includes HVAC piping, sheet metal, and equipment which takes installation labor into account, the totals for each trade can be found in Table 16: Mechanical First Cost. This accounts for 7% of the entire construction cost. The mechanical cost does not include insulation, controls, fire stopping, core drilling, and TAB.

Table 16: Mechanical First Cost

Mechanical Cost	
Piping	$13,819,850
Sheet Metal	$13,716,769
Equipment	$11,376,449
Total	$38,913,068

Loss of Usable Space

The majority of the mechanical space is located in the central utility plant and the basement. The only space that is lost due to mechanical systems on floors 5 and 6 are due to mechanical shafts. On level 5, only 371 sq. ft. is lost by mechanical shafts for risers and stair pressurization, the 6th floor loses the same amount of space. The mechanical systems are on separate floors called the IBS floors. The floors have a floor to ceiling height of 8 ft., and exist for the sole purpose of the building systems. Since the IBS levels are designed only for access for maintenance, and the floors are not designed for a heavy live load, it can be assumed that theses floors are not usable. However, the IBS floors cause the medical center to be twice in height. The army medical center's bed tower is currently 120 ft. tall in height, however, if the IBS floors were converted into 5 ft. plenums, the medical center would be 102 ft. in height. With a shorter medical center, pumps can be reduced in pressure because water does not have to overcome as large of a head pressure. Less concrete and façade material would be needed thus reducing costs.

Existing Mechanical Systems

Cooling Equipment

Chilled Water System Equipment

The central utility plant provides chilled water to the medical center for cooling. The chilled water mainly serves the air handlers as well as fan coil units, blower coil units, and a few computer room air conditioning units (CRACs). The chilled water loop provides a 44˚F supply to the building. The chilled water loop's main equipment are the four water cooled centrifugal chillers which use R-134a to provide a cooling capacity of 1,305 tons. The water from the chiller is distributed using variable primary flow pumps. The chilled water pumps are in line designed for 1,900 gpm and provide a head pressure of 185 ft. wc. In Table 17 Motor Horsepower Schedule below, lists more information about the pumps in the heating water, chilled water, and heat recovery systems. A heat recovery chiller also provides chilled water and heating hot water to their respectable systems by absorbing heat from the return chilled water and ejecting it into the return heating hot water.

Table 17 Motor Horsepower Schedule

ID Tag	Service	Flow (GPM)	Head (ft wc)	NPSH (ft wc)	Pump Efficiency (%)	RPM	Number on Emergency Power
HWP-(1-3)	Heating Water	650	180	17.7	76%	3,600	1
CHWP-(1-4)	Chilled Water	1,900	185	10.6	81%	1,800	2
CWP-(1-4)	Condenser Water	2,945	75	22.7	79%	1,770	2
HRP-(1-2)	Heating Water	175	25	9.5	76%	1,800	0
HRP-(3-4)	Chilled Water	220	15	5.8	76%	1,800	0

Condenser Water System

The heat from the centrifugal chiller is rejected into the condenser water which is sprayed through four 13˚F range induced draft counter-flow cooling towers one of them in standby mode. Each cooling tower is designed for a minimum of 690 gpm flow and a maximum of 1,885 gpm. The system uses a continuously drained concrete basin which improves the protection during cold weather and reduces maintenance. The cooling tower blowdown water is re-used for irrigation because the system is chemical free. Condenser water pumps provide a pressure of 75 ft wc each.

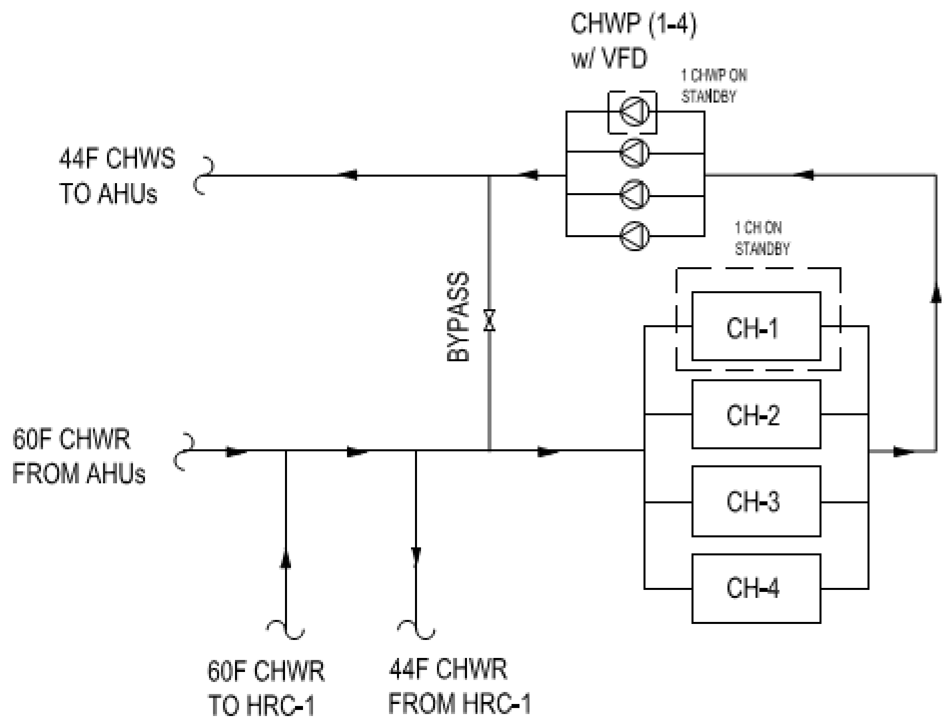

Figure 15 Chilled Water Loop

Chilled Water System Sequence of Operation

The medical center is served chilled water from a central utility plant detached from the building via a utilities tunnel. Upon entering the building, the water branches off the chilled water return main and feeds into the heat recovery chiller loop as seen Figure 15 above. During colder months, HRC-1 can provide chilled water for the base load of the building. If the HRC-1 can cool the chilled water to the required 44˚F, then the chilled water bypasses the centrifugal chillers and distributes back to the medical center. If the temperature of the chilled water leaving the heat recovery chiller rises above 46˚F, then the bypass valve closes, and one of the four centrifugal chillers in parallel turns on. The chillers will turn on sequentially if the leaving temperature of the chiller is at 46F for more than 15 minutes. The chilled water from the HRC-1 returns to the chilled water return main and mixes with the remaining water from the hospital. The chilled water feeds into one of the four in line pumps. One chilled water pump and chiller will be in standby mode, and the lead chiller will alternate weekly, so none of them sit unused for months at a time. Lead pumps alternate weekly in order to ensure equal wear on them. The chilled water loop is a variable primary flow, so the chilled water pumps are accompanied with VFDs to ensure the proper amount of chilled water is distributed within the medical center.

Heating Equipment

The central utility plant provides 140˚F heating hot water to the medical center for the AHUs, and the reheat coils on the CAVs. The returning 110˚F heating hot water is used to preheat domestic hot water, absorb heat from the chilled water return, and it is heated through a heat exchanger by steam.

Steam Boiler

The steam plant produces 150 psig steam by four dual-fuel forced draft steam boilers. The two fuel types used are natural gas, and #2 fuel oil. Each boiler is sized for a gross output of 11,716 MBH. In order to maximize on efficiency, each boiler has a boiler stack economizer which recovers heat from the combustion process. The steam is mainly used for the heating hot water, however, some of it will be distributed within the medical center to serve kitchens and sterilizing equipment.

Humidification Clean Steam Generator

In the penthouse there is a humidification clean steam generator which produces steam for the humidifier in the air handlers. Medium pressure steam comes in at 85 psig from the basement, and is generated into low pressure clean steam at 15 psig. The low pressure steam is supplied to the humidifier in the air handler. The steam entering the humidifier is 40.7F, and after it humidifies the incoming outdoor air, it rises 6˚F, and the outdoor air humidity rises from 37.6% RH to 59.3RH.

Heat Exchangers

The return heating water is used to preheat the domestic hot water using a preheat heat exchanger. This heat exchanger, PHX-1, is double wall shell and tube type. The preheat exchanger has a design capacity of 4,489 MBH and uses the design temp of the return heating hot water of 120˚F to preheat the domestic hot water. Later in the heating water loop, the water passes through the steam and hot water heat exchanger. This heat exchanger is also a shell and tube U-shape type, with the steam in the shell heating the heating water in the tubes. The heat exchangers have a capacity of 9,618lb/hr of steam. The temperature of the incoming steam is 280˚F at 35 psig. The steam heats the incoming 600 gpm water from 110˚F to 140˚F.

Hot Water Pumps

Three in line variable primary pumps distribute heating water to the reheat coils in the CAVs and the heating coils in the air handlers. These pumps operate in parallel which allows one pump in standby mode. Each pump is designed for 650 gpm, and provides 180ft WC head in order to distribute water to the air handlers in the penthouses. Each pump is paired with a variable frequency drive, and two of the pumps are on emergency power. There is enough room and capacity for a future fourth heating water pump.

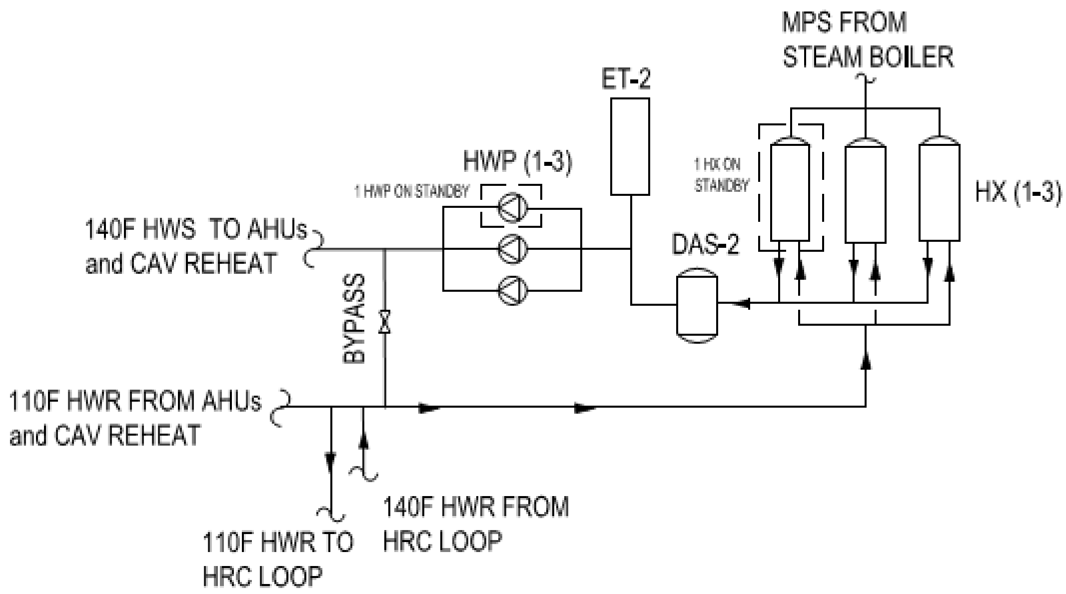

Figure 16 Heating Water Loop

Heating Water System Sequence of Operation

The central utility plant uses steam from the steam boilers to heat the heating hot water. As seen above in Figure 16, the hot water returns from the medical center and branches off to feed into the heat recovery chiller loop. The returning heating water from the heat recovery chiller returns to the heating water main and enters the steam and water heat exchangers each sized for 60% of the building heating load capacity. Medium pressure steam enters from the steam boiler and heats the incoming water to 140˚F. If the incoming water rises above 850 gpm, then the second heat exchanger switches on, the third staying in standby mode. The leaving 140˚F heating water enters the heating water pumps. The minimum flow through the pumps is set at 130gpm, if this is met, then the bypass valve opens and the pumps are maintained at a constant speed. Each pump is controlled by a VFD, and one is always in standby mode. The heating pumps distribute 140F to the heating coils in the AHUs and the reheat coils in the CAVs.

Heat Recovery Chiller

The heat recovery chiller provides a base cooling load during the colder months, if chilled water is in demand. The heat recovery chiller is a water cooled scroll chiller. The chiller is rated for a 202 ton capacity, and the condenser side is designed to reject 2,634 MBH of heat. The returned chilled water from the building first enters an in line pump and then enters the evaporator side at 60F. Heat from the 217 gpm of returning chilled water is rejected into the 132 gpm of return heating water. The chiller is designed to produce leaving heating water at 140˚F and leaving chilled water at 44˚F.

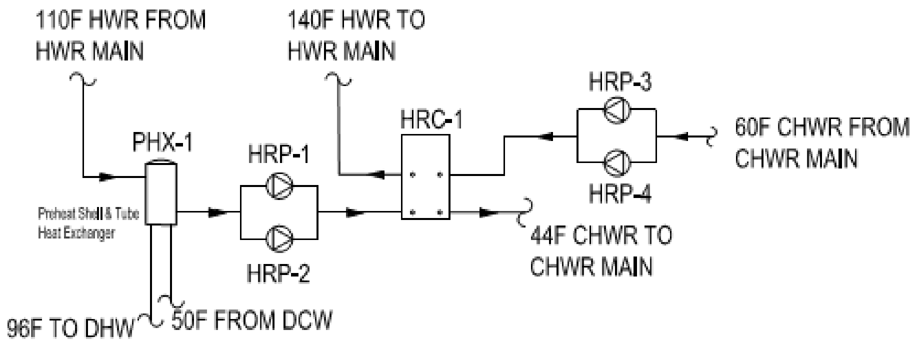

Figure 17 Heat Recovery Chiller Loop

Heat Recovery Chiller System Sequence of Operations

The entering heating water from the medical center first passes through the preheat heat exchanger. Figure 17, above shows how the heat recovery chiller cools the chilled water loop and heats the heating water loop. This heat exchanger preheats the incoming domestic cold water to 96˚F domestic water to serve the medical center's domestic heating needs. The heat exchanger produces 175 gpm of heating hot water which then feeds into one of the two heat recovery pumps rated at 25 ft. wc. The pump efficiency of these pumps is 76%, and they are both parallel in line pumps, one of the two pumps is in standby mode. The heating water proceeds to the heat recovery chiller and heats up to 140˚F and is sent back to the heating water main. On the evaporator side, the chilled water from the chilled water return main enters one of two in line pumps at 217 gpm. The pump provides 15 ft. wc head at 76% efficiency. The water then flows to the heat exchanger where it is cooled down to 44˚F and flows back to the chilled water return main.

Airside System Equipment

Air Handling Units

The two air handlers supplying conditioned outdoor air to the spaces on the fifth and sixth floors are designed for 100% outside air. Both are designed for an outside airflow of 45,000 cfm, and supply the spaces with 55F conditioned air. Before entering the air handlers, outdoor air enters through an enthalpy wheel and is preconditioned with the general exhaust air. The outdoor air is drawn through the AHU by the fan. It is further heated if necessary by the heating coil. After, it is humidified using the 15 psig steam from the clean steam generator. It is then cooled down to the supply temperature of 55F, and passes through the fan and the MERV 14 filter, then it is supplied to the building after passing through the MERV 7 filter in the second bank. Figure 18, below shows the path of outdoor air in the air handler.

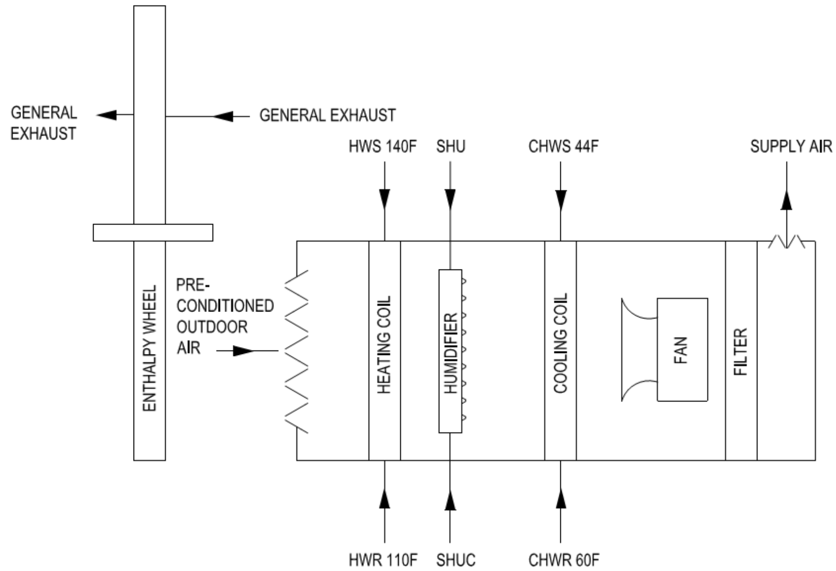

Figure 18 Air Handling Unit

Terminal Units

The supply air from the air handlers supply CAV boxes on the fifth and sixth floors. The CAV boxes have a heating coil to provide the proper conditions for the space. Each patient room is on its own CAV box, and the thermostat is located within the room.

Fan Coil Units

Electrical rooms are provided with fan coil units that supply anywhere from 750 to 1,225 cfm for each space. The chilled water supplies the cooling coils, so the equipment in the room can be properly maintained. The fan coil units have a 1" MERV 7 filter for circulating air within the space.

Operating History

Since the army medical center is new construction, there is no history on the consumption of energy nor metering of energy.

LEED Analysis

At the time of design, the army medical center was aiming for LEED Gold, projected to earn 43 credits by completion. The LEED checklist used was version 2.2 for new construction, however, since the design, version 4 has been released, and the following analysis is made in respect to the newest version.

Energy & Atmosphere Credits

EA Prerequisite: Fundamental Commissioning and Verification Required

In order to guarantee the owner's project requirements, the commissioning authority will create basis of design documents. Maintenance plans must be created for operating the systems which include sequence of operations, equipment run-time, set points for HVAC equipment, and any other documents that will inform the building operator of the systems.

Prerequisite: Minimum Energy Performance Required

The medical center will follow option 1: whole building energy simulation. The medical center demonstrates an improvement of over 5% for new construction compared to the baseline building performance according to ASHRAE Standard 90.1.

EA Prerequisite: Building Level Energy Metering

Metering devices will be installed in order to monitor the total building energy consumption of electricity, natural gas, chilled water, steam, fuel oil and other fuel sources.

EA Prerequisite: Fundamental Refrigerant Management

The medical center does not use CFC based refrigerants in any of the HVAC or refrigeration systems. The HVAC systems strictly use R-134a refrigerant.

EA Credit: Enhanced Commissioning (3/6)

The commissioning authority will follow the commissioning process for the mechanical, electrical, plumbing and fuel systems. This includes seasonal testing, operator training, reviewing contractor submittals, and other requirements. Since v2.2, monitor based commissioning and thermal envelope commissioning was added to the attainable credits. It is unknown if the commissioning authority will be commissioning for either. At least 3 credits are earned.

EA Credit: Optimize Energy Performance (13/20)

The medical center must outperform the ASHRAE baseline by at least 6% in order to attain any points. The medical center out performs the ASHRAE baseline by 26.2%, so the medical center is awarded 13 credits. Table 18 Credits for Improvement in Energy Performance, shown below, displays the distribution of the credits for the percentage improvement in energy performance is shown below.

Table 18 Credits for Improvement in Energy Performance

Points for Percentage Improvement in Energy Performance	
New Construction	Points Healthcare
6%	3
8%	4
10%	5
12%	6
14%	7
16%	8
18%	9
20%	10
22%	11
24%	12
26%	13
29%	14
32%	15
35%	16
38%	17
42%	18
46%	19
50%	20

EA Credit: Advanced Energy Metering (1/1)

All energy sources consumed by the medical center will be recorded using advanced energy metering. The meters are permanently installed, recording at on hour or less of intervals. They are located within the central utility plant. Although, it is unknown if the meters can store the data for more than 36 months.

EA Credit: Demand Response (0/2)

The army medical center is ineligible to be considered for the demand response program of the electric company.

EA Credit: Renewable Energy Production (0/3)

Although a combined heat and power system and a wind power system were first considered during design, the medical center has not adopted any renewable energy production systems.

EA Credit: Enhanced Refrigerant Management (1/1)

The refrigerants selected for the HVAC and refrigeration equipment do not reach the requirement of LCGWP+LCODP*10^5 <= 100, therefore no credit is rewarded. The calculations for worst case scenario are displayed below in Table 19 Refrigerant Impact.

Table 19 Refrigerant Impact

Refrigerant	GWP	ODP	LCODP	LCGWP	LCGWP+LCODP*10^5	Credit? (LCGWP+LCODP*10^5<=100)
HFC-134a	93	0.02	0.003	13.95	313.95	No
Lr	2%					
Refrigerant Charge (Rc)	5					
Equipment Life	10					
End of Life Loss (Mr)	10%					

EA Credit: Green Power and Carbon Offsets (0/2)

The design engineers ruled green power out during the design development phase of this project, therefore, are not eligible for this credit.

Indoor Environmental Air Quality Credits

IEQ Prerequisite: Minimum Indoor Air Quality Performance Required

The mechanically ventilated medical center surpasses both ASHRAE 170-2013 and ASHRAE 62.1-2013 requirements for minimum outdoor air flow because of the 100% outdoor air system. In spaces of high occupancy, CO_2 monitors were installed in order to maintain the minimum outdoor airflow.

IEQ Prerequisite: Environmental Tobacco Smoke Control Required

Smoking is prohibited everywhere within the medical center. Proper warnings are along the exterior of the medical center prohibiting smoking within 25 feet of the entries and outdoor air intakes.

IEQ Prerequisite: Minimum Acoustic Performance

The minimum acoustic performance prerequisite is only required for educational buildings, therefore this prerequisite is not applicable to the army medical center.

IEQ Credit: Enhanced Indoor Air Quality Strategies (0/2)

The entryways of the medical center do not have a system that is 10 feet long in the direction of travel to capture dirt and particulates entering the building. Although, it does have a unit heater, the return grilles are not the correct size, nor is there a filter on the unit heater. Entryway vestibules are not pressurized either.

Medical rooms in which activities that emit gases are properly enclosed with self-closing doors, and deck to deck partitions. The rooms are also properly exhausted as required by the prerequisite minimum indoor air quality performance.

All ventilation systems have a MERV reporting value of 14 which surpasses the requirement of 13.

IEQ Credit: Low-Emitting Materials (1/3)

The materials for the interior paints, interior adhesives and sealants, flooring, and composite wood are all low emitting materials. Four of the seven categories of materials will be met in order to attain at least one credit. Since the design engineers are achieving LEED certification from LEED version 2.2, they are not tracking the ceiling, wall, thermal, and acoustic insulation, the furniture or the exterior product materials for emissions.

IEQ Credit: Construction Indoor Air Quality Management Plan (1/1)

Proper actions will be taken during construction to protect absorptive materials, and any materials prone to mold growth from moisture in order to prevent occupants from breathing mold particles in the building. During construction, filters prevent particulates from entering the ventilation system. Tobacco use will be prohibited within the building as well as 25 feet from the building during construction. Construction workers must wear ear protection when using equipment with a decibel level 85 or over as specified by OSHA.

IEQ Credit: Indoor Air Quality Assessment (1/2)

Before occupancy, filters will be changed and a flush-out of the ventilation system will occur of 14,000 cfm of outdoor air per square foot in order to rid the building of particulates. The air will be between 60˚F and 80˚F and have a relative humidity of no higher than 60% as required by the credit.

IEQ Credit: Thermal Comfort (0/1)

In order to meet pressurization requirements for certain procedural rooms, ASHRAE 55 is not met for all of the patient rooms and 50% of the remaining individual occupant spaces. Due to the range of activities occurring and equipment emitting thermal energy and moisture, the thermal comfort controls cannot offset these factors.

IEQ Credit: Interior Lighting (1/1)

Lighting controls are located in the medical supporting areas for the staff. At least 90% of the patient rooms have lighting controls within reach of the bed. There are also lighting controls for both patients within a multi-occupant patient room.

IEQ Credit: Daylight (0/2)

Daylighting studies resulted in a small amount of day lit floor area. Due to exterior shading from awnings, the daylighting credit is not met.

IEQ Credit: Quality Views (0/2)

The patient rooms along the perimeter of the building have direct views to the Texan landscape. Due to the size of the medical center, there are more interior rooms than there are rooms along the exterior, so this credit is not awarded.

IEQ Credit: Acoustic Performance (2/2)

In order to achieve speech privacy for critical rooms, deck-to-deck partition walls enclose the room. The medical center was designed to meet the Design criteria for Minimum Sound Isolation Performance between Enclosed Rooms in the 2010 FGI Guidelines and 2010 SV Guidelines. All mechanical, plumbing and electrical systems were designed with minimum sound pressure levels. Acoustical finishes were chosen in order to meet 2010 FGI guidelines and the 2010 SV guidelines.

LEED Analysis Summary

The LEED scorecard has changed significantly in the Energy & Atmosphere section since version 2.2. The army medical center scored 18 of the 35 possible credits because of the optimal performance. The medical center did not score many of the points because of the design engineer's decision to not pursue green power or renewable energy production.

Many credits were added to the indoor environmental quality section since version 2.2. The overall credits attained during the analysis were 6 of the 16. Three more low emitting materials have been added to the list, however the number of possible credits have decreased. Since the medical center failed the entryway system requirement for the enhanced indoor air quality credit, two credits were not attained. The medical center is a large mass with a lot of its rooms located in the interior zones. These rooms are not able to receive daylighting or views of the landscape which means four possible credits are loss.

There is a potential for an improvement in the energy and atmosphere credits by changing equipment or adding a renewable energy productions system. More indoor environmental quality credits can be achieved by changing the entry way systems, however, the daylight and quality view credits are a little difficult to attain due to the set design of the medical center.

Existing Mechanical Systems Evaluation

It is evident in the design of the Carl R. Darnall Army Medical Center one of the biggest goals was to have a mechanical system that can be easily maintained. The IBS floors allow for facility operators to monitor systems and fix any problems that come up without displacing patients. Although the IBS floors allow for easier maintenance, the extra floor adds construction costs to the project including the extra metal deck, and duct fittings in order to create the accessible walkways.

The 100% outdoor air system surpasses the ventilation requirements presented in ASHRAE 62.1 by a significant amount. Having a 100% outdoor air system requires a large amount of cooling during summer months because the weather is hot and dry. An area worth looking into is this system because it takes up space on the IBS floors due to the size of the ducts. The air handlers require large amounts of chilled water when cooling is in demand. By changing the system to supplying the minimum outdoor airflows, the cooling plant could downsize.

There are opportunities for the army medical center to gain LEED credits. A new LEED analysis after small changes may push it to become LEED platinum by tracking the low-emitting materials and researching into the thermal comfort of the patients in the building.

Proposed Redesign

The mechanical system for the medical center receives chilled water and heating water from the central utility plant located next to the building via an underground tunnel. The building also receives steam from the plant for equipment cleaning purposes. The heating water is distributed to heating coils in the air handlers in the penthouses as well as the heating coils in the constant air volume terminal units throughout the building. The chilled water is supplied to the cooling coils within the air handlers. The air handlers preheat the 100% outdoor air using a heat recovery wheel to transfer heat from the general exhaust before it leaves the building.

Airside

The air handlers' intake 100% outdoor air and humidify it using steam from the humidification clean steam generator. All air handlers have two filter banks outperforming the combined MERV rating of 13 prescribed by ASHRAE 170-2013. BAHU-1 and BAHU-2 each supply 40,000 cfm of conditioned outdoor air to levels 5 and 6 respectively. The air handlers handle the cooling and heating loads while the CAV units heat the supply air to the room conditions. The air handlers also use enthalpy wheels to use the general exhaust from the medical surgery rooms and restrooms to precondition the outdoor air before the air is exhausted by constant speed fans.

Terminal Units

The air handlers serve the constant air volume terminal units located in the offices and medical rooms. The CAVs are served by the hot water loop for their reheat coils. There are also fan coil units for the electrical rooms that are served by the chilled water loop for the cooling coils.

Zoning

The general medical surgery rooms and pediatric patient rooms are located on level 5 along with the waiting rooms, isolation rooms, and various medical support rooms. The administrative offices for the different departments and commanders are on the sixth floor. There are also conference rooms and a library. Between the two floors there are various activities occurring in adjacent spaces. The floors are separated by 9 feet dedicated to the interstitial floor (IBS). The IBS floor allows maintenance to easily access the terminal units, diffusers, and other building communication systems. It allows the medical rooms to remain in service while the systems can be maintained.

Cooling

The central utility plant supplies the medical center with chilled water produced by four water cooled centrifugal chillers for a combined capacity of 5220 tons of 44F chilled water. This chilled water loop supplies to computer room air conditioning units, fan coil units, blower coil units, and the air handlers located in the penthouses. A heat recovery chiller covers the base cooling load during the winter. It is a water cooled scroll chiller with a 200 ton capacity, and it preconditions the domestic hot water.

Heating

The steam plant is used to produce the hot water for the heating coils in the CAVs and the air handlers. Four forced draft steam boilers use natural gas and fuel oil to produce 150 psig steam for heating and cleaning purposes. The steam passes through a shell and tube heat exchanger to produce hot water for the reheat coils in the CAV units. The steam is brought to the building to serve as sterilization for equipment and it is used for humidification in the air handlers.

Alternatives Considered

Several alternative design systems were considered for this in depth analysis of a new system. Throughout the initial investigation of the preexisting systems, the following alternatives were considered, but eventually dismissed:

- Combined heat and power plant
- Water Source Heat Pumps
- Dedicated Outdoor Air System
- Chilled beams on the sixth floor
- Condensate recovery for cooling towers
- Solar hot water heating system for domestic water

A few of the alternatives will be analyzed during thesis, however, some were eliminated due to complexity, time restrictions, and costs. The central utility plant will not be investigated during thesis because of the inability to accurately model the entire medical center in a load simulation program.

Proposed Redesign

The current design of the medical center conditions the spaces by providing 100% conditioned outdoor air to the spaces. The VAV units at each zone reheat the air according to the room conditions. The airside system currently contributes to the high amount of energy in

The alternatives chosen were in part due to the energy conservation it may bring to the medical center. Alternatives were chosen based on climate, cost benefits, and educational purposes. The list of alternatives above all have potential to make for an intellectual analysis.

The redesign is based on changing the system to a dedicated outdoor air system. The dedicated outdoor air system will only condition the minimum ventilation air and supply it to the terminal units at the zones. A dedicated outdoor air system was chosen in order to demonstrate that indoor air quality can be maintained at lower outdoor air flows, and the air ducts can reduce in size, thus eliminating the IBS floors.

Dedicated Outdoor Air System

The medical center is currently supplied with 100% outdoor air well above the minimum ventilation requirements set by ASHRAE 170-2013. The current design is based on the ventilation requirements set by UFC 4-510-2012, which are more stringent than ASHRAE 170-2013. For the offices on level 6, the air handler supplies over double the amount of ventilation air required. During the analysis of the medical center, reducing to ventilation air will

The first redesign component will be to use a dedicated outdoor air unit (DOAS) to supply the minimum ventilation air requirement. The result of this change will reduce the size of the air handlers and reduce the cooling and heating loads provided by the air handlers. By supplying the minimum ventilation air flows, the air ducts will reduce in size for both the supply and exhaust side. The height of the IBS floors will reduce to a large plenum, thus unable to be accessible via walkways, but reducing the height of the building thus cost.

The purpose of this new redesigned system is to investigate the effect of the outdoor air reduction on the indoor air quality while reducing the overall size of the system. Since this medical center treats both soldiers and their families, there must be a guarantee of optimum quality of health starting with the indoor air quality.

Furthermore, the DOAS units remove the latent and sensible heat from the ambient air, however, another system must be implemented for the terminal units in order to condition the air for each zone. The system paired with the DOAS unit must remove the latent and sensible heat of the zone it serves. A few options were considered for the type of system: variable refrigerant flow, fan coil units, and water source heat pumps.

Variable Refrigerant Flow

The sensible loads within the spaces will be conditioned using a variable refrigerant flow system. This system allows better control over each spaces' conditions by using valve controls for each unit. By implementing a VRF system, the benefits of the heat recovery side can be used to displace heat from one space to condition another. There will no longer be a need for the terminal units' heating coils to use the hot water loop, however, the DOAS units will still need hot water for the heating coils when the heat recovery wheels cannot provide enough preconditioning. The variable refrigerant system will be used alongside the fan coil units. The fan coil units will supply the minimum ventilation air requirements while using the variable refrigerant flow for the cooling coils. The fan coil units may present higher savings when used on the 6th floor due to the ability to recirculate the class 1 air in the offices. The fan coil units can be placed directly above each space due to their size, however, they may present disturbance among patients which could present another breadth to analyze.

Variable refrigerant flow system require condensing units which will be placed on the roof. A structural breadth will result from the addition of condensing units for the terminal units, as well as the downsizing of the air handlers which will change the structural load on the roof.

Water Source Heat Pump

Water Source Heat Pump is another valid system to use in parallel with the dedicated outdoor air unit to remove the sensible loads in rooms. Investigation of parallel systems has led to closed loop water-source heat pumps with a cooling tower to handle the heat rejection. Due to the high capital cost of a ground source heat pump, the cooling tower and boiler combinations for the WSHP was considered because of the minimal heating the building requires. Since the cold season lasts from the end of November until March, it might be possible to eliminate the boiler or provide a small boiler, if the heat pumps are balanced and reject heat into other spaces within the building. On the other hand, due to the higher average ambient air temperature, an efficient cooling tower designed for a larger approach will need to be considered for this system. The WSHP system utilizes 2 pipes which allows them to reverse from condenser to evaporator during heating and cooling modes. The climate in Killeen is optimal for water source heat pumps because there is a long period of the year when balancing heating between the units can save energy. The two designs will be compared by their energy consumption, air quality, life cycle costs, and installation costs.

Breadth

Construction

By switching to a DOAS unit supplying minimum ventilation air, the amount of air supplied to the zones will decrease by half. The IBS floors which are only used for maintenance, currently consume up to 9 feet per floor of the entire building. However, with the proposed system, the IBS floors can be converted into large plenums for the building's systems. The large plenums will reduce the overall height of the building, thus saving structural and façade materials. The cost benefit of reducing the overall height of the building will be analyzed to determine if the loss in maintenance accessibility is worth the savings. A cost estimate will be created in order to compare the cost savings between the original design and the new system. The effect of these design changes on the schedule will be reviewed as well.

Structural

The structural loads on the roof will change by converting the air handler into a smaller dedicated outdoor air unit. The structural loads for each system will vary as well. With the implement of a variable refrigerant flow system, condensing units will be placed on the roof, thus adding to the dedicated outdoor air unit. The water source heat pump will need a cooling tower which will most likely be located on the central utility plant, however, it may be placed on the roof of the medical center in order to reduce the amount of piping.

Masters Coursework

Content from Centralized Cooling Production and Distribution Systems, AE 557, will be used in the analysis of the three systems being considered. Since the supply air will be reduced to the minimum ventilation air, an indoor air quality analysis will use the course content of AE 552: Air Quality in Buildings.

Tools

Trane Trace 700 was used during the original technical reports in order to compare the energy consumption of the original design. For the redesign proposed, IES Virtual Environment will be used to run load simulations comparing the three different air systems. Engineering Equation Solver will be used when evaluating complex equations presented during the redesign of the HVAC system.

With the proposed DOAS unit consuming the minimum ventilation air requirements, Contam 3.1 will be used to ensure the quality of indoor air remains up to LEED v4 standard as did the original design.

Research

Variable Refrigerant Flow System w Fan Coil Units

Goetzler, William. "Variable Refrigerant Flow Systems."

ASHRAE Journal, April 2007. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 7 Dec. 2013.

In the article, Goetzler identifies the benefits of the variable refrigerant flow system over a chiller system. The VRF modules are lightweight and can be easily installed into small plenums. Since the VRF system provides heating and cooling, it can be paired with a system to provide the ventilation air. Although the VRF system has a shorter life expectancy than chillers, it requires minimal maintenance, changing of filters and cleaning the coils. Newer VRF systems using R-410a and compressors with ECM motors achieve energy savings of 30% to 40% more than chillers. Contractors concerns are the long refrigerant piping will be hard to comply with ASHRAE standard 15-2001 for safe refrigerant systems.

Water Source Heat Pump

Trane. "Energy-Saving Strategies for Water-Source Heat Pump Systems." Trane Engineers Newsletter, vol. 36-2. 7 Dec. 2013. Retrieved from http://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/energy-environment/admapn024en_0507.pdf

In the newsletter, the benefits of both water source heat pump system and ground source heat pump systems are discussed. Although the ground source heat pump eliminates the boiler and cooling tower, it requires a large heat exchanger to adjust for the imbalance between heat stored and extracted from the ground. In a cooling climate, the ground source heat pump can be paired with a cooling tower in order to keep the ground temperature from rising. A ground source heat pump system may also have a bypass valve when the temperature is within a certain range, the refrigerant may bypass the exchanger and reduce pumping energy.

Part 3: Proposed Design Analysis

Proposed Design Introduction

The existing mechanical system provides the patient rooms with 100% conditioned outdoor air through constant air volume terminals. While this provides high air quality to the rooms, it consequentially takes up a lot of space with the duct system. The interstitial floors provide enough space for the ducts, however, a new system was identified to decrease the size of the IBS floors to large plenums while providing the minimum ventilation air and meeting the occupant's thermal comfort standards.

In order to meet the minimum ventilation air requirements, the proposed design adopted a dedicated outdoor air system similar to the original design, however, it provides a lower amount of ventilation air. The dedicated outdoor air system will provide the minimum outdoor air flow as required by ASHRAE Standard 170-2013 and ASHRAE Standard 62.1-2013. The DOAS unit will condition the outdoor air to 55°F by dehumidifying and cooling in the summer, and heating during the winter months. There will be an enthalpy wheel after the intake louver as did the original design, so it is not a part of the DOAS unit. The general exhaust air will precondition the outdoor air before it passes through the cooling and heating coils.

The dedicated outdoor air system must be paired with an airside system to condition the air at the space. The two alternatives considered are the variable refrigerant flow system and the water source heat pump system.

The variable refrigerant flow system, VRF, has many benefits by using refrigerant to condition its spaces. By implementing a VRF system, the spaces can operate according to their own set point controls. A patient room can operate at a 75°F dry bulb set point, while a nurse's team center can operate at a higher cooling temperature set point. The VRF system consists of inverter compressors which allow the VRF units to efficiently run at part load operation. VRF systems can be installed fairly easily because of their modular lightweight design.

The water source heat pump system, WSHP, is the second alternative considered for the proposed design. Similar to a VRF system, it uses a loop to transport heat between spaces and reject it to the atmosphere when needed. The WSHP system also provides individual zone temperature control, so the indoor units do not affect one another's controls. Although a WSHP system uses a cooling tower and a boiler, they do not operate as often as they would in a chilled water system do the reclaim of the heat in the loop.

