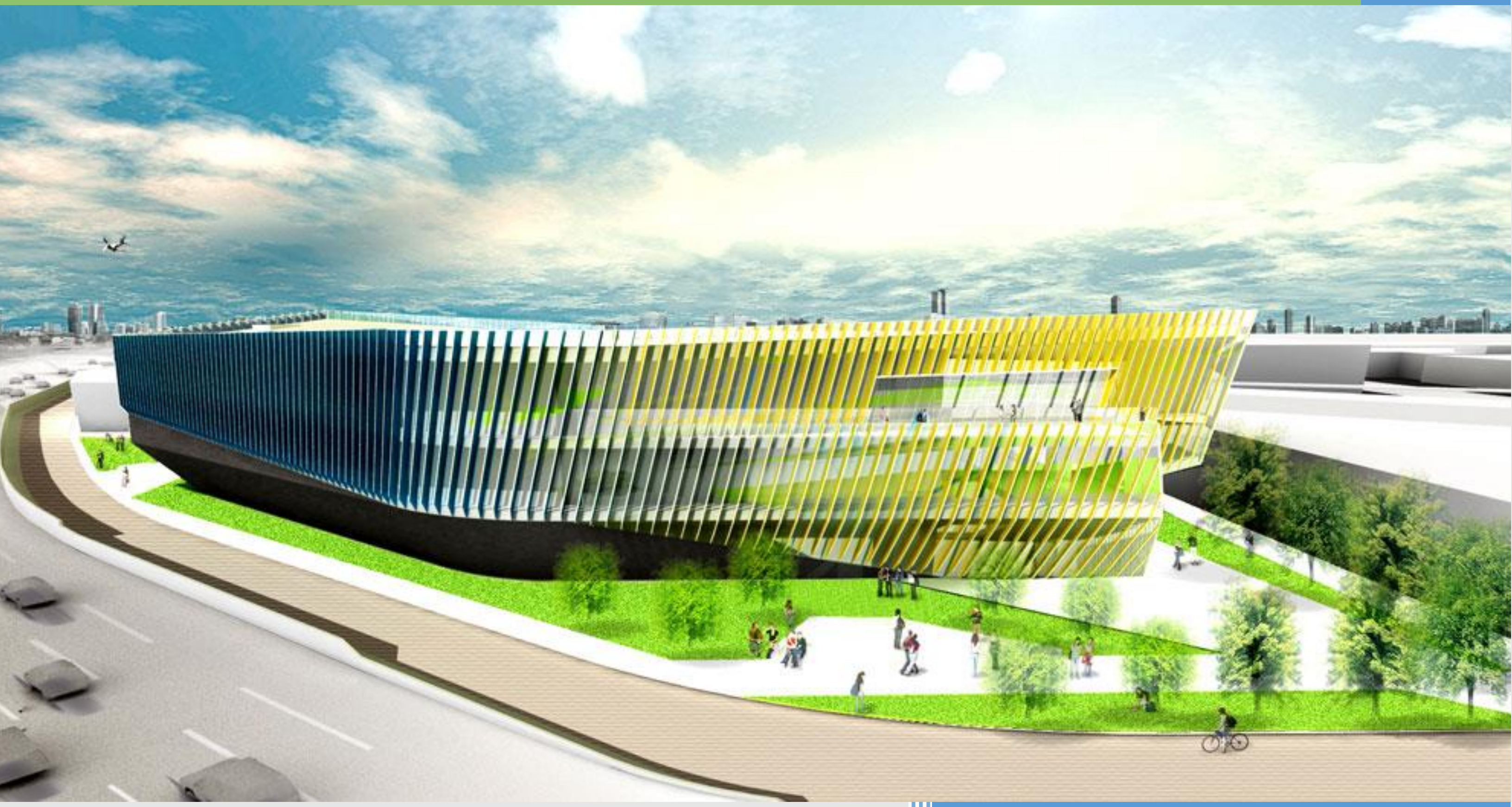
NEIU El Centro

Chicago, Illinois

Final Report



Michael Gramarossa

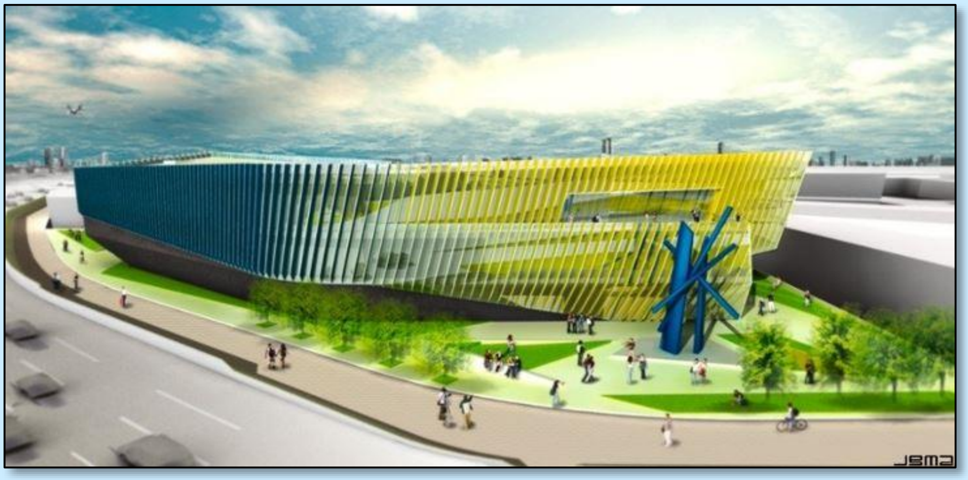
Mechanical Option

Advisor: Dr. James Freihaut

Spring 2015

NEIU El Centro

Chicago, Illinois



Bird's Eye View

Project Overview

Occupant:	Northeastern Illinois University
Building Type:	Classrooms, labs, lounges, etc.
Size:	55,000 SF
Stories:	3 (No Basement)
Construction:	May 2013 – September 2014
Delivery:	Design-Bid-Build

Project Team

Architect:	JGMA
Landscape Arch:	Site Design Group
MEP Engineer:	Primera
Struct. Engr:	Forefront
Civil Engineer:	Prism
Constr. Mngr.:	N/A (Multiple Prime)

Architecture

- The building is located along the Kennedy Expressway and will be passed by over 400,000 Vehicles each day.
- Nearly the entire building is enveloped in a curtain wall façade.
- The curtain wall has fins that are designed to limit solar gains and control the amount of natural daylight entering the building.
- The fins appear gold when driving into the city and blue when leaving the city reflecting the school colors

Structural System

- The building has no basement and the foundation consists of concrete footings and grade beams.
- The first floor is supported by a slab on grade
- The building is framed with ASTM A992 Grade 50 steel
- The floors are supported by a 20 gage composite metal deck with 4 ½" of concrete

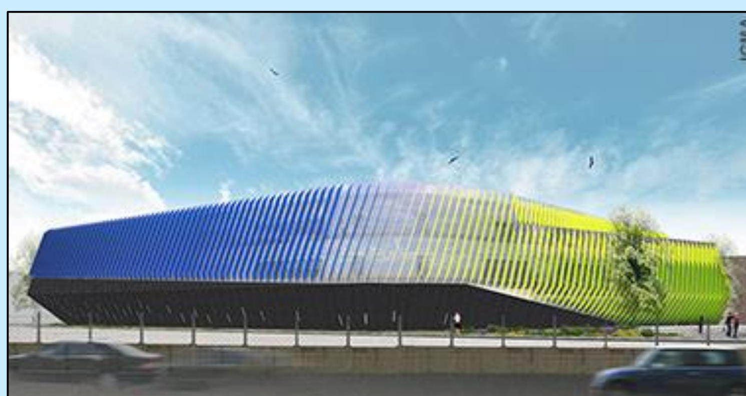
Lighting & Electrical System

- Daylight sensors and occupancy sensors control the lighting levels
- Most of the lighting system consists of energy efficient fluorescent fixtures.
- The electrical system originates from a dedicated service room on the first floor (480V/277V, 3 phase, 4 wire)
- A photovoltaic array on the roof provides additional power to the building.

Mechanical System

- The cooling and ventilation requirements of the building are served by two roof top air handling units.
- Each AHU is served by an air cooled condensing unit
- The AHU's serve the 71 VAV boxes located in the building.
- The buildings heating loads are served by two 750 MBH natural gas fired hot water boilers.
- The boilers serve hot water radiant finned tubes that are located along the perimeter of the building.

Student Lounge



Southwest Elevation

Michael Gramarossa | Mechanical Option | Advisor: Dr. Freihaut

www.engr.psu.edu/ae/thesis/portfolios/2014/mvg5182 | Images courtesy of JGMA

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Acknowledgments

I'd like to thank the following people for counseling me and answering questions throughout the past year. I could not have done this without them.

- Lindsay Bose | Primera Engineers
- Margaret McNamara | Primera Engineers
- John Palasz | Primera Engineers
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- Primera Engineers for giving me the opportunity to have a summer internship and for teaching and guiding me as I enter the engineering field.
- Penn State AE faculty and staff.
- Friends and Family
- The good folks at Rumors Lounge for giving me a safe haven to escape Thesis Lab and my fellow AE classmates when I needed to get away, grab a beer, and play some pool.

Executive Summary

The purpose of this report is to investigate the design of the mechanical system for Northeastern Illinois University's new building: El Centro. Upon investigation of the mechanical system and talking with the lead mechanical engineer, it was discovered that the system exceeds the ventilation requirements set forth by ASHRAE. This is because the system was designed using the 2012 Chicago Building Code (CBC), which has stricter mechanical system requirements than the International Mechanical Code (IMC). The IMC is what most building codes across the United States utilize and reference.

