Final Report

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Architectural Engineering Senior Thesis

MORTON HOSPITAL EXPANSION

TAUNTON, MA

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Mechanical Option
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BAE/MAE Integrated Program

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Executive Summary

The purpose of this evaluation is to investigate alternative mechanical system designs of the Morton Hospital Expansion Project, and their impact on the additional building disciplines. The main criteria in which the redesign was evaluated was the mechanical system first cost, energy consumption, and an overall economic analysis. It should be noted that this report in no way suggests that the current design of the Morton Hospital design is flawed in any way. This investigation was done purely for educational purposes.

The current mechanical system receives its heating from the existing building steam system, providing low pressure steam that enters steam to hot water heat exchangers that provide building reheat, preheat, perimeter heating, and domestic water heating. The primary cooling source is an air-cooled chiller providing chilled water to 2 air handling units chilled water coils. The first AHU supplies conditioned air to Phase 1 of the project by a rooftop packaged DX unit containing a steam preheat coil and direct expansion cooling coil. The second AHU supplies air to Phase 2 of the project and contains a hot water preheat coil and chilled water cooling coil. Both will be variable air volume, supply return type, controlled by minimum outside air monitoring and airside economizer control. Humidifiers are included within the units, and supply and return fans are driven by variable frequency drives. Phase 1 will have electric reheat coils at each zone, while Phase 2 will utilize terminal supply boxes with hot water reheat coils.

The proposed redesign includes two alternative system designs. Alternative 1 replaces the air cooled chiller with a water cooled chiller and cooling tower, and also utilizes an air-to-air heat recovery. Alternative 2 employs variable refrigerant flow and dedicated outdoor air units. Alternative 1 will utilize two air handling units (AHU). AHU-1 supplies air to critical zones that require isolated, 100% exhaust to the outside, and has an EAHU that utilizes a glycol solution heat recovery coil that transfers heat from the EAHU to the AHU without cross-contaminating the infectious exhaust air with the supply air. AHU-2 supplies air to other non-critical zones, and has an EAHU with an enthalpy wheel that transfers both sensible and latent heat from exhaust air to supply air, where cross-contamination is not a problem. AHU-1 and AHU-2 will both receive cooling from a water-cooled chiller and cooling tower. Alternative 2 will use VRF technology in applicable zones, as well as employing dedicated outdoor air units to satisfy the ventilation requirements. Critical zones will be supplied by a separate DOAS unit. Both units employ the same air-to-air heat recovery system, and also receive cooling from a smaller chiller and cooling tower, since the load on the air handlers is reduced by the use of VRF heating and cooling.

When compared to the baseline design, both alternatives are more costly up front, but more cost effective over the lifetime (25 years) of the system, and also more energy conscious. Alternative 1 has an estimated cost savings of 14% over the 25 year lifetime with a 1.5 year payback period. As well, Alternative 1 has a 10% estimated annual energy consumption savings. Alternative 2 has an estimated cost savings of 23% over the lifetime, and a payback of 4.6 years. There is a 26% annual energy savings for this alternative.

An electrical breadth study as well as a structural breadth study were completed to evaluate the impact the proposed design has on these disciplines. Electrically, a photovoltaic array analysis was completed in conjunction with the Alternative 2 mechanical redesign. This was evaluated in an attempt to achieve a zero carbon footprint, and reduce the overall electric consumption. The more on site electric generation there is, the less grid production is required, and the smaller the resulting footprint. This resulted in employing a system with a payback period of 14.6 years, and saving 8% annual energy consumption. Structurally, calculations were completed to see if the added cooling tower of Alternative 1 would affect the current roof structure. It was found that the current roof structure, including the metal roof deck, steel beams, and steel girders, is sufficient in supporting the new cooling tower.

Building Overview

Morton Hospital, originally built in 1988, is located in Taunton, MA serving the Greater Taunton Area. In 2010, Steward Healthcare acquired ownership of the hospital and soon after decided to expand its facility. It is currently a 100,000 SF 2-story hospital providing services including emergency and expressMed care, cardiology, orthopedics, maternity, and outpatient surgery. The expansion will be split into two phases totaling 40,000 SF. Phase 1 is a new MRI, while the Phase 2 includes the Emergency Department, Psychiatric Ward, imaging suite, various treatment and triage rooms, and decontamination and isolation rooms. Figure 1 below shows the key plan with the Phase 1 expansion being the boxed out grey section directly in the middle, Phase 2 expansion in white, and the existing hospital in the remaining grey.

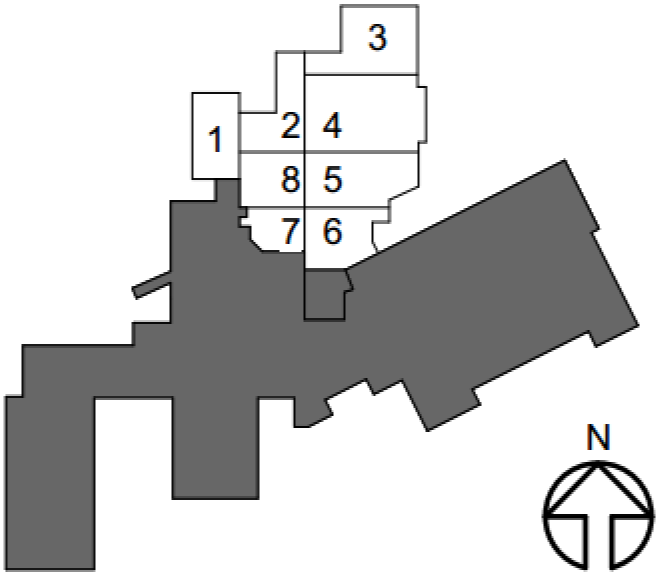


Figure 1: Key plan of existing versus expansion

This expansion will be built around an existing covered parking area that will be fit out for interior space. Both phases will begin construction at the same time, and Phase 1 will be complete and opened while phase 2 remains under construction. The addition will be accessed from the existing building through an additional vestibule, and will also have multiple entryways from the exterior including an ambulance entry vestibule and emergency room vestibule.

Part 1: Existing System Evaluation

Existing Mechanical System

The Morton Hospital mechanical system has numerous components, all of which are interconnected and described in the following section. Below is a description of all major equipment, as well as schematic flow diagrams and a description of the system operation. An analysis of the lost usable mechanical space and mechanical first cost are also included.

Heating

Steam Plant

The existing hospital steam plant will provide low pressure steam to the addition. Unfortunately, the existing hospital drawings could not be obtained for further investigation. Because the building has been built over time with numerous additions, documentation is missing.

Heat Exchangers

There are two 4-pass shell and tube heat exchangers employed in the project, one being on standby. Steam from the existing steam plant enters the shell side at a temperature of 375 °F and a pressure of 150 psi. Return water enters the tube at a flow rate of 80 GPM with a temperature of 140 °F. The exiting water leaves at 180 °F and supplies the hot water preheat coil in AHU-2, as well as the radiant panels throughout the project, and the reheat coils located on the terminal boxes within each zone.

Radiant Panel Heating

Few spaces within the addition require additional heating below exterior windows or storefronts. Hot water supplied by the steam-to-water heat exchangers flows through the panel at an average temperature of 160 °F. Panels vary in active length and total 69 linear feet. Each panel has three passes and a minimum of 260 Btu/hr per linear foot. The maximum temperature difference between the entering and leaving water is 40 °F.

Steam and Hot Water Schematic

Figure 2, below, is a schematic drawing of the steam and hot water flow diagram of the hospital addition. Low pressure steam is supplied from the existing campus steam plant. Both air handling units use steam humidifiers. AHU-1 utilizes a steam preheat coil in which steam is supplied at a pressure of 5 psig and a flow rate of 150 lb/hr. Steam also enters one of the heat exchangers, described above, and converts to hot water. This water enters one of the hot water pumps and is supplied to the hot water preheat coil within AHU-2 at a flow rate of 86 gpm at 180 °F water. Water returns from the coil at 140 °F, enters the heat exchanger, and again leaves at a temperature of 180 °F. After the heat transfer process occurs within the heat exchanger, steam is returned to the existing condensate pump, with a 210 °F suction temperature. Additionally, hot water is supplied and returned to radiant panels, discussed above, and terminal box reheat coils, discussed below.

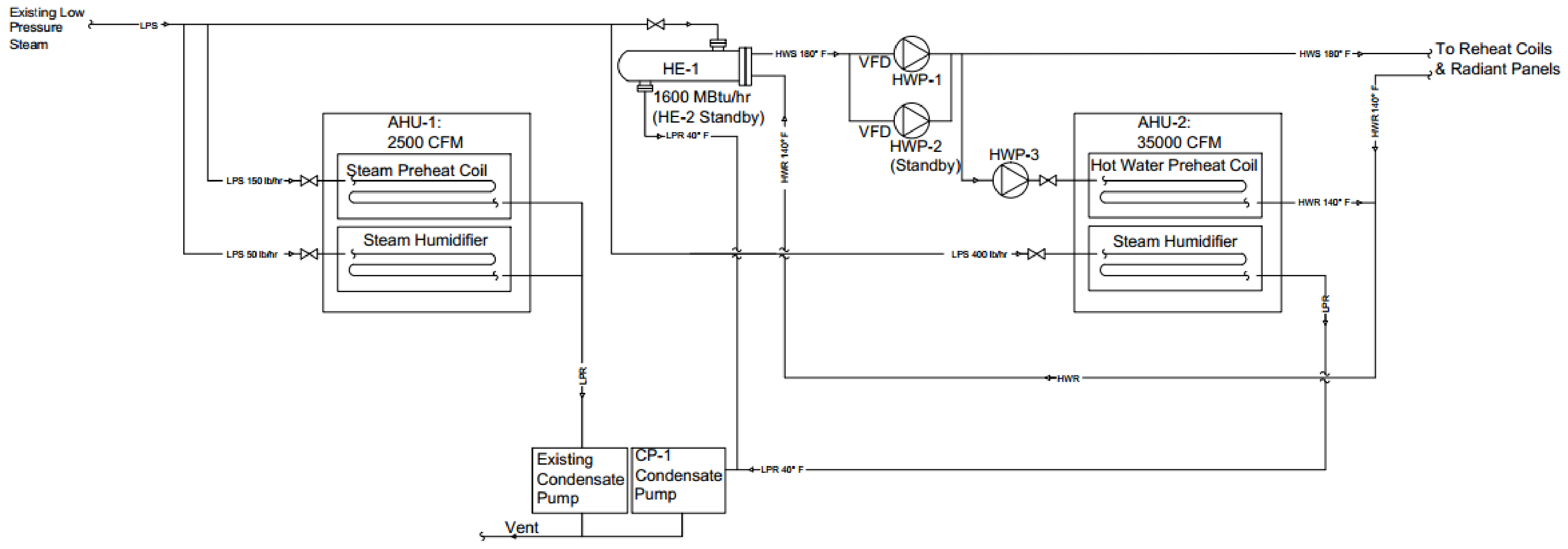


Figure 2: Current Design Steam and Hot Water Flow Diagram

Cooling

Air Cooled Chiller

The primary source of cooling for Phase 2 of the Morton Hospital addition is the 155 ton air cooled chiller. Basis of the design of the packaged chiller is Trane Model RTAC, Helical Rotary Chiller. Within the chiller is an evaporator, condenser, and compressor. The fluid used in the evaporator is water, which enters at 323 gpm and 55 °F, and exits the evaporator at 43 °F. The condenser has 13 fans and an ambient temperature of 95 °F. There are two direct drive compressors rated at 158.2 kW. The chiller manufacturer must also provide a prefabricated pump room including chilled water pumps, air separator, expansion tank, and flywheel tank.

Chilled Water Schematic

Figure 3, below, describes the flow of hot water through Phase 2 of the addition. Chilled water is supplied by the air cooled chiller, as described above, and enters the prefabricated pump package provided by the manufacturer. Supply chilled water enters the cooling coil within AHU-2 at a flow rate of 276 gpm and temperature of 43 °F. Water is then returned at 55 °F to the pump package and then back to the air cooled chiller. The chilled water loop has a variable primary flow configuration. This means that variable flow enters the chiller from the chiller pump, which is controlled by a variable frequency drive (VFD), rather than a primary-secondary flow configuration.

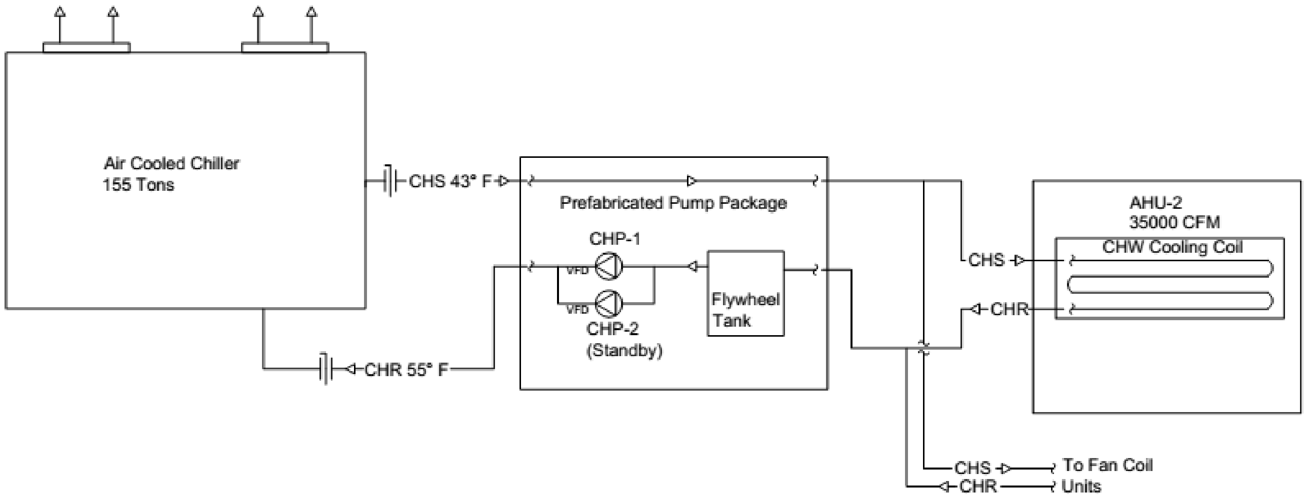


Figure 3: Current Design Chilled Water Flow Diagram

Airside

Air Handling Units

Two air handling units supply the necessary air to the Morton Hospital expansion, both being located on the roof. AHU-1 supplies a total of 2500 CFM to Phase 1, and a minimum of 850 CFM of outside air to the spaces. It includes a pre-filter before the coils, with an efficiency rating of MERV 8, and a final filter after the coils and supply fan with a rating of MERV 14. There is one supply fan and one return fan within this air handling unit, both being double width, double inlet (DWDI) type, and having an airflow measurement station at each fan inlet. AHU-2 supplies 35000 CFM of total air to Phase 2, and has a minimum of 9450 CFM outside air. There is a pre-filter and after filter located before the coils, with efficiency ratings of MERV 8 and MERV 11 respectively. The final filter has a rating of MERV 14. There are four supply fans and four return fans, all being centrifugal type, with an airflow measurement station at each fan inlet. The leaving air temperature of both AHUs is 55 °F.

Air Cooled Condensing Units

Phase 1 of the addition uses direct expansion cooling coils to cool the spaces. Two air cooled condensing units are used to supply refrigerant to AHU-1 and the computer room air conditioning unit (CRAC-1) located in the MRI control room. The first air cooled condensing unit, ACCU-1, corresponds to AHU-1, and contains two 10-ton semi-hermetic compressors using refrigerant R410A. The composition of R410A is 50% HFC-32 and 50% HFC-125. ACCU-2 corresponds to the computer room air conditioning unit, CRAC-1, and contains one 3 ton scroll compressors using refrigerant R407C. The composition of R407C is 23% HFC-32, 25% HFC-125, and 52% HFC-34A. Both refrigerants are offered by DuPont Suva, and are alternatives to R-22, which is currently being phased out.

Refrigerant Schematic

Figure 4, below, demonstrates the refrigerant flow within phase 1 of the project. Refrigerant liquid, RL, enters both the direct expansion cooling coils and refrigerant suction, RS, exits the coils to return to the condensing units, as described above.

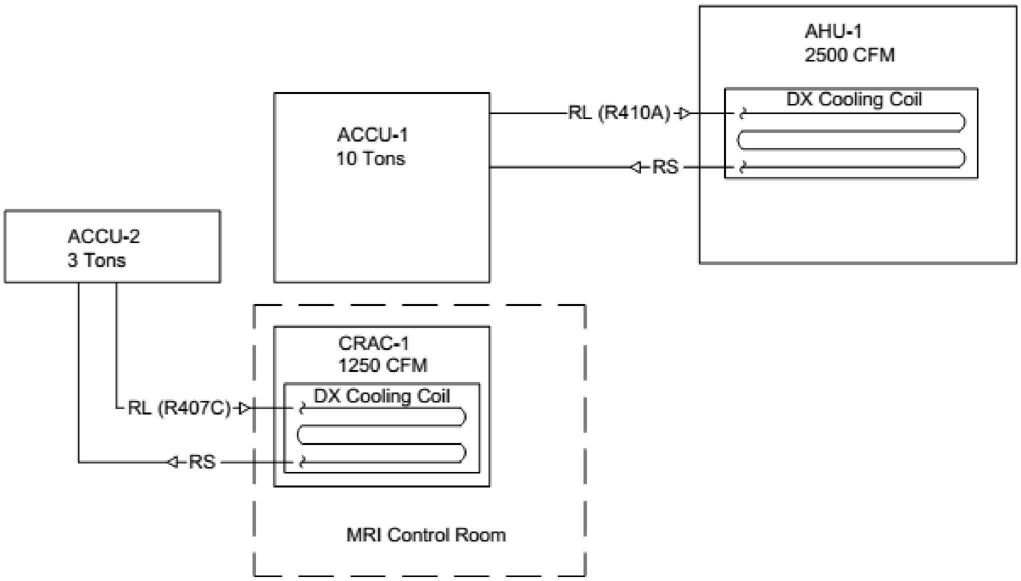


Figure 4: Current Design Refrigerant Flow Diagram

Electric Heating Coil

Phase 1 employs electric heating coils at each zone, each coil being 3 phase 480 Volts. Coils range from 3-15 kW in terms of electricity, and 8.1-38.9 MBtu/hr in terms of capacity. Each coil has an entering air temperature of 55 °F and leaving air temperature of 85 °F.

Terminal Boxes

Phase 2 of the project utilizes a total of 58 supply air terminal boxes with a hot water reheat coil at each zone. Each terminal box will include a unit controller to control airflow and temperature within that zone. Areas in which a positive or negative pressure relationship is required utilize a constant volume box. These critical areas include isolation rooms, trauma rooms, and the emergency department waiting room. Non-critical areas utilize a variable volume box with a minimum turn down volumetric flow rate. Each terminal box also has an attached in-duct sound attenuator to minimize unwanted noise within each zone.

Terminal boxes in Phase 2 also have an attached hot water reheat coil, provided by hot water converted using the heat exchangers, as described above. Water enters at 180 °F and exits at 140 °F, heating the air from 55 °F to 85 °F.

Fan Coil Units

Some areas within the hospital require separate horizontal fan coil units because of excessive/unexpected loads, including all entry vestibules and electrical and Tel/Data rooms. Fan coils located in entry vestibules have both a hot water and chilled water coil to ensure that extreme outdoor air does not affect the indoor air temperature. The electrical rooms and Tel/Data rooms only include a chilled water coil to cool the equipment within these spaces, which give off excessive heat year round. All FCUs have a single phase 115 Volt motor at 60 Hz.

Airflow Schematic

Figure 5 demonstrates the airflow throughout the building expansion. Air enters both AHUs from a ducted return, since it is a hospital and plenum return is not practical, and reaches the return fan(s), which are described above. This return air mixes with the required outdoor air within the mixing plenum and then is filtered through a pre-filter and an after filter (only in AHU-2). Following the filters, air enters the preheat coil, humidifier, cooling coil, and supply fans, all of which are described above. Air leaves both AHUs at 55 °F, and enters the respected zones. As seen in the schematic, air going to a temperature control zone in Phase 1 enters an electric reheat coil before being distributed to the zone. Air being supplied to a temperature control zone in Phase 2 is modulated by a constant or variable volume terminal box with hot water reheat coil before entering the zone. It should also be noted that there are four separate ducted exhaust schemes that discharge 10 feet above the roof. This includes the general exhaust, isolation exhaust, decontamination exhaust, and ED waiting room exhaust, all of which must be separated from each other. The latter three are 100% exhausted.

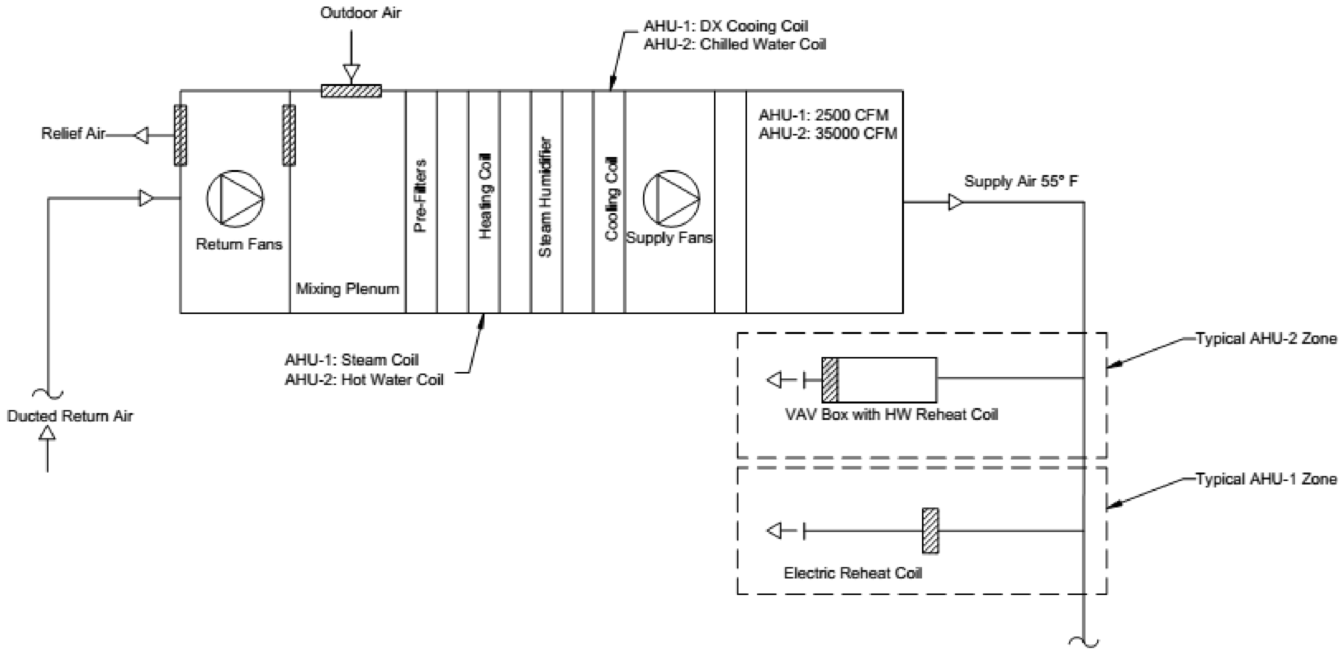


Figure 5: Current Design Airflow Diagram

Pumps

Hot water is pumped to the reheat coils, radiant panels, and AHU-2 heating coil by pumps HWP-1 and HWP-2. Both pumps are sized for 100% of the building total load, one being active and one being on standby. Both these pumps are end-suction type and have a variable frequency drive (VFD) that controls the flow through the pumps. AHU-2 also requires an in-line pump, HWP-3, to pump hot water to the preheat coil within it. This pump does not have a variable frequency drive, and the flow through this pipe is determined by how much flows through the pumps before it.

Chilled water is pumped to the chiller on the return side of the chilled water loop by pumps CHP-1 and CHP-2. Each pump is sized for 100% load, one pump on standby and one being active. Both pumps are end suction type and flow is controlled by a VFD.

Pump efficiency is equal to the hydraulic power (whp) divided by the brake power (bhp), where whp = Flow Rate (gpm) * Head (ft)/3960. Table 1 summarizes the five pumps located in the building addition.

Table 1: Building Water Pump Data

Water Pumps						
Unit Number	Location	Service	Capacity (GPM)	Head (ft H_20)	Efficiency (%)	VFD
CHP-1	AHU-2	AHU-2 CHWR	323	76	71%	Yes
CHP-2	AHU-2	AHU-2 CHWR	323	76	71%	Yes
HWP-1	Mechanical Room	Hot Water Loop	80	45	65%	Yes
HWP-2	Mechanical Room	Hot Water Loop	80	45	65%	Yes
HWP-3	AHU-2	AHU-2 HWS	86	20	58%	No

Lost Usable Space

All major components of the mechanical system are either located in the basement or on the roof. Because the addition is only one floor, no mechanical shafts are found within the space besides a small insignificant piping shaft. The basement mechanical area totals 1400 SF, taking up about 4% of the total usable space.

Mechanical System First Cost

As indicated in the bidding documents, the total cost of the HVAC system is $2,965,365. This comes to $73.95/SF of total building area, and accounts for 20.43% of the total estimated construction cost. Phase 1 mechanical cost totals $404,328 or $158.13/SF, and the Phase 2 mechanical cost comes to $2,561,037 or $68.21/SF.

Design Considerations

Objectives

The objective of the expansion was to satisfy Morton Hospital's growing demands as one of Massachusetts's top hospitals. The mechanical system's main objective was to uphold the health and safety of all patients, physicians, doctors, and staff by maintaining proper indoor air quality within all spaces.

Requirements

Outdoor Design Conditions

Morton Hospital, located in Taunton MA, is classified as Zone 5A according to ASHRAE 90.1. The closest location listed in the ASHRAE Handbook of Fundamentals – 2009 is Providence, RI, and the design conditions given at that location are specified in Table 2 below. Considering that the building is classified as a hospital, it is crucial that it must operate during severe conditions, and therefore was designed using 99.6% heating/winter conditions, and 0.4% cooling/summer conditions.

Table 2: ASHRAE Handbook of Fundamentals - 2009 Providence, RI Design Conditions

Heating DB 99.6% (°F)	Cooling DB 0.4% (°F)	Evaporation (0.4%)		Dehumidification (0.4%)		
		DB (°F)	MCDB (°F)	DP (°F)	HR (grains)	MCDB (°F)
11.9	86.7	74.9	82	72.6	121.2	78.6

DB: Dry Bulb Temperature
MCDB: Mean Coincidence Dry Bulb
DP: Dew Point Temperature
HR: Humidity Ratio

Indoor Design Conditions

Dry bulb temperatures were set to 75° F for cooling and 72° F for heating. Relative Humidity was set to 40% RH for Phase 1 and 30% RH for Phase 2, as specified in the HVAC drawing set.

Ventilation Requirements

Ventilation requirements were calculated using ASHRAE Standard 170 – 2013 Ventilation for Healthcare Facilities. Table 7.1 – Design Parameters was used to calculate the required minimum outdoor air changes, total air changes, and exhaust requirements. A more detailed description of this analysis can be found in Technical Report 1. Table 3 summarizes the requirements found in Technical Report 1 and compares it to the current building design. AHU-1 is designed for a total of 27% outdoor air, while AHU-2 is designed for a total of 33% outdoor air. As summarized, both AHUs meet ASHRAE 170 Design Parameters.

Table 3: A summary of the design ventilation versus calculated ventilation requirements based on ASHRAE 170

	Design			Required	
	Total System Supply Air (CFM)	**Minimum Outside Air (CFM)**	**Minimum Exhausted Air (CFM)**	**Minimum Outside Air (CFM)**	**Minimum Exhausted Air (CFM)**
AHU-1	2500	850	400	750	-
AHU-2	35000	9450	8600	7890	7100
Total	37500	10300	9000	8640	7100

Heating and Cooling Loads

Heating and cooling loads were calculated using Trane Trace 700. As shown in Table 4, the system design appears to be oversized when compared to the modeled results. Specifically when looking at the total supply CFM, AHU-1 is 46% larger than the modeled results, and AHU-2 is 28% larger. This oversizing could be a result of designing system capacities based on several safety factors. As a result, for the majority of the year the system is working at part load, making it less efficient.

Table 4: Heating and Cooling Loads, Trane Trace model versus actual design

	System	Total Supply CFM	Total OA CFM	Exhaust CFM	AHU OA %	Heating MBh	Cooling Tons
Model	Phase 1	1709	75	-	4.4%	70	5.8
	Phase 2	27309	7890	7104	28.9%	1166	138.6
	TOTAL	**29018**	**7965**	**7104**	**27.4%**	**1236**	**144.4**

	System	Total Supply CFM	Total OA CFM	Exhaust CFM	AHU OA %	Heating MBh	Cooling Tons
Design	Phase 1	2500	850	400	34.0%	81	10
	Phase 2	35000	9450	8600	27.0%	1700	155
	TOTAL	**37500**	**10300**	**9000**	**27.5%**	**1781**	**165**

Energy Consumption and Operational Cost

Energy Sources

Morton Hospital is supplied by the existing steam plant for heating and existing chilled water plant for cooling, as well as an additional air cooled chiller. The chilled water plant is powered by electricity supplied by Taunton Municipal Light and Power (TMLP). Table 5 summarizes the electrical rates provided by TMLP. These rates apply to commercial use in which the load is in excess of 150 KVA and the customer owns the equipment.

Table 5: Electrical rates provided by Taunton Municipal Light and Power

TMLP Electrical Service Rates				
Energy Charges	Distribution Charge	First 300 hours	$0.00810	per kWh
		Excess 300 hours	$0.00270	per kWh
	Transmission Charge		$ -	per kWh
	Transition Charge		$0.01484	per kWh
Demand Charges	Distribution Charge		$ 3.45	per KVA
	Transmission Charge		$ 4.99	per KVA
	Transition Charge		$ 4.51	per KVA
Supplier Sevices	Generation Charge	Under 300 hours	$0.05799	per kWh
		Over 300 hours	$0.05078	per kWh
Total Energy Charge under 300 hours			$0.08093	per kWh
Total Energy Charge over 300 hours			$0.06832	per kWh
Total Demand			$ 12.95	per KVA

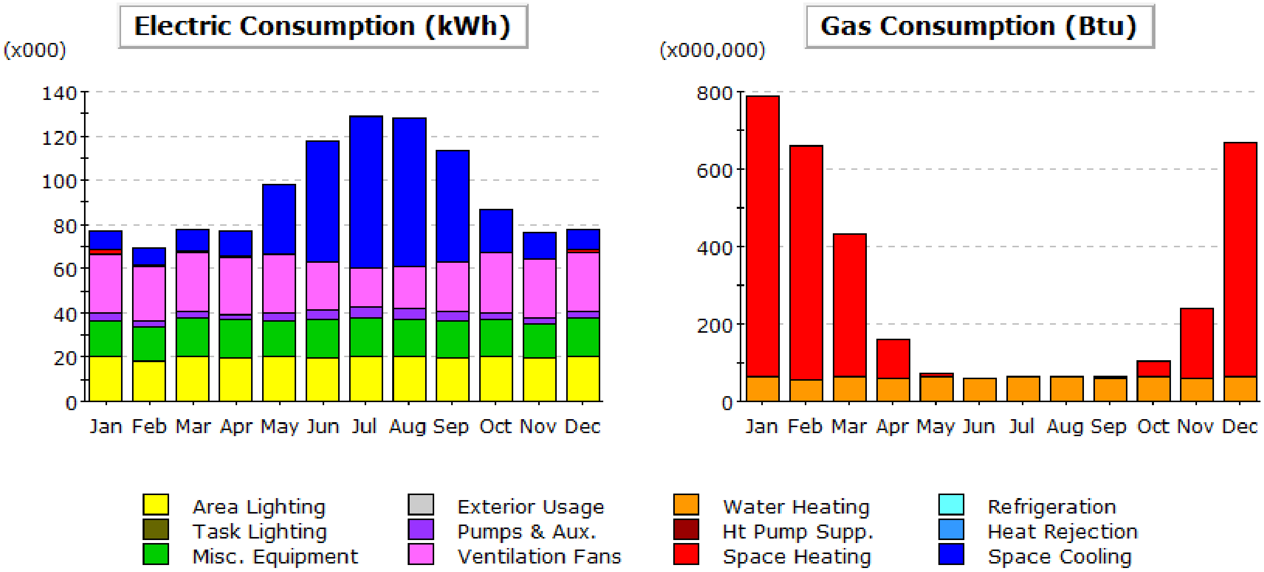
Heating is provided by natural gas. In order to estimate steam rates, the district steam rate equation found in LEED was utilized:

Steam Rate ($/MBtu) = 1.81*gas rate ($/MBtu) + 3*electric rate ($/kWh)

Using the Massachusetts averages for gas and electric rates of $3.95/MBtu and $0.1463/kWh, the steam rate is $7.59/MBtu.

Annual Energy Use

Figure 6 below summarizes the annual energy consumption by electricity and natural gas broken up by use. Consumption values were found using eQuest 3.65 for energy simulation. It can be seen that electricity peaks in the summer months, when space cooling predominates. Inversely, gas consumption peaks in the winter months when space heating is predominate.



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	8.3	7.3	9.2	11.5	31.1	54.8	68.7	67.4	50.6	20.1	11.7	8.9	349.8
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.7	1.3	0.7	0.2	0.0	0.0	-	-	0.0	0.0	0.2	1.3	5.5
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	26.8	24.2	26.8	25.9	26.6	21.7	17.1	18.8	22.8	26.8	25.9	26.7	290.2
Pumps & Aux.	3.1	2.8	3.0	2.7	3.3	4.4	5.1	4.9	4.0	2.9	2.8	3.0	42.0
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	16.4	15.2	17.2	16.9	16.4	16.9	17.1	16.8	16.5	16.8	15.7	17.2	198.9
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	20.3	18.4	20.5	19.9	20.3	19.9	20.5	20.4	19.8	20.4	19.6	20.5	240.7
Total	76.7	69.2	77.4	77.1	97.7	117.7	128.6	128.3	113.7	87.0	76.0	77.7	1,127.2

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	726.3	601.3	368.0	100.3	8.0	-	-	-	0.9	39.1	180.9	606.6	2,631.4
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	63.0	57.0	63.3	61.4	62.9	61.3	63.2	63.1	61.2	63.1	60.8	63.3	743.7
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	789.2	658.3	431.3	161.7	70.9	61.3	63.2	63.1	62.1	102.2	241.7	669.9	3,375.1

Figure 6: Annual Energy Consumption calculated using eQuest

Annual Utility Cost

Based on the eQuest analysis, the annual operating cost of the addition is $215,256, averaging at $5.28/SF. Figure 7 summarizes the monthly utility costs, Electricity based on a virtual rate of $0.158/KWh, and Natural Gas based on a virtual rate of $1.101/therm. This results in 1,127,167 KWh per year of electricity, and 33,751 therm per year of natural gas. Electricity is predominant, and should be improved upon in the redesign.

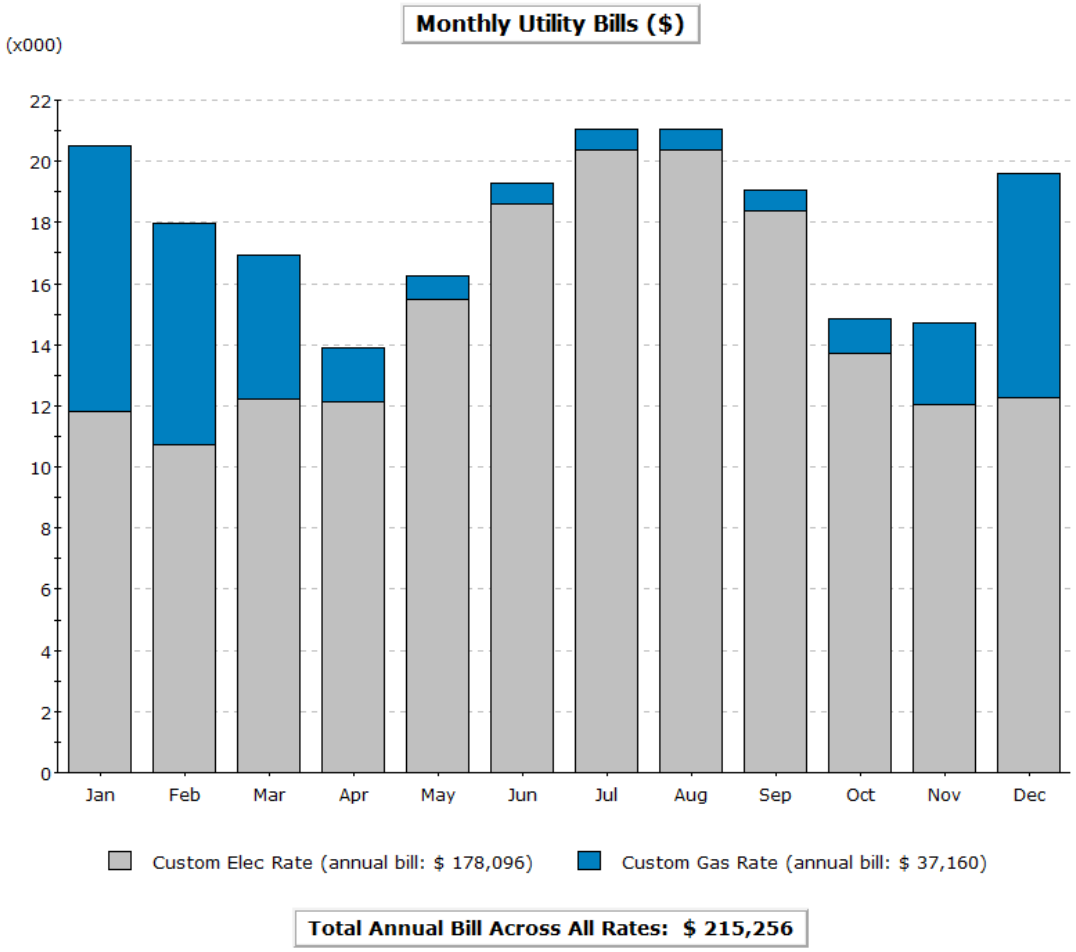


Figure 7: Monthly Utility Rates based on Electrical Demand and Natural Gas Demand

Equipment Operating Cost

From the eQuest 3.65 analysis, the monthly and annual equipment costs were calculated by end use, categorized as cooling equipment, heating equipment, fans, lighting, and miscellaneous equipment. Table 6 summarizes these energy costs.

Table 6: Monthly and Annual Equipment Costs

Monthly Equipment Costs by End Use					
	Cooling	**Heating**	**Fans**	**Lighting**	**Misc**
January	$ 1,214.29	$ 8,245.27	$ 3,920.84	$ 2,969.89	$ 2,399.32
February	$ 1,067.99	$ 6,810.50	$ 3,540.46	$ 2,691.92	$ 2,223.76
March	$ 1,345.96	$ 4,154.09	$ 3,920.84	$ 2,999.15	$ 2,516.36
April	$ 1,682.45	$ 1,133.56	$ 3,789.17	$ 2,911.37	$ 2,472.47
May	$ 4,549.93	$ 88.08	$ 3,891.58	$ 2,969.89	$ 2,399.32
June	$ 8,017.24	$ -	$ 3,174.71	$ 2,911.37	$ 2,472.47
July	$10,050.81	$ -	$ 2,501.73	$ 2,999.15	$ 2,501.73
August	$ 9,860.62	$ -	$ 2,750.44	$ 2,984.52	$ 2,457.84
September	$ 7,402.78	$ 9.91	$ 3,335.64	$ 2,896.74	$ 2,413.95
October	$ 2,940.63	$ 430.49	$ 3,920.84	$ 2,984.52	$ 2,457.84
November	$ 1,711.71	$ 2,020.97	$ 3,789.17	$ 2,867.48	$ 2,296.91
December	$ 1,302.07	$ 6,868.86	$ 3,906.21	$ 2,999.15	$ 2,516.36
TOTAL	**$51,146.48**	**$29,761.73**	**$42,441.63**	**$35,185.15**	**$29,128.33**

Emissions

Based on emission factors provided by the National Renewable Energy Laboratory – Source Energy and Emission Factors for Energy Use in Buildings, Table 7 summarizes the amount of pollutant emitted annually.

Table 7: Pollutant Emissions caused by the delivered Electrical Demand

Emmissions for Delivered Electricity			
Pollutant	Eastern US Emission Factor (lb pollutant/kWh electricity)	Electricity Usage (kWh)	Amount of Pollutant (lb)
CO2	1.64E+00	1,127,200.00	1,848,608.00
NOX	3.00E-03	1,127,200.00	3,381.60
SOX	8.57E-03	1,127,200.00	9,660.10

In order to maintain occupant comfort, the electrical demand must be maintained, and therefore these greenhouse gases are emitted as a result. To reduce this impact, a study on the emissions/refrigerants will be evaluated in the redesign.

LEED Evaluation

The original design of the hospital expansion did not aim to achieve a LEED rating. However, an analysis of the Energy and Atmosphere (EA) Credits and the Indoor Environmental Quality (EQ) Credits point breakdown is given below. This analysis used USGBC LEED Volume 4 for Building Design and Construction for New Construction.

Energy and Atmosphere Credits (EA)

✓ *EA Prerequisite 1: Fundamental Commissioning and Verification*

A detailed commissioning plan will be provided, as stated in the specifications. A commission authority also fulfills the stated requirements. This prerequisite is met.

✖ *EA Prerequisite 2: Minimum Energy Performance*

There are three options given to reduce environmental harms, only two of which apply to healthcare. Either option 1 or option 2 must be satisfied to meet this prerequisite.

Option 1: Whole-Building Simulation: An improvement of 3% for major renovations compared to the base building must be demonstrated. The baseline performance is based on ASHRAE Standard 90.1. As discussed in the ASHRAE 90.1 analysis, the addition does not completely comply with this standard because no heat recovery system is utilized.

Option 2: Prescriptive Compliance: ASHRAE 50% Advanced Energy Design Guide. Because the addition does not comply with ASHRAE 90.1, this option does not apply either. Therefore, the addition does not reach this prerequisite.

✓ *EA Prerequisite 3: Building-Level Energy Metering*

Energy meters are provided in the project to provide energy consumption data, as described in the building specifications.

✓ *EA Prerequisite 4: Fundamental Refrigerant Management*

The use of chlorofluorocarbon-based refrigerants, CFCs, is not prohibited because of its high global warming potential (GWP). The refrigerants used in the project are R410A and R407C, satisfying this prerequisite.

Indoor Environmental Quality Credits (EQ)

✓ *EQ Prerequisite 1: Minimum Indoor Air Quality Performance Required*

Because it is a healthcare facility, the ventilation must comply with ASHRAE 170 Section 7. As already discussed in technical report 1, Morton meets this prerequisite. Spaces also have an outdoor airflow measurement device.

✓ *EQ Prerequisite 2: Environmental Tobacco Smoke Control*

Smoking is prohibited inside the building, and therefore this prerequisite is met.

✓ *EQ Credit 1: Enhanced Indoor Air Quality Strategies (1 out of 2)*

There are two options, both with separate requirements, to achieving two possible credits. Option 1: Enhanced IAQ Strategies. Since all spaces are mechanically ventilated, there are three requirements:

A. Entryway Systems
B. Interior Cross-contamination prevention
C. Filtration

There are entryway systems at least 10 feet wide at all exterior entryways, sufficient exhaust in hazardous contaminated areas maintaining a minimum of 0.5 CFM/SF, and final filters within both AHUs are MERV 14, meeting the minimum requirement of MERV 13 specified by LEED. All three of these requirements are met for Option 1, and 1 credit is awarded.