Dedicated Outdoor Air System

Overview

A dedicated outdoor air system was implemented in order to meet the minimum ventilation requirements for the occupied spaces. By providing enough airflow to meet the ventilation requirements, the majority of the cooling and heating is met using the HVAC unit at the space. The original design provided airflow to meet cooling loads, so it provided more ventilation air than required. By adopting a dedicated outdoor air system that supplies minimum ventilation air, the DOAS unit is smaller in capacity and the amount of cfm it intakes.

A ventilation analysis was conducted and the ventilation airflow rates were found for each space. Ventilation Requirements can be found either in section ASHRAE Standard 62.1-2013 Compliance earlier in this document, or appendix A. The design engineers used UFC-4-510 and ASHRAE 62.1-2007 to calculate the minimum ventilation air requirements. All government buildings are designed to Unified Facilities Criteria standard. The UFC takes from standard building codes, but provides more stringent requirements for some aspects of the design such as the heating and air conditioning. The design engineers on this project compared ventilation requirements between UFC-4-510 and ASHRAE 62.1-2007 to obtain the conservative minimum outdoor airflow. The airflow necessary to meet the cooling load was computed and the maximum between the two was chosen in order to meet the cooling load and the minimum ventilation requirements.

The DOAS units meet the spaces latent cooling load, so the ventilation air is only required for each space. Each individual HVAC space unit meets the space sensible load by conditioning the room air. The new sizes of the air handlers are located below in Table 20. The DOAS unit selected is a Johnson Controls dedicated outdoor air system unit. Since the HVAC terminal units, VRF or WSHP units, meet the sensible cooling load, the ventilation air is only required for each space. The new air handlers are listed in Table 20 DOAS Units. Since the DOAS units provide less outdoor cfm, they were reduced in weight. The original air handlers had an operating weight of 23,000 lb, the new DOAS units only have an operating weight of under 5,000 lb. The reduction in weight will be further analyzed in the structural breadth after the depth discussions.

Table 20 DOAS Units

DOAS Unit	Original Design	DOAS Unit	DX Cooling Coil	Natural Gas Coil
	Supply OA (cfm)	OA Supply (cfm)	Total Capacity (MBH)	Total Capacity (MBH)
L5 AHU	26,090	7,380	360	80
L6 AHU	37,075	10,366	300	60

The new ventilation airflow was calculated using strictly ASHRAE standard 170-2013 and standard 62.1-2013. A slight variation was found between the fifth floor required cfm, but the sixth floor ventilation air varied a significant amount. UFC-4-510 is more stringent than ASHRAE 62.1-2013, and it has specific requirements for each room.

Since the new HVAC systems have been disconnected from the chilled water loop and hot water loop, a DX DOAS air handler was chosen. The refrigerant used is R-410A similar to the VRF system. The condensing unit is a part of the DOAS unit, so there is no need for refrigerant piping. The DX coil is responsible for dehumidifying the outdoor air in the summer. In the Trace 700 model, the dedicated outdoor air system was modeled as dehumidification being the priority or it is in heating/cooling mode. By providing cold air to the spaces, part of the sensible load of the room is handled by the dehumidification. A dedicated outdoor air system can either provide neutral or cold air to the space. If neutral air is provided then the HVAC unit at the space reheats the air to meet the space conditions, however, this wastes sensible cooling gained from dehumidifying the air. DOAS units can either provide the conditioned outdoor air upstream of the space HVAC unit or directly to the space as shown in Figure 19 Common DOAS Configurations.

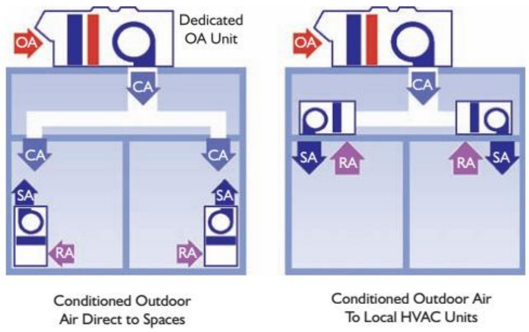

Figure 19 Common DOAS Configurations

By providing air directly to the space, excessive cooling does not occur. This also lessens the load on the individual unit in the space. As discussed later, VRF cassettes were chosen to condition the room air in the patient rooms. The LG cassettes are non-ducted VRF units, so air is supplied directly to the space in the design. For the water source heat pump design, the conditioned outdoor air is provided upstream of the water source heat pump.

Fan Energy

Lastly, since the DOAS units provide significantly less air, the fan energy has decreased. The fan energy for most buildings usually dominate the equipment energy consumption as observed previously in the Annual Energy Consumption section. Figure 20 displays the fan energy consumption for each design which includes the energy for the fan in the HVAC unit.

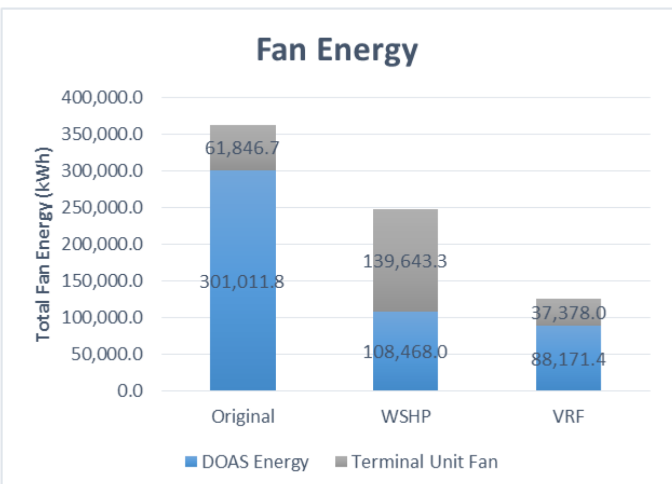

Figure 20 Fan Energy Consumption

The graph shows the drastic energy savings between the DOAS units designed for a total of 78,163 cfm and the new DOAS units designed for 17,746 cfm. The total fan consumption for the terminal units are included as well. The terminal units handle the majority of the air supplied to the space. The original DOAS unit provided the constant air volume units with more ventilation air than was required. Since the DOAS unit received an abundance of air for CAVs, it did not have the setting to turn down when spaces were unoccupied. For the new design, by giving the controls to the terminal units, terminal units can turn down in order to conserve energy instead of wasting fan energy on unoccupied rooms. The savings between the VRF system and WSHP system is small because ideally fan energy should not be different because both systems have the same design ventilation air requirements. However, the terminal units vary in fan energy because the VRF system terminal fan recirculates air in the room, and the WSHP terminal units supply both the ventilation air and the room air back to the room.

The WSHP system reduced the fan energy by over 32%, and the VRF system reduced the energy by over 65%. The VRF system was able to reduce the energy by more because the terminal units only handle the room air and not the room air plus the ventilation air. The decrease in the ventilation air requirements affected the reduction in the dedicated outdoor air system fan energy as well.

Analysis 1: Variable Refrigerant Flow System

Overview

A variable refrigerant flow (VRF) system uses refrigerant to transport heat between spaces. A VRF system can either operate as a heat pump or a heat recovery system. If the VRF system is a heat pump system, than the system has two pipes, a hot and cold refrigerant line, and it operates in either cooling or heating mode. The schematic in Figure 21, is a heat recovery VRF system which was chosen as the first alternative. A heat recovery VRF system has three pipes: a high pressure, low pressure, and a vapor suction line. In the schematic below, the red line is the high pressure vapor line, the blue line is the low pressure line and the green line is the liquid suction line. The major benefit of this system is the water loop can provide simultaneous heating and cooling. If an indoor unit is in cooling mode, then the low pressure line provides cold refrigerant and the suction line brings the refrigerant back to the outdoor condensing unit thus turning the indoor unit into an evaporator. If an indoor unit is in heating mode, then the high pressure line provides hot refrigerant and the low pressure line brings the chilled refrigerant back to the loop and provides cold refrigerant to any spaces in cooling mode.

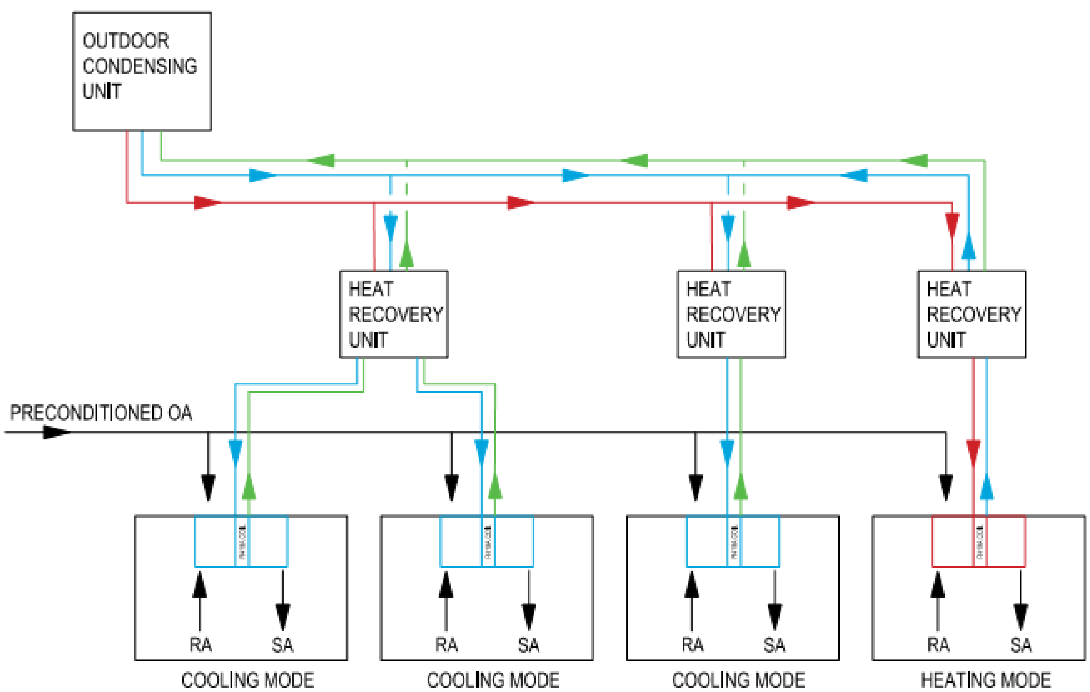

Figure 21 Variable Refrigerant Flow Schematic

The heat recovery units in the schematic provide simultaneous heating and cooling to the indoor units on the system. The heat recovery units can connect to a maximum of eight VRF room units, it acts as a heat exchanger between the indoor and outdoor units. It controls which indoor unit receives high pressure and which receives low pressure, so it can simultaneously provide heating and cooling. By using refrigerant R410-a to transport heat between spaces, the lower condensing and evaporating temperatures can be used, 115 ˚F and 43˚F.

The main benefit of the variable refrigerant flow system is the ability to save energy by sharing it between zones. This also allows each zone to have its own control of the room conditions. If one zone is unoccupied, then the electronic expansion valve, EEV, in the heat recovery unit will close, and the rest of the rooms will still receive refrigerant as needed.

The VRF indoor units are designed to operate off backup electric resistance for heat in case of a defrost operation. In the event of a defrost operation, the system reverses the refrigerant flow in order to melt any frost on the outdoor unit coils by running the outdoor coil in cooling mode. Although, the design day temperature in Aberdeen, Texas is 23.7˚F, so it is rarely expected to run in defrost operation.

Zoning

The two levels were split up according to orientation of the spaces. Originally, a heat pump type VRF system was chosen for the analysis, so spaces were split into zones according to similar room classification. Figure 22 and Figure 23 show the initial zoning of the floors for a VRF heat pump system. Spaces in the northern exterior zone were grouped together and placed on one outdoor unit. Since they all experience the same northern exposure, and they are mainly patient rooms, they will have internal loads. Their demand cooling loads are similar because they are designed for three people, and they have northern glazing exposure. The patient rooms along the southern exterior zones were also grouped together and placed on one outdoor unit. This zone may be of concern because it has a higher cooling demand than the northern rooms because of the load from the glazing. VRF outdoor condensing units have limits on the number of indoor units it may have on the loop, for some condensing units, the maximum can be 20 to 40 indoor units depending on the size of the outdoor unit. The VRF systems were also grouped according to location. Since the safety of the patients is of the utmost importance, refrigerants must be used with caution, so there should not be long spans of refrigerant piping. Initial zoning of the spaces lead to the decision of a heat recovery type VRF system.

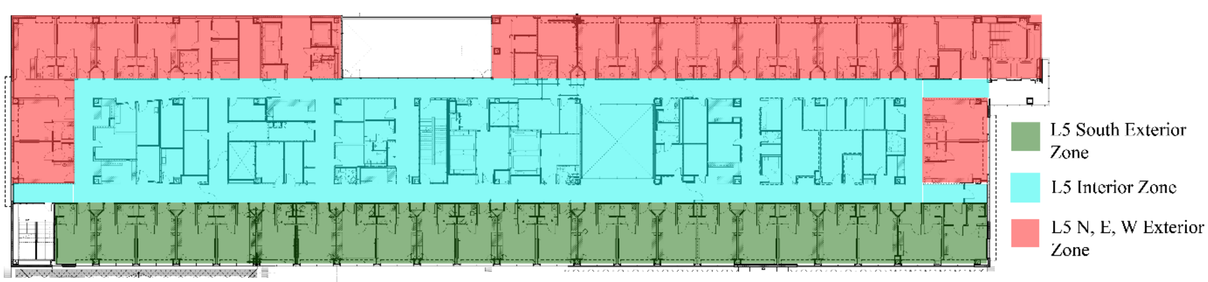

Figure 22 L5 Preliminary Zoning

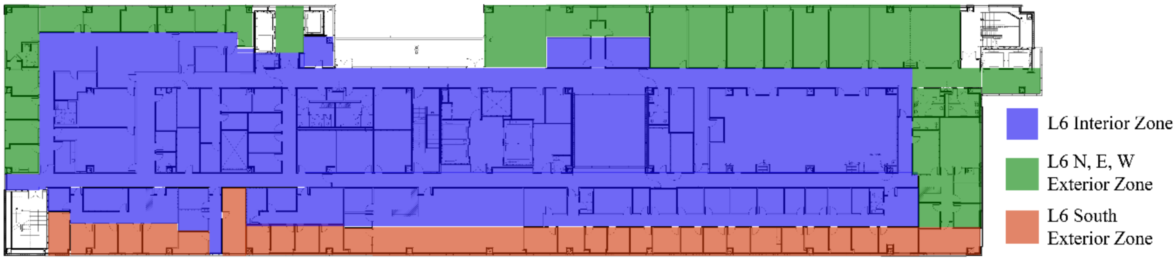

Figure 23 L6 Preliminary Zoning

Levels 4 and 5 were divided into three systems: the interior zone, the southern exterior zone, and the north, east and west exterior zone. The peak cooling room loads for common spaces are listed in Table 21 VRF Cassette Sizing. Level 5 mainly consists of medical / surgery bed rooms, and the core is dedicated to the medical support spaces. As shown in table 19, the patient rooms require a large amount of cooling to offset the large equipment and occupant loads.

Table 21 VRF Cassette Sizing

Room	Room #	Min OA (cfm)	Sensible from AHU (Btu/h)	Total Room Load (Btu/h)	Adjusted Load (Btu/h)	Design Cooling (Btu/h)	Unit Size	Piping (gpm)
Medical / Surgery Bed	5232-04	147	1,109	10,528	9,419	9,600	93	0.25
NOUR Center	5173-11	22	239	15,134	14,895	15,400	153	0.25
Lab/SAT Poct	5174-05	20	115	2,649	2,534	5,500	53	0.25
Personal Property Lockers	5232-02	25	271	1,650	1,379	5,500	53	0.25
Staff Lounge	5232-01	83	893	2,348	1,456	5,500	53	0.25
Conference	6271-06	89	959	7,451	6,492	7,500	73	0.25
Paralegals	6172-04	25	265	5,168	4,903	5,500	53	0.25

As discussed in the previous section: Dedicated Outdoor Air System, the DOAS unit will supply cold air in order to maximize the use of the sensible cooling from dehumidifying the air to 52 ˚F WB. The adjusted load column in the figure above, is the adjusted room load after sensible cooling from the air handler is factored in. The indoor units are sized based on the adjusted loads.

Non-ducted units were chosen to eliminate the wasted energy from reheating the neutral air. The minimum outdoor air is supplied directly to the space, and the cassette cools the room air when it rises above 78˚F for medical support rooms and 75 ˚F for patient rooms. The cassette allows full range of cooling and heating via four ways, and the guide vanes allow the air to be dispersed from 20˚ to 70˚ of a downward angle. The four way cassette can meet a span of 16 feet wide, and they have higher cooling capacities than the two way cassettes. Two way cassettes will be used in the corridors. The throw profile of the four way cassettes are below in Figure 24. The multiple orientation angles allow the cassettes to maximize their throw across the larger patient rooms. The cassettes can also be oriented to blanket the patient's bed with airflow for surgical rooms or isolation rooms, however, the 70˚ will most likely not be necessary for the medical patient rooms.

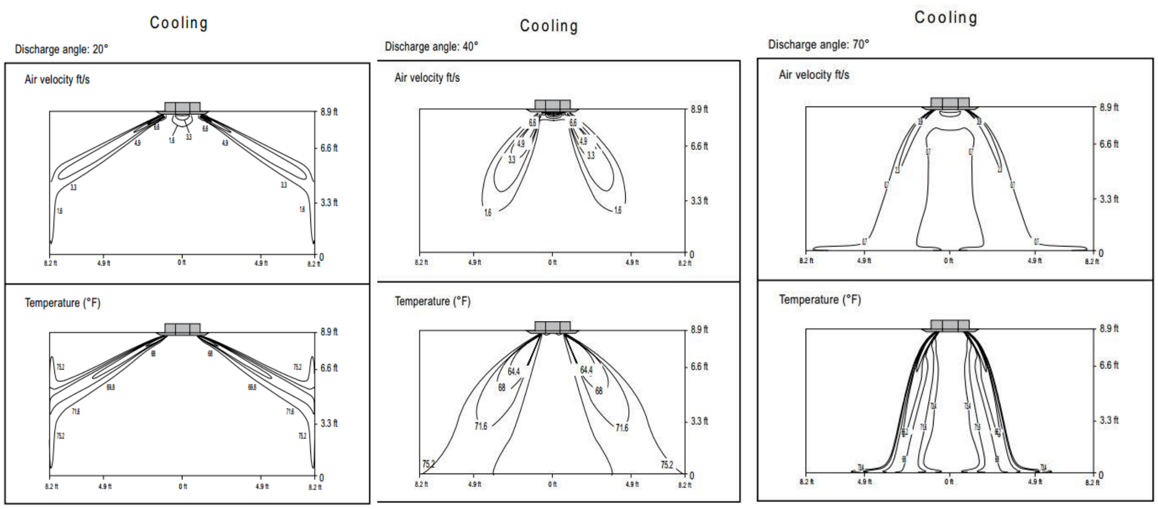

Figure 24 Throw Profiles for 20˚, 40˚, 70˚ Orientation

The total cooling and heating loads for the rooms on each zone are listed in Table 22 Critical Loads. The critical loads for each zone are identified as well. When choosing outdoor units, they should be designed to meet the critical load, and be sufficient to meet the smaller load as well. According to these designed zones, the lowest number of rooms assigned to one outdoor unit is 23, and the highest is 92. ASHRAE Heating, Ventilating, and Air-Conditioning Systems Handbook states the maximum number of indoor units an outdoor unit can handle is roughly 40, however it depends on the manufacturer's specifications.

Table 22 Critical Loads

Zone	Cooling		Heating	Critical Load		Number
	MBH	Tons	MBH		MBH	of Rooms
L5 Interior Zone	182,262	15.2	54,410	Cooling	182,262	60
L5 S Exterior Zone	261,968	21.8	213,737	Cooling	261,968	24
L5 N,E,W Exterior Zone	178,066	14.8	195,688	Heating	195,688	23
L6 Interior Zone	212,468	17.7	218,357	Heating	218,357	92
L6 S Exterior Zone	191,411	16.0	72,507	Cooling	191,411	29
L6 Exterior Zone (N,E,W)	164,248	13.7	185,828	Heating	185,828	28

ASHRAE Standard 15 Compliance

The occupant's safety is of the utmost importance throughout the process of redesigning the building. Since the variable refrigerant flow system has potentially dangerous fluids to the environment and people, certain precautions must be taken. Throughout the design of the VRF system, ASHRAE standard 15-2013 was paid close attention to in order to provide safe practice of the refrigerant in the system.

First of all, the practice of handling refrigerant in this system depends on the type of occupancy in the building. Since the building is meant for occupants whom are disabled, confined or cannot move without the assistance of a nurse, the medical center meets the institutional occupancy as defined in section 4.1.1. Thus during a malfunction of the VRF system, the design must factor in the occupants disability to leave the building easily. The VRF system in this design is classified as an indirect closed system. The VRF system has one main refrigerant loop which the indoor units reject and collect heat from, but each indoor unit also has its own refrigerant loop. The two loops transport heat to and from each other by means of the heat exchanger in the indoor unit which then cools or heats the room air with the refrigerant coil.

According to figure 6.1.4 in ASHRAE standard 34-2013, R410A is considered to have no flame propagation and a very low toxicity. Since the safety group is A1, it is considered one of the safer refrigerants. In case of a complete discharge of refrigerant in a circuit, the concentration of refrigerant may not exceed 50% of the amount listed in table 4-1 of ASHRAE standard 34-2013, as required for an institutional occupancy. The R-410A refrigerant charge limit from table 4-1 of ASHRAE standard 34-2013 is listed in Table 23 below. Note the refrigerant charge limit for an institutional occupancy is half of the 26 lb/mcf listed, so it is 13 lb/mcf.

Table 23 R-410A Refrigerant Charge Limit

	OEL (ppm/v/v)	Safety Group	RCL			Highly Toxic or Toxic Under Code Classification
			ppm v/v	lb/Mcf	g/m^3	
R-410A	1,000	A1	140,000	26	420	Neither

The original zoning was used during the analysis of the refrigerant charge limit in order to determine the compliance. The refrigerant charge calculations were conducted using the Multi-V Refrigerant Charge Calculator provided by LG using their specifications on refrigerant piping sizing. The RCL calculations for zone L5 South West Exterior can be found in appendix C. The typical refrigerant layout for zone South West Exterior Zone can be found in the Construction Breadth section for approximate sizing. Table 24 Refrigerant Charge for L5 Exterior Zones, shows the compliance of each zone with ASHRAE 15-2013. The first refrigerant charge calculation of the south exterior zone of level 5 had over 25 indoor units on one outdoor unit which is more than the condensing unit could withstand. The refrigerant charge calculation determined the indoor units and outdoor unit added more refrigerant to the system than the volume of the patient room could contain. The south exterior zone was split into two zones, and the zone with 11 indoor limits met the limit, however, the 12 indoor unit zone did not. The south

Table 24 Refrigerant Charge for L5 Exterior Zones

	Zone	Outdoor Unit		Capacity (tons)	# Indoor Units	RCL (lb/Mcf)	Comply with ASHRAE 15?
		Cooling	Heating				
Zoning 1	L5 South Exterior	264,000	297,000	22	23	22.1436	NO
Zoning 2	L5 South East Ext	144,000	162,000	12	12	19.4969	NO
	L5 South West Ext	120,000	135,000	10	11	19.7589	NO
Zoning 3	L5 South West Ext	96,000	108,000	8	11	12.171	YES
	L5 S Exterior Zone	96,000	108,000	8	10	12.1502	YES
	L5 SE Exterior Zone	96,000	108,000	8	10	11.8223	YES
	L5 SE Corner Zone	96,000	108,000	8	10	11.6762	YES

facing exterior rooms were finally split into four zones with roughly 10 indoor cassettes and in-duct units assigned to each outdoor condensing unit. In order to meet the refrigerant charge limit requirement, multiple rooms have to be served by an in-duct unit because the volume of the rooms were too small. By giving these rooms an in-duct unit, in case of a malfunction, the refrigerant would leak into the duct system which is a bigger volume for the refrigerant to disperse to, thus lowering the concentration.

Rezoning

As concluded from the ASHRAE standard 15-2013 analysis, the zones had to reduce in size and contain less indoor units. By reducing in size, the refrigerant piping would cover a smaller area, thus decreasing the refrigerant charge of each system. The new zoning layout for levels 5 and 6 are shown in Figure 25 and Figure 26; the rooms on level 5 are broken into 7 zones with 7 outdoor condensing units. Each zone is a combination of interior and exterior rooms. By combining rooms, heat produced in the exterior rooms during the mild months can be redistributed to the insulated interior rooms. By having zones with a mixture of interior and exterior spaces, the VRF heat recovery process will be maximized by rejecting less heat to the environment and reusing the energy for the spaces requiring heat.

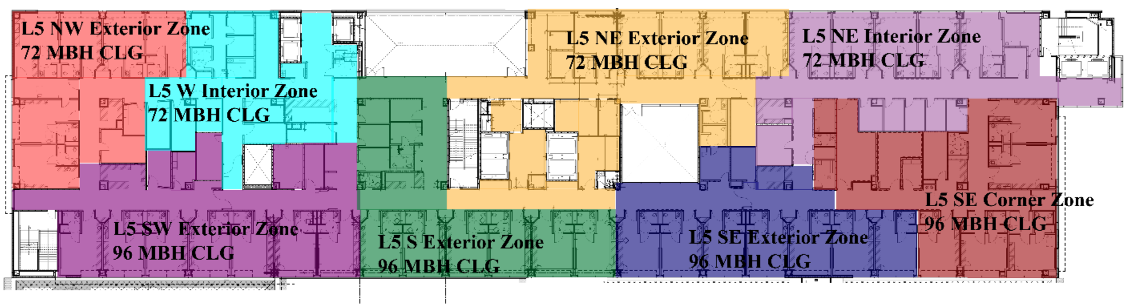

Figure 25 Level 5 New Zoning

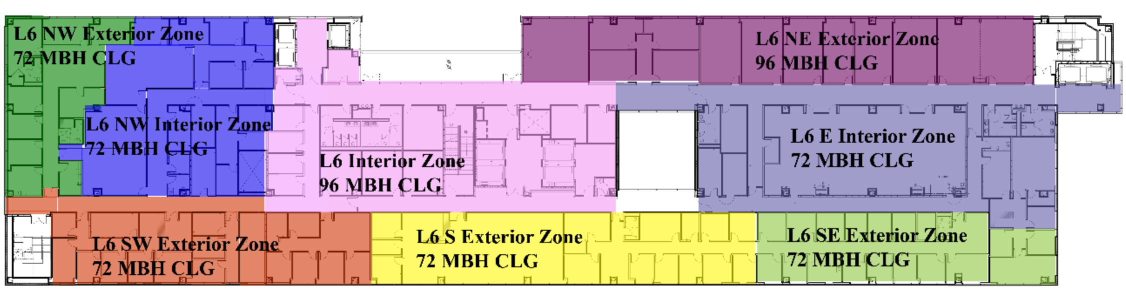

Figure 26 Level 6 New Zoning

Sizing

The new zoning determined in the past section was used to size the outdoor condensing units. The rooms were paired and assigned to indoor units in order to ensure the outdoor condensing unit could handle the indoor units. In order to size the outdoor condensing units, they should be able to handle the range of 50% to 130% of the peak indoor loads. The combination ratio is the sum of the indoor unit capacities to the outdoor unit capacity. This ratio determines the temperature of the saturated suction temperature. Examining L5 SW Zone, the combination ratio is 111% which is in the range of 50% to 130%, however, the heat transfer capability of the indoor units are higher than that of the outdoor unit. If the combination ratio rises above 130% than the VRF system could malfunction, on the other hand if it fell below 50% than the temperature may drop, and also result in a malfunction.

The zones were adjusted until the each condensing unit could handle the number of indoor units on the system. Table 25 below lists each zone and the cooling and heating capacities for each. The rows highlighted are the zones analyzed in the ASHRAE 15 Compliance Section.

Table 25 Outdoor Condensing Unit Sizing

Zone	Cooling		Heating	Critical Load		Outdoor Unit		Number of	Max	Comply?
	MBH	Tons	MBH	Load	MBH	Cooling	Heating	Units	Number	
L5 NW Exterior Zone	66,238	5.5	57,052	Cooling	66,238	72,000	81,000	11	13	YES
L5 W Interior Zone	55,708	4.6	47,146	Cooling	55,708	72,000	81,000	13	13	YES
L5 SW Exterior Zone	76,585	6.4	50,949	Cooling	76,585	96,000	108,000	10	16	YES
L5 S Exterior Zone	78,562	6.5	53,958	Cooling	78,562	96,000	108,000	13	16	YES
L5 SE Corner Zone	87,183	7.3	51,082	Cooling	87,183	96,000	108,000	13	13	YES
L5 SE Exterior Zone	77,507	6.5	56,239	Cooling	77,507	96,000	108,000	10	16	YES
L5 NE Exterior Zone	51,079	4.3	29,271	Cooling	51,079	72,000	81,000	13	13	YES
L5 NE Interior Zone	35,727	3.0	37,148	Heating	37,148	72,000	81,000	16	16	YES
L6 NW Interior Zone	51,814	4.3	48,651	Cooling	51,814	72,000	81,000	13	13	YES
L6 Interior Zone	52,251	4.4	48,248	Cooling	52,251	72,000	81,000	12	13	YES
L6 E Interior Zone	68,708	5.7	67,874	Cooling	68,708	72,000	81,000	12	13	YES
L6 SW Exterior Zone	68,374	5.7	12,423	Cooling	68,374	72,000	81,000	13	13	YES
L6 S Exterior Zone	45,069	3.8	38,126	Cooling	45,069	72,000	81,000	13	13	YES
L6 SE Exterior Zone	55,377	4.6	44,841	Cooling	55,377	72,000	81,000	13	13	YES
L6 NE Exterior Zone	82,378	6.9	68,567	Cooling	82,378	96,000	108,000	14	16	YES
L6 NW Exterior Zone	59,672	5.0	5,872	Cooling	59,672	72,000	81,000	9	13	YES

The outdoor condensing units must be sized for the maximum peak heating or cooling load whichever is larger. The effect of local ambient conditions on the system performance must be considered, especially in Texas. The cooling output deration factor is 0.99 for an outdoor dry bulb temperature of 98˚F which is the design ambient temperature. The heating output derating factor must be also be considered in order to ensure the chosen unit will provide enough heating. For a design temperature of 25˚F during the winter, the air-cooled outdoor unit's heating output is derated by a factor of 0.85. The derating factors can be found in chapter 18 of the 2012 ASHRAE Handbook Heating, Ventilating and Air-Conditioning Systems and Equipment. Table 26 below lists the factored heating and cooling capacities for each condensing unit.

Table 26 Derated Cooling & Heating Loads

Zone	Cooling	Heating	Outdoor Unit			
	MBH	MBH	Cooling	Derated Cooling	Heating	Derated Heating
L5 NW Exterior Zone	23,279	3,362	72,000	71,280	81,000	68,850
L5 W Interior Zone	55,708	47,146	72,000	71,280	81,000	68,850
L5 SW Exterior Zone	76,585	50,949	96,000	95,040	108,000	91,800
L5 S Exterior Zone	78,562	53,958	96,000	95,040	108,000	91,800
L5 SE Corner Zone	79,286	16,221	96,000	95,040	108,000	91,800
L5 SE Exterior Zone	52,481	42,629	96,000	95,040	108,000	91,800
L5 NE Exterior Zone	32,939	21,248	72,000	71,280	81,000	68,850
L5 NE Interior Zone	81,187	40,699	72,000	71,280	81,000	68,850
L6 NW Interior Zone	51,814	48,651	72,000	71,280	81,000	68,850
L6 Interior Zone	52,251	48,248	72,000	71,280	81,000	68,850
L6 E Interior Zone	0	67,874	72,000	71,280	81,000	68,850
L6 SW Exterior Zone	48,608	18,413	72,000	71,280	81,000	68,850
L6 S Exterior Zone	45,069	38,126	72,000	71,280	81,000	68,850
L6 SE Exterior Zone	85,880	32,628	72,000	71,280	81,000	68,850
L6 NE Exterior Zone	65,207	29,670	96,000	95,040	108,000	91,800
L6 NW Exterior Zone	31,391	7,019	72,000	71,280	81,000	68,850

Energy Consumption

The variable refrigerant flow depends heavily on electrical energy to deliver heat to and from the spaces. Figure 27, breaks down the electrical energy consumption by equipment for each month. The cooling equipment is broken down to the energy consumption of the VRF indoor units in cooling mode and the DX coil in the dedicated outdoor air system. The heat rejection represents the operation of the outdoor unit. The monthly energy consumption for the VRF system varies from the original design consumption because it does not have a chiller or pumps in the design. The peaks in energy consumed occurs during the summer months of July and August. The consumption varies most by the cooling energy from month to month. The original design energy distribution graph can be found in appendix C.

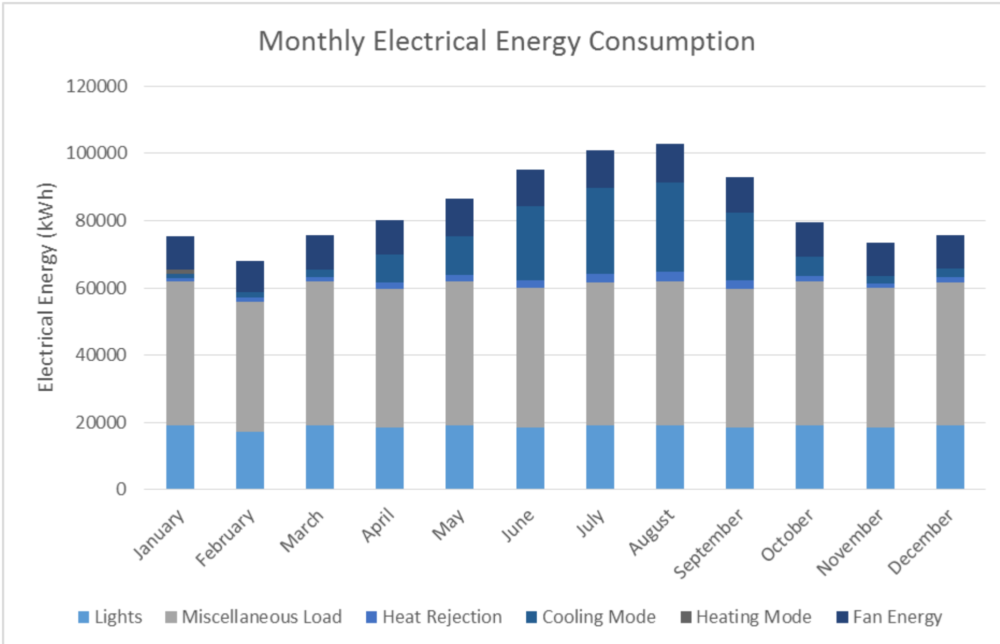

Figure 27 VRF Monthly Electrical Energy Consumption

The receptacle load dominates the energy distribution between the types of building equipment for both the original design and the VRF alternative. However, after the reduction in fan energy, the receptacle load accounts for a little under a half of the total energy consumed. The heat rejection also decreases by a significant amount because the cooling tower only rejects the heat from the room load. Figure 28 and Figure 29 breakdown the energy between the equipment and room loads.

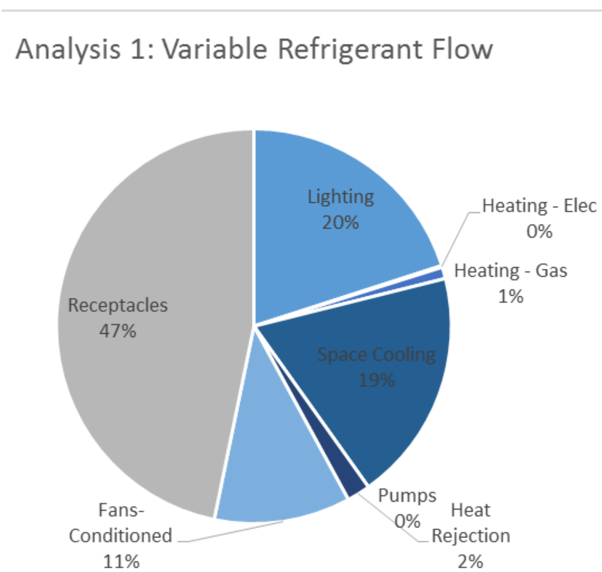

Figure 28 VRF Energy Breakdown

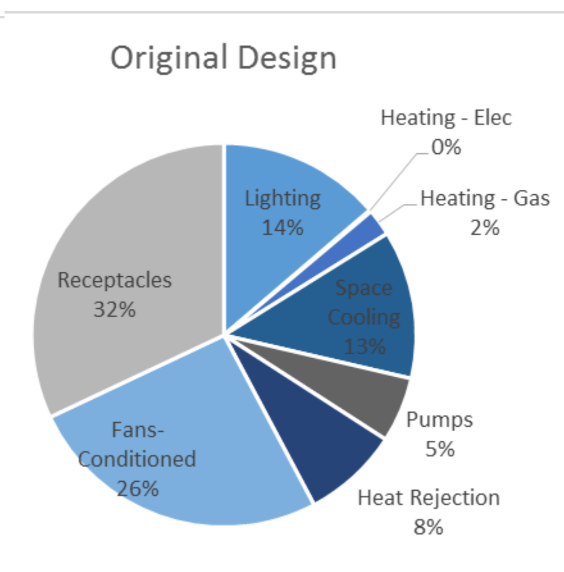

Figure 29 Original Design Energy Breakdown

Analysis 2: Water Source Heat Pump System

Overview

A water source heat pump system uses a water loop to move the heat from and to the spaces. Each space has a WSHP which allows for different operating systems. The two pipe system allows the movement of hot water and cold water to the fan coils. The water loop operates most efficiently at a temperature range of 60°F and 90°F. Figure 30, the WSHP schematic diagram, shows the configuration of a typical water source heat pump loop. If the temperature of the water loops drop below 60°F than the gas fired hot water boiler will turn on to meet the temperature in order to supply heat to the fan coils. If the temperature rises above 90°F than the cooling tower will turn on to reject heat. During strictly cooling seasons, the loop remains at in the upper range, and rejects heat through the cooling tower to the atmosphere.

During mild seasons, the interior zone will require cooling due to the large equipment loads. The heat from the exterior zones can be used to condition the interior spaces and avoid turning on the cooling tower and boiler. Since level 6 comprises of offices, during weekends, most offices will be unoccupied, so Monday morning, the boiler will be used in order to meet the occupied spaces loads. Although the boiler and cooling tower are sized to handle the peak heating and cooling loads, they do not operate as often as required in the original chilled water system.