The CBC requires a certain amount of airflow provided to each space, regardless of the associated load. 1/3 of this supply air must be outside air. In the past decade or so, with advancements in lighting efficiencies and thermal envelopes, the difference between the CBC required airflow and what is required by the load has increased significantly. For example, certain interior classrooms required twice as much supply air than what was required by the peak load. It is important to note however that the CBC required supply air is allowed to be reduced if the building employs a method of monitoring and controlling CO_2 levels in the space, which El Centro does. However, the ventilation required is calculated by the 1/3 of supply air required as stated previously and cannot be reduced. The CBC required ventilation often exceeds what the IMC and ASHRAE 62.1 require.

A study is conducted in this report to redesign the current mechanical system as if it were to comply with the IMC in lieu of the baseline design (CBC). This lead to smaller equipment requirements as well as energy and emission savings. It was discovered that two identical 90 ton RTUs would be sufficient to satisfy the loads associated with the IMC, while 100 ton RTUs would be necessary to satisfy the CBC.

The reduction in the size of the RTUs allowed for there to be a slight reduction in the amount of steel and the amount of electrical wiring. However, these reductions were not as a result of the load reductions associated with the IMC. They were a result of a different design strategy used by choosing packaged RTUs from Carrier that included condensing units, rather than separate condensing units which were in the existing design. Designing to the IMC in lieu of the CBC will most likely not lead to savings in steel or electrical wiring.

Furthermore, there are energy savings associated with complying with the IMC instead of the CBC. A study was also conducted to see the potential energy savings if the entire city of Chicago's mechanical systems were designed to the IMC instead of the CBC. See the table below. It is estimated that this results in removing 1.5 billion lbs. of CO_2/yr which is equivalent to removing 184,000 cars off the road.

Summary of Savings	Energy Savings		Annual Cost Savings		Emission Savings	
	%	kBtu/year	%	$/year	%	lbs. CO_{2e}/yr
NEIU El Centro	6.70%	232,000	2.90%	$1,850	2.42%	33,600
City of Chicago	6.70%	10.4 billion	2.90%	$87 million	2.42%	1.5 billion

Building Overview

Northeastern Illinois University (NEIU) El Centro is a new educational facility that is being built in the northwest side of Chicago, Illinois. It is located along Kennedy Expressway and will be passed by an estimated 400,000 vehicles per day. The building is set to be completed September 2014, in time for Fall Semester classes. It is a 55,000 square foot building with three stories; there is no basement in El Centro. The building will include classrooms, art studios, computer rooms, lecture halls, music studios, wet labs, damp labs, a library, student lounges, resource rooms, administrative space, and offices.

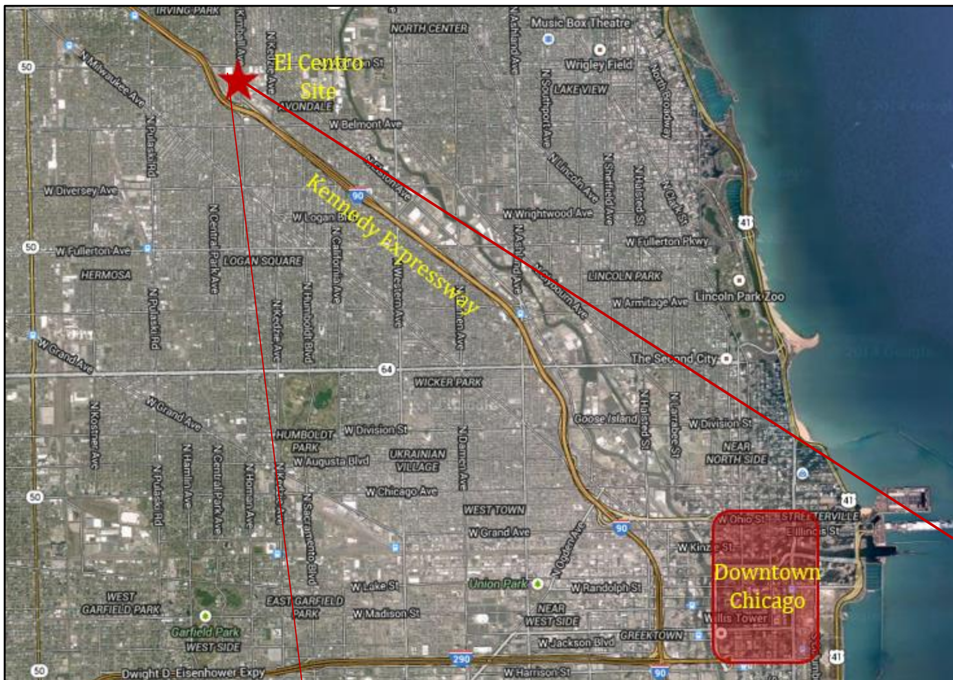


Figure 1 (above) – Map of the northern half of Chicago

Figure 2 (right) – Building Outline of El Centro

Nearly the entire building is enveloped in a curtain wall façade. The curtain wall features fins that are designed to limit solar gains on the building and to control the amount of natural daylight into the building. The fins will appear gold when driving into the city, and blue when leaving the city, reflecting the school colors as can be seen in the rendering below (courtesy of JGMA). Photovoltaic panels are mounted to the majority of the roof area. Other green initiatives include low flow plumbing fixtures, high-efficiency equipment, and creative lighting that have made this project eligible for a LEED gold rating.

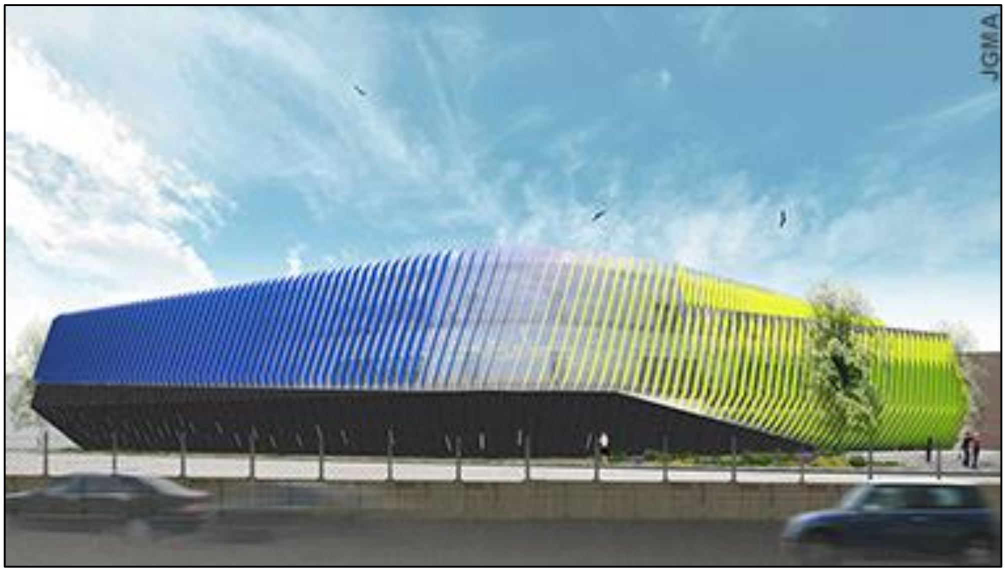


Figure 3 – El Centro's curtain wall and unique dual coloring of the fins

Figure 4 – El Centro's solar fins were designed to limit solar gains into the building

Part I: Existing Mechanical System Evaluation

Air Side: Cooling and Ventilation Plant

Roof Top Air Handling Units

There are two identical packaged roof top air handling units (RTU-1 & RTU-2). They serve all of the ventilation and cooling requirements of the building supplying 55°F air year round. Each RTU is served by a separate air cooled condensing unit, also located on the roof. Architecturally and mechanically, the buildings three floors are split up into two distinct zones: A and B. See the accompanying figures for an understanding of the mechanical layout of the building.

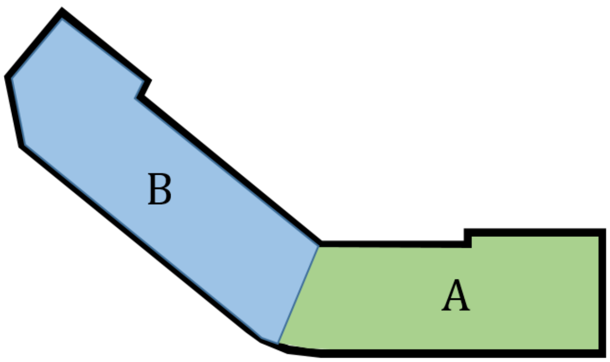
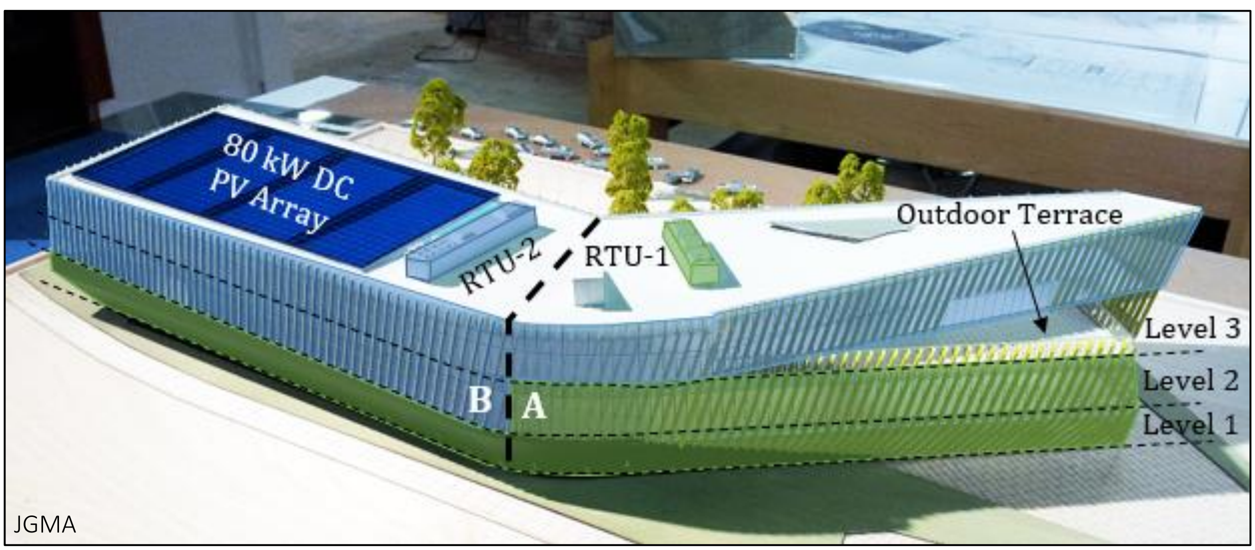