Option 2: Additional Enhanced IAQ Strategies. Select one of the following:

A. Exterior contamination prevention
B. Increase ventilation
C. Carbon dioxide monitoring
D. Additional source control monitoring

The first selection must ensure that the project minimizes pollutants entry with a computational fluid model. This has not been done, and therefore does not comply with this option. Secondly, increasing the outdoor air rates by 30% has not been done. Thirdly, CO_2 monitors are not provided for all occupied spaces. And lastly, other contaminant monitoring is not provided. Only 1 of the 2 available credits are awards.

✖ *EQ Credit 2: Low-Emitting Materials (0 out of 3)*

The intent of this credit is to reduce contaminant concentrations, and is measured by threshold percentages of materials. These threshold values have not been provided, and therefore credits are not awarded.

✖ *EQ Credit 3: Construction Indoor Air Quality Management Plan (0 out of 1)*

There are seven components of this credit that must be met for healthcare facilities. Six of the seven components are met, and consequently no credit is given.

A. Moisture control plan: this is being utilized during construction of the addition.

B. Particulate control: A MERV of at least 8 is being used in all operating AHUs.
C. Minimize VOC emissions: Exposure to VOCs is minimized during construction processes by having specified limitations on material VOCs.
D. Minimize Outdoor emissions: Outdoor activities monitor emission rates to avoid infiltrating spaces.
E. Tobacco: Construction areas do not permit smoking within 25 feet of the site.
F. Noise and Vibration: No mention of complying with British Standard BS 5228 to reduce noise is mentioned, therefore it does not meet all requirements.
G. Infection control: As stated in building specifications, construction follows FGI 2010 Guidelines for Design and Construction of Healthcare Facilities.

✖ ***EQ Credit 4: Indoor Air Quality Assessment (0 out of 2)***

There are two options in achieving either 1 or 2 credits.

Option 1: Flush-Out, 1 point: A flush out before or during occupancy was not completed, and no point is awarded.

Option 2: Air Testing, 2 points: Only a CRI (Carpet & Rug Institute) IAQ Testing Procedure is stated in the specifications. LEED lists ASTM, EPA, or ISO methods as acceptable, all of which have not been discussed.

✖ ***EQ Credit 5: Thermal Comfort (0 out of 1)***

Specifications state that ASHRAE Standard 55 – 2004 Thermal Comfort Conditions for Human Occupancy is met. LEED states that the 2010 version must be met, so the credit is not awarded.

✖ ***EQ Credit 6: Interior Lighting (0 out of 1)***

All patient stations are provided with build in lighting control. However, staff areas do not specify any form of lighting control.

✖ ***EQ Credit 7: Daylight (0 out of 2)***

There is no discussion on daylight provided in the building specifications or other documents. It is assumed that this credit has not been met.

✖ ***EQ Credit 8: Quality Views (0 out of 2)***

Requirements for healthcare facilities is to have a direct line of sight for 75% of all inpatient units. However, all inpatient units within the Morton Expansion are psychiatric rooms, which have no windows. No points are awarded.

✓ ***EQ Credit 9: Acoustic Performance (1 out of 2)***

There are two options and two possible points to be awarded for acoustic performance.

Option 1: Speech Privacy, Sound Isolation, and Background Noise, 1 point: There is no mention within the provided building documentation of following the required Sound and Vibration Design Guidelines for Healthcare Facilities (2010 SV Guidelines). This option is not met.

Option 2: Acoustical Finishes and Site Exterior Noise, 1 point: Finishes within the project all meet FGI Table 1.2-1, Design Room Sound Absorption Coefficients, as provided in the specifications. One point is awarded.

LEED Summary

It is unlikely that any sort of LEED rating is attainable based on the analysis completed above. No points were awarded in the Energy and Atmosphere section, and only two points were awarded in the Indoor Environmental Quality section.

ASHRAE Standard 62.1 Evaluation

This section will discuss the current building addition's mechanical design compliance with ASHRAE 62.1-2013 Ventilation for Acceptable Indoor Air Quality. Sections 1 through 4 discuss the purpose, scope, and definitions of the standard, as well as outdoor air quality and therefore are not discussed. Note that because Morton is a health care facility, it must also comply with ASHRAE 170, Ventilation for Health Care Facilities. In lieu of the ventilation rate, IAQ, and natural ventilation procedures outlined in Standard 62.1 Section 6, Morton was designed using ventilation procedures outline in Standard 170. This evaluation can be found below.

Section 5.0: Systems and Equipment

Section 5.1: Ventilation Air Distribution

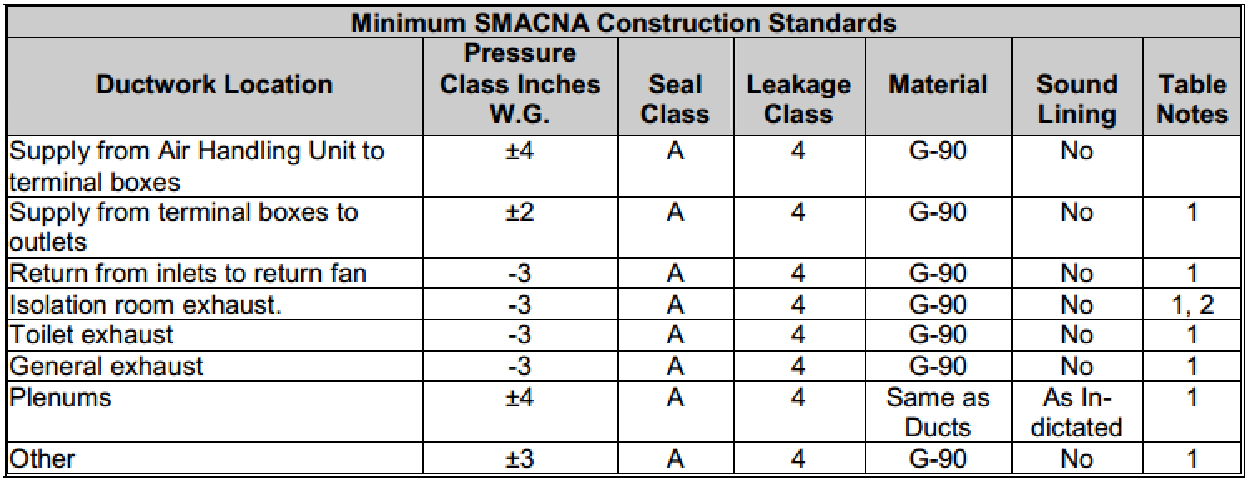
Section 5.1.1 requires the building ventilation system be provided with means to adjust to achieve the minimum airflow while maintaining a balancing of airflow at all times. Within the addition, each zone is controlled by either a constant or variable volume terminal box provided with supply/return air tracking control via supply return fan offset control.

Section 5.1.2 discusses using the plenum to recirculate and distribute air. All air within the hospital will be ducted, both supply and return, and therefore this section is not applicable.

Section 5.1.3 requires documentation for air balance testing. This can be found in the building specifications section 23 05 93 Part 3.1 *Air system Balancing and Testing Procedures*, which specifies its compliance with *The Associated Air Balance Council* (AABC).

Section 5.2: Exhaust Duct Location

This section requires that all exhaust ducts with potentially harmful contaminants be negatively pressurized to avoid exhaust leakage into adjacent spaces. Within the addition, spaces that do require negative pressure include the ER waiting room, triage rooms, patient restrooms, and airborne infection isolation rooms. Negative pressure is achieved by exhausting more air than is supplied within each of these spaces, and forcing airflow from adjacent spaces into these spaces. Additionally, specifications also indicate SMACNA Construction Standards, Figure 8 below, that designate seal and leakage classes required for all ductwork.



Minimum SMACNA Construction Standards

Ductwork Location	Pressure Class Inches W.G.	Seal Class	Leakage Class	Material	Sound Lining	Table Notes
Supply from Air Handling Unit to terminal boxes	±4	A	4	G-90	No	
Supply from terminal boxes to outlets	±2	A	4	G-90	No	1
Return from inlets to return fan	-3	A	4	G-90	No	1
Isolation room exhaust.	-3	A	4	G-90	No	1, 2
Toilet exhaust	-3	A	4	G-90	No	1
General exhaust	-3	A	4	G-90	No	1
Plenums	±4	A	4	Same as Ducts	As In-dictated	1
Other	±3	A	4	G-90	No	1

Figure 8: Minimum SMACNA Construction Standards for Ductwork within the Project

Section 5.3 Ventilation System Controls

All systems' controls must maintain, at a minimum, the outdoor air intake flow at all times. The temperature control system (ATC) and overall building automation system (BAS) will employ a DDC with electric actuation connected to the existing Facilities Management System. Each zone will be provided with a terminal box controller to control temperature settings and zone airflow. The air handling unit and BAS work together to ensure that the minimum outdoor airflow is always achieved.

Section 5.4 Airstream Surfaces

Airstream surfaces are required to resist mold growth and erosion with a standardized test. Material standards of the addition are required to adhere to UL 181 – *Factory-Made Air Ducts and Connectors*, as stated in the building specifications.

Section 5.5 Outdoor Air Intakes

Considering that Morton Hospital is a health care facility, ASHRAE 170, *Ventilation for Health Care Facilities* Section 6.3, *Outdoor Air Intakes and Exhaust Discharge*, is analyzed below in lieu of ASHRAE 62.1 Section 5.5. The ASHRAE 170 standard is more stringent than the 62.1 standard, and therefore will also be compliant with 62.1.

Section 5.6 Local Capture of Contaminants

There is no equipment within the project that generates contaminants, and therefore this section is not applicable.

Section 5.7 Combustion Air

The main source of heat for the building is the existing steam plant, and therefore there is no fuel-burning appliances. This section is not applicable.

Section 5.8 Particulate Matter Removal

As stated in the filter section of the building specifications, Section 23 41 00, filters must have an average efficiency between 30-35%, an average arrestance between 90-92%, and have a MERV 8 rating in accordance with ASHRAE Standards 52-1 and 52.2. Thus, the filters comply with this section. ASHRAE Standard 170 discusses filters in more detail, see below.

Section 5.9 Dehumidification Systems

Humidification is provided by having air handling unit humidifiers in both AHUs. The baseline relative humidity is 30%, and therefore far exceeds that of the Section 5.9.1 requirement of no greater than 65%. As discussed in the standard, general exhaust, totaling 7400 CFM, does not exceed the minimum outside air intake, 9450 CFM, satisfying section 5.9.2.

Section 5.10 Drain Pans

Building specifications indicate that the drain pan slope is a minimum of 1/8”/foot, in compliance with section 5.10.1. Drain pans must extend 6 inches beyond each side of the pan to ensure sufficient collection of water droplets, in accordance with section 5.10.4. Drains are also piped to floor drains or utility sinks and are provided with a seal trap.

Section 5.11 Finned-Tube Coils and Heat Exchangers

The project heat exchangers and cooling coils are provided with a drain pan in accordance with 5.11.1. All heat exchangers are shell-and-tube type, thus section 5.11.2 does not apply.

Section 5.12 Humidifiers and Water-Spray Systems

Both AHU Humidifiers are steam humidifiers that receive steam at low pressure, or supply pressure, and exit at atmospheric pressure. Potable water standards are met, and obstructions must be at least 8 feet downstream of the humidifier, as specified by the manufacturer.

Section 5.13 Access for Inspection, Cleaning, and Maintenance

All equipment, including AHUs, terminal boxes, fan coil units, etc., will include access doors and sufficient working space for inspection purposes, in accordance with sections 5.13.1 and 5.13.2. As stated in section 26 05 20 of the building specification, all access panels shall be a minimum of 12” by 12”, and located in closets, storage rooms, or other non-public areas when possible.

Section 5.14 Building Envelope and Interior Surfaces

Sheet membrane vapor barriers will be used below the concrete slab-on-grade to prevent water penetration through the slab. Also, a continuous bituminous sheet air barrier within the building enclosure will prevent vapor diffusion, and all penetrations due to joints or seams will be properly sealed. Ethylene propylele diene monomer (EDPM) single ply membrane roofing will be used to prevent water penetration through the roof. These key components all comply with ASHRAE 62.1 section 5.14.1.

Ductwork insulation will be faced flexible fiber glass insulation, with a thermal conductivity of 0.3 at 75° F. This satisfies section 5.14.2 in being sufficient to prevent the form of condensation.

Section 5.15 Building with Attached Parking Garages

Morton Hospital existing building and proposed addition will not be attached to a parking garage, thus this section is not applicable.

Section 5.16 Air Classification and Recirculation

Because Morton Hospital is a healthcare facility, and therefore many spaces are not designated an air class within ASHRAE 62.1. Rather spaces including, but not limited to, the ER waiting room, patient restrooms, isolation rooms, and decontamination rooms have different exhaust requirements which will be outlines in the

ASHRAE 170, *Ventilation of Health Care Facilities* Evaluation below. Spaces such as corridors, offices, or reception areas are designated Air Class 1 or 2, and can be returned to the air handling unit to be treated by pre-filters, after filters, and final filters to be reused throughout the hospital.

Section 5.17 Requirements for Buildings Containing ETS Areas and ETS-Free Areas

Morton Hospital is a non-smoking facility and classified as an ETS-free space. This section does not apply to the project.

ASHRAE 62.1 Compliance Summary

Morton's current mechanical design complies with all ASHRAE 62.1 - 2013 Section 5 requirements for acceptable indoor air quality. Following these requirements will help the hospital maintain a healthy system, and therefore minimizes adverse health effects. This is the only section thouroughly evaluated within the standard because ASHRAE 170 has been evaluated in lieu of ASHRAE 62.1 section 6 ventilation procedures.

ASHRAE Standard 170 Evaluation

This section will discuss the current building addition's mechanical design compliance with ASHRAE 170, Ventilation for Health Care Facilities. Because this standard is much more applicable to Morton Hospital's application, it is being evaluated as a replacement for ASHRAE Standard 62.1 Section 6 Procedures evaluation. Original analysis of the addition was done using ASHRAE 170. Note that sections 1 through 5 are related to the scope of the standard and are not discussed below.

Section 6: Systems and Equipment

Section 6.1 Utilities

Section 6.1.1 discusses the ventilation requirement upon loss of electrical power for limited types of spaces. The Morton addition does include airborne infection isolation (AII) rooms that must maintain ventilation and pressure relationships at all times. Drawings specify two isolation exhaust fans, one active and one standby for emergency situations. AII room exhaust also utilizes phoenix venture valves to ensure correct ventilation.

Section 6.2 Air-Handling Unit Design

The modular air handling units supplying air to the Morton Addition include casing that is a double wall galvanized steel construction. Panels shall provide a minimum R value of 12 and coated with 1.5 mil enamel finish, as stated in section 23 74 13 of the building specifications. This is in compliance with that of section 6.2 of ASHRAE 170.

Section 6.3 Outdoor Air Intakes and Exhaust Discharge

AHU outdoor air intakes are on the top of the roof mounted AHU, and therefore are well above the six feet above grade minimum and the 3 feet above roof level minimum. Intakes are also greater than 25 feet from all exhaust and vent discharges, in compliance with section 6.3.1. Isolation room exhaust and emergency department exhaust is discharged a minimum of 10 feet above the roof level and is more than 10 feet horizontally from air intakes or windows, also in compliance with section 6.3.2.

Section 6.4 Filtration

Filters must comply with Table 6.4, *Minimum Filter Efficiencies*, of ASHRAE 170. As seen from the table below, *Figure 9*, there are two required filter banks with listed minimum MERV ratings based on space designations. The first filtration bank is placed upstream of the heating and cooling coils and filters all mixed air. The second bank is installed downstream of the coils.

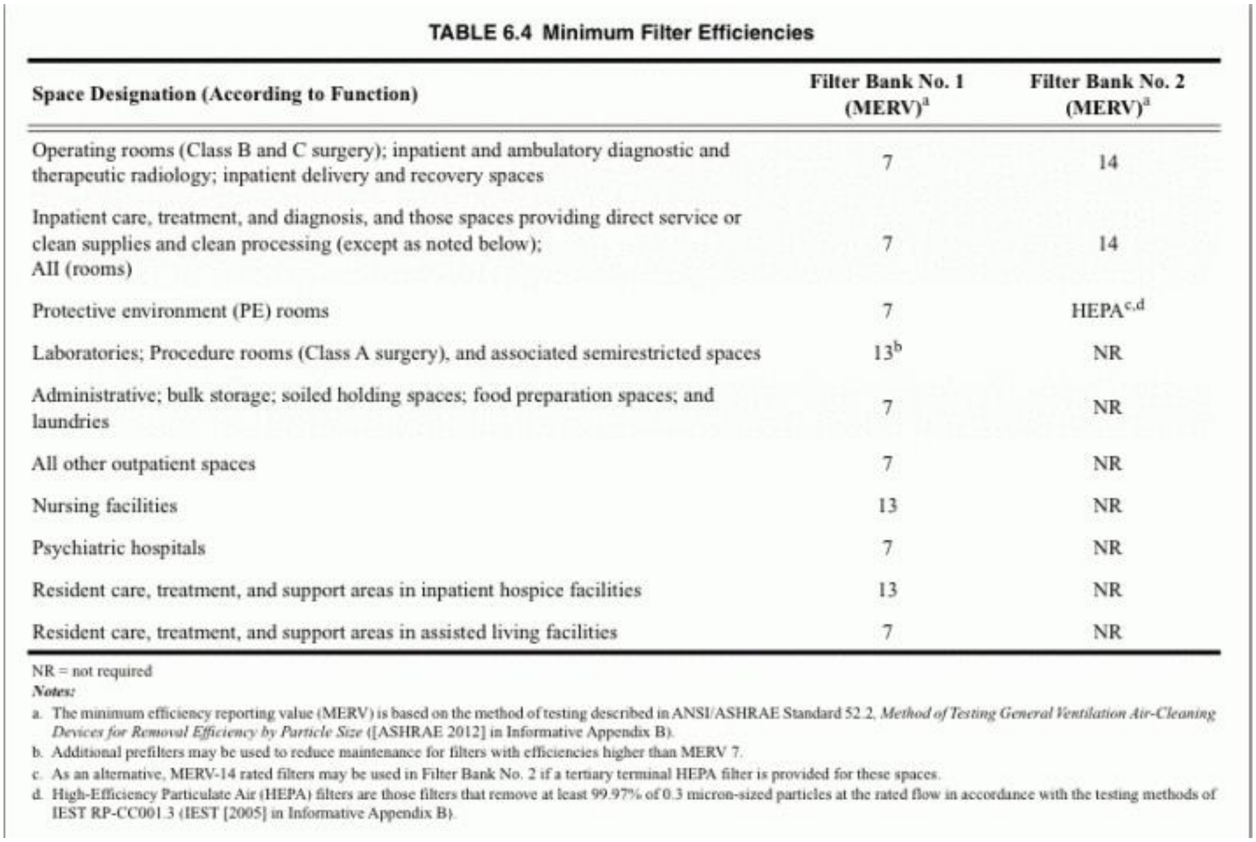


TABLE 6.4 Minimum Filter Efficiencies

Space Designation (According to Function)	Filter Bank No. 1 (MERV)[a]	Filter Bank No. 2 (MERV)[a]
Operating rooms (Class B and C surgery); inpatient and ambulatory diagnostic and therapeutic radiology; inpatient delivery and recovery spaces	7	14
Inpatient care, treatment, and diagnosis, and those spaces providing direct service or clean supplies and clean processing (except as noted below); All (rooms)	7	14
Protective environment (PE) rooms	7	HEPA[c,d]
Laboratories; Procedure rooms (Class A surgery), and associated semirestricted spaces	13[b]	NR
Administrative; bulk storage; soiled holding spaces; food preparation spaces; and laundries	7	NR
All other outpatient spaces	7	NR
Nursing facilities	13	NR
Psychiatric hospitals	7	NR
Resident care, treatment, and support areas in inpatient hospice facilities	13	NR
Resident care, treatment, and support areas in assisted living facilities	7	NR

NR = not required

Notes:

a. The minimum efficiency reporting value (MERV) is based on the method of testing described in ANSI/ASHRAE Standard 52.2, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size* ([ASHRAE 2012] in Informative Appendix B).

b. Additional prefilters may be used to reduce maintenance for filters with efficiencies higher than MERV 7.

c. As an alternative, MERV-14 rated filters may be used in Filter Bank No. 2 if a tertiary terminal HEPA filter is provided for these spaces.

d. High-Efficiency Particulate Air (HEPA) filters are those filters that remove at least 99.97% of 0.3 micron-sized particles at the rated flow in accordance with the testing methods of IEST RP-CC001.3 (IEST [2005] in Informative Appendix B).

Figure 9: ASHRAE 170 Minimum Filter Efficiencies

Modular AHU-1 services phase 1 of the project which includes the MRI. The pre-filter is located upstream of the coils and has a MERV rating of 8. The final filter is located downstream of all coils, the steam humidifier, and supply fan, and has a MERV rating of 14, both complying with Table 6.4. Modular AHU-2 services phase 2 which includes an array of spaces ranging from the ED, psych ward, and isolation rooms. Within AHU-2, there are three filter; the pre-filter with a MERV 8 rating and the after-filter with a MERV 11 rating are both downstream of the mixing plenum and upstream of the coils. The final filter is located downstream of the coils and supply fan and has a MERV rating of 14. With the additional filter, AHU-2 is well above the minimum standards listed in Table 6.4.

Section 6.5 Heating and Cooling Systems

Subsection 6.5.1 refers back to ASHRAE 62.1 Section 5.10 which has already been evaluated above, and does comply. Radiant cooling systems are not utilized in this project and therefore subsection 6.5.2 does not apply. Radiant heating systems are used, but not in the specified spaces, and therefore subsection 6.5.3 also does not apply.

Section 6.6 Humidifiers

Steam humidifiers are located within the air handling units, and chemical additives used comply with FDA requirements, as stated in the building specifications Section 23 25 00, *Chemical Water Treatment*, in compliance with section 6.2.

Section 6.7 Air Distribution Systems

Pressure relationships are maintained at all times based on requirements listed in Table 7.1 of ASHRAE 170. Airstream surfaces comply with ASHRAE 62.1, evaluated above, and therefore comply with this section.

All diffusers are non-aspirating, or Group E Classification, in accordance with Table 6.7.2 *Supply Air Outlets* Classifications. Rooms designated as psychiatric treatment rooms include Type M diffusers, or supply grilles in security areas, specifically Tuttle and Bailey – SG500. This diffuser meets the requirements discussed in section 6.7.2.

Section 7: Space Ventilation

Section 7.1 General Requirements

Spaces must be ventilated in accordance with ASHRAE 170 Table 7.1. Each space must be designated a certain function of space, each requiring a pressure relationship to adjacent spaces, minimum outdoor air changes, minimum total air changes, exhaust requirements, relative humidity guidelines, and design temperature guidelines. This table can be found in Appendix A.

Each space's requirements were found based on these minimums, and ventilation calculations can be found in Appendix C. Only health care spaces were considered in this calculation. For instance, the few offices, electrical rooms, and conference rooms contained in the addition are not specified in ASHRAE 170 Table 7.1. These spaces were designed to assume an occupant ventilation requirement of 20 CFM per person, which assumes a higher requirement than ASHRAE Standard 62.1 Table 6.2.1, and were not analyzed further.

The number of air changes is defined as the number of times air is replaced within a space in one hour, with units of ach/hour. Defining airflow rates by air changes (ach) is done using the following equation:

Airflow rate (CFM) = Room Volume (ft^3) x #ach/60 min per hour

Specified pressurization relationships are met, ensuring that contaminants/diseases are not spread to adjacent spaces. Also, spaces that require all room air to be exhausted are grouped by "general exhaust", "ED room exhaust", and "Isolation Room exhaust" accordingly and are exhausted using centrifugal fans on the roof. All design parameters are met, satisfying section 7.1.

Section 7.2 Additional Room Specific Requirements

There are a number of additional space requirements found in this section. Section 7.2.1 *Airborne Infection Isolation (AII) Rooms* is the only applicable section for the Morton Addition. These spaces contain a pressure monitor that ensures that the correct pressure differential is met. All exhaust air is discharged to the outdoors and does not mix with general exhaust. Exhaust diffusers must also be located directly above the patient's bed. All requirements have been satisfied within the AII rooms.

ASHRAE 170 Compliance Summary

The Morton Hospital Expansion project satisfies the requirements stated in ASHRAE 170 – 2013. This is not surprising since this standard was the basis of design for the mechanical system ventilation rates. Being a healthcare facility, the indoor air quality of the building is exceedingly important to ensure the prevention in spreading diseases or other contaminants.

ASHRAE Standard 90.1 Evaluation

Section 5.0: Building Envelope

Section 5.1.4: Climate

The climate region must be determined using Figure B1-1 in Appendix B of ASHRAE 90.1, shown below (*Figure 10*). According to this figure, Taunton, MA classifies as *Zone 5A*.

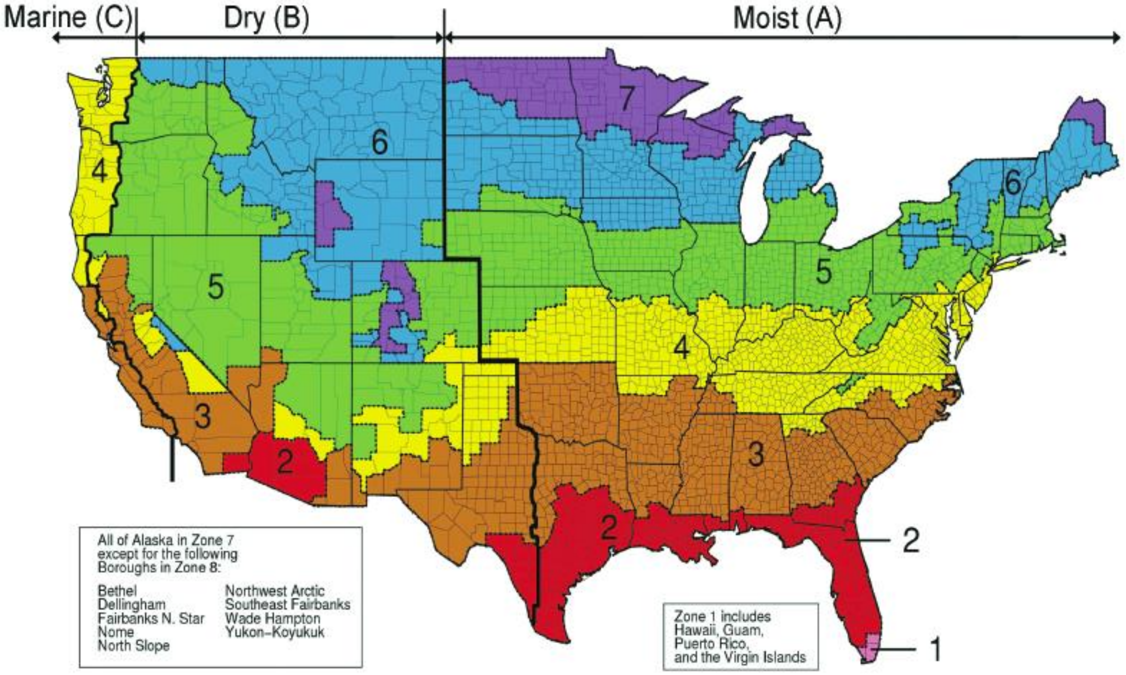


Figure 10: ASHRAE 90.1-2013 Figure B1-1 US Climate Zone Map

Section 5.2: Compliance Paths

Based on the fenestration requirements listed in section 5.5, it is allowable for Morton Hospital to use the “Prescriptive Building Envelope Option.” These requirements state that a building’s vertical fenestration cannot exceed 40% of the total wall area, and skylight fenestration cannot exceed 5% of the total roof area. Because Morton is well below these requirements, section 5.5, described below, is utilized.

Section 5.4: Mandatory Provisions

A continuous air barrier is utilized to ensure no air leakage through the envelope. Fenestration and doors are properly sealed to comply with section 5.4.3.2. All entrances to Morton Hospital have entrance vestibules in order to separate the exterior from the interior, in accordance with 5.4.3.4. This includes an ambulance vestibule that is conditioned with a fan coil unit, and air is supplied through linear diffusers along automated doors.

Section 5.5: Prescriptive Building Envelope Option

ASHRAE 90.1 Table 5.5-5 (Figure 11) can be used to meet building envelope requirements for climate zone 5A. All exterior walls, roofs, slab-on-grade floors, as well as fenestration meet the required building envelope U-values and R-values.

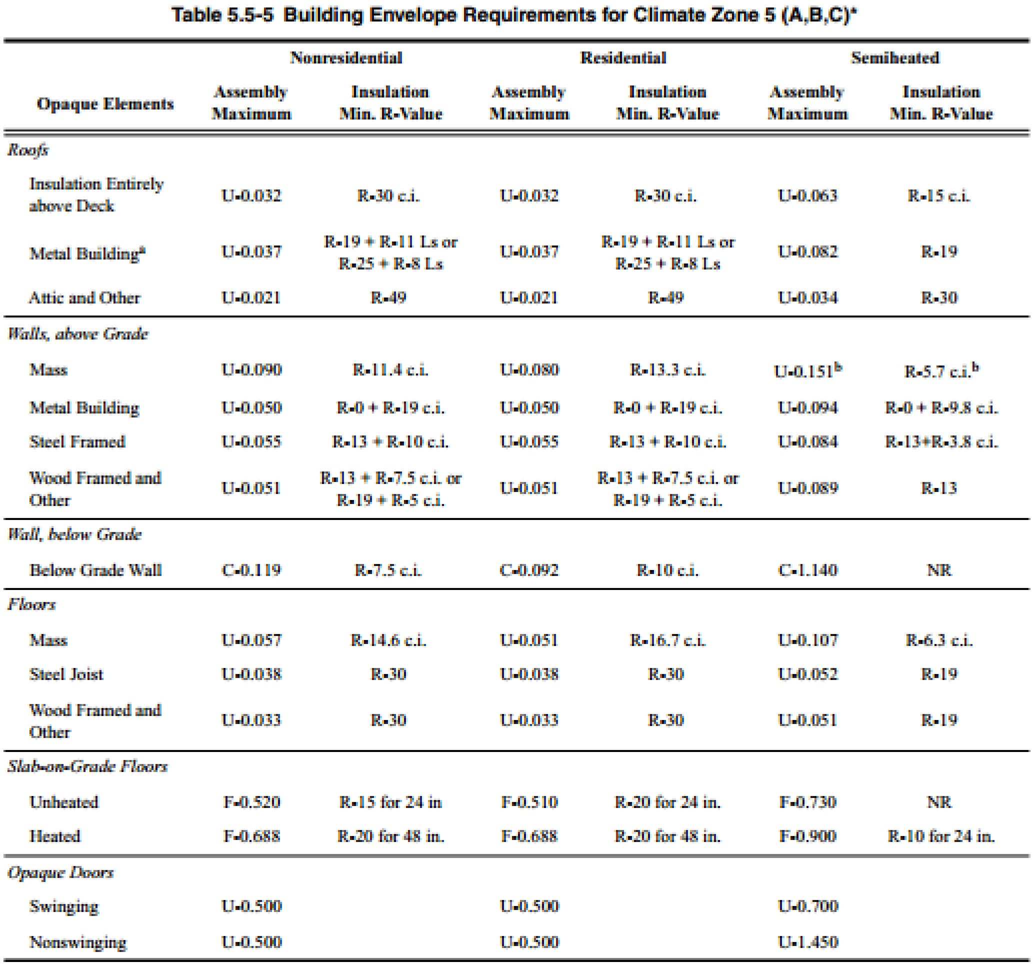


Table 5.5-5 Building Envelope Requirements for Climate Zone 5 (A,B,C)[a]

	Nonresidential		Residential		Semiheated	
Opaque Elements	**Assembly Maximum**	**Insulation Min. R-Value**	**Assembly Maximum**	**Insulation Min. R-Value**	**Assembly Maximum**	**Insulation Min. R-Value**
Roofs						
Insulation Entirely above Deck	U-0.032	R-30 c.i.	U-0.032	R-30 c.i.	U-0.063	R-15 c.i.
Metal Building[a]	U-0.037	R-19 + R-11 Ls or R-25 + R-8 Ls	U-0.037	R-19 + R-11 Ls or R-25 + R-8 Ls	U-0.082	R-19
Attic and Other	U-0.021	R-49	U-0.021	R-49	U-0.034	R-30
Walls, above Grade						
Mass	U-0.090	R-11.4 c.i.	U-0.080	R-13.3 c.i.	U-0.151[b]	R-5.7 c.i.[b]
Metal Building	U-0.050	R-0 + R-19 c.i.	U-0.050	R-0 + R-19 c.i.	U-0.094	R-0 + R-9.8 c.i.
Steel Framed	U-0.055	R-13 + R-10 c.i.	U-0.055	R-13 + R-10 c.i.	U-0.084	R-13+R-3.8 c.i.
Wood Framed and Other	U-0.051	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	U-0.051	R-13 + R-7.5 c.i. or R-19 + R-5 c.i.	U-0.089	R-13
Wall, below Grade						
Below Grade Wall	C-0.119	R-7.5 c.i.	C-0.092	R-10 c.i.	C-1.140	NR
Floors						
Mass	U-0.057	R-14.6 c.i.	U-0.051	R-16.7 c.i.	U-0.107	R-6.3 c.i.
Steel Joist	U-0.038	R-30	U-0.038	R-30	U-0.052	R-19
Wood Framed and Other	U-0.033	R-30	U-0.033	R-30	U-0.051	R-19
Slab-on-Grade Floors						
Unheated	F-0.520	R-15 for 24 in	F-0.510	R-20 for 24 in.	F-0.730	NR
Heated	F-0.688	R-20 for 48 in.	F-0.688	R-20 for 48 in.	F-0.900	R-10 for 24 in.
Opaque Doors						
Swinging	U-0.500		U-0.500		U-0.700	
Nonswinging	U-0.500		U-0.500		U-1.450	

Figure 11: ASHRAE 90.1 - 2013 Table 5.5-5

Section 6.0 Heating, Ventilating, and Air Conditioning

Section 6.4: Mandatory Provisions

Morton Hospital Expansion equipment must comply with the minimum performance rating listed in ASHRAE 90.1 Tables 6.8-1 through 6.8-4, 6.8-8, and 6.8-11 through 13. The other tables listed do not apply to the types of equipment within the project. As stated in the building specifications section 23 05 00, all of these requirements have been met.

Each zone has its own thermostatic controls located within each zone to control the supply of heating and cooling. However, psychiatric patient rooms within the hospital psych ward have temperature controls located in the corridor for safety purposes. This is an exception to the standard and therefore still complies. Furthermore, humidity and pressure sensors are provided for spaces that require a specific relative humidity and pressure relationship, defined by ASHRAE 170 above, in accordance with 6.4.3. Additionally, ductwork insulation complies with ASHRAE 90.1 Table 6.8.2-2, *Minimum Duct Insulation R-Values, Combined Heating and Cooling Supply Ducts and Return Ducts*.

Section 6.5: Prescriptive Path

As stated in the building specifications section 25 90 00, the air handling units shall be in economizer mode when the return dry bulb temperature is greater than the outside dry bulb temperature. In accordance with ASHRAE 90.1 section 6.5.1.1, this air economizer modulates return and outdoor air to provide 100% of the load at all times. Below is Table 6.5.6.1-2 (Figure 12), *Exhaust Air Energy Recovery Requirements*, which requires an energy recovery system based on zone and percent outdoor air. The average outdoor airflow percentage of the whole addition is 27% (9450 CFM OA/35000 CFM total), and the zone classification is 5A. Based on these conditions, an exhaust air recovery system is required for any design supply fan airflow rate.

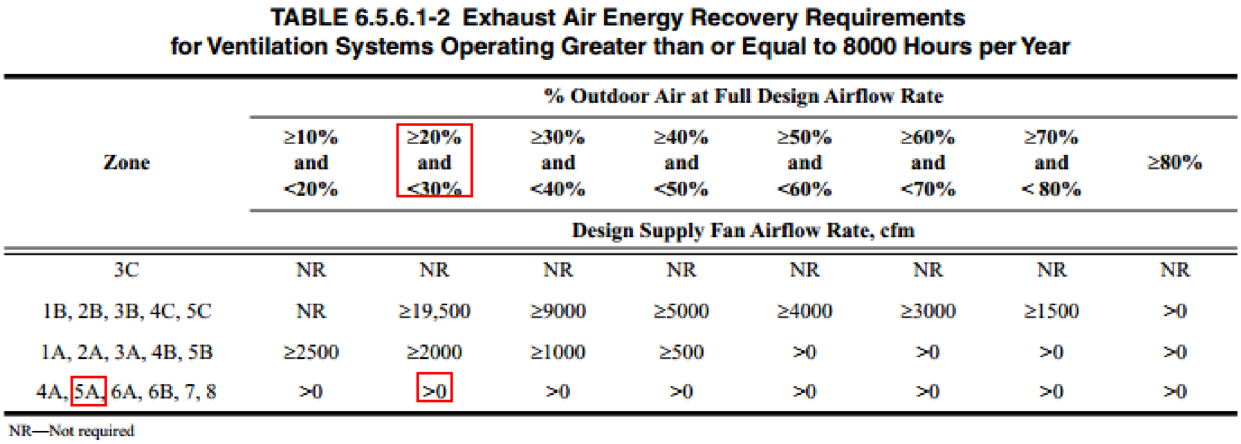


TABLE 6.5.6.1-2 Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Greater than or Equal to 8000 Hours per Year

Zone	% Outdoor Air at Full Design Airflow Rate							
	≥10% and <20%	≥20% and <30%	≥30% and <40%	≥40% and <50%	≥50% and <60%	≥60% and <70%	≥70% and < 80%	≥80%
	Design Supply Fan Airflow Rate, cfm							
3C	NR	NR	NR	NR	NR	NR	NR	NR
1B, 2B, 3B, 4C, 5C	NR	≥19,500	≥9000	≥5000	≥4000	≥3000	≥1500	>0
1A, 2A, 3A, 4B, 5B	≥2500	≥2000	≥1000	≥500	>0	>0	>0	>0
4A, 5A, 6A, 6B, 7, 8	>0	>0	>0	>0	>0	>0	>0	>0

NR—Not required

Figure 12: ASHRAE 90.1-2013 Table 6.5.6.1-2

However, heat recovery is not utilized within the design. This is because as of July 1, 2014, Massachusetts adopted ASHRAE 90.1 – 2010 as the statewide energy code requirement. In the 2013 predecessor, there are no outdoor air percentage requirements listed below 30%, and therefore the project satisfies the state code, but does not satisfy ASHRAE 90.1 Section 6.5 requirements. This will be a significant design factor in the redesign.

Section 7.0 Service Water Heating

The primary source of heat for the addition is provided by the existing low pressure steam system and therefore does not need to comply with section 7. However this steam is used to supply new steam to hot water shell and tube heat exchangers, which must comply with the standard. Service hot-water piping insulation does comply with *Table 6.8.3-1 Minimum Piping Insulation Thickness Heating and Hot Water Systems.* Also, temperature controls are provided for each supply terminal box that control the amount of heat needed for each zone.

Section 8.0 Power

All feeders adhere to the maximum 2% voltage drop, and all branch circuits adhere to the maximum 3% voltage drop. Since most spaces are not classified as an office, conference rooms, or classrooms, the automatic receptacle control requirement does not apply to the critical spaces within Morton Hospital.

Section 9.0 Lighting

Based on the Compliance Path outlined in the standard, the *Building Area Method* can be used to determine compliance. According to Table 9.5.1 of ASHRAE 90.1, the average allowable lighting power density of a hospital is 1.05 W/ft^2. Most fixtures are fluorescent type and satisfy this requirement.

Section 10.4.1 Electric Motor

Motors used to power all fan coil units and cabinet and unit heaters are all under 1 hp, and do not have performance requirements in this section. Applicable motors powering fans and water pumps meet the efficiency requirements of Table 10.8-1, seen below in Figure 13. For example, water pump “HWP-1” uses a 60 Hz motor at 3 hp and 1800 rpm. Based on Table 10.8.1, the full-load efficiency should be 89.5%, which is satisfied by the motor.

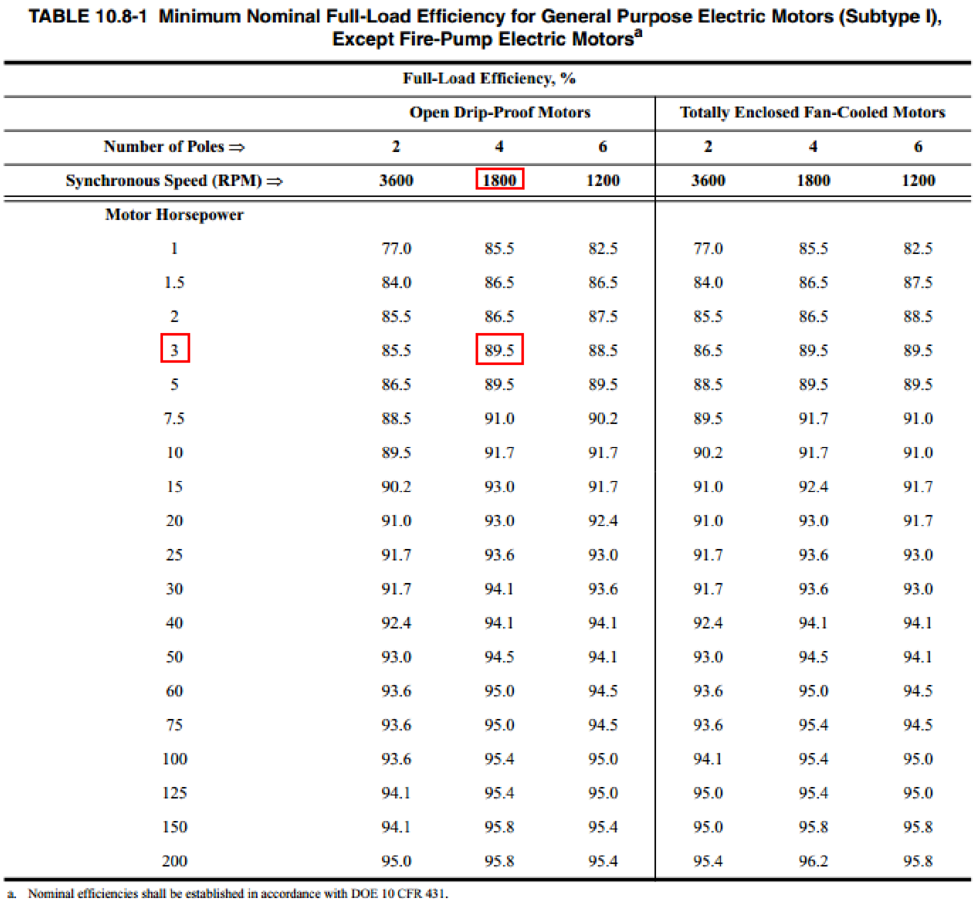


TABLE 10.8-1 Minimum Nominal Full-Load Efficiency for General Purpose Electric Motors (Subtype I), Except Fire-Pump Electric Motors[a]

	Full-Load Efficiency, %					
	Open Drip-Proof Motors			Totally Enclosed Fan-Cooled Motors		
Number of Poles ⇒	2	4	6	2	4	6
Synchronous Speed (RPM) ⇒	3600	1800	1200	3600	1800	1200
Motor Horsepower						
1	77.0	85.5	82.5	77.0	85.5	82.5
1.5	84.0	86.5	86.5	84.0	86.5	87.5
2	85.5	86.5	87.5	85.5	86.5	88.5
3	85.5	89.5	88.5	86.5	89.5	89.5
5	86.5	89.5	89.5	88.5	89.5	89.5
7.5	88.5	91.0	90.2	89.5	91.7	91.0
10	89.5	91.7	91.7	90.2	91.7	91.0
15	90.2	93.0	91.7	91.0	92.4	91.7
20	91.0	93.0	92.4	91.0	93.0	91.7
25	91.7	93.6	93.0	91.7	93.6	93.0
30	91.7	94.1	93.6	91.7	93.6	93.0
40	92.4	94.1	94.1	92.4	94.1	94.1
50	93.0	94.5	94.1	93.0	94.5	94.1
60	93.6	95.0	94.5	93.6	95.0	94.5
75	93.6	95.0	94.5	93.6	95.4	94.5
100	93.6	95.4	95.0	94.1	95.4	95.0
125	94.1	95.4	95.0	95.0	95.4	95.0
150	94.1	95.8	95.4	95.0	95.8	95.8
200	95.0	95.8	95.4	95.4	96.2	95.8

a. Nominal efficiencies shall be established in accordance with DOE 10 CFR 431.