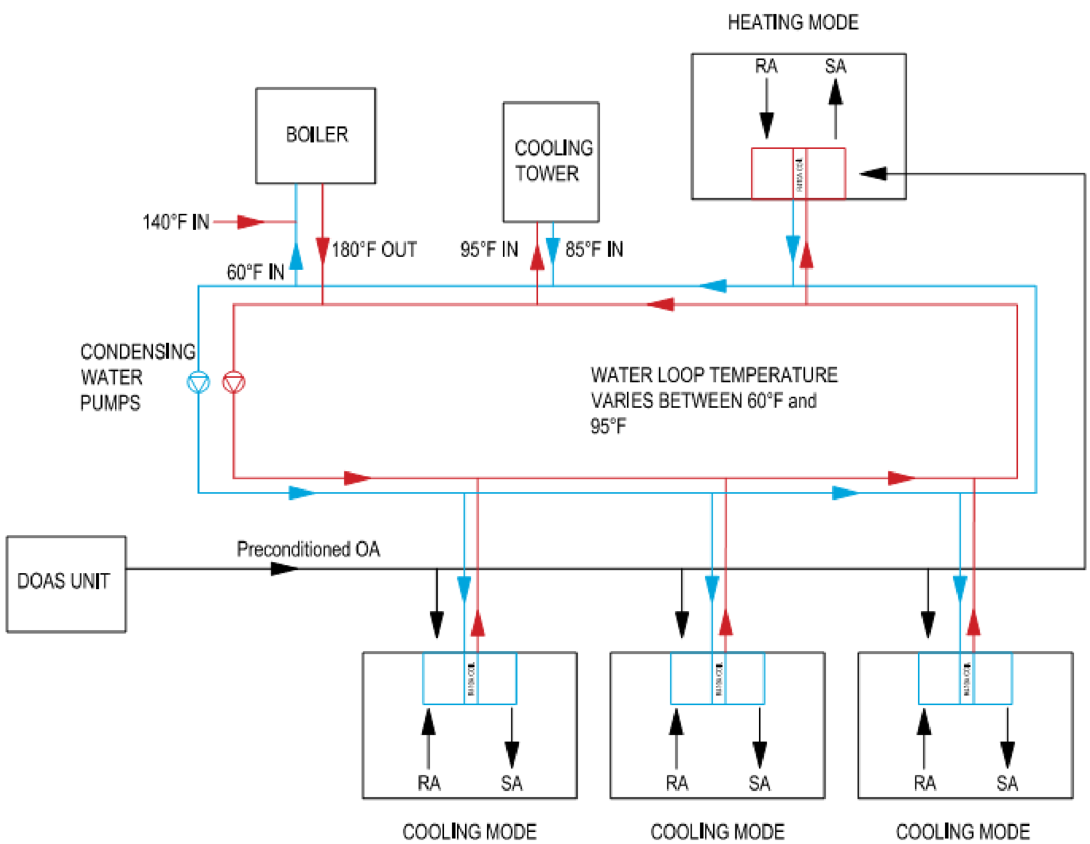

Figure 30 Water Source Heat Pump Schematic

A water source heat pump system was chosen instead of a ground source heat pump because the average ground temperature in Texas is over 70°F, so the heat rejected through the ground bores may raise the ground temperature significantly. If the ground temperature was closer to a normal 55°F, the ground may have been used as a heat source and heat sink.

Sizing

The water source heat pumps have the benefit of using rejected heat from other units to heat the space. Since all of the water source heat pump units can connect to one common loop, then the units can maximize the use of the rejected heat. For instance, an interior office on level 6, containing little to no equipment loads, can be used as a heat sink for an exterior patient room with three occupants on level 5.

The water source heat pump horizontal units were sized based off of the Trace 700 results used previously for sizing the VRF indoor units. A few typical rooms are listed below in Table 27, complete with cooling capacity and water flow rate to each WSHP unit.

Table 27 WSHP Unit Sizing

Room	Room #	Min OA (cfm)	Sensible from AHU (Btu/h)	Total Room Load (Btu/h)	Adjusted Load (Btu/h)	Design Cooling (Btu/h)	Unit Size	Piping (gpm)
Medical / Surgery Bed	5232-04	147	1,109	10,528	9,419	9,700	9	2
NOUR Center	5173-11	22	239	15,134	14,895	15,300	15	3.8
Lab/SAT Poct	5174-05	0	2,649	2,649	2,649	8,000	7	2.2
Personal Property Lockers	5232-02	25	271	1,650	1,379	8,000	7	2
Staff Lounge	5232-01	83	893	2,348	1,456	8,000	7	2
Conference	6271-06	89	959	7,451	6,492	8,000	7	2
Paralegals	6172-04	25	265	5,168	4,903	8,000	7	2

Since the office spaces had smaller cooling loads, two offices were placed to a water source heat pump indoor unit. Although the two offices will now have to use the same thermostat, the smaller indoor unit does not have to run at a low part load efficiency during off peak hours.

During the highest peak cooling load which occurs in the month of August. Most of the indoor units will be operating in cooling mode, therefore, all room load heat will be rejected to the water loop. A cooling tower must be sized to reject the heat gained from all of the water source heat pump units, so it must have a flow rate of all of the WSHPs combined. The design flow rate of the whole system is 621 gpm, so the cooling tower must be designed for this flow rate.

The higher end of the range of the water loop is 85°F, so the water source heat pumps are designed to operate in a range from 55F to 85F. Since the water loop is constantly changing because heat is added and removed, the water source heat pumps are designed to operate in a large range of entering temperatures. Since the highest temperature the WSHP can operate at is 85F, the leaving cooling tower water temperature is 85F.

Using Marley Equipment Selection Program, a cooling tower was selected based on the design entering and leaving water temperatures, and the water flow downstream of the water source heat pumps. The cooling tower must be sized for the entire peak load during the summer because there is no secondary source of chilled water besides the cooling tower. The design information for the cooling tower is located in Table 28. The induced draft cooling towers were designed based on a design ambient wet bulb temperature of 78°F, and a circulated 3 gpm of water per cooling capacity ton. The cut sheet for the Marley cooling tower is located in appendix C. The cooling tower will only operate when the condensate water loop is 85°F or above. The cooling design day for Aberdeen, Texas, is an ambient wet bulb temperature of 73.4°F, so the cooling tower will design properly in this climate. This additional cooling tower will be located along with the other cooling towers in the central utility plant, so it will not be added to the roof.

Table 28 Cooling Tower Characteristics

Equipment Tag	Design Nominal Tonnage	Motor Hp	Fluid Flow (gpm)	Design Ambient WB (°F)	Design EWT (°F)	Design LWT (°F)
Cooling Tower - 01	228.0	7.5	636	78	95	85

Although Texas does not have as harsh winters as the northern states, a boiler was chosen for the water loop system. During the mild seasons, the water source heat pump indoor units can recover heat from the loop from exterior zones. However, during colder months, if the loop drops below 60°F, then the boiler will turn on. The boiler is designed for an entering temperature of 140°F and has a leaving temperature of 180°F. In order to meet the 140°F entering water temperature, the condensing water will have to mix with a hot water source to meet the 140°F. This may be done by combining the water source heat pump loop with the existing hot water loop serving the remaining building.

Table 29: Gas Fired Boiler Characteristics

Equipment Tag	Type	Capacity (Btu/h)	Boiler Horse Power (BHP)	Fluid Flow (gpm)	Primary Fuel	NOX Emissions (ppm)
Boiler - 01	Gas Fired	511,011	20.0	621.0	Natural Gas	40

Since they are all on the same loop, the two levels can share heat between one another. Therefore, during the weekend when the majority of the offices on the 6th floor are empty, heat can be distributed from the occupied rooms to the unoccupied rooms, however, once the rooms become occupied, the boiler may be turned on to warm up the loop.

Energy Consumption

The energy breakdown for the original design and the water source heat pump are shown in Figure 23 and Figure 24. As shown, the receptacle and lighting energy consumption remain the same in value, however, the receptacle energy consumption dominates the energy in the water source heat pump system. In the water source heat pump system, the cooling plant uses the most energy because the WSHP units provide cooling through electrical energy. The heat rejection in the original constant air volume system is used to reject the heat from conditioning the outdoor air and conditioning the return air, so the heat rejection consumes more energy than the WSHP. The WSHP cooling tower is only used when the loop temperature rises too high. The

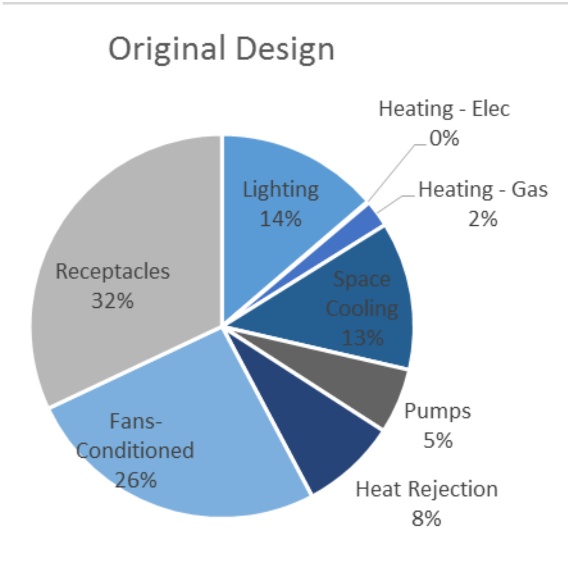

Figure 31 Original Design Energy Breakdown

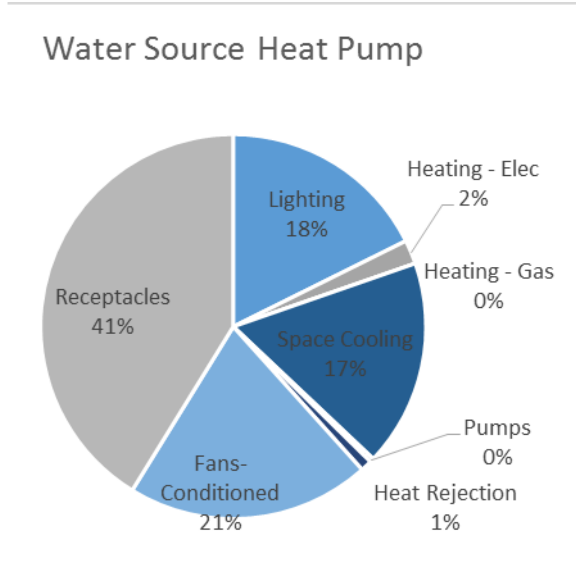

Figure 24 Water Source Heat Pump Energy Breakdown

WSHP system uses both a boiler and a gas fired heat exchanger to heat the outdoor air, but the boiler is only used when the loop cannot provide enough heat, so the WSHP does not consume enough natural gas to dominate the energy consumption. As discussed in the dedicated outdoor air system section, the fan energy decreases by a lot because of the lower amount of ventilation air that is provided to the spaces.

The electrical energy only varies within the cooling plant equipment. The fan energy remains constant through the months, and the heat rejection varies per month, but it consumes minimal energy compared to the cooling plant. The cooling plant consists of the water source heat pump which uses electrical energy to move the heat to and from the water loop. Figure 32 below shows the monthly energy distribution. As noted the pump energy is shown below, however, the pump energy is minimal in comparison to the other equipment.

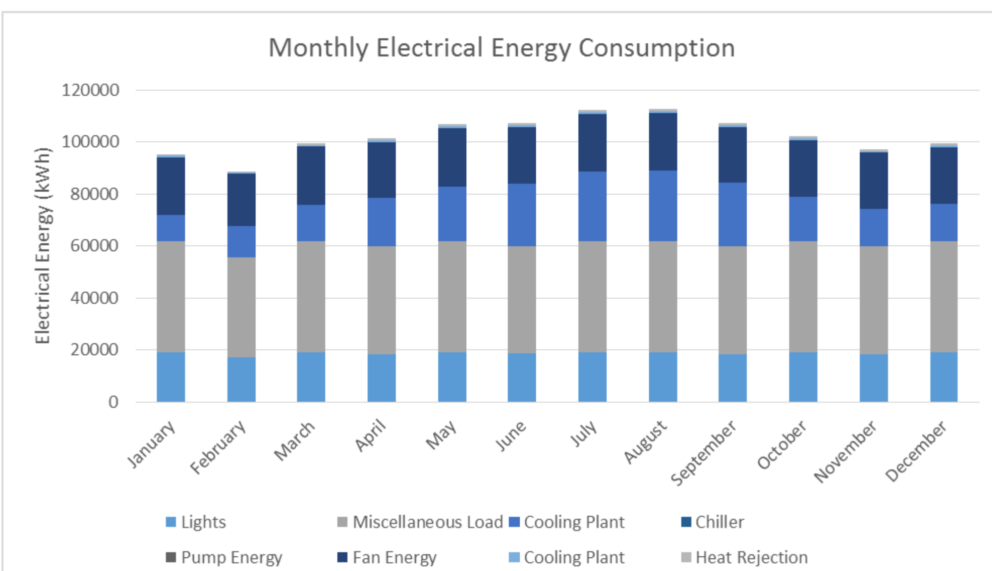

Figure 32 Monthly Electrical Energy Consumption

Emissions

The original design had a gas fired boiler, and a centrifugal chiller producing the hot water and the chilled water loop respectively. By switching to a water source heat pump, a gas fired hot water boiler is required, however, it does not run as much as the boiler in the original design is required to run. Since the WSHP gas fired hot water boiler only operates to maintain the water loop temperature for the WSHPs to condition the room air, the boilers do not require a large quantity of natural gas thus, they do not emit as large of CO2 and NOx. During mild months, the water source heat pumps can exchange heat between exterior and interior zones, this eliminates the need for the boiler besides warm up in the morning. The VRF system only has the gas fired heat exchanger in the DOAS unit to provide heat, so this equipment produces a majority of the CO2 and NOx. Figure 33 Emissions for the Alternatives is shown below, the original design produces under 50% more CO2 than the next highest alternative, WSHP.

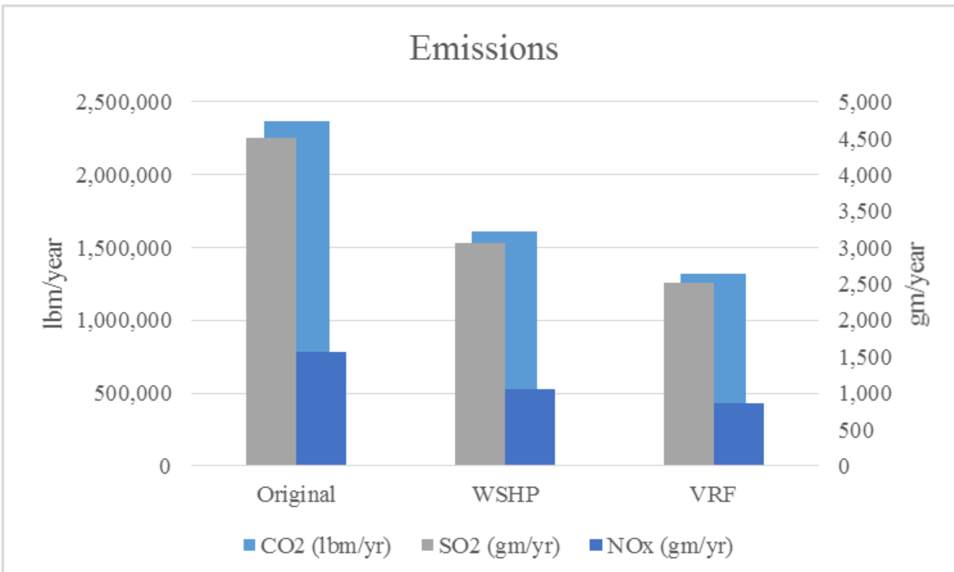

Figure 33 Emissions for the Alternatives

Cost Analysis

The utility costs for each system were compared in order to evaluate the costs of operating the systems. The utility rates assumed are the utility rates first presented in section Annual Operating Cost. The main energy consumption topics were analyzed in order to identify the differences in cost, Table 30 lists the energy differences. The largest differences in cost were seen in the heat rejection energy, fan distribution energy and the chiller energy. The heat rejection energy costs more for the variable refrigerant flow system and the water source heat pump system than the original design. The two proposed designs rely heavily on heat rejection in order to cool the spaces. By removing the systems from the chilled water loop, the chiller was completely eliminated from the sequence, however, cooling is achieved via the heat rejection devices. The cost between the heat rejection energy and savings on removing the chiller balance each other out for the water source heat pump system. By removing the chiller and gaining a cooling tower, $15,344 is saved between the changes.

Table 30 Annual Energy Cost Comparison

Equipment	Original Design	VRF	Difference	WSHP	Difference
Distribution Fan Energy	$42,672.16	$14,764.54	$27,907.62	$30,672.38	$11,999.77
Pump Energy	$10,622.66	$0.00	$10,622.66	$507.49	$10,115.16
Heat Rejection Energy	$15,659.85	$17,548.86	-$1,889.01	$27,492.29	-$11,832.44
Chiller Energy	$23,009.02	$0.00	$23,009.02	$0.00	$23,009.02
Receptacles	$59,164.41	$59,164.41	$0.00	$59,164.41	$0.00
Lights	$26,486.93	$26,486.93	$0.00	$26,486.93	$0.00
Natural Gas (therms)	$12,626.99	$3,572.81	$9,054.17	$8,729.46	$3,897.53
Water (kgal)	$3,146.73	$0.00	$3,146.73	$2,214.79	$931.93
TOTAL	$193,388.73	$121,537.55	$71,851.18	$155,267.76	$38,120.97

The largest savings seen is in the fan energy because of the downsizing in the ventilation fan. By reducing the ventilation fan from supplying 40,000 cfm to roughly 10,000 cfm, the systems saved roughly 60% of the distribution fan energy. The receptacle and lighting energy did not change, so no savings or losses were seen between the three systems.

Energy Comparison

Although the design ventilation changed for the medical center based on ASHRAE 170, the equipment and lighting loads remained the same. The electrical energy consumed annual is higher for the original design than it is for the proposed designs. As shown below in Figure 34 Monthly Electrical Energy Consumption, the decrease in electrical energy is over 40% from the original design to the proposed design. The reduction in energy is mainly due to the removal of a chiller and the decrease in fan energy. The month with the highest amount of electrical energy consumption is during the summer months which are June, July, August and September. During these months, the heat rejection equipment and chillers have increased operation times. However, the variable flow refrigerant system consumes roughly the same amount of electrical energy month by month because the outdoor condensing units use the electrical energy for removing heat during heating and cooling modes.

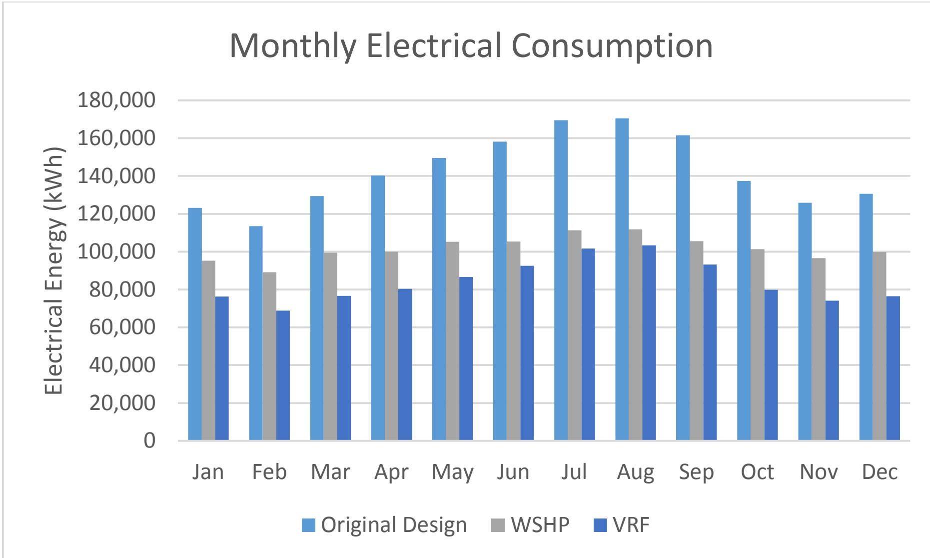

Figure 34 Monthly Electrical Energy Consumption

The natural gas consumption is fairly different for each system. The original design consists of a boiler to meet the heating load for both the DOAS unit and the constant air volume reheat terminal units. The water source heat pump system also uses a boiler, but since the WSHP loop provides heating and cooling, the boiler only turns on during the most harsh winter months during the year. Therefore, the gas fired heat exchanger is the main heating equipment consuming natural gas. For the VRF system, the DOAS unit is the only piece of equipment that consumes natural gas. The condensing units and terminal units strictly used electricity to provide heating and cooling to the spaces. The DOAS unit uses a gas fired heat exchanger to heat the incoming air during the winter months. The natural gas consumption graph, Figure 35 below, shows the lack of natural gas consumption during the summer. During January, the natural gas consumption is the highest during the year.

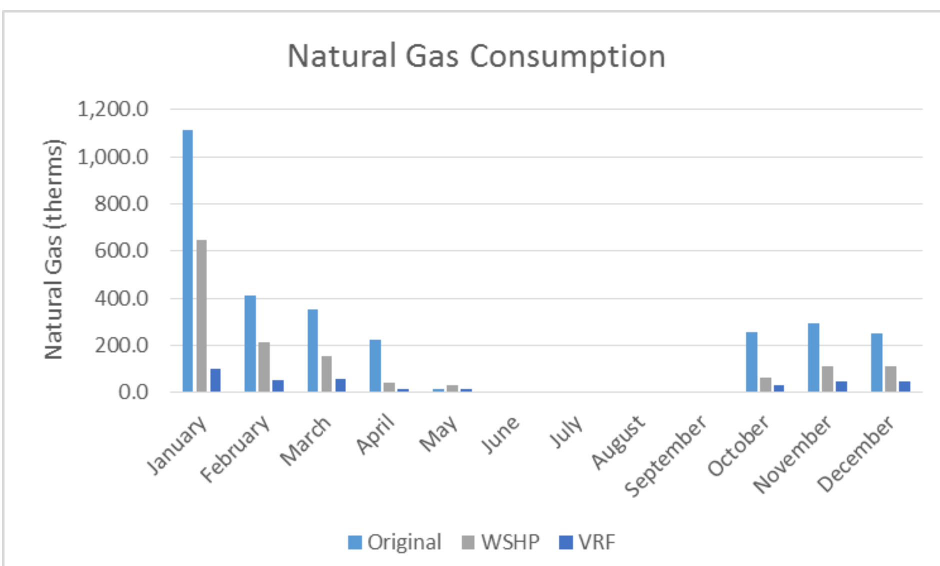

Figure 35 Natural Gas Consumption Comparison

Analysis 3: Indoor Air Quality

In order to ensure the safety of the medical center's patients and staff, the HVAC system must provide the spaces with clean air, and the spaces must be properly ventilated. By using the knowledge gained in AE 552: Indoor Air Quality, a model of three patient rooms was created in CONTAM 3.1 and analyzed to ensure the production of clean air.

In order to correctly obtain concentration levels for one patient room, the adjacent rooms were also modeled in order to have the correct differential pressures across the walls. The rooms were designed with tight exterior walls, and tight interior walls. Although not required, the patient rooms should not have air flow traveling between them. In case someone has a sickness in one room that a patient in the next room could catch extra precautions are taken. The first model created is the original design that supplied 100% outdoor air which exceeded the minimum ventilation air required. The second model is the proposed design that supplies only the minimum ventilation air required. Figure 36 and Figure 37 below display the carbon dioxide concentration in the middle room. As shown, the concentration in the original design is higher than the proposed design.

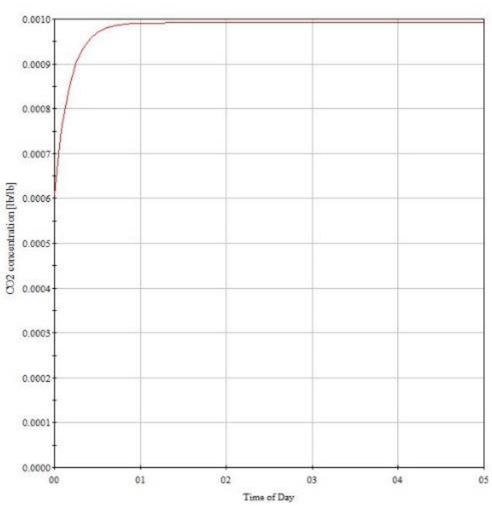

Figure 37 Original CO2 Concentration

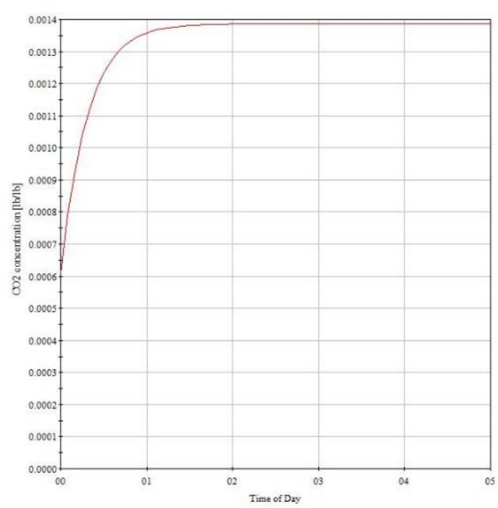

Figure 36 Proposed Design CO2 Concentration

As expected, the CO2 concentration for the original design is lower than the concentration of the proposed design. The concentration after an hour remains at a constant 0.001 ppm for the original design, and the proposed design has a concentration of 0.0014 ppm. Since both designs meet minimum ventilation requirements, the increase in concentration is acceptable because there is enough outdoor air for the occupants.

A simulation was created in order to see the effects of a malfunction in the HVAC system causing a refrigerant leak. The analysis was executed as a contaminant analysis. ASHRAE standard 34-2013 has leak testing in appendix B. The leak test is simulated by assuming a vapor leak at a rate of 2% by mass of the starting charge per hour shall be created. The refrigerant charge is 13 lb as mentioned in the ASHRAE standard 15 analysis above. The occupational exposure limit is 1,000 ppm which means a person can handle up working in an environment

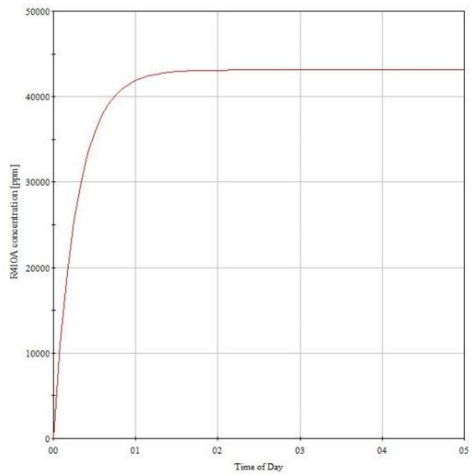

Figure 38 Refrigerant Concentration

with 1,000ppm of R-410a without immediate health issues. Figure 38 plots the R-410a concentration for an hour of refrigerant leaking. The concentration immediately passes the occupational exposure limit, so patients should leave the room immediately and as safely as possible.

Refrigerant detectors should be considered for the design of the patient rooms to ensure their safety. One of the components of the VRF cassette is an electronic expansion valve. If a refrigerant leak is identified quickly with the refrigerant detector, then the facility operator or the building automation system can send a signal to the system to shut down and stop the movement of refrigerant through the system.

Depth Conclusion

The two alternatives prove to consume less energy than the original design. The two alternatives provide individual zone control for each terminal unit. Since most of the rooms are patient rooms with the same dimensions, most operate under the same controls and set points.

Designing to ASHRAE 170-2013 instead of UFC 4-510: The Whole Building Design Guide, the amount of ventilation air decreased by a significant amount, and the operation controls are more lenient than required by Unified Facilities Criteria.

The natural gas consumption decreases signifcantly because the only equipment that requires it is the gas fired heat exchanger for the DOAS units. The emissions are proportional to the natural gas reduction since the boiler in the original design emits a signficant amount of CO_2 and NOx.

Both alternatives save energy, thus saving cost on energy annually. The water source heat pump system saves over 19% in annual energy costs, and the VRF system saves over 37% in annual energy costs. Although the VRF system has higher initial costs due to the VRF outdoor units, refrigerant and the 3 pipe system.

Since both alternatives are designed for minimum ventilation air requirements, the escalated concentration in CO2 is acceptible, however the refrigerant leak scenario in the air quality model raises a few concerns. Although an accurate refrigerant leak is not quite possible to model, the refrigerant leak scenario presented by ASHRAE standard 15 shows dangerous levels of refrigerant if there is a leak in the patient room.

Structural Breadth

The army medical center was designed to withstand certain forces most buildings would not be subjected to. The medical center structure was designed for anti-terrorism force protection as well as progressive collapse resistance. The medical center was designed for the Department of Defense (DoD), thus their standard was used, UFC-4-510: Whole Building Design. The Unified Facilities Criteria is more stringent than standard building codes. The structural design for UFC-4-010: Department of Defense Anti-Terrorism Force Protection, states that construction standoff distances must be achieved in order to minimize the risk of casualties from a terrorist attack.

UFC-4-023-03, the DoD standard for progressive collapse resistance, provides more requirements for a 7-story government building. With the penthouse, the medical center meets the 7 story application for reinforced concrete progressive collapse resistance design. Under these requirements, buildings must be designed for more stringent requirements. The reinforced concrete section replaces many tables of ASCE-41 with tables from UFC 4-023. The new tables provide acceptance criteria for linear models of reinforced concrete beams, including the reinforcement required for concrete slabs. After preliminary research on UFC 4-023-03, it is evident the structural design of the current design is complicated for a structural breadth, however, the reinforcement for the penthouse will be sized down based on the reduction in the DOAS unit's weight. The new equipment is listed in Table 31 below and cut-sheets and calculations for this breadth can be found in appendix D. The outdoor condensing units do not add a significant amount of weight to the existing structure, so DOAS unit's weight reduction was analyzed instead.

Table 31 Equipment Weight

Equipment	Cooling Capacity (Btu/h)	Number	Operating Weight (lb)
Outdoor Condensing Unit	72,000	11	4,972
	96,000	5	2,865
L5 DOAS Unit	360,000	1	4,284
L6 DOAS Unit	300,000	1	4,282

The outdoor condensing units must be close to the spaces it is conditioning to, so they need to be placed on the roof. The cooling tower and boiler can be placed in the central utility plant which is located off site. This central utility plant has enough space for the boiler and cooling tower because it has allotted space for future cooling towers and future boilers. Therefore, the boiler and cooling towers were not included in this structural analysis.

The Structural Concrete Building Code was analyzed in order to verify the two-way reinforced concrete roof meets the minimum slab thickness presented by ACI 318-011. Chapter 13 of ACI 318-011 presents the typical design of a two-way slab.

13.2.4 Monolithic construction, a beam includes the portion of the slab on each side of drop panel that extends a distance equal to the slab thickness.

13.2.5 A drop panel used to reduce the amount of negative moment reinforcement over a column shall project below the slab at least one quarter of the thickness and it must extend each direction from the centerline not less than one-sixth the span length. The drop panel is 6 feet in each direction.

The minimum thickness of the slab without interior beams must meet table 9.5 (c) because there are not interior beams on all sides of the supports. The minimum thickness of the slab must also be greater than 4 inches because it is designed with drop panels. Appendix C displays all structural calculations made through this analysis. Below is the equation taken from 9.5 (c) for the minimum thickness:

$$h > \frac{\boldsymbol{\ell_n}}{\mathbf{36}} = \mathbf{10.67}\ \boldsymbol{in}$$

The penthouse is located on the edge of the building, next to the louvered opening to the 6th floor balcony. The concrete pad for AHU-2 and AHU-3 is located on a bay, so the minimum thickness of the slab is 10.67 inches for the interior panel with drop panels. The current roof is designed with a 12 inch slab for the penthouse, so the slab meets this requirement.

The drop panel must project at least a quarter of the slab thickness below the slab in order to properly reduce the amount of negative moment reinforcement over the columns. The drop panel adds 12 inches to the existing 12” slab. The drop panel also must extend past the center of the support by at least one sixth of the span length measured from center to center of the supports. The drop panel is 12’ wide which is 6 feet off the centerline of the supports. This surpasses the required 5.66 feet needed for the one sixth of the span.

The reinforcement shall provide at least a ratio of reinforcement area to gross concrete area of 0.0018. The reinforcement in the slab shall abide by table 13.3.8 for the minimum extension for the reinforcement in the slab.

The design load information for the current roof two-way slab are listed as the following:

f'_c = 5000 psi

f_k = 60 ksi

Live Load: L = 30 psf (as listed in the structural drawings)

Superimposed Dead Load = Roof = 15 psf

Self Weight = 150 psf

ADDED LOAD: Air Handler (2) Weight = 8.365 psf

Direct Design Method can be used to design two-way concrete slabs based on distributed moments on the slab and beams as long as a few prerequisites are met:

- There are a minimum of three continuous spans in each direction
- Panels must have a ratio of longer to shorter span of supports not greater than 2

- Span lengths in each direction should not differ by more than 1/3 of the long span
- Offset of column by a max of 10% of the span from the centerline is allowed
- The loads due to gravity shall be distributed over the entire panel, and the unfactored live load is less than or equal to twice the dead load

The absolute sum of the positive and average negative factored moments in each direction shall not exceed the equation:

$$M_o = \frac{w_u \boldsymbol{\ell} * \boldsymbol{\ell_n}^2}{8} = 1{,}114\ ft * kips$$

The absolute sum of the positive and average negative factored moments in each direction must not be less than the total factored static moment. The total static moment in an interior span should be distributed as follows:

Negative factored moment = $0.65*M_o$

Positive factored moment = $0.35*M_o$

In section 13.6.4, the factored moments in the column strips are $0.75*M^-$ for the negative moment on the interior support face, and $0.60*M^+$ for the positive moment at the interior panel. Table 32 lists the original rebar sizes to counter act each moment in the column and middle strips of the bay. The new rebar sizes used are smaller because the CRSI design flat slab tables used were for a concrete strength of 4,000psi instead of 5,000 psi which was listed on the structural plans. Even though the DOAS units are smaller, the rebar was resized by a significant amount because anti-force protection and progressive collapse resistance were not taken into account.

Table 32 Design Moments of Proposed Design

Design	Column Strip		Middle Strip	
	Neg. Moment	Pos. Moment	Neg. Moment	Pos. Moment
Original	11 (#11)	18 (#11)	24 (#6)	18 (#11)
Reduced Load	16 (#7)	18 (#6)	12 (#6)	14 (#6)

Although the new rebar listed for the negative moment in the column strip is designed as #7, it was bumped up to a #8 rebar size due to constructability. Since the diameter of each rebar vary by only 0.125 in, it becomes difficult for laborers to quickly distinguish the differences between #6 and #7. The cost savings for designing the 5,000psi concrete to meet the 4,000psi requirements is over half the cost of the original design. The cost breakdown is listed in Table 33, and the total cost was taken from RS Means 2015: Building Construction Data.

Table 33 Rebar Cost Reduction

	Rebar Size	lb/ft	Number	Weight (lb)	Cost	Total	Savings
Original Design	#6	1.50	24	1,219.9	$1,205	$7,542	$4,248
	#11	5.28	47	8,443.7	$6,337		
Proposed Design	#6	1.50	44	2,236.5	$2,209	$3,294	
	#8	2.66	16	1,445.8	$1,085		

Although the proposed design does not factor in the force protection and progressive collapse resistance, the rebar was sized according to a concrete of lesser strength. The positive and negative moments the roof load impose on the slab are lower than the slab can hold with the minimum reinforcement.

Construction Breadth

The proposed design does not call for an abundance of outdoor air as the original system prescribed for. Therefore, the IBS floors were allowed to reduce in size because there is no need for as large of a space for the mechanical system and building systems such as medical gas, pneumatic tubes, and electrical wiring. The following breadth evaluates cost reduction in removing the IBS floors, and the proposed system costs, and impact to the schedule.

By removing the IBS floors, the mechanical equipment located on this floor will now belong in a plenum above the space. Since the IBS floors are meant for the building systems, the structure is fairly simple in order to construct it is quickly and efficiently as possible. Table 34 lists the main materials installed that will take a majority of the construction time of the IBS floor. The construction of the IBS floor begins after the roof and IBS floor are finished for the fourth floor. The floor takes roughly 36 days to construct before the preparation for the mechanical and electrical equipment can begin.

Table 34 IBS Floor Costs

Material	Unit	Amount	Crew	Daily Output	Labor-Hours	2015 Bare Costs				Total	Total	Time(days)
						Material	Labor	Equipment	Total	Incl. O&P		
W6x20	ft	4,148	8	600	0.093	29.00	4.83	2.52	36.35	43.00	$178,364	6.91
Floor Decking (3" deep, 18 ga)	sq-ft	39,304	5	2850	0.011	2.90	0.60	0.05	3.55	4.29	$168,614	13.79
Polypropylene Fiber Rebar Mat	ft^3	6,550	4	9500	0.004	0.71	0.19	0	0.9	1.07	$7,009	0.69
LW Concrete, 2-1/2"	sq-ft	39,304	8	2585	0.022	1.08	0.91	0.28	2.65	3.3	$129,703	15.20
										Total	$483,690	36.60

The table above lists the costs and duration for each task in the construction of the IBS floor. The majority of the cost is due to the material of the steel beams and the floor decking. By removing the IBS floors for both the fifth and sixth floor, over two months are saved for the schedule. The time saved can be dedicated to the amount of time for the terminal units to be installed into a ceiling plenum. The interstitial floor concept allows laborer's to easily place mechanical equipment without the use of any ladders or lifts. By removing the interstitial floors, this will impact the schedule because of the amount of time to install the system overhead.