Figure 5 (left) – Simplified typical floor plan sketch. The building is "split" into two halves: Zone A and Zone B.

Figure 6 (below) – Bird's Eye view of El Centro. RTU-1 will serve Level 1 and Zone A of Level 2. RTU-2 will serve Zone B of Level 2 and Level 3.



Each air handling unit utilizes refrigerant R-410A. They also each contain an indirect natural gas fired burner to allow reheat and humidity control. Table 1 illustrates a basic summary of each air handling unit.

Tag	Condensing Unit	Capacity (CFM)	Min. OA (CFM)	DX Cooling Coil			Indirect Gas Fired Heating		
				EDB (°F)	LDB (°F)	Refrig.	EDB (°F)	LDB (°F)	Fuel
RTU-1	CU-1	38,000	12,000	79.8	55	R-410A	18.9	55	NG
RTU-2	CU-2	38,000	12,000	79.8	55	R-410A	18.9	55	NG

Table 1 – Air Handling Unit Operation

Air Cooled Condensing Units

Each RTU is served by a separate air cooled condensing unit (CU). Each CU uses refrigerant R410-A which is environmentally friendly. The CU's also employ a hermetic scroll compressor. See Table 2 below for further properties of the condensing units.

Tag	RTU Served	Condenser E.A.T. (°F)	Fan		Refrig.	Efficiency	
			No. of Fans	CFM		EER (BTUH/W)	IPLV (BTUH/W)
CU-1	RTU-1	95	6	15,600	R-410A	11.3	15.6
CU-2	RTU-2	95	6	15,600	R-410A	11.3	15.6

Table 2 – Air Cooled Condensing Unit Operation

Cooling Plant System Operation and Schematic

Each RTU has two supply fans and two return fans with separate VFD control for each. The exhaust air, return air, and outside air dampers fluctuate depending on outdoor air temperature and relative humidity. Both RTU's employ an economizer cycle. The minimum volume of outdoor air incorporated is about 33% of the total supply air.

The rooftop air handling units combine the return conditioned air and outdoor air. The mixed air then passes through the filter (prefilter MERV-7 & final filter MERV-13). The differential pressure between the upstream and downstream sides of the filter is measured. Then the air passes over the direct expansion cooling coil served by the air cooled condensing unit. The air then passes through the modulating indirect natural gas fired burner which is used during the heating season. A final supply air temperature and duct static pressure are measured to ensure conditions are met. Please refer to Figure 7 for a schematic of each RTU.

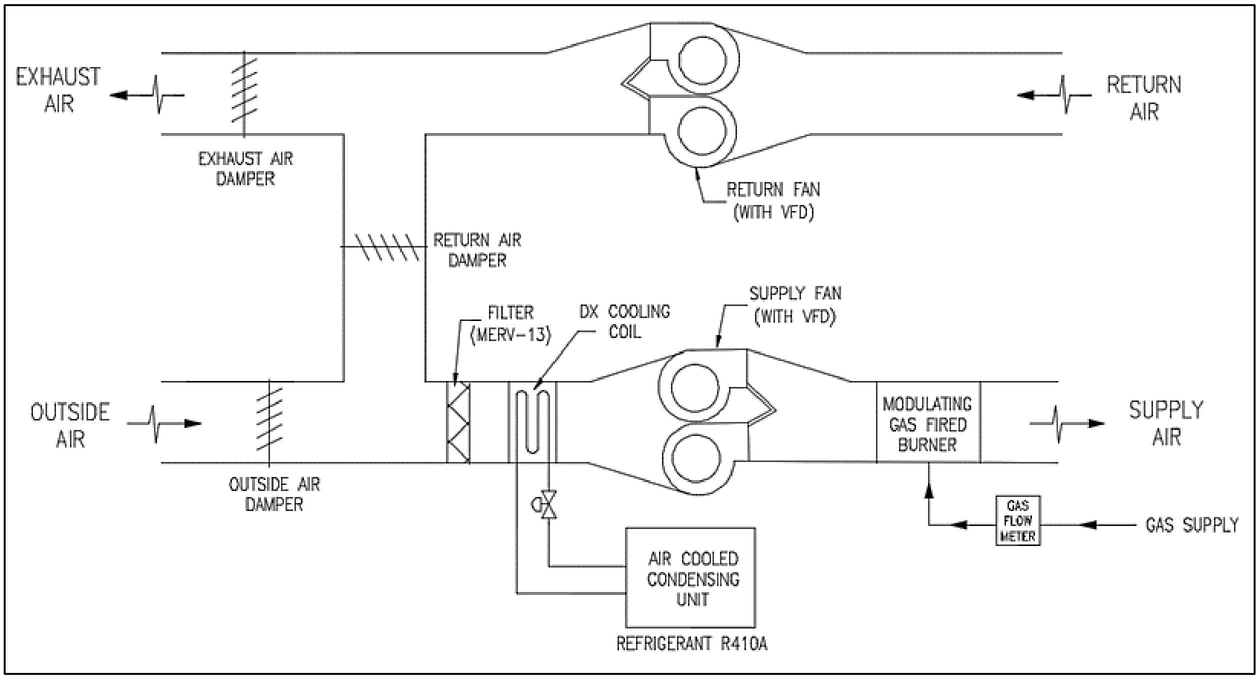


Figure 7 – RTU Schematic and Operation

Water Side: Heating Plant

Boilers

The mechanical room located on the first floor houses two identical 750 MBH natural gas fired hot water boilers. These boilers serve the heating loads of the building by supplying hot water radiant finned tubes, VAV reheat coils, and a few cabinet heaters located throughout the building. A corridor wraps around the entire perimeter of the building to shield the classrooms from the noisy Kennedy Expressway. Hot water radiant finned tubes run the length of this perimeter in the corridor (See Figure 8 for clarification). Table 3 shows the design intent of the two boilers.

Tag	Fuel Type	Rating (MBH)		Water Temperature (°F)		Flow Rate (GPM)	Min. Thermal Efficiency (%)
		Input	Output	Entering	Leaving		
B-1	NG	750	657	130	150	66	90
B-2	NG	750	657	130	150	66	90