Figure 13: ASHRAE 90.1 Table 10.8.1 Minimum Full-Load Efficiencies for Electric Motors

ASHRAE 90.1 Compliance Summary

The Morton Hospital Expansion project does not completely comply with ASHRAE 90.1 – 2013. As discussed in section 6.5, a heat recovery system is required given that Taunton is located in Zone 5A and the percentage of outdoor air is 27%. Also, the use of a DX system, although compliable, has room for improvement. The air cooled chiller could also be updated to a water cooled chiller for added energy performance. Redesigning the system based on these and other suggestions would be greatly beneficial to the energy consumption of the building.

Overall Existing Mechanical System Summary

The primary source for the building addition heating is provided by the existing hospital steam system. The low pressure steam system will employ heat exchangers to provide building reheat, preheat, perimeter heating, and domestic water heating. The steam connection will originate from the existing basement below the proposed MRI space. The primary cooling source will be a new 155 ton air cooled chiller. The chilled water system is a variable primary flow type.

The central air handling system will be served by two modular air handling units. Phase 1 will be provided by a rooftop packaged DX unit containing a steam preheat coil and direct expansion cooling coil, provided by existing steam plant and air cooled condensing unit respectfully. Phase 2 will employ a roof mounted chilled water air handling unit containing a hot water preheat coil and chilled water cooling coil, supplied by a steam-to-water heat exchanger and air cooled chiller respectfully. Both will be variable air volume, supply return type, controlled by minimum outside air monitoring and airside economizer control. Humidifiers are included within the units, and supply and return fans are driven by variable frequency drives. Phase 1 will have electric reheat coils at each zone, while Phase 2 will utilize terminal supply boxes with hot water reheat coils.

The mechanical system first cost was estimated at $2,965,365, or $73.95/SF of total building area. The Phase 1 mechanical cost per square foot is significantly higher than the Phase 2 cost, $158.13/SF versus $68.21/SF, respectfully.

Based on the LEED analysis, it is unlikely that any sort of LEED rating is achievable. No points were awarded in the Energy and Atmosphere section, and only two points were awarded in the Indoor Environmental Quality section.

Part 2: Proposed Redesign

Alternatives Considered

To improve upon the current mechanical design of The Morton Expansion, several alternatives were considered. The following investigations considered the impact on overall energy savings, first and operating cost, controllability, and system feasibility:

- Air-to-air Energy Recovery
    - Enthalpy wheel
    - Runaround Coils/Heat Recovery Coils
- Chilled water distribution
    - Tapping into the existing building plant
    - A new water cooled chiller with cooling tower
- Ground Coupled Heat Pumps
- Variable Refrigerant Flow
- Displacement Ventilation/Underfloor Air Distribution
- Dedicated Outdoor Air System for Ventilation
- Solar Domestic Hot Water

Because of time constraints and limited information provided, some alternatives cannot be evaluated. Since obtaining the existing building drawings and documents is not possible, an evaluation of the chilled water plant would not be accurate. Also, ASHRAE 170 – 2013 Table 6.7.2 *Supply Air Outlets* only permits the use of vertical discharge floor diffusers in single patient rooms. Considering the hospital is a single story, UFAD would require the floor to be raised, and would not be a practical solution. The main focus of the redesign will be on the use of a water cooled chiller, air-to-air energy recovery, and Variable Refrigerant Flow with DOAS ventilation.

Proposed Redesign

An analysis of three systems will be evaluated: the current system, a water cooled chiller (WCCH) with an open cooling tower, and a VRF System in conjunction with a dedicated outdoor air system. Both alternatives will also evaluate energy recovery systems and grey water usage. These alternatives will be compared primarily based on their first cost, energy usage, and life cycle cost to determine which option is the most practical, while also being sustainable. An important note is that these recommendations are in no way an implication of the insufficiency of the current design of the Morton Hospital Addition, and are only being evaluated for educational purposes.

Depth

Energy Recovery

As discussed in the ASHRAE 90.1 evaluation, a heat recovery system must be utilized to comply with the standard. Considering that Morton is a health care facility, cross contamination must be avoided in critical zones within the addition in order to satisfy ASHRAE 170 – 2013 Section 6.8.3. Therefore, two new air handling units will be implemented. One will supply air to spaces including the ER waiting room, isolation rooms, and operating rooms, must utilize an exhaust air recovery system that ensures the separation of exhaust air with supply air. Glycol solution coils is one possibility of a system that does not create cross-contamination. Another air handling unit will supply air to the other spaces that do not require isolation of air. This AHU will utilize an enthalpy wheel between exhaust and supply air because those spaces do not have the risk of harmful contaminants within it.

Water Cooled Chiller and Cooling Tower

Currently, Phase 1 cooling is provided by an air cooled condenser supplying a direct expansion coil in AHU-1. Phase 2 is provided by an air cooled chiller supplying a chilled water coil within AHU-2. The basis of the current design was a lower first cost. The proposed plan is to include a chilled water coil in both air handling units, and connect these coils to a water cooled chiller. In order to do so, a new cooling tower must also be provided. An evaluation on the increased first cost versus the expected decrease in life cycle cost will be completed.

Also, considering the climate, the use of an economizer with the cooling tower will provide the benefit of free cooling. Not only will this improve the life cycle cost, but will also result in a lower overall energy use. Another method of decreasing energy usage is to evaluate the benefits of using grey water within the cooling tower.

Variable Refrigerant Flow

VRF systems have many advantages over the typical VAV system and DX system design that Morton currently has. Mainly, the increase in controllability and efficiency, and decrease in energy consumption and footprint. This system allows for operation at varying speeds, therefore only supplying as much refrigerant as needed to a specified zone. This is done with the use of an inverter driven compressor that varies motor speed to precisely meet all zone load requirements, reducing power consumption. Utilizing heat recovery VRFs allows each zone to heat or cool while the internal heat recovery reduces the compressor load. A VRF system can allow patients to set their own temperature to individualize comfort. In addition, VRF systems have small footprints, and do not require ductwork which would greatly free up plenum space.

Another aspect that must be evaluated is how outside air minimum requirements will be met. Because of the spaces that require 100% exhaust air, a DOAS is needed for those zones, discussed below. A DOAS will also supplement the VRF system OA requirements.

As well, an evaluation of ASHRAE Standard 15 – *Safety Standard for Refrigeration Systems* will be done to ensure compliance.

Dedicated Outdoor Air System

Many critical spaces within the addition require 100% outside air, including the ER waiting room and isolation rooms. Because of this, these spaces will not utilize the VRF technology, and will employ a DOAS AHU in conjunction with a heat recovery system, as described above. Because of the VRF technology, the AHU size will drastically decrease compared to the original design.

Breadth

Structural

The addition of a cooling tower located on the roof of the addition requires a reevaluation of the roof structure. This is a large increase in the dead load that the roof must be able to support. Currently, the roof includes a light colored membrane roof over rigid insulation on a concrete and metal deck roof slab.

Electrical

Since VRFs are all electric, an analysis in powering the VRF units with photovoltaic panels will be completed. This is in an attempt to be carbon neutral, or emission free.

Masters Coursework

The proposed alternatives will include aspects from multiple MAE courses. Utilizing a water cooled chiller and cooling tower will use knowledge from AE 557 – Centralized Cooling Production and Distribution Systems when evaluating chilled water systems and cooling tower selection. Also, when implementing a VRF system, knowledge from AE 557 will be used to determine the impact of refrigerants. Knowledge from AE 552 – Indoor Air Quality will also be used to evaluate the hospital's possible ventilation systems.

In addition, a computational fluid dynamics analysis will be completed to study the airflow in an isolation room located in the hospital. Knowledge from AE 559 – Computational Fluid Dynamics will be used to model the spaces in the program Star CCM+ to analyze the nature of airflow throughout the isolation room.

Tools

Energy Modeling

eQuest 3.65 will be used to examine the mechanical systems in more detail. First it will be used to model the current design, and then will be modeled to evaluate the two alternative designs to determine which system will be the most appropriate considering efficiency, energy consumption, and operating cost.

Load Simulation

Trane Trace 700 will be used for load simulation to evaluate the required loads for the current design, as well as the two proposed alternative designs.

Computational Fluid Dynamics

Star CCM+ will be used as the CFD program to model the isolation room and analyze the airflow in that room, as well as adjacent spaces to ensure its isolation requirements are met.

Schedule

The current progress schedule for Spring 2015 can be found in Appendix E. Milestones were set to keep in check with the overall project goals and are as follows:

- Milestone #1 – January 23: Completed preliminary research, existing eQuest Model developed, and CPEP up-to-date
- Milestone #2 – February 14: Completed eQeust model for the proposed redesign, chilled water plant redesign complete, and VRF design in progress
- Milestone#3 – March 9: VRF design complete, structural & electrical breadth complete
- Milestone #4 – April 3: Completed cost analysis. Only revisions on final report and final presentation are needed.

Part 3: Proposed Redesign Analysis

Mechanical Depth Analysis

Two alternatives were evaluated during this investigation to determine the most beneficial for the given conditions. Alternative 1 replaces the air cooled chiller with a water cooled chiller with cooling tower, while also employing an air-to-air heat recovery system. Alternative 2 utilizes variable refrigerant flow technology and dedicated outdoor air units, in addition to the water cooled chiller, cooling tower, and energy recovery system. An evaluation of the overall mechanical system, energy consumption, and economic analysis is the basis of the comparison of these options. Alternative 1 and Alternative 2 design load estimations were calculated using Trane Trace 700.

Alternative 1 | Water-Cooled Chiller and Cooling Tower

Mechanical System Overview

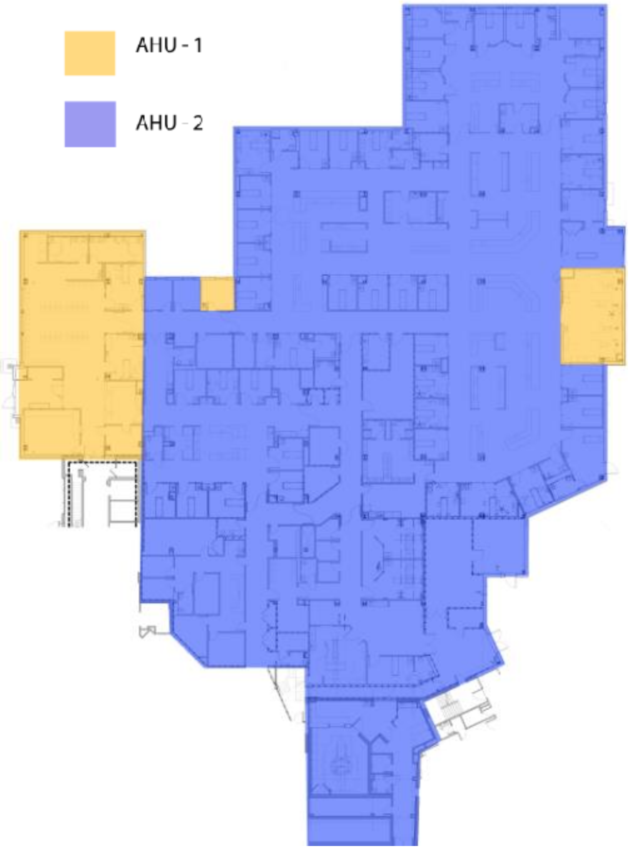


Figure 14: Alternative 1 Zoning

Alternative 1 will utilize two air handling units that supply separate zones than that of the original design. As seen in Figure 14, zones shaded in yellow will be supplied by AHU-1. These zones include the emergency department waiting room, isolation treatment, and trauma rooms, all of which require isolated, 100% exhaust. Zones shaded in blue are provided by AHU-2, and include all other zones. No special exhaust requirements are necessary. The following section will discuss the specific mechanical operation of Alternative 1.

Heating

Alternative 1 heating will be provided by the existing steam boiler plant. However, instead of one air handling unit utilizing a steam preheat coil and one utilizing a hot water coil, both new air handling units will use hot water preheat coils. This is to reduce the maintenance and operation costs that is required for steam coils. Since the corresponding steam-to-hot water heat exchangers are oversized, the total heat capacity of 1230 MBtu/hr is met by the existing two heat exchangers with capacities of 1600 MBtu/hr, one being on standby. Figure 15 is a schematic diagram of the steam and hot water loop.

As well, the introduction of air-to-air heat recovery reduces the heat load on the hot water coils from 1810 MBtu per year to 715 MBtu per year, a reduction of 60%. The heat recovery system is further discussed below, in the *Airside* section.

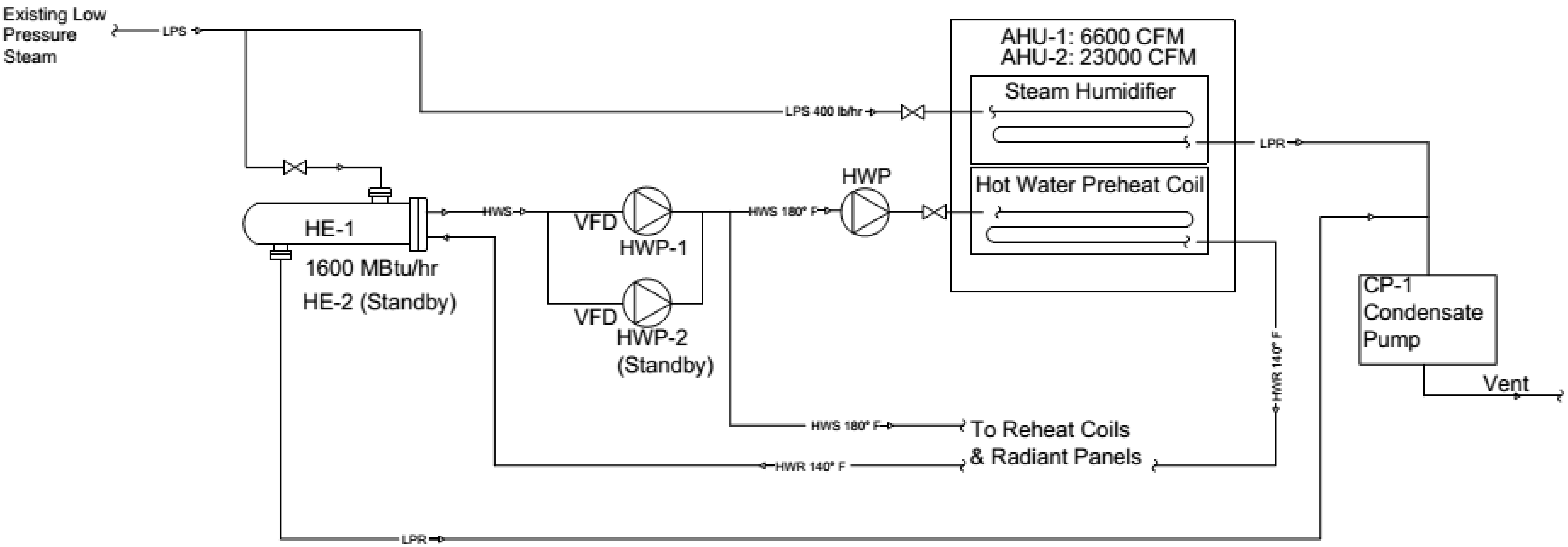


Figure 15: Alternative 1 Steam & Hot Water Flow Diagram

Cooling

Cooling will be provided by a new 145 ton open cooling tower and 145 ton water-cooled centrifugal chiller. The technical data of the selected chiller, provided by Daikin, can be found in Appendix B. Both air handling units will utilize a chilled water coil, rather than one using chilled water and the second using direct expansion cooling. AHU-1 requires 25 tons of cooling, and AHU-2 requires 120 tons of cooling. Figure 16 is a schematic diagram of the condenser water and chilled water loop. Chiller and cooling tower sizing procedures is discussed in the sizing overview section below.

The cooling tower was selected using Marley Cooling Tower Selection Software. An NC Steel 1 cell cooling tower, model NC8401KAN1, with a heat rejection of 1726200 Btu/hr was selected. The Marley Software Data sheet can be found in Appendix B.

Airside

All zones are being supplied by a variable volume terminal box, which includes a hot water reheat coil. The original design utilizes electric reheat coils in the Phase 1 zones, and terminal boxes in the Phase 2 zones. Removing the electric reheat coils from all zones reduces the overall electric consumption.

Air-to-Air Heat Recovery

In an effort to reduce wasted energy, an air-to-air heat recovery system is also employed. AHU-1 employs a glycol solution loop, which transfers energy from exhausted air in EAHU-1 to supply air in AHU-1 through a closed loop that connects the two energy recovery coils. This ensures that contaminated air from the critical zones does not pollute the supply air. Both configurations require exhaust air handling units, EAHU-1 and EAHU-2, for the proper transfer of energy. AHU-2 employs an enthalpy wheel to recover energy from the exhausted air of the non-critical zones. This wheel is placed upstream of the hot water and chilled water coils in AHU-2, and downstream of the filters in EAHU-2, and results in a lower load on both coils. Figure 17 is a schematic diagram of AHU-1 and EAHU-1, and Figure 18 is a schematic diagram of AHU-2 and EAHU-2. The resulted reduction in energy from the heat recovery system is discussed in the following section.

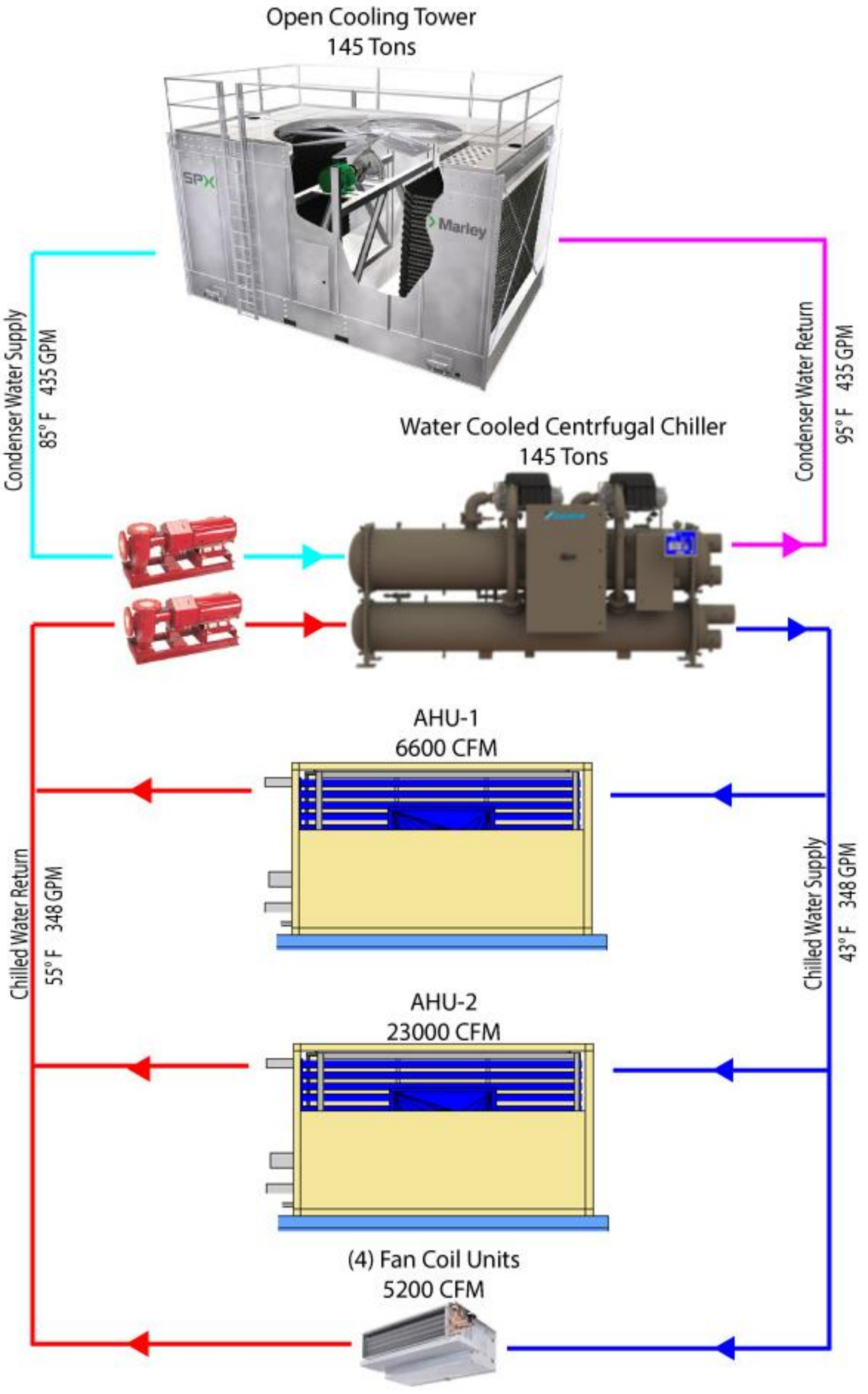


Figure 16: Alternative 1 Condenser Water and Chilled Water Loop Schematic

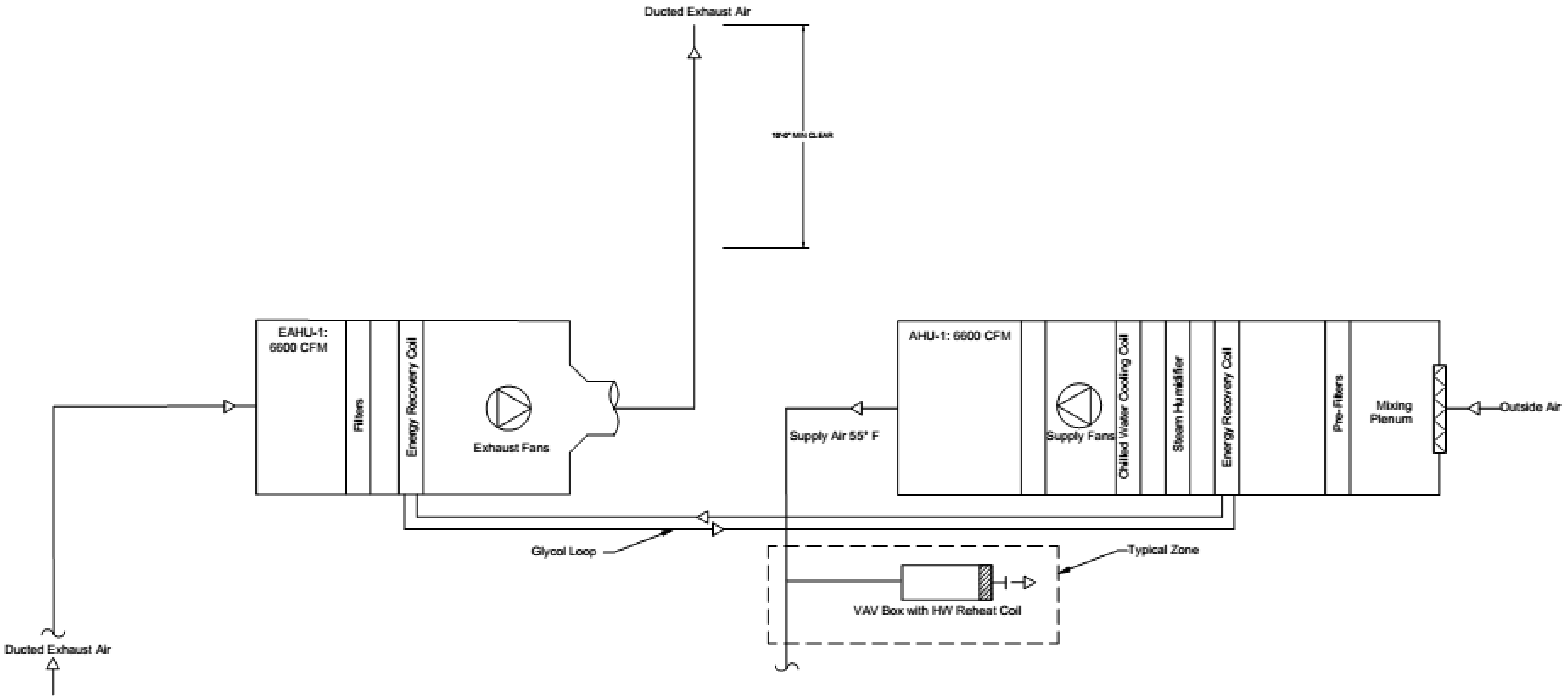


Figure 17: Alternative 1 AHU-1 and EAHU-1 Airflow and Heat Recovery Schematic

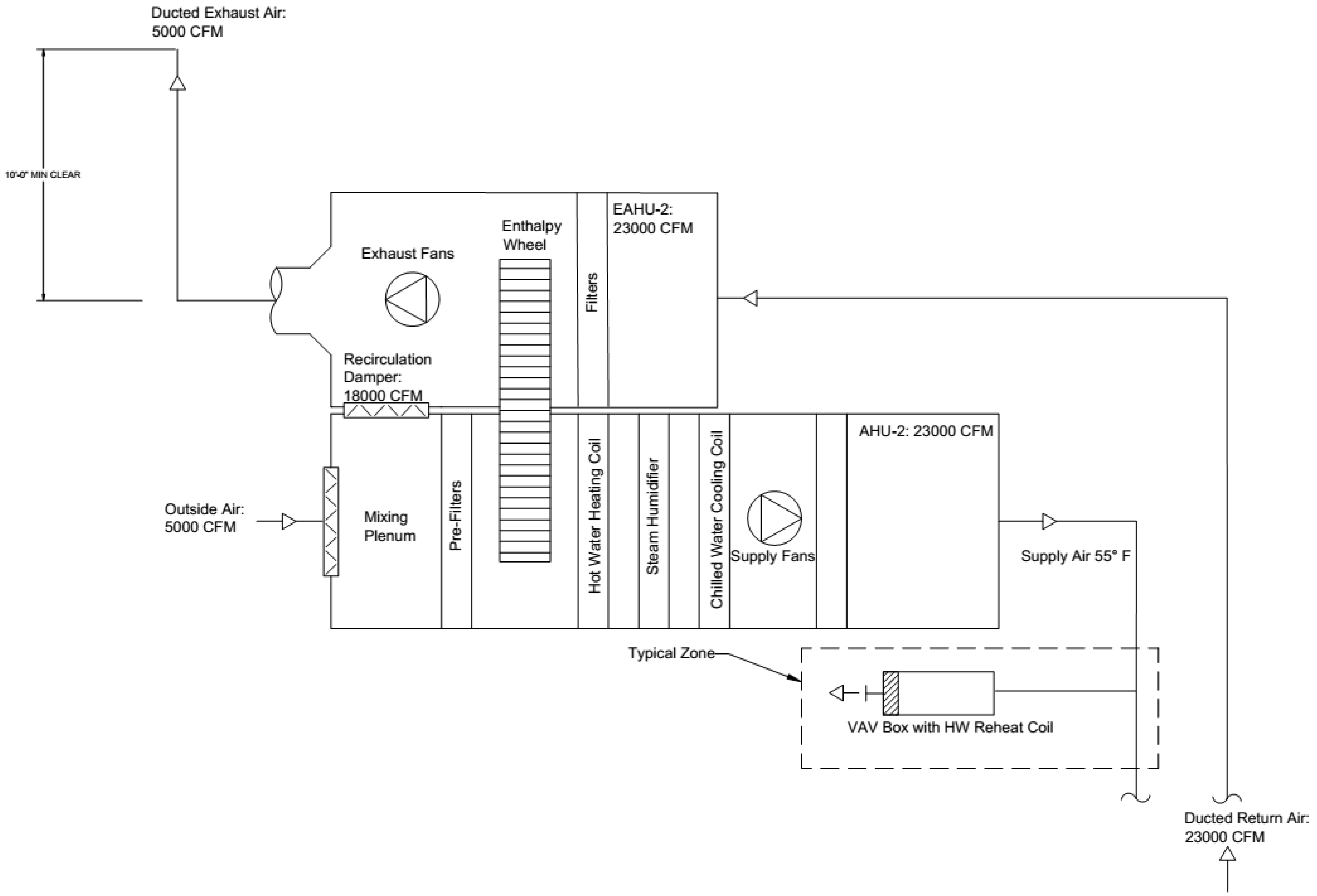
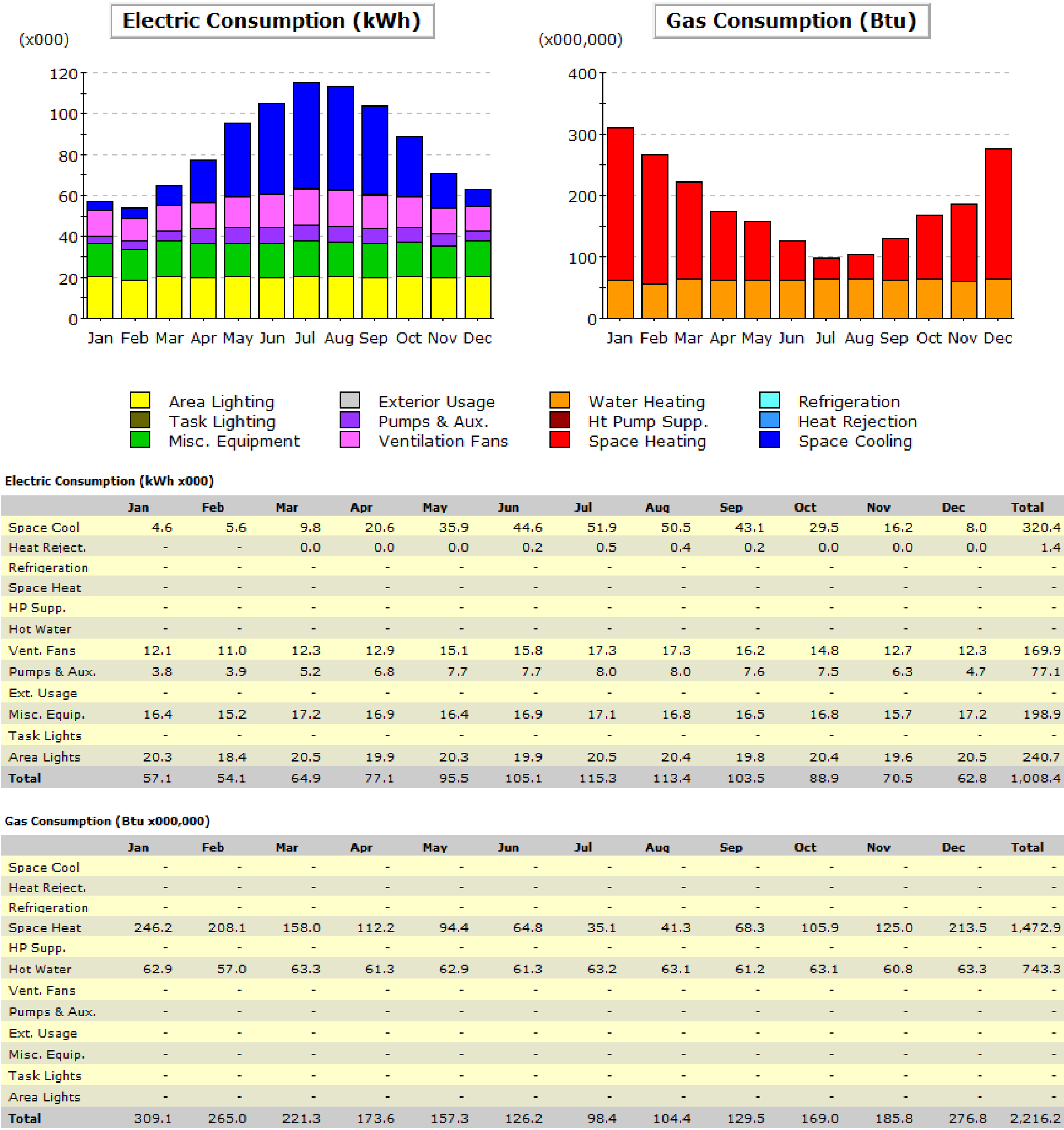


Figure 18: Alternative 1 AHU-2 and EAHU-2 Airflow and Heat Recovery Schematic

Energy Consumption & Operational Cost

Figure 19, below, represents the annual electrical and natural gas consumption of the proposed alternative, calculated using eQuest. A summary table of these results can be found in the Overall System Comparison on page __.



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	4.6	5.6	9.8	20.6	35.9	44.6	51.9	50.5	43.1	29.5	16.2	8.0	320.4
Heat Reject.	-	-	0.0	0.0	0.0	0.2	0.5	0.4	0.2	0.0	0.0	0.0	1.4
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	12.1	11.0	12.3	12.9	15.1	15.8	17.3	17.3	16.2	14.8	12.7	12.3	169.9
Pumps & Aux.	3.8	3.9	5.2	6.8	7.7	7.7	8.0	8.0	7.6	7.5	6.3	4.7	77.1
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	16.4	15.2	17.2	16.9	16.4	16.9	17.1	16.8	16.5	16.8	15.7	17.2	198.9
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	20.3	18.4	20.5	19.9	20.3	19.9	20.5	20.4	19.8	20.4	19.6	20.5	240.7
Total	57.1	54.1	64.9	77.1	95.5	105.1	115.3	113.4	103.5	88.9	70.5	62.8	1,008.4

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	246.2	208.1	158.0	112.2	94.4	64.8	35.1	41.3	68.3	105.9	125.0	213.5	1,472.9
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	62.9	57.0	63.3	61.3	62.9	61.3	63.2	63.1	61.2	63.1	60.8	63.3	743.3
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	309.1	265.0	221.3	173.6	157.3	126.2	98.4	104.4	129.5	169.0	185.8	276.8	2,216.2

Figure 19: Annual Energy Consumption of Alternative 1 calculated using eQuest

Overall, the electrical consumption decreases by more than 10% compared with the original design, and the natural gas consumption decreases by about 34%. The most significant changes are in the decrease in space cooling, space heating, and ventilation fans, and the increase in pump energy.

Chilled Water Plant Analysis

As indicated, the new water-cooled chiller in conjunction with an open cooling tower reduces the overall electrical by more than 10%, saving 118,800 kWh per year. Evaluating further, the space cooling is reduced by about 8.5%. The biggest reduction is in fan energy, with a reduction of 41%, or 120,000 kWh per year. However, there is an increase in pump energy of 83%, or 35,100 kWh. This is because an air-cooled chiller has more fan usage and a water-cooled chiller has more pump usage. Since water has a much higher thermal capacitance than air, pumps are much more efficient than fans. A summary of these reductions can be found in the Overall System Comparison Section.

Air-to-Air Energy Recovery Analysis

The most significant decrease in energy consumption can be found in the space heating, with a 44% reduction, or a savings of 1,158.5 MBtu per year. This is because of the implementation of two air-to-air heat recovery systems. As discussed in the ASHRAE 90.1 evaluation found in *Part 1*, no form of energy recovery is used, and therefore does not comply with the standard. The redesign employs two systems as discussed in the previous section: a glycol solution coil in AHU-1, and an enthalpy wheel in AHU-2. As a result, the boiler and hot water loop both consume about 700 MBtu per year, versus the original 1800 MBtu per year. The hot water loop peak reduces from 2109.7 kBtu/hr to 511.4 kBtu/hr. However, the steam is coming from the existing building steam boiler plant, and therefore a change in boiler is impractical and not evaluated. Nevertheless, both energy recovery systems greatly reduce the air handling unit hot water coil loads. A table summary of these results can be found in the Overall System Comparison Section.

Monthly Utility Costs

Based on the eQuest analysis, the annual operating cost of Alternative 1 is $182,169, averaging at $4.47/SF. This is a savings of 15% compared to the original design. Figure 20 summarizes the monthly utility costs, Electricity based on a virtual rate of $0.158/KWh, and Natural Gas based on a virtual rate of $1.101/therm. This results in 1,008,388 KWh per year of electricity, and 22,162 therm per year of natural gas.

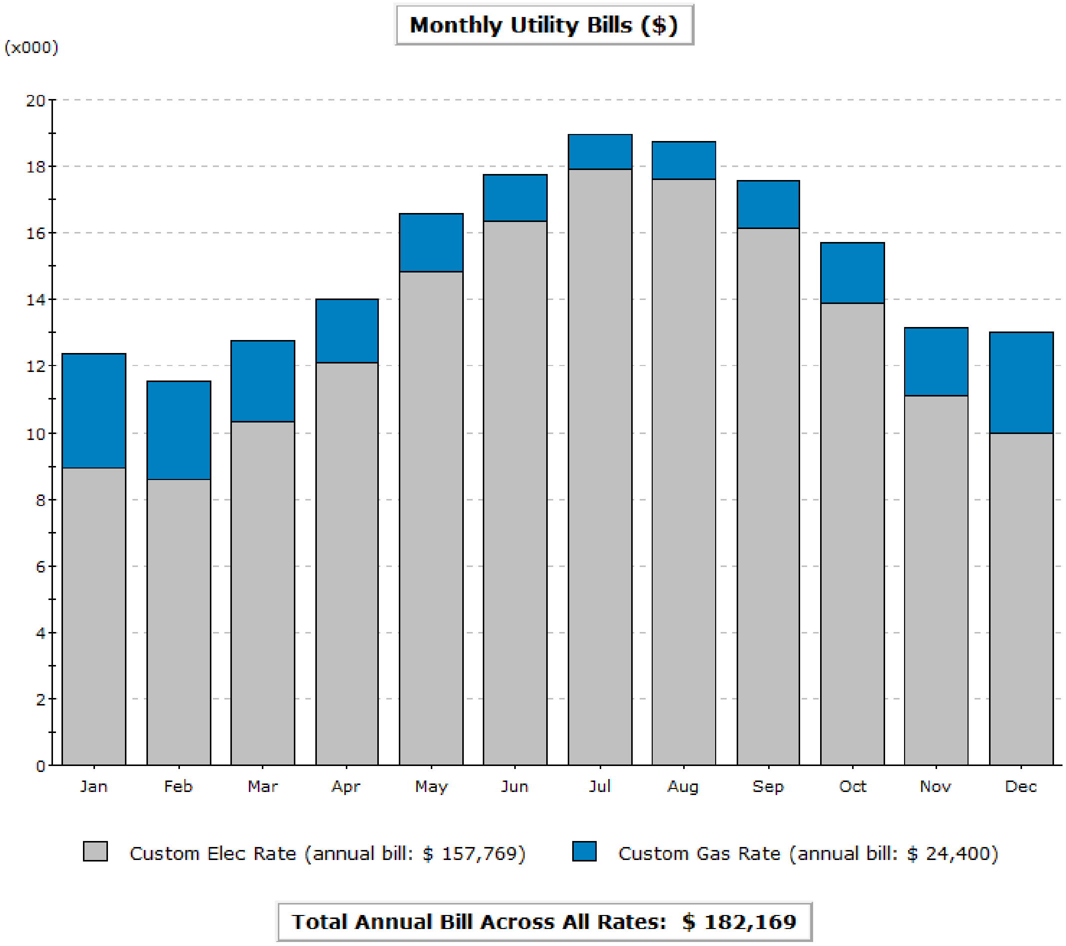


Figure 20: Monthly Utility Rates of Alternative 1 based on Electrical Demand and Natural Gas Demand

Monthly Equipment Costs

From the eQuest 3.65 analysis, the monthly and annual equipment costs were calculated by end use, categorized as cooling equipment, heating equipment, fans, lighting, and miscellaneous equipment. Table 8 summarizes these energy costs. The lighting and miscellaneous equipment has not been changed, so the savings occur in the heating, cooling, and fan costs, saving a total of 29%

Table 8: Monthly and Annual Equipment Costs of Alternative 1

Monthly Equipment Costs by End Use					
	Cooling	**Heating**	**Fans**	**Lighting**	**Misc**
January	$ 672.98	$ 2,710.66	$ 1,770.23	$ 2,969.89	$ 2,399.32
February	$ 819.28	$ 2,291.18	$ 1,609.30	$ 2,691.92	$ 2,223.76
March	$ 1,433.74	$ 1,739.58	$ 1,799.49	$ 2,999.15	$ 2,516.36
April	$ 3,013.78	$ 1,235.32	$ 1,887.27	$ 2,911.37	$ 2,472.47
May	$ 5,252.17	$ 1,039.34	$ 2,209.13	$ 2,969.89	$ 2,399.32
June	$ 6,524.98	$ 713.45	$ 2,311.54	$ 2,911.37	$ 2,472.47
July	$ 7,592.97	$ 386.45	$ 2,530.99	$ 2,999.15	$ 2,501.73
August	$ 7,388.15	$ 454.71	$ 2,530.99	$ 2,984.52	$ 2,457.84
Septembe	$ 6,305.53	$ 751.98	$ 2,370.06	$ 2,896.74	$ 2,413.95
October	$ 4,315.85	$ 1,165.96	$ 2,165.24	$ 2,984.52	$ 2,457.84
Novembe	$ 2,370.06	$ 1,376.25	$ 1,858.01	$ 2,867.48	$ 2,296.91
Decembe	$ 1,170.40	$ 2,350.64	$ 1,799.49	$ 2,999.15	$ 2,516.36
TOTAL	**$ 46,859.89**	**$ 16,215.53**	**$ 24,841.74**	**$ 35,185.15**	**$ 29,128.33**

within these three categories. Specifically, cooling equipment saves $4300 per year, heating equipment saves $13,500 per year, and fans save $17,600 per year. A summary of these costs can be found in the Overall System Comparisons section.

Emissions

Based on emission factors provided by the National Renewable Energy Laboratory – Source Energy and Emission Factors for Energy Use in Buildings, Table 9 summarizes the amount of pollutant emitted annually for Alternative 1. This is an 11% decrease in pollutants when compared to the original design because there is a decrease in electricity usage.