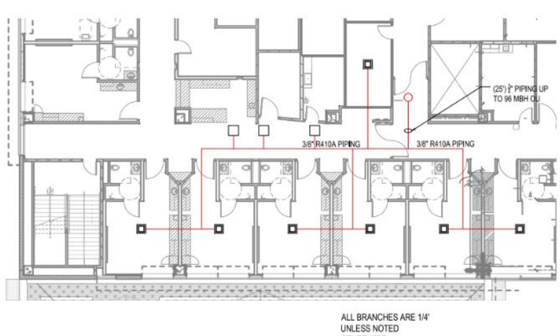

Figure 39 VRF System Layout

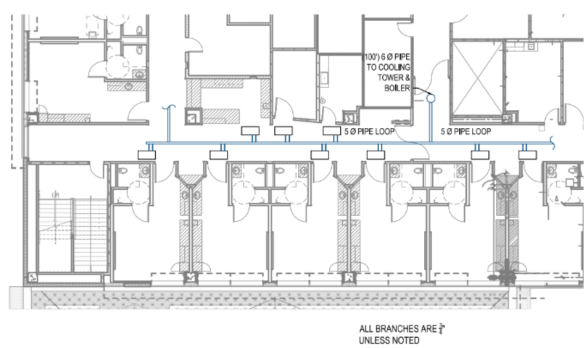

Figure 40 WSHP System Layout

Since the ductwork will reduce in size between the three designs: the original, the VRF, and the WSHP systems. The three systems were estimated in cost according to one zone. Figure 39 and Figure 40, show the mechanical layout for the VRF and WSHP systems. Figure 39 is a layout of the VRF system for one condensing unit in zone L5 SW Exterior. Each patient room in this zone has an indoor 0.8 ton cassette, and indoor in-duct VRF units serve the medical support spaces. The indoor units for this zone are listed in Table 35. The cassettes and in-duct units are served by an outdoor condensing unit on the roof. Figure 40 shows part of the WSHP loop for the L5 SW Exterior Zone. Since the WSHPs can be placed outside the rooms, there is less piping involved in the WSHP system than the VRF system. The WSHP units branch off from the main pipe sized at 5", this pipe is significantly larger because it must handle the entire flow rate of all of the WSHP units combined.

Table 35 Zone VRF & WSHP Indoor Unit Sizes

Zone	Room	Room Name	VRF Indoor Unit		WSHP Unit	
			Cooling	Heating	Cooling	Heating
L5 SW Exterior Zone	5172-05	Pediatric Medical / Surgery Bed RM	9,600	10,900	9,700	12,000
	5174-07	Pediatric Medical	9,600	10,900	9,700	12,000
	5174-09	Pediatric Medical / Surgery Bed	9,600	10,900	9,700	12,000
	5174-10	Pediatric Medical / Surgery Bedroom	9,600	10,900	9,700	12,000
	5174-13	Medical / Surgery Bed	9,600	10,900	9,700	12,000
	5232-04	Medical / Surgery Bed	9,600	10,900	9,700	12,000
	5174-17	Pediatric Equipment	7,500	8,500	8,000	9,800
	5174-16	Soiled Utility	7,500	8,500	8,000	9,800
	5174-03	Nurse Team Center	7,500	8,500	8,000	9,800
	5174-04	Remote Monitor Station				
	5174-05	Lab/SAT Poct				

A basic payback period was determined by the initial costs and the annual energy costs of the three systems. RS Means Mechanical Cost Data 2014 was used to determine the initial costs of the equipment. Table 36 contains the initial and energy costs of each system. The two alternatives vary in costs between the additional expenses and the maintenance costs. The maintenance costs used are for replacing large equipment every 15 years. The maintenance costs do not include annual or monthly maintenance costs. The VRF system has a higher up-front cost, because of the expensive condensing units, however it has a low maintenance cost because it does not include a boiler or chiller which require more maintenance than the condensing units. Since the WSHP system is similar to the original design of CAV units, the initial costs do not vary by a significant amount. The initial costs of the terminal units vary because of the installation rate, and the piping is larger for the water loop, so the initial expenses are slightly more than the original design. However, since the equipment is similar to the original design, the maintenance costs are the same for the original design, however since there is no chiller, $190,000 is saved from the chiller maintenance costs. Overall, the VRF system has a payback period of over 3 years, and the WSHP system has a payback of 1.06 years.

Table 36 Payback Period

Initial Cost	VRF	WSHP
Expenses / Savings	Additional Costs	Initial Costs
Cooling Tower	-$29,868	$0
Boiler - 765 MBH	-$17,800	$0
Outdoor Condensing Unit	$528,000	$0
Chiller 270 ton	-$190,500	-$190,500
Terminal Units	$170,825	$285,600
Piping	$74,176	$444,200
DOAS Unit	-$361,000	-$361,000
Costs	$173,833	$178,300
		Maitnenance Costs
16 Air Cooled Condensers	$138,480	$0
Cooling Tower	-$8,872	$0
Chiller - 270 ton	-$104,744	-$104,744
Boiler - 765 MBH	-$5,835	$0
Maitnenance Costs	$19,030	-$104,744
Expenses	$245,596	$73,556
Annual Energy Costs	$71,763	$69,108
Payback Period	3.42	1.06

The payback period for the original design and the two alternatives are significantly different because of the energy costs. The VRF system saves more money on energy than the water source heat pump because the VRF system uses mainly electricity to operate. The piping for the cost analysis does not include valves or pumps, and the piping is based on the layout in figures 39 and 40, and averaged for the remaining 15 zones. The short payback period is partially due to the high savings from reducing the size of the DOAS unit.

Schedule Impact

The main benefit of the interstitial floors is to provide the facilities maintenance workers with easily accessible workspace for checking the terminal units and building systems. Not only does it eliminate time to check the systems, but it also eliminates time during construction. Of course, there is the added time to construct the IBS floors, however, since they are only supporting the live load of the maintenance workers, and the dead load of the slab and mechanical equipment, it is a fairly redundant structure.

Table 37 Duration of IBS Tasks

Task	Duration - Man Days					
	Original		VRF		WSHP	
	Man - Days	Total Days	Man - Days	Total Days	Man - Days	Total Days
FR&P Interstitial Floors	79.96	10	0.00	0	0.00	0
Install Interstitial Floor Deck	65.36	8	0.00	0	0.00	0
Install terminal units	51.00	26	76.98	38	76.98	38
Piping	4.14	4	16.82	17	12.83	13
Sheetmetal	32.00	11	21.33	11	21.33	11
	Total	58		66		62
	Difference in Duration			**-8**		**-4**

The table above, Table 37 Duration of IBS Tasks, lists the most important tasks for the IBS floor. The tasks listed vary from system to system. For instance, the IBS floor construction should only be accounted for in the original design because it is eliminated in the two alternatives. The IBS floor's construction takes only 18 days per floor, but it reduces the amount of time spent installing terminal units because the laborers do not have to use ladders because the terminal units are installed on the ground. The sheet metal reduction was averaged for the entire building based on the most congested area which is by the mechanical shafts. The values in the table are based on RS Means 2014 Mechanical Cost Data, however, the cost data assumes a plenum and does not account of the constructability changes in an interstitial floor design. Therefore, the duration for the tasks dependent on the plenum size are subject to change.

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Appendix A

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FORT HOOD/GRAY AAF, TX, USA

WMO#: **722576**

Lat: **31.07N** Long: **97.83W** Elev: **1024** StdP: **14.16** Time Zone: **-6.00 (NAC)** Period: **82-06** WBAN: **99999**

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
1	23.7	28.2	9.8	9.4	33.5	14.8	12.1	37.6	25.8	52.7	23.4	53.6	8.8	350

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
8	21.6	99.9	73.4	98.1	73.3	95.8	73.5	77.7	90.0	76.9	89.1	76.0	88.0	9.4	160

Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours 8 to 4 & 55/69
0.4%			1%			2%			0.4%		1%		2%		
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	
75.0	136.4	81.0	73.6	130.2	80.1	73.0	127.2	79.8	41.9	89.7	40.9	89.1	40.1	87.7	707

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
22.0	19.4	17.8	84.0	18.5	103.4	7.1	2.7	13.3	105.3	9.2	106.8	5.2	108.3	0.0	110.3

Monthly Climatic Design Conditions

		Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours	Tavg	67.6	49.7	52.7	59.7	67.4	74.7	80.5	84.3	84.7	78.4	69.3	58.6	50.1
	Sd		10.17	10.55	8.97	7.38	5.90	4.06	3.39	3.81	6.36	7.72	9.47	10.41
	HDD50	396	131	84	24	1	0	0	0	0	0	2	30	124
	HDD65	1870	480	360	210	60	5	0	0	0	5	47	233	470
	CDD50	6822	123	159	324	524	767	916	1064	1076	852	601	289	127
	CDD65	2817	7	15	44	132	307	466	599	611	406	181	41	8
	CDH74	30323	49	124	331	1070	2713	4999	7441	7634	4210	1470	243	39
	CDH80	14713	6	34	71	319	1066	2380	4074	4228	1996	499	37	3
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB	79.3	84.2	86.3	92.7	97.2	99.7	102.3	102.5	100.2	92.5	84.2	79.0
		MCWB	59.7	60.1	63.5	67.6	71.8	74.7	72.6	73.4	73.1	70.8	67.7	61.6
	2%	DB	73.5	77.3	81.4	86.9	92.5	95.5	99.8	100.0	96.0	89.0	80.2	73.3
		MCWB	59.6	59.5	63.8	67.0	72.7	74.4	73.7	73.2	72.9	69.0	65.8	61.8
	5%	DB	70.0	72.5	77.5	83.6	89.6	93.1	97.4	98.5	93.1	85.9	76.7	70.0
		MCWB	58.3	58.8	62.7	66.7	72.1	74.0	73.5	73.2	72.3	68.9	65.2	60.6
	10%	DB	66.1	68.5	73.5	80.5	86.1	90.8	95.1	96.2	90.3	82.0	72.9	66.3
		MCWB	57.7	58.3	61.9	65.4	71.5	74.1	73.7	73.5	72.0	68.1	64.0	59.3
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB	67.4	67.3	70.2	74.1	78.3	79.1	78.4	78.4	78.1	76.1	72.1	68.4
		MCDB	70.8	71.7	77.4	82.5	88.5	90.9	91.1	92.0	88.5	83.4	78.4	71.5
	2%	WB	64.8	65.6	68.2	72.2	75.9	77.4	77.2	77.2	76.5	74.2	69.9	66.0
		MCDB	68.9	70.9	74.9	80.1	85.8	89.5	90.6	90.4	86.7	81.7	75.5	69.8
	5%	WB	62.4	63.3	66.7	70.6	74.4	76.5	76.2	76.3	75.3	72.7	68.3	63.5
		MCDB	67.2	68.9	72.9	77.9	83.9	88.0	89.5	89.4	85.5	80.3	73.4	68.1
	10%	WB	58.6	60.1	64.7	69.0	73.1	75.4	75.4	75.3	74.3	71.1	66.5	60.2
		MCDB	64.7	66.8	70.6	76.0	82.3	86.3	88.3	88.3	84.5	78.5	71.5	65.0
Mean Daily Temperature Range		MDBR	20.3	19.8	20.6	21.2	19.6	19.6	21.3	21.6	20.9	20.4	19.9	19.6
	5% DB	MCDBR	26.1	25.3	24.4	25.2	22.6	22.0	24.1	24.2	23.5	23.1	22.2	23.7
		MCWBR	15.8	14.0	12.6	12.0	8.4	6.7	5.9	6.0	7.0	9.8	12.3	14.6
	5% WB	MCDBR	20.0	20.0	19.0	19.3	19.2	19.4	21.1	21.2	19.5	18.2	18.3	19.1
		MCWBR	14.8	14.1	12.5	11.2	9.0	7.5	6.2	6.2	7.0	9.4	13.1	14.6
Clear Sky Solar Irradiance	taub		0.324	0.343	0.356	0.388	0.416	0.437	0.440	0.443	0.411	0.360	0.339	0.321
	taud		2.470	2.379	2.338	2.231	2.179	2.143	2.161	2.148	2.259	2.416	2.441	2.523
	Ebn,noon		287	291	294	287	278	270	269	267	273	282	279	283
	Edh,noon		31	36	39	45	47	49	48	48	42	34	31	28

CDD*n* Cooling degree-days base n°F, °F-day
CDH*n* Cooling degree-hours base n°F, °F-hour
DB Dry bulb temperature, °F
DP Dew point temperature, °F
Ebn,noon } Clear sky beam normal and diffuse hori-
Edh,noon } zontal irradiances at solar noon, Btu/h/ft2
Elev Elevation, ft
Enth Enthalpy, Btu/lb
HDD*n* Heating degree-days base n°F, °F-day
Hours 8/4 & 55/69 Number of hours between 8 a.m. and 4 p.m with DB between 55 and 69 °F
HR Humidity ratio, grains of moisture per lb of dry air

Lat Latitude, °
Long Longitude, °
MCDB Mean coincident dry bulb temperature, °F
MCDBR Mean coincident dry bulb temp. range, °F
MCDP Mean coincident dew point temperature, °F
MCWB Mean coincident wet bulb temperature, °F
MCWBR Mean coincident wet bulb temp. range, °F
MCWS Mean coincident wind speed, mph
MDBR Mean dry bulb temp. range, °F
PCWD Prevailing coincident wind direction, °, 0 = North, 90 = East

Period Years used to calculate the design conditions
Sd Standard deviation of daily average temperature, °F
StdP Standard pressure at station elevation, psi
taub Clear sky optical depth for beam irradiance
taud Clear sky optical depth for diffuse irradiance
Tavg Average temperature, °F
Time Zone Hours ahead or behind UTC, and time zone code
WB Wet bulb temperature, °F
WBAN Weather Bureau Army Navy number
WMO# World Meteorological Organization number
WS Wind speed, mph

ASHRAE Standard 170-2013 Table 7.1

TABLE 7.1 Design Parameters

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
SURGERY AND CRITICAL CARE							
Operating room (Class B and C) (m), (n), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Operating/surgical cystoscopic rooms, (m), (n) (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Delivery room (Caesarean) (m), (n), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Substerile service area	NR	2	6	NR	No	NR	NR
Recovery room	NR	2	6	NR	No	20–60	70–75/21–24
Critical and intensive care	NR	2	6	NR	No	30–60	70–75/21–24
Intermediate care (s)	NR	2	6	NR	NR	max 60	70–75/21–24
Wound intensive care (burn unit)	NR	2	6	NR	No	40–60	70–75/21–24
Newborn intensive care	Positive	2	6	NR	No	30–60	72–78/22–26
Treatment room (p)	NR	2	6	NR	NR	20–60	70–75/21–24
Trauma room (crisis or shock) (c)	Positive	3	15	NR	No	20–60	70–75/21–24
Medical/anesthesia gas storage (r)	Negative	NR	8	Yes	NR	NR	NR
Laser eye room	Positive	3	15	NR	No	20–60	70–75/21–24
ER waiting rooms	Negative	2	12	Yes (q)	NR	max 65	70–75/21–24
Triage	Negative	2	12	Yes (q)	NR	max 60	70–75/21–24
ER decontamination	Negative	2	12	Yes	No	NR	NR
Radiology waiting rooms	Negative	2	12	Yes (q), (w)	NR	max 60	70–75/21–24
Procedure room (Class A surgery) (o), (d)	Positive	3	15	NR	No	20–60	70–75/21–24
Emergency department exam/treatment room (p)	NR	2	6	NR	NR	max 60	70–75/21–24
INPATIENT NURSING							
Patient room	NR	2	4 (y)	NR	NR	max 60	70–75/21–24
Nourishment area or room	NR	NR	2	NR	NR	NR	NR
Toilet room	Negative	NR	10	Yes	No	NR	NR
Newborn nursery suite	NR	2	6	NR	No	30–60	72–78/22–26
Protective environment room (t)	Positive	2	12	NR	No	max 60	70–75/21–24
AII room (u)	Negative	2	12	Yes	No	max 60	70–75/21–24
Combination AII/PE room	Positive	2	12	Yes	No	Max 60	70-75/21-24
AII anteroom (u)	(e)	NR	10	Yes	No	NR	NR
PE anteroom (t)	(e)	NR	10	NR	No	NR	NR

Note: NR = no requirement

ASHRAE Standard 170-2013 Table 7.1

TABLE 7.1 Design Parameters *(Continued)*

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
Autopsy room (n)	Negative	2	12	Yes	No	NR	68–75/20–24
Pharmacy (b)	Positive	2	4	NR	NR	NR	NR
Examination room	NR	2	6	NR	NR	max 60	70–75/21–24
Medication room	NR	2	4	NR	NR	max 60	70–75/21–24
Gastrointestinal endoscopy procedure room (x)	NR	2	6	NR	No	20–60	68–73/20–23
Endoscope cleaning	Negative	2	10	Yes	No	NR	NR
Treatment room (x)	NR	2	6	NR	NR	max 60	70–75/21–24
Hydrotherapy	Negative	2	6	NR	NR	NR	72–80/22–27
Physical therapy	Negative	2	6	NR	NR	Max 65	72–80/22–27
STERILIZING							
Sterilizer equipment room	Negative	NR	10	Yes	No	NR	NR
CENTRAL MEDICAL AND SURGICAL SUPPLY							
Soiled or decontamination room	Negative	2	6	Yes	No	NR	72–78/22–26
Clean workroom	Positive	2	4	NR	No	max 60	72–78/22–26
Sterile storage	Positive	2	4	NR	NR	max 60	72–78/22–26
SERVICE							
Food preparation center (i)	NR	2	10	NR	No	NR	72–78/22–26
Warewashing	Negative	NR	10	Yes	No	NR	NR
Dietary storage	NR	NR	2	NR	No	NR	72–78/22–26
Laundry, general	Negative	2	10	Yes	No	NR	NR
Soiled linen sorting and storage	Negative	NR	10	Yes	No	NR	NR
Clean linen storage	Positive	NR	2	NR	NR	NR	72–78/22–26
Linen and trash chute room	Negative	NR	10	Yes	No	NR	NR
Bedpan room	Negative	NR	10	Yes	No	NR	NR
Bathroom	Negative	NR	10	Yes	No	NR	72–78/22–26
Janitor's closet	Negative	NR	10	Yes	No	NR	NR
SUPPORT SPACE							
Soiled workroom or soiled holding	Negative	2	10	Yes	No	NR	NR
Clean workroom or clean holding	Positive	2	4	NR	NR	NR	NR
Hazardous material storage	Negative	2	10	Yes	No	NR	NR

Note: NR = no requirement

Ventilation Schedule AHU-2

Room Number	Room		Area	Floor to Ceiling	Volume	Occupancy Density	Space Type - ASHRAE 170-2013	Minimum Air Changes per Hour			Minimum OA	Supply OA	Space Type (ASHRAE 62.1)	Minimum Ventilation Rate		Minimum	Exhaust	Minimum Ventilation OA	Design Minimum OA (100% DOAS)
		System	Ft^2	Ft	Ft^3	# People		OA (ach)	Supply (ach)	Exhaust	CFM	CFM		CFM/Person	CFM/SF	CFM	CFM	CFM	CFM
5171-01	Isolation Bed	B-AHU-2	364	9	3276	3	AII Room	2	12	Yes	109	655					655	109	350
5171-02	Toilet/Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5171-03	Isolation ANTE Room	B-AHU-2	203	9	1827	0	Toilet Room	NR	10	Yes	0	305					305	0	260
5171-04	Isolation Bed	B-AHU-2	365	9	3285	3	AII Room	2	12	Yes	110	657					657	110	250
5171-05	Toilet/Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5171-06	Pediatric Medical / Surgery Bed	B-AHU-2	329	9	2961	3	Procedure Room (Class A Surgery)	3	15	NR	148	740					0	148	180
5171-07	Toilet/Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	215
5171-C01	Corridoridor	B-AHU-2	292	8.5	2482	0	Toilet Room	NR	10	Yes	0	414					414	0	85
5172-01	Pediatric Medical / Surgery Bed RM	B-AHU-2	359	9	3231	3	Procedure Room (Class A Surgery)	3	15	NR	162	808					0	162	250
5172-02	Toilet/Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5172-04	Toilet/Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5172-05	Pediatric Medical / Surgery Bed RM	B-AHU-2	326	9	2934	3	Procedure Room (Class A Surgery)	3	15	NR	147	734					0	147	260
5173-01	Pediatric Medical / Surgery Bed	B-AHU-2	329	9	2961	3	Procedure Room (Class A Surgery)	3	15	NR	148	740					0	148	255
5173-02	Nurse Sub-Team Center	B-AHU-2	96	8	768	1	Patient Corridor	NR	2	NR	0	26					0	0	90
5173-03	Medical Prep	B-AHU-2	108	8	864	0	Clean Workroom	2	4	NR	29	58					0	29	140
5173-04	TREATMENT	B-AHU-2	176	9	1584	3	Treatment Room	2	6	NR	53	158					0	53	160
5173-05	Electrical	B-AHU-2	178	10	1780	0							Electrical	0	0.06	11		11	0
5173-06	Communication	B-AHU-2	131	10	1310	0							Telecom	0	0.06	8		8	40
5173-07	Clean Utility	B-AHU-2	132	8	1056	0	Clean Linen Storage	NR	2	NR	0	35					0	0	75
5173-08	Playroom	B-AHU-2	138	9	1242	5							Daycare sickroom	10	0.18	75		75	120
5173-09	Vending Area	B-AHU-2	26	8	208	0							Breakroom	5	0.12	3		3	0
5173-10	Family Waiting	B-AHU-2	212	9	1908	5	ER Waiting Room	2	12	Yes	64	382					382	64	190
5173-11	NOUR Center	B-AHU-2	83	8	664	0	Food Prep	2	10	NR	22	111					0	22	375
5173-12	Office	B-AHU-2	89	8	712	2							Office Space	5	0.06	15		15	95
5173-13	Office	B-AHU-2	91	8	728	2							Office Space	5	0.06	15		15	145
5173-14	Office	B-AHU-2	120	8	960	2							Office Space	5	0.06	17		17	135
5173-15	Staff Toilet	B-AHU-2	69	8	552	0	Bathroom	NR	10	Yes	0	92					92	0	-
5173-16	CC	B-AHU-2	16	8	128	0							Storage	0	0.12	2		2	10
5173-17	Pediatric Medical / Surgery Bed	B-AHU-2	329	9	2961	3	Procedure Room (Class A Surgery)	3	15	NR	148	740					0	148	255
5173-18	Toilet/Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5173-19	Toilet/Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5173-C01	Corridor	B-AHU-2	756	8.5	6426	0	Patient Corridor	NR	2	NR	0	214					0	0	215
5173-C02	Corridor	B-AHU-2	207	8.5	1759.5	0	Patient Corridor	NR	2	NR	0	59					0	0	60
5173-C03	Corridor	B-AHU-2	115	8.5	977.5	0	Patient Corridor	NR	2	NR	0	33					0	0	80
5174-01	Clinician Chart/Workroom	B-AHU-2	120	8	960	2							Office Space	5	0.06	17		17	100
5174-02	Nurse Workroom	B-AHU-2	100	8	800	2							Office Space	5	0.06	16		16	135
5174-03	Nurse Team Center	B-AHU-2	90	8	720	2	Patient Corridor	NR	2	NR	0	24					0	0	220
5174-04	Remote Monitor Station	B-AHU-2	57	8	456	1	Patient Corridor	NR	2	NR	0	15					0	0	195
5174-05	Lab/SAT Poct	B-AHU-2	20	8	160	0	Patient Corridor	NR	2	NR	0	5					0	0	60
5174-06	Toilet/Shower	B-AHU-2	64	8	512	0	Toilet Room	NR	10	Yes	0	85					85	0	-
5174-07	Pediatric Medical	B-AHU-2	332	8	2656	3	Procedure Room (Class A Surgery)	3	15	NR	133	664					0	133	330
5174-08	Toilet/Shower	B-AHU-2	64	8	512	0	Toilet Room	NR	10	Yes	0	85					85	0	-
5174-09	Pediatric Medical / Surgery Bed	B-AHU-2	332	8	2656	3	Procedure Room (Class A Surgery)	3	15	NR	133	664					0	133	330
5174-10	Pediatric Medical / Surgery Bedroom	B-AHU-2	332	8	2656	3	Procedure Room (Class A Surgery)	3	15	NR	133	664					0	133	350
5174-11	Toilet/Shower	B-AHU-2	64	8	512	0	Toilet Room	NR	10	Yes	0	85					85	0	-
5174-12	Toilet/Sink	B-AHU-2	64	8	512	0	Toilet Room	NR	10	Yes	0	85					85	0	-
5174-13	Medical / Surgery Bed	B-AHU-2	332	8	2656	3	Procedure Room (Class A Surgery)	3	15	NR	133	664					0	133	350
5174-14	Electrical	B-AHU-2	185	10	1850	0							Electrical	0	0.06	11		11	0
5174-15	MOBILE X-RAY	B-AHU-2	38	8	304	0	Patient Corridor	NR	2	NR	0	10					0	0	25
5174-16	Soiled Utility	B-AHU-2	127	8	1016	0	Soiled	2	6	Yes	34	102					102	34	0
5174-17	Pediatric Equipment	B-AHU-2	139	9	1251	0	Clean Workroom	2	4	NR	42	83					0	42	85

5174-C01	Corridor	B-AHU-2	721	8.5	6128.5	0	Patient Corridor	NR	2	NR	0	204					0	0	205
5231-01	Elevator Vestibule	B-AHU-2	302	8.5	2567	0	Patient Corridor	NR	2	NR	0	86					0	0	275
5231-02	Janitor	B-AHU-2	58	8	464	0	Janitor's Closet	NR	10	Yes	0	77					77	0	0
5231-03	Reception / Control	B-AHU-2	184	8	1472	2	Patient Corridor	NR	2	NR	0	49					0	0	175
5231-04	Clean Supply	B-AHU-2	88	8	704	0	Clean Linen Storage	NR	2	NR	0	23					0	0	45
5231-05	Litter / WC Storage	B-AHU-2	65	8	520	0	Clean Workroom	2	4	NR	17	35					0	17	30
5231-06	Social Workers	B-AHU-2	111	8	888	2							Office Space	5	0.06	17		17	140
5231-07	On-Call / Sleep	B-AHU-2	107	8	856	1	Resident room	2	2	NR	29	29					0	29	150
5231-08	Consulting	B-AHU-2	114	8	912	2							Office Space	5	0.06	17		17	95
5231-09	Equipment Storage	B-AHU-2	107	9	963	0	Clean Workroom	2	4	NR	32	64					0	32	65
5231-10	Public Toilet	B-AHU-2	64	8.5	544	0	Bathroom	NR	10	Yes	0	91					91	0	40
5231-11	Public Toilet	B-AHU-2	64	8.5	544	0	Bathroom	NR	10	Yes	0	91					91	0	40
5231-C01	Corridor	B-AHU-2	1564	8.5	13294	0	Patient Corridor	NR	2	NR	0	443					0	0	1275
5231-C02	Corridor	B-AHU-2		8.5	0	0	Patient Corridor	NR	2	NR	0	0					0	0	
5231-C03	Corridor	B-AHU-2	285	8.5	2422.5	0	Patient Corridor	NR	2	NR	0	81					0	0	85
5232-01	Staff Lounge	B-AHU-2	155	8	1240		Resident gathering/activity	4	4	NR	83	83					0	83	235
5232-02	Personal Property Lockers	B-AHU-2	47	8	376		Resident gathering/activity	4	4	NR	25	25					0	25	25
5232-03	Equipment Storage	B-AHU-2	135	8.5	1147.5		Clean Workroom	2	4	NR	38	77					0	38	85
5232-04	Medical / Surgery Bed	B-AHU-2	326	9	2934		Procedure Room (Class A Surgery)	3	15	NR	147	734					0	147	330
5232-05	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5232-06	Medical / Surgery Bed	B-AHU-2	326	9	2934	3	Procedure Room (Class A Surgery)	3	15	NR	147	734					0	147	350
5232-07	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5232-08	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	330
5232-09	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	330
5232-10	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5232-11	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5232-12	Litter / Wheelchair Storage	B-AHU-2	62	8	496	0	Clean Workroom	2	4	NR	17	33					0	17	35
5232-13	CC	B-AHU-2	35	8	280	0							Storage	0	0.12	4		4	20
5232-14	Nurse Sub-Team Center	B-AHU-2	98	8	784	1	Patient Corridor	NR	2	NR	0	26					0	0	155
5232-15	On-Call / Toilet / Shower	B-AHU-2	82	8	656	0	Resident room	2	2	NR	22	22					0	22	0
5232-16	Staff Toilet	B-AHU-2	53	8	424	0	Bathroom	NR	10	Yes	0	71					71	0	-
5232-17	Clinical Pharmacist	B-AHU-2	115	8	920	1							Office Space	5	0.06	12		12	100
5232-C01	Corridor	B-AHU-2	434	8.5	3689	0	Patient Corridor	NR	2	NR	0	123					0	0	125
5232-C02	Corridor	B-AHU-2	1531	8.5	13013.5	0	Patient Corridor	NR	2	NR	0	434					0	0	745
5232-C03	Corridor	B-AHU-2	295	8.5	2507.5	0	Patient Corridor	NR	2	NR	0	84					0	0	85
5233-02	Trash Linen Collect	B-AHU-2	160	8	1280	0	Soiled Linen Sorting and Storage	NR	10	Yes	0	213					213	0	60
5233-03	Electrical	B-AHU-2	230	10	2300	0							Electrical	0	0.06	14		14	0
5233-04	Electrical	B-AHU-2	115	10	1150	0							Electrical	0	0.06	7		7	0
5233-05	Family Toilet	B-AHU-2	64	8	512	0	Bathroom	NR	10	Yes	0	85					85	0	-
5233-06	Conference	B-AHU-2	326	9	2934	8							Conference					0	315
5233-07	Vending Area	B-AHU-2	64	9	576	0							Breakroom	5	0.12	8		8	0
5233-08	Family Waiting	B-AHU-2	286	9	2574	9	ER Waiting Room	2	12		86	515					0	86	415
5233-09	Personal Property Lockers	B-AHU-2	95	8	760	0	Resident gathering/activity	4	4	NR	51	51					0	51	55
5234-01	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5234-02	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	350
5234-03	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	330
5234-04	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5234-05	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	350
5234-06	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5234-07	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5234-08	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	350
5234-09	Janitor	B-AHU-2	46	9	414	0	Janitor's Closet	NR	10	Yes	0	69					69	0	-
5234-10	AGV Staging	B-AHU-2	278	8	2224	0	Patient Corridor	NR	2	NR	0	74					0	0	140
5234-11	Elevator Vestibule	B-AHU-2	257	8.5	2184.5	0	Patient Corridor	NR	2	NR	0	73					0	0	235
5234-12	Mobile X-RAY	B-AHU-2	53	8	424	0	Patient Corridor	NR	2	NR	0	14					0	0	25

5234-13	Alcove	B-AHU-2	44	8	352	0	Patient Corridor	NR	2	NR	0	12					0	0	25
5271-01	Medical / Surgery Bed	B-AHU-2	328	9	2952	3	Procedure Room (Class A Surgery)	3	15	NR	148	738					0	148	255
5271-02	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5271-04	On-Call / Toilet / Shower	B-AHU-2	82	8	656	0	Resident room	2	2	NR	22	22					0	22	40
5271-05	Shower / Tub	B-AHU-2	91	9	819	0	Resident room	2	2	NR	27	27					0	27	40
5271-06	Electrical	B-AHU-2	186	10	1860	0							Electrical	0	0.06	11		11	0
5271-07	Charting Workroom	B-AHU-2	139	8	1112	2							Office Space	5	0.06	18		18	175
5271-08	Physician Chart / DCT	B-AHU-2	81	8	648	2							Office Space	5	0.06	15		15	95
5271-09	Lab/SAT Poct	B-AHU-2	20	8	160	0	Patient Corridor	NR	2	NR	0	5					0	0	90
5271-10	Nurse Team Center	B-AHU-2	114	8	912	2	Patient Corridor	NR	2	NR	0	30					0	0	265
5271-11	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5271-12	Medical / Surgery Bed	B-AHU-2	328	9	2952	3	Procedure Room (Class A Surgery)	3	15	NR	148	738					0	148	230
5271-13	Medical / Surgery Bed	B-AHU-2	328	9	2952	3	Procedure Room (Class A Surgery)	3	15	NR	148	738					0	148	250
5271-14	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5271-15	Medical / Surgery Bed	B-AHU-2	328	9	2952	3	Procedure Room (Class A Surgery)	3	15	NR	148	738					0	148	230
5271-16	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5271-C01	Corridor	B-AHU-2	290	8.5	2465	0	Patient Corridor	NR	2	NR	0	82					0	0	85
5272-01	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5272-02	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	330
5272-03	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	350
5272-04	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5272-05	Medical / Surgery Bed	B-AHU-2	326	9	2934	3	Procedure Room (Class A Surgery)	3	15	NR	147	734					0	147	325
5272-06	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5272-07	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5272-08	Medical / Surgery Bed	B-AHU-2	325	9	2925	3	Procedure Room (Class A Surgery)	3	15	NR	146	731					0	146	325
5272-09	Nurse Team Center	B-AHU-2	123	8	984	3	Patient Corridor	NR	2	NR	0	33					0	0	170
5272-10	COMM	B-AHU-2	130	10	1300	0							Telecom	0	0.06	8		8	40
5272-11	On-Call / Sleep	B-AHU-2	145	8	1160	1	Resident room	2	2	NR	39	39					0	39	150
5272-12	CC	B-AHU-2	21	8	168	0							Storage	0	0.12	3		3	15
5272-C01	Corridor	B-AHU-2	943	8.5	8015.5	0	Patient Corridor	NR	2	NR	0	267					0	0	155
5273-01	Medical / Surgery Bed	B-AHU-2	329	9	2961	3	Procedure Room (Class A Surgery)	3	15	NR	148	740					0	148	255
5273-02	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5273-03	Medical Prep	B-AHU-2	111	8	888	0	Substerile service area	2	6	NR	30	89					0	30	140
5273-04	Janitor	B-AHU-2	41	8	328	0	Janitor's Closet	NR	10	Yes	0	55					55	0	-
5273-05	Clean Supply	B-AHU-2	73	8	584	0	Clean Linen Storage	NR	2	NR	0	19					0	0	40
5273-06	Equipment Storage	B-AHU-2	237	9	2133	0	Clean Workroom	2	4	NR	71	142					0	71	145
5273-07	Ortho Equipment Storage	B-AHU-2	53	9	477	0	Clean Workroom	2	4	NR	16	32					0	16	35
5273-08	Clean Utility	B-AHU-2	213	8	1704	0	Clean Linen Storage	NR	2	NR	0	57					0	0	125
5273-09	Admin Cubicle	B-AHU-2	109	8	872	2							Office Space	5	0.06	17		17	160
5273-10	NCOIC	B-AHU-2	97	8	776	2							Office Space	5	0.06	16		16	95
5273-11	Medical Surgery / ICU	B-AHU-2	109	8	872	2							Office Space	5	0.06	17		17	95
5273-12	Intensivist / Hospitalist	B-AHU-2	94	8	752	2							Office Space	5	0.06	16		16	95
5273-13	Clinical Nurse Specialist	B-AHU-2	91	8	728	2							Office Space	5	0.06	15		15	95
5273-14	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5273-15	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	230
5273-16	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	230
5273-17	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5273-18	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	250
5273-19	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5273-C01	Corridor	B-AHU-2	1098	8.5	9333	0	Patient Corridor	NR	2	NR	0	311					0	0	315
5274-01	NOUR Center	B-AHU-2	96	8	768	0	Food Prep	2	10	NR	26	128					0	26	375
5274-02	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5274-03	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	295
5274-04	Medical / Surgery Bed	B-AHU-2	332	9	2988	3	Procedure Room (Class A Surgery)	3	15	NR	149	747					0	149	295
5274-05	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-

5274-06	Bariatric Medical / Surgery Bed	B-AHU-2	330	9	2970	3	Procedure Room (Class A Surgery)	3	15	NR	149	743					0	149	350
5274-07	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5274-08	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5274-09	Bariatric Medical / Surgery Bed	B-AHU-2	330	9	2970	3	Procedure Room (Class A Surgery)	3	15	NR	149	743					0	149	350
5274-10	Nurse Sub-Team Center	B-AHU-2	85	8	680	2	Patient Corridor	NR	2	NR	0	23					0	0	170
5274-11	Staff Toilet	B-AHU-2	67	8	536	0	Bathroom	NR	10	Yes	0	89					89	0	-
5274-12	Electrical	B-AHU-2	176	10	1760	0							Electrical	0	0.06	11		11	0
5274-13	Soiled Utility	B-AHU-2	95	8	760	0	Soiled Linen Sorting and Storage	NR	10	Yes	0	127					127	0	0
5274-14	Clean Linen Cart Alcove	B-AHU-2	61	8	488	0	Clean Linen Storage	NR	2	NR	0	16					0	0	40
5274-15	Clean Linen Cart Alcove	B-AHU-2	63	8	504	0	Clean Linen Storage	NR	2	NR	0	17					0	0	35
5274-16	Soiled Utility	B-AHU-2	127	8	1016	0	Soiled	2	6	Yes	34	102					102	34	0
5274-17	Medical Gas	B-AHU-2	39	8	312	0	Medical/anesthesia gas storage	NR	8	Yes	0	42					42	0	0
5311-01	Medical / Surgery Bed	B-AHU-2	322	9	2898	3	Procedure Room (Class A Surgery)	3	15	NR	145	725					0	145	250
5311-02	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5311-03	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5311-04	Medical / Surgery Bed	B-AHU-2	374	9	3366	3	Procedure Room (Class A Surgery)	3	15	NR	168	842					0	168	235
5311-05	Elevator Vestibule	B-AHU-2	292	8.5	2482	0	Patient Corridor	NR	2	NR	0	83					0	0	840
5311-07	Staff Lounge	B-AHU-2	199	8.5	1691.5	8	Resident gathering/activity	4	4	NR	113	113					0	113	400
5311-08	Clean Utility	B-AHU-2	135	8	1080	0	Clean Linen Storage	NR	2	NR	0	36					0	0	60
5311-C01	Corridor	B-AHU-2	288	8.5	2448	0	Patient Corridor	NR	2	NR	0	82					0	0	85
5311-C02	Corridor	B-AHU-2	95	8.5	807.5	0	Patient Corridor	NR	2	NR	0	27					0	0	40
5312-01	Toilet / Shower	B-AHU-2	64	9	576	0	Toilet Room	NR	10	Yes	0	96					96	0	-
5312-02	Medical / Surgery Bed	B-AHU-2	380	9	3420	3	Procedure Room (Class A Surgery)	3	15	NR	171	855					0	171	320
5312-03	Isolation ANTE Room	B-AHU-2	74	9	666	3	AII anteroom	NR	10	Yes	0	111					111	0	105
5312-04	Isolation Bed	B-AHU-2	298	9	2682	3	AII Room	2	12	Yes	89	536					536	89	525
5312-05	Toilet / Shower	B-AHU-2	63	9	567	0	Toilet Room	NR	10	Yes	0	95					95	0	-
5312-06	Isolation ANTE Room	B-AHU-2	80	9	720	0	AII anteroom	NR	10	Yes	0	120					120	0	120
5312-07	Bariatric Isolation Bed	B-AHU-2	293	9	2637	3	AII Room	2	12	Yes	88	527					527	88	465
5312-08	Toilet / Shower	B-AHU-2	63	9	567	0	Toilet Room	NR	10	Yes	0	95					95	0	40
5312-09	Clean Supply	B-AHU-2	73	8	584	0	Clean Linen Storage	NR	2	NR	0	19					0	0	45
5312-C01	Corridor	B-AHU-2	135	8.5	1147.5	0	Patient Corridor	NR	2	NR	0	38					0	0	40