Table 3 – Boiler Operation

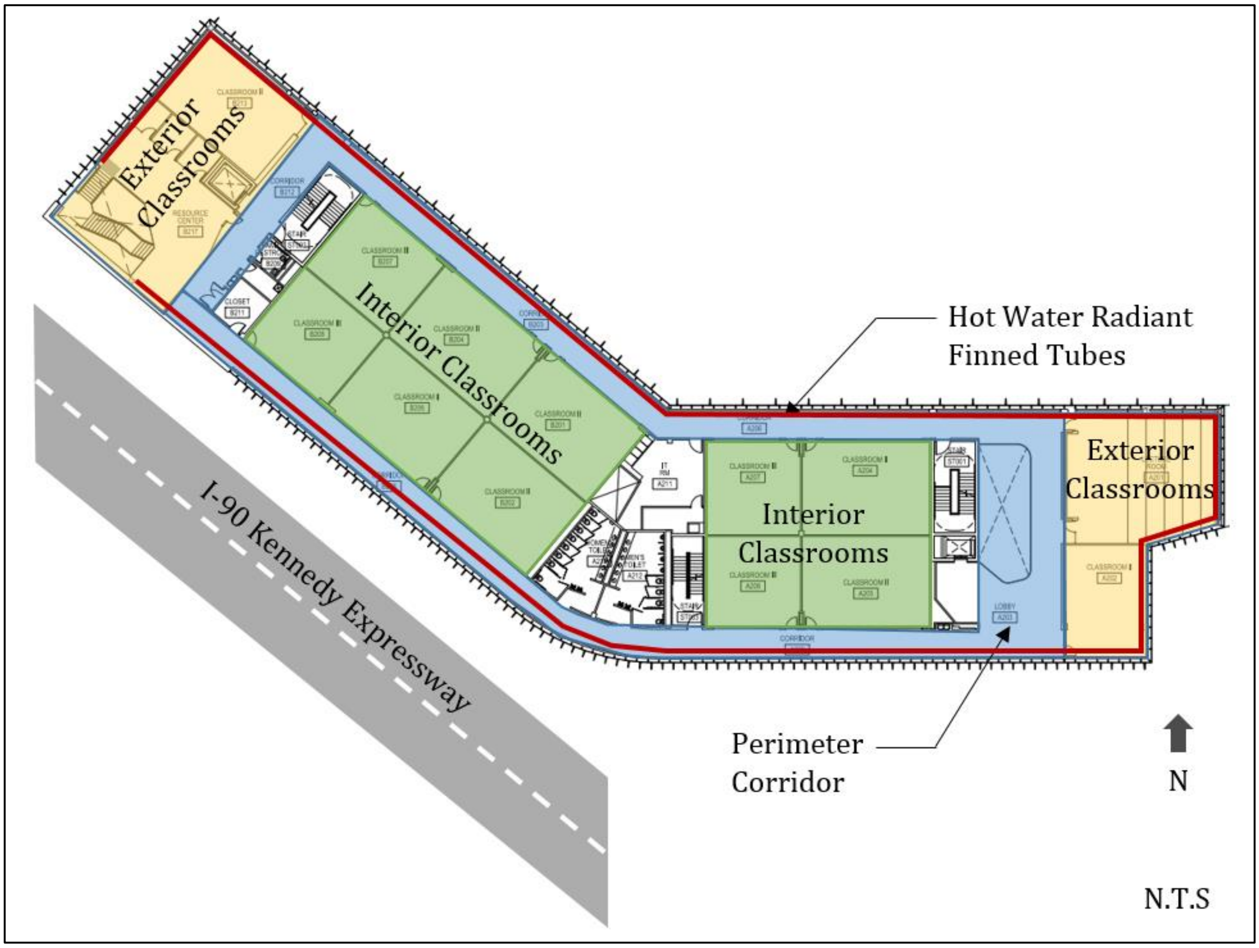


Figure 8 – Second Floor Plan Hot Water Schematic

Hot Water Pumps

The mechanical room contains two centrifugal, hydronic hot water pumps that serve the boilers. Hot water is pumped to the 71 VAV boxes throughout the building, the hot water radiant finned tubes, and the 10 unit heaters throughout the building. Both pumps are base mounted and end suction. Only one pump will operate at a time and can supply a flow of 100 GPM and a pressure head of 90 feet. Each pump has VFD control and a disconnect switch. See the table below for further properties.

Tag	Flow (GPM)	Head (FT)	Motor		
			HP	RPM	Motor Control
HWP-1	100	90	7.5	1750	VFD
HWP-2	100	90	7.5	1750	VFD

Table 4 – Hot Water Pump Operation

Heating Equipment

Hot water radiant finned tubes run along the length of the curtain wall. They are designed to have a mean water temperature of 140°F. They are made up of copper tubing and aluminum fins. There are also three hot water unit heaters and seven hot water cabinet unit heaters that provide heat for miscellaneous spaces not served by the radiant tubes such as staircases. 71 hot water reheat coils in the VAV boxes are also available to heat the building during the heating season.

Heating Plant System Operation and Schematic

The mechanical heating hot-water system is comprised of two natural-gas fed boilers capable of providing a combined total of 1500 MBH of sensible heat. The boilers are variable flow condensing type, and the hot water system is variable-primary.

The hot water produced in the boilers will first pass through a 300 gallon buffer tank where excess hot water can be stored. It will then pass through an 84 GPM air-separator and then be distributed to the building via the hot water pumps. The HW pumps operate in a lead/standby mode. Only one pump will operate at any given time. Each pump will have VFD control. The VFD speed for the lead pump will modulate to maintain differential pressure in the hydronic loop as measured by the differential pressure transmitter (DPT).

All of this equipment is located in the mechanical room on the first floor. The hot water system will serve the radiant finned tubes, the 71 VAV reheat coils, and the ten cabinet unit heaters. Refer to Figure 7 for a detailed flow diagram.

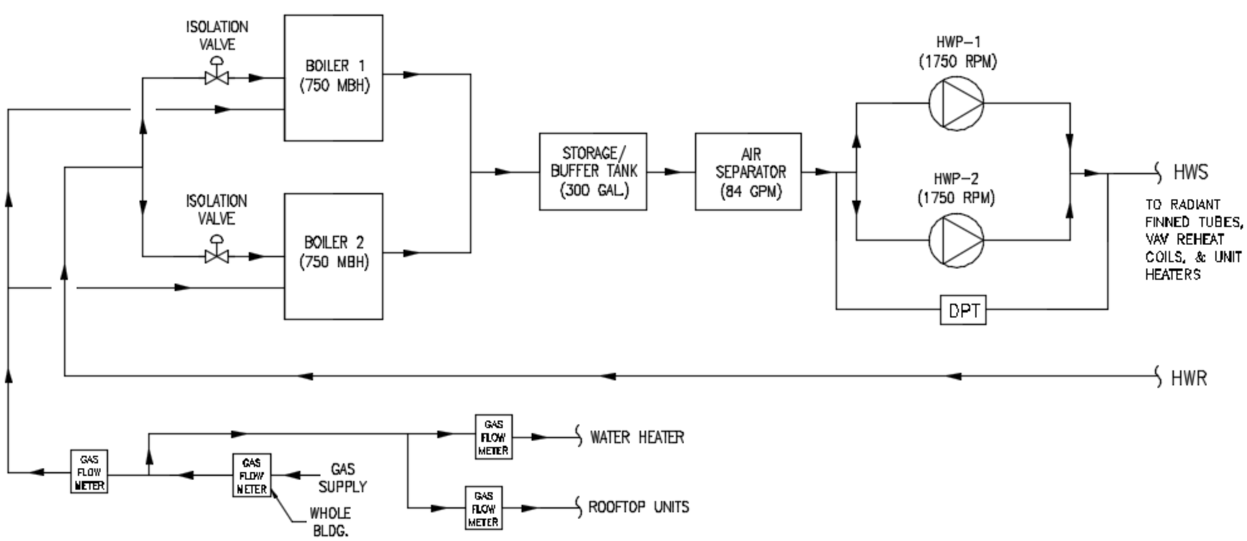


Figure 9 – Hot Water Flow Diagram

Mechanical System Design

Design Objectives

El Centro is the first building to be built on Northeastern Illinois's newest campus. There is no existing campus cooling, heating, or steam plants/districts. The mechanical HVAC system was designed to exhibit energy efficiency goals outlined in LEED and will aim to achieve a LEED Gold Certification. The design provides fresh outside air in conformance with The Chicago Building Code and thermal comfort based on ASHRAE standards. Heating and cooling will be provided to all occupied spaces. Spaces that have high moisture and/or odor content, such as laboratories and bathrooms, are exhausted to the outside and supplemented with conditioned makeup air. The spaces with large exposure to glass is supplemented with radiant heat from perimeter tubes, as can be seen in the previous figure (Figure 8). Mechanical equipment such as boilers and pumps are located on the first floor in a designated mechanical room and ventilation equipment such as AHU's are located on the roof. All equipment, such as VAV boxes, are located appropriately to achieve LEED required sound levels.

Weather Data & Design Conditions

NEIU El Centro is located on the northwest side of Chicago, Illinois and falls under climate zone 5A. This zone is described as moist and humid and has moderately hot summers and cold winters. Weather data for this area was taken from the 2009 ASHRAE Handbook of Fundamentals for Midway Airport which is located near the site. The design conditions for the building are set points of an indoor air temperature of 75°F for the cooling season and 70°F for the heating season and 50% RH for both seasons. Table 1 below summarizes the design temperatures and set points used in the building.

Heating 99.6%*	Cooling 0.4%*		Dehumidification 0.4%*			Design Set Point		
DB (°F)	DB (°F)	MCWB (°F)	DP (°F)	HR	MCDB (°F)	Cooling DB (°F)	Heating DB (°F)	% RH
-1.6	92.1	74.9	75	134.1	84.3	75	70	50

Table 5 – Design Conditions *(Source: ASHRAE 2009 Handbook of Fundamentals)

Building Envelope

El Centro is enveloped almost entirely in a curtain wall. Most classrooms and offices do not have exterior walls so that they are shielded from the noisy Kennedy Expressway (Refer to previous Figure 8). They are surrounded by a corridor that runs the perimeter of the building which is enclosed by the curtain wall. The building has solar fins that help limit the amount of direct sunlight into the spaces. Table 6 is a summary of the U-values used in this energy analysis (courtesy of Primera Engineers and JGMA).

Surface	Description	U-Value
Curtain Wall	Glazing	0.29
Solid Wall	CMU, metal studs, Insulation, GWB	0.056
Roof	Metal deck, NWC, PVC membrane	0.033

Table 6 – Building Envelope U-Values

Ventilation Requirements

Adequate ventilation is supplied to all spaces through the two roof top air handling units (RTU-1 & RTU-2) and variable air volume boxes according to ASHRAE 62.1-2013. Each RTU can supply up to 12,000 CFM of outside air. The design complies with more stringent ventilation requirements of the Chicago Building Code (CBC). These CBC requirements will be discussed in more detail later in the report. The supply air entering the building has a 32% ratio of outdoor air to indoor air. Table 7 summarizes the design outside air CFM and the required outside air CFM for each RTU.

System	Design Total Supply CFM	Design OA CFM	Required OA CFM	AHU OA %
RTU-1	38,000	12,000	7,500	32%
RTU-2	38,000	12,000	7,800	32%

Table 7 – RTU Ventilation

Exhaust Requirements

Table 6.5 in ASHRAE 62.1-2013 outlines minimum exhaust rates for types of spaces. The table below summarizes the exhaust fan design results of El Centro. All of the exhaust fans were found to be in compliance with ASHRAE. Table 8 lists the exhaust fans located throughout the building.