Table 9: Alternative 1 Pollutant Emissions caused by the delivered Electrical Demand

Emmissions for Delivered Electricity				
Pollutant	Eastern US Emission Factor (lb pollutant/kWh electricity)	Electricity Usage (kWh)	Amount of Pollutant (lb)	Savings compared to Original
CO2	1.64E+00	1,008,400	1,653,776.00	11%
NOX	3.00E-03	1,008,400	3,025.20	11%
SOX	8.57E-03	1,008,400	8,641.99	11%

Alternative 2 | Variable Refrigerant Flow

Mechanical System Overview

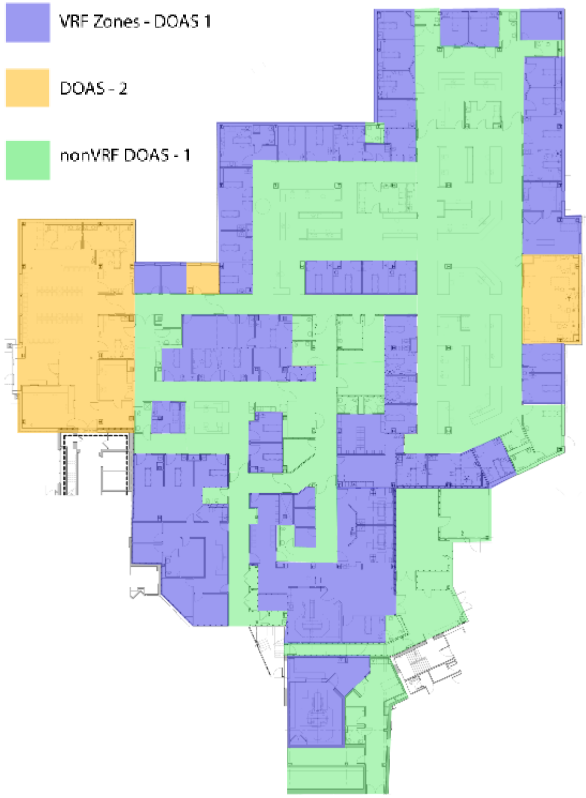


Figure 21: Alternative 2 Zoning

Alternative 2 will introduce the use of Variable Refrigerant Flow technology, and will also utilize two dedicated outdoor air units, DOAS, which supply the same zones as Alternative 1 air handling units, separating critical zones supplied by DOAS 2 from noncritical zones supplied by DOAS 1. Furthermore, applicable zones supplied by DOAS 1 utilize variable refrigerant flow technology, receiving the ventilation requirements from the DOAS unit, and the heating and cooling requirements from the VRF units. These zones include patient treatment rooms, offices, etc., totaling 80 spaces within the addition. The remaining zones will be supplied by variable volume terminal boxes, and include corridors, bathrooms, nurses stations, and electrical rooms. As seen in Figure 21, zones shaded in yellow will be supplied by DOAS 2. These zones include the emergency department waiting room, isolation treatment, and trauma rooms, all of which require isolated, 100% exhaust. Zones shaded in blue are the VRF zones provided by DOAS 1, and zones shaded in green are the remaining zones provided by DOAS 1. No special exhaust requirements are necessary. The following section will discuss the specific mechanical operation of Alternative 2.

DOAS Heating, Colling, and Ventilation

Alternative 2 heating will be provided by the existing steam boiler plant, as well as the VRF equipment. As previously stated, DOAS 1 supplies the required ventilation rates to the VRF zones, and DOAS 2 supplies air to critical spaces. Both new DOAS units will use hot water preheat coils. The same air-to-air heat recovery system used in Alternative 1 will be implemented for the DOAS units. With the introduction to the VRF technology, there is a reduction in load in the hot water coils located in the DOAS units of about 76% when compared to the original, and about 41% when compared to Alternative 1. A summary of these comparisons can be found in the Overall system Comparisons section.

Cooling for both DOAS units will be provided by a water cooled scroll chiller supplying two chilled water coils within the units. Introducing the VRFs reduces the chilled water coil loads by 86% when compared to the original design, and 66% when compared to alternative 2 chilled water coils. This results in a 75 ton water cooled chiller, and 75 ton open cooling tower, which is about 50% that of the Alternative 1 sizes. This reduction in size will also result in a reduction in mechanical equipment first cost as well as equipment annual costs. Both DOAS units are designed as a "dehumidify and reheat/heat" configuration. In cooling mode the air is dehumidified to the dew point, and then reheated to the dry bulb, and in heating mode air is heated to dry bulb temperature. The technical data of the selected chiller, provided by Daikin, can be found in Appendix B. A schematic diagram of the chilled water is displayed in Figure 22.

The cooling tower was selected using the Marley software. An MCW Series, model MCW901136HRR1, was selected with 1 cell and a capacity of 970,400 Btu/hr. This results in a cooling tower that is about 43% the size of Alternative 1 CT, resulting in a cheaper first cost and annual utility cost. The Marley Software Data sheet can be found in Appendix B.

VRF zones are mostly patient rooms, requiring a total of 2 air changes of outside air, provided by the DOAS unit, and 6 air changes total. Therefore, 4 air changes will be provided by the variable refrigerant flow units. Within the space, 4 air changes will be returned to the VRF unit, conditioned, and recirculated throughout the room, while 2 air changes will be exhausted to the exhaust air handling unit where heat is recovered by use of an enthalpy wheel. This satisfies the requirements laid out in ASHRAE 170 – Ventilation of Health Care Facilities.

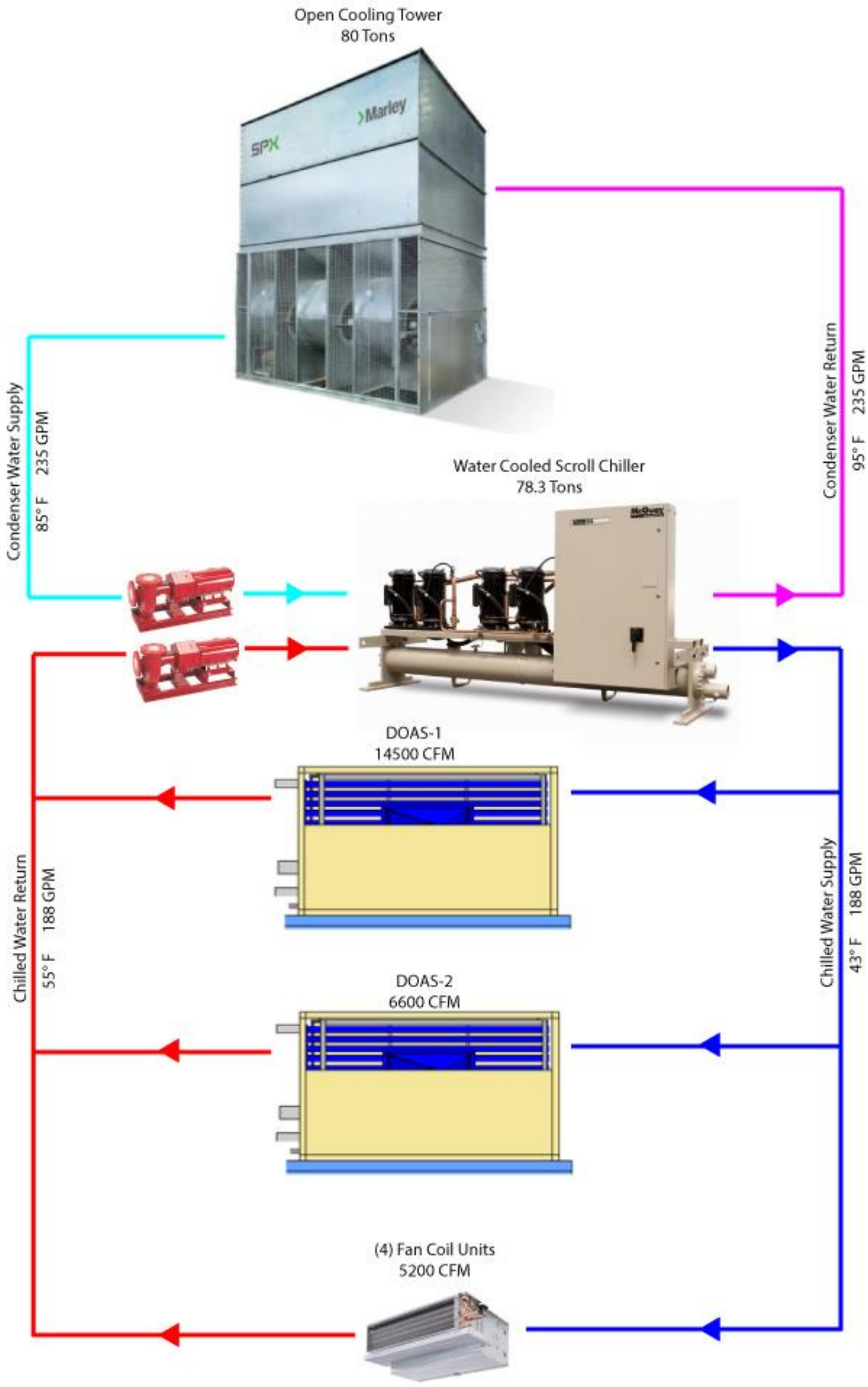


Figure 22: Alternative 2 Condenser Water and Chilled Water Loop Schematic

Variable Refrigerant Flow Analysis

There are a total of 80 spaces within the project that will be receiving heating and cooling from the VRF units, resulting in 8 zones. Figure 23 demonstrates the zone layouts, which are controlled based on the capacity of the outdoor unit. All zones have an indoor ceiling unit and a branch selector unit, or a heat recovery unit. Each zone is supplied by a 10 ton outdoor heat recovery units that supply the required refrigerant to its corresponding indoor units.

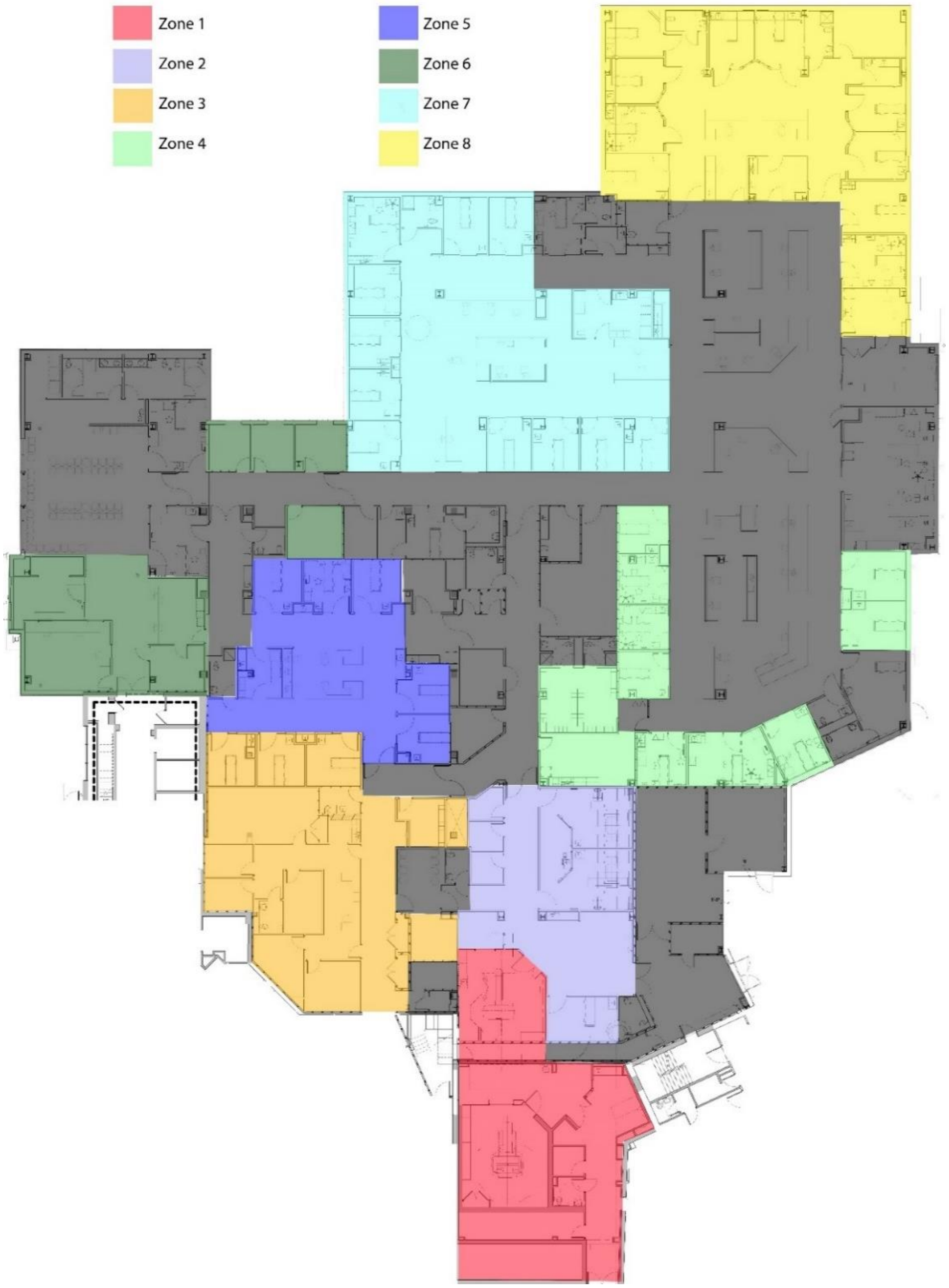


Figure 23: Alternative 2 Variable Refrigerant Zones

The refrigerant being used is R410A, which is a blend of difluoromethane, R32, and pentafluoroethane, R125. The system is a three pipe system, allowing for simultaneous heating and cooling among different spaces. As seen from Figure 24, the refrigerant leaves the outdoor heat recovery unit and first enters the branch selector unit, and then enters the indoor ceiling unit. Within the branch selector, the controls select which refrigerant line enters the ceiling unit, based on whether it is in cooling or heating mode. Figure 24 demonstrates that in cooling mode, the suction gas line is selected, and in heating mode, the discharge gas line is selected. This configuration allows for the heat extracted from zones in cooling mode to be utilized in zones in heating mode. This allows for individual thermal control, while also being efficient.

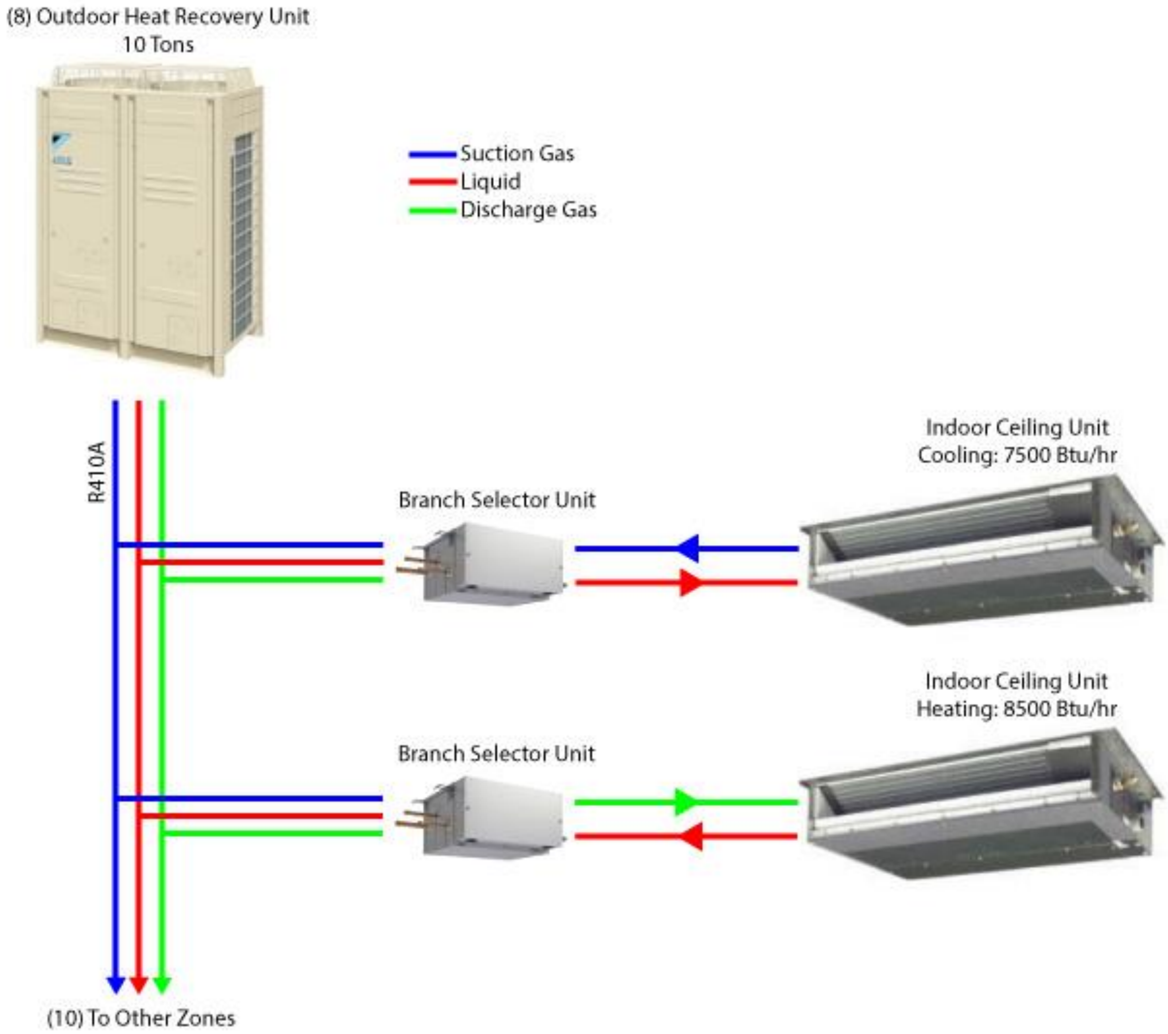


Figure 24: Alternative 2 Refrigerant Loop, in both cooling mode and heating mode.

To satisfy ASHRAE Standard 15, discussed below, all units must be placed in the corridors, and ducted to the rooms. Also, since the VRF system only satisfies heating and cooling, ventilation must be provided by a DOAS, as described above. Each space receives its ventilation requirement by connecting ducted outdoor air to the indoor VRF unit, and then ducting it into the room, as demonstrated in Figure 25 Supply air leaves the DOAS at 55° F, mixes with the air being heated/cooled by the VRF, and then is either heated to 85° F, or cooled to 55° F.

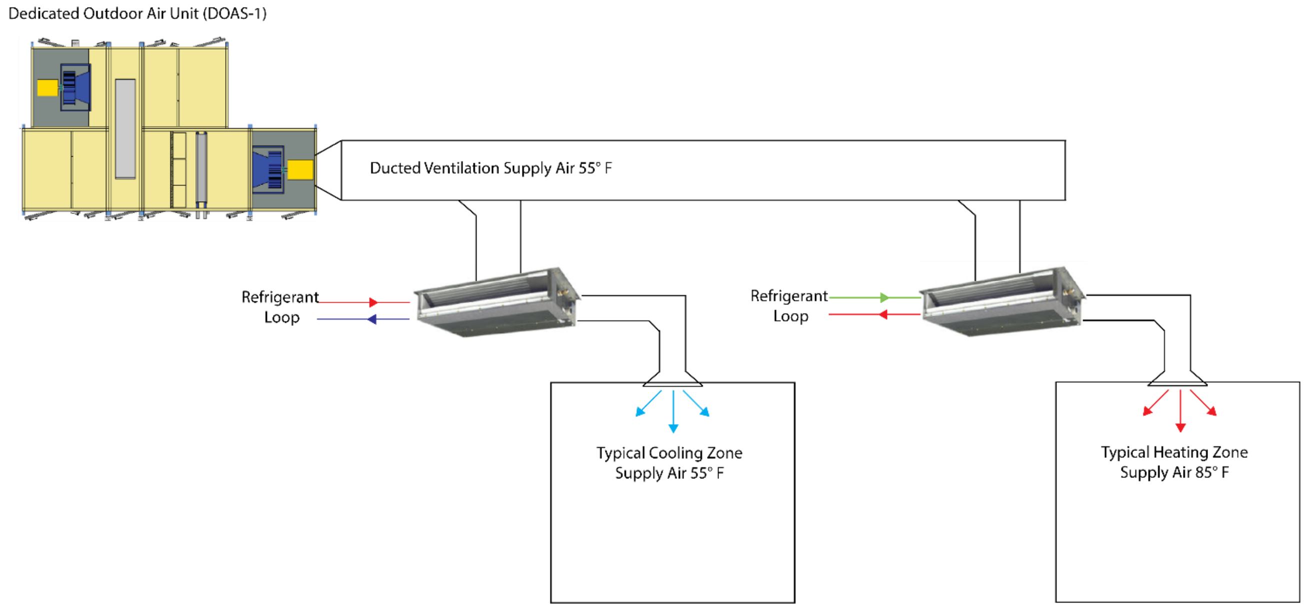


Figure 25: Alternative 2 Airflow Schematic

Sizing Overview

Required sizing for the VRF units was found using Trane Trace load simulation. Based on these outputs, two VRF indoor unit sizes were selected, one having a maximum cooling load of 6282 Btu/hr and heating load of 8500 Btu/hr, and the other having a cooling load of 10074 Btu/hr and heating load of 13500 Btu/hr. For spaces requiring less than 8500 Btu/hr of heating and 6282 Btu/hr cooling, the smaller unit was selected. For spaces that require more than that, but not exceeding 13500 Btu/hr heating and 10074 Btu/hr cooling, the larger unit was selected. Table 10 demonstrates the sizing criteria of Zone 1 of 8 zones. The remainder zone load results can be found in Appendix C. Submittal data sheets of the selected Daikin indoor units can be found in Appendix B.

One 10 ton VRV outdoor heat recovery unit was chosen to fulfill all 8 zone loads. The nominal heating capacity is 77543 Btu/hr, and cooling capacity is 109833 Btu/hr. The data sheet for this selected unit can be found in Appendix B. This unit allows for up to 64 indoor units to be connected to it, and the maximum number of units in one zone is 13 spaces. Note that some outdoor units do not fully meet the design full loads of the designated spaces. The unit was selected to fullfill the loads of most zones without being wasteful in energy. This is acceptable because in most conditions, not all units will be running at full capacity simultaneously. However, these reductions may lead to reduced comfort levels during extreme conditions.

Table 10: Zone 1 indoor and outdoor units sizing overview

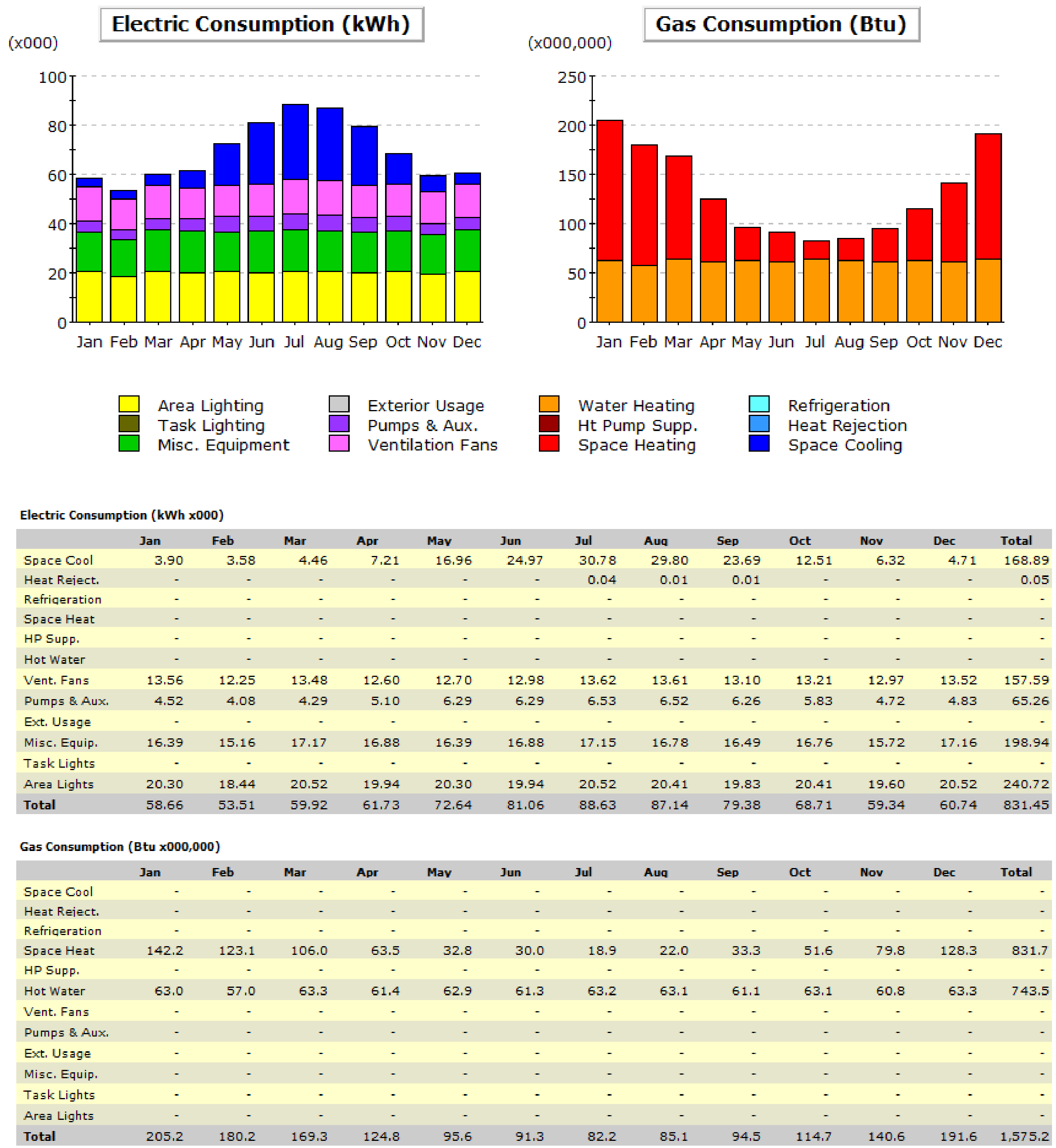
Zone 1				
	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
Room	Required	Unit Capacity	Required	Unit Capacity
MRI PHASE 1 ZONE 1	13120	13500	10000	10074
MRI PHASE 1 ZONE 2	13120	13500	10000	10074
MRI PHASE 1 ZONE 3	13120	13500	10000	10074
MRI PHASE 1 ZONE 4	13120	13500	10000	10074
MRI PHASE 1 ZONE 5	13120	13500	10000	10074
CT	1520	8500	6200	6282
Total	67120	76000	56200	56652
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	67120	77543	56200	109833

Energy Consumption & Operational Cost

Figure 26, below, represents the annual electrical and natural gas consumption of Alternative 2, modeled using eQuest.

Overall, the electrical consumption decreases by 26% compared with the original design, and the natural gas consumption decreases by more than 50%. Similarly, when compared with Alternative 1 results, electric consumption decreases by about 17%, and natural gas consumption decreases by 29%. As expected, the prevalent influences in this change are a result of space heating and space cooling. A summary table of these results can be found in the Overall System Comparison.

Just like Alternative 1, the electrical consumption decreases because of the use of a water cooled chiller, and the gas consumption decreases because of the heat recovery system. In addition, Alternative 2 has decreases in space cooling and heating because of the heat recovery VRF units. Both space heating and cooling consumption decreases by more than 40% when compared to the Alternative 1 values. This is due to the precise individual control and the ability of the VRF heat recovery unit to only circulate the minimum amount of refrigerant to meet the demand.



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	3.90	3.58	4.46	7.21	16.96	24.97	30.78	29.80	23.69	12.51	6.32	4.71	168.89
Heat Reject.	-	-	-	-	-	-	0.04	0.01	0.01	-	-	-	0.05
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	13.56	12.25	13.48	12.60	12.70	12.98	13.62	13.61	13.10	13.21	12.97	13.52	157.59
Pumps & Aux.	4.52	4.08	4.29	5.10	6.29	6.29	6.53	6.52	6.26	5.83	4.72	4.83	65.26
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	16.39	15.16	17.17	16.88	16.39	16.88	17.15	16.78	16.49	16.76	15.72	17.16	198.94
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	20.30	18.44	20.52	19.94	20.30	19.94	20.52	20.41	19.83	20.41	19.60	20.52	240.72
Total	58.66	53.51	59.92	61.73	72.64	81.06	88.63	87.14	79.38	68.71	59.34	60.74	831.45

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	142.2	123.1	106.0	63.5	32.8	30.0	18.9	22.0	33.3	51.6	79.8	128.3	831.7
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	63.0	57.0	63.3	61.4	62.9	61.3	63.2	63.1	61.1	63.1	60.8	63.3	743.5
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	205.2	180.2	169.3	124.8	95.6	91.3	82.2	85.1	94.5	114.7	140.6	191.6	1,575.2

Figure 26: Annual Energy Consumption of Alternative 2 calculated using eQuest

Monthly Utility Costs

Based on the eQuest analysis, the annual operating cost of Alternative 2 is $146,842, averaging at $3.60/SF. This is a savings of 32% compared to the original design, and 19% compared to Alternative 1. Figure 27 summarizes the monthly utility costs, Electricity based on a virtual rate of $0.158/KWh, and Natural Gas based on a virtual rate of $1.101/therm. This results in 831,453 KWh per year of electricity, and 129,499 therm per year of natural gas. A summary of these comparisons can be found in the Overall Comparisons section.

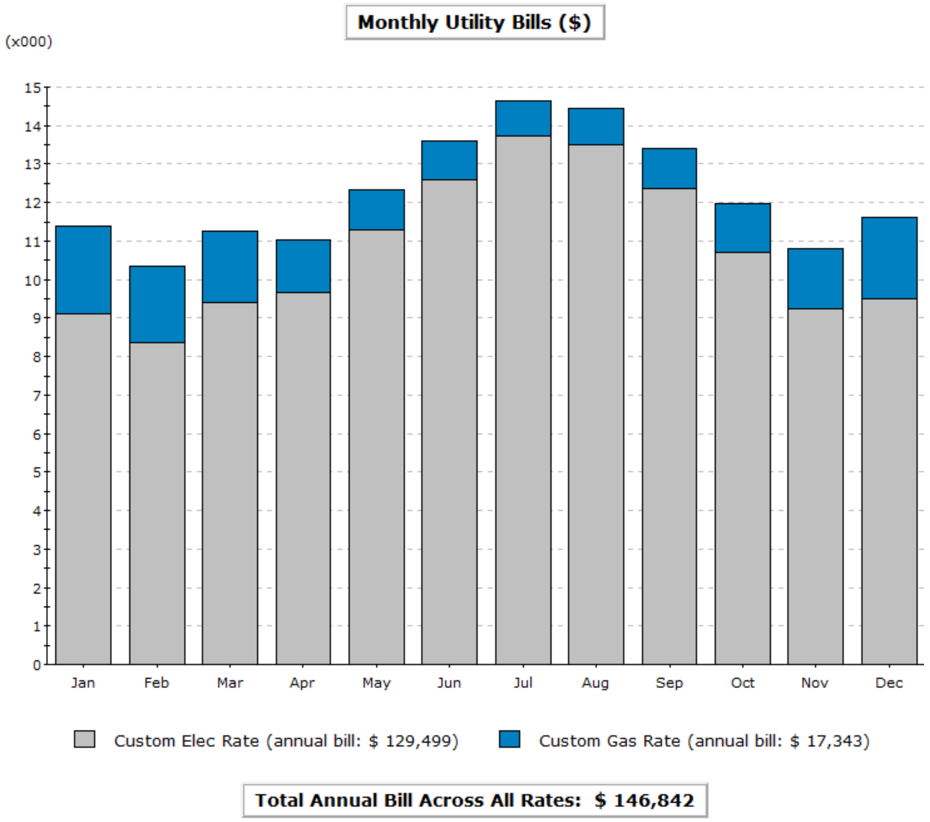


Figure 27: Alternative 2 Monthly Utility Bills, developed using eQuest

Monthly Equipment Costs

Using the eQuest output, a breakdown of monthly and annual equipment costs was calculated using end use. Since lighting and miscellaneous equipment is unchanged, saving occur in the heating, cooling, and fan costs, saving 54% annual cost when compared to the original base design. Table 11 summarizes these costs.

Table 11: Alternative 2 Monthly Equipment Costs

Monthly Equipment Costs by End Use					
	Cooling	**Heating**	**Fans**	**Lighting**	**Misc**
January	$ 570.57	$ 1,565.62	$ 1,983.83	$ 2,969.89	$ 2,399.32
February	$ 523.75	$ 1,355.33	$ 1,792.18	$ 2,691.92	$ 2,223.76
March	$ 652.50	$ 1,167.06	$ 1,972.12	$ 2,999.15	$ 2,516.36
April	$ 1,054.82	$ 699.14	$ 1,843.38	$ 2,911.37	$ 2,472.47
May	$ 2,481.25	$ 361.13	$ 1,858.01	$ 2,969.89	$ 2,399.32
June	$ 3,653.11	$ 330.30	$ 1,898.97	$ 2,911.37	$ 2,472.47
July	$ 4,503.11	$ 208.09	$ 1,992.61	$ 2,999.15	$ 2,501.73
August	$ 4,359.74	$ 242.22	$ 1,991.14	$ 2,984.52	$ 2,457.84
Septembe	$ 3,465.85	$ 366.63	$ 1,916.53	$ 2,896.74	$ 2,413.95
October	$ 1,830.21	$ 568.12	$ 1,932.62	$ 2,984.52	$ 2,457.84
Novembe	$ 924.62	$ 878.60	$ 1,897.51	$ 2,867.48	$ 2,296.91
Decembe	$ 689.07	$ 1,412.58	$ 1,977.98	$ 2,999.15	$ 2,516.36
TOTAL	**$ 24,708.61**	**$ 9,154.82**	**$ 23,056.88**	**$ 35,185.15**	**$ 29,128.33**

Emissions

Emissions were calculated based on emission factors provided by the National Renewable Energy Laboratory – Source Energy and Emission Factors for Energy Use in Buildings. This results in a 26% reduction in pollutants when compared to the base. Table 12 reviews the amount of pollutant emitted annually for Alternative 2.

Table 12: Alternative 2 Pollutant Emissions

Emmissions for Delivered Electricity				
Pollutant	Eastern US Emission Factor (lb pollutant/kWh	Electricity Usage (kWh)	Amount of Pollutant (lb)	Savings compared to Original
CO2	1.64E+00	831,450	1,363,578.00	26%
NOX	3.00E-03	831,450	2,494.35	26%
SOX	8.57E-03	831,450	7,125.53	26%

ASHRAE Standard 15 Evaluation

Because the VRF technology requires the use of refrigerant, an analysis of ASHRAE Standard 15 – Safety Standard for Refrigeration Systems 2013 was completed.

Section 4: Occupancy Classification

The Morton Expansion falls under the classification of *Institutional Occupancy* because it is a hospital, in which occupants cannot readily leave without the assistance of others.

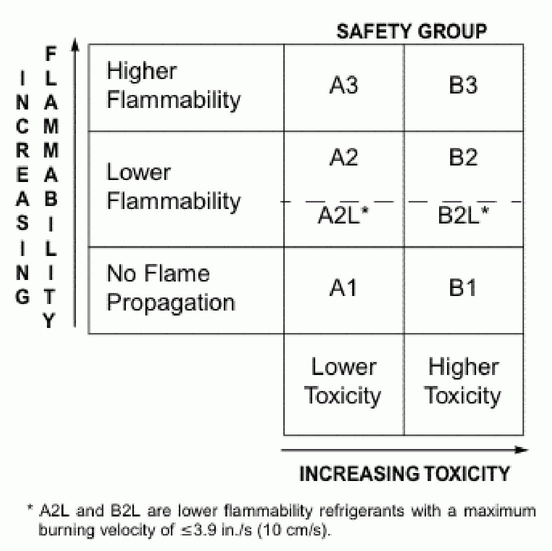
Section 5: Refrigerating System Classification

The VRF system is classified as an indirect closed system, in which “a secondary coolant passes through a closed circuit in the air or other substance to be cooled or heated.” It is also defined as a *Low Probability System*, being that if leakage occurs from a failed connection, it has a low probability of entering the occupied space.

Section 6: Refrigerant Safety Classification

The system will utilize the refrigerant R410A, which a mixture of difluoromethane, R32, and pentafluoroethane, R125, and is therefore defined as a blend. As specified in ASHRAE 34 – Designation and Safety Classification of Refrigerants, *Table 4-2 Data and Safety Classifications for Refrigerant Blends* (found in

Appendix A) R410A is classified in the safety group A1. The "A" designates that the occupational exposure limit (OEL) is 400 ppm or greater. OEL is defined as: "the time-weighted average (TWA) concentration for a normal eight-hour workday and a 40-hour workweek to which nearly all workers can be repeatedly exposed without adverse effect, based on the OSHA PEL, ACGIH TLV-TWA, AIHA WEEL, or consistent value." R410A has an OEL of 1000 ppm. The "1" in the safety designation is the flammability classification, and does not show flame propagation when tested at 140° F and 14.7 psia air. As shown in Figure 28, the A1 safety group has the lowest flammability and lowest toxicity.



SAFETY GROUP

INCREASING FLAMMABILITY	Lower Toxicity	Higher Toxicity
Higher Flammability	A3	B3
Lower Flammability	A2 A2L*	B2 B2L*
No Flame Propagation	A1	B1

INCREASING TOXICITY

* A2L and B2L are lower flammability refrigerants with a maximum burning velocity of ≤3.9 in./s (10 cm/s).

Figure 28: ASHRAE 34 Refrigerant Safety Group Classifications

Section 7: Restrictions on Refrigerant Use

Because of the institutional occupancy designation, the refrigerant concentration limit listed in Table 4-2 shall be reduced by 50%, resulting in a refrigerant concentration limit (RCL) of 13 lb/MCF. The volume used to calculate whether the RCL is satisfied is based on the volume of space in which the refrigerant disperses in the event of a refrigerant leak. Each outdoor heat recovery unit is 10 tons, with a refrigerant charge of 23.8 lbs. The smallest spaces that are served by these units is the patient rooms with a volume of 1145 CF. If the units are placed directly in the rooms, the refrigerant concentration would be 20.8 lb/MCF, which does not satisfy the standard. Therefore, the units must be placed in the corridor and then ducted to the rooms. The smallest corridor in which the VRF indoor units will be placed is 3000 CF, resulting in a refrigerant concentration of 7.9 lb/MCF (23.8 lb/ 3000 CF), satisfying the criteria of ASHRAE 15 Section 7.

Overall System Comparison

Economic Analysis

An overall economic analysis of the base and two alternatives was completed over the estimated equipment lifetime of 25 years. The basis of the life cycle cost comparison includes equipment first cost, equipment maintenance cost, and annual utility cost. First cost was found using *RS Means Mechanical Cost Data 2015*, maintenance cost was found using *RS Means Facilities Maintenance & Repairs 2015*, and utility cost was calculated using eQuest, which is discussed previously in Monthly Utility Costs for both Alternative 1 and 2. In addition, escalation factors found in NIST Handbook 135 – Life Cycle Costing Manual for the Federal Energy Management Program. These escalation factors as well as a discount of 3% was applied to the annual utility rates in order to get a complete life cycle cost. Table 13 below summarizes these results. Appendix C details the breakdown of all costs calculated. Compared with the base design of the Morton Hospital, the Alternative 1 mechanical design has an estimated cost savings of 12% over 25 years, and Alternative 2 has an estimated savings of 20%. In addition, a simple payback period was calculated for both alternatives. This was found using the following equation:

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Cash Inflow per Period}}$$

Initial investment was considered to be the additional cost of the alternative system, and the cash inflow per period was considered to be the savings in annual maintenance and utility costs for the first year. This resulted in a payback period of 1.85 years for Alternative 1, and 5 years for Alternative 2, as seen in Table 13.

Table 13: A summary of the life cycle cost of all three options over an equipment lifetime of 25 years

Life Cycle Cost							
	First Cost	Maintenance Cost	Electric Utility Cost	Natural Gas Utility Cost	Total Life Cycle Cost	Savings	Payback Period
Base	$ 615,813.00	$88,100.08	$3,232,358.19	$790,496.82	**$ 4,726,768.09**		
Alternative 1	$ 676,813.00	$97,938.51	$2,863,432.75	$519,056.04	**$ 4,157,240.30**	12%	1.85
Alternative 2	$ 957,200.00	$95,412.73	$2,350,345.62	$368,933.97	**$ 3,771,892.32**	20%	4.98

Overall Energy Comparison

When comparing site-to-source energy consumption, it can be seen that both alternatives use less energy both at the site and at the energy source. Alternative 1 saves 22% of site energy, 16% of total source energy when compared to the base, while Alternative 2 saves 39% and 32%, respectively. This is shown in Table 15 and Figure 29. The site-to-source ratio describes the ratio of energy generated at the source that is actually utilized at the site. Unfortunately, the site-to-source ratio does and decrease with each alternative, but overall energy consumption is still being reduced.

Table 15: eQuest Building Energy Performance summary

Building Energy Performance								
	Base		Alternative 1			Alternative 2		
	Mbtu	Kbtu/SF-YR Gross Area	Mbtu	Kbtu/SF-YR Gross Area	Savings	Mbtu	Kbtu/SF-YR Gross Area	Savings
Total Site Energy	7222.1	177.0	5657.8	138.7	22%	4412.9	108.2	39%
Total Source Energy	14916.1	365.7	12541.0	307.4	16%	10088.4	247.3	32%
Site-to-Source Ratio	0.48		0.45			0.44		

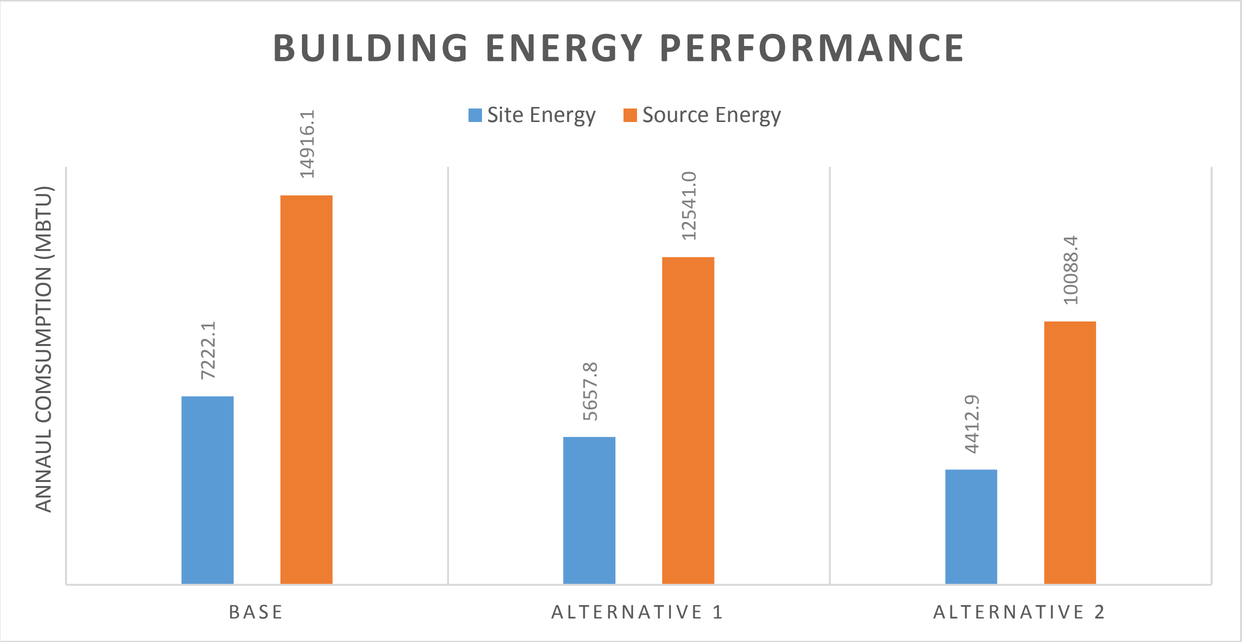


Figure 29: eQuest Building Energy Performance summary

In summary, Alternative 1 and 2 are both improvements in energy consumption and cost over the base design. Figure 30 and Table 16 summarizes the electric consumption of all three options, showing a yearly savings of 10% for Alternative 1 and a savings of 26% for Alternative 2 when compared to the base design.