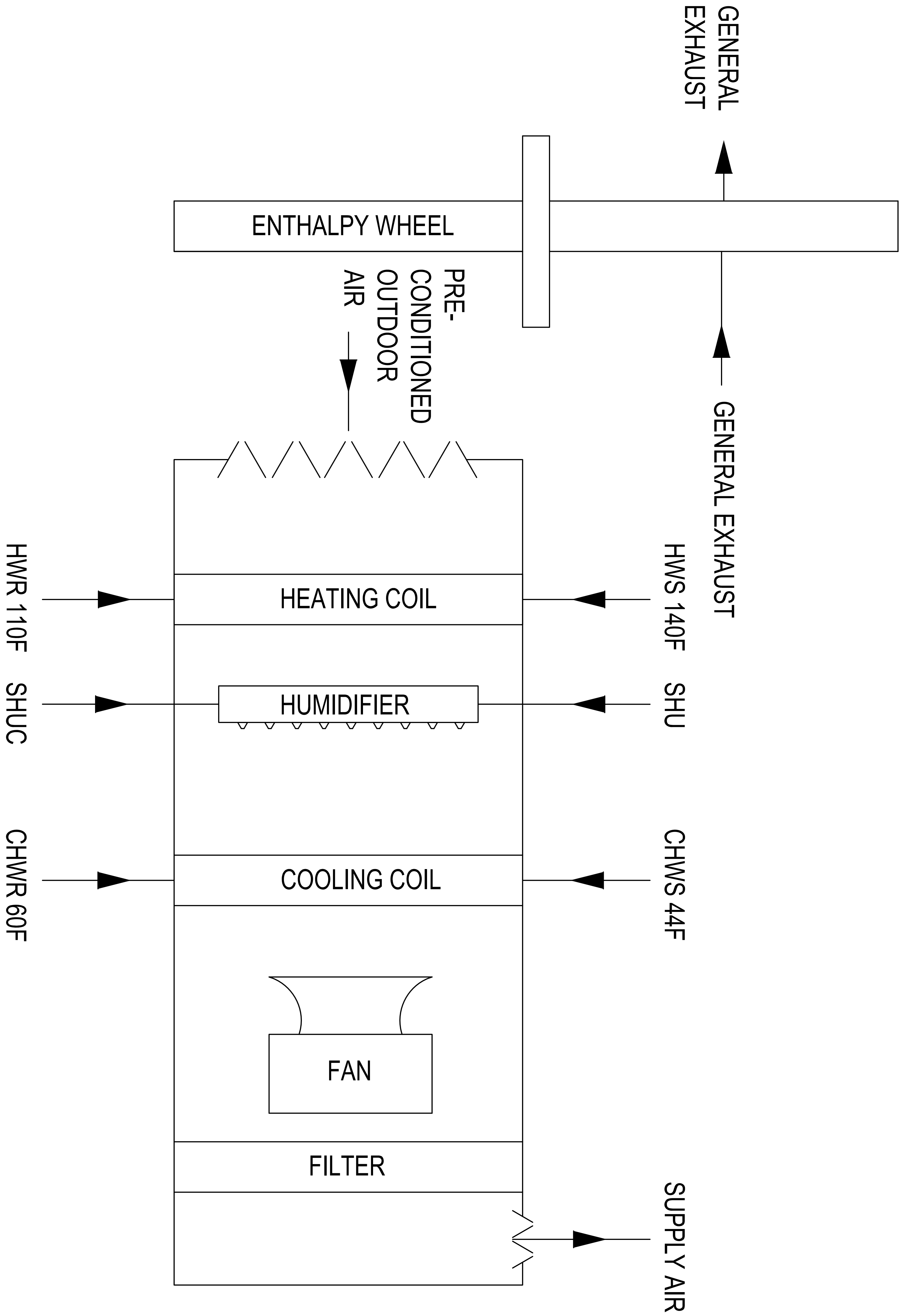
Ventilation Schedule AHU-3

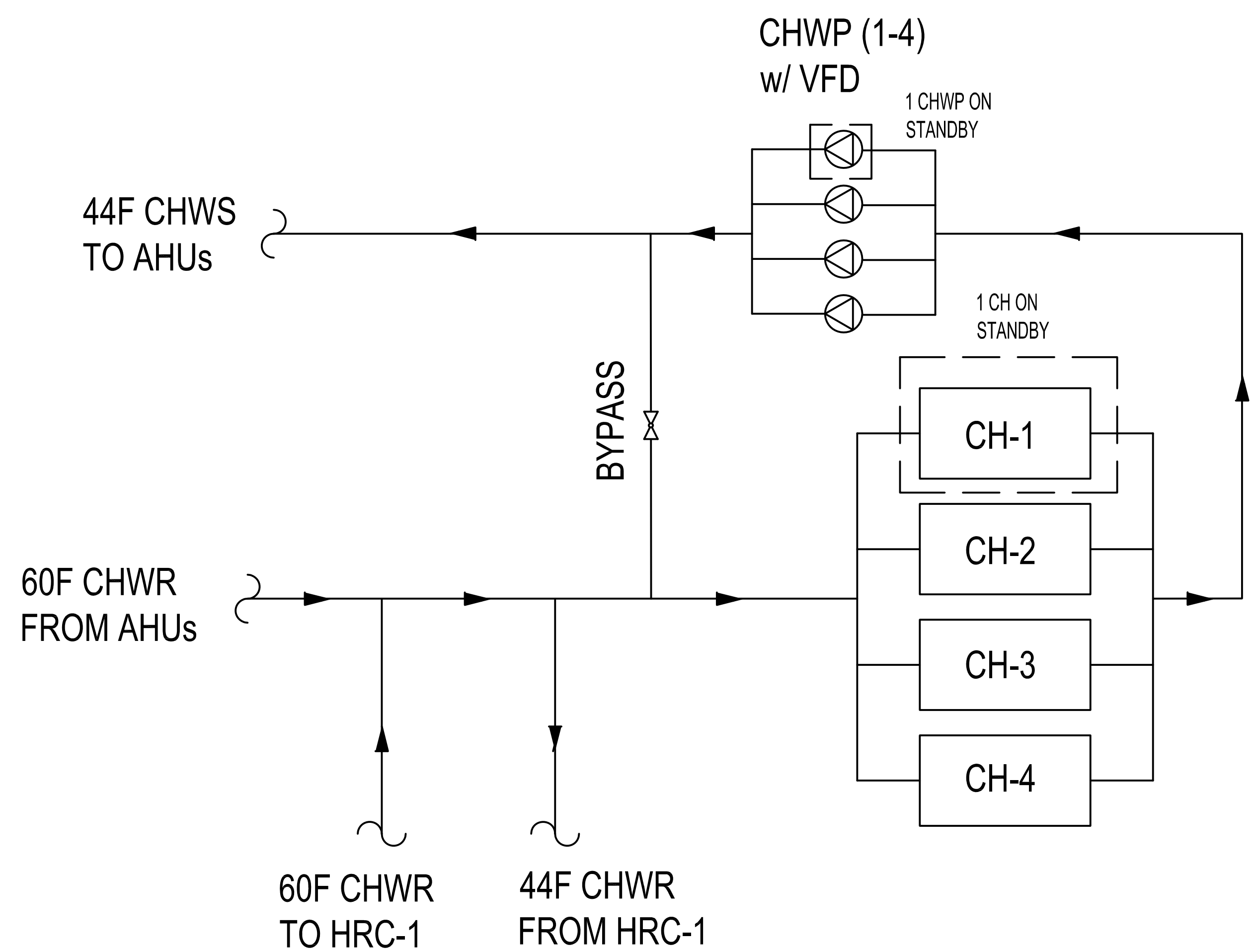
Room Number	Room Name	System	Area - Az	Wall Height	Volume	Occupancy Density (Pz)	Space Type - ASHRAE 170-2013	ASHRAE People Air Rate		Exhaust Air	Calculated Minimum OA	Design Supply OA (100% DOAS)
			Ft^2	Ft	Ft3			Rp (Per Person)	Ra (Per SqFt)	CFM	Vbz CFM	CFM
6171-01	Hospital Commander	B-AHU-3	245	8	1960	7	Office Space	5	0.06		50	350
6171-02	Toilet / Shower	B-AHU-3	66	8	528	1	Restroom			70		-
6171-03	Command Driver w/ File Storage	B-AHU-3	134	8	1072	3	Office Space	5	0.06		23	260
6171-04	Executive Officer	B-AHU-3	132	8	1056	3	Office Space	5	0.06		23	250
6171-05	Toilet / Shower	B-AHU-3	101	8	808	1	Restroom			70		-
6171-06	Kitchen	B-AHU-3	116	9	1044	1	Breakroom	5	0.12	35	19	180
6171-07	Copy	B-AHU-3	112	8	896	1	Storage	0	0.12	56	13	215
6171-08	Commander Secretary	B-AHU-3	95	8	760	3	Office Space	5	0.06		21	180
6171-09	Command Sergeant Major	B-AHU-3	182	8	1456	3	Office Space	5	0.06		26	215
6171-10	DCN Secretary	B-AHU-3	95	8	760	3	Office Space	5	0.06		21	0
6171-11	Command File	B-AHU-3	59	8	472	0	Storage	0	0.12		7	0
6171-12	Closet	B-AHU-3	20	9	180	0	Storage	0	0.12		2	0
6171-C01	Corridor	B-AHU-3	336	8.5	2856	0	Corridor	0	0.06		20	100
6172-01	Files and Storage	B-AHU-3	128	8	1024	0	Storage	0	0.12		15	225
6172-02	Command Staff Lounge	B-AHU-3	151	8	1208	4	Breakroom	5	0.12		38	355
6172-04	Paralegals	B-AHU-3	159	8	1272	3	Office Space	5	0.06		25	185
6172-05	Medical Claims	B-AHU-3	87	8	696	3	Office Space	5	0.06		20	95
6172-06	SJA (Staff Judge Advocate)	B-AHU-3	111	8	888	3	Office Space	5	0.06		22	190
6172-07	Conference	B-AHU-3	505	8.5	4292.5	26	Conference	5	0.06		160	690
6173-01	DCN	B-AHU-3	153	8	1224	3	Office Space	5	0.06		24	185
6173-02	DCCS	B-AHU-3	159	8	1272	3	Office Space	5	0.06		25	160
6173-03	Waiting Room	B-AHU-3	106	9	954	6	Reception Area	5	0.06		36	160
6173-04	Conference, Commander	B-AHU-3	376	8.5	3196	19	Office Space	5	0.06		118	365
6173-05	Electrical	B-AHU-3	141	8	1128	0	Storage	0	0.12		17	0
6173-06	COMM	B-AHU-3	157	8	1256	0	Storage	0	0.12		19	40
6173-07	Manager	B-AHU-3	77	8	616	1	Office Space	5	0.06		10	60
6173-08	Chief, MAO	B-AHU-3	126	8	1008	3	Office Space	5	0.06		23	90
6173-09	Protocol	B-AHU-3	122	8	976	3	Office Space	5	0.06		22	90
6173-10	Admin Resident	B-AHU-3	133	8	1064	3	Office Space	5	0.06		23	90
6173-11	DCN SGM	B-AHU-3	160	8	1280	3	Office Space	5	0.06		25	145
6173-12	DCOS	B-AHU-3	137	8	1096	3	Office Space	5	0.06		23	205
6173-13	DCA	B-AHU-3	154	8	1232	3	Office Space	5	0.06		24	145
6173-14	DCCS Secretary	B-AHU-3	107	8	856	3	Office Space	5	0.06		21	205
6173-15	DCA Secretary	B-AHU-3	93	8	744	3	Office Space	5	0.06		21	0
6173-16	Reception Filing	B-AHU-3	195	8	1560	3	Office Space	5	0.06		27	135
6173-C01	Corridor	B-AHU-3	145	8.5	1232.5	0	Corridor	0	0.06		9	55
6173-C02	Corridor	B-AHU-3	47	8.5	399.5	0	Corridor	0	0.06		3	0
6173-C03	Corridor	B-AHU-3	290	8.5	2465	0	Corridor	0	0.06		17	85
6173-C04	Hallway	B-AHU-3	319	8.5	2711.5	0	Corridor	0	0.06		19	95
6173-C05	Hallway	B-AHU-3	103	8.5	875.5	0	Corridor	0	0.06		6	0
6173-C06	Hallway	B-AHU-3	63	8.5	535.5	0	Corridor	0	0.06		4	0
6173-C07	Corridor	B-AHU-3	384	8.5	3264	0	Corridor	0	0.06		23	110
6174-01	Copy/File/Storage	B-AHU-3	179	8	1432	1	Office Space	5	0.06	90	16	235

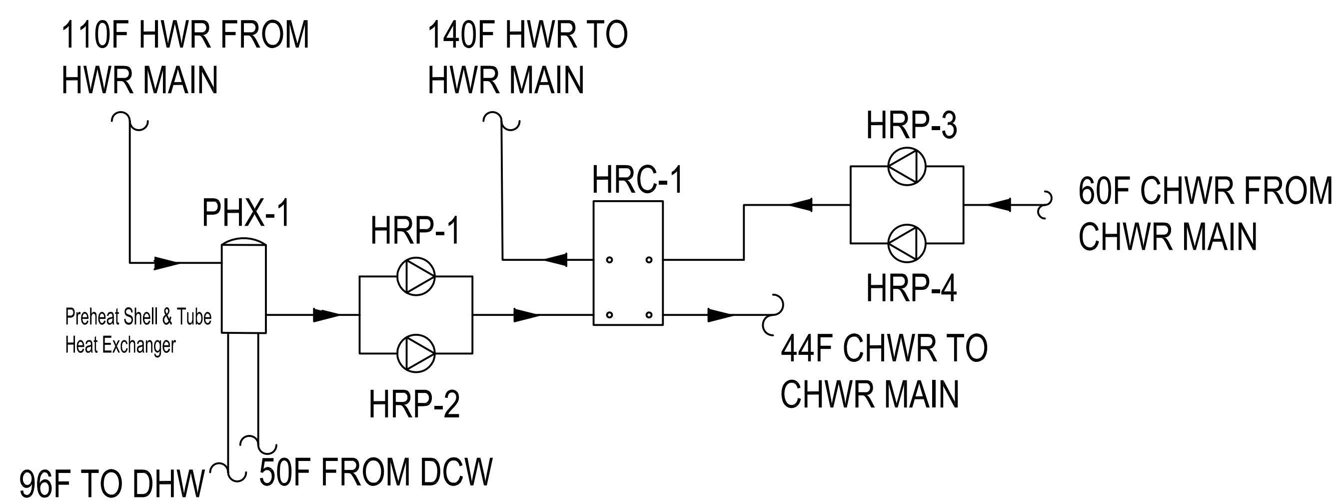
6174-02	Attorney	B-AHU-3	122	8	976	3	Office Space	5	0.06		22	185
6174-03	Attorney	B-AHU-3	116	8	928	3	Office Space	5	0.06		22	140
6174-04	Paralegals	B-AHU-3	169	8	1352	3	Office Space	5	0.06		25	280
6174-05	Pub Affairs Officer	B-AHU-3	125	8	1000	3	Office Space	5	0.06		23	285
6174-06	Electronic Illustration	B-AHU-3	276	8	2208	3	Office Space	5	0.06		32	545
6174-07	DCCS SGM	B-AHU-3	102	8	816	3	Office Space	5	0.06		21	100
6174-08	Electrical	B-AHU-3	176	8	1408	0	Storage	0	0.12		21	0
6174-09	Janitor	B-AHU-3	56	8	448	0	Storage	0	0.12	56	7	-
6174-10	UPS	B-AHU-3	77	8	616	0	Storage	0	0.12		9	40
6174-11	Reception	B-AHU-3	100	9	900	2	Reception Area	5	0.06		16	125
6174-12	Waiting Room	B-AHU-3	69	9	621	4	Reception Area	5	0.06		24	80
6174-13	Copy/File/Storage	B-AHU-3	115	8	920	0	Reception Area	5	0.06	58	7	180
6174-14	Admin Cubicle	B-AHU-3	110	8	880	2	Office Space	5	0.06		17	130
6174-C01	Corridor	B-AHU-3	921	8.5	7828.5	0	Corridor	0	0.06		55	335
6174-C02	Corridor	B-AHU-3	278	8.5	2363	0	Corridor	0	0.06		17	80
6174-C03	Corridor	B-AHU-3	122	8.5	1037	0	Corridor	0	0.06		7	0
6231-01	Elevator Vestibule	B-AHU-3	273	9	2457	1	Main Entry Lobbies	5	0.06		21	250
6231-02	Janitor	B-AHU-3	58	8	464	0	Storage	0	0.12	58	7	-
6231-03	Adjutant Office	B-AHU-3	113	8	904	3	Office Space	5	0.06		22	90
6231-04	Female Toilet	B-AHU-3	243	8	1944	4	Restroom			280		90
6231-05	Male Toilet	B-AHU-3	251	8	2008	4	Restroom			280		90
6231-06	Conference	B-AHU-3	274	8.5	2329	14	Conference	5	0.06		86	295
6231-07	Conference	B-AHU-3	180	8.5	1530	6	Conference	5	0.06		41	175
6231-08	Command Support	B-AHU-3	120	8	960	3	Office Space	5	0.06		22	90
6231-C01	Corridor	B-AHU-3	1438	8.5	12223	0	Corridor	0	0.06		86	1430
6231-C02	Corridor	B-AHU-3	215	8.5	1827.5	0	Corridor	0	0.06		13	65
6232-01	Adjutant Office	B-AHU-3	111	8	888	3	Office Space	5	0.06		22	100
6232-02	Adjutant Office	B-AHU-3	110	8	880	3	Office Space	5	0.06		22	100
6232-03	Copy	B-AHU-3	108	8	864	1	Office Space	5	0.06	54	11	180
6232-04	Chaplain Assistant	B-AHU-3	119	8	952	3	Office Space	5	0.06		22	145
6232-05	Chaplain Office	B-AHU-3	112	8	896	3	Office Space	5	0.06		22	195
6232-06	Chaplain Office	B-AHU-3	117	8	936	3	Office Space	5	0.06		22	230
6232-07	Chaplain Office	B-AHU-3	128	8	1024	3	Office Space	5	0.06		23	245
6232-08	Chaplain Office	B-AHU-3	111	8	888	3	Office Space	5	0.06		22	225
6232-09	Librarian Office	B-AHU-3	119	8	952	3	Office Space	5	0.06		22	220
6232-10	PC Workstation	B-AHU-3	144	10	1440	8	Science Libraries	10	5		800	350
6232-11	Circulation Reference	B-AHU-3	99	10	990	2	Science Libraries	10	5		515	165
6232-12	Book Cart / Assembly	B-AHU-3	118	10	1180	2	Science Libraries	10	5		610	0
6232-13	Conference	B-AHU-3	271	8.5	2303.5	14	Conference	5	0.06		86	295
6232-14	Conference / Interview	B-AHU-3	274	8.5	2329	14	Conference	5	0.06		86	295
6232-15	Conference	B-AHU-3	271	8.5	2303.5	14	Conference	5	0.06		86	300
6232-16	Secretary w/ Visitor	B-AHU-3	143	8	1144	4	Office Space	5	0.06		29	190
6232-17	Library Staff Workroom	B-AHU-3	120	8	960	2	Office Space	5	0.06		17	100
6232-18	Copy	B-AHU-3	71	8	568	1	Office Space	5	0.06	36	9	175
6232-C01	Corridor	B-AHU-3	1016	8.5	8636	0	Corridor	0	0.06		61	630
6232-C02	Corridor	B-AHU-3	137	8.5	1164.5	0	Corridor	0	0.06		8	0
6232-C03	Hallway	B-AHU-3	137	8.5	1164.5	0	Corridor	0	0.06		8	0

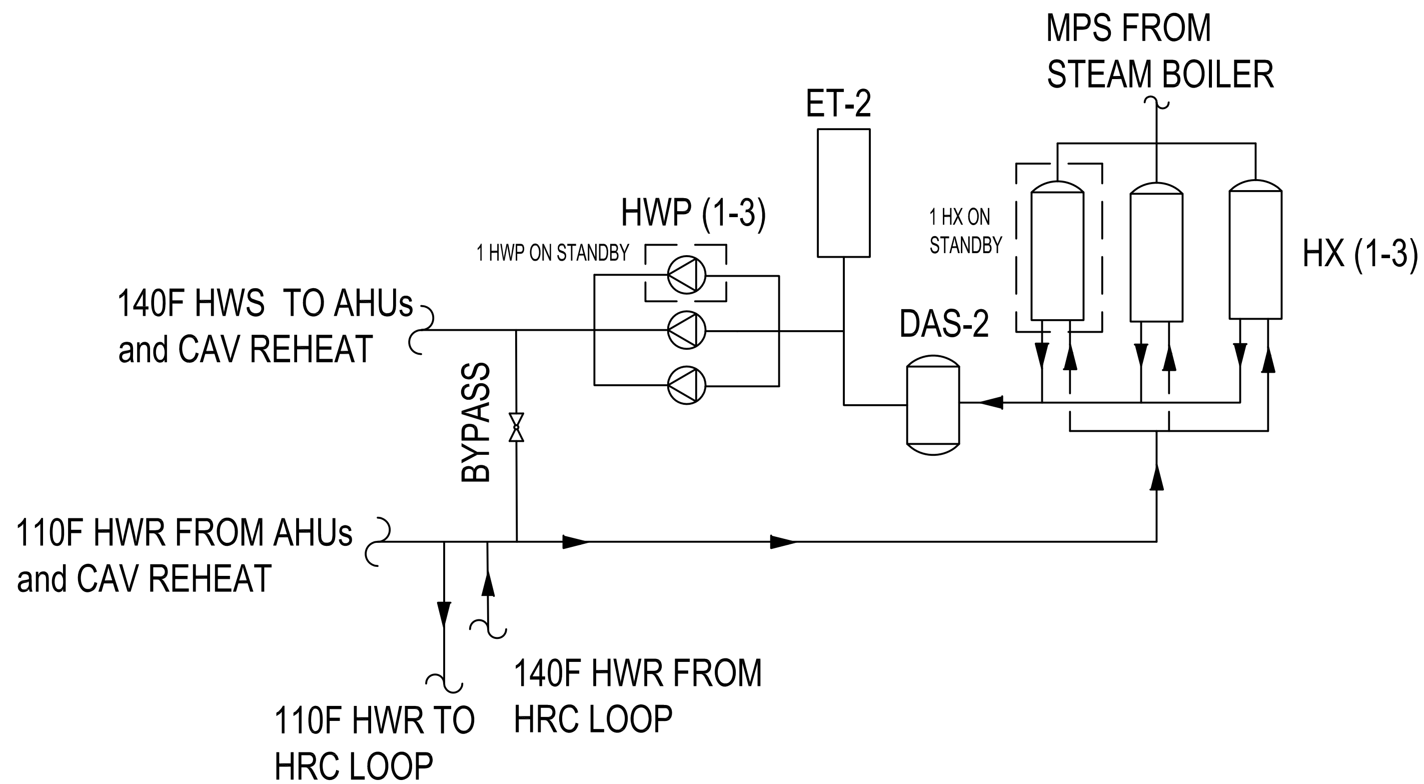
6233-02	Pneumatic Chute	B-AHU-3	171	8	1368	0	Mechanical					50
6233-03	Electrical	B-AHU-3	188	8	1504	0	Electrical					0
6233-04	Electrical	B-AHU-3	153	8	1224	0	Electrical					0
6233-05	Vending Area	B-AHU-3	171	8.5	1453.5	0	Reception Area	5	0.06		10	550
6233-06	Vending Area	B-AHU-3	498	8.5	4233	0	Reception Area	5	0.06		30	550
6234-01	Elevator Vestibule	B-AHU-3	257	9	2313	1	Main Entry Lobbies	5	0.06		20	235
6234-02	Periodical Area	B-AHU-3	120	8	960	0	Science Libraries	10	5		600	140
6234-03	Reading Area	B-AHU-3	244	8	1952	4	Science Libraries	10	5		1260	350
6234-04	Reference Holdings	B-AHU-3	359	8	2872	0	Science Libraries	10	5		1795	210
6234-05	Book Stack Area	B-AHU-3	408	8	3264	0	Science Libraries	10	5		2040	590
6234-06	Patient Advocate	B-AHU-3	242	8	1936	4	Office Space	5	0.06		35	260
6234-07	Patient Advocate Wait	B-AHU-3	148	9	1332	4	Office Space	5	0.06		29	270
6234-08	Janitor	B-AHU-3	40	8	320	0	Storage	0	0.12	20	5	-
6234-09	AGV Staging	B-AHU-3	272	8	2176	0	Storage	0	0.12		33	145
6234-10	Alcove	B-AHU-3	34	8	272	0	Storage	0	0.12		4	
6271-01	Conference	B-AHU-3	245	8.5	2082.5	8	Conference	5	0.06		55	310
6271-02	Conference	B-AHU-3	231	8.5	1963.5	7	Conference	5	0.06		49	230
6271-03	Female Toilet	B-AHU-3	123	8	984	0	Restroom			70		75
6271-04	Electrical	B-AHU-3	186	8	1488	0	Electrical					0
6271-05	Conference	B-AHU-3	424	8.5	3604	22	Conference	5	0.06		135	535
6271-06	Conference	B-AHU-3	396	8.5	3366	13	Conference	5	0.06		89	605
6271-07	Conference	B-AHU-3	255	8.5	2167.5	9	Conference	5	0.06		60	350
6271-08	Conference	B-AHU-3	233	8.5	1980.5	3	Conference	5	0.06		29	210
6271-C01	Corridor	B-AHU-3	119	8.5	1011.5	0	Corridor	0	0.06		7	40
6271-C02	Corridor	B-AHU-3	194	8.5	1649	0	Corridor	0	0.06		12	55
6272-01	Red Cross	B-AHU-3	175	8	1400	3	Office Space	5	0.06		26	180
6272-02	SEC W/Visitor Wait	B-AHU-3	128	8	1024	3	Office Space	5	0.06		23	260
6272-03	Senior Clinical NCO	B-AHU-3	95	8	760	3	Office Space	5	0.06		21	190
6272-04	Chief/Customer Service	B-AHU-3	99	8	792	3	Office Space	5	0.06		21	195
6272-05	Healthcare NCO	B-AHU-3	95	8	760	3	Office Space	5	0.06		21	195
6272-06	Chief/Nursing Admin	B-AHU-3	122	8	976	3	Office Space	5	0.06		22	190
6272-07	Admin/Nurse Recruiter	B-AHU-3	98	8	784	3	Office Space	5	0.06		21	145
6272-08	Night Admin	B-AHU-3	122	8	976	3	Office Space	5	0.06		22	205
6272-09	Interview	B-AHU-3	119	8	952	3	Office Space	5	0.06		22	85
6272-10	AV Equipment	B-AHU-3	60	8	480	1	Storage	0	0.12		7	50
6272-11	COMM	B-AHU-3	157	8	1256	0	Storage	0	0.12		19	40
6272-12	Electrical	B-AHU-3	165	8	1320	0	Electrical					0
6272-13	Copy/File	B-AHU-3	76	8	608	1	Office Space	5	0.06	38	10	175
6272-14	Interview	B-AHU-3	115	8	920	3	Office Space	5	0.06		22	85
6272-15	Interview	B-AHU-3	119	8	952	3	Office Space	5	0.06		22	85
6272-C02	Corridor	B-AHU-3	831	8.5	7063.5	0	Corridor	0	0.06		50	220
6273-01	Conference	B-AHU-3	389	8.5	3306.5	0	Conference	5	0.06		23	575
6273-02	Conference	B-AHU-3	294	8.5	2499	0	Conference	5	0.06		18	305
6273-03	Assembly Hall	B-AHU-3	2600	9	23400	220	Auditorium seating area	7.5	0.06		1806	4680
6273-04	Emergency OPS	B-AHU-3	434	8	3472	9	Office Space	5	0.06		71	690
6273-05	Classroom Writing	B-AHU-3	397	8	3176	20	Lecture Classroom	7.5	0.06		174	495
6273-06	Computer Training	B-AHU-3	388	8	3104	8	Lecture Classroom	7.5	0.06		83	480

6273-C01	Corridor	B-AHU-3	1166	8.5	9911	0	Corridor	0	0.06		70	335
6274-01	Infection Control	B-AHU-3	119	8	952	3	Office Space	5	0.06		22	90
6274-02	DIR CNTP	B-AHU-3	96	8	768	3	Office Space	5	0.06		21	195
6274-03	Staff Lounge	B-AHU-3	143	8	1144	4	Office Space	5	0.06		29	280
6274-04	Nurse Research	B-AHU-3	100	8	800	2	Office Space	5	0.06		16	195
6274-05	Nurse Research	B-AHU-3	98	8	784	2	Office Space	5	0.06		16	195
6274-06	Nurse Research	B-AHU-3	99	8	792	2	Office Space	5	0.06		16	225
6274-07	Chief/Nursing Research	B-AHU-3	112	8	896	2	Office Space	5	0.06		17	250
6274-08	Copy/File	B-AHU-3	81	8	648	1	Office Space	5	0.06	41	10	175
6274-09	Nurse Research	B-AHU-3	100	8	800	3	Office Space	5	0.06		21	95
6274-10	Nurse Methods	B-AHU-3	100	8	800	3	Office Space	5	0.06		21	95
6274-11	Staff Toilet	B-AHU-3	51	8	408	1	Restroom			70		-
6274-12	Staff Toilet	B-AHU-3	51	8	408	1	Restroom			70		-
6274-13	Storage	B-AHU-3	92	9	828	0	Storage	0	0.12		11	60
6274-14	Infection Control Staff	B-AHU-3	119	8	952	3	Office Space	5	0.06		22	145
6274-C01	Corridor	B-AHU-3	708	8.5	6018	0	Corridor	0	0.06		42	200
6311-01	Classroom	B-AHU-3	641	8	5128	29	Lecture Classroom	7.5	0.06		256	715
6311-02	Male Toilet	B-AHU-3	142	8	1136	2	Restroom			140		60
6311-03	Female Toilet	B-AHU-3	136	8	1088	2	Restroom			140		-
6311-04	Janitor	B-AHU-3	55	8	440	0	Storage	0	0.12	28	7	-
6311-05	Elevator Vestibule	B-AHU-3	348	10	3480	0	Main Entry Lobbies	5	0.06		21	840
6311-C01	Corridor	B-AHU-3	49	8.5	416.5	0	Corridor	0	0.06		3	0
6312-01	Storage	B-AHU-3	204	8	1632	0	Storage	0	0.12		24	125
6312-02	Secretary w/ Visitor	B-AHU-3	146	8	1168	4	Office Space	5	0.06		29	135
6312-03	Research Asst/Protocol	B-AHU-3	177	8	1416	3	Office Space	5	0.06		26	340
6312-04	Training Personnel	B-AHU-3	278	8	2224	6	Office Space	5	0.06		47	470
6312-05	Copy/File	B-AHU-3	95	8	760	0	Office Space	5	0.06	48	6	140
6312-06	Chief, Training	B-AHU-3	108	8	864	3	Office Space	5	0.06		21	145
6312-07	Reception (Secretary)	B-AHU-3	59	8	472	3	Office Space	5	0.06		19	105
6312-08	NCOIC	B-AHU-3	96	8	768	3	Office Space	5	0.06		21	190
6312-09	AV Supply	B-AHU-3	55	8	440	0	Office Space	5	0.06		3	40
6312-10	Computer Training	B-AHU-3	376	8	3008	10	Office Space	5	0.06		73	645
6312-C01	Hallway	B-AHU-3	70	8.5	595	0	Corridor	0	0.06		4	0
6312-C02	Hallway	B-AHU-3	73	8.5	620.5	0	Corridor	0	0.06		4	0
6312-C03	Corridor	B-AHU-3	141	8.5	1198.5	0	Corridor	0	0.06		8	40
6312-C04	Corridor	B-AHU-3	74	8.5	629	0	Corridor	0	0.06		4	0

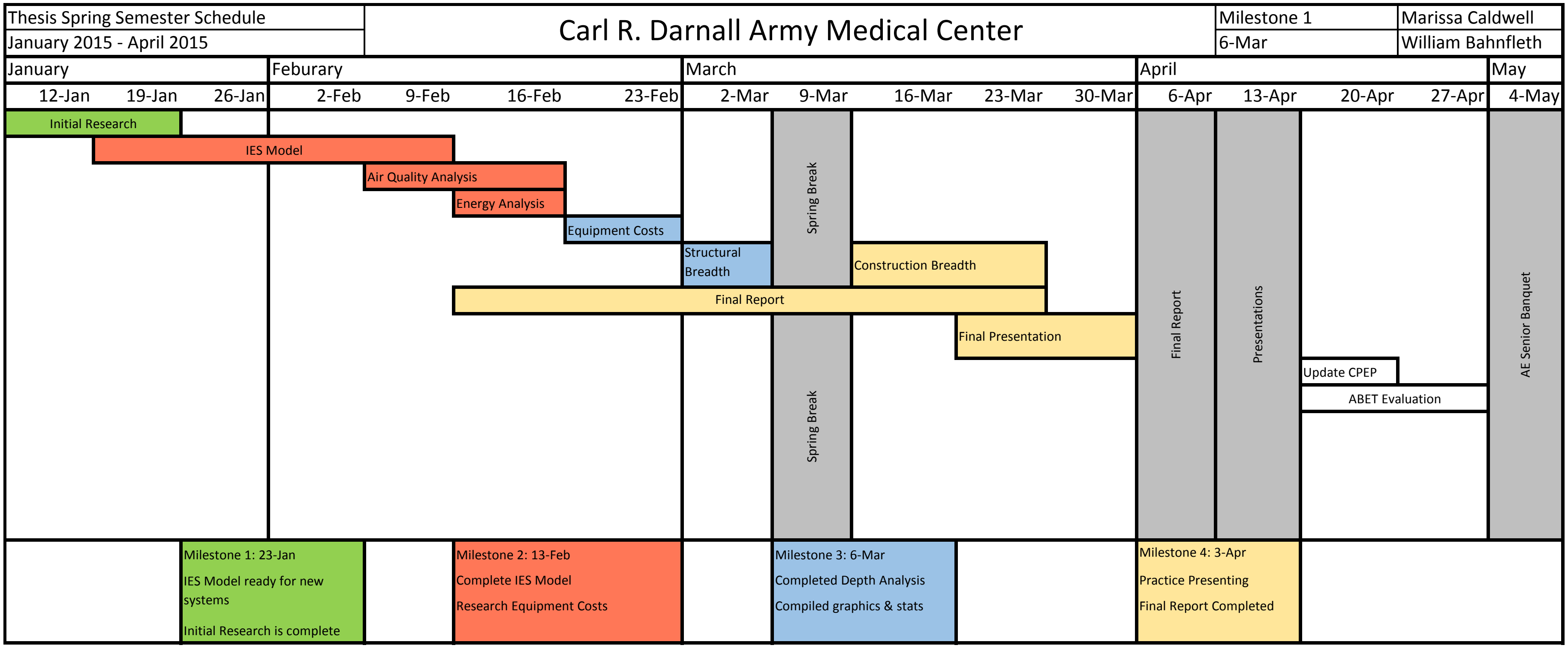

GENERAL EXHAUST
ENTHALPY WHEEL
PRE-CONDITIONED OUTDOOR AIR
GENERAL EXHAUST
HEATING COIL
HWR 110F
HWS 140F
HUMIDIFIER
SHUC
SHU
COOLING COIL
CHWR 60F
CHWS 44F
FAN
FILTER
SUPPLY AIR


CHWP (1-4)
w/ VFD
1 CHWP ON
STANDBY
44F CHWS
TO AHUs
1 CH ON
STANDBY
BYPASS
CH-1
CH-2
CH-3
CH-4
60F CHWR
FROM AHUs
60F CHWR
TO HRC-1
44F CHWR
FROM HRC-1


110F HWR FROM
HWR MAIN
140F HWR TO
HWR MAIN
HRP-3
HRC-1
60F CHWR FROM
CHWR MAIN
PHX-1
HRP-1
Preheat Shell & Tube
Heat Exchanger
HRP-4
44F CHWR TO
CHWR MAIN
HRP-2
96F TO DHW
50F FROM DCW

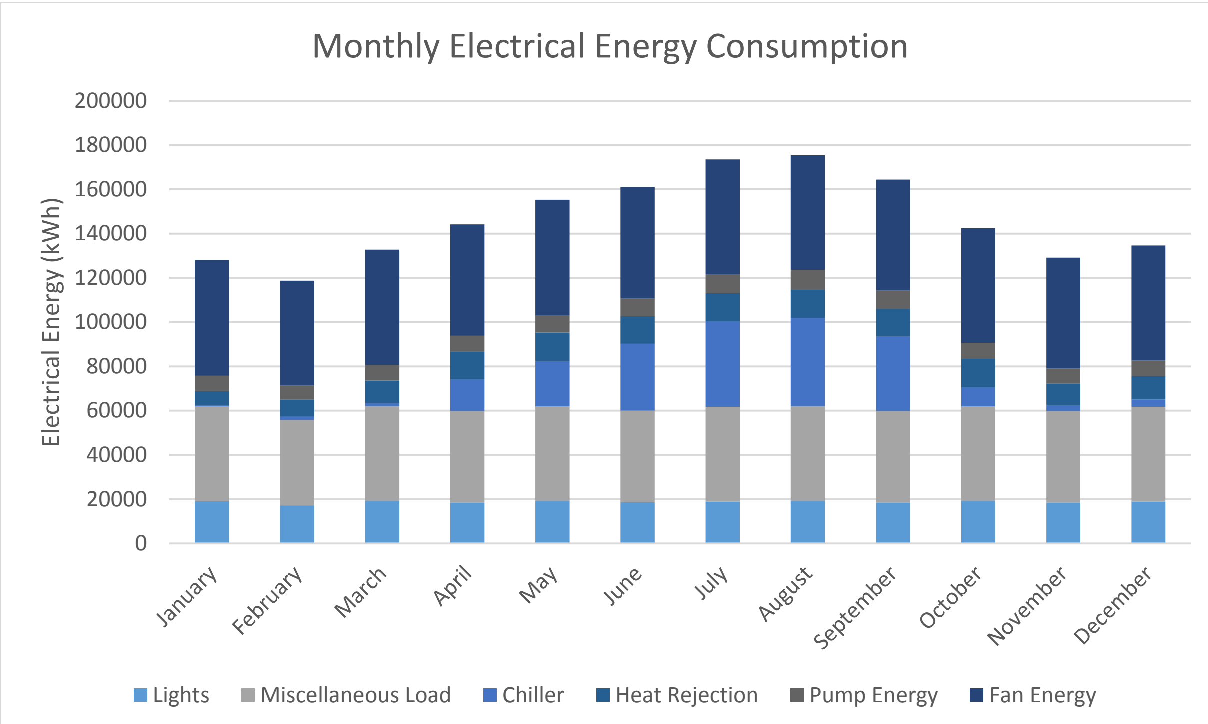

MPS FROM
STEAM BOILER
ET-2
HWP (1-3)
1 HWP ON STANDBY
1 HX ON
STANDBY
HX (1-3)
140F HWS TO AHUs
and CAV REHEAT
DAS-2
BYPASS
110F HWR FROM AHUs
and CAV REHEAT
140F HWR FROM
HRC LOOP
110F HWR TO
HRC LOOP