Exhaust Fan	Area Served	# of Units	CFM/Unit	SF	CFM /SF	Standard 62.1 Min Airflow (CFM)	Design Airflow (CFM)	Comp-liance
EF-1	ART RM. A304	-	-	900	0.7	630	1450	Y
EF-2	WET LAB B304	-	-	1368	1	1368	3635	Y
EF-3	PREP. RM. B302	-	-	333	1.5	500	1250	Y
EF-4	NOT USED	-	-	-	-	-	NOT USED	-
EF-5	IT ROOM A211	-	-	412	0.5	206	420	Y
EF-6	SHOWER RM B128	-	-	47	0.5	24	100	Y
EF-7	RECYCLING B126	-	-	439	1	439	450	Y
EF-8	HAZ. WASTE B131	-	-	11	1.5	17	50	Y
EF-9	WORK RM. A115/ BREAK RM. A109	-	-	288	0.3	86	700	Y
EF-10	CYLINDER STOR. B129	-	-	18	1.5	27	50	Y
TEF-1	M & W TOILET	46	70	1788	-	3220	3640	Y
TEF-2	FAMILY ROOMS, JC-B120,B210,B312	3	70	175	1	385	800	Y

Table 8 – Exhaust Fan Requirements

Lighting & Miscellaneous Loads

The same lighting loads as the design engineer were used and were done on a watt per square foot basis. Miscellaneous loads were included to account for computers and other office equipment located throughout the building. The miscellaneous loads were also done on a watt per square foot basis, reflecting the same method used by the design engineer. Table 9 summarizes the loads used.

Type of Space	Lighting (W/SF)	Miscellaneous (W/SF)
Classroom	1.0	0.5
Office	1.0	0.5
Corridor	0.5	-
Storage	0.5	-
Restroom	0.5	-
Lounge	1.0	0.5

Table 9 – Lighting & Miscellaneous Loads

Infiltration

The building is tightly constructed and contains no operable windows. However, the design engineer used 0.4 air changes per hour for any space that had an exterior wall. This may be an overestimation but the same method was applied to this model.

Schedules

El Centro is a university building and will be open 24 hours a day for students who will be studying late. The greatest load is expected to be 8:00 AM to 6:00 PM when classes will be in session. The following schedule reflects the expected occupancy of the building throughout the day and was used in the energy model.

Start Time	End Time	Rate
Midnight	8:00 A.M.	Off-Peak
8:00 A.M.	6:00 P.M.	Peak
6:00 P.M.	9:00 P.M.	Mid-Peak
9:00 P.M.	Midnight	Off-Peak

Table 10 – Weekday Occupancy Schedule

Load and Energy Analysis

Heating & Cooling Requirements

The heating and cooling loads were calculated by developing a Trane TRACE 700 model. Both the heating and cooling loads are achieved by the designed system and the RTU's seem to be a little oversized. This could be due to a multitude of reasons, such as the designer relying on previous experience to adequately size the equipment, or an error in the model created for this report. The difference in heating loads is probably due to the designer using an outdoor air temperature of -10°F design point, well below the -1.6°F required by ASHRAE for Chicago. The loads calculated by the model are summarized below in Table 11.

	System	Area Served (SF)	Total Supply (CFM)	Heating (MBh)	Cooling (Ton)	Final Size (CFM)	Final Size (MBh)
My Model	RTU-1	24,000	20,700	741	93	-	-
	RTU-2	27,800	22,200	810	97	-	-
Designer Model	RTU-1	24,000	21,700	806	93	38,000	1,250
	RTU-2	27,800	27,800	1,013	114	38,000	1,250

Table 11 – Heating and Cooling Loads

Energy Sources

El Centro has two energy sources: electricity and natural gas. Natural gas serves the two 750 MBH hot water boilers in the mechanical room and also serves the indirect gas fired furnaces in both roof top air handling units. El Centro's natural gas needs are served by a pipeline provided by Peoples Gas of Chicago. The following table summarizes the average utility rates for this location.

Fuel Type	Average Rate
Electricity Cost	0.081 $/kWh
Natural Gas Cost	0.795 $/therm

Table 12 – Average Utility Rates

Energy Consumption

The largest consumer of power in the building is the heating plant. This makes sense because the curtain wall enveloping El Centro causes high heating loads during the cold winters of Chicago. The best way to combat this problem is to use glazing with a lower u-value or architecturally reducing the size of the curtain wall. Table 13 and Figure 10 display a breakdown of the total energy usage of the building. Please refer to Technical Report 2 for a more detailed analysis of this energy usage.

Equipment	Electricity Consumption (kWh)	Natural Gas Consumption (kBtu)	Total Building Energy (kBtu/yr)	% of Total Building Energy
Cooling Plant	257,578	-	879,115	21.6
Heating Plant	4,964	1,516,747	1,533,689	37.6
Lights	388,218	-	1,324,987	32.5
Receptacles	99,337	-	338,038	8.3
Total	*750,097*	*1,516,747*	*4,075,829*	*100*

Table 13 – Energy Consumption Results

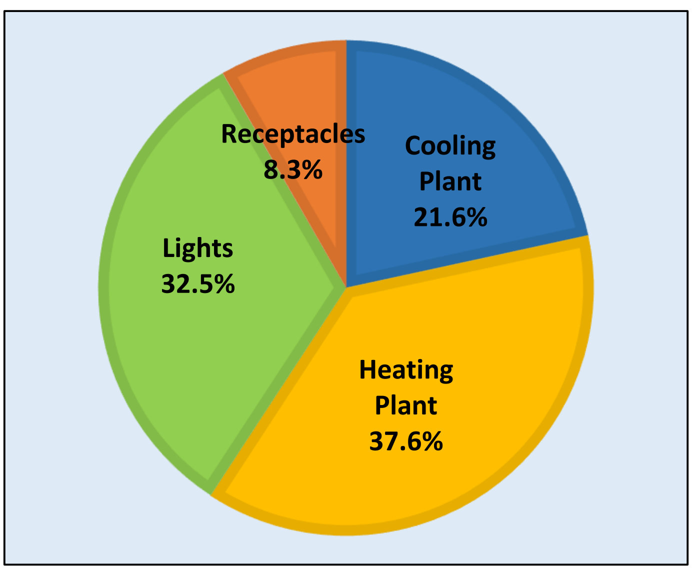


Figure 10 – Breakdown of Energy Consumption

Monthly Operating Cost

The following graph summarize the monthly operating costs of each system. As expected, heating and cooling operating costs vary with the season. Cooling demand is higher in the summer months and heating demand is higher in the winter months. Lighting and receptacle loads are fairly consistent throughout the year.

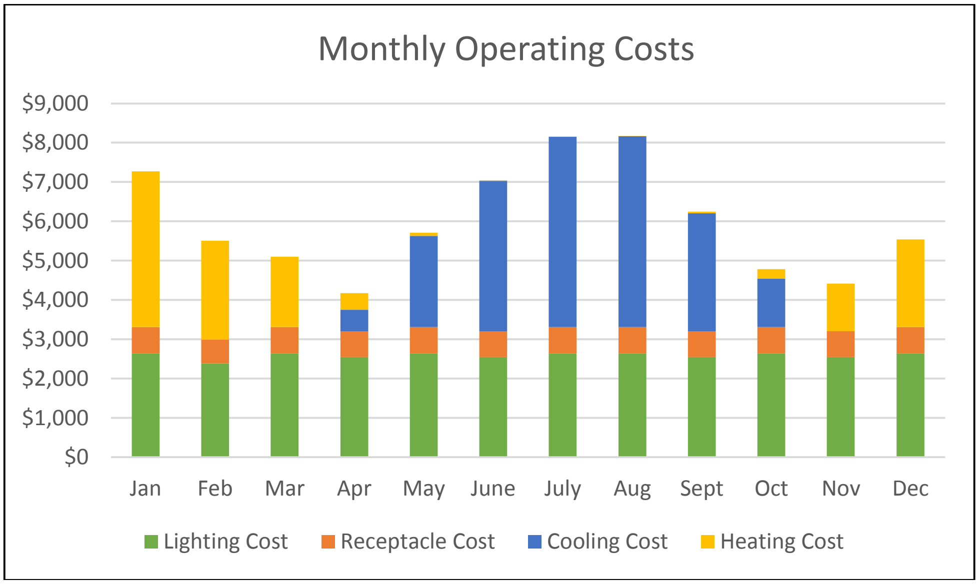


Figure 11 – Monthly Operating System Cost

Monthly Energy Usage by Source

The largest electricity consumption occurs during the summer months. This is expected because of the high cooling loads required and the roof top air handling units consume electric energy. The highest rates of natural gas consumption occur during the winter months. This is also expected because of the high heating loads associated with the winter and the boilers are fired from natural gas. The figures below summarize the electric and natural gas consumption of El Centro.