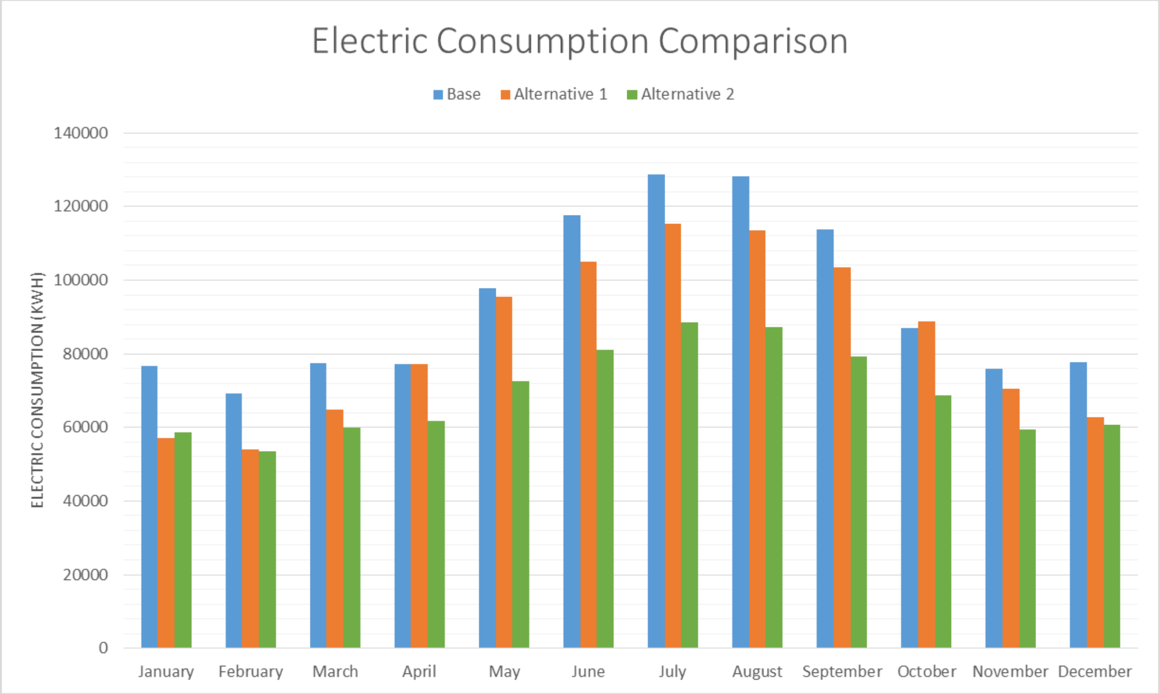


Figure 30: A summary of the annual electric consumption for all three options

Likewise, Figure 31 and Table 17 summarizes the natural gas consumption of all three options, showing a yearly savings of 34% for Alternative 1 and a savings of 54% for Alternative 2 when compared to the base design. It can be seen that there is a substantial decline during the winter months, proving that the energy recovery system utilizes in both alternatives is effective.

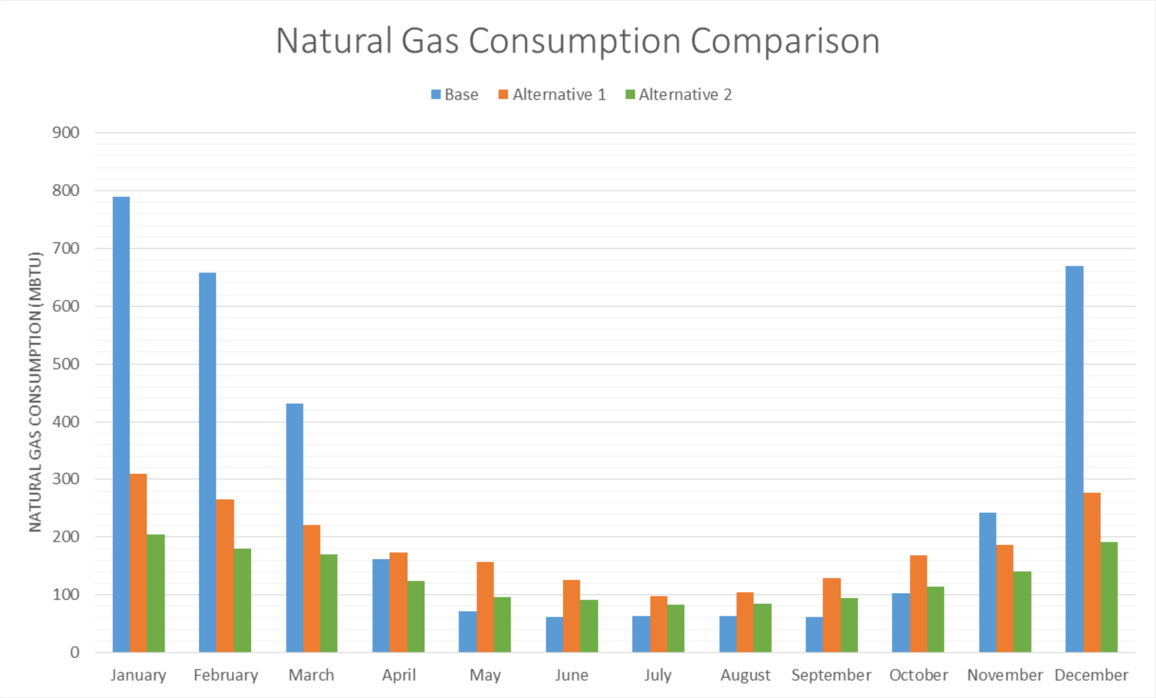


Figure 31: A summary of the annual natural gas consumption for all three options

Table 16: A summary of the annual electric consumption for all three options

Electric Consumption (kWh)			
	Base	**Alternative 1**	**Alternative 2**
January	76700	57100	58660
February	69200	54100	53510
March	77400	64900	59920
April	77100	77100	61730
May	97700	95500	72640
June	117700	105100	81060
July	128600	115300	88630
August	128300	113400	87140
September	113700	103500	79380
October	87000	88900	68710
November	76000	70500	59340
December	77700	62800	60740
Total	**1127100**	**1008200**	**831460**

Table 17: A summary of the annual natural gas consumption for all three options

Natural Gas Consumption (MBtu)			
	Base	**Alternative 1**	**Alternative 2**
January	789.2	309.1	205.2
February	658.3	265	180.2
March	431.3	221.3	169.3
April	161.7	173.6	124.8
May	70.9	157.3	95.6
June	61.3	126.2	91.3
July	63.2	98.4	82.2
August	63.1	104.4	85.1
September	62.1	129.5	94.5
October	102.2	169	114.7
November	241.7	185.8	140.6
December	669.9	276.8	191.6
Total	**3374.9**	**2216.4**	**1575.1**

Similarly, annual energy cost decreases with each option. As summarized in Table 18, cost per square foot of are decreases from the base design of $5.28/SF to $4.47/SF and $3.60/SF for Alternative 1, and Alternative 2, respectively. Figure 31 demonstrates that all three options are spending significantly more on electric over gas, as expected, but the utility bill decreases for both electric and gas considerably with each alternative.

Table 18: Annual energy cost summary of all three options

Energy Cost Summary								
	Base		Alternative 1			Alternative 2		
	Metered Energy Units/Yr	Total Charge ($)	Metered Energy Units/Yr	Total Charge	Savings	Metered Energy Units/Yr	Total Charge	Savings
Electric (KWh)	1127167	$ 178,096.00	1008388	$ 157,769.00	11%	831453	$ 129,499.00	26%
Natural Gas (Therm)	33751	$ 37,160.00	22162	$ 24,400.00	34%	15752	$ 17,343.00	53%
Energy Cost/SF	$ 5.28		$ 4.47			$ 3.60		

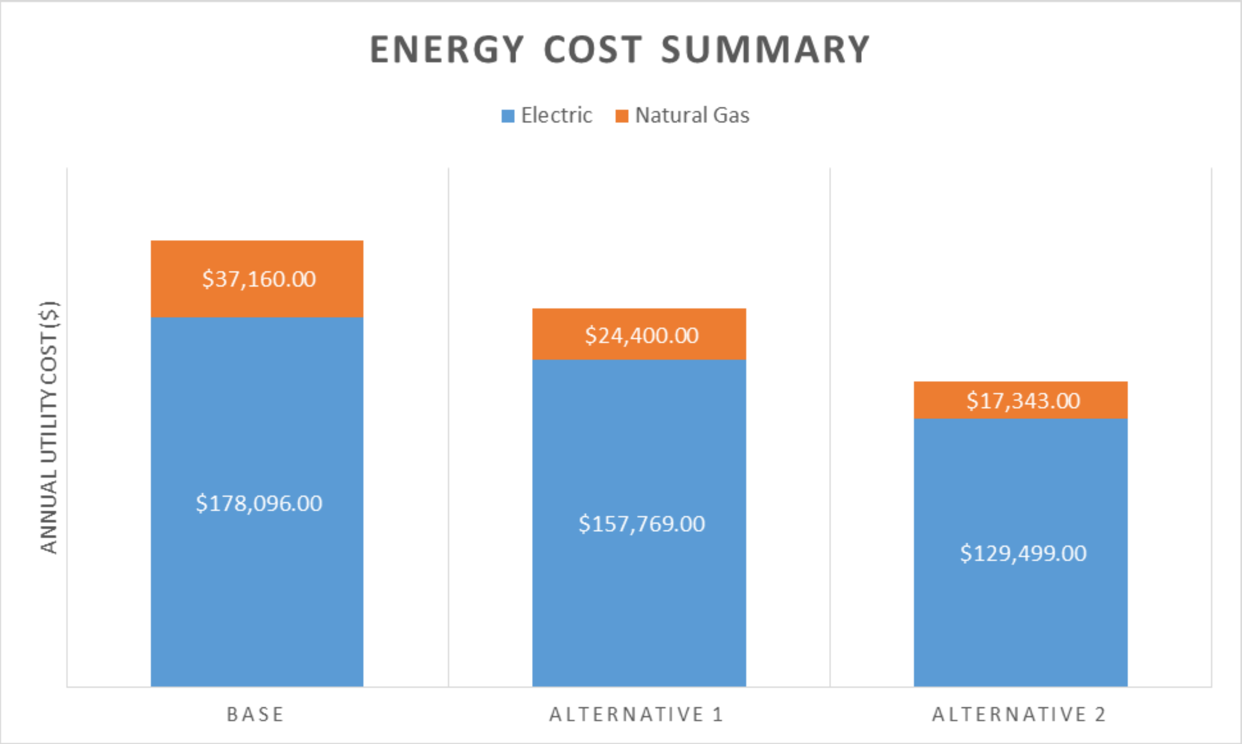


Figure 32: Annual energy cost summary of all three options

Master’s Coursework

Computational Fluid Dynamics

A simple computational fluid dynamics model was created to analyze the airflow in a hospital isolation room of Morton Hospital Expansion. The air in the isolation room must be 100% exhausted to the outside. The program Star CCM+ was used, modeling the geometry of the isolation room, ante-isolation room, and the attached patient toilet room, as shown in Figure 33. Both the isolation room and ante room are connected to the corridor by a door providing an under cut, as shown. There is one supply diffuser supplying 325 CFM of air, and three exhaust diffusers exhausting the indicated amount of air. The doors from the isolation room to the toilet room and ante room also provide a 100 CFM undercut. The patient bed is located below the exhaust diffuser in the isolation room, to ensure that any infection is directly exhausted to the outdoors.

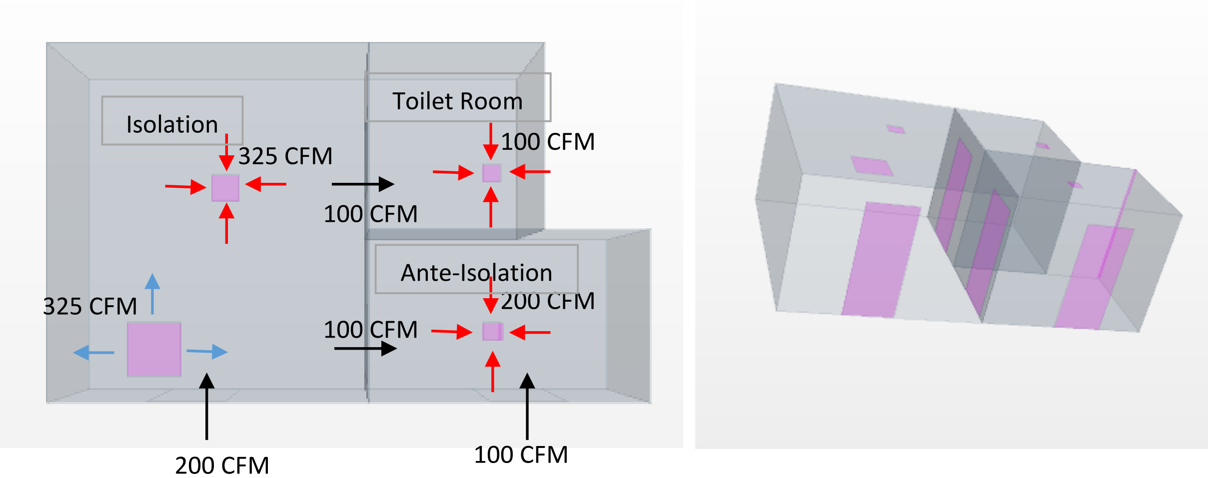


Figure 33: Star CCM+ Geometry of the Isolation Room and connected spaces

Three variables were measured in the CFD analysis: pressure, temperature, and velocity. As required by ASHRAE Standard 170 – Ventilation of Healthcare Facilities, an isolation room must maintain a negative pressure relationship to all adjacent spaces, must maintain a design temperature of 70-75° F, and must also maintain an air change rate of 12 air changes per hour. These requirements ensure patient thermal comfort and prevent the spread of infectious diseases.

In order to perform the analysis, a method had to be specified. The Reynold’s Average Navier Stokes Standard k-ε model was chosen. In a RANS model, there are more unknowns, or Reynold’s Stress terms, than there are equations. Using the k-ε model simplifies the equations using Boussinesq assumptions. Using this application is appropriate for most engineering situations, including the airflow in a space.

Boundary conditions had to be specified in order to simulate the correct airflow throughout the room. The supply diffuser was set as a velocity inlet, with air entering the room with a velocity of (1.1667, 1.1667, 0) m/s, or a magnitude of 1.65 m/s (325 CFM/1 SF diffuser area = 325 fpm, or 1.65 m/s). The entering supply air temperature was specified to be 55° F, and the room static temperature was set at 70° F. The exhaust diffusers and doors were defined as pressure outlets, and the remainder of the surfaces were left as solid walls.

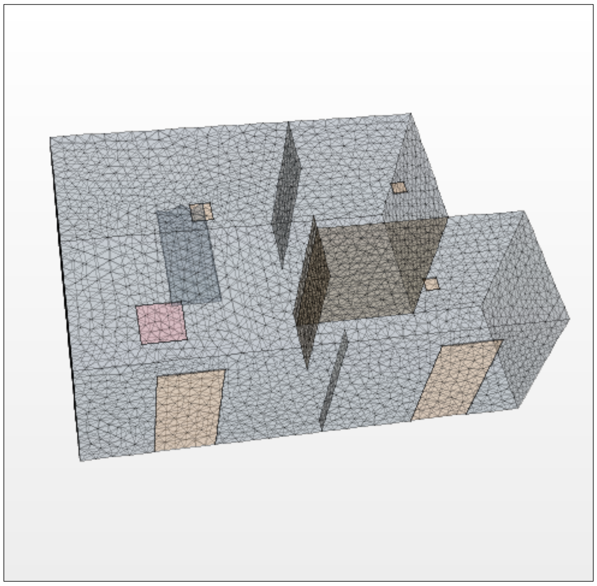


Figure 34: Star CCM+ surface mesh

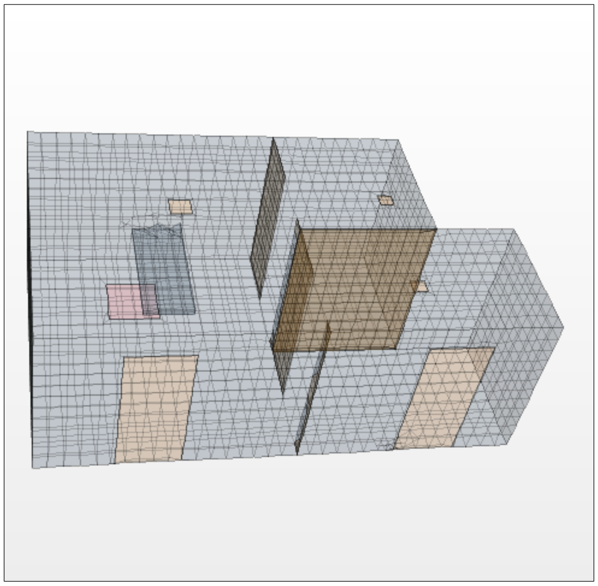


Figure 35: Star CCM+ volume mesh

Modeling in Star CCM+, both a surface mesh and volume mesh must be created. A mesh is the subdivision of the domain into sub-domains, creating a grid of cell that create multiple control volumes that can be analyzed. Figure 34 and 35 demonstrate the surface mesh and volume mesh, respectively, in Star CCM+.

After defining the physics models, setting the boundary conditions, and creating the mesh, the variables were tested by running the simulation. Figure 36 represents the relative total pressure gradient throughout the spaces. As demonstrated, the center of the space is under negative relative pressure while the edges have a zero relative pressure signifying that the space has a negative pressure relationship with adjacent spaces satisfying the ASHRAE 170 requirement. Figure 37 demonstrates the temperature throughout the spaces. The patient isolation room and patient toilet room are at a constant temperature of 70° F, also satisfying the temperature requirements of an isolation room, specified ASHRAE 170. The ante-room room temperature varies below 70° F in certain areas, but according to ASHRAE 170, the ante-room has no temperature requirements.

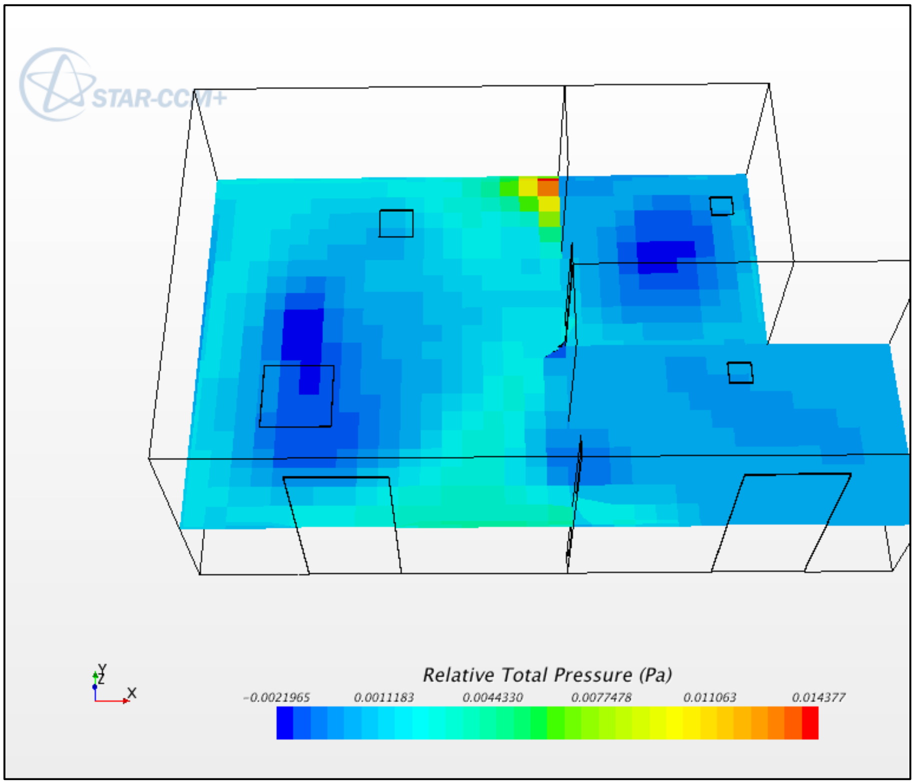


Figure 36: The relative total pressure gradient of the three spaces simulated using Star CCM+

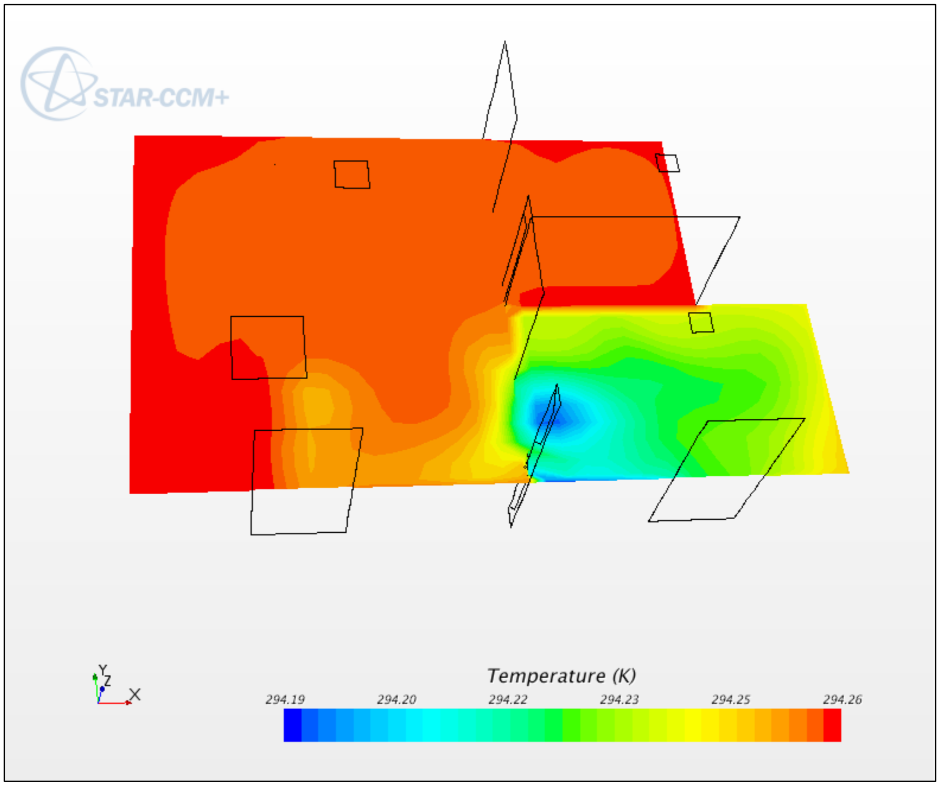


Figure 37: Temperature gradient of the three spaces simulated using Star CCM+

Figure 38 demonstrates the age of air through the supply diffuser. It can be seen that the highest age of air throughout the room is five minutes, which therefore satisfies the 12 air changes per hour requirement laid out in ASHRAE 170. The shortest age of air occurs near the supply diffuser, then air is evenly distributed throughout the room.

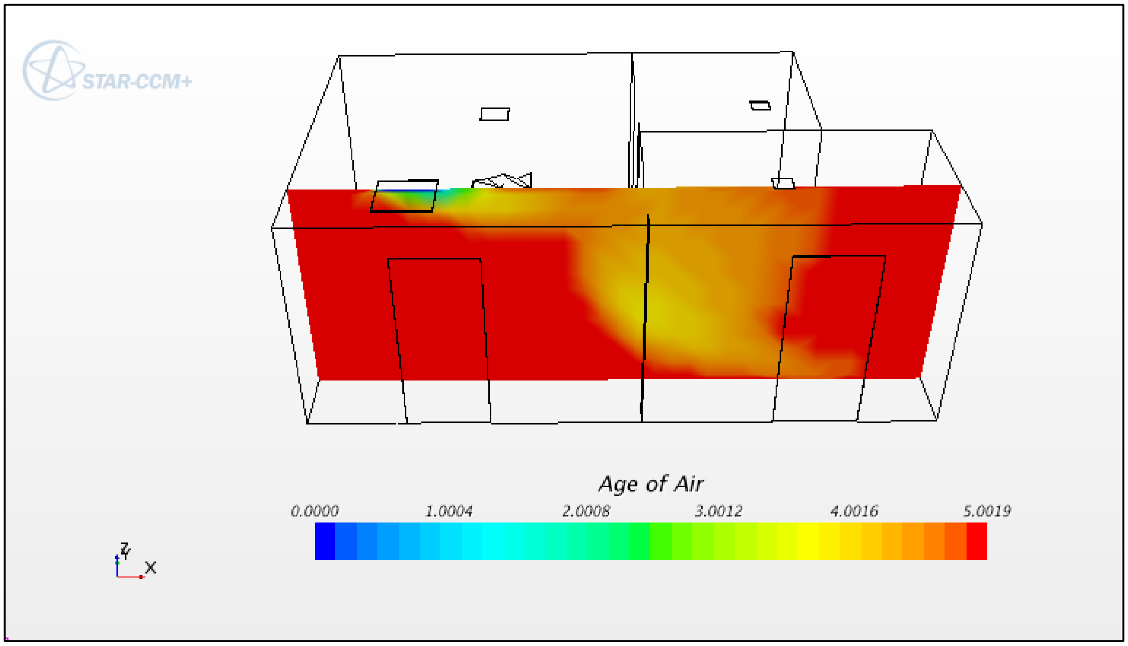


Figure 2: Age of Air through the supply diffuser simulated using Star CCM+.

In summary, the Star CCM+ computational fluid dynamics model justifies that ASHRAE 170 standards are met, and that air is being properly circulated throughout the spaces.

Overall Mechanical Depth Summary

In summary, the mechanical depth consisted of investigating 2 alternatives, and determining the benefits over the baseline design. Alternative 1 replaces the air cooled chiller with a water cooled chiller and cooling tower, and also utilizes an air-to-air heat recovery. Alternative 2 employs variable refrigerant flow and dedicated outdoor air units. The standards in which the Alternatives were compared were the mechanical system first cost, energy consumption, and an overall economic analysis. A computational fluid dynamics simulation was also completed as part of the depth study.

Alternative 1 will utilize two air handling units (AHU), one supplying air to critical zones that require isolated, 100% exhaust to the outside, and one supplying air to other non-critical zones. Both AHUs employ air-to-air heat recovery and require 2 exhaust air handling units (EAHU). AHU-1, supplying the critical zones, has an

EAHU that utilizes a glycol solution heat recovery coil that transfers heat from the EAHU to the AHU without cross-contaminating the infectious exhaust air with the supply air. AHU-2, supplying the remainder of the zones, has an EAHU with an enthalpy wheel that transfers both sensible and latent heat from exhaust air to supply air, where cross-contamination is not a problem. AHU-1 and AHU-2 will both receive cooling from a water-cooled chiller and cooling tower.

Alternative 2 will use VRF technology in applicable zones, as well as employing dedicated outdoor air units to satisfy the ventilation requirements. Critical zones will be supplied by a separate DOAS unit. Both units employ the same air-to-air heat recovery system, and also receive cooling from a smaller chiller and cooling tower, since the load on the air handlers is reduced by the use of VRF heating and cooling.

When compared to the baseline design, both alternatives are more costly up front, but more cost effective over the lifetime (25 years) of the system, and also more energy conscious. Alternative 1 has an estimated cost savings of 14% over the 25 year lifetime with a 1.5 year payback period. As well, Alternative 1 has a 10% estimated annual energy consumption savings. Alternative 2 has an estimated cost savings of 23% over the lifetime, and a payback of 4.6 years. There is a 26% annual energy savings for this alternative.

The computational fluid dynamics simulation verifies that ASHRAE 170 requirements for isolation rooms is being met at all times, and that air is being properly circulated throughout the room for proper patient thermal comfort.

In conclusion, this report in no way suggests that the current design of the Morton Hospital design is flawed in any way. This investigation was done purely for educational purposes.

Electrical Breadth

A photovoltaic array will be analyzed for Alternative 2 electric consumption in order to attempt to achieve a zero carbon footprint. The more on site electric generation there is, the less grid production is required, and the smaller the resulting footprint. Monocrystalline PV panels will be used because they are the best conductors of electricity. Current panels can turn more than 15% of sunlight into electricity. These panels are the most efficient, but also the most expensive considering the added labor of cutting the crystals into usable octagonal solar cells.

Site Information

The location of Morton Hospital is in Taunton, MA, with a latitude and longitude of 41.5° N and -71.0 ° W and an elevation of 19 feet above sea level. The site data used for the SAM software was selected as Providence, RI - TMY-2, the closest weather station available. As seen in Figure 39, the site is surrounded by short buildings with few obstructions, making roof placement of the PV arrays a viable option.

Using System Advisor Model software (SAM), the annual direct normal solar radiation is 1388.7 kWh/m^2, and the Global Horizontal solar radiation is 1454.4 kWh/m^2. Figure 40 below represents the monthly profiles of Providence, RI, showing the diffuse radiation in red, and the beam normal in purple. It can be seen that the peak solar radiation occurs year-round at around 11:30 am. As expected, winter months have much less radiation than summer months. The peak occurs in July at more than 800 W/m^2, and the lowermost occurs in December at about 375 W/m^2.

Figure 39: An aerial view of the site and surroundings

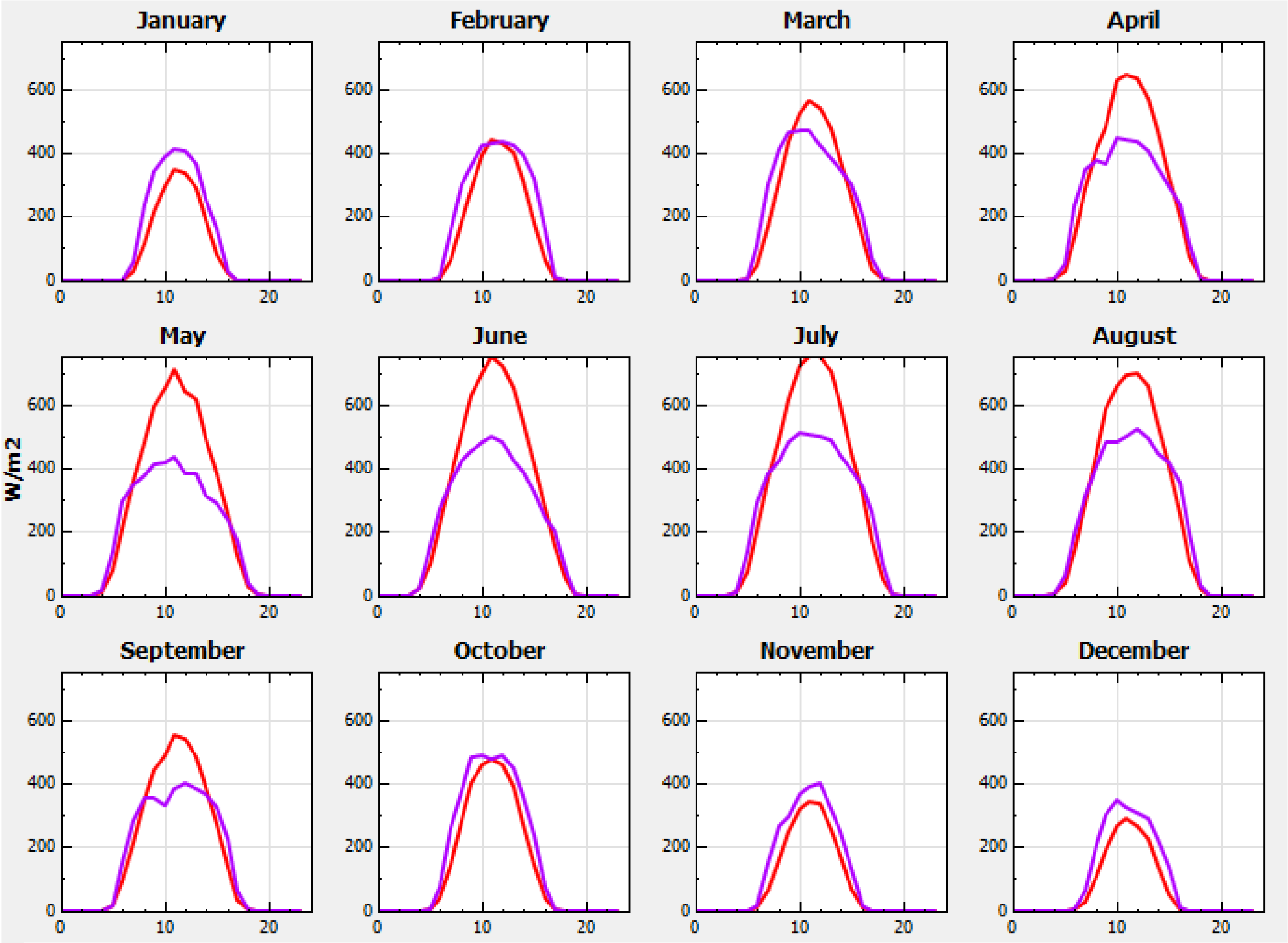


Figure 40: Monthly Profiles of Solar Radiation, global horizontal being in red, and beam normal being in purple.

Photovoltaic System Design and Electric Generation

Based on the eQuest results, the annual electric consumption of Alternative 2 is 831,450 kWh, resulting in 95 kW peak. Although it is desired to have all electricity generated on site by the photovoltaic arrays, it is not possible because of site restrictions. Panels will be placed in available space located on the addition's roof, and will be laid out in strings of ten. Because of existing roof drains and mechanical equipment, the available roof area is limited. A total of 18 strings can be placed. Each panel is 21 SF, resulting in 180 panels at 3802.5 SF of total PV system area. A roof plan of the designed array can be seen in Figure 41.

The selected panel module is a Sunpreme GxB350 with a nameplate capacity of 350 W, the module efficiency being 18%. The data sheet for the panel can be found in Appendix D. With 180 panels, this gives a system nameplate capacity of 63 kW DC power. However, there is a DC-to-AC voltage conversion loss of 77% that must be taken into account. Through the inverter, to PV panels feed the switchgear through a back feed circuit breaker.

Having flat horizontal panels will be most beneficial in the summer because sunlight is directly above, while in the winter having 90° panels is most beneficial to accommodate for the low sun. Therefore, in order to receive the most solar gain year round, panels will be tilted to match the site latitude of 41.7°. Inputting this information into the SAM software results in a total generated electricity of 103,349 kWh annually, 12% of the total site electrical consumption. The resulting 728,101 kWh will continue to be produced by the grid. Figure 42 represents the monthly output in kWh of the designed system. As expected, the most solar gain occurs in the summer, which is also when the most electric consumption occurs.

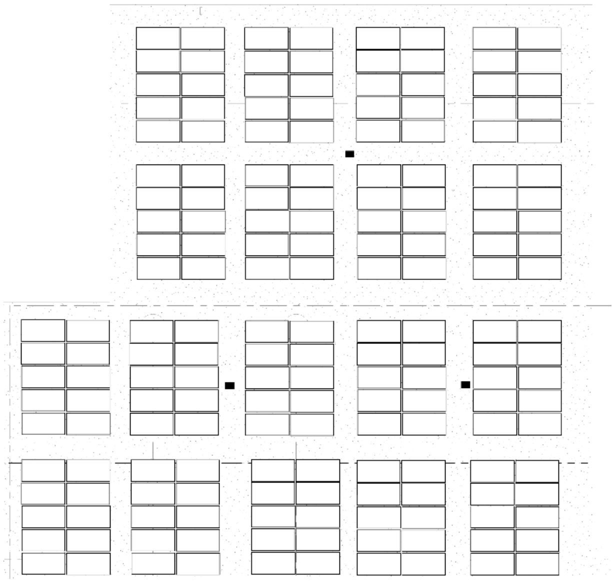


Figure 41: A roof plan of the photovoltaic array layout

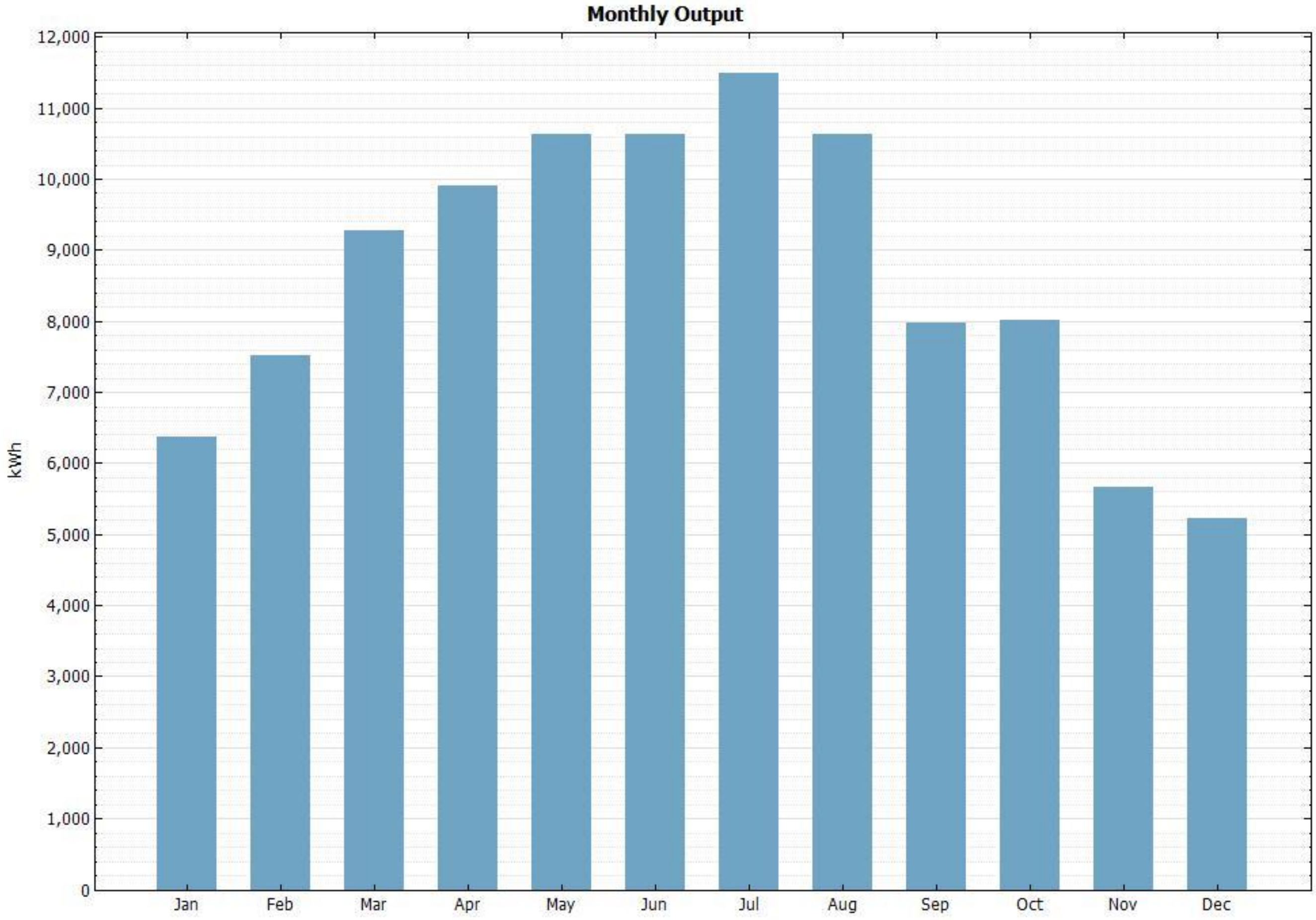


Figure 42: Monthly electric output produced by the on-site photovoltaic array

Photovoltaic System Economics

Totaling up the direct and indirect capital costs, as well as installation costs gives a first cost of the whole system to be $161,154. However this results in a savings of $11,022.58 per year, an 8% yearly savings from the calculated $129,499 annual electric consumption bill. Payback was found to be 14.6 years, using the following simple payback equation:

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Cash Inflow per Period}}$$

Structural Breadth

With the addition of mechanical equipment located on the roof, an analysis of the roof structure was completed. The focus of the analysis was on the Alternative 1 cooling tower, because it is significantly heavier than the Alternative 2 cooling tower, because of the difference in required chilled water cooling load in both air handling units. Although there is additional equipment being placed on the roof, such as the VRF outdoor units, the analysis was only done on the added cooling tower because it was the heaviest piece of equipment being added. Table 19 summarizes the added equipment weights that contribute to the total roof load. As can be seen, the cooling tower is not the heaviest piece of equipment, but both air handling units are being *modified*, and are not considered *new* pieces of equipment.

Table 19: A Summary of the additional equipment being placed on the roof

Alternative 1					
	Length (in)	Width (in)	Height (in)	Total Volume (CF)	Weight (lb)
Cooling Tower	78.2	154.0	122.3	852.4	7573
Water Cooled Chiller	169.7	58.2	69.7	398.4	8358
AHU-1	140	88	46	328.0	2856
Energy Recovery Unit 1	128	88	46	299.9	1510
AHU-2	312	104	114	2140.7	10119
Energy Recovery Unit 2	228	104	114	1564.3	9523

Alternative 2					
	Length (in)	Width (in)	Height (in)	Total Volume (CF)	Weight (lb)
Cooling Tower	107.7	49.2	100.6	308.6	3210
Water Cooled Chiller	149.6	35	65.5	198.5	4128
DOAS-1	140	88	46	328.0	2856
Energy Recovery Unit 1	128	88	46	299.9	1510
DOAS-2	266	74	96	1093.6	7023
Energy Recovery Unit 2	178	74	96	731.8	6335
(8) Refrigerant Condensers	51.2	66.1	30.1	59.0	732
(92) Photovoltaics	78	39	0.24	0.4	61

There are two types of roof decks used in the Morton addition: a 3” 20 GA composite metal deck with 3 ¼” light weight concrete with reinforcing, and a 3” 18 GA Type N galvanized metal roof deck. The cooling tower is being placed on the deck without the concrete and reinforcing, as can be seen by the roof layout below in Figure 43. Two W12X16 beams, one W16X31 girder, and one W18X35 girder are all supporting this cooling tower.

The current metal roof deck, steel beams, and steel girders were all examined to distinguish whether the additional load would affect the structure. It was found that the current roof structure is sufficient in supporting the new cooling tower. Hand calculations can be found in Appendix D.