Appendix B

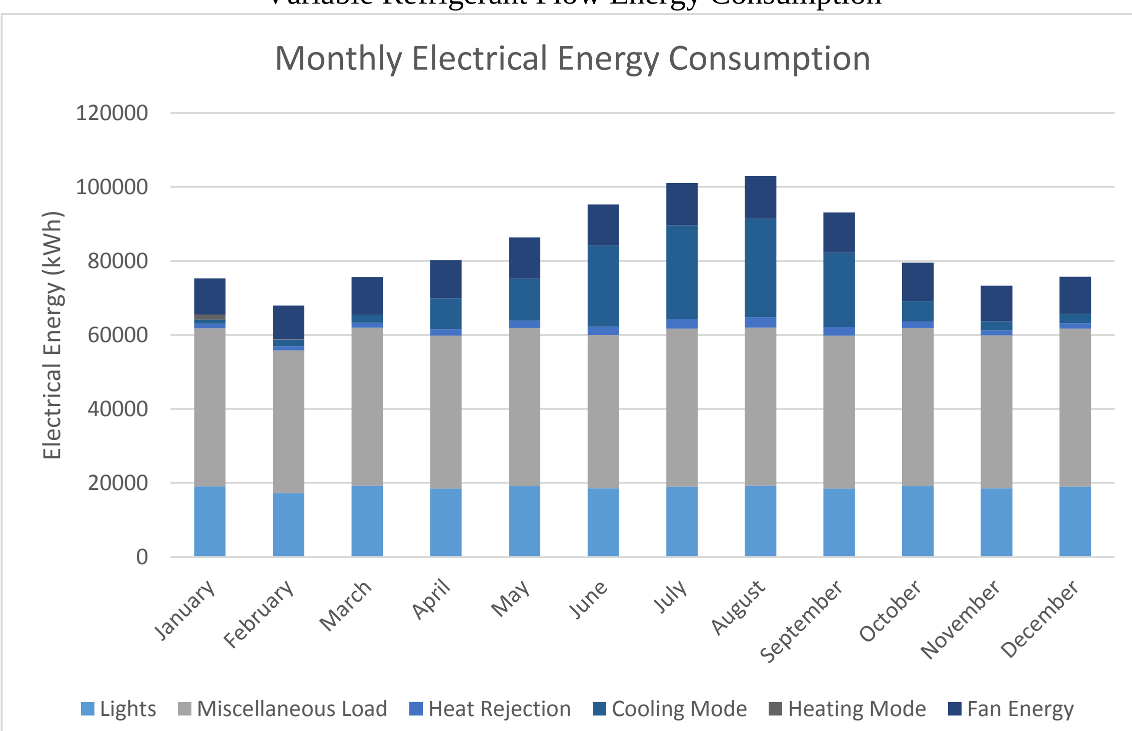

Thesis Spring Semester Schedule
January 2015 - April 2015
Carl R. Darnall Army Medical Center
Milestone 1
6-Mar
Marissa Caldwell
William Bahnfleth
January
Feburary
March
April
May
12-Jan
19-Jan
26-Jan
2-Feb
9-Feb
16-Feb
23-Feb
2-Mar
9-Mar
16-Mar
23-Mar
30-Mar
6-Apr
13-Apr
20-Apr
27-Apr
4-May
Initial Research
IES Model
Air Quality Analysis
Energy Analysis
Equipment Costs
Structural Breadth
Spring Break
Construction Breadth
Final Report
Final Presentation
Spring Break
Final Report
Presentations
Update CPEP
ABET Evaluation
AE Senior Banquet
Milestone 1: 23-Jan
IES Model ready for new systems
Initial Research is complete
Milestone 2: 13-Feb
Complete IES Model
Research Equipment Costs
Milestone 3: 6-Mar
Completed Depth Analysis
Compiled graphics & stats
Milestone 4: 3-Apr
Practice Presenting
Final Report Completed

Appendix C

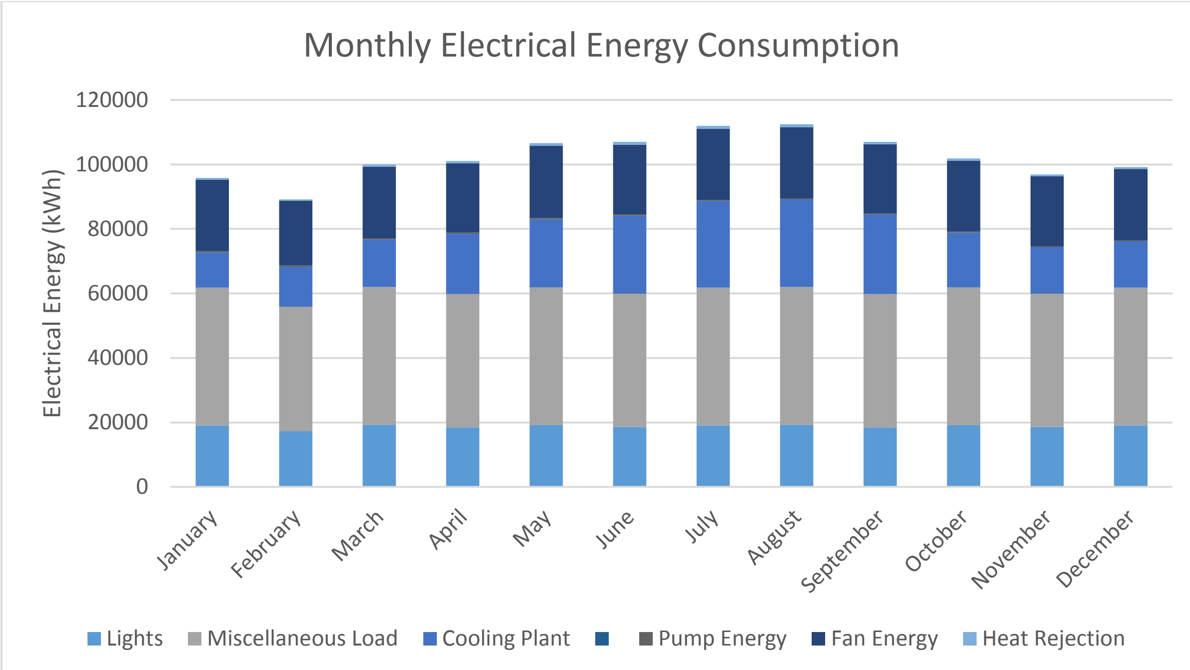
Original Design Energy Consumption



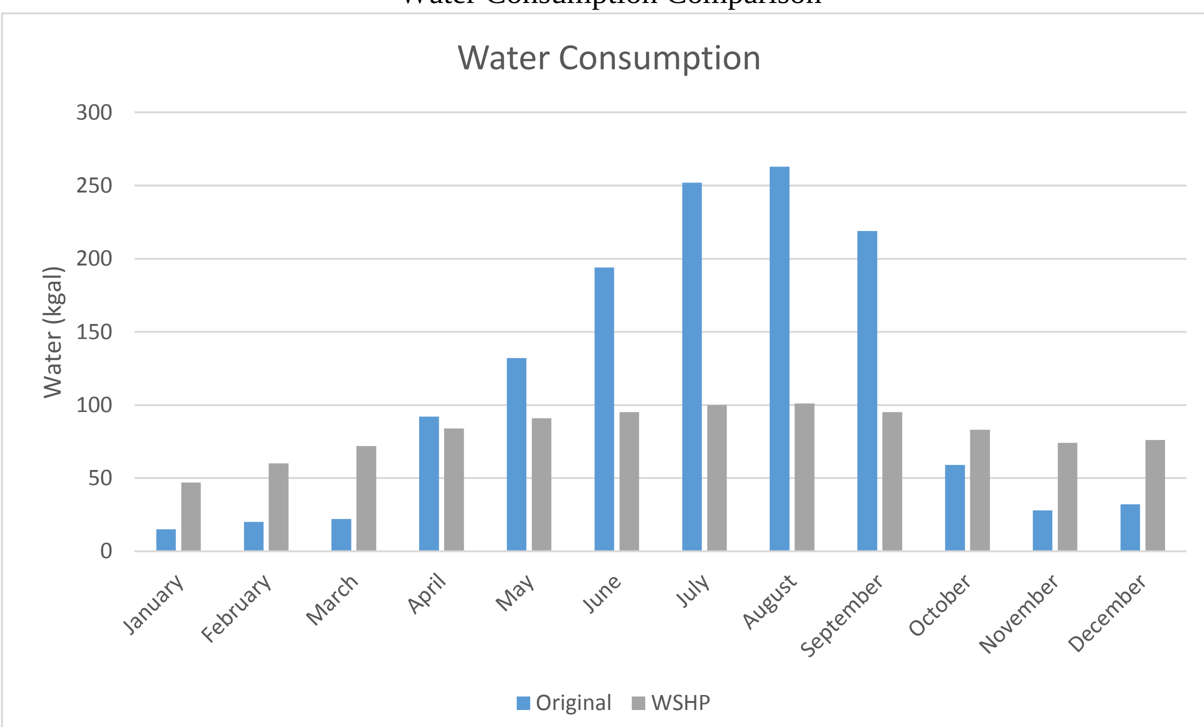
Variable Refrigerant Flow Energy Consumption

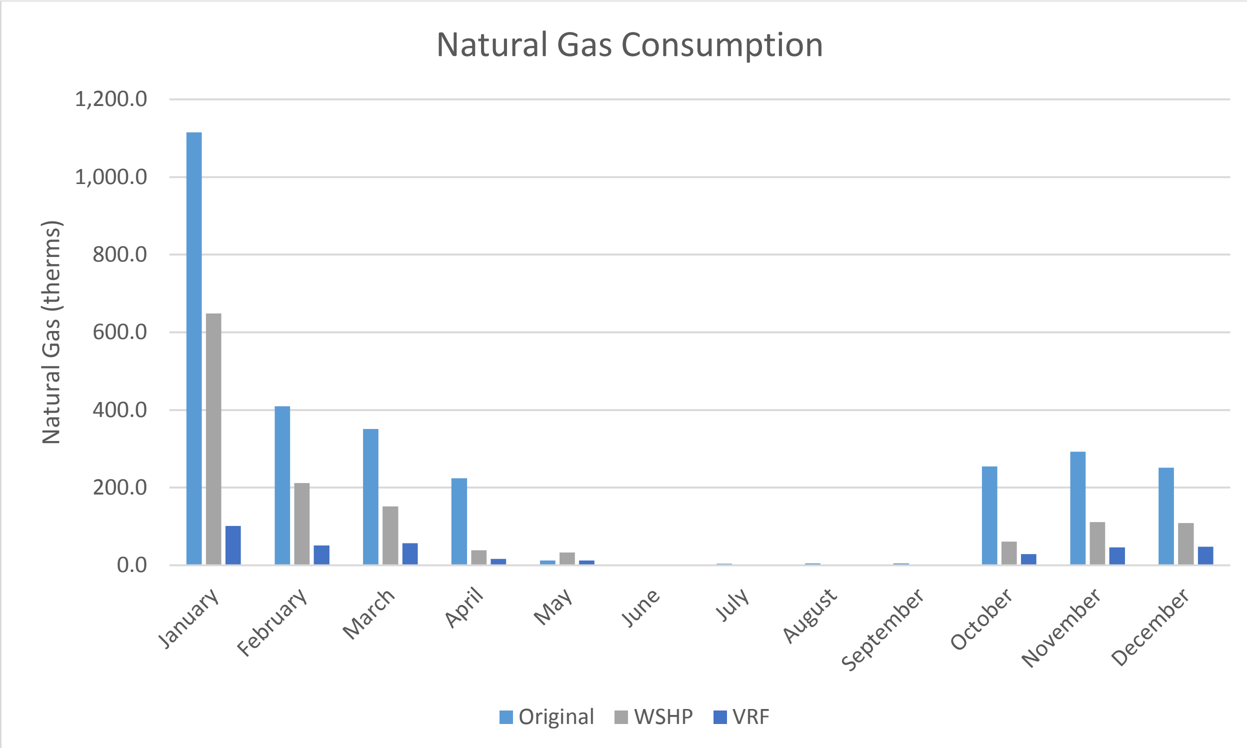


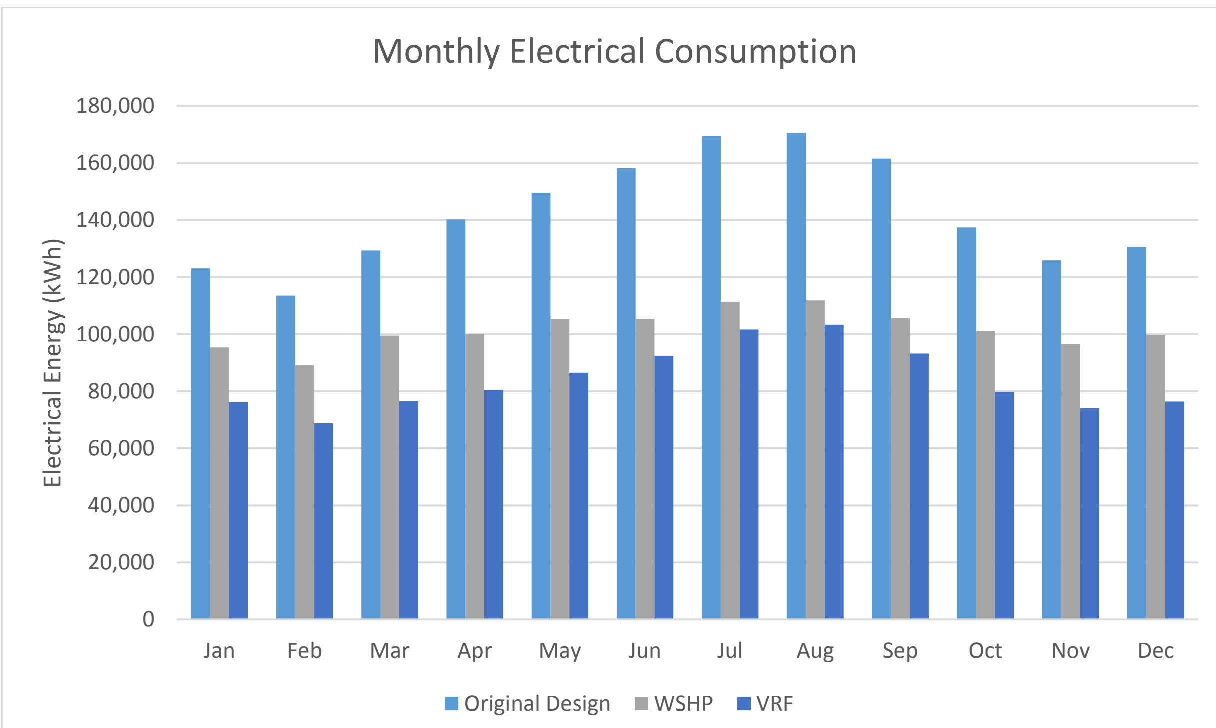
Water Source Heat Pump Energy Consumption



Water Consumption Comparison




Natural Gas Consumption
Natural Gas (therms)
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
January
February
March
April
May
June
July
August
September
October
November
December
Original
WSHP
VRF


Monthly Electrical Consumption
Electrical Energy (kWh)
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Original Design
WSHP
VRF

Multi V III & Mini

Liquid line diameter	ft.	lbs./ft.	charge (lbs.)
7/8	0	0.237	0
3/4	25	0.178	4.45
5/8	0	0.116	0
1/2	0	0.079	0
3/8	102	0.041	4.182
1/4	161.5	0.015	2.4225
			11.0545

		CF	charge (lbs.)
Enter ODU Size →	96	0	20.7
max number of IDU's	16		

Quantity of IDU's by Frame (capacity)				
Number of HR units		3	1.1	3.30
	B1/B3/CE	0	0.37	0.00
	B2/B4	0	0.82	0.00
	BG	3	0.97	2.91
	BR	0	1.37	0.00
	BH	0	0.57	0.00
	B8	0	2.2	0.00
	CF	0	0.82	0.00
	NJ (12-30k)	0	1.04	0.00
	NJ (36k)	0	1.57	0.00
	NK	0	2.00	0.00
	S5/S8	0	0.62	0.00
	SE	0	0.53	0.00
	TJ	0	0.44	0.00
	TL	0	0.35	0.00
	TN (9-15k)	8	1.06	8.48
	TN (36k)	0	1.41	0.00
	TM(18-24k)	0	1.41	0.00
	TM (42-48k)	0	1.41	0.00
	TP	0	1.06	0.00
	TQ	0	0.71	0.00
	TR (5-7k)	0	0.40	0.00
	TR (9-12k)	0	0.55	0.00
	VE	0	0.22	0.00
	VJ	0	0.77	0.00
		11		14.69

Data and calculations subject to change without notice

VRF-CA-EK-001-US 013A02

ODU size	Max # of IDUs	Factory Ref. Cha	CF (lbs)
36	6	6.6	-1.1
47	8	6.6	0
53	9	6.6	0
72	13	12.1	0
96	16	20.7	0
121	20	20.7	0
144	23	20.7	0
168	29	32.8	0
192	32	32.8	0
216	35	32.8	0
240	39	41.4	0
264	42	41.4	0
288	45	41.4	0
312	52	53.5	0
336	55	53.5	0
360	58	53.5	0
384	61	62.1	0
408	64	62.1	0
432	64	62.1	0

Trim Charge	25.74
Factory Refrigerant Charge	20.7
Total Refrigerant Charge	46.4445

You must fill in all of the blue boxes in order to get the proper refrigerant charge

Forgetting to enter even just one value could throw off your charge calculation

If there the correct value is 0 (zero) enter "0" into the box

Y-Branches, Headers, and Elbows are not considered in the spreadsheet

LATS calculates Y-Branches and Headers by their component lengths

You could account for Y-Branches and Headers by their component lengths as does LATS

The yellow region on the left side of the spreadsheet is for equations, calculations and notes

You may delete or enter anything you wish here and it will not effect the refrigerant calculation

Note: This program is not a substitute for the technician's own calculations.
All results from this program are approximate and should be verified by the technician's own calculations.
LG Electronics U.S.A. Inc, does not warranty the results of this program nor does it make any

TABLE 4-2 Data and Safety Classifications for Refrigerant Blends

Refrigerant Number	Composition (Mass %)	Composition Tolerances	OEL[b], ppm v/v	Safety Group	RCL[a] (ppm v/v)	RCL[a] (lb/Mcf)	RCL[a] (g/m^3)	Highly Toxic or Toxic[f] Under Code Classification
Zeotropes								
400	R-12/114 (must be specified)			A1				Neither
	(50.0/50.0)		1000	A1	28,000	10	160	
	(60.0/40.0)		1000	A1	30,000	11	170	
401A	R-22/152a/124 (53.0/13.0/34.0)	(±2.0/+0.5, −1.5/±1.0)	1000	A1	27,000	6.6	110	Neither
401B	R-22/152a/124 (61.0/11.0/28.0)	(±2.0/+0.5, −1.5/±1.0)	1000	A1	30,000	7.2	120	Neither
401C	R-22/152a/124 (33.0/15.0/52.0)	(±2.0/+0.5, −1.5/±1.0)	1000	A1	20,000	5.2	84	Neither
402A	R-125/290/22 (60.0/2.0/38.0)	(±2.0/+0.1,−1.0/±2.0)	1000	A1	66,000	17	270	Neither
402B	R-125/290/22 (38.0/2.0/60.0)	(±2.0/+0.1,−1.0/±2.0)	1000	A1	63,000	15	240	Neither
403A	R-290/22/218 (5.0/75.0/20.0)	(+0.2, −2.0/±2.0/±2.0)	1000	A2	33,000	7.6	120	Neither
403B[g]	R-290/22/218 (5.0/56.0/39.0)	(+0.2, −2.0/±2.0/±2.0)	1000	A1	70,000	18	290	Neither
404A[i]	R-125/143a/134a (44.0/52.0/4.0)	(±2.0/±1.0/±2.0)	1000	A1	130,000	31	500	Neither
405A	R-22/152a/142b/C318 (45.0/7.0/5.5/42.5)	individual components = (±2.0/±1.0/±1.0/±2.0); sum of R-152a and R-142b = (+0.0, −2.0)	1000		57,000	16	260	Neither
406A	R-22/600a/142b (55.0/4.0/41.0)	(±2.0/±1.0/±1.0)	1000	A2	21,000	4.7	25	Neither
407A[g]	R-32/125/134a (20.0/40.0/40.0)	(±2.0/±2.0/±2.0)	1000	A1	83,000	19	300	Neither
407B[g]	R-32/125/134a (10.0/70.0/20.0)	(±2.0/±2.0/±2.0)	1000	A1	79,000	21	330	Neither
407C[g]	R-32/125/134a (23.0/25.0/52.0)	(±2.0/±2.0/±2.0)	1000	A1	81,000	18	290	Neither
407D	R-32/125/134a (15.0/15.0/70.0)	(±2.0/±2.0/±2.0)	1000	A1	68,000	16	250	Neither
407E[g]	R-32/125/134a (25.0/15.0/60.0)	(±2.0/±2.0/±2.0)	1000	A1	80,000	17	280	Neither
407F	R-32/125/134a (30.0/30.0/40.0)	(±2.0/±2.0/±2.0)	1000	A1	95,000	20	320	Neither
408A[g]	R-125/143a/22 (7.0/46.0/47.0)	(±2.0/±1.0/±2.0)	1000	A1	95,000	21	340	Neither
409A	R-22/124/142b (60.0/25.0/15.0)	(±2.0/±2.0/±1.0)	1000	A1	29,000	7.1	110	Neither
409B	R-22/124/142b (65.0/25.0/10.0)	(±2.0/±2.0/±1.0)	1000	A1	30,000	7.3	120	Neither
410A[i]	R-32/125 (50.0/50.0)	(+0.5, −1.5/+1.5, −0.5)	1000	A1	140,000	26	420	Neither
410B[i]	R-32/125 (45.0/55.0)	(±1.0/±1.0)		A1	140,000	27	430	Neither
411A[e]	R-1270/22/152a (1.5/87.5/11.0)	(+0.0, −1.0/+2.0, −0.0/+0.0, −1.0)	990	A2	14,000	2.9	46	Neither
411B[e]	R-1270/22/152a (3.0/94.0/3.0)	(+0.0, −1.0/+2.0, −0.0/+0.0, −1.0)	980	A2	13,000	2.8	45	Neither
412A	R-22/218/142b (70.0/5.0/25.0)	(±2.0/±2.0/±1.0)	1000	A2	22,000	5.1	82	Neither
413A	R-218/134a/600a (9.0/88.0/3.0)	(±1.0/±2.0/+0.0,−1.0)	1000	A2	22,000	5.8	94	Neither

a. Data taken from J.M. Calm, "ARTI Refrigerant Database," Air- Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 2001; J.M. Calm, "Toxicity Data to Determine Refrigerant Concentration Limits," Report DE/CE 23810-110, Air- Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, September 2000; J.M. Calm, "The Toxicity of Refrigerants," *Proceedings of the 1996 International Refrigeration Conference*, Purdue University, West Lafayette, IN, pp. 157–62, 1996; D.P. Wilson and R.G. Richard, "Determination of Refrigerant Lower Flammability Limits (LFLs) in Compliance with Proposed Addendum p to ANSI/ASHRAE Standard 34-1992 (1073-RP)," *ASHRAE Transactions* 2002, 108(2); D.W. Coombs, "HFC-32 Assessment of Anesthetic Potency in Mice by Inhalation," Huntingdon Life Sciences Ltd., Huntingdon, Cambridgeshire, England, February 2004 and amendment February 2006; D.W. Coombs, "HFC-22 An Inhalation Study to Investigate the Cardiac Sensitization Potential in the Beagle Dog," Huntingdon Life Sciences Ltd., Huntingdon, Cambridgeshire, England, August 2005; and other toxicity studies.

b. Azeotropic refrigerants exhibit some segregation of components at conditions of temperature and pressure other than those at which they were formulated. The extent of segregation depends on the particular azeotrope and hardware system configuration.

c. The exact composition of this azeotrope is in question, and additional experimental studies are needed.

d. R-507, R-508, and R-509 are allowed alternative designations for R-507A, R-508A, and R-509A due to a change in designations after assignment of R-500 through R-509. Corresponding changes were not made for R-500 through R-506.

e. The RCL values for these refrigerant blends are approximated in the absence of adequate data for a component comprising less than 4% m/m of the blend and expected to have only a small influence in an acute, accidental release.

f. *Highly toxic*, *toxic*, or *neither*, where *highly toxic* and *toxic* are as defined in the *International Fire Code*, *Uniform Fire Code*, and OSHA regulations, and *neither* identifies those refrigerants having lesser toxicity than either of those groups.[1,2,3]

g. At locations with altitudes higher than 4920 ft (1500 m), the ODL and RCL shall be 69,100 ppm.

h. The OELs are eight-hour TWAs as defined in Section 3 unless otherwise noted; a "C" designation denotes a ceiling limit.

i. At locations with altitudes higher than 3300 ft (1000 m) but below or equal to 4920 ft (1500 m), the ODL and RCL shall be 112, 000 ppm, and at altitudes higher than 4920 ft (1500 m), the ODL and RCL shall be 69,100 ppm.

	OEL (ppm/v/v)	Safety Group	RCL			Highly Toxic or Toxic Under Code Classification
			ppm v/v	lb/Mcf	g/m^3	
R-410A	1,000	A1	140,000	26	420	Neither

Note: Institutional Occupancies require 50% of this value

	Zone	Outdoor Unit		Capacity (tons)	# Indoor Units	RCL (lb/Mcf)	Comply with ASHRAE 15?
		Cooling	Heating				
Zoning 1	L5 South Exterior	264,000	297,000	22	23	22.1436	NO
Zoning 2	L5 South East Ext	144,000	162,000	12	12	19.4969	NO
	L5 South West Ext	120,000	135,000	10	11	19.7589	NO
Zoning 3	L5 South West Ext	96,000	108,000	8	11	12.171	YES
	L5 S Exterior Zone	96,000	108,000	8	10	12.1502	YES
	L5 SE Exterior Zone	96,000	108,000	8	10	11.8223	YES
	L5 SE Corner Zone	96,000	108,000	8	10	11.6762	YES

SmartSource™ Single-Stage Horizontal Water Source Heat Pumps

SmartSource™ water source heat pumps are designed using the latest technology to achieve some of the highest efficiency single-stage products in the market today. Daikin is the first manufacturer to offer ECM variable fan motors as a standard option across the whole product line, even in the smallest cabinet sizes, for unmatched performance and comfort in the industry.

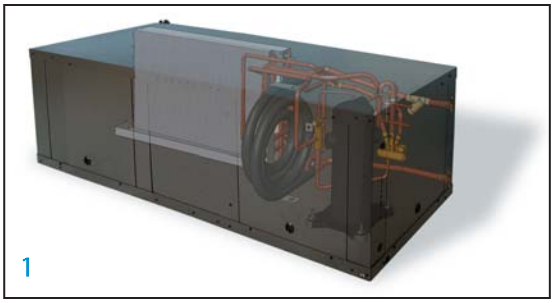
High EERs that far exceed ASHRAE 90.1 standards make these units perfect for LEED projects and rebate opportunities. All units are available geothermal ready from the factory with many features to easily match your application requirements.

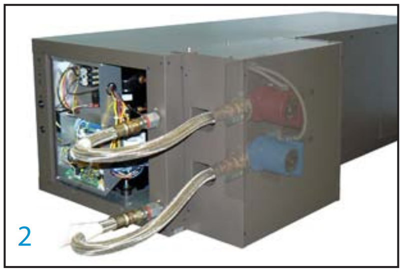
1. **ECM Fan Motor:** 4 field adjustable fan speeds with 5 operating mode options provide a wide range of airflow selections for quieter operation and lower energy consumption.
2. **Copeland K-5 Scroll:** or LG Rotary available in a variety of commercial voltages, mounted on a double isolation system for reduced sound and vibration.
3. **Refrigerant Circuit:** Utilizes R-410A refrigerant with a bi-flow thermal expansion valve for easy metering and four way solenoid reversing valve.
4. **MicroTech III Controls:** Easy open-protocol integration with optional LonWorks® or BACnet®.
5. **Unit Status LED:** Instant visuals on unit operation for easy troubleshooting and advanced diagnostics.
6. **4-Sides Filter Rack with Standard 2" or Optional 4" Filters:** Designed for easy filter maintenance.
   MERV 8 & 13 filter options with gasketed filter rack meet LEED-NC EQc5 applications with leakage rate at less than 4 CFM per square foot of filter area at 0.5"ESP.
7. **Stainless Steel Drain Plan:** Sloped with lipless drain connection for positive condensate flow, meets ASHRAE 62.1 Section 5.11.
8. **Flush Mounted Fittings:** Easy one wrench connection, securely fastened to the cabinet corner posts.
9. **Blower and Motor Orifice Ring:** Easy service removal without having to remove the blower housing or disconnecting the unit from the duct work.
10. **Durable Cabinet Construction:** Heavy gauge steel with powder coated textured paint, lined with cleanable foil-faced insulation on the airside.

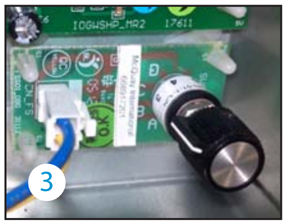
Performance Data

Unit Size	Stage	CFM	GPM	Water Loop (Boiler Tower)				Ground Loop (Geothermal)			
				Cooling		Heating		Cooling		Heating	
				Btu/hr	EER	Btu/hr	COP	Btu/hr	EER	Btu/hr	COP
007	Full Load	250	2.2	8000	16.8	9800	5.5	8400	19.8	6200	3.9
009	Full Load	300	2.4	9700	16.0	12000	5.5	10200	18.8	7500	3.8
012	Full Load	400	3.3	12700	15.5	15700	5.4	13300	18.1	10000	3.9
015	Full Load	500	3.8	15300	18.1	19100	5.9	16000	21.2	11700	4.1
019	Full Load	600	4.4	17500	17.3	22600	5.7	18700	20.6	13800	4.1
024	Full Load	800	6.5	26,200	18.8	28,900	6.0	27,500	22.2	17,700	4.1
030	Full Load	1,000	7.5	30,000	17.3	33,600	5.8	31,300	20.1	21,600	4.1
036	Full Load	1,250	9.0	37,300	19.2	40,800	6.0	38,500	22.0	26,200	4.3
042	Full Load	1,400	10.5	43,900	17.5	48,600	5.4	45,500	20.2	31,300	4.0
048	Full Load	1,600	12.2	50,500	17.2	57,100	5.3	52,700	19.9	36,900	4.0
060	Full Load	2,000	16.0	63,700	17.4	74,200	5.2	66,300	20.0	46,500	3.8
070	Full Load	2,160	17.5	73,400	15.9	89,000	5.0	75,700	18.0	55,800	3.7

Many Factory-Mounted Options and Accessories







1. Hot Gas Reheat
2. Loop Circulating Pumps
3. Field Adjustment of ECM Fan Motor
4. Waterside Economizer

Dimensions in inches (mm)

Unit Size	Overall Cabinet Dimensions		
	W	L	H
007, 009, 012	21.60" (549)	45.00" (1143)	17.30" (439)
015, 019	22.40" (569)	50.30" (1278)	19.30" (490)
024, 030	22.40" (569)	63.30" (1608)	19.30" (490)
036	25.00" (635)	73.00" (1854)	21.30" (541)
042, 048	25.00" (635)	78.40" (1991)	21.30" (541)
060, 070	25.00" (635)	83.80" (2129)	21.30" (541)

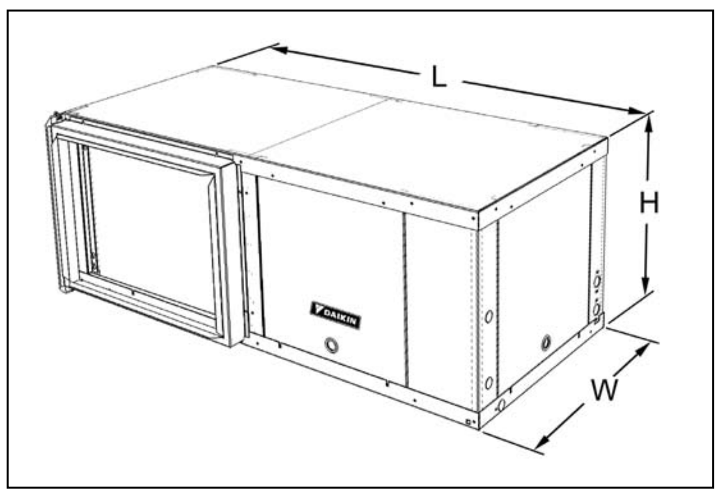
Voltages

Unit Size	Horizontal Unit		
	Volts	Hz	Phase
007-012	208-230	60	1
	265	60	1
	115	60	1
019	208-230	60	1
	265	60	1
024-036	208-230	60	1
	265	60	1
	208-230	60	3
	460	60	3
042-070	208-230	60	1
	208-230	60	3
	460	60	3

Four Unique Dehumidification Options:

- **Smart Dehumidification –** Uses hot gas reheat, humidistat, 2-stage thermostat & smart air flow management for precise humidity control.
- **Simplified Dehumidification –** Uses a 3-stage thermostat to optimize unit capacity and fan speed for maximum latent capacity while decreasing room humidity levels.
- **Humidistat Controlled Dehumidification –** Uses a humidistat and 2-stage thermostat to control room humidity levels.
- **Dehumidification Only –** Uses a humidistat in cooling only mode.

Waterside Economizer - Reduces compressor energy consumption by using a cold water coil for cooling under unfavorable conditions.
Loop Pumps – Convenient factory mounted pumps with flow and head capabilities for most geothermal applications.
5, 10, 15 & 20 kW Electric Heat – For alternate heat source with controls for primary, supplemental, boilerless or emergency heat. (Available as a field-installed duct heater kit)
Non-Fused Disconnect Option – Convenient Power shut-off and lockout at the unit.
Extended Range Coaxial Heat Exchanger Coil and Piping Insulation – for geothermal application.
Insulation Options – Foil faced, closed cell or 1/2" standard fiberglass options for the air and compressor side of the unit.
Epoxy Coated Coils – For extra corrosion protection to meet ASTM B-11 3000 hour salt spray test.
Deluxe Sound Package – Reduces sound levels for quieter operation.
5-Year Extended Parts Warranty Available

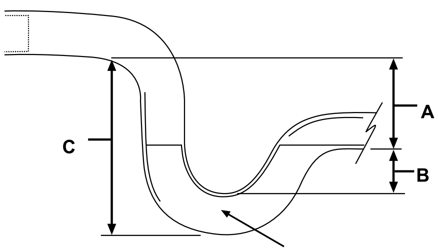


DAIKIN

Condensate Drain

Vertical units are factory provided with a condensate drain trap located inside the cabinet. Condensate removal piping must be pitched away from the unit not less than 1/4" per foot. A vent is required after the trap so that the condensate will drain away from the unit. The vent can also act as a clean out if the trap becomes clogged. To avoid having waste gases entering the building, the condensate drain should not be directly piped to a drain/waste/vent stack. See local codes for the correct application of condensate piping to drains.

Figure 22: Condensate trap detail



Improper trapping can lead to several problems. If the trap is too tall, negative pressure will prevent drainage, causing condensate backup. If the trap is too short the seal will be destroyed or nonexistent, producing the same effect as a non-trapped system.

Construct the trap of 7/8" clear plastic piping. The condensate piping from the drain trap must be sloped to facilitate proper drainage. The clear plastic trap should be clamped and removable for cleaning. It may be necessary to manually fill the trap at system startup, or to run the unit for sufficient time to build a condensate seal. The condensate trap and condensate piping drainage should be free of any foreign debris. Debris can prevent proper drainage and unit operation and result in condensate buildup.

Table 12: Condensate drain static pressures

Static Pressure	A	B	C
Standard	1-1/4"	5/8"	2-3/4"
High	1-1/2"	3/4"	3-1/8"

Operating Limits

Table 13: Air limits in °F (°C)

Air Limits	Standard Range Units		Geothermal Range Units	
	Cooling	Heating	Cooling	Heating
Minimum Ambient Air[1]	50°F (10°C)	50°F (10°C)	40°F (4°C)	40°F (4°C)
Rated Ambient	80°F (27°C)	70°F (21°C)	80°F (27°C)	70°F (21°C)
Maximum Ambient Air[2]	100°F (38°C)	85°F (29°C)	100°F (38°C)	85°F (29°C)
Minimum Entering Air[1]	50°F (10°C)	50°F (10°C)	50°F (10°C)	40°F (4°C)
Rated Entering Air	80/67°F (27°/19°C)	70°F (21°C)	80/67°F (27°/19°C)	70°F (21°C)
Maximum Entering Air[2]	100/83°F (38/28°C)	80°F (27°C)	100/83°F (38/28°C)	80°F (27°C)

Table 14: Water limits

Water Limits	Standard Range Units		Geothermal Range Units	
	Cooling	Heating	Cooling	Heating
Minimum Entering Water	55°F (13°C)	55°F (13°C)	30°F (-1°C)	20°F (-6°C)
Normal Entering Water	85°F (29°C)	70°F (21°C)	77°F (25°C)	40°F (4°C)
Maximum Entering Water	110°F (43°C)	90°F (32°C)	110°F (43°C)	90°F (32°C)
Minimum GPM/Ton	1.5			
Nominal GPM/Ton	3.0			
Maximum GPM/Ton	4.0			

Notes: *1. Maximum and minimum values may not be combined. If one value is at maximum or minimum, the other two conditions may not exceed the normal condition for standard units. Extended range units may combine any two maximum conditions, but not more than two, with all other conditions being normal conditions.*

2. This is not a normal or continuous operating condition. It is assumed that such a start-up is for the purpose of bringing the building space up to occupancy temperature.