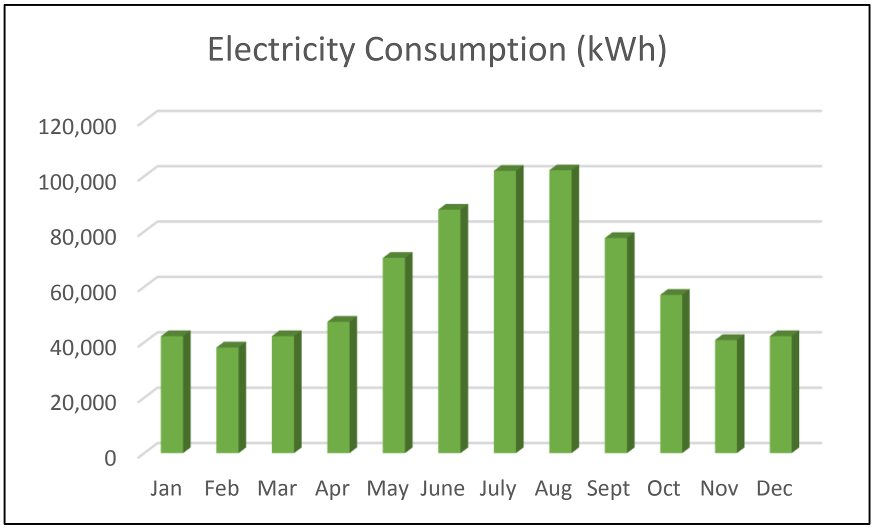


Figure 12 – Monthly Electricity Consumption

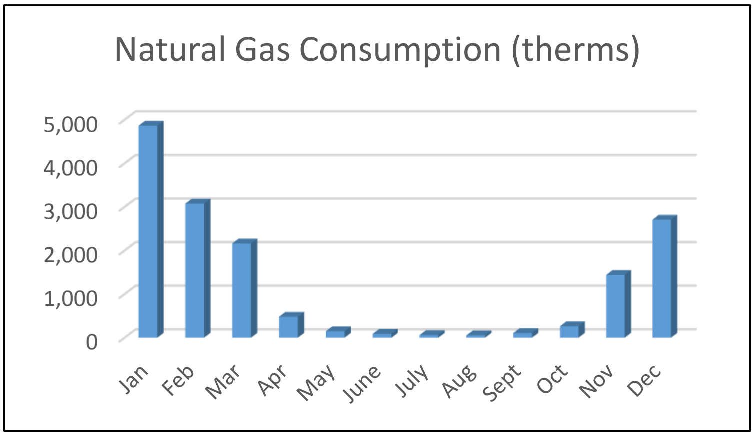


Figure 13 – Monthly Natural Gas Consumption

Energy Costs

The model has predicted a total annual cost of electricity of about $60,000 and the total cost of natural gas to be about $12,000. This results in a total annual cost of $72,000 to heat and power the building. The cost per square foot of the energy is about 1.31 $/SF. An energy analysis was also conducted by the MEP engineer, Primera, using a TRACE model. The energy analysis was conducted to apply for energy efficient LEED credits. Primera estimated that the annual cost of operating the building would be $64,000. These results are summarized in the table below. Since El Centro was recently completed in September 2014, there are not actual utility bills available to compare this data.

Analysis	Total Annual Cost	Cost/SF	% Difference From Design
Modeled	$72,000	1.31 $/SF	11%
Designer	$64,000	1.18 $/SF	-

Table 14 – Annual Fuel Cost Comparison

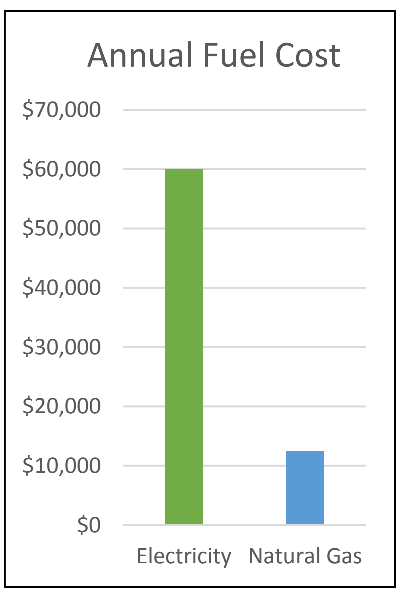


Figure 13 – Annual Fuel Cost

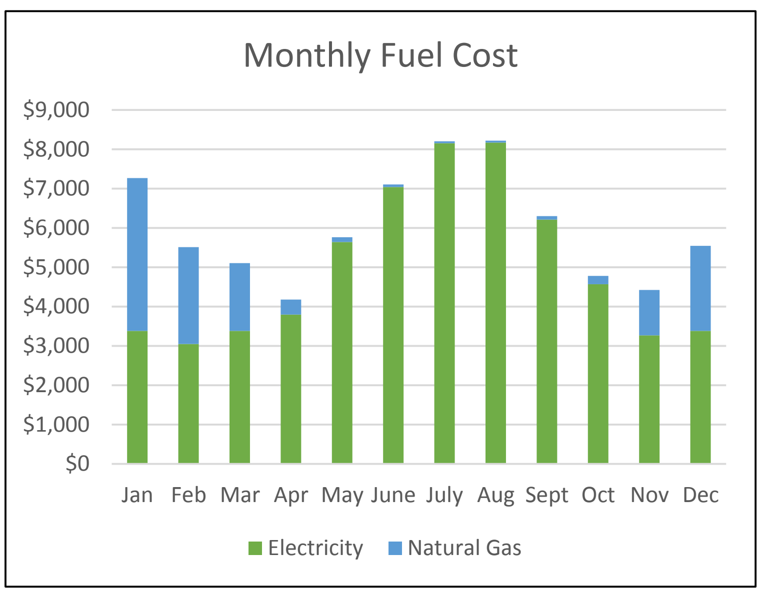


Figure 14 – Monthly Fuel Costs

Energy Grants

The following energy grants from the government are projected to be received:

$125,000 for sustainable design and enhanced commissioning.
$275,000 for the 80 kW DC PV array

These grants have not yet been awarded but have been applied for and the project team expects the project to receive them in the near future.

Mechanical System Installation and Operation

Lost Useable Space

The mechanical room on the first floor houses the hot water heating plant and is 650 ft^2. There are mechanical shafts on the 2nd and 3rd floors to allow for the ductwork from the roof top air handling units to enter the building. Each shaft is about 105 ft^2. This results in a total loss of 860 ft^2 or 1.4% of the gross area of the building.

Mechanical System First Cost

The overall project construction cost is approximately $22 million dollars. The HVAC system of the building was estimated to cost $2.4 million dollars, or 38 $/SF. This results in the installing of the mechanical system to be about 11% of the total project cost.

Operation History of the System

El Centro was recently completed in September of 2014 so there is currently no data available for actual operating conditions. The engineer of record has been contacted and permission was granted to access the BAS system by the owner. The engineer is currently waiting for login information from the manufacturer as of the date of the submission of this report.

ASHRAE Standard 62.1 Compliance

5. Systems and Equipment

5.1 Ventilation Air Distribution

The ventilation air distribution system has a set minimum ventilation airflow rate and is in compliance. A return plenum is not used on this project. All returns are ducted back to the two air handling units. The design documents specify minimum requirements for air balance testing by referring to the procedures contained in NEBB's "Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems."

5.2 Exhaust Duct Locations

Exhaust ducts carrying potentially harmful substances are negatively pressurized through the spaces from which they pass in compliance with this section.

5.3 Ventilation System Controls

A fully integrated BAS system is used to control the mechanical systems in El Centro. During times of the day when the building is occupied, the RTU's will maintain the set point. During times when the building is not occupied, the RTU will enter a cool-down mode and will warm up again before the next occupied time is.

5.4 Airstream Surfaces

All duct is required to comply with UL 181, including resistance to mold growth and resistance to erosion, in compliance with this section.

5.5 Outdoor Air Intakes

All outdoor air intakes are required to be 15'-0" from any contaminant source as per the drawings in compliance with this section. Water penetration is limited to values set forth in this section. Outdoor units and duct work are required to have rain and snow drains per the specifications. Outdoor intakes shall also include bird screens and is in compliance with this section.

5.6 Local Capture of Contaminants

Exhaust ducts are located in areas where contaminants are produced including restrooms, showers, laboratories, etc. These ducts are negatively pressurized by exhaust fans located on the roof.

5.7 Combustion Air

The boilers on the first floor are provided with 1500 CFM of outside air for combustion and removes combustion products in accordance with manufacturer instructions.

5.8 Particulate Matter Removal

Equipment is specified to have a prefilter of MERV 7 and a final filter of MERV 13 for credit EQ5 of LEED and is in compliance with this section which requires MERV 8.

5.9 Dehumidification System

The building is specified to have a maximum relative humidity of 65%. The building will be positively pressurized ensuring that the volume of outside air entering in is always more than the volume of air being exhausted.

5.10 Drain Pans

The drain pan slopes are in compliance with this section. The drain pan outlet is located at the lowest point of the drain pan. Drain pans are located under all devices capable of producing water and have sufficient widths to collect this water in compliance with this section.

5.11 Finned-Tube

Drain pans are required for the two roof top units per the specifications, therefore the building is in compliance with this section.

5.12 Humidifiers and Water-Spray Systems

NEIU El Centro does not employ humidifiers or water-spray systems, therefore this section does not apply.

5.13 Access for Inspection, Cleaning, and Maintenance

The roof top units are installed with sufficient access for inspection, cleaning, and maintenance. Access doors are provided for duct work, dampers, and other equipment throughout the building in compliance with this section.

5.14 Building Envelope and Interior Surfaces

A fluid-applied membrane vapor-retarder air barrier is used throughout the building envelope. Nearly the entire façade is a curtain wall with exterior fins. A sealant is used at exterior joints to limit air leakage into the building. All HVAC ducts and pipes with potential for condensation in the building are insulated in compliance with this section.

5.15 Buildings with Attached Parking Garages

NEIU El Centro does not have an attached parking garage, therefore this section does not apply.