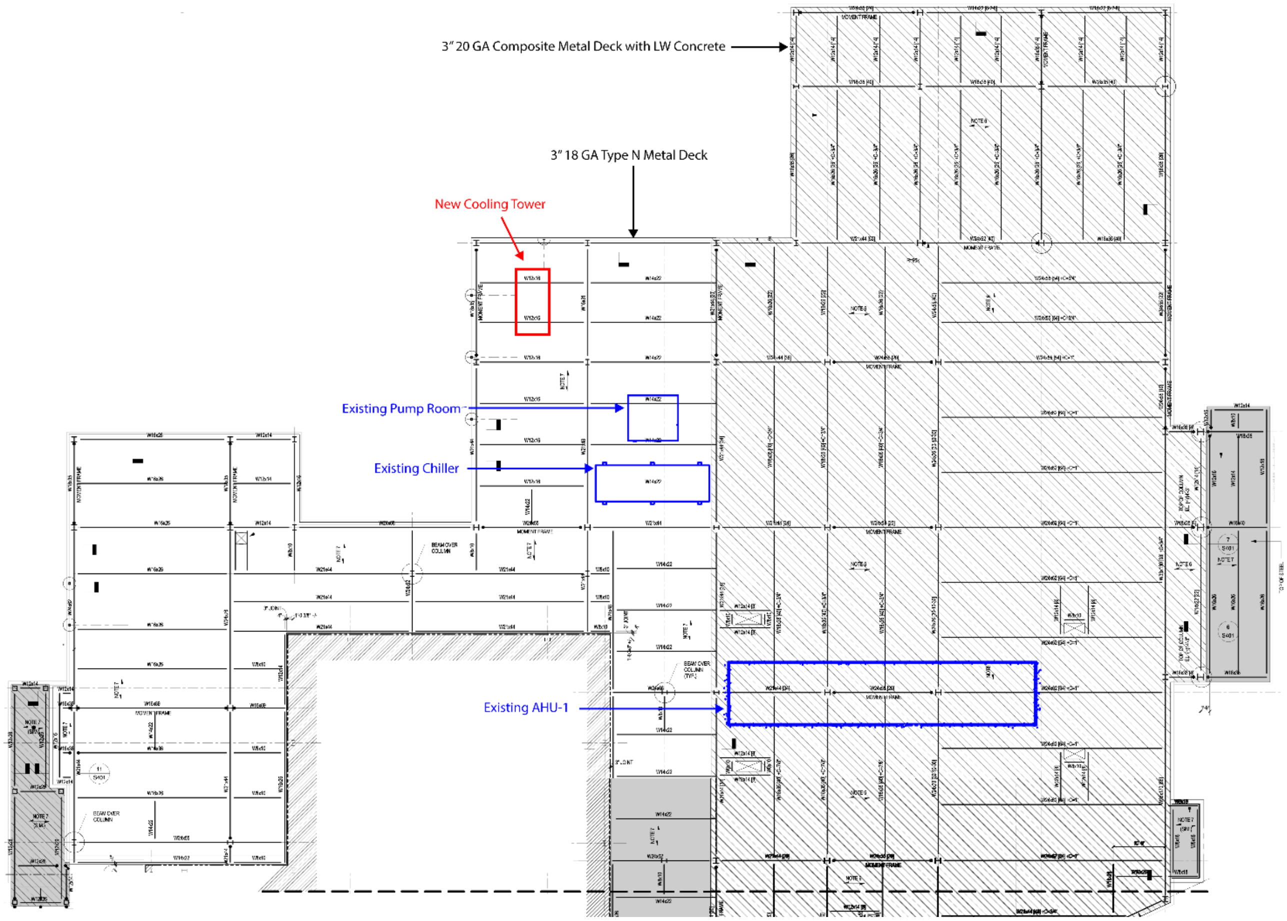


Figure 43: Roof Framing Plan

References

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Appendix A: ASHRAE Standards

Appendix B: Mechanical Equipment Data Sheets

Appendix C: Calculations

Appendix D: Breadth Data

Appendix E: Progress Schedule

Appendix A: ASHRAE Standards

Appendix B: Mechanical Equipment Data Sheets

Appendix C: Calculations

Appendix D: Breadth Data

Appendix E: Progress Schedule

Appendix A: ASHRAE 170 Table 7.1

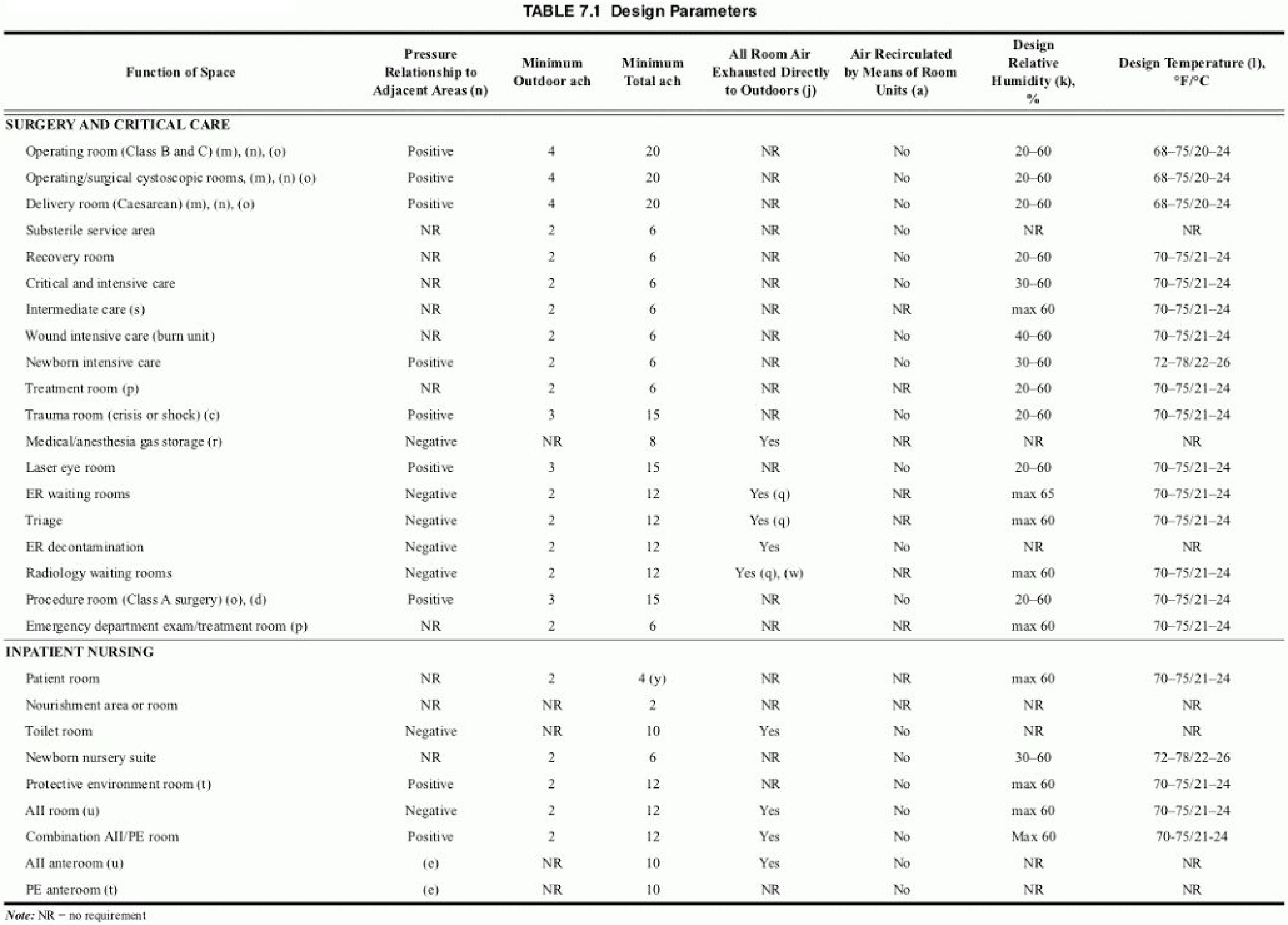


TABLE 7.1 Design Parameters

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

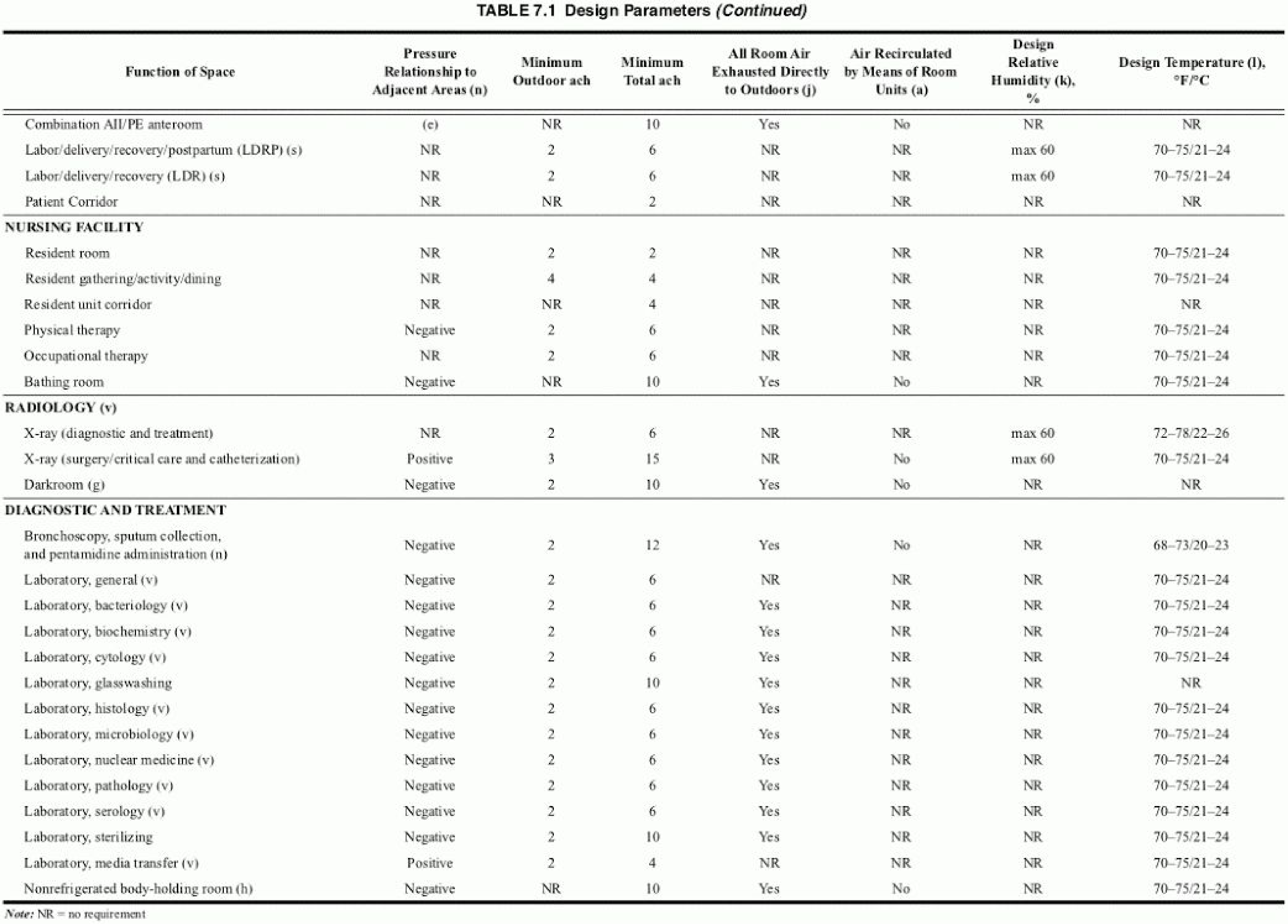


TABLE 7.1 Design Parameters *(Continued)*

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
Combination AII/PE anteroom	(e)	NR	10	Yes	No	NR	NR
Labor/delivery/recovery/postpartum (LDRP) (s)	NR	2	6	NR	NR	max 60	70–75/21–24
Labor/delivery/recovery (LDR) (s)	NR	2	6	NR	NR	max 60	70–75/21–24
Patient Corridor	NR	NR	2	NR	NR	NR	NR
NURSING FACILITY							
Resident room	NR	2	2	NR	NR	NR	70–75/21–24
Resident gathering/activity/dining	NR	4	4	NR	NR	NR	70–75/21–24
Resident unit corridor	NR	NR	4	NR	NR	NR	NR
Physical therapy	Negative	2	6	NR	NR	NR	70–75/21–24
Occupational therapy	NR	2	6	NR	NR	NR	70–75/21–24
Bathing room	Negative	NR	10	Yes	No	NR	70–75/21–24
RADIOLOGY (v)							
X-ray (diagnostic and treatment)	NR	2	6	NR	NR	max 60	72–78/22–26
X-ray (surgery/critical care and catheterization)	Positive	3	15	NR	No	max 60	70–75/21–24
Darkroom (g)	Negative	2	10	Yes	No	NR	NR
DIAGNOSTIC AND TREATMENT							
Bronchoscopy, sputum collection, and pentamidine administration (n)	Negative	2	12	Yes	No	NR	68–73/20–23
Laboratory, general (v)	Negative	2	6	NR	NR	NR	70–75/21–24
Laboratory, bacteriology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, biochemistry (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, cytology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, glasswashing	Negative	2	10	Yes	NR	NR	NR
Laboratory, histology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, microbiology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, nuclear medicine (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, pathology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, serology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, sterilizing	Negative	2	10	Yes	NR	NR	70–75/21–24
Laboratory, media transfer (v)	Positive	2	4	NR	NR	NR	70–75/21–24
Nonrefrigerated body-holding room (h)	Negative	NR	10	Yes	No	NR	70–75/21–24

Note: NR = no requirement

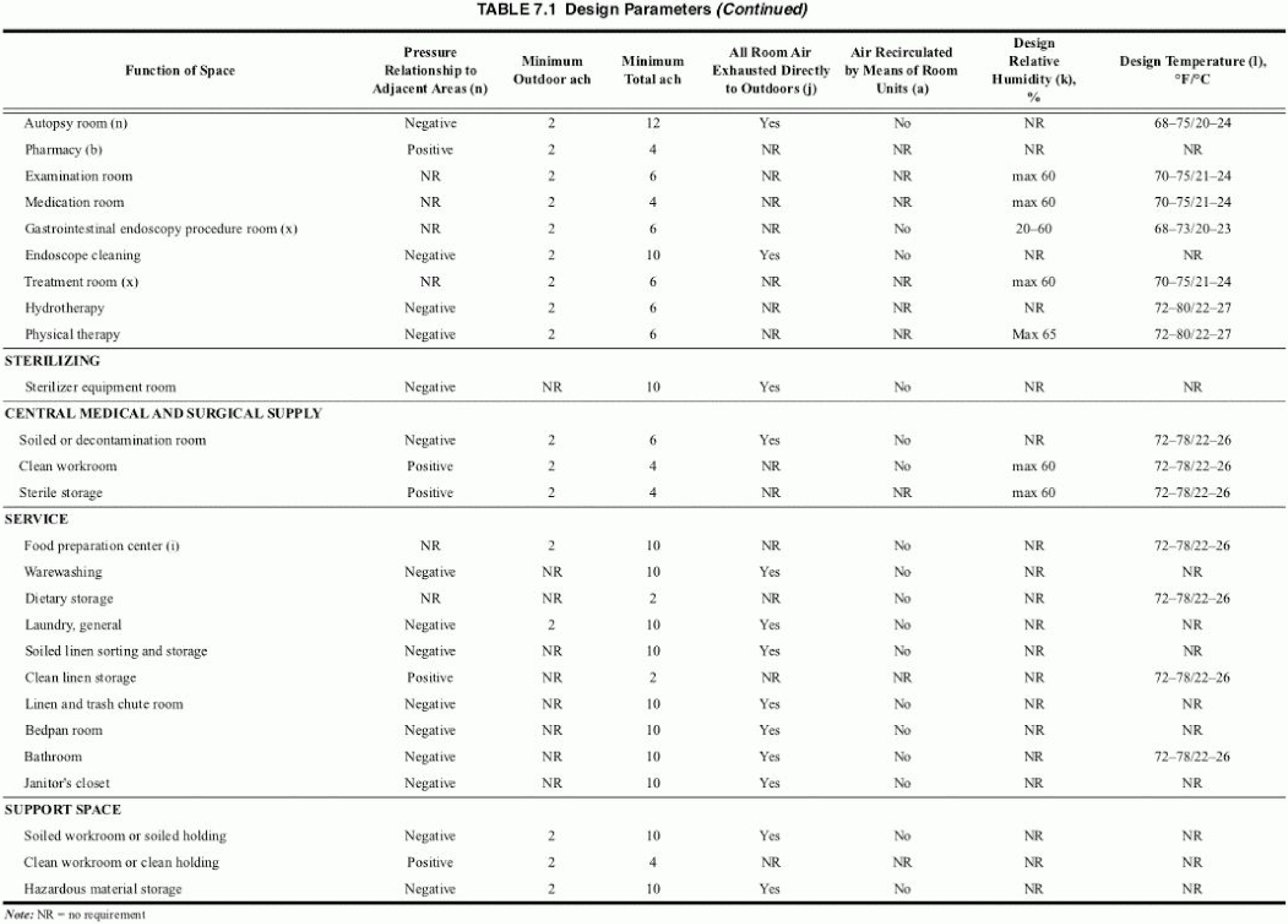
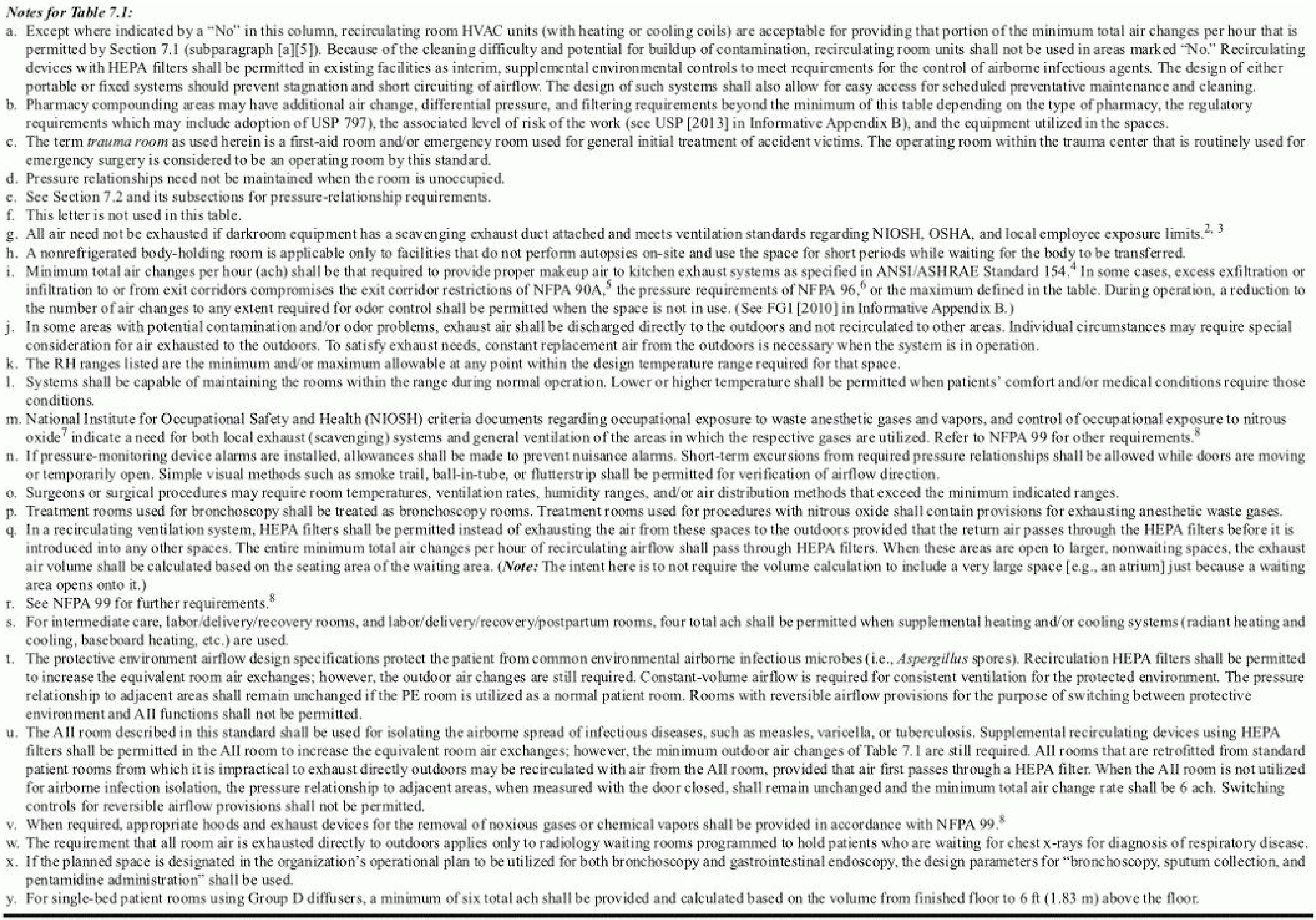


TABLE 7.1 Design Parameters *(Continued)*

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



Notes for Table 7.1:

a. Except where indicated by a "No" in this column, recirculating room HVAC units (with heating or cooling coils) are acceptable for providing that portion of the minimum total air changes per hour that is permitted by Section 7.1 (subparagraph [a][5]). Because of the cleaning difficulty and potential for buildup of contamination, recirculating room units shall not be used in areas marked "No." Recirculating devices with HEPA filters shall be permitted in existing facilities as interim, supplemental environmental controls to meet requirements for the control of airborne infectious agents. The design of either portable or fixed systems should prevent stagnation and short circuiting of airflow. The design of such systems shall also allow for easy access for scheduled preventative maintenance and cleaning.

b. Pharmacy compounding areas may have additional air change, differential pressure, and filtering requirements beyond the minimum of this table depending on the type of pharmacy, the regulatory requirements which may include adoption of USP 797), the associated level of risk of the work (see USP [2013] in Informative Appendix B), and the equipment utilized in the spaces.

c. The term *trauma room* as used herein is a first-aid room and/or emergency room used for general initial treatment of accident victims. The operating room within the trauma center that is routinely used for emergency surgery is considered to be an operating room by this standard.

d. Pressure relationships need not be maintained when the room is unoccupied.

e. See Section 7.2 and its subsections for pressure-relationship requirements.

f. This letter is not used in this table.

g. All air need not be exhausted if darkroom equipment has a scavenging exhaust duct attached and meets ventilation standards regarding NIOSH, OSHA, and local employee exposure limits.[2, 3]

h. A nonrefrigerated body-holding room is applicable only to facilities that do not perform autopsies on-site and use the space for short periods while waiting for the body to be transferred.

i. Minimum total air changes per hour (ach) shall be that required to provide proper makeup air to kitchen exhaust systems as specified in ANSI/ASHRAE Standard 154.[4] In some cases, excess exfiltration or infiltration to or from exit corridors compromises the exit corridor restrictions of NFPA 90A,[5] the pressure requirements of NFPA 96,[6] or the maximum defined in the table. During operation, a reduction to the number of air changes to any extent required for odor control shall be permitted when the space is not in use. (See FGI [2010] in Informative Appendix B.)

j. In some areas with potential contamination and/or odor problems, exhaust air shall be discharged directly to the outdoors and not recirculated to other areas. Individual circumstances may require special consideration for air exhausted to the outdoors. To satisfy exhaust needs, constant replacement air from the outdoors is necessary when the system is in operation.

k. The RH ranges listed are the minimum and/or maximum allowable at any point within the design temperature range required for that space.

l. Systems shall be capable of maintaining the rooms within the range during normal operation. Lower or higher temperature shall be permitted when patients' comfort and/or medical conditions require those conditions.

m. National Institute for Occupational Safety and Health (NIOSH) criteria documents regarding occupational exposure to waste anesthetic gases and vapors, and control of occupational exposure to nitrous oxide[7] indicate a need for both local exhaust (scavenging) systems and general ventilation of the areas in which the respective gases are utilized. Refer to NFPA 99 for other requirements.[8]

n. If pressure-monitoring device alarms are installed, allowances shall be made to prevent nuisance alarms. Short-term excursions from required pressure relationships shall be allowed while doors are moving or temporarily open. Simple visual methods such as smoke trail, ball-in-tube, or flutterstrip shall be permitted for verification of airflow direction.

o. Surgeons or surgical procedures may require room temperatures, ventilation rates, humidity ranges, and/or air distribution methods that exceed the minimum indicated ranges.

p. Treatment rooms used for bronchoscopy shall be treated as bronchoscopy rooms. Treatment rooms used for procedures with nitrous oxide shall contain provisions for exhausting anesthetic waste gases.

q. In a recirculating ventilation system, HEPA filters shall be permitted instead of exhausting the air from these spaces to the outdoors provided that the return air passes through the HEPA filters before it is introduced into any other spaces. The entire minimum total air changes per hour of recirculating airflow shall pass through HEPA filters. When these areas are open to larger, nonwaiting spaces, the exhaust air volume shall be calculated based on the seating area of the waiting area. (***Note:*** The intent here is to not require the volume calculation to include a very large space [e.g., an atrium] just because a waiting area opens onto it.)

r. See NFPA 99 for further requirements.[8]

s. For intermediate care, labor/delivery/recovery rooms, and labor/delivery/recovery/postpartum rooms, four total ach shall be permitted when supplemental heating and/or cooling systems (radiant heating and cooling, baseboard heating, etc.) are used.

t. The protective environment airflow design specifications protect the patient from common environmental airborne infectious microbes (i.e., *Aspergillus* spores). Recirculation HEPA filters shall be permitted to increase the equivalent room air exchanges; however, the outdoor air changes are still required. Constant-volume airflow is required for consistent ventilation for the protected environment. The pressure relationship to adjacent areas shall remain unchanged if the PE room is utilized as a normal patient room. Rooms with reversible airflow provisions for the purpose of switching between protective environment and AII functions shall not be permitted.

u. The AII room described in this standard shall be used for isolating the airborne spread of infectious diseases, such as measles, varicella, or tuberculosis. Supplemental recirculating devices using HEPA filters shall be permitted in the AII room to increase the equivalent room air exchanges; however, the minimum outdoor air changes of Table 7.1 are still required. AII rooms that are retrofitted from standard patient rooms from which it is impractical to exhaust directly outdoors may be recirculated with air from the AII room, provided that air first passes through a HEPA filter. When the AII room is not utilized for airborne infection isolation, the pressure relationship to adjacent areas, when measured with the door closed, shall remain unchanged and the minimum total air change rate shall be 6 ach. Switching controls for reversible airflow provisions shall not be permitted.

v. When required, appropriate hoods and exhaust devices for the removal of noxious gases or chemical vapors shall be provided in accordance with NFPA 99.[8]

w. The requirement that all room air is exhausted directly to outdoors applies only to radiology waiting rooms programmed to hold patients who are waiting for chest x-rays for diagnosis of respiratory disease.

x. If the planned space is designated in the organization's operational plan to be utilized for both bronchoscopy and gastrointestinal endoscopy, the design parameters for "bronchoscopy, sputum collection, and pentamidine administration" shall be used.

y. For single-bed patient rooms using Group D diffusers, a minimum of six total ach shall be provided and calculated based on the volume from finished floor to 6 ft (1.83 m) above the floor.

Appendix A: ASHRAE 34 Table 4-2

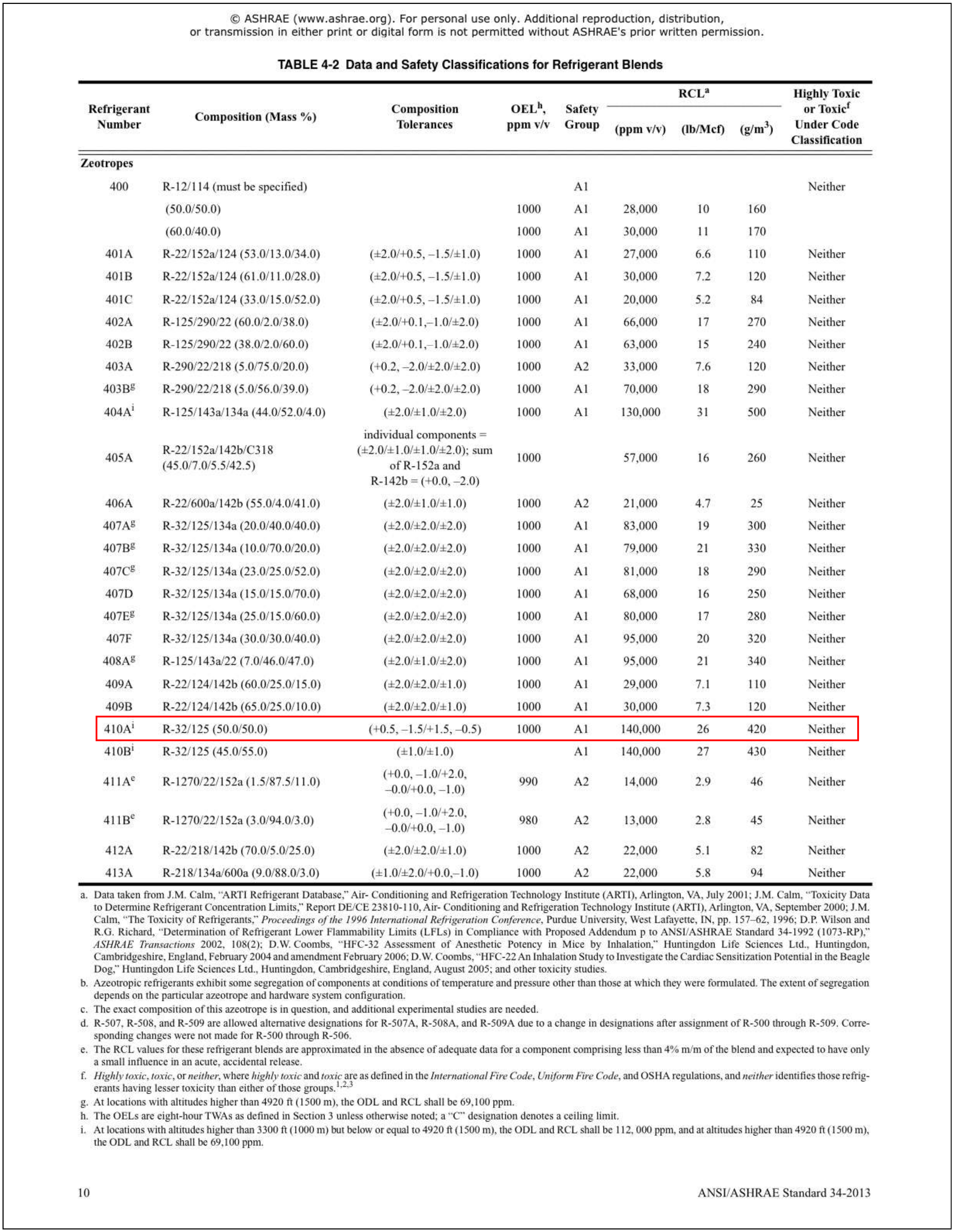


TABLE 4-2 Data and Safety Classifications for Refrigerant Blends

Refrigerant Number	Composition (Mass %)	Composition Tolerances	OEL[h], 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.

MAGNITUDE™ Water Cooled Centrifugal Chiller

Job Information	***Technical Data Sheet***
Job Name	Penn State study for thesis
Date	3/7/2015
Submitted By	Stacie Suh
Software Version	10.10
Unit Tag	Alternate 1
Country of Origin	USA

Unit Overview

Model Number	Capacity ton	IPLV kW/ton	Voltage	Drive Type	ASHRAE 90.1	LEED EA Credit 4
WMC150DC	145.0	0.358	460 V / 60 Hz	VFD	'04, '07 & '10	Does not qualify

Unit

Model Number:	WMC150DCSN13/E2212-UD2C-2/C2012-HB2C-2/R134-DAABA-U
Approval:	AHRI and ETL / cETL
Vessel Code:	ASME

Compressor Quantity	Capacity Control	Refrigerant Type	Refrigerant Weight
2	VFD / Inlet Guide Vanes	R134a	630 lb

Evaporator

Entering Fluid Temperature	Leaving Fluid Temperature	Fluid Type	Actual Fluid Flow	Minimum Fluid Flow
53.99 °F	44.00 °F	Water	348.00 gpm	119.4 gpm

Length	Diameter	Number of Passes	Tube		Fouling Factor
			Material	Wall Thickness	
12 ft	22 in	2	Copper	0.025 in	0.00010 °F.ft^2.h/Btu

Condenser

Entering Fluid Temperature	Leaving Fluid Temperature	Fluid Type	Fluid Flow
85.00 °F	94.44 °F	Water	435.00 gpm

Length	Diameter	Number of Passes	Tube		Fouling Factor
			Material	Wall Thickness	
12 ft	20 in	2	Copper	0.025 in	0.00025 °F.ft^2.h/Btu

Unit Performance

Design

Capacity ton	Input kW	Efficiency kW/ton	RLA A	IPLV kW/ton	Part Load Efficiency			Evaporator Fluid		Condenser Fluid	
					75% kW/ton	50% kW/ton	25% kW/ton	Pressure Drop ft H_2O	Entering Temperature °F	Pressure Drop ft H_2O	Leaving Temperature °F
145.0	88.9	0.613	126	0.358	0.452	0.314	0.292	10.4	53.99	8.6	94.44

Performance Points Rated at AHRI Condenser Relief

Point #	% of Design Load	Capacity ton	Input kW	Efficiency kW/ton	RLA A	Evaporator Fluid				Condenser Fluid			
						Flow gpm	Temperature		Pressure Drop ft H_2O	Flow gpm	Temperature		Pressure Drop ft H_2O
							Entering °F	Leaving °F			Entering °F	Leaving °F	
1	100.0	145.0	88.9	0.613	126	348.00	53.99	44.00	10.4	435.00	85.00	94.44	8.6
2	75.0	108.8	49.2	0.452	76	348.00	51.49	44.00	10.4	435.00	75.00	81.79	8.9
3	50.0	72.5	22.8	0.314	40	348.00	48.99	44.00	10.4	435.00	65.00	69.35	9.3
4	25.0	36.3	10.6	0.292	20	348.00	46.50	44.00	10.4	435.00	65.00	67.16	9.3

MAGNITUDE™ Water Cooled Centrifugal Chiller

Service Data

Physical

Evaporator

Inlet Location	Header Type	Header Material	Tube Sheet Material	Design Pressure (Waterside)
Left	Dished, Grooved	Carbon Steel	Carbon Steel	150 psig

Condenser

Inlet Location	Header Type	Header Material	Tube Sheet Material	Design Pressure (Waterside)
Left	Dished, Grooved	Carbon Steel	Carbon Steel	150 psig

Electrical

Voltage	RLA (per unit)	LRA* (per compressor)	Power Connection	MCA	MOCP	Lug Size (wires per phase)
460 V / 60 Hz / 3 Phase	126 A	69 A	Single Point	142 A	200 A	(1) #6 - 300MCM

** The field wiring must be sized in accordance with the MCA and not the RLA as some selections may be below the minimum required protection.*

Drive

Type	Model	Location	Enclosure Type	Motor Protection
VFD	Integral	Terminal Mounted	NEMA 1	Standard

Line Reactor	Compressor Circuit Breaker	Disconnect Switch	Power Connection	Short Circuit Current Rating	Approval
Standard	Standard	Standard	Single Point	Standard	ETL, ETLc

Sound (without insulation)

Sound Pressure

Load	Overall	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
100%	75.5	37.5	49.5	56.0	65.0	72.0	70.0	66.5	64.0
75%	72.5	39.5	48.5	55.0	61.0	69.5	64.5	64.0	60.0
50%	68.5	35.5	48.0	54.5	58.0	66.0	61.0	58.5	53.5
25%	68.0	36.0	48.5	54.5	57.5	65.5	60.5	57.5	52.0

Sound Pressure (dB) measured in accordance with ANSI/AHRI Standard 575-2008 ('A' weighted)

Options

Basic Unit

Packaging:	Bagging only

Insulation

Thermal:	0.75" on evap shell, suction piping, compressor inlet & motor barrel
Head:	Evaporator return and connection heads insulated

Drive

Disconnect / Breaker Type:	Disconnect Switch

Lifecycle Cost

Operation	Electricity Cost	Annual Energy Cost	Life of Equipment	Total Lifecycle Equipment and Energy Cost
2340 hours / year	0.12 $/kWh	$9280	25 years	$328703

Warranty

Unit Startup:	Domestic by Daikin Factory Service (Std.)
Standard Warranty:	Domestic, First Year Standard Warranty (Parts & Labor)
Delayed Warranty Start:	None (Startup 12-18 months after ship date)

AHRI Certification

Certified in accordance with the AHRI Water-Cooled Water Chilling Packages Using Vapor Compression Cycle Certification Program, which is based on AHRI Standard 550/590 (I-P) and AHRI Standard 551/591 (SI). Certified units may be found in the AHRI Directory at www.ahridirectory.org

Notes

1. Above RLA values are per Unit.
2. Performance kW & kW/ton values are total values unless noted otherwise.
3. Minimum flow is based upon standard condenser water relief and not increased lift due to constant condenser water temperature.
4. The field wiring must be sized in accordance with the MCA and not the RLA as some selections may be below the minimum required protection.
5. Use only copper supply wires with ampacity based on 75°C conductor rating. Connections to terminals must be made with copper lugs and copper wire.

Appendix B: Alternative 1 Cooling Tower Data

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

3/22/2015 2:42:53 PM

Job Information

Thesis - Morton Expansion
Courtney Millett
Taunton, MA

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	1800 rpm
Product	NC Steel	Fan Motor Capacity per cell	5.000 BHp
Model	NC8401KAN1	Fan Motor Output per cell	5.000 BHp
Cells	1	Fan Motor Output total	5.000 BHp
CTI Certified	Yes	Air Flow per cell	47010 cfm
Fan	6.000 ft, 5 Blades	Air Flow total	47010 cfm
Fan Speed	370 rpm, 6974.3 fpm	Static Lift	10.425 ft
Fans per cell	1	Distribution Head Loss	0.000 ft
		ASHRAE 90.1 Performance	103 gpm/Hp

Model Group	Standard Low Sound (A)
Sound Pressure Level	73 dBA (Single Cell), 5.000 ft from Air Inlet Face. See sound report for details.

Conditions

Tower Water Flow	358.7 gpm	Air Density In	0.07061 lb/ft³
Hot Water Temperature	94.66 °F	Air Density Out	0.07126 lb/ft³
Range	9.66 °F	Humidity Ratio In	0.01835
Cold Water Temperature	85.00 °F	Humidity Ratio Out	0.02879
Approach	5.18 °F	Wet-Bulb Temp. Out	87.59 °F
Wet-Bulb Temperature	79.81 °F	Estimated Evaporation	4.1 gpm
Relative Humidity	50.0 %	Total Heat Rejection	1726200 Btu/h
Capacity	100.0 %		

- This selection satisfies your design conditions.

Weights & Dimensions

	Per Cell	Total
Shipping Weight	3746 lb	3746 lb
Heaviest Section	3746 lb	
Max Operating Weight	7573 lb	7573 lb
Width	12.830 ft	12.830 ft
Length	6.520 ft	6.520 ft
Height	10.190 ft	

Minimum Enclosure Clearance

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

Solid Wall	3.449 ft
50 % Open Wall	3.000 ft

Weights and dimensions do not include options; refer to sales drawings. For CAD layouts refer to file 8401_ALN.dxf

Cold Weather Operation

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

Heater kW/Cell	9.0	7.5	6.0	4.5	3.0
Ambient Temperature °F	-26.64	-14.92	-3.20	8.52	20.23

Technical Data Sheet for CH-1

JOB NAME	UTN9S0	**REP. OFFICE**	Stebbins-Duffy, Inc. (Boston)
JOB DESCRIPTION	Penn State Study	**SALESMAN**	Stebbins-Duffy, Inc. (Boston)
		CUSTOMER	
MODEL NUMBER	WGZ080D - Standard Efficiency		
UNIT TAGGING	CH-1	**VERSION**	8.90.001

PHYSICAL DATA			
Length (ins)	149.6	Shipping weight (lb)	3971.0
Width (ins)	35.0	Operating weight (lb)	4128.0
Height (ins)	65.5	Refrigerant	R410a
		Refrigerant charge (lb)	160.0

DESIGN PERFORMANCE

Capacity (tons)	Input Power (kW)	Performance (EER)	Flow (gpm)	IPLV	Evaporator			Condenser		
					P.D. (ftHd)	T in (°F)	T out (°F)	P.D. (ftHd)	T in (°F)	T out (°F)
78.3	59.5	15.8	187.9	20.3	12.0	54.0	44.0	9.5	85.0	95.0

EVAPORATOR DATA		**CONDENSER DATA**	
Design Flow (gpm) / P.D. (ftHd)	187.9 / 12.0	Design Flow (gpm) / P.D. (ftHd)	234.9 / 9.5
Fluid type	Water	Fluid type	Water
Percentage of fluid	100	Percentage of fluid	100
Number of passes	2	Number of passes	2
Fouling Factor (F.ft².h/Btu)	0.00010	Fouling Factor (F.ft².h/Btu)	0.00025
Type	Brazed Plate	Tube material	Cu
Tube wall thickness (ins)	Contact factory	Tube wall thickness (ins)	0.025
Water volume (gal)	6.3	Water volume (gal)	27.5
Min flow (gpm) / P.D. (ftHd)	117.4 / 4.9	Min flow (gpm) / P.D. (ftHd)	146.8 / 3.9
Max flow (gpm) / P.D. (ftHd)	313.2 / 31.7	Max flow (gpm) / P.D. (ftHd)	391.5 / 25.1

PART LOAD PERFORMANCE AT AHRI STANDARD CONDITIONS

P#	%load request	Capacity (tons)	Total unit input power (kW)	Performance (EER)
1	100	78.3	59.5	15.8
2	75	58.7	37.3	18.9
3	50	39.2	22.0	21.4
4	25	19.6	11.0	21.4

SOUND DATA

Sound pressure (at 1 meter) – octave band at center frequency (Without sound insulation)

63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz	Overall
75	69	73	78	78	76	72	63	82

Sound power – octave band at center frequency (Without sound insulation)

63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz	Overall
83	77	81	86	86	84	81	71	90

Octave band is non 'A' weighted and overall readings are 'A' weighted. Sound data rated in accordance with AHRI Standard-575.

Technical Data Sheet for CH-1

UNIT ELECTRICAL DATA (ETL / Canadian ETL Listed and Labeled) ***

Volts	460	Hertz		60
	Single Point$^+$	Multi Point$^+$		
[with external overload]		Ckt 1	Ckt 2	Ckt 3
MCA	131 [106]	69 [56]	69 [56]	N/A
Field Wire Gauge	1/0 AWG [2 AWG]	4 AWG [6 AWG]	4 AWG [6 AWG]	N/A
Field Wire Qty	3 [3]	3 [3]	3 [3]	N/A
Conduit Qty	1 [1]	1 [1]	1 [1]	N/A
Conduit Nom Size	1.50 [1.25]	1.00 [0.75]	1.00 [0.75]	N/A
Rec Fuse Size	150 [125]	100 [80]	100 [80]	N/A
Max Fuse Size	150 [125]	100 [80]	100 [80]	N/A
Terminal Amps for Standard Power Block**	175	175	175	N/A
Connector Wire Range for Standard Power Block**	(1) 2/0 - #14	(1) 2/0 - #14	(1) 2/0 - #14	N/A
Terminal Amps for Optional Disconnect Switch**	250	100	100	N/A
Connector Wire Range for Optional Disconnect Switch**	(1) 350 - #6	(1) 1/0 - #10	(1) 1/0 - #10	N/A

$^+$ Both single and multiple point data are shown for user convenience.