UPDATE™ Version 4.16.3
Product Data: 9/25/2014 (Current)

3/22/2015 9:28:54 AM

Job Information

Selected By

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

PSUAE
Tel 814-863-2076

SPX Cooling Technologies Contact

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

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

Cooling Tower Definition

Manufacturer	Marley	Fan Motor Speed	1200 rpm
Product	NC Steel	Fan Motor Capacity per cell	7.500 BHp
Model	NC8402MAN1	Fan Motor Output per cell	7.500 BHp
Cells	1	Fan Motor Output total	7.500 BHp
CTI Certified	Yes	Air Flow per cell	66630 cfm
Fan	7.000 ft, 5 Blades	Air Flow total	66630 cfm
Fan Speed	313 rpm, 6883.2 fpm	Static Lift	10.571 ft
Fans per cell	1	Distribution Head Loss	0.000 ft
		ASHRAE 90.1 Performance	104 gpm/Hp

Model Group: Standard Low Sound (A)
Sound Pressure Level: 74 dBA (Single Cell), 5.000 ft from Air Inlet Face. See sound report for details.

Conditions

Tower Water Flow	621.0 gpm	Air Density In	0.07094 lb/ft³
Hot Water Temperature	94.77 °F	Air Density Out	0.07119 lb/ft³
Range	10.00 °F	Humidity Ratio In	0.01712
Cold Water Temperature	84.77 °F	Humidity Ratio Out	0.02920
Approach	6.77 °F	Wet-Bulb Temp. Out	88.01 °F
Wet-Bulb Temperature	78.00 °F	Estimated Evaporation	6.7 gpm
Relative Humidity	50.0 %	Total Heat Rejection	3094200 Btu/h
Capacity	100.0 %		

- This selection satisfies your design conditions.

Weights & Dimensions

	Per Cell	Total
Shipping Weight	4650 lb	4650 lb
Heaviest Section	4650 lb	
Max Operating Weight	10080 lb	10080 lb
Width	14.170 ft	14.170 ft
Length	8.400 ft	8.400 ft
Height	10.250 ft	

Minimum Enclosure Clearance

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

Solid Wall	4.514 ft
50 % Open Wall	3.131 ft

Weights and dimensions do not include options; refer to sales drawings. For CAD layouts refer to file 8402_ALN.dxf

Cold Weather Operation

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

Heater kW/Cell	12.0	9.0	7.5	6.0	4.5	3.0
Ambient Temperature °F	-23.34	-6.55	1.85	10.24	18.64	27.03

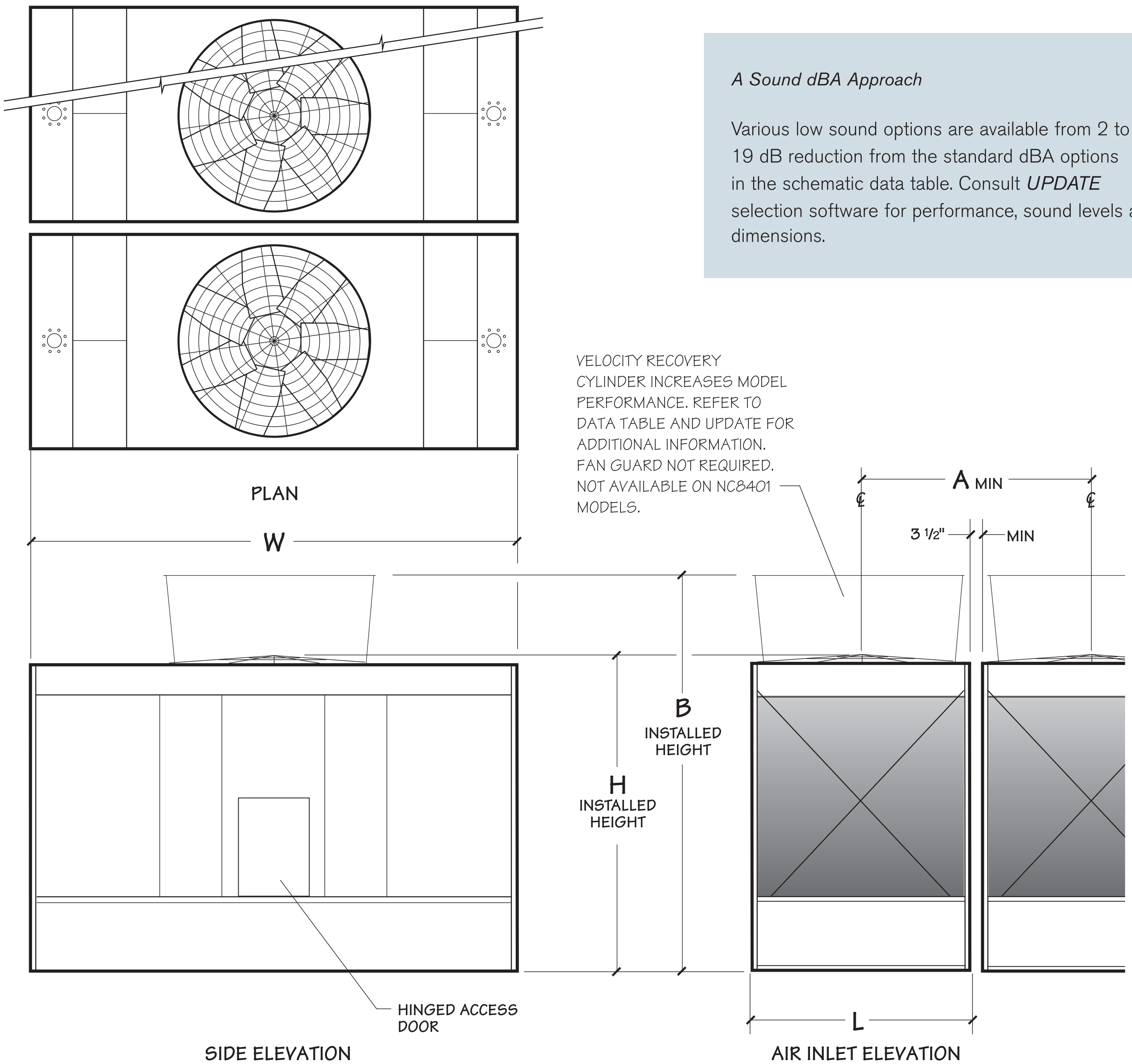
NC8401 NC8402 NC8403 NC8405

Use this data for preliminary layouts only. Obtain current drawing from your Marley sales representative.

UPDATE™ web-based selection software, available at spxcooling.com/update provides NC model recommendations based on customer's specific design requirements.

A Sound dBA Approach

Various low sound options are available from 2 to 19 dB reduction from the standard dBA options in the schematic data table. Consult *UPDATE* selection software for performance, sound levels and dimensions.



NC8401 NC8402 NC8403 NC8405

Model note 2	Nominal Tons note 3	Nominal Tons with VR Cylinder note 3	Motor hp	dBA 5'-0" from air inlet face	Design Operating Weight lb	Shipping Weight lb	Dimensions				
							L	W	H	B	A
NC8401G-1	101	–	2	69	7810	4062	6'-6¼"	12'-10"	10'-2½"	–	6'-9¾"
NC8401H-1	117	–	3	69							
NC8401K-1	139	–	5	73							
NC8401M-1	159	–	7.5	75							
NC8401N-1	175	–	10	77							
NC8401P-1	198	–	15	80							
NC8402G-1	136	149	2	66	10171	4890	8'-4¾"	14'-2"	10'-3"	14'-9"	8'-8¼"
NC8402H-1	156	168	3	66							
NC8402K-1	186	199	5	72							
NC8402M-1	212	228	7.5	74							
NC8402N-1	236	252	10	76							
NC8402P-1	265	283	15	79							
NC8402Q-1	288	308	20	81							
NC8403H-1	196	211	3	67	15812	7442	8'-4¾"	18'-2"	11'-11¼"	16'-5¼"	8'-8¼"
NC8403K-1	233	251	5	72							
NC8403M-1	265	284	7.5	74							
NC8403N-1	290	314	10	76							
NC8403P-1	329	357	15	79							
NC8403Q-1	361	389	20	80							
NC8403R-1	386	415	25	81							
NC8403S-1	407	437	30	84							
NC8403T-1	446	480	40	85							
NC8405H-1	231	237	3	66	19691	8685	9'-10¾"	19'-11"	11'-11¼"	16'-5¼"	10'-2¼"
NC8405K-1	277	290	5	67							
NC8405M-1	315	328	7.5	69							
NC8405N-1	346	361	10	72							
NC8405P-1	392	410	15	75							
NC8405Q-1	426	444	20	78							
NC8405R-1	458	478	25	81							
NC8405S-1	484	503	30	84							
NC8405T-1	528	547	40	87							

NOTE

1 **Use this bulletin for preliminary layouts only.** Obtain current drawings from your Marley sales representative. All table data is per cell.
2 Last numeral of model number indicates number of cells. Change as appropriate for your selection.
3 Nominal tons are based upon 95°F HW, 85°F CW, 78°F WB and 3 gpm/ton. The UPDATE web-based selection software provides NC model recommendations based on specific design requirements.
4 Standard overflow is a 4" dia. standpipe in the collection basin floor. The standpipe removes for flush-out and draining. See page 18 for side overflow option.
5 Outlet sizes vary according to gpm and arrangement. See pages 18 and 19 for outlet sizes and details.
6 Makeup water connection may be 1" or 2" dia., depending upon tower heat load, water pressure, and desired connections. See page 13 for additional information.

FOUR-WAY CEILING CASSETTE

General Data

Table 36: Four-Way Ceiling Cassette (2' x 2' Frames) Indoor Unit General Data.

Model No.	ARNU053TRC4	ARNU073TRC4	ARNU093TRC4	ARNU123TRC4	ARNU153TQC4	ARNU183TQC4
Cooling Mode Performance						
Capacity (Btu/h)	5,500	7,500	9,600	12,300	15,400	19,100
Power Input[1] (W)	30	30	30	30	30	30
Heating Mode Performance						
Capacity (Btu/h)	6,100	8,500	10,900	13,600	17,100	21,500
Power Input[1] (W)	30	30	30	30	30	30
Entering Mixed Air						
Cooling Max. (°F WB)	76	76	76	76	76	76
Heating Min. (°F DB)	59	59	59	59	59	59
Unit Data						
Refrigerant Type[2]	R410A	R410A	R410A	R410A	R410A	R410A
Refrigerant Control	EEV	EEV	EEV	EEV	EEV	EEV
Sound Pressure[3] dB(A) (H/M/L)	29 / 27 / 26	29 / 27 / 26	30 / 29 / 27	32 / 30 / 27	36 / 34 / 32	37 / 35 / 34
Net Unit Weight (lbs.)	29	29	32	32	35	35
Shipping Weight (lbs.)	34	34	38	38	40	40
Grille Weight (lbs)	7	7	7	7	7	7
Grille Shipping Weight (lbs)	11	11	11	11	11	11
Communication Cable[4] (No. x AWG)	2 x 18	2 x 18	2 x 18	2 x 18	2 x 18	2 x 18
Fan						
Type	Turbo	Turbo	Turbo	Turbo	Turbo	Turbo
Quantity	1	1	1	1	1	1
Motor/Drive	Brushless Digitally Controlled / Direct					
Airflow Rate H/M/L (CFM)	265 / 247 / 212	265 / 247 / 212	283 / 265 / 251	307 / 283 / 247	388 / 353 / 328	396 / 388 / 353
Piping						
Liquid Line (in., O.D.)	1/4 Flare	1/4 Flare	1/4 Flare	1/4 Flare	1/4 Flare	1/4 Flare
Vapor Line (in., O.D.)	1/2 Flare	1/2 Flare	1/2 Flare	1/2 Flare	1/2 Flare	1/2 Flare
Condensate Line (in., I.D.)	1	1	1	1	1	1

EEV: Electronic Expansion Valve

Power wiring is field supplied and must comply with the applicable local and national codes.

This unit comes with a dry nitrogen charge.

This data is rated 0 ft above sea level, with 25 ft of refrigerant line per indoor unit and a 0 ft level difference between outdoor and indoor units. All capacities are net with a combination ratio between 95-105%.

Cooling capacity rating obtained with air entering the indoor coil at 80°F dry bulb (DB) and 67°F wet bulb (WB) and outdoor ambient conditions of 95°F dry bulb (DB).

Heating capacity rating obtained with air entering the indoor unit at 70°F dry bulb (DB) and outdoor ambient conditions of 47°F dry bulb (DB) and 43°F wet bulb (WB).

[1]Power Input is rated at high speed.

[2]Take appropriate actions at the end of HVAC equipment life to recover, recycle, reclaim or destroy R410A refrigerant according to applicable regulations (40 CFR Part 82, Subpart F) under section 608 of CAA.

[3]Sound Pressure levels are tested in an anechoic chamber under ISO Standard 3745.

[4]All communication cable to be minimum 18 AWG, 2-conductor, stranded, shielded and must comply with the applicable local and national codes. Ensure the communication cable is properly grounded at the master outdoor unit only. Do not ground the ODU-IDU communications cable at any other point.

Table 11: Ducted High Static (BG Frame) Indoor Unit General Data.

Model No.	ARNU073BGA4	ARNU093BGA4	ARNU123BGA4	ARNU153BGA4	ARNU183BGA4
Cooling Mode Performance					
Capacity (Btu/h)	7,500	9,600	12,300	15,400	19,100
Power Input[1] (W)	450	450	450	450	450
Heating Mode Performance					
Capacity (Btu/h)	8,500	10,900	13,600	17,100	21,500
Power Input[1] (W)	450	450	450	450	450
Entering Mixed Air					
Cooling Max. (°F WB)	76	76	76	76	76
Heating Min. (°F DB)	59	59	59	59	59
Unit Data					
Refrigerant Type[2]	R410A	R410A	R410A	R410A	R410A
Refrigerant Control	EEV	EEV	EEV	EEV	EEV
Sound Pressure[3] dB(A) (H/M/L)	35 / 35 / 34	35 / 35 / 34	36 / 35 / 34	37 / 36 / 33	41 / 39 / 37
Net Unit Weight (lbs.)	83.8	83.8	83.8	83.8	83.8
Shipping Weight (lbs.)	94.8	94.8	94.8	94.8	94.8
Communication Cable[4] (No. x AWG)	2 x 18	2 x 18	2 x 18	2 x 18	2 x 18
Fan					
Type	Sirocco	Sirocco	Sirocco	Sirocco	Sirocco
Motor	1	1	1	1	1
Housing	2	2	2	2	2
Motor/Drive	Brushless Digitally Controlled / Direct				
Airflow Rate H/M/L (CFM) Standard Mode	516 / 484 / 434	533 / 484 / 434	586 / 533 / 484	477 / 427 / 318	547 / 470 / 427
Airflow Rate H/M/L (CFM) High Mode (Factory Set)	441 / 406 / 332	452 / 406 / 332	477 / 427 / 332	487 / 417 / 293	537 / 487 / 417
External Static Pressure (in. wg) Standard Mode	0.15	0.15	0.15	0.23	0.23
External Static Pressure (in. wg) High Mode (Factory Set)	0.23	0.23	0.23	0.31	0.31
Piping					
Liquid Line (in., O.D.)	3/8 Flare	3/8 Flare	3/8 Flare	3/8 Flare	3/8 Flare
Vapor Line (in., O.D.)	5/8 Flare	5/8 Flare	5/8 Flare	5/8 Flare	5/8 Flare
Condensate Line (in., I.D.)	1	1	1	1	1

EEV: Electronic Expansion Valve

Power wiring is field supplied and must comply with the applicable local and national codes.

This unit comes with a dry nitrogen charge.

This data is rated 0 ft above sea level, with 25 ft of refrigerant line per indoor unit and a 0 ft level difference between outdoor and indoor units. All capacities are net with a combination ratio between 95-105%.

Cooling capacity rating obtained with air entering the indoor coil at 80ºF dry bulb (DB) and 67ºF wet bulb (WB) and outdoor ambient conditions of 95ºF dry bulb (DB).

Heating capacity rating obtained with air entering the indoor unit at 70ºF dry bulb (DB) and outdoor ambient conditions of 47ºF dry bulb (DB) and 43ºF wet bulb (WB).

[1]Power Input is rated at high speed.

[2]Take appropriate actions at the end of HVAC equipment life to recover, recycle, reclaim or destroy R410A refrigerant according to applicable regulations (40 CFR Part 82, Subpart F) under section 608 of CAA.

[3]Sound Pressure levels are tested in an anechoic chamber under ISO Standard 3745.

[4]All communication cable to be minimum 18 AWG, 2-conductor, stranded, shielded and must comply with applicable and national code. Ensure the communication cable is properly grounded at the master outdoor unit only. Do not ground the ODU-IDU communication cable at any other point.

Device Connection Limitations

- The minimum number of connected and operating indoor units to Multi V IV systems is one, taking into consideration of the minimum combination ratio.
- The maximum number of indoor units on Multi V IV outdoor heat pump and heat recovery systems is:

ARUN072BTE4-DTE4 / ARUB072BTE4-DTE4 = 13
ARUN096BTE4-DTE4 / ARUB096BTE4-DTE4 = 16
ARUN121BTE4-DTE4 / ARUB121BTE4-DTE4 = 20
ARUN144BTE4-DTE4 / ARUB144BTE4-DTE4 = 24
ARUN168BTE4-DTE4 / ARUB168BTE4-DTE4 = 29
ARUN192BTE4-DTE4 / ARUB192BTE4-DTE4 = 32
ARUN216BTE4-DTE4 / ARUB216BTE4-DTE4 = 35
ARUN240BTE4-DTE4 / ARUB240BTE4-DTE4 = 39
ARUN264BTE4-DTE4 / ARUB264BTE4-DTE4 = 42
ARUN288BTE4-DTE4 / ARUB288BTE4-DTE4 = 45
ARUN312BTE4-DTE4 / ARUB312BTE4-DTE4 = 52
ARUN336BTE4-DTE4 / ARUB336BTE4-DTE4 = 55
ARUN360BTE4-DTE4 / ARUB360BTE4-DTE4 = 58
ARUN384BTE4-DTE4 / ARUB384BTE4-DTE4 = 61
ARUN408BTE4-DTE4 / ARUB408BTE4-DTE4 = 64
ARUN432BTE4-DTE4 / ARUB432BTE4-DTE4 = 64
ARUN456BTE4-DTE4 / ARUB456BTE4-DTE4 = 64
ARUN480BTE4-DTE4 / ARUB480BTE4-DTE4 = 64
ARUN504BTE4-DTE4 / ARUB504BTE4-DTE4 = 64

One of the most critical elements of a Multi V IV system is the refrigerant piping. The table below lists pipe length limits that must be followed in the design of a Multi V IV refrigerant pipe system:

Table 45: Multi V IV Refrigerant Piping System Limitations.

Pipe Length (ELF = Equivalent Length of pipe in Feet)	Longest total equivalent piping length	3,280 feet
	Longest distance from outdoor unit to indoor unit	656 feet (Actual) 738 feet (Equivalent)
	Distance between fittings and indoor units	≥20 inches
	Distance between fittings and Y-branches	≥20 inches
	Distance between two Y-branches	≥20 inches
	Distance between two series-piped heat recovery units	≥20 inches
	Minimum distance between indoor unit to any Y-branch	3 feet from indoor unit to Y-branch
	Maximum distance between first Y-branch to farthest indoor unit	131 feet (295 feet for conditional applications)
Elevation (All Elevation Limitations are Measured in Actual Feet)	If outdoor unit is above or below indoor unit	360 feet
	Between indoor units on heat pump systems or indoor units connected to separate parallel heat recovery units (HRUs)	131 feet
	Between indoor units connected to single HRU or series HRUs	49 feet

Table 46: Equivalent Piping Length for Y-branches, Headers, and Other Piping Components.

Component	Size (Inches)													
	1/4	3/8	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2	1-5/8	1-3/4	2-1/8
Elbow (ft.)	0.5	0.6	0.7	0.8	1.2	1.3	1.5	1.6	1.8	2.0	2.1	2.3	2.5	2.8
Y-branch (ft.)[1]	1.6													
Header (ft.)	3.3													
Heat Recovery Unit (ft.) (For ARUB Heat Recovery Units only)	8.2													

[1]Kit for ARUN Heat Pump systems contains two Y-branches: one for liquid and one for vapor; Kit for ARUB Heat Recovery systems contains three Y-branches: one for liquid, one for low-pressure vapor, one for high-pressure vapor.

Figure 21: Typical VRF Heat Pump System Building Layout.

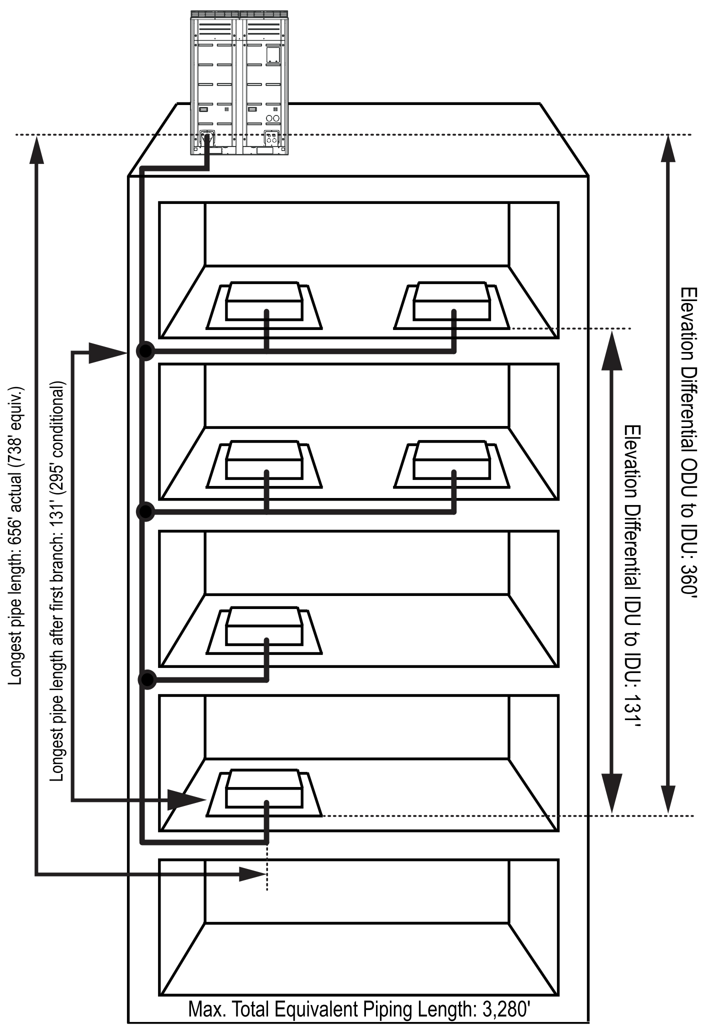
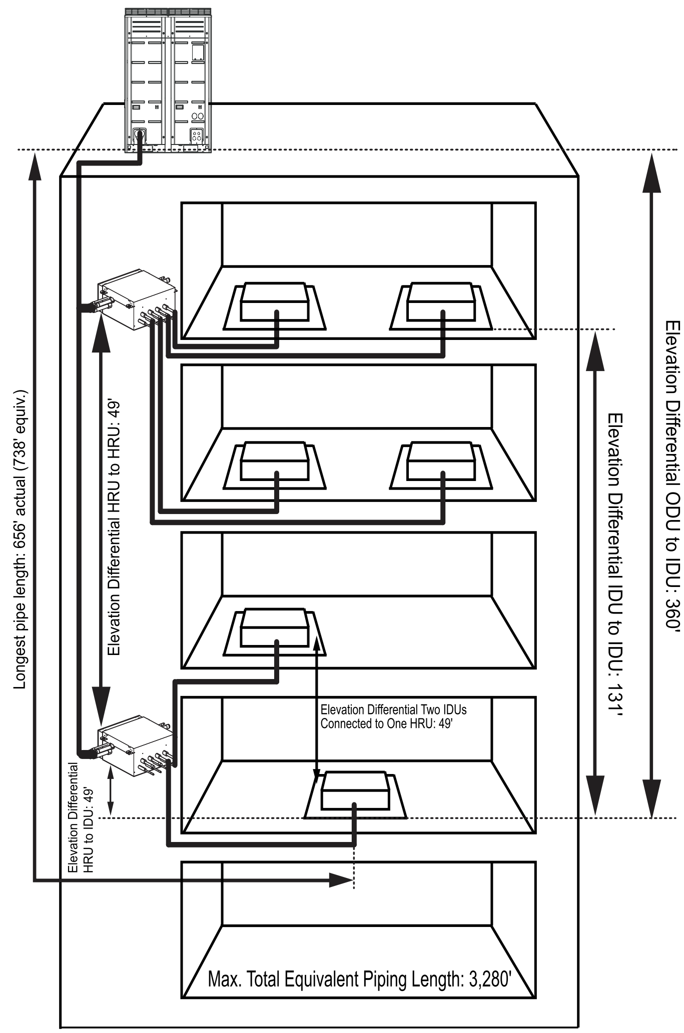
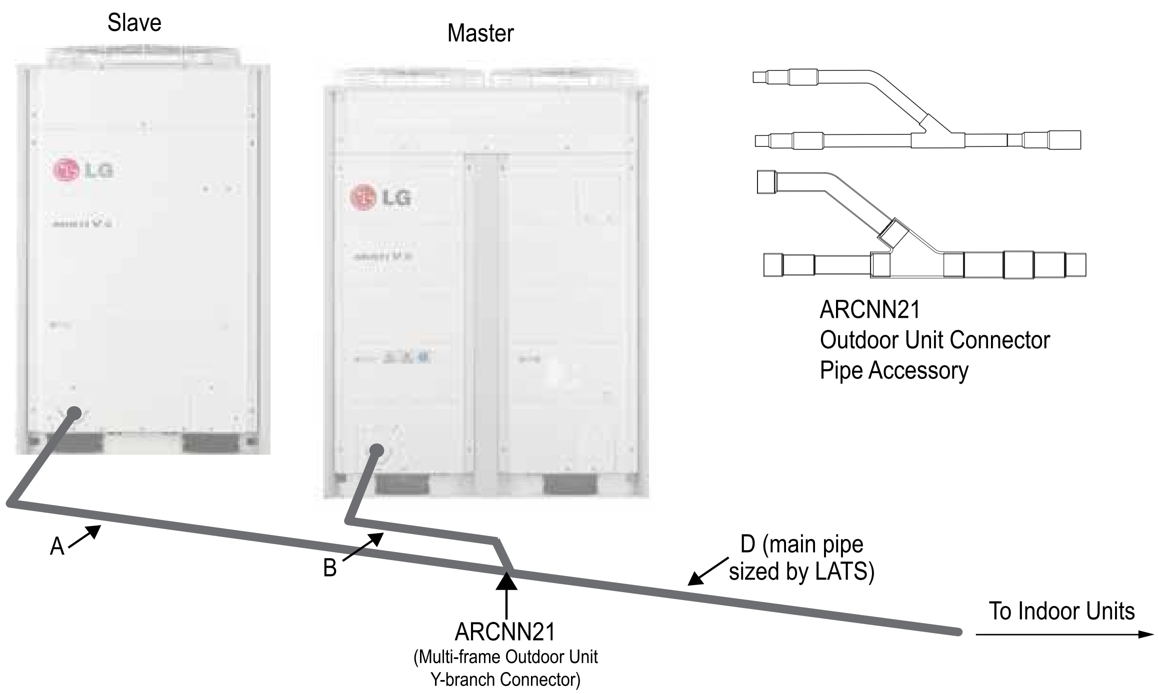


Figure 22: Typical VRF Heat Recovery System Building Layout.



Dual-Frame Heat Pump Outdoor Unit Connections

Figure 23: Heat Pump Dual-Frame Connections.



A and B diameters match outdoor unit connection diameters. Main pipe D diameters are sized by LATS.

Table 47: Heat Pump Dual-Frame Connection Pipe Sizes.

Size (tons)	Model	Master	Slave
16	ARUN192BTE4	ARUN121BTE4	ARUN072BTE4
	ARUN192DTE4	ARUN121DTE4	ARUN072DTE4
18	ARUN216BTE4	ARUN144BTE4	ARUN072BTE4
	ARUN216DTE4	ARUN144DTE4	ARUN072DTE4
20	ARUN240BTE4	ARUN144BTE4	ARUN096BTE4
	ARUN240DTE4	ARUN144DTE4	ARUN096DTE4
22	ARUN264BTE4	ARUN144BTE4	ARUN121BTE4
	ARUN264DTE4	ARUN144DTE4	ARUN121DTE4
24	ARUN288BTE4	ARUN144BTE4	ARUN144BTE4
	ARUN288DTE4	ARUN144DTE4	ARUN144DTE4

Note:

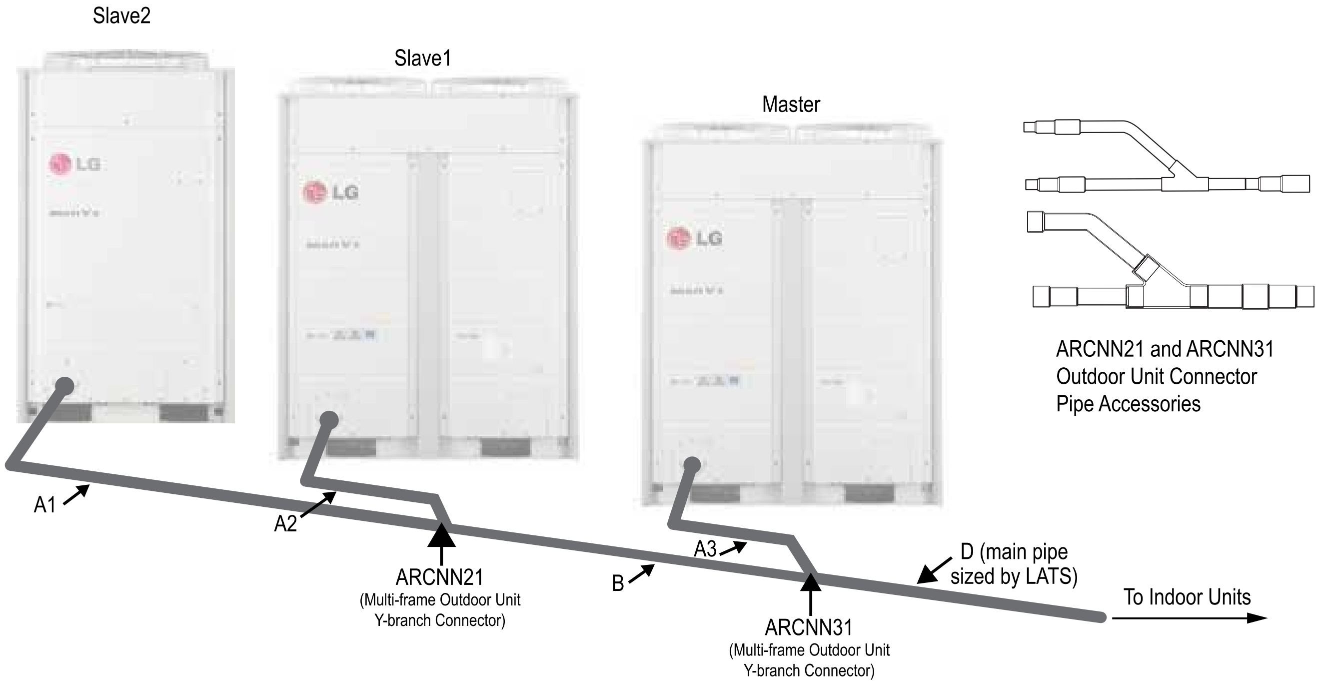
- *Larger-capacity outdoor units must be the master in a multi-frame system.*
- *Single-compressor outdoor units (72,000 Btu/h capacity) cannot be the master outdoor units in a multi-frame system.*
- *Master outdoor unit capacity must be greater than or equal to the slave1 outdoor unit capacity, and, where applicable, slave1 outdoor unit capacity must be greater than or equal to the slave2 outdoor unit capacity.*
- *Insulate all refrigerant system piping and piping connections as detailed on page 317.*
- *Common pipe no longer required between frames.*

REFRIGERANT PIPING DESIGN

Pipe Sizing for ARUN Series Heat Pump Systems

Triple-Frame Heat Pump Outdoor Unit Connections

Figure 24: Heat Pump Triple-Frame Connections.



A1, A2, and A3 diameters match the outdoor unit connection diameters. Main pipe D diameters are sized by LATS. See the table below for B diameters.

Table 48: Heat Pump Triple-Frame Connection Pipe Sizes.

Size (tons)	Model	Master	Slave1	Slave2	B	
					Liquid	Vapor
26	ARUN312BTE4	ARUN144BTE4	ARUN096BTE4	ARUN072BTE4	5/8"	1-1/8"
	ARUN312DTE4	ARUN144DTE4	ARUN096DTE4	ARUN072DTE4		
28	ARUN336BTE4	ARUN144BTE4	ARUN096BTE4	ARUN096BTE4		
	ARUN336DTE4	ARUN144DTE4	ARUN096DTE4	ARUN096DTE4		
30	ARUN360BTE4	ARUN144BTE4	ARUN121BTE4	ARUN096BTE4		
	ARUN360DTE4	ARUN144DTE4	ARUN121DTE4	ARUN096DTE4		
32	ARUN384BTE4	ARUN145BTE4	ARUN145BTE4	ARUN096BTE4		1-3/8"
	ARUN384DTE4	ARUN145DTE4	ARUN145DTE4	ARUN096DTE4		
34	ARUN408BTE4	ARUN145BTE4	ARUN145BTE4	ARUN121BTE4	3/4"	
	ARUN408DTE4	ARUN145DTE4	ARUN145DTE4	ARUN121DTE4		
36	ARUN432BTE4	ARUN145BTE4	ARUN145BTE4	ARUN145BTE4		
	ARUN432DTE4	ARUN145DTE4	ARUN145DTE4	ARUN145DTE4		
38	ARUN456BTE4	ARUN169BTE4	ARUN145BTE4	ARUN145BTE4		
	ARUN456DTE4	ARUN169DTE4	ARUN145DTE4	ARUN145DTE4		
40	ARUN480BTE4	ARUN169BTE4	ARUN169BTE4	ARUN145BTE4		
	ARUN480DTE4	ARUN169DTE4	ARUN169DTE4	ARUN145DTE4		
42	ARUN504BTE4	ARUN169BTE4	ARUN169BTE4	ARUN169BTE4		
	ARUN504DTE4	ARUN169DTE4	ARUN169DTE4	ARUN169DTE4		

Note:

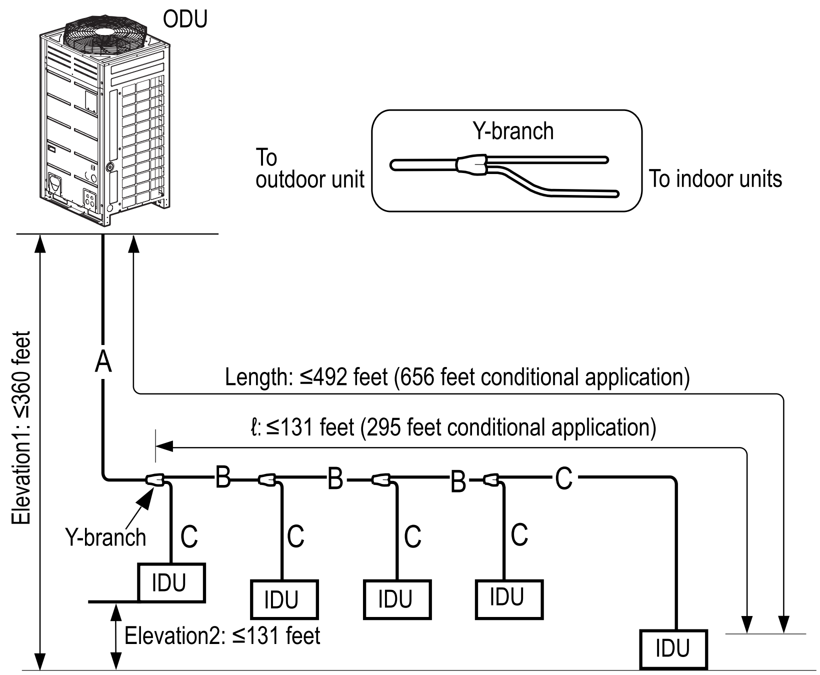
- *Larger-capacity outdoor units must be the master in a multi-frame system.*
- *Single-compressor outdoor units (72,000 Btu/h capacity) cannot be the master outdoor units in a multi-frame system.*
- *Master outdoor unit capacity must be greater than or equal to the slave1 outdoor unit capacity, and, where applicable, slave1 outdoor unit capacity must be greater than or equal to the slave2 outdoor unit capacity.*
- *Insulate all refrigerant system piping and piping connections as detailed on page 317.*
- *Common pipe no longer required between frames.*

The following is an example of manual pipe size calculations. Designers are highly encouraged to use LATS instead of manual calculations.

Y-branch Pipe Sizing for a Single Outdoor Unit System

Example: Five (5) indoor units connected

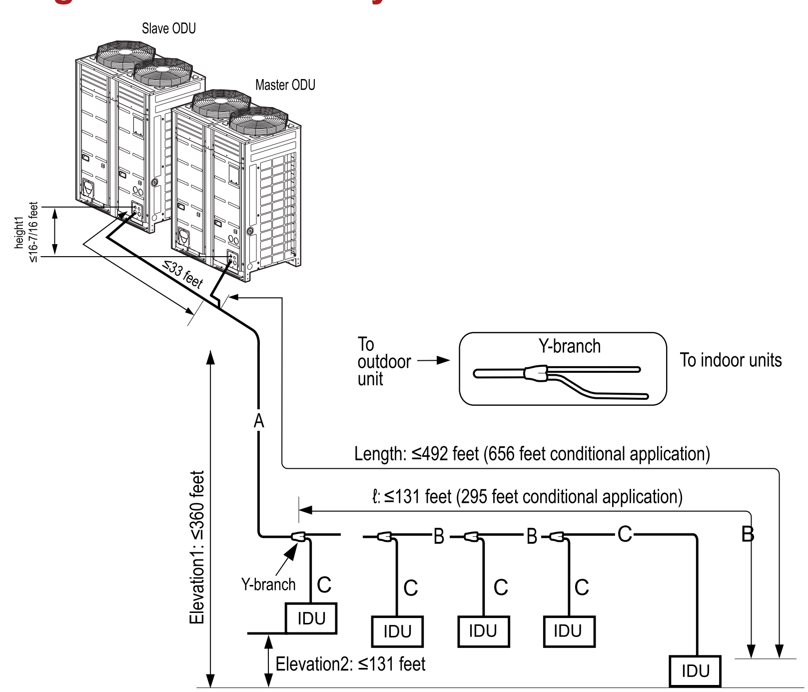
ODU: Outdoor Unit.
IDU: Indoor Units.
A: Main Pipe from Outdoor Unit to Y-branch.
B: Y-branch to Y-branch.
C: Y-branch to Indoor Unit.