5.16 Air Classification and Recirculation

The air in most of the building is classified as Type 1 and can be recirculated throughout the building. The air in all of the restrooms is directly exhausted to the outdoors with ducts and exhaust fans located on the roof. There is one wet and one dry lab in El Centro and the air is classified as Type 4. This air is recirculated into RTU-2 and is not in compliance with this section.

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

This section does not apply to El Centro.

6. Procedures

Ventilation Rate Procedure

Breathing Zone Outdoor Airflow (V_{bz})

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

Where R_p = outdoor airflow rate per person (CFM/person)
P_z = zone population (person)
R_a = outdoor airflow rate required per unit area (CFM/ft^2)
A_z = zone floor area (ft^2)

Zone Air Distribution Effectiveness (E_z)

E_z is determined from table 6.2.2.2.
For this project: E_z = 1.0 (Ceiling supply of cool air).

Zone Outdoor Airflow (V_{oz})

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

Primary Outdoor Air Fraction (Z_{pz})

$Z_{pz} = V_{oz}/V_{pz}$

Where V_{pz} = zone primary airflow
This is a VAV system so V_{pz} is the lowest zone primary airflow value.

System Ventilation Efficiency (E_v)

E_v is determined from Table 6.2.5.2.
For this project E_v = 1.

Occupant Diversity (D)

This was not taken into account because this is an educational building and is expected to be fully occupied during the peak times of the day.

ASHRAE Standard 90.1 Compliance

5. Building Envelope

5.1 General

NEIU El Centro is located in Chicago which is climate zone 5A as determined in Figure B1-1 in appendix B of ASHRAE Standard 90.1. Climate zone 5A is described as moist and humid and has moderately hot summers and cold winters.

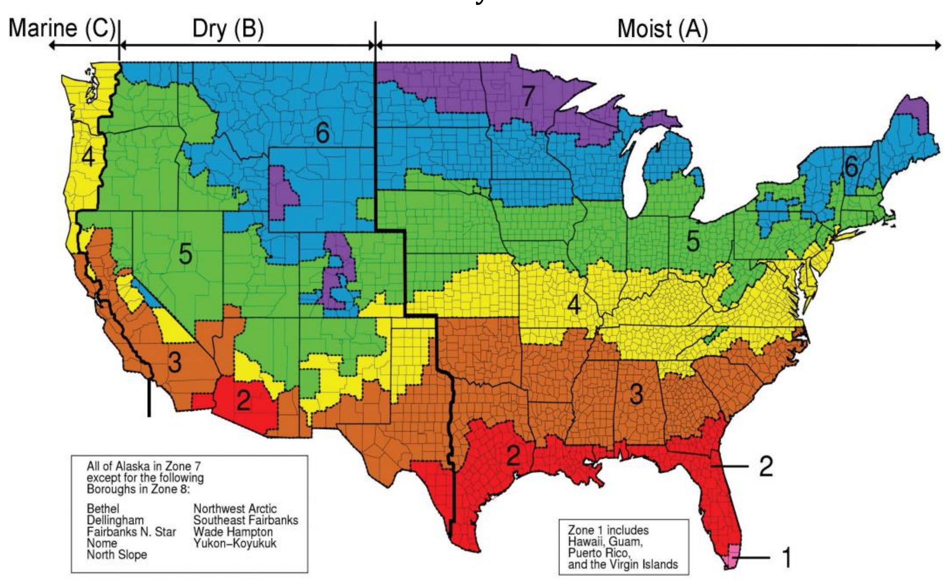


Figure B1-1 U.S. climate zone map (*ASHRAE Transactions*, Briggs et al., 2003).

Figure 15 – ASHRAE 90.1 (2013) Climate Zone Map

5.4 Mandatory Provisions

The fenestration product information shall be determined by an accredited laboratory and shall be labelled correctly. Air leakage is avoided by having the entire building envelope designed and constructed with a continuous air barrier as noted on the construction documents. The building entrance has a vestibule that separates conditioned space from the exterior. The exterior doors are located about 12 feet from the interior doors and is in compliance with this section.

5.5. Prescriptive Building Envelope Option

El Centro is enclosed almost entirely by a curtain wall. The curtain wall has solar fins on it to limit natural daylight into the building. The total square footage of the exterior walls of the building is about 42,000 SF, while the total area of glazing is about 28,000. El Centro comprises of about 68% vertical glazing on the exterior walls, well above the 40% required for the Prescriptive Building Method provided by ASHRAE 90.1. Therefore the building does not comply with this section.

5.6 Building Envelope Trade-Off Option

The building is deemed in compliance with this standard if it meets the criteria set forth in Sections 5.1, 5.4, 5.7 and 5.8. Submittal documentation that labels of space conditioning categories are required as well as correct labelling of all product information and installation requirements in compliance with this section, therefore in compliance with this standard.

6. Heating, Ventilation, and Air Conditioning

6.1 Building Envelope Trade-Off Option

El Centro is a new building and must comply with the requirements set forth in Section 6.2.

6.2 Compliance Paths

The building must comply with sections 6.1 "General", Section 6.7 "Submittals", Section 6.8 "Minimum Equipment Efficiency Tables" and Section 6.4 "Mandatory Provisions" to be in compliance with this standard.

6.3 Simplified Approach Option for HVAC Systems

This building has a gross square footage of 55,000 SF which is over 25,000 SF so this section does not apply.

6.4 Mandatory Provisions

ASHRAE Standard 90.1 lists equipment minimum efficiencies in tables in Section 6.8. Electrically operated condensing units, electrically operated heat pumps, electrically operated packaged terminal air conditioners, and gas fired boilers apply to this project. In the construction documents, efficiencies can only be found for the two natural gas fired hot water boilers and the two roof top condensing units. In the table below, a summary of these results can be found

Equipment Type	Size Cateogry	Standard 90.1 Minimum Efficiency	Design Minimum Efficiency	Standard 90.1 Compliance
Air Cooled Condensing Units	≥135,000 Btu/h	10.5 EER	11.3 EER	Y
(2) HW Boiler, Gas Fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	80% E_t	88% E_t	Y

Table 15 – Annual Fuel Cost Comparison

All efficiencies are to be certified by a recognized certification board. All mechanical equipment shall have nameplates that are clearly labelled. Load calculations were made using the Chicago Building Code (CBC) which references ASHRAE standards. The supply of heating and cooling energy to each zone are controlled individually by thermostats which control the VAV boxes. Morning warm up, night cool down, and unoccupied control modes are specified in the sequence of operation to save energy when students are not in the building in compliance with this section. All dampers in the building will automatically shut when their respective system is not in service.

6.5 Prescriptive Path

Both roof top air handling units have economizers that are capable of modulating outdoor air and return air dampers to provide up to 100% of the design supply air quantity as outdoor air for cooling to their respective zones. Humidifiers cannot be found anywhere in the construction documents. Below is a table of allowable horsepowers for the fans throughout the building. Each RTU has (2) 30 hp fans that are not in compliance with this section. Exhaust fans 8 & 10 are also not in compliance.

Unit	Allow. nameplate motor hp	CFM	VAV cfm *0.0015	Compliance hp ≤ cfm*0.0015
RTU-1 (2)	30	17100	25.65	**N**
RTU-2 (2)	30	17100	25.65	**N**
EF-1	3/4	1450	2.175	Y
EF-2	5	3635	5.4525	Y
EF-3	1/4	1250	1.875	Y
EF-4	NOT USED	-	-	N/A
EF-5	1/4	420	0.63	Y
EF-6	N/A	100	N/A	N/A
EF-7	1/6	450	0.675	Y
EF-8	1/4	50	0.075	**N**
EF-9	1/4	700	1.05	Y
EF-10	1/4	50	0.075	**N**
TEF-1	1 1/2	3640	5.46	Y
TEF-2	1/4	800	1.2	Y

Table 16 – Allowable Horsepower

6.7 Submittals

Construction documents of the actual systems installed in the building are to be submitted to the owner within 90 days after system acceptance. El Centro is scheduled to be completed in September of 2014 and the as-built drawings have not been submitted to date.

7. Service Water Heating

El Centro has one gas fired domestic water heater that is a high efficiency condensing type. It has two 750 MBH boilers that are also gas fired. All of this equipment is located in the mechanical room on the first floor. Below is a table that summarizes the data of the two boilers which displays their compliance.

Standard 90.1			Design			
Equipment Type	Subcategory	Performance Required	Equipment Tag	Rating Btu/h	Min. Thermal Efficiency	Compliance
Hot-water supply boilers, gas	≥4000 (Btu/h)/gal and ≥ 10 gal	80% E_t	B-1	750	88%	Y
Hot-water supply boilers, gas	≥4000 (Btu/h)/gal and ≥ 10 gal	80% E_t	B-2	750	88%	Y

Table 17 – Hot Water Equipment Efficiencies

8. Power

El Centro complies with standards set by the National Electric Code (NEC), therefore all feeder conductors are sized for a maximum voltage drop of 2% at design load, and branch circuits are sized for a maximum voltage drop of 3% at design load. Power plans and riser diagrams are also provided in the construction documents. This project also complies with the Energy Conservation of the Municipal Code of Chicago which references ASHRAE 90.1.

9. Lighting

The building area method was used to determine the lighting power compliance with Section 9. Table 9.5.1 lists the lighting power density (LPD) for schools and universities at 0.87 W/ft^2. The building uses energy efficient fluorescent fixtures and nearly the entire façade of the building is a curtain wall and interior partitions with glazing allow natural daylight to enter the classrooms resulting in a lower LPD then required. Most spaces contain occupancy sensors and when a space is not occupied all lights shall be turned off. When the vacancy or occupancy sensor is triggered, the daylight harvesting feature will determine the lighting level based on photocell readings. Minimum light levels for all spaces are listed in the figure to the left (courtesy of the construction documents).