*** Both standard power block and optional disconnect data are shown for user convenience.*

**** Electrical data does not include items configured in the Job Editor such as a pump package.*

For all options refer to the order acknowledgement for the actual configuration

COMPRESSOR ELECTRICAL DATA

Type / Quantity	Scroll/4					
	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6
RLA	31.4	31.4	31.4	31.4	N/A	N/A
LRA						
Across the Line	220.0	220.0	220.0	220.0	N/A	N/A
Reduced Inrush / Part Winding	N/A	N/A	N/A	N/A	N/A	N/A
Reduced Inrush / Solid State	N/A	N/A	N/A	N/A	N/A	N/A

AHRI 550/590 CERTIFICATION

This unit is certified in accordance with the AHRI Water-Cooled Water Chilling Packages Using Vapor Compression Cycle Certification Program, which is based on AHRI Standard 550/590 (I-P) and AHRI Standard 551/591 (SI). Certified units may be found in the AHRI Directory at www.ahridirectory.org

0A

WGZ080DW Packaged Water-Cooled Scroll Chiller

Unit Dimensions

Certified Drawings, WC Scroll Packaged, REV0A, WGZ-DW 080_Drawing for CH-1

Job Number: LITNOSCN

Job Name: Penn State Study

Page 6 of 54

Prepared Date: 2/7/2015

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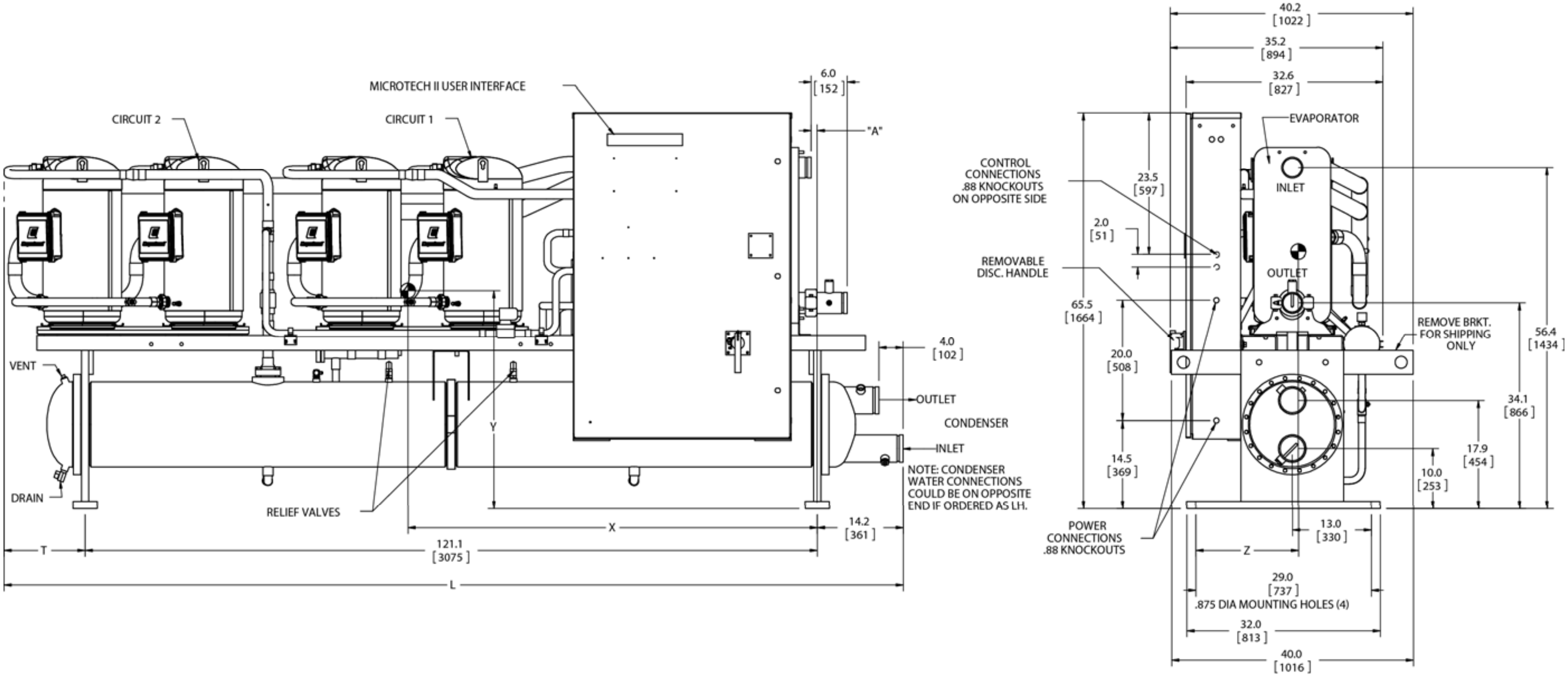
Dimensions								
Units	Maximum Overall Length	Chilled Water Connection Grooved		Condenser Water Connection Grooved	Piping Overhang	Center of Gravity		
	L	Nominal Size (OD)	A	Nominal Size (OD)	T	X	Y	Z
in	149	3	8.8	4	13.8	64.2	29.5	15
mm	3785	76	224	102	351	1631	749	381

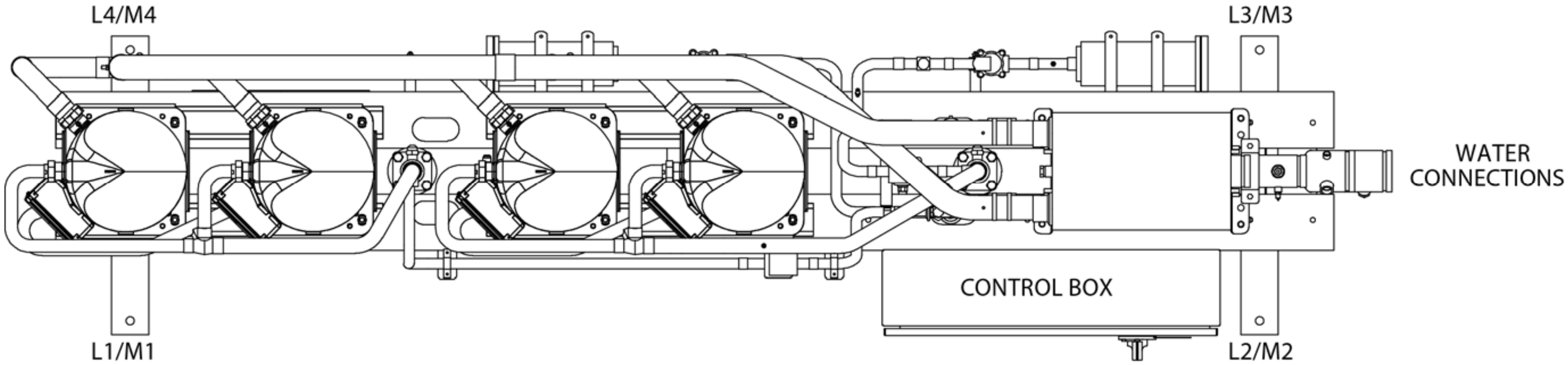
Diagram Notes
The drawings shown on sheet 1 and 2 are for the default configuration; your unit may be configured differently. Consult the Item Summary sheet for exact configuration.



Certified Drawings, WC Scroll Packaged, REV0A, WGZ-DW 080_Drawing for CH-1

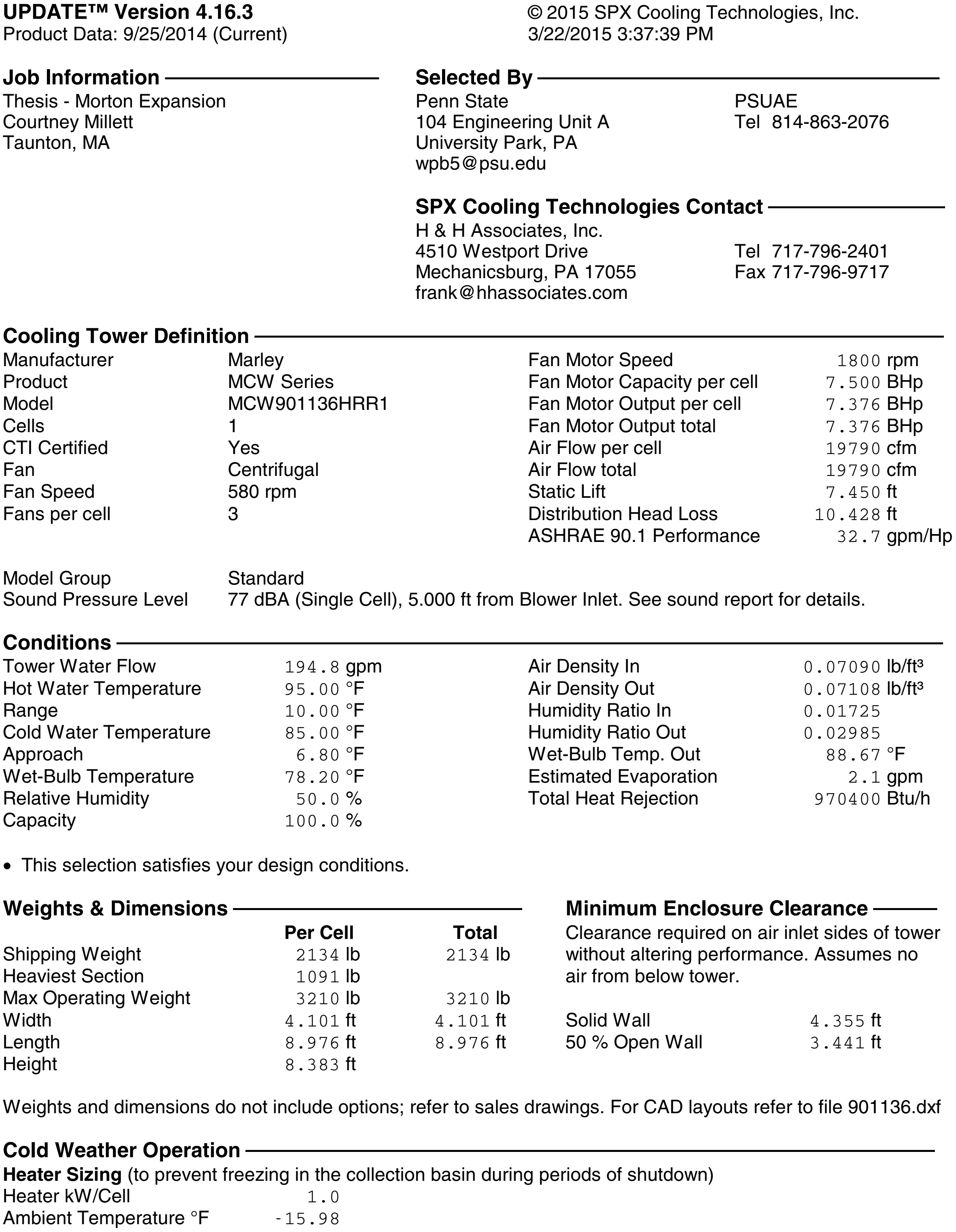
No change to this drawing may be made unless approved in writing by Daikin Applied. Purchaser must determine that the equipment is fit and sufficient for the job specifications.

Lifting and Mounting



Unit Weight Data										
Units	Lifting Weight				Mounting Load				Weight	
	L1	L2	L3	L4	M1	M2	M3	M4	Shipping	Operating
lb	1016	900	965	1090	1056	935	1003	1133	3971	4128
kg	461	408	438	494	479	424	455	514	1801	1872

Prepared Date:



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

3/22/2015 3:37:39 PM

Job Information

Thesis - Morton Expansion
Courtney Millett
Taunton, MA

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	1800 rpm
Product	MCW Series	Fan Motor Capacity per cell	7.500 BHp
Model	MCW901136HRR1	Fan Motor Output per cell	7.376 BHp
Cells	1	Fan Motor Output total	7.376 BHp
CTI Certified	Yes	Air Flow per cell	19790 cfm
Fan	Centrifugal	Air Flow total	19790 cfm
Fan Speed	580 rpm	Static Lift	7.450 ft
Fans per cell	3	Distribution Head Loss	10.428 ft
		ASHRAE 90.1 Performance	32.7 gpm/Hp

Model Group	Standard
Sound Pressure Level	77 dBA (Single Cell), 5.000 ft from Blower Inlet. See sound report for details.

Conditions

Tower Water Flow	194.8 gpm	Air Density In	0.07090 lb/ft³
Hot Water Temperature	95.00 °F	Air Density Out	0.07108 lb/ft³
Range	10.00 °F	Humidity Ratio In	0.01725
Cold Water Temperature	85.00 °F	Humidity Ratio Out	0.02985
Approach	6.80 °F	Wet-Bulb Temp. Out	88.67 °F
Wet-Bulb Temperature	78.20 °F	Estimated Evaporation	2.1 gpm
Relative Humidity	50.0 %	Total Heat Rejection	970400 Btu/h
Capacity	100.0 %		

- This selection satisfies your design conditions.

Weights & Dimensions

	Per Cell	Total
Shipping Weight	2134 lb	2134 lb
Heaviest Section	1091 lb	
Max Operating Weight	3210 lb	3210 lb
Width	4.101 ft	4.101 ft
Length	8.976 ft	8.976 ft
Height	8.383 ft	

Minimum Enclosure Clearance

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

Solid Wall	4.355 ft
50 % Open Wall	3.441 ft

Weights and dimensions do not include options; refer to sales drawings. For CAD layouts refer to file 901136.dxf

Cold Weather Operation

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

Heater kW/Cell	1.0
Ambient Temperature °F	-15.98

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Submittal Data Sheet

Project Name:
Location:
Engineer:
Submitted to:
Submitted by:
Reference:

Approval:
Date:
Construction:
Unit #:
Drawing #:

Performance

Indoor Unit Model No:	FXDQ07MVJU
Rated Cooling Capacity (Btu/hr):	7500
Sensible Capacity (Btu/hr):	6300
Cooling Input Power (kW):	0.092
Rated Heating Capacity (Btu/hr):	8500
Heating Input Power (kW):	0.073

Indoor Unit Type:	Duct Mounted Slim Type (Low Static)
Rated Cooling Conditions	Indoor: 80°F DB/67°F WB Ambient: 95°F DB/75°F WB
Rated Heating Conditions	Indoor: 70°F DB/60°F WB Ambient: 47°F DB/43°F WB
Rated Piping Length (ft)	25
Rated Height Separation (ft)	0

Indoor Unit Details

Power Supply (V/Hz/Ph:)	208-230/60/1ph
Power Supply Connections:	L1, L2, Ground
Min. Circuit Amps MCA (A):	0.9
Max. Overcurrent Protection (MOP) (A):	15
Dimensions (HxWxD):	7-7/8x27-9/16x24-7/16
Panel (HxWxD):	N/A
Net Weight (lbs):	51
Net Weight with Panel (lbs):	

Airflow Rate (CFM wet coil)	280//226
Moisture Removal (pt/h):	
Gas Pipe Connection (inch):	1/2
Liquid Pipe Connection (inch):	1/4
Condensate Connection (inch):	1-1/32
Sound Pressure Level (dBA):	33
Sound Power Level (dBA):	50.8 c/h
External Static Pressure/Max (inWg):	0.04 / 0.12
Controller Name:	

FXDQ07MVJU

FXDQ07MVJU

Std U.S. Warranty: 7yrs Compressor, 1yrs Parts

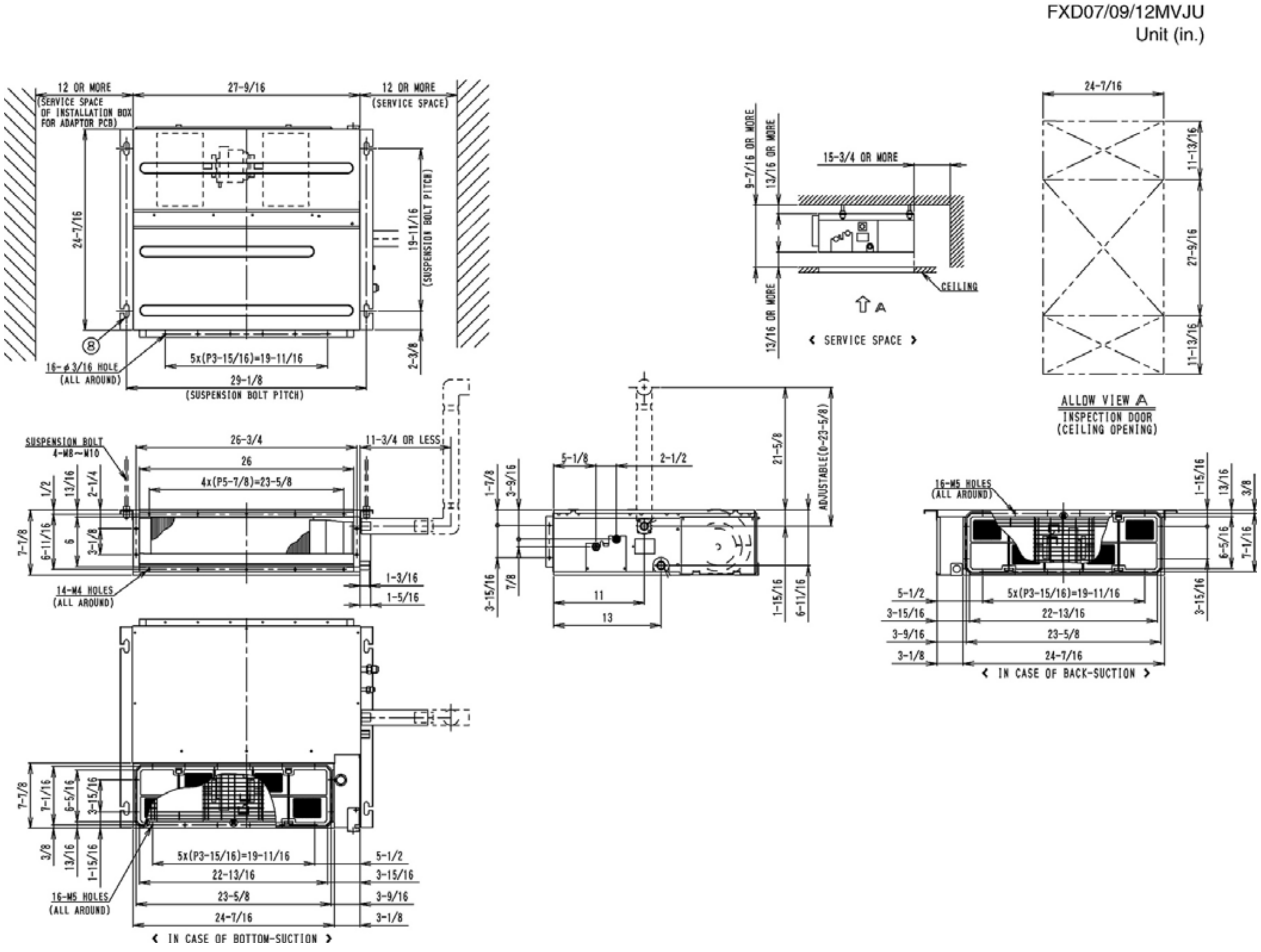
Submittal Data Sheet

Project Name:
Location:
Engineer:
Submitted to:
Submitted by:
Reference:

Approval:
Date:
Construction:
Unit #:
Drawing #:

Dimensional Drawing - Indoor Unit

FXDQ07MVJU



Appendix B: Alternative 2 VRF Indoor Unit 2

Submittal Data Sheet

Project Name:	
Location:	
Engineer:	
Submitted to:	
Submitted by:	
Reference:	

Approval:	
Date:	
Construction:	
Unit #:	
Drawing #:	

Performance

Indoor Unit Model No:	FXDQ12MVJU
Rated Cooling Capacity (Btu/hr):	12000
Sensible Capacity (Btu/hr):	8800
Cooling Input Power (kW):	0.095
Rated Heating Capacity (Btu/hr):	13500
Heating Input Power (kW):	0.076

Indoor Unit Type:	Duct Mounted Slim Type (Low Static)
Rated Cooling Conditions	Indoor: 80°F DB/67°F WB Ambient: 95°F DB/75°F WB
Rated Heating Conditions	Indoor: 70°F DB/60°F WB Ambient: 47°F DB/43°F WB
Rated Piping Length (ft)	25
Rated Height Separation (ft)	0

Indoor Unit Details

Power Supply (V/Hz/Ph:)	208-230/60/1ph
Power Supply Connections:	L1, L2, Ground
Min. Circuit Amps MCA (A):	0.9
Max. Overcurrent Protection (MOP) (A):	15
Dimensions (HxWxD):	7-7/8x27-9/16x24-7/16
Panel (HxWxD):	N/A
Net Weight (lbs):	51
Net Weight with Panel (lbs):	

Airflow Rate (CFM wet coil)	280//226
Moisture Removal (pt/h):	
Gas Pipe Connection (inch):	1/2
Liquid Pipe Connection (inch):	1/4
Condensate Connection (inch):	1-1/32
Sound Pressure Level (dBA):	33
Sound Power Level (dBA):	50.8 c/h
External Static Pressure/Max (inWg):	0.04 / 0.12
Controller Name:	

FXDQ12MVJU

FXDQ12MVJU

Std U.S. Warranty: 7yrs Compressor, 1yrs Parts

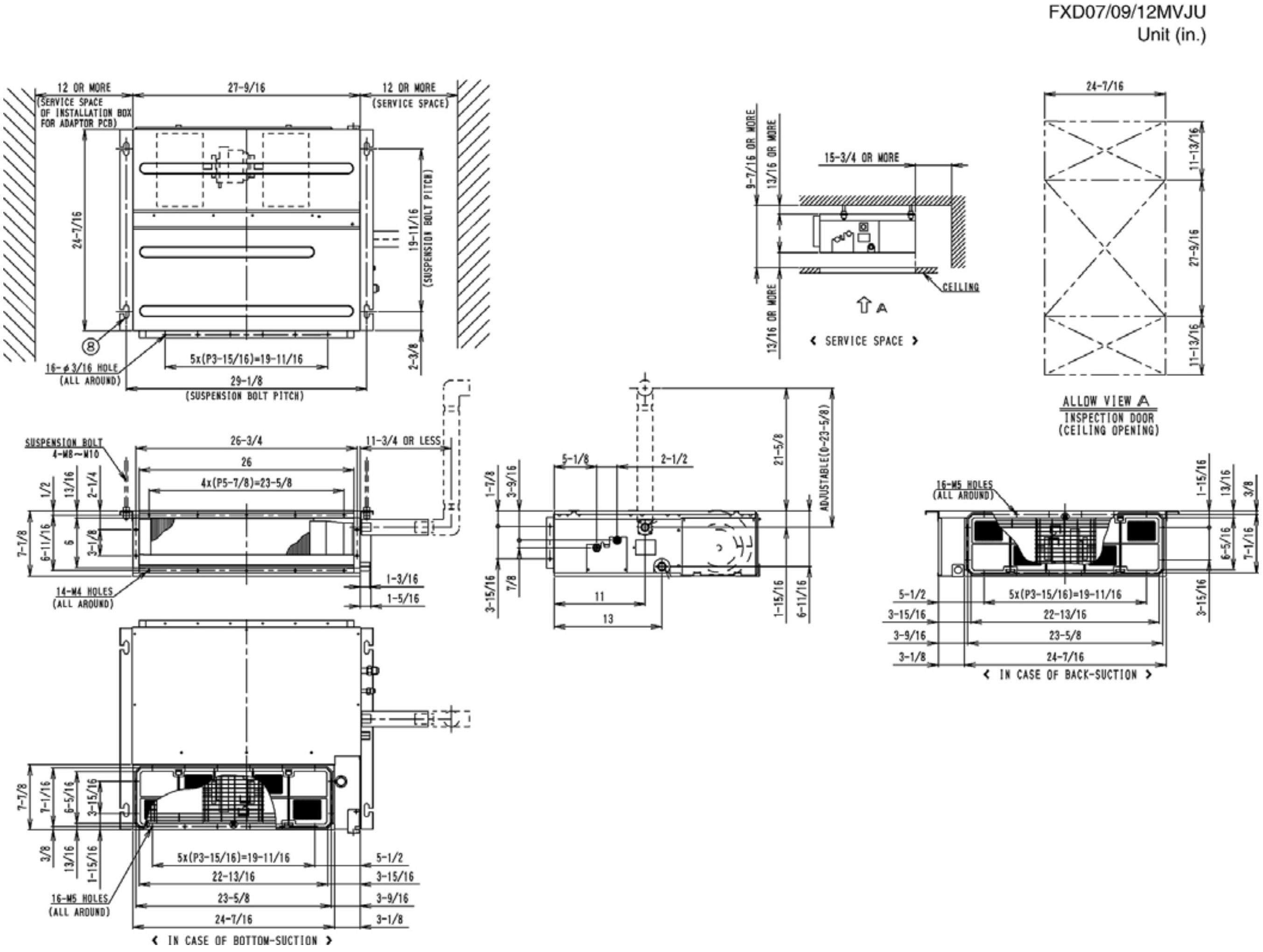
Submittal Data Sheet

Project Name:
Location:
Engineer:
Submitted to:
Submitted by:
Reference:

Approval:
Date:
Construction:
Unit #:
Drawing #:

Dimensional Drawing - Indoor Unit

FXDQ12MVJU



DAIKIN

Submittal Data Sheet

10-Ton VRV-III Heat Recovery Unit

REYQ120PBTJ

FEATURES

- Extended operating range with the ability to operate at outdoor ambient conditions down to -4°F in heating with an option down to -4°F in cooling mode.
- Fans and grilles designed for low sound level and efficient operation
- Long refrigerant piping lengths with up to 3,280 ft. of total 'One-Way' piping in the complete piping network
- Advanced continuous heating during defrost cycle
- Automatic charge function
- Automatic check of wiring, shut off vales, sensors and refrigerant volume
- Standard Limited Warranty: 10-year warranty on compressor and all parts

BENEFITS

- Automatic diagnose of errors and malfunctions to speed up troubleshooting
- Can operate up to 62 indoor units on a single piping network
- Integrated inverter technology deliver maximum efficiency during part load conditions and provide precise individual zone control
- Very low sound levels allows flexibility in layout of systems
- Continuous heating during oil return allows constant comfort control
- Modular and lightweight - enables flexibility in system layout and installation
- DC fan motors improves efficiency, especially at low fan speed

VRV III AHRI CERTIFIED www.ahridirectory.org C INTERTEK ETL LISTED US R-410A INVERTER

Submittal Data Sheet

10-Ton VRV-III Heat Recovery Unit
REYQ120PBTJ

PERFORMANCE

Outdoor Unit Model No.	REYQ120PBTJ	Outdoor Unit Name:	10-Ton VRV-III Heat Recovery Unit
Type:	Heat Recovery	Unit Combination:	
Rated Cooling Capacity (Btu/hr):	114,000	Rated Cooling Conditions:	Indoor (°F DB/WB): 80 / 67 Ambient (°F DB/WB): 95 / 75
Nom Cooling Capacity (Btu/hr):		Rated Heating Conditions:	Indoor (°F DB/WB): 70 / 70 Ambient (°F DB/WB): 47 / 43
Cooling Input Power (kW):	10.09	Rated Piping Length(ft):	
Rated Heating Capacity (Btu/hr):	129,000	Rated Height Difference (ft):	0.00
Nom Heating Capacity (Btu/hr):		IEER (Non-Ducted/Ducted):	21.30 / 21.30
Heating Input Power (kW):	11.12	Heating COP (Non-Ducted/Ducted):	3.6 / 3.4
		Heating COP 17F (Non-Ducted/Ducted):	2.6 / 2.4

OUTDOOR UNIT DETAILS

Power Supply (V/Hz/Ph):	208-230 / 60 / 3	Compressor Type	Inverter
Power Supply Connections:	L1, L2, L3 Ground	Capacity Control Range (%):	14 - 100
Min. Circuit Amps MCA (A):		Capacity Index Limit:	60.0 - 156.0
Max Overcurrent Protection (MOP) (A):		Airflow Rate (H) (CFM):	7,410
Max Starting Current MSC(A):	131.00	Gas Pipe Connection (inch):	1/2
Rated Load Amps RLA(A):	25.6	Liquid Pipe Connection (inch):	1/4
Dimensions (Height) (in):	66-1/8	H/L Pressure Connection (inch)	3/4
Dimensions (Width) (in):	51-3/16	H/L Equalizing Connection (inch)	
Dimensions (Depth) (in):	30-1/8	Sound Pressure (H) (dBA):	60
Net Weight (lb):	730	Sound Power Level (dBA):	
		Max. No. of Indoor Units:	20

Submittal Data Sheet

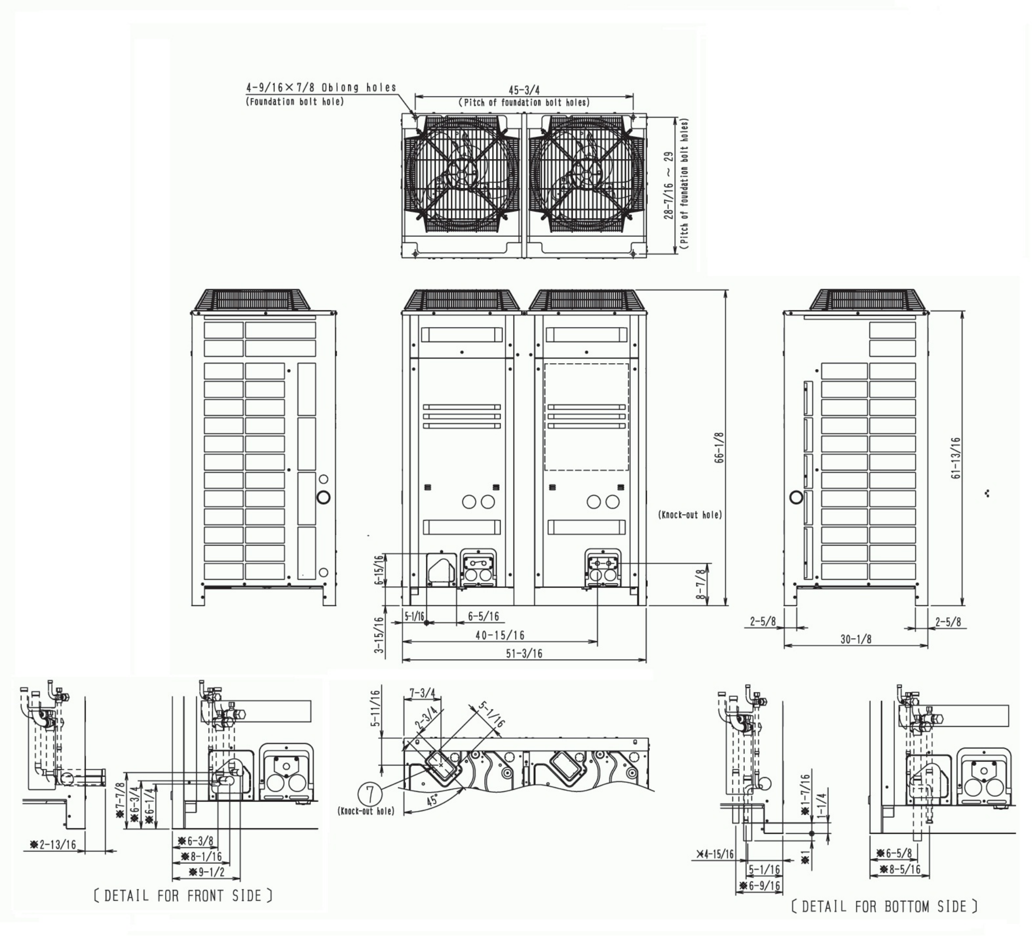
10-Ton VRV-III Heat Recovery Unit

REYQ120PBTJ

SYSTEM DETAILS

Refrigerant Type:	R-410A	Cooling Operation Range (°F DB):	23 - 122
Holding Refrigerant Charge (lbs):	23.8	Heating Operation Range (°F WB):	0 - 77
Additional Charge (lb/ft):		Max. Pipe Length (Vertical) (ft):	295
Pre-charge Piping (Length) (ft):		Cooling Range w/Baffle (°F DB):	-
Max. Pipe Length (Total) (ft):	540	Heating Range w/Baffle (°F WB):	4 - 60
Max Height Separation (Ind to Ind ft):	0		

DIMENSIONAL DRAWING



Appendix C: Ventilation Calculations

Ventilation Report															
					ASHRAE 170 Design Parameters						Actual Design Airflow Rates				
Room Number	Room Name	Function of Space (defined by ASHRAE 170)	Pressure Relationship to Adjacent Spaces	Area (SF)	Ceiling Height	Minimum Outdoor ACH	Minimum Total ACH	Minimum OA Supply Airflow (CFM)	Minimum Total Supply Airflow (CFM)	Required Exhausted Air (CFM)	Outdoor Airflow (CFM)	Supply Airflow (CFM)	Exhausted Air (CFM)	ASHRAE 170 Design Parameters met?	Outdoor Air Percentage
ED009	MEN'S RESTROOM	Inpatient Toilet Room	Negative	140	8.00	0	10	0	187	187	0	200	200	Yes	0%
ED008	WOMEN'S RESTROOM	Inpatient Toilet Room	Negative	185	8.00	0	10	0	247	247	0	250	250	Yes	0%
G000C01	CORR.	Patient Corridor	NR	080	8.00	0	2	0	21	0	0	25	0	Yes	0%
ED007	TRIAGE A	Triage	Negative	230	8.00	2	12	61	368	368	70	400	400	Yes	18%
ED000C01	WAITING	ER waiting room	Negative	1100	8.00	2	12	293	1,760	1,760	300	1,950	1,950	Yes	15%
ED006	TRIAGE B	Triage	Negative	240	8.00	2	12	64	384	384	70	400	400	Yes	18%
ED100C01	CORR.	Patient Corridor	NR	375	8.00	0	2	0	100	0	0	300	0	Yes	0%
ED100C02	CORR.	Patient Corridor	NR	225	8.00	0	2	0	60	0	0	150	0	Yes	0%
ED105	P TLT	Inpatient Toilet Room	Negative	050	8.00	0	10	0	67	67	0	100	100	Yes	0%
ED228	ANTE	AII anteroom	Note 1	100	8.00	0	10	0	133	133	0	200	200	Yes	0%
ED227	ISOLATION TRTMNT-14	AII room	Negative	175	8.00	2	12	47	280	280	50	300	300	Yes	17%
ED226	P. TLT	Inpatient Toilet Room	Negative	075	8.00	0	10	0	100	100	0	100	100	Yes	0%
ED109	TRTMNT-33	Treatment Room	NR	140	8.17	2	6	38	114	0	40	150	0	Yes	27%
ED110	TRTMNT-34	Treatment Room	NR	140	8.17	2	6	38	114	0	40	150	0	Yes	27%
ED111	TRTMNT-35	Treatment Room	NR	140	8.17	2	6	38	114	0	40	150	0	Yes	27%
ED112	WAITING	ER waiting room	Negative	125	8.00	2	12	33	200	200	40	200	200	Yes	20%
ED100C03	CORR.	Patient Corridor	NR	515	8.00	0	2	0	137	0	0	150	0	Yes	0%
ED108	P TLT	Inpatient Toilet Room	Negative	065	8.00	0	10	0	87	87	0	100	100	Yes	0%
ED114	TRTMNT-36	Treatment Room	NR	140	8.17	2	6	38	114	0	40	150	0	Yes	27%
ED100C05	CORR.	Patient Corridor	NR	300	8.00	0	2	0	80	0	0	100	0	Yes	0%
ED100C04	CORR.	Patient Corridor	NR	250	8.00	0	2	0	67	0	0	75	0	Yes	0%
ED115	TRTMNT-37	Treatment Room	NR	140	8.17	2	6	38	114	0	40	150	0	Yes	27%
ED118	TRTMNT-40	Treatment Room	NR	140	8.17	2	6	38	114	0	40	150	0	Yes	27%
ED117	TRTMNT-39	Treatment Room	NR	140	8.17	2	6	38	114	0	40	150	0	Yes	27%
ED116	GYN TRTMNT-38	Treatment Room	NR	160	8.00	2	6	43	128	0	50	175	0	Yes	29%
ED610	SOILED WORKROOM	Support Space Soiled Workroom	Negative	070	8.00	2	10	19	93	93	20	100	100	Yes	20%
ED500C05	CORR.	Patient Corridor	NR	640	8.00	0	2	0	171	0	0	175	0	Yes	0%
G600C03	CORR.	Patient Corridor	NR	200	8.00	0	2	0	53	0	0	75	0	Yes	0%
ED667	STAFF TOILET	Inpatient Toilet Room	Negative	050	8.00	0	10	0	67	67	0	75	75	Yes	0%
G600C04	CORR.	Patient Corridor	NR	080	8.00	0	2	0	21	0	0	25	0	Yes	0%
ED506	PATIENT DRESS	Patient Room	NR	060	8.00	2	4	16	32	0	20	75	0	Yes	27%
ED505	PATIENT DRESS	Patient Room	NR	060	8.00	2	4	16	32	0	20	75	0	Yes	27%
ED501	WAITING	ER waiting room	Negative	160	8.00	2	12	43	256	256	50	275	275	Yes	18%
ED503	P TLT	Inpatient Toilet Room	Negative	050	8.00	0	10	0	67	67	0	75	75	Yes	0%
ED504	PATIENT DRESS	Patient Room	NR	060	8.00	2	4	16	32	0	20	75	0	Yes	27%
ED500C02	CORR.	Patient Corridor	NR	100	8.00	0	2	0	27	0	0	50	0	Yes	0%
ED234	GYN TRTMNT-19	Treatment Room	NR	200	8.00	2	6	53	160	0	60	200	0	Yes	30%
ED200C06	CORRIDOR	Patient Corridor	NR	500	8.00	0	2	0	133	0	0	150	0	Yes	0%
ED235	PAT TOILET	Inpatient Toilet Room	Negative	075	8.00	0	10	0	100	100	0	100	100	Yes	0%
ED236	TRTMNT-20	Treatment Room	NR	150	8.17	2	6	41	122	0	50	175	0	Yes	29%
ED237	TRTMNT-21	Treatment Room	NR	140	8.17	2	6	38	114	0	40	150	0	Yes	27%
ED238	ISOLATION TRTMNT-22	AII room	Negative	160	12.00	2	10	64	320	320	70	325	325	Yes	22%
ED239	P TLT	Inpatient Toilet Room	Negative	050	8.00	0	10	0	67	67	0	75	75	Yes	0%
ED224	MED PREP	Medication room	Positive	210	8.00	2	4	56	112	0	60	225	0	Yes	27%

Ventilation Report

					ASHRAE 170 Design Parameters						Actual Design Airflow Rates				
Room Number	Room Name	Function of Space (defined by ASHRAE 170)	Pressure Relationship to Adjacent Spaces	Area (SF)	Ceiling Height	Minimum Outdoor ACH	Minimum Total ACH	Minimum OA Supply Airflow (CFM)	Minimum Total Supply Airflow (CFM)	Required Exhausted Air (CFM)	Outdoor Airflow (CFM)	Supply Airflow (CFM)	Exhausted Air (CFM)	ASHRAE 170 Design Parameters met?	Outdoor Air Percentage
ED220	TRTMNT-13	Treatment Room	NR	130	8.17	2	6	35	106	0	40	150	0	Yes	27%
ED219	TRTMNT-12	Treatment Room	NR	130	8.17	2	6	35	106	0	40	150	0	Yes	27%
ED218	TRTMNT-11	Treatment Room	NR	130	8.17	2	6	35	106	0	40	150	0	Yes	27%
ED217	TRTMNT-10	Treatment Room	NR	130	8.17	2	6	35	106	0	40	150	0	Yes	27%
ED401	SOILED WORKROOM	Soiled workroom or soiled holding	Negative	130	8.00	2	10	35	173	173	40	175	175	Yes	23%
ED402	CLEAN SUPPLY	Clean workroom	Positive	450	8.00	2	4	120	240	0	120	450	0	Yes	27%
ED216	TRTMNT-9	Treatment Room	NR	150	8.17	2	6	41	122	0	50	175	0	Yes	29%
ED215	TRTMNT-8	Treatment Room	NR	150	8.17	2	6	41	122	0	50	175	0	Yes	29%
ED214	TRTMNT-7	Treatment Room	NR	150	8.17	2	6	41	122	0	50	175	0	Yes	29%
ED213	TRTMNT-6	Treatment Room	NR	150	8.17	2	6	41	122	0	50	175	0	Yes	29%
ED212	TRTMNT-5	Treatment Room	NR	150	8.17	2	6	41	122	0	50	175	0	Yes	29%
ED507	X-RAY	X-ray (diagnostic and treatment)	NR	350	9.00	2	6	105	315	0	110	700	0	Yes	16%
ED508	X-RAY	X-ray (diagnostic and treatment)	NR	350	9.00	2	6	105	315	0	110	750	0	Yes	15%
ED211	BARIATRIC TRTMNT-4	Treatment Room	NR	250	8.17	2	6	68	204	0	70	275	0	Yes	25%
ED241	SOILED WORKROOM	Soiled workroom or soiled holding	Negative	150	8.00	2	10	40	200	200	40	200	200	Yes	20%
ED242	TRTMNT-23	Treatment Room	NR	200	8.17	2	6	54	163	0	60	225	0	Yes	27%
ED301	PSYCH TRTMNT-24	Treatment Room	NR	160	9.00	2	6	48	144	0	50	200	0	Yes	25%
ED302	PSYCH TRTMNT-25	Treatment Room	NR	150	9.00	2	6	45	135	0	50	175	0	Yes	29%
ED303	PSYCH TRTMNT-26	Treatment Room	NR	150	9.00	2	6	45	135	0	50	175	0	Yes	29%
ED304	P TLT	Inpatient Toilet Room	Negative	050	8.00	0	10	0	67	67	0	75	75	Yes	0%
ED300C01	CORR.	Patient Corridor	NR	400	8.00	0	2	0	107	0	0	125	0	Yes	0%
ED305	PSYCH TRTMNT-27	Treatment Room	NR	150	9.00	2	6	45	135	0	50	175	0	Yes	29%
ED306	PSYCH TRTMNT-28	Treatment Room	NR	150	9.00	2	6	45	135	0	50	175	0	Yes	29%
ED300C03	CORR.	Patient Corridor	NR	300	8.00	0	2	0	80	0	0	100	0	Yes	0%
ED307	P TLT	Inpatient Toilet Room	Negative	070	8.00	0	10	0	93	93	0	100	100	Yes	0%
ED300C02	CORR.	Patient Corridor	NR	315	8.00	0	2	0	84	0	0	100	0	Yes	0%
ED313	MED PREP	Medication room	Positive	140	8.00	2	4	37	75	0	40	150	0	Yes	27%
ED309	SOILED WORKROOM	Soiled workroom or soiled holding	Negative	060	8.00	2	10	16	80	80	20	100	100	Yes	20%
ED310	PSYCH TRTMNT-30	Medication room	Positive	160	9.00	2	6	48	144	0	50	200	0	Yes	25%
ED311	PSYCH TRTMNT-29	Medication room	Positive	120	9.00	2	6	36	108	0	40	150	0	Yes	27%
ED245	TRTMNT-31	Treatment Room	NR	200	8.17	2	6	54	163	0	60	225	0	Yes	27%
ED246	TRTMNT-32	Treatment Room	NR	200	8.17	2	6	54	163	0	60	225	0	Yes	27%
ED200C04	LINEN STORAGE	Clean linen storage	Positive	200	8.00	0	2	0	53	0	0	75	0	Yes	0%
ED202A	TRAUMA 1 RESUSC. A	Trauma room	Positive	375	9.00	3	15	169	844	0	170	850	0	Yes	20%
ED202B	TRAUMA 1 RESUSC. B	Trauma room	Positive	375	9.00	3	15	169	844	0	170	850	0	Yes	20%
ED203	TRTMNT-1	Treatment Room	NR	175	8.17	2	6	48	143	0	50	200	0	Yes	25%
ED204	TRTMNT-2	Treatment Room	NR	175	8.17	2	6	48	143	0	50	200	0	Yes	25%
ED205	DECONTAM ROOM	ER decontamination	Negative	300	8.00	2	12	80	480	480	80	500	500	Yes	16%
ED209	P TLT	Inpatient Toilet Room	Negative	060	8.00	0	10	0	80	80	0	100	100	Yes	0%
ED206	P TLT	Inpatient Toilet Room	Negative	060	8.00	0	10	0	80	80	0	100	100	Yes	0%
ED210	TRTMNT-3	Treatment Room	NR	200	8.17	2	6	54	163	0	60	225	0	Yes	27%