Y-branch Pipe Sizing When Installing a Dual-Frame System

Example: Five (5) indoor units connected

ODU: Outdoor Units.
IDU: Indoor Units.
A: Main Pipe from Outdoor Unit to Y-branch.
B: Y-branch to Y-branch.
C: Y-branch to Indoor Unit.



⚠ *Note:*

- *Larger-capacity ODUs must be the master in a multi-frame system.*
- *Single-compressor ODUs (72,000 Btu/h capacity) cannot be the master ODU in a multi-frame system.*
- *Master ODU capacity must be greater than or equal to the slave ODU capacity.*

⚠ *Note:*

See pages 289-290 for refrigerant pipe diameter and pipe length tables.

Pipe Sizing for ARUN Series Heat Pump Systems

The following is an example of manual pipe size calculations. Designers are highly encouraged to use LATS instead of manual calculations.

Y-branch Pipe Sizing When Installing a Triple-Frame System

Example: Five (5) indoor units connected

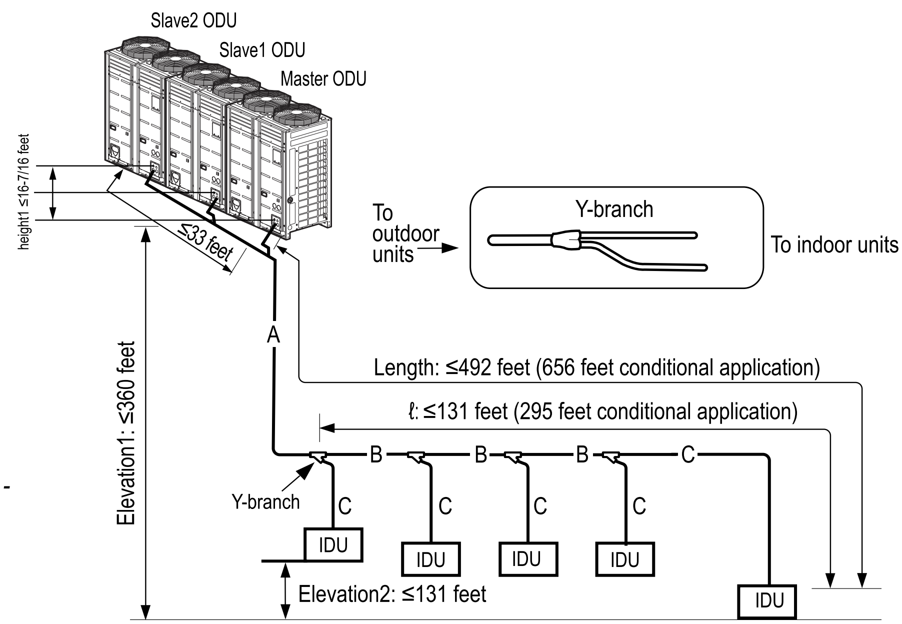
ODU: Outdoor Units.

IDU: Indoor Units.

A: Main Pipe from Outdoor Unit to Y-branch.

B: Y-branch to Y-branch.

C: Y-branch to Indoor Unit.



Note:

- *Larger-capacity outdoor units must be the master in a multi-frame system.*
- *Single-compressor outdoor units (72,000 Btu/h capacity) cannot be the master outdoor unit in a multi-frame system.*
- *Master outdoor unit capacity must be greater than or equal to the slave1 outdoor unit capacity, and, where applicable, slave1 outdoor unit capacity must be greater than or equal to the slave2 outdoor unit capacity.*

Header Pipe Sizing When Installing a Single Outdoor Unit System

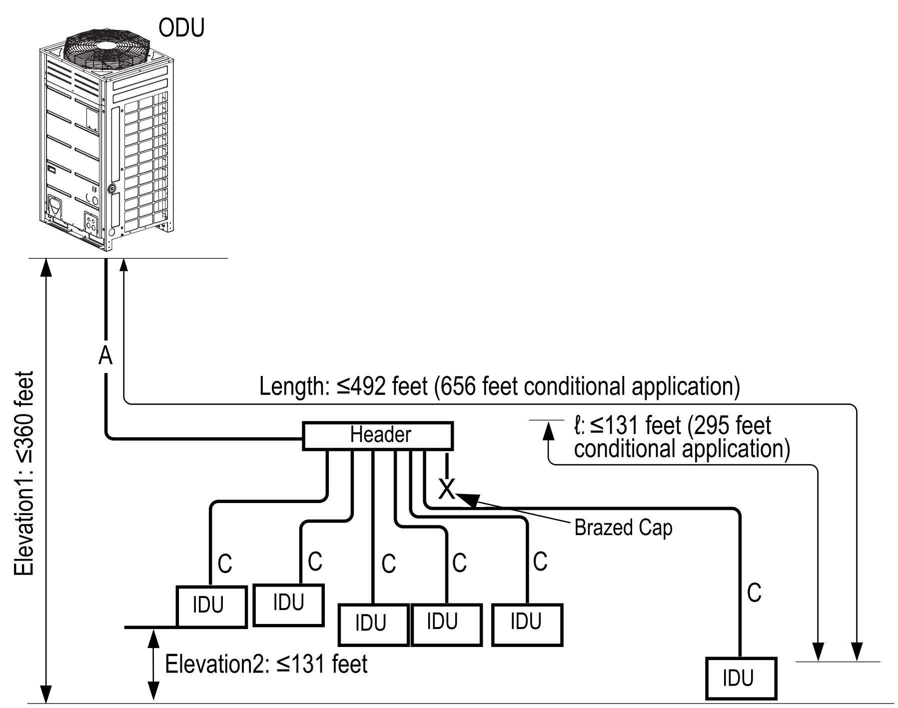
Example: Six (6) indoor units connected

ODU: Outdoor Unit.

IDU: Indoor Units.

A: Main Pipe from Outdoor Unit to Header.

C: Header to Indoor Unit.



Note:

See pages 289-290 for refrigerant pipe diameter and pipe length tables.

The following is an example of manual pipe size calculations. Designers are highly encouraged to use LATS instead of manual calculations.

Combination Y-branch Pipe and Header Pipe Sizing When Installing a Dual-Frame System

Example: Five (5) indoor units connected

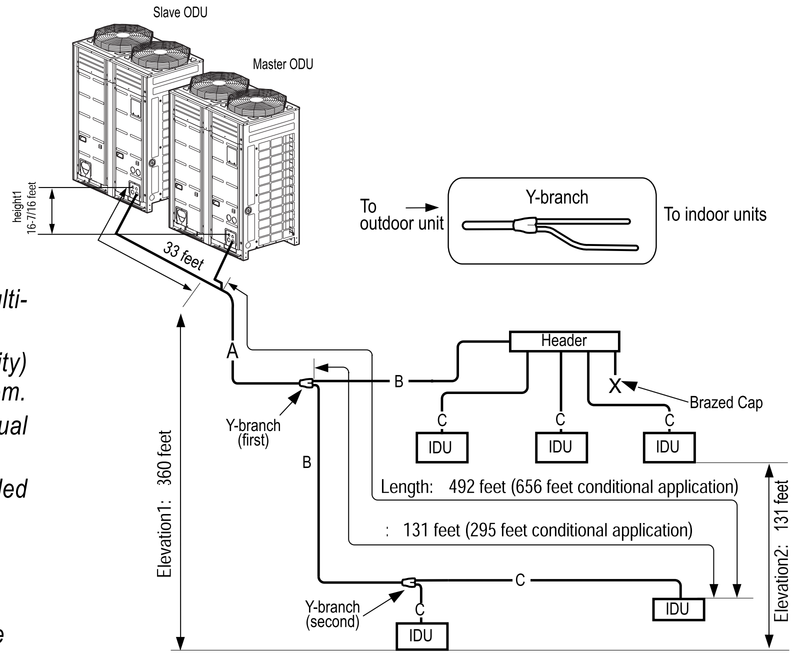
ODU: Outdoor Units.

IDU: Indoor Units.

A: Main Pipe from Outdoor Unit to First Y-branch.

B: Y-branch to Y-branch / Header.

C: Y-branch / Header to Indoor Unit.



⚠ Note:

- *Larger-capacity outdoor units must be the master in a multi-frame system.*
- *Single-compressor outdoor units (72,000 Btu/h capacity) cannot be the master outdoor units in a multi-frame system.*
- *Master outdoor unit capacity must be greater than or equal to the slave outdoor unit capacity.*
- *Y-branches and other header branches cannot be installed downstream of the initial header branch.*

⚠ Note:

See pages 289-290 for refrigerant pipe diameter and pipe length tables.

Table 49: Main Pipe (A) Diameter from Outdoor Unit to First Y-branch / Header Branch.

ODU Capacity (ton)	Pipe diameter when pipe length is <295 feet (Standard)		Pipe diameter when pipe length is ≥295 feet (ODU ↔ IDU)		Pipe diameter when height differential (ODU ↔ IDU) is >164 feet	
	Liquid pipe (inches OD)	Vapor pipe (inches OD)	Liquid pipe (inches OD)	Vapor pipe (inches OD)	Liquid pipe (inches OD	Vapor pipe (inches OD)
6	3/8Ø	3/4Ø	1/2Ø	7/8Ø	1/2Ø	No Increase
8	3/8Ø	7/8Ø	1/2Ø	1-1/8Ø	1/2Ø	No Increase
10-12	1/2Ø	1-1/8Ø	5/8Ø	No Increase	5/8Ø	No Increase
12-14*	5/8Ø	1-1/8Ø	3/4Ø	1-1/4Ø	3/4Ø	No Increase
14-18	5/8Ø	1-1/8Ø	3/4Ø	1-1/4Ø	3/4Ø	No Increase
20	5/8Ø	1-3/8Ø	3/4Ø	No Increase	3/4Ø	No Increase
22-28	3/4Ø	1-3/8Ø	7/8Ø	1-1/2Ø	7/8Ø	No Increase
30-42	3/4Ø	1-5/8Ø	7/8Ø	No Increase	7/8Ø	No Increase

*ARUN145BTE4 / ARUN145DTE4 and ARUN169BTE4 / ARUN169DTE4 only.

Table 50: Refrigerant Pipe Diameter (B) from Y-branch to Y-branch / Header.

Downstream Total Capacity of IDUs (Btu/h)[1]	Liquid pipe (inches OD)	Vapor pipe (inches OD)
≤19,100	1/4Ø	1/2Ø
≤54,600	3/8Ø	5/8Ø
≤76,400	3/8Ø	3/4Ø
≤114,700	3/8Ø	7/8Ø
≤172,000	1/2Ø	1-1/8Ø
≤229,400	5/8Ø	1-1/8Ø
≤248,500	5/8Ø	1-3/8Ø
≤344,000	3/4Ø	1-3/8Ø
≤592,500	3/4Ø	1-5/8Ø

[1]For the first branch pipe, use the branch pipe that matches main pipe A diameter.

Table 51: Indoor Unit Connecting Pipe from Branch (C).

Indoor Unit Capacity[1]	Liquid pipe (inches OD)	Vapor pipe (inches OD)
≤19,100	1/4Ø	1/2Ø
≤54,600	3/8Ø	5/8Ø
≤76,400	3/8Ø	3/4Ø

[1]9,600-24,200 Btu/h 4-way 3 feet x 3 feet Cassette and 15,400-24,200 Btu/h High Static Ducted indoor untis have 3/8Ø (liquid) and 5/8Ø (vapor).

Zone	Cooling		Heating	Critical Load		Outdoor Unit	
	MBH	Tons	MBH		MBH	Cooling	Heating
L5 Interior Zone	182,262	15.2	54,410	Cooling	182,262	192,000	216,000
L5 SW Exterior Zone	79,729	6.6	65,050	Cooling	79,729	96,000	108,000
L5 Exterior Center	91,119	7.6	74,343	Cooling	91,119	96,000	108,000
L5 SE Exterior Zone	91,119	7.6	74,343	Cooling	91,119	96,000	108,000
L5 N,E,W Exterior Zone	178,066	14.8	195,688	Heating	195,688	216,000	243,000
L6 Interior Zone	212,468	17.7	218,357	Heating	218,357	240,000	270,000
L6 S Exterior Zone	191,411	16.0	72,507	Cooling	191,411	192,000	216,000
L6 Exterior Zone (N,E,W)	164,248	13.7	185,828	Heating	185,828	216,000	243,000

Zone	Cooling		Heating	Critical Load		Outdoor Unit		Number of Units	Max Number	Comply?
	MBH	Tons	MBH	Load	MBH	Cooling	Heating			
L5 NW Exterior Zone	66,238	5.5	57,052	Cooling	66,238	72,000	81,000	11	13	YES
L5 W Interior Zone	55,708	4.6	47,146	Cooling	55,708	72,000	81,000	13	13	YES
L5 SW Exterior Zone	76,585	6.4	50,949	Cooling	76,585	96,000	108,000	10	16	YES
L5 S Exterior Zone	78,562	6.5	53,958	Cooling	78,562	96,000	108,000	13	16	YES
L5 SE Corner Zone	87,183	7.3	51,082	Cooling	87,183	96,000	108,000	13	13	YES
L5 SE Exterior Zone	77,507	6.5	56,239	Cooling	77,507	96,000	108,000	10	16	YES
L5 NE Exterior Zone	51,079	4.3	29,271	Cooling	51,079	72,000	81,000	13	13	YES
L5 NE Interior Zone	35,727	3.0	37,148	Heating	37,148	72,000	81,000	16	16	YES
L6 NW Interior Zone	51,814	4.3	48,651	Cooling	51,814	72,000	81,000	13	13	YES
L6 Interior Zone	52,251	4.4	48,248	Cooling	52,251	72,000	81,000	12	13	YES
L6 E Interior Zone	68,708	5.7	67,874	Cooling	68,708	72,000	81,000	12	13	YES
L6 SW Exterior Zone	68,374	5.7	12,423	Cooling	68,374	72,000	81,000	13	13	YES
L6 S Exterior Zone	45,069	3.8	38,126	Cooling	45,069	72,000	81,000	13	13	YES
L6 SE Exterior Zone	55,377	4.6	44,841	Cooling	55,377	72,000	81,000	13	13	YES
L6 NE Exterior Zone	82,378	6.9	68,567	Cooling	82,378	96,000	108,000	14	16	YES
L6 NW Exterior Zone	59,672	5.0	5,872	Cooling	59,672	72,000	81,000	9	13	YES

Zone	Cooling	Heating	Outdoor Unit			
	MBH	MBH	Cooling	Derated Cooling	Heating	Derated Heating
L5 NW Exterior Zone	23,279	3,362	72,000	71,280	81,000	68,850
L5 W Interior Zone	55,708	47,146	72,000	71,280	81,000	68,850
L5 SW Exterior Zone	76,585	50,949	96,000	95,040	108,000	91,800
L5 S Exterior Zone	78,562	53,958	96,000	95,040	108,000	91,800
L5 SE Corner Zone	79,286	16,221	96,000	95,040	108,000	91,800
L5 SE Exterior Zone	52,481	42,629	96,000	95,040	108,000	91,800
L5 NE Exterior Zone	32,939	21,248	72,000	71,280	81,000	68,850
L5 NE Interior Zone	81,187	40,699	72,000	71,280	81,000	68,850
L6 NW Interior Zone	51,814	48,651	72,000	71,280	81,000	68,850

L6 Interior Zone	52,251	48,248	72,000	71,280	81,000	68,850
L6 E Interior Zone	0	67,874	72,000	71,280	81,000	68,850
L6 SW Exterior Zone	48,608	18,413	72,000	71,280	81,000	68,850
L6 S Exterior Zone	45,069	38,126	72,000	71,280	81,000	68,850
L6 SE Exterior Zone	85,880	32,628	72,000	71,280	81,000	68,850
L6 NE Exterior Zone	65,207	29,670	96,000	95,040	108,000	91,800
L6 NW Exterior Zone	31,391	7,019	72,000	71,280	81,000	68,850

ARUN Series Heat Pump Outdoor Unit Specifications

Table 1: Single-Frame 208-230V Heat Pump Units.

Combination Unit Model Number		6.0 Ton ARUN072BTE4	8.0 Ton ARUN096BTE4	10.0 Ton ARUN121BTE4	12.0 ARUN144BTE4	14.0 ARUN168BTE4
Individual Component Model Numbers		-	-	-	-	-
Cooling Performance						
Nominal Cooling Capacity (Btu/h)[1]		72,000	96,000	120,000	144,000	168,000
Rated Cooling Capacity (Btu/h)[2]		69,000	92,000	114,000	138,000	160,000
Heating Performance						
Nominal Heating Capacity (Btu/h)[1]		81,000	108,000	135,000	162,000	189,000
Rated Heating Capacity (Btu/h)[2]		77,000	103,000	129,000	154,000	180,000
Operating Range						
Cooling (°F DB)[3]		14 to 122	14 to 122	14 to 122	14 to 122	14 to 122
Heating (°F WB)		-13 to +61	-13 to +61	-13 to +61	-13 to +61	-13 to +61
Compressor						
Inverter Quantity		HSS DC Scroll x 1	HSS DC Scroll x 1	HSS DC Scroll x 1	HSS DC Scroll x 2	HSS DC Scroll x 2
Oil/Type		PVE/FVC68D	PVE/FVC68D	PVE/FVC68D	PVE/FVC68D	PVE/FVC68D
Fan (Top Discharge)						
Type		Propeller (BLDC)	Propeller (BLDC)	Propeller (BLDC)	Propeller (BLDC)	Propeller (BLDC)
Motor Output (kW) x Qty.		0.75 x 1	0.60 x 2	0.60 x 2	0.60 x 2	0.60 x 2
Motor/Drive		Brushless Digitally Controlled/Direct				
Operating Range (RPM)	Cooling	0 - 850	0 - 1,050	0 - 1,050	0 - 1,100	0 - 1,100
	Heating	80 - 850	80 - 1,050	80 - 1,050	80 - 1,100	80 - 1,100
Maximum Air Volume (CFM)		7,400	9,850	9,850	10,200	10,200
Unit Data						
Refrigerant Type		R410A	R410A	R410A	R410A	R410A
Refrigerant Control/Location		EEV/Indoor Unit	EEV/Indoor Unit	EEV/Indoor Unit	EEV/Indoor Unit	EEV/Indoor Unit
Max. Number Indoor Units/System[4]		13	16	20	24	29
Sound Pressure dB(A)[5]		58.5	59.0	59.0	59.5	59.5
Net Unit Weight (lbs.)		430	540	540	628	628
Shipping Weight (lbs.)		452	573	573	661	661
Communication Cables[6,7]		2 x 18	2 x 18	2 x 18	2 x 18	2 x 18
Heat Exchanger						
Material and Fin Coating		Copper Tube/Aluminum Fin and GoldFin™/Hydrophilic				
Rows/Fins per inch		3/14	3/14	3/14	3/14	3/14
Piping[8]						
Liquid Line Connection (in., OD)		3/8 Braze	3/8 Braze	1/2 Braze	1/2 Braze	5/8 Braze
Vapor Line Connection (in., OD)		3/4 Braze	7/8 Braze	1-1/8 Braze	1-1/8 Braze	1-1/8 Braze
Factory Charge lbs. of R410A		16.9	23.6	23.6	23.6	23.6

[1]Nominal capacity applied with non-ducted indoor units, and is rated 0 ft. above sea level with 25 ft. of refrigerant line per indoor unit and a 0 ft. level difference between outdoor and indoor units. All capacities are net with a Combination Ratio between 95–105%.

Nominal cooling capacity rating obtained with air entering the indoor unit at 80ºF dry bulb (DB) and 67ºF wet bulb (WB) and outdoor ambient conditions of 95ºF dry bulb (DB) and 75ºF wet bulb (WB). Nominal heating capacity rating obtained with air entering the indoor unit at 70ºF dry bulb (DB) and 59ºF wet bulb (WB) and outdoor ambient conditions of 47ºF dry bulb (DB) and 43ºF wet bulb (WB).

[2]Rated capacity is certified under AHRI Standard 1230. See www.ahrinet.org for information.

[3]Cooling range with Low Ambient Baffle Kit (sold separately) is -9.9°F to +122°F.

[4]The System Combination Ratio must be between 50–130%.

[5]Sound pressure levels are tested in an anechoic chamber under ISO Standard 3745.

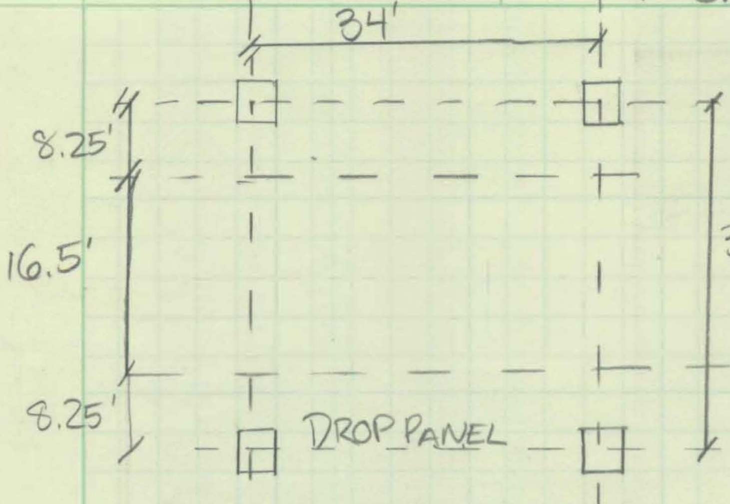
[6]All communication cable to be minimum 18 AWG, 2-conductor, stranded, shielded, and must comply with applicable local and national codes. Ensure the communication cable is properly grounded at the master unit only. Do not ground the ODU-IDU communication cable at any other point.

[7]Power wiring cable is field provided and must comply with the applicable local and national codes. See page 31 for detailed electrical data.

[8]Refer to the Refrigerant Piping section of this manual for correct line sizing. Contractor must use LG manufactured Y-Branch and Header Kits only. Designer must verify refrigerant piping design configuration using LG's computerized refrigerant piping (LATS Multi V) software to validate the pipe design.

Appendix D

(G) REDESIGN OF 1-BAY → AHU 2+3



COLUMN SIZE = 24"×24"
2-WAY 12" SLAB
$f_y' = 60,000$ psi
DROP PANEL = 12"
$f_c' = 5,000$ psi
(AS NOTED IN STRUCTURAL PLANS)

DROP PANEL
1/4 of slab → 3" < 12" ✓

ACI 318-11 TABLE 9.5 (c)

MINIMUM THICKNESS $h = \frac{l_n}{36} = \frac{34'-2'}{36} = \frac{32}{36} \cdot \frac{12"}{1ft} = 10.66in < 12"$ (slab THICKNESS) ✓

DIRECT DESIGN METHOD (ACI 318-11 13.6)

$\beta = 0.8$ $f_c' = 5,000psi$

LIMITATIONS

1. 3 continuous spans in each direction ✓
2. Panel Ratio ≤ 2
   $\frac{34'}{34'} = 1 \leq 2$ ✓

3) $l_1 \geq \frac{2}{3} l_2$
   $34' \geq 22.66'$ ✓

4) No Column is offset by more than 10% of the span ✓

5) All loads due to gravity and distributed over an entire panel.

$L_L < 2D$

SuperImposed Dead Load = 15 psf(roof) + ~~15(IBS)~~

$S_{ELF} = \left(\frac{12''}{12''/ft}\right)(150\ cf) = 150\ psf$

$A_T = (32')(32')$
$= 1{,}024\ ft^2$

$L_L = 30\ psf$

$W_{AHU} = 4284 + 4282\ lb = \frac{8566\ lb}{1024\ ft^2} = 8.365\ psf$

$L_L \leq 2D$

$30\ psf \leq 2(150 + 15 + 8.365) = 346.7\ psf$ ✓

Determine $W_U = 1.2D + 1.6(L_L)$

For Roof → $w_u = 1.2D + 1.6(L)$

$D = 150 + 15 + 8.365 = 173.4\ psf$

$W_U = 1.2(173.4\ psf) + 1.6(30) = 256\ psf$

13.6.2.2 Absolute sum of positive and average negative factored moments in each direction must not be less than

$All\ M^+ + All\ M^- \leq \frac{w_u\, l\, l_n^2}{8}$

$l = 34\ ft$
$l_n = 32\ ft$
$w_u = 256\ psf$

$M_o \leq \frac{(256\ psf)(34\ ft)(32\ ft)^2}{8}$

$M_o \leq 1{,}114.\ ft\text{-}kips$

13.6.3.2 Interior Span, total static moment, M_o distribute:

$M^- = 0.65 M_o$

$M^+ = 0.35 M_o$

13.6.4 Factored Moments in Column Strips

Column strips must resist

$0.75\ M^-$ @ interior support face

$0.60\ M^+$ @ interior panel

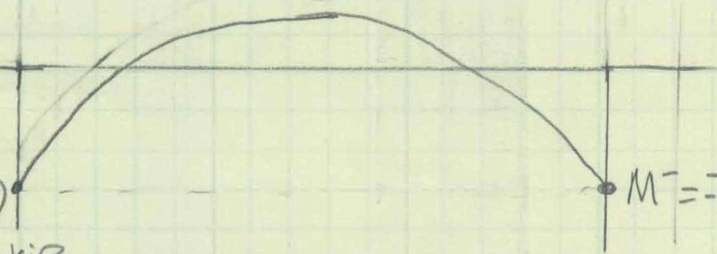
Since (only drop panel)

$\alpha_f = 0$

$l_1/l_2 = 1$

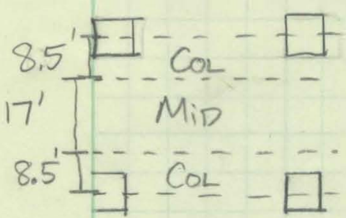
$\beta_t = 0$

$+0.35 M_o = 0.35(1{,}114)$
$M^+ = 390$ ft-kip



$-0.65 M_o$
$-0.65(1{,}114)$
$M^- = -724$ ft-kip

$M^- = -724$ ft-kip



COLUMN STRIP

$M^- = 0.75 M^- = 0.75(-724) = -543$ ft-kip

$M^+ = 0.6 M^+ = 0.6(390) = 234$ ft-kip

MIDDLE STRIP

$M^- = 0.25 M^- = 0.25(-724) = -181$ ft-kip

$M^+ = 0.4 M^+ = 0.4(390) = 156$ ft-kip

ACI 10.2.7

Concrete stress of $0.80 f_c'$ assumed uniformly distributed over a compression zone bounded

$f_c' = 5000$ psi $\longrightarrow \beta = 0.8$

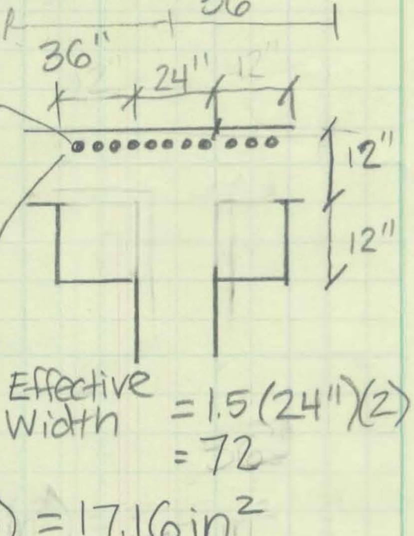
COLUMN STRIP

$a = \dfrac{A_s f_y}{0.80 f_c' b}$ $\qquad M_n = A_s f_y (d - a/2)$

$M_u = \phi M_n$ $\qquad$ Tension controlled: $\phi = 0.9$

$M_n = \dfrac{M_u}{\phi} = \dfrac{-543}{0.9} = -603$ ft-kip

$A_s = \dfrac{M_n}{f_y(d - a/2)}$ $\qquad b = 48"$



$a = \dfrac{(17.16)(60)}{0.8(5)(72")} = 3.575$

$M_n = A_s f_y (d - a/2)$

$M_n = (17.16)(60)(20.465 - \frac{3.575}{2}) \cdot \frac{ft}{12"}$

$M_n = 1602$ ft-kip $\gg 603$ ft-kip $\quad A_s = 11(1.56) = 17.16\ in^2$

CRSI → 10-3 $f_c' = 4{,}000$ psi flat slab w/ drop panels $\quad d = 24" - 1.5 - 5/8 - 1.41 = 20.465$ (cover, stirrup, #11)

Span = 34' Super Imposed = 200

$A_s = 16(0.6) = 9.6$ in

$\#7 \rightarrow d = 0.875 \quad A = 0.6$

$A_{s,new} = 9.6 in$

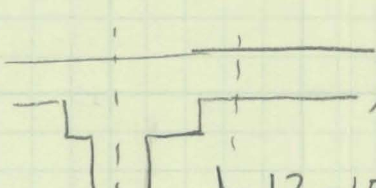
$d_{new} = 24'' - \underset{cover}{1.5} - \underset{stirrup}{5/8} - \underset{\#7}{0.875} = 21''$

$$a = \frac{A_s f_y}{0.80 (f_c')(b)} = \frac{(9.6)(60)}{(0.8)(5)(72)} = 2$$

$$M_n = A_s f_y (d - a/2)$$
$$= 9.6(60)(21 - \tfrac{2}{2}) \cdot \frac{1 ft}{12''}$$
$$M_n = 960 \text{ ft-kip}$$
$$\phi M_n = 0.9(960) = 864 >> 603 \text{ ft-kip}$$

NEGATIVE MOMENT IN COLUMN STRIP

$$M_n = \frac{M_u}{0.9} = \frac{234}{0.9} = 260 \text{ ft-kip}$$



$$A_s = \frac{M_n}{f_y (d - a/2)}$$

$d = 12 - \underset{cover}{1.5} - \underset{stirrup}{5/8} = 9.875 in$

$\#11$

$A_s = 18(1.56) = 28.08 in^2$

$b = 72''$

$$a = \frac{A_s f_y}{0.8 (f_c')(b)} = \frac{(28.08 in^2)(60)}{(0.8)(5)(72)} = 5.85$$

$$M_n = A_s f_y (d - a/2)$$
$$= (28.08 in^2)(60)(9.875 - \tfrac{5.85}{2}) \cdot \tfrac{1}{12}$$
$$= 977.8 \text{ ft-kip} >> 260 \text{ ft-kip}$$

AS REQUIRED BY CRSI Table 10-38 $f_c' = 4{,}000$ psi span = 34'

Column Strip: Bottom → 18 #6

$A_{s\,min} = 18(0.44) = 7.92$

$A_{s\,new} = 7.92 in^2$

$$a = \frac{A_s f_y}{0.8 f_c' b} = \frac{(7.92)(60)}{0.8(5)(72)} = 1.65 in$$

$$M_n = A_s f_y (d - a/2)$$
$$= (7.92)(60)(9.875 - 1.65/2)$$
$$M_n = 358 >> 260 \text{ ft-kip}$$

POSITIVE MOMENT IN MIDDLE STRIP

$b = 16.5' \cdot \frac{12''}{1ft} = 198in$ $d = 12'' - 1.5 - 5/8 - 1.415 = 8.465in$

$M_n = \frac{M_u}{0.9} = \frac{156}{0.9} = 173 \text{ ft-kip}$ $A_s = 18(1.56) = 28.08in^2$

$a = \frac{A_s f_y}{0.8 f_c' b} = \frac{(28.08)(60)}{0.8(5)(198)} = 2.127$

$M_n = A_s f_y (d - a/2)$

$= (28.08)(60)(8.465 - 2.127/2) \cdot \frac{1}{12}$

$M_n = 1{,}039 \text{ ft-kip} >> 173 \text{ ft-kip}$ ✓

$A_{new} = 6.16in^2$

$a = 0.467in$ $M_n = (6.16)(60)(9.125 - 0.467/2) \cdot \frac{1}{12}$

$M_n = 274 \text{ ft-kip} >> 173 \text{ ft-kip}$ ✓

CRSI Tables flat slab

MIDDLE STRIP

$A_s = 14(0.44) = 6.16in^2$

$d_{new} = 12 - 1.5 - 5/8 - 0.75$
$= 9.125in$

NEGATIVE MOMENT IN MIDDLE STRIP

$d = 12'' - 1.5 - 5/8 - 0.75 = 9.125in$

$M_n = \frac{M_u}{0.9} = \frac{181}{0.9} = 201 \text{ ft-kip}$

$a = \frac{A_s f_y}{0.8 f_c' b} = \frac{(10.56)(60)}{0.8(5)(198)} = 0.8$

$M_n = A_s f_y (d - a/2) = 10.56(60)(9.125 - \frac{0.8}{2}) \cdot \frac{1}{12}$

$M_n = 460 \text{ ft-kip} >> 201 \text{ ft-kip}$

$a_{new} = 0.4$ $M_n = 235 \text{ ft-kip} >> 201 \text{ ft-kip}$

#6@12" + #6@24"

$\frac{198in}{12in} = 16 \text{ bars}$

$\frac{198in}{24in} = 8 \text{ bars}$

Rebar = 24(#6

$A_s = 24(0.44) = 10.56in^2$

CRSI $A_{smin} = 12(0.44) = 5.28in^2$

R.S. Means Mechanical Cost Data													
Design	Material		Crew	Daily Output	Labor-Hours	Material	Labor	Equipment	Total	Incl. O&P	Total	Man Power	Days
VRF	Outdoor Condensing Units - 8 ton	16	2	1.3	12.308	29100	660	0	29760	33000	$528,000	196.93	12.31
	Indoor Cassette -7,200	97	2	2.6	6.154	1625	330	0	1955	2275	$220,675	596.94	37.31
	Indoor Cassette -12,000	44	2	2.97	5.387	2000	290	0	2290	2625	$115,500	237.03	14.81
	Indoor - In-duct - 9,000	47	2	2.6	6.154	1675	330	0	2005	2350	$110,450	289.24	18.08
	Indoor - In-duct - 18,000	16	2	2.6	6.154	1825	330	0	2155	2525	$40,400	98.46	6.15
	Refrigerant Piping - Copper (1/4")	1,536	1	84	0.095	4.62	5.5	0	10.12	13.4	$20,582	145.92	18.24
	Copper Piping (3/8")	8,352	1	78	0.103	4.47	5.9	0	10.37	13.8	$115,258	860.26	107.53
	Copper Piping (3/4")	2,304	1	74	0.108	7.8	6.2	0	14	18	$41,472	248.83	31.10
	DOAS - 35 ton	1	4	0.28	113	122500	6475	0	128975	144500	$144,500	113.00	3.53
										Total	$1,336,837	2,786.60	249.07
WSHP	Cooling Tower - 120 ton, induced	120	3	109	0.22	180	12.3	0	192.3	218	$26,160	26.40	1.10
	Boiler - 765 MBH	1	4	0.46	70.022	10900	3900	0	14800	17,800	$17,800	70.02	2.19
	WSHP - 1 ton	204	2	2	8	2,075	430	0	2,505	2,950	$601,800	1,632.00	102.00
	Water Piping - 3/4"	7,680	1	74	0.108	7.8	6.2	0	14	18	$138,240	829.44	103.68
	Water Piping - 5 in pipe	2,992	1	32	0.5	109	26	0	1.73	136.73	$409,096	1,496.00	187.00
	DOAS - 35 ton	1	4	0.28	113	122500	6475	0	128975	144500	$144,500	113.00	3.53
										Total	$1,337,596	6,953.47	399.50
Base	Cooling Tower - 258 ton, induced	228	3	129	0.186	105	10.4	0	115.4	131	$29,868	42.41	1.77
	Boiler - 765 MBH	1	4	0.46	70.022	10900	3900	0	14800	17,800	$17,800	70.02	2.19
	Chiller - 270 ton	1	4	0.21	156	161500	8700	0	170200	190500	$190,500	156.00	4.88
	CAV w/ Reheat	204	3	8	2	1275	108	0	1383	1550	$316,200	408.00	17.00
	Water Piping (1 3/4")	1952	1	50	0.16	17.15	9.2	0	26.35	33	$64,416	312.32	39.04
	Water Piping (1")	1760	1	66	0.121	10.6	7	0	17.6	22	$38,720	212.96	26.62
	DOAS - 170 ton	1	4	0.1	320	434500	18200	0	452700	505500	$505500	320.00	10.00
										Total	$1,163,004	1,521.71	101.49

Initial Costs v. Energy Costs								
Material	Original Design		VRF System			WSHP System		
	Initial Cost	Energy Consumption	Initial Cost	Duration	Energy Consumption	Initial Cost	Duration	Energy Consumption
Cooling Tower	$29,868	$18,807	0	-	-	$26,160	26	$3,212
Boiler - 765 MBH	$17,800	$12,627	0	-	-	$17,800	70.02	$8,728
Outdoor Condensing Unit	0	-	$528,000	197	$9,241	-	-	-
Chiller - 270 ton	$190,500	$22,560	0	-	-	0	-	-
Terminal Units	$316,200	$7,273	$487,025	1,222	$6,953	$601,800	1,632.00	$40,550
Piping	$103,136	-	$177,312	1,109	-	$547,336	2,325.44	-
DOAS Unit	$505,500	$46,383	$144,500	113	$19,693	$144,500	113.00	$16,617
Total	$1,163,004	$107,650	$1,336,837	2,641	$35,886	$1,337,596	4,167	$69,108

Payback Period			
Initial Cost	Original Design	VRF	WSHP
Expenses / Savings	Initial Cost	Additional Costs	Initial Costs
Cooling Tower	$29,868	-$29,868	$0
Boiler - 765 MBH	$17,800	-$17,800	$0
Outdoor Condensing Unit	-	$528,000	$0
Chiller 270 ton	$190,500	-$190,500	-$190,500
Terminal Units	$316,200	$170,825	$285,600
Piping	$103,136	$74,176	$444,200
DOAS Unit	$505,500	-$361,000	-$361,000
Costs	$1,163,004	$173,833	$178,300
Maitnenance Costs			
16 Air Cooled Condensers	0	$138,480	$0
Cooling Tower	$8,872	-$8,872	$0
Chiller - 270 ton	$104,744	-$104,744	-$104,744
Boiler - 765 MBH	$5,835	-$5,835	$0
Maitnenance Costs	$119,450	$19,030	-$104,744
Expenses	$1,282,454	$245,596	$73,556
Annual Energy Costs	$107,650	$71,763	$69,108
Payback Period	11.91	3.42	1.06