Appendix C: VRF Zone Calculations

Zone 1				
	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
Room	Required	Unit Capacity	Required	Unit Capacity
MRI PHASE 1 ZONE 1	13120	13500	10000	10074
MRI PHASE 1 ZONE 2	13120	13500	10000	10074
MRI PHASE 1 ZONE 3	13120	13500	10000	10074
MRI PHASE 1 ZONE 4	13120	13500	10000	10074
MRI PHASE 1 ZONE 5	13120	13500	10000	10074
CT	1520	8500	6200	6282
Total	67120	76000	56200	56652
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	67120	77543	56200	109833

Zone 2				
	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
Room	Required	Unit Capacity	Required	Unit Capacity
X-RAY	11300	13500	10000	10074
X-RAY	11300	13500	10000	10074
PATIENT DRESS	1200	8500	3600	6282
PATIENT DRESS	1200	8500	3600	6282
PATIENT DRESS	1800	8500	4300	6282
TRTMNT-23	7800	8500	6200	6282
TRTMNT-31	11000	13500	6200	6282
OBS-15	7600	8500	6250	6282
Total	53200	83000	50150	57840
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	53200	77543	50150	109833

Zone 3				
	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
Room	Required	Unit Capacity	Required	Unit Capacity
OBS-15	7600	8500	6250	6282
OBS-16	7600	8500	6250	6282
OBS-17	7600	8500	6250	6282
OBS-18	7600	8500	6250	6282
CONFERENCE	6500	8500	9800	10074
ADMIN OFFICE	2400	8500	3700	6282
NURSE EDUC.	2400	8500	3700	6282
NURSE MGR.	2400	8500	3700	6282
ADMIN ASSIST	4300	8500	6400	10074
ADMIN DIR.	2600	8500	3900	6282
MEDICAL DIR.	2600	8500	3900	6282
MD WORK AND LOCKERS	3900	8500	6100	6282
Total	57500	102000	66200	82968
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	57500	77543	66200	109833

Zone 4				
	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
Room	Required	Unit Capacity	Required	Unit Capacity
STAFF LOUNGE	8700	13500	10000	10074
STAFF LOCKERS	11900	13500	10000	10074
TRTMNT-5	7700	8500	6200	6282
BARIATRIC TRTMNT-4	9800	13500	6200	6282
TRTMNT-32	7800	8500	6200	6282
TRTMNT-11	7800	8500	6200	6282
TRTMNT-10	7800	8500	6200	6282
TRTMNT-9	7900	8500	6200	6282
TRTMNT-8	7700	8500	6200	6282
TRTMNT-7	7700	8500	6200	6282
TRTMNT-6	7900	8500	6200	6282
TRTMNT-3	7700	8500	6200	6282
Total	100400	117000	82000	82968
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	100400	77543	82000	109833

Zone 5				
Room	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
	Required	Unit Capacity	Required	Unit Capacity
REG OFFICE	5100	8500	8400	10074
OBS-11	7599	8500	6250	6282
OBS-12	7600	8500	6250	6282
OBS-13	7600	8500	6250	6282
OBS-14	7600	8500	6250	6282
NURSE STATION	2800	8500	4300	6282
FINANCIAL COUNSELOR	2700	8500	6400	10074
CHA OFFICE	5100	8500	8400	10074
BEREAVEMENT	5700	8500	8500	10074
Total	51799	76500	61000	71706
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	51799	**77543**	**61000**	**109833**

Zone 6				
Room	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
	Required	Unit Capacity	Required	Unit Capacity
RECEPTION	2700	8500	6400	10074
FINANCIAL COUNSELOR	2700	8500	6400	10074
LOBBY ZONE 1	7200	8500	6200	6282
LOBBY ZONE 2	7200	8500	6200	6282
OFFICE	5100	8500	8400	10074
NURSE STATION	2800	8500	4300	6282
EMS	9200	13500	10000	10074
EMS/STORAGE	1000	8500	4400	6282
Total	37900	73000	52300	65424
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	37900	**77543**	**52300**	**109833**

Zone 7				
Room	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
	Required	Unit Capacity	Required	Unit Capacity
TRTMNT-33	7800	8500	6200	6282
TRTMNT-34	7800	8500	6200	6282
TRTMNT-35	7800	8500	6200	6282
TRTMNT-36	7800	8500	6200	6282
CHARTING	1400	8500	4000	6282
TRTMNT-37	7800	8500	6200	6282
TRTMNT-40	7800	8500	6200	6282
TRTMNT-39	7800	8500	6200	6282
TRTMNT-20	7800	8500	6200	6282
GYN TRTMNT-38	7800	8500	6200	6282
TRTMNT-21	7800	8500	6200	6282
TRTMNT-13	7800	8500	6200	6282
GYN TRTMNT-19	7800	8500	6200	6282
Total	95000	110500	78400	81666
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	95000	77543	78400	109833

Zone 8				
Room	Indoor VRF Units			
	Heat Load (Btu/h)		Cool Load (Btu/h)	
	Required	Unit Capacity	Required	Unit Capacity
PSYCH TRTMNT-24	10200	13500	6200	6282
PSYCH TRTMNT-25	10200	13500	6200	6282
PSYCH TRTMNT-26	10200	13500	6200	6282
PSYCH TRTMNT-27	10200	13500	6200	6282
PSYCH TRTMNT-28	10200	13500	6200	6282
PSYCH TRTMNT-30	10700	13500	6200	6282
PSYCH TRTMNT-29	11000	13500	6200	6282
TRTMNT-12	7800	8500	6200	6282
TRTMNT-1	7700	8500	6200	6282
TRTMNT-2	7700	8500	6200	6282
Total	95900	120000	62000	62820
	Outdoor Heat Recovery Unit			
	Heat Load (Btu/hr)		Cool Load (Btu/hr)	
	Required	Unit Capacity	Required	Unit Capacity
	95900	77543	62000	109833

Appendix C: Cost Breakdown Calculations

Base

First Cost - RS Means Mechanical Cost Data 2015

			2015 Bare Costs				
	Description	Size	Material	Labor	Total	Total inc. O&P	**TOTAL**
AHU-1	Central AHU Var. Vol	10000	$ 66,000.00	$ 2,675.00	$ 68,675.00	$ 77,000.00	$ 77,000.00
AHU-2	Central AHU Var. Vol	30000	$ 154,500.00	$ 6,700.00	$ 161,200.00	$ 180,000.00	$ 180,000.00
(58) Terminal Boxes	packaged cabinet type	42000 btuh cool, 10kW heat	$ 2,750.00	$ 860.00	$ 3,610.00	$ 4,325.00	$ 250,850.00
	HW reheat inc		5%	10%			
	HW reheat inc		$ 137.50	$ 86.00		$ 223.50	$ 12,963.00
Chiller	Pricing Documents						$ 95,000.00
							$ 615,813.00

Maintenance Cost - RS Means Facilities Maintenance & Repairs 2015

			2015 Bare Costs				
	Description	Size	Frequency (year)	Labor hours	Total	Total inc. O&P	**Total/year**
Chiller	Centrifugal Repair	100 TON	10	179.02	$ 38,317.50	$ 45,109.00	$ 4,510.90
AHU-1	Central AHU repair	8000 CFM	10	4.211	$ 849.45	$ 1,137.00	$ 113.70
AHU-2	Central AHU repair	33500 CFM	10	8.096	$ 3,368.95	$ 4,348.00	$ 434.80
							$ 5,059.40

d= 0.03
N= 25
Electric first year cost $ 178,096.00
Gas first year cost $ 37,160.00

Annual Utility Bill - eQuest Output

First Year Utility Bill	Life (years)
$ 215,256.00	25

Net Present Value Calculation

Year	Y1 Elec Cost	MA Elec Escalation	Yearly Elec Cost	Y1 Gas Cost	MA Gas Escalation	Yearly Gas Cost	Maintenance	Total Yearly Cost
2015	$ 178,096.00	1.00	$ 178,096.00	$ 37,160.00	1.03	$ 38,274.80	$ 5,059.40	$ 221,430.20
2016	$ 178,096.00	1.01	$ 179,876.96	$ 37,160.00	1.04	$ 38,646.40	$ 5,059.40	$ 223,582.76
2017	$ 178,096.00	1.02	$ 181,657.92	$ 37,160.00	1.06	$ 39,389.60	$ 5,059.40	$ 226,106.92
2018	$ 178,096.00	1.02	$ 181,657.92	$ 37,160.00	1.07	$ 39,761.20	$ 5,059.40	$ 226,478.52
2019	$ 178,096.00	1.04	$ 185,219.84	$ 37,160.00	1.08	$ 40,132.80	$ 5,059.40	$ 230,412.04
2020	$ 178,096.00	1.05	$ 187,000.80	$ 37,160.00	1.09	$ 40,504.40	$ 5,059.40	$ 232,564.60
2021	$ 178,096.00	1.04	$ 185,219.84	$ 37,160.00	1.11	$ 41,247.60	$ 5,059.40	$ 231,526.84
2022	$ 178,096.00	1.04	$ 185,219.84	$ 37,160.00	1.13	$ 41,990.80	$ 5,059.40	$ 232,270.04
2023	$ 178,096.00	1.03	$ 183,438.88	$ 37,160.00	1.13	$ 41,990.80	$ 5,059.40	$ 230,489.08
2024	$ 178,096.00	1.02	$ 181,657.92	$ 37,160.00	1.17	$ 43,477.20	$ 5,059.40	$ 230,194.52
2025	$ 178,096.00	1.03	$ 183,438.88	$ 37,160.00	1.19	$ 44,220.40	$ 5,059.40	$ 232,718.68
2026	$ 178,096.00	1.03	$ 183,438.88	$ 37,160.00	1.2	$ 44,592.00	$ 5,059.40	$ 233,090.28
2027	$ 178,096.00	1.03	$ 183,438.88	$ 37,160.00	1.25	$ 46,450.00	$ 5,059.40	$ 234,948.28
2028	$ 178,096.00	1.04	$ 185,219.84	$ 37,160.00	1.28	$ 47,564.80	$ 5,059.40	$ 237,844.04
2029	$ 178,096.00	1.04	$ 185,219.84	$ 37,160.00	1.3	$ 48,308.00	$ 5,059.40	$ 238,587.24
2030	$ 178,096.00	1.05	$ 187,000.80	$ 37,160.00	1.33	$ 49,422.80	$ 5,059.40	$ 241,483.00
2031	$ 178,096.00	1.05	$ 187,000.80	$ 37,160.00	1.35	$ 50,166.00	$ 5,059.40	$ 242,226.20
2032	$ 178,096.00	1.06	$ 188,781.76	$ 37,160.00	1.37	$ 50,909.20	$ 5,059.40	$ 244,750.36
2033	$ 178,096.00	1.07	$ 190,562.72	$ 37,160.00	1.39	$ 51,652.40	$ 5,059.40	$ 247,274.52
2034	$ 178,096.00	1.07	$ 190,562.72	$ 37,160.00	1.41	$ 52,395.60	$ 5,059.40	$ 248,017.72
2035	$ 178,096.00	1.07	$ 190,562.72	$ 37,160.00	1.43	$ 53,138.80	$ 5,059.40	$ 248,760.92
2036	$ 178,096.00	1.08	$ 192,343.68	$ 37,160.00	1.45	$ 53,882.00	$ 5,059.40	$ 251,285.08
2037	$ 178,096.00	1.09	$ 194,124.64	$ 37,160.00	1.48	$ 54,996.80	$ 5,059.40	$ 254,180.84
2038	$ 178,096.00	1.10	$ 195,905.60	$ 37,160.00	1.5	$ 55,740.00	$ 5,059.40	$ 256,705.00
2039	$ 178,096.00	1.10	$ 195,905.60	$ 37,160.00	1.52	$ 56,483.20	$ 5,059.40	$ 257,448.20
NPV			**$3,232,358.19**			**$790,496.82**	**$88,100.08**	**$4,110,955.09**

TOTAL **$ 4,726,768.09**

Alternative 1

First Cost - RS Means Mechanical Cost Data 2015

			2015 Bare Costs				
	Description	Size	Material	Labor	Total	Total inc. O&P	**TOTAL**
CT	Blow thru Cent type	200 ton	$ 27,900.00	$ 2,225.00	$ 30,125.00	$ 34,100.00	$ 34,100.00
Chiller	Centrifugal WCCH	200 Ton	$ 90,000.00	$ 9,800.00	$ 99,800.00	$ 114,000.00	$ 114,000.00
AHU-1	Central AHU Var. Vol	5000 CFM	$ 30,800.00	$ 1,825.00	$ 32,625.00	$ 36,600.00	$ 36,600.00
AHU-2	Central AHU Var. Vol	30000 CFM	$ 154,500.00	$ 6,700.00	$ 161,200.00	$ 180,000.00	$ 180,000.00
Energy Recovery 1	glycol	4000 CFM	$ 8,725.00	$ 1,200.00	$ 9,925.00	$ 11,400.00	$ 11,400.00
Energy Recovery 2	enthalpy wheel	25000 CFM	$ 31,100.00	$ 1,800.00	$ 32,900.00	$ 36,900.00	$ 36,900.00
(58) Terminal Boxes	packaged cabinet type	42000 btuh cool, 1	$ 2,750.00	$ 860.00	$ 3,610.00	$ 4,325.00	$ 250,850.00
	HW reheat inc		5%	10%			
	HW reheat inc		$ 137.50	$ 86.00		$ 223.50	$ 12,963.00
							$ 676,813.00

Maintenance Cost - RS Means Facilities Maintenance & Repairs 2015

			2015 Bare Costs				
	Description	Size	Frequency (year)	Labor hours	Total	Total inc. O&P	**Total/year**
CT	Repair	100 ton	10	28.275	$ 4,129.88	$ 5,650.00	$ 565.00
Chiller	Centrifugal Repair	100 TON	10	179.02	$ 38,317.50	$ 45,109.00	$ 4,510.90
AHU-1	Central AHU repair	8000 cfm	10	4.211	$ 849.45	$ 1,137.00	$ 113.70
AHU-2	Central AHU repair	33500 CFM	10	8.096	$ 3,368.95	$ 4,348.00	$ 434.80
							$ 5,624.40

d=	0.03
N=	25
Electric first year cost	$ 157,769.00
Gas first year cost	$ 24,400.00

Annual Utility Bill - eQuest Output

Annual Utility Bill	Life (years)
$ 182,169.00	25

Net Present Value Calculation

Year	Y1 Elec Cost	MA Elec Escalation	Yearly Elec Cost	Y1 Gas Cost	MA Gas Escalation	Yearly Gas Cost	Maintenance	Total Yearly Cost
2015	$ 157,769.00	1.00	$ 157,769.00	$ 24,400.00	1.03	$ 25,132.00	$ 5,624.40	$ 188,525.40
2016	$ 157,769.00	1.01	$ 159,346.69	$ 24,400.00	1.04	$ 25,376.00	$ 5,624.40	$ 190,347.09
2017	$ 157,769.00	1.02	$ 160,924.38	$ 24,400.00	1.06	$ 25,864.00	$ 5,624.40	$ 192,412.78
2018	$ 157,769.00	1.02	$ 160,924.38	$ 24,400.00	1.07	$ 26,108.00	$ 5,624.40	$ 192,656.78
2019	$ 157,769.00	1.04	$ 164,079.76	$ 24,400.00	1.08	$ 26,352.00	$ 5,624.40	$ 196,056.16
2020	$ 157,769.00	1.05	$ 165,657.45	$ 24,400.00	1.09	$ 26,596.00	$ 5,624.40	$ 197,877.85
2021	$ 157,769.00	1.04	$ 164,079.76	$ 24,400.00	1.11	$ 27,084.00	$ 5,624.40	$ 196,788.16
2022	$ 157,769.00	1.04	$ 164,079.76	$ 24,400.00	1.13	$ 27,572.00	$ 5,624.40	$ 197,276.16
2023	$ 157,769.00	1.03	$ 162,502.07	$ 24,400.00	1.13	$ 27,572.00	$ 5,624.40	$ 195,698.47
2024	$ 157,769.00	1.02	$ 160,924.38	$ 24,400.00	1.17	$ 28,548.00	$ 5,624.40	$ 195,096.78
2025	$ 157,769.00	1.03	$ 162,502.07	$ 24,400.00	1.19	$ 29,036.00	$ 5,624.40	$ 197,162.47
2026	$ 157,769.00	1.03	$ 162,502.07	$ 24,400.00	1.2	$ 29,280.00	$ 5,624.40	$ 197,406.47
2027	$ 157,769.00	1.03	$ 162,502.07	$ 24,400.00	1.25	$ 30,500.00	$ 5,624.40	$ 198,626.47
2028	$ 157,769.00	1.04	$ 164,079.76	$ 24,400.00	1.28	$ 31,232.00	$ 5,624.40	$ 200,936.16
2029	$ 157,769.00	1.04	$ 164,079.76	$ 24,400.00	1.3	$ 31,720.00	$ 5,624.40	$ 201,424.16
2030	$ 157,769.00	1.05	$ 165,657.45	$ 24,400.00	1.33	$ 32,452.00	$ 5,624.40	$ 203,733.85
2031	$ 157,769.00	1.05	$ 165,657.45	$ 24,400.00	1.35	$ 32,940.00	$ 5,624.40	$ 204,221.85
2032	$ 157,769.00	1.06	$ 167,235.14	$ 24,400.00	1.37	$ 33,428.00	$ 5,624.40	$ 206,287.54
2033	$ 157,769.00	1.07	$ 168,812.83	$ 24,400.00	1.39	$ 33,916.00	$ 5,624.40	$ 208,353.23
2034	$ 157,769.00	1.07	$ 168,812.83	$ 24,400.00	1.41	$ 34,404.00	$ 5,624.40	$ 208,841.23
2035	$ 157,769.00	1.07	$ 168,812.83	$ 24,400.00	1.43	$ 34,892.00	$ 5,624.40	$ 209,329.23
2036	$ 157,769.00	1.08	$ 170,390.52	$ 24,400.00	1.45	$ 35,380.00	$ 5,624.40	$ 211,394.92
2037	$ 157,769.00	1.09	$ 171,968.21	$ 24,400.00	1.48	$ 36,112.00	$ 5,624.40	$ 213,704.61
2038	$ 157,769.00	1.10	$ 173,545.90	$ 24,400.00	1.5	$ 36,600.00	$ 5,624.40	$ 215,770.30
2039	$ 157,769.00	1.10	$ 173,545.90	$ 24,400.00	1.52	$ 37,088.00	$ 5,624.40	$ 216,258.30
NPV			**$2,863,432.75**			**$519,056.04**	**$97,938.51**	**$3,480,427.30**

TOTAL **$ 4,157,240.30**

Alternative 2

First Cost - RS Means Mechanical Cost Data 2015

			2015 Bare Costs				
	Description	Size	Material	Labor	Total	Total inc. O&P	**TOTAL**
CT	Blow thru Cent type	100 ton	$ 18,300.00	$ 1,100.00	$ 19,400.00	$ 21,800.00	$ 21,800.00
Chiller	Reciprocating WCCH	80 Tons	$ 56,000.00	$ 7,000.00	$ 63,000.00	$ 72,000.00	$ 72,000.00
DOAS 1	DOAU multi zone, cool/heat, var vol	50 Ton	$ 11,300.00	$ 9,325.00	$ 122,325.00	$ 138,000.00	$ 138,000.00
DOAS 2	DOAU multi zone, cool/heat, var vol	50 Ton	$ 11,300.00	$ 9,325.00	$ 122,325.00	$ 138,000.00	$ 138,000.00
Energy Recovery 1	enthalpy wheel	20000 CFM	$ 25,400.00	$ 1,575.00	$ 26,975.00	$ 30,400.00	$ 30,400.00
Energy Recovery 2	glycol	4000 CFM	$ 8,725.00	$ 1,200.00	$ 9,925.00	$ 11,400.00	$ 11,400.00
(8) Refrigerant Condensers	VRF mulit zone split outdoor unit, 33 zones	15 ton	$ 38,600.00	$ 860.00	$ 39,460.00	$ 43,700.00	$ 349,600.00
(80) VRF Units	FCU ceiling concealed w/ OA connection	1 ton	$ 1,775.00	$ 330.00	$ 2,105.00	$ 2,450.00	$ 196,000.00
							$ 957,200.00

Maintenance Cost - RS Means Facilities Maintenance & Repairs 2015

			2015 Bare Costs				
	Description	Size	Frequency (year)	Labor hours	Total	Total inc. O&P	**Total/year**
CT	Repair	50 ton	10	8.167	$ 1,110.85	$ 1,533.00	$ 153.30
Chiller	Reciprocating WCCH Repair	50 ton	10	114.016	$ 38,183.75	$ 49,718.00	$ 4,971.80
DOAS 1	Central AHU repair	8000 cfm	10	4.211	$ 849.45	$ 1,137.00	$ 113.70
DOAS 2	Central AHU repair	16000 CFM	10	4.698	$ 1,257.95	$ 1,646.00	$ 164.60
(8) Refrigerant Condensers	Air Cooled repair	5 tons	10	4.611	$ 636.50	$ 759.50	$ 75.95
							$ 5,479.35

d=		0.03
N=		25
Electric first year cost	$	129,499.00
Gas first year cost	$	17,343.00

Annual Utility Bill - eQuest Output

Annual Utility Bill	Life (years)	
$ 146,842.00	25	**$ 3,671,050.00**

Net Present Value Calculation

Year	Y1 Elec Cost	MA Elec Escalatio	Yearly Elec Cost	Y1 Gas Cost	MA Gas Escalation	Yearly Gas Cost	Maintenance	Total Yearly Cost
2015	$ 129,499.00	1.00	$ 129,499.00	$ 17,343.00	1.03	$ 17,863.29	$ 5,479.35	$ 152,841.64
2016	$ 129,499.00	1.01	$ 130,793.99	$ 17,343.00	1.04	$ 18,036.72	$ 5,479.35	$ 154,310.06
2017	$ 129,499.00	1.02	$ 132,088.98	$ 17,343.00	1.06	$ 18,383.58	$ 5,479.35	$ 155,951.91
2018	$ 129,499.00	1.02	$ 132,088.98	$ 17,343.00	1.07	$ 18,557.01	$ 5,479.35	$ 156,125.34
2019	$ 129,499.00	1.04	$ 134,678.96	$ 17,343.00	1.08	$ 18,730.44	$ 5,479.35	$ 158,888.75
2020	$ 129,499.00	1.05	$ 135,973.95	$ 17,343.00	1.09	$ 18,903.87	$ 5,479.35	$ 160,357.17
2021	$ 129,499.00	1.04	$ 134,678.96	$ 17,343.00	1.11	$ 19,250.73	$ 5,479.35	$ 159,409.04
2022	$ 129,499.00	1.04	$ 134,678.96	$ 17,343.00	1.13	$ 19,597.59	$ 5,479.35	$ 159,755.90
2023	$ 129,499.00	1.03	$ 133,383.97	$ 17,343.00	1.13	$ 19,597.59	$ 5,479.35	$ 158,460.91
2024	$ 129,499.00	1.02	$ 132,088.98	$ 17,343.00	1.17	$ 20,291.31	$ 5,479.35	$ 157,859.64
2025	$ 129,499.00	1.03	$ 133,383.97	$ 17,343.00	1.19	$ 20,638.17	$ 5,479.35	$ 159,501.49
2026	$ 129,499.00	1.03	$ 133,383.97	$ 17,343.00	1.2	$ 20,811.60	$ 5,479.35	$ 159,674.92
2027	$ 129,499.00	1.03	$ 133,383.97	$ 17,343.00	1.25	$ 21,678.75	$ 5,479.35	$ 160,542.07
2028	$ 129,499.00	1.04	$ 134,678.96	$ 17,343.00	1.28	$ 22,199.04	$ 5,479.35	$ 162,357.35
2029	$ 129,499.00	1.04	$ 134,678.96	$ 17,343.00	1.3	$ 22,545.90	$ 5,479.35	$ 162,704.21
2030	$ 129,499.00	1.05	$ 135,973.95	$ 17,343.00	1.33	$ 23,066.19	$ 5,479.35	$ 164,519.49
2031	$ 129,499.00	1.05	$ 135,973.95	$ 17,343.00	1.35	$ 23,413.05	$ 5,479.35	$ 164,866.35
2032	$ 129,499.00	1.06	$ 137,268.94	$ 17,343.00	1.37	$ 23,759.91	$ 5,479.35	$ 166,508.20
2033	$ 129,499.00	1.07	$ 138,563.93	$ 17,343.00	1.39	$ 24,106.77	$ 5,479.35	$ 168,150.05
2034	$ 129,499.00	1.07	$ 138,563.93	$ 17,343.00	1.41	$ 24,453.63	$ 5,479.35	$ 168,496.91
2035	$ 129,499.00	1.07	$ 138,563.93	$ 17,343.00	1.43	$ 24,800.49	$ 5,479.35	$ 168,843.77
2036	$ 129,499.00	1.08	$ 139,858.92	$ 17,343.00	1.45	$ 25,147.35	$ 5,479.35	$ 170,485.62
2037	$ 129,499.00	1.09	$ 141,153.91	$ 17,343.00	1.48	$ 25,667.64	$ 5,479.35	$ 172,300.90
2038	$ 129,499.00	1.10	$ 142,448.90	$ 17,343.00	1.5	$ 26,014.50	$ 5,479.35	$ 173,942.75
2039	$ 129,499.00	1.10	$ 142,448.90	$ 17,343.00	1.52	$ 26,361.36	$ 5,479.35	$ 174,289.61
NPV			**$2,350,345.62**			**$368,933.97**	**$95,412.73**	**$2,814,692.32**
						TOTAL	**$ 3,771,892.32**	

Appendix D: Electrical Breadth Solar Panel Data Sheet

MAXIMA GxB 340W Bifacial Module

A Trusted Quality Brand in Solar

High Performance

Bifacial technology generates power from both the front and back faces of the module, resulting in up to 20% higher energy harvest (kWh). N-type cells packaged in frameless double glass modules yield higher power and do not suffer from light-induced degradation (LID) or potential induced degradation (PID).

Quality & Reliability

Double glass modules designed for durability. Certified to international certification body standards: IEC, UL, and CEC listed. Manufactured according to the International Quality Management System ISO9001.

Extreme Climate Performance

As temperatures rise, our patented SmartSilicon hybrid cell technology produces more power [kW] than conventional crystalline silicon solar panels at the same elevated temperature.

Guaranteed Performance

All modules have a 10 year product warranty and 25 year power output warranty.

Superior Aesthetics

Thin profile double-glass construction provides superior aesthetics that are a perfect complement to roofs, carports, and canopies.

About Sunpreme

Sunpreme is an innovative solar PV module manufacturer headquartered in Sunnyvale, California with manufacturing facilities in the United States and China. We provide high quality, reliable and aesthetically superior modules to residential, commercial, and utility customers globally. Sunpreme solar systems are delivering clean energy in 9 different countries.

Sunpreme solar panels are designed and engineered in Silicon Valley, CA, USA.

SmartSilicon Technology

Sunpreme modules use our patented SmartSilicon technology that combines a crystalline silicon substrate with innovative thin-film materials to achieve high-efficiency power output and reliable energy production for increased project returns.

Unlike conventional silicon or thin-film technologies, Sunpreme uses highly-scalable process to deliver high efficiency solar power at very competitive Levelized Cost of Energy (LCOE).

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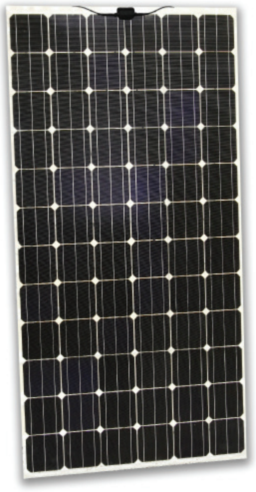
Front view



Back view

High Efficiency

18% Module Efficiency (Mono-facial),
20% Efficiency with 10% Backside Power Boost, and over 21% with 20% Backside Power Boost

Bifacial Energy Boost

Harvests sun from the backside to increase power output up to 20%

Dual-Glass Frameless Design

Sunpreme Design is more robust, and does not require module grounding

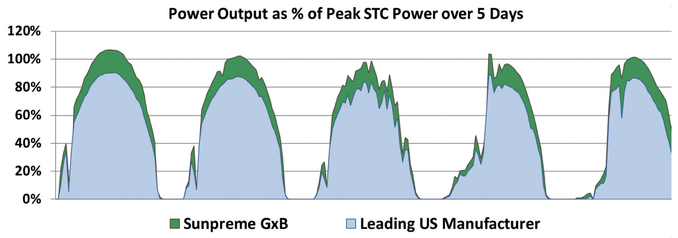
10 YEAR

PRODUCT WARRANTY

25 YEAR

POWER WARRANTY

In head-to-head testing with a leading US manufacturer, Sunpreme's Maxima GxB panel outperforms the competition with over 20% higher power output, exceeding the STC Power rating under real world conditions



Maxima GxB 340W Bifacial Solar Module

High Performance 72-cell N-type Solar Module

ELECTRICAL SPECIFICATIONS[1]	330	340	350
STC rated output P_{MPP} (W)	330	340	350
Cell Efficiency	20%	20.5%	21%
Standard sorted output	-3%/+5%	-3%/+5%	-3%/+5%
Open Circuit Voltage V_{OC} (V)	51.1	51.4	51.6
Short circuit current I_{SC} (A)	9.1	9.3	9.4
Rated Voltage V_{MPP} (V)	39.7	40.0	40.3
Rated Current I_{MPP} (A)	8.3	8.5	8.7

[1] Standard Test Conditions for front-face of panel: 1000 W/m², 25°C.

MECHANICAL SPECIFICATIONS	
Dimensions	1,946 x 976 x 6 mm (6.4 x 3.2 x 0.02 ft)
Weight	27 kg
Area	1.90m² (20.34 ft²)
Cell type	Bifacial Mono N-type with proprietary SmartSilicon Hybrid Cell Technology (HCT)
Module type	72 Cells, Frameless double glass design with tempered glass, no grounding required
Glass	Tempered 2.9mm anti-reflective coating, low-iron
Junction Box	Tyco IP-67 rated; 1,000V UL/IEC, 3 diodes
Cables	4mm² x 0.9 m cable: MC4 or MC4 compatible Tyco connectors

TEST OPERATING CONDITIONS	
Operating Temperature	- 40 to + 85°C
Storage Temperature	- 40 to + 85°C
Maximum Series Fuse	15 A
Maximum System Voltage	1,000VDC (UL & IEC)
Power/Sq.Ft. w/ 20% backside power boost	20.1 W / Sq. Foot
Maximum load capacity	5,400 Pa (snow load) 185 mph wind rating
Fire Class	Class C

BI-FACIAL OUTPUT	330	340	350
With 10% Backside Power Boost			
Power Output (W)	363	374	385
Module Efficiency	19.1%	19.7%	20.3%
With 20% Backside Power Boost			
Power Output (W)	396	408	420
Module Efficiency	20.8%	21.5%	22.1%

WARRANTY AND STANDARDS

10 year extended product warranty

95% power warranty first 5 years

-0.6% per year degradation for the following 20 years

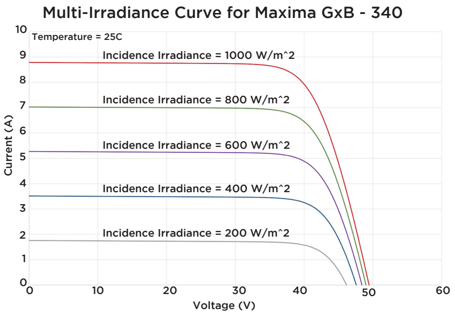
Certified to UL 1703, IEC 61646, IEC 61730-01, IEC 61730-02, IEC 61701 standards, CEC & FSEC listed, and CE mark.

TEMPERATURE COEFFICIENTS	
Temperature coefficient P_{MPP}	-0.31%/C
Temperature coefficient I_{SC}	+0.06%/C
Temperature coefficient V_{OC}	-0.27%/C
Normal operating cell temperature (NOCT)°C	46C +/- 2

PACKAGING	
Modules per pallet	26 modules
Pallets per shipping container	22 crates

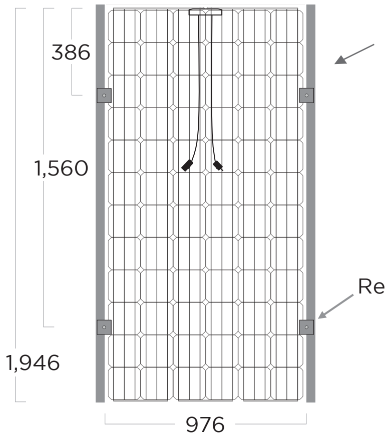
CERTIFICATIONS

Current - Voltage (IV) Curve



Covered by one or more of the following U.S. patents: 7,951,640; 7,956,283; 7,960,644

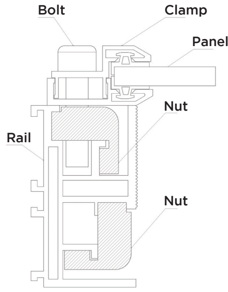
Rear View (mm)



Mounting method

- Rail structure runs parallel to long-side of module
- Compatible with bifacial module (minimizes back-side shading)
- Uniform mounting method for ground, roof, or carport installations

Side View (mm)



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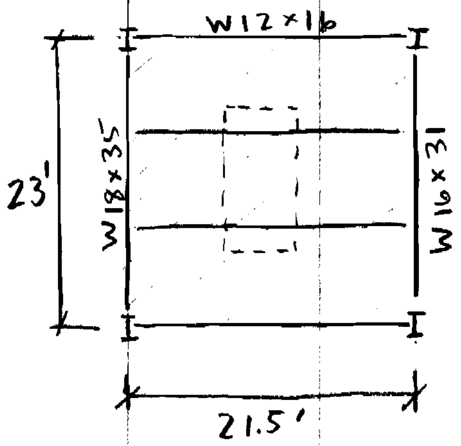
Appendix D: Structural Breadth Hand Calculations

Project: Morton Expansion
Job No:
Subject: Structural Breadth
Page: 1
Date: 3/26/15
By: Millett

CURRENT ROOF DECK:

3" D.P. × 18 GA Type Galvanized Metal Roof Deck



New cooling Tower: 7573 lb
12.8' × 6.5' × 10.2'

$K_{LL}A_T = 21.5' \times 23' = 494.5\#$

Mech Superimposed DL = $\boxed{15.3\text{ psf}}$

Vulcraft: 3N18 → DL = $\boxed{3.56\text{ psf}}$

$W_{TL} = \boxed{85.06\text{ psf}}$

Snow: $\boxed{46.2\text{ psf}}$ (MA)

Roof Live Load: $\boxed{20\text{ psf}}$

Check Conditions:

① Max SDI Span = 18'-1"
23'/3 spans = 7'-7" < 18'-1" ✓

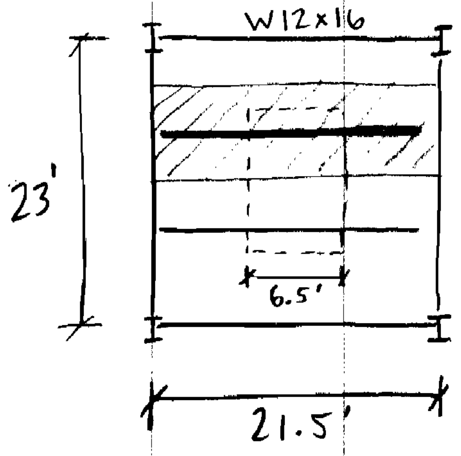
② Allowable Total PSF = 122 psf
93.86 psf < 122 psf ✓

③ Load causing Deflection of $L/240 = 165 \times \frac{240}{180} = 220\text{ psf}$ (load causing L/180)
85.06 psf < 220 ✓

The current deck supports the addition of the selected Cooling Tower.

Project: Morton Expansion
Subject: Structural Breadth
Date: 3/26/15
Job No:
Page: 2
By: Millett

Current Bay:



CT = 7573 lbs

12.8' x 6.5' x 10.2'

to each joist: 3786.5 lb

$W_u = \frac{3786.5 \text{ lb}}{6.5'} = 582.5 \text{ plf}$

$DL_{(w/o\ CT)} = \underbrace{3.56 \text{ psf}}_{\text{roof deck}} + \underbrace{5 \text{ psf}}_{\text{beam allowance}} = 8.56 \text{ psf}$

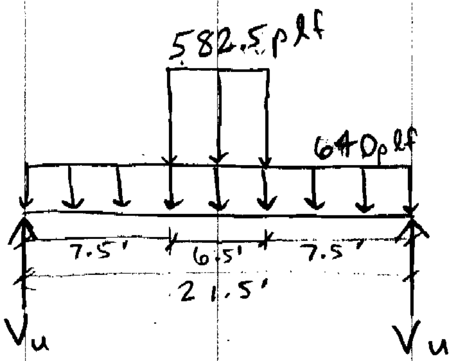
$LL = \underbrace{46.2 \text{ psf}}_{\text{snow}}$

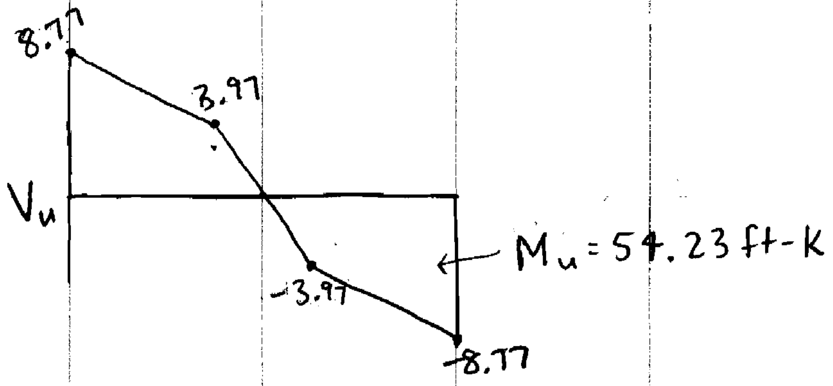
$W_u = 1.2D + 1.6L = 84.2 \text{ psf}$

$w_u = 84.2 \times 7.6 \text{ span} = 639.9 \text{ plf}$

$V_u = \frac{1}{2}\left[640 \times 21.5 + 582.5 \times 6.5\right]$

$= 8.77 \text{ kip}$





Using Z_x tables:

W12x16 $\phi_b M_{px} = 75.4 \text{ ft-kip}$

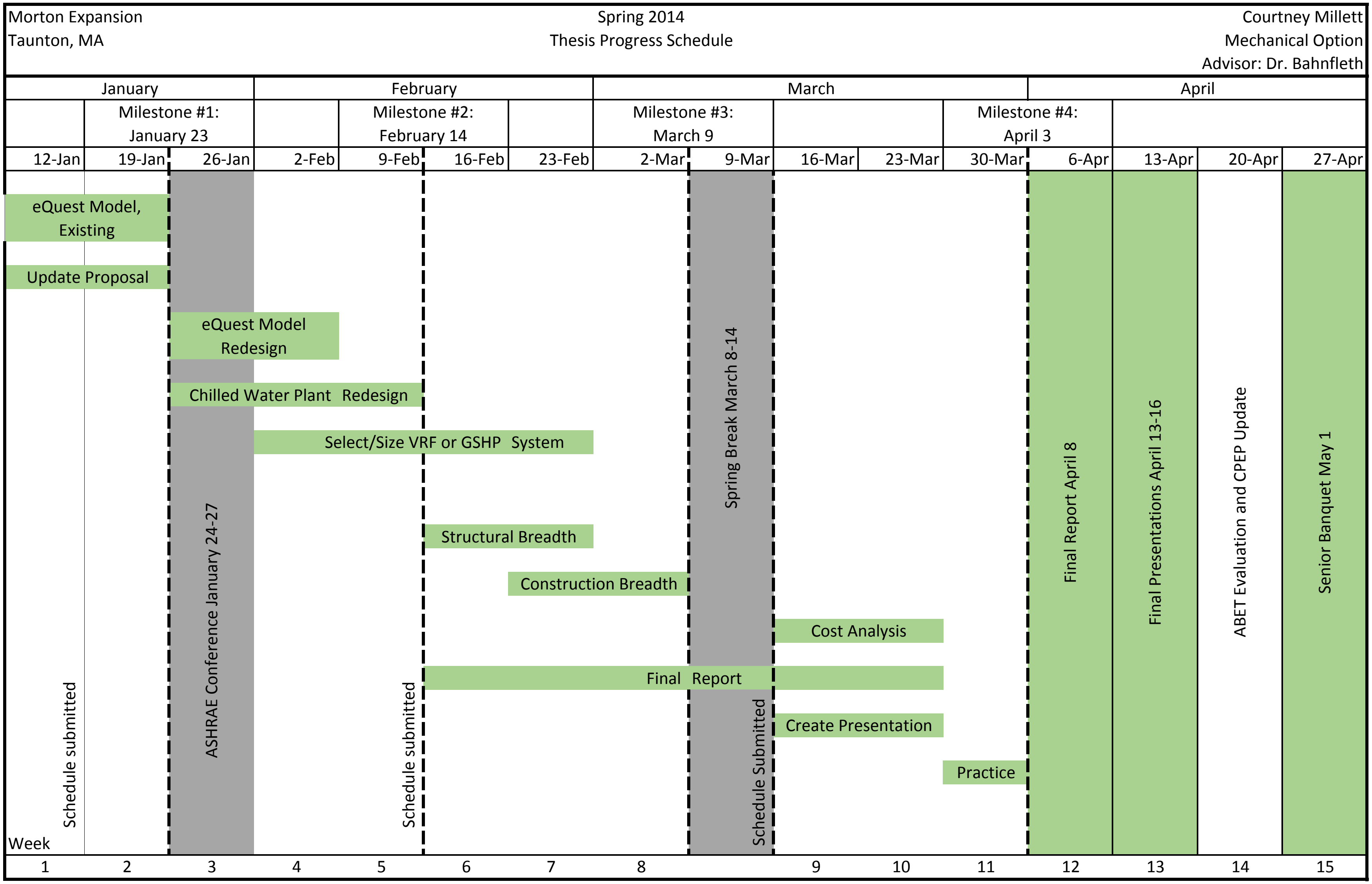
$\phi_v V_{nx} = 79.2 \text{ kips}$

$V_u << \phi_v V_{nx}$ ✓

$M_u < \phi_b M_{px}$ ✓

The current W12x16 beam is adequate the support the additional load.

Appendix E: Progress Schedule



Milestones
1: Completed preliminary research, existing IES Model developed, and CPEP up-to-date
2: Completed IES model for the proposed redesign, chilled water plant redesign complete, and VRF/GSHP design in progress
3: VRF/GSHP design complete, structural & construction breadth complete
4: Completed cost analysis. Only revisions on final report and final presentation are needed.