TARGET LIGHTING LEVELS FOR DAYLIGHT HARVESTING	
SPACE TYPE	AVG. LIGHT LEVEL (MIN.)
SCIENCE LABS	50fc
CLASSROOMS	40fc
LOBBY	20fc
CORRIDORS	15fc
PRIVATE OFFICES	40fc
OPEN OFFICES	40fc
STAIRS	10fc

Figure 16 – Target Lighting Levels for Daylight Harvesting

10. Other Equipment

The boilers and hot water system is served by two pumps located on the first floor of the mechanical room. Efficiencies could not be found for the pumps anywhere in the construction documents but a summary of the pumps can be found in the table below.

Pump	System Served	RPM	HP	Efficiency	Min. Efficiency	Compliance
HWP-1	Hot Water	1750	5	N/A	89.5%	N/A
HWP-2	Hot Water	1750	5	N/A	89.5%	N/A

Table 18 – Hot Water Pump Characteristics

90.1 Compliance Summary

El Centro exceeds most of the requirements set forth by ASHRAE Standard 90.1. The building contains over 40% vertical glazing on the exterior walls, therefore it may have to comply with other sections of 90.1 that are beyond the scope of this report. The two roof top air handling units (RTU-1 & RTU-2) return fans do not meet the required efficiencies set forth by 90.1. A more detailed look at these results is required to inquire why this is the case. Two of the exhaust fans (EF-8 & EF-10) do not comply with the required efficiencies as well. It is possible that he fans are oversized because they serve very small storage or waste rooms and a smaller size fan may have been unavailable.

LEED Evaluation

El Centro aimed to achieve a LEED Gold Certification. Below is a breakdown of points that the mechanical system is eligible for by the USGBC LEED v4 for Building Design and Construction (note there are other points available in the EA and EQ sections, but they do not relate to the mechanical system so they will not be analyzed in this report). This project was designed by the project team using LEED v3 which has some variations from LEED v4.

Energy & Atmosphere Credits (19/35 pts)

✓ EA Prerequisite 1: Fundamental Commissioning and Verification

The purpose of this prerequisite is to verify that the mechanical system is installed and operates as the engineer intended. Proposals were received from three separate third party commissioning agents and one was chosen for this project.

✓ EA Prerequisite 2: Minimum Energy Performance

The purpose of this prerequisite is to reduce environmental and economic harm by unnecessary energy usage and ensure an energy efficient system. The design engineer claims that this project has achieved an energy cost savings of 31.36% using the ASHRAE90.1-2007 Appendix G methodology. A minimum energy cost savings of 5% is required for all new construction projects. Energy efficient measures incorporated into the building design include high efficiency glazing, reduced interior lighting power density, occupancy sensors, and high efficiency HVAC equipment.

✓ EA Prerequisite 3: Building-Level Energy Metering

The purpose of this prerequisite is to ensure that energy usage by the building is tracked. There is a natural gas meter installed where the natural gas supply pipeline enters the building. It is assumed that Commonwealth Edison (ComEd) has installed a meter to track total electricity usage of the building,

✓ EA Prerequisite 4: Fundamental Refrigerant Management

This prerequisite bans chlorofluorocarbon (CFC) based refrigerants from being used in HVAC equipment. The cooling system of the building uses refrigerant R-410A which does not contribute to ozone depletion.

✓ EA Credit 1: Enhanced Commissioning (3/6 pts)

As previously stated, three separate commissioning agencies submitted proposals to the architect and they included enhanced commissioning in their proposals. This would follow Path 1 of this credit and be eligible for 3 points.

✓ EA Credit 2: Optimize Energy Performance (12/20 pts)

This credit is to enhance energy performance beyond that of prerequisite 2. As previously stated, the project was predicted to have an energy cost savings of 31.36% which would make this project eligible to receive 12 points out of the 20 possible.

✓ EA Credit 3: Advanced Energy Metering (1/1 pts)

The purpose of this credit is to ensure that all whole-building energy sources used by the building are being tracked to allow for possible energy savings in the future. As previously stated in prerequisite 3, a natural gas meter is installed and it is assumed that ComEd has installed an electricity meter for the building.

X EA Credit 4: Demand Response (0/2 pts)

EA credit 4 requires that a demand response technology be used to help make energy generation and distribution systems more efficient. This is a new credit for LEED v4 and was not included in v3. Demand response technology cannot be found anywhere in the project documents.

✓ EA Credit 5: Renewable Energy Production (3/3 pts)

A building can receive up to 3 points for using on-site renewable energy. There is a photovoltaic array located on the roof of El Centro that produces solar energy and it is expected to produce about 9% of the buildings energy needs. This will qualify the project for three LEED points according to the figure to the right.

Percentage renewable energy	Points (except CS)	Points (CS)
1%	1	1
3%	—	2
5%	2	3
10%	3	—

Figure 17 – Points for Renewable Energy

X EA Credit 6: Enhanced Refrigerant Management (0/1 pts)

The intent of this credit is to reduce ozone depletion and to comply with the Montreal Protocol. The air cooled condensing units utilize refrigerant R-410A. To comply with this credit: $LCGWP + LCODP \times 10^5 \leq 100$. This project fails to meet this requirement. See Table 19 below for the calculation.

Refrigerant	ODP	GWP	LCODP	LCGWP	LCGWP + LCODP*10^5	Credit?
R-410A	0	1725	0	258.75	258.75	No

<u>Varaibles: Assume Worst Case</u>
Lr = 2% Leakage Rate
Mr = 10% End of Life Refrigerant Loss
Life = 10 year life expectancy
Rc = 5 lbm/ton

Table 19 – EA Credit 6 Calculation

X EA Credit 7: Green Power and Caron Offsets (0/2 pts)

To receive this credit, the building owner must engage in a contract for a minimum of 5 years to be delivered at least 50% of the projects power consumption from green power, carbon offsets, or renewable energy certificates (RECs). Green power delivery could not be found anywhere in the project documents.

Indoor Environmental Quality Credits (4/7 pts)

✓ EQ Prerequisite 1: Minimum Indoor Air Quality Performance

The project complies with this section because it meets the minimum ventilation requirements set forth by ASHRAE 62.1-2013. See Technical Report 1 for a detailed calculation and analysis of the procedure.

✓ EQ Prerequisite 2: Environmental Tobacco Smoke Control

Smoking is prohibited inside of El Centro. Signage will be posted to prohibit smoking within 25 feet of all entries, outdoor air intakes, and operable windows in compliance with this prerequisite.

✓ EQ Prerequisite 3: Minimum Acoustic Performance

This is a new prerequisite that was not included in LEED v3. It requires a maximum background noise level of 40dBA from HVAC systems in classrooms and acoustical treatment for schools located near noisy exterior sources. This project had an acoustical consultant on the design team who ensured that all classrooms are NC 30-35 which is in compliance with this section. The building is also located along the Kennedy Expressway in Northwest Chicago. There is a corridor that runs along the perimeter of the building that "shields" the classrooms from the noisy expressway.

✓ EQ Credit 1: Enhanced Indoor Air Quality Strategies (1/2 pts)

The purpose of this credit is to improve indoor air quality. A CO_2 sensor has been installed within each densely occupied space. Drawings confirming the location of the CO_2 sensors are provided in the project documents allowing the project to be eligible for one point.

X EQ Credit 4: Indoor Air Quality Assessment (0/2 pts)

The purpose of this credit is to establish better indoor air quality (IAQ) after building construction and during occupancy. One method is to flush-out the entire building by supplying a certain amount of total outside air volume. This is a new credit for LEED v4 and nothing was found in the project documents to comply with this section.

✓ EQ Credit 5: Thermal Comfort (1/1 pts)

This project complies with ASHRAE 55-2007 which identifies the range of design for temperature, humidity, and air movement that provide satisfactory thermal comfort for a minimum of 80% of the building occupants. Temperature sensors are set to automatically adjust to winter, summer, and unoccupied conditions.

✓ EQ Credit 9: Acoustical Performance (2/2 pts)

This is a new credit for LEED v4 that sets minimum reverberation times and background noise levels for different spaces. As stated previously, an acoustical consultant was on the project team and responsible for the acoustical performance of the building. The criteria provided by USGBC for this credit seem to be in line with industry standards and guidelines set by ASHRAE so it is probably safe to assume that the project would be eligible for this credit.

Mechanical Systems Evaluation

The goal for this new construction project is to establish a sustainable building that will be the forefront of Northeastern Illinois University's new campus. El Centro's mechanical system exceeds all of the requirements to adequately heat, cool, and ventilate the building. There is sufficient data to suggest that the project will achieve satisfactory indoor air quality and comfort to most of the occupants.

The overall project cost is $22 million dollars while the mechanical system first cost is expected to have been $2.4 million (38$/SF). Only 1.4% of the gross building area was dedicated to the mechanical system, yet it was 11% of the total project cost. The design utilizes minimal occupiable space for the mechanical system. The project team also expects for the building to receive $400,000 in rebates from the government for its impressive sustainable design.

The rooftop air handling units seem to be a bit oversized and exceed the minimum requirements for heating, ventilation, and air conditioning. They supply more ventilation than what is required by ASHRAE 62.1. It seems that smaller air handling units could be appropriate that would consume less energy but the design engineer could have been relying on past experience when sizing the equipment.

El Centro is projected to achieve a LEED Gold Rating but further energy savings could be improved by adding energy recovery devices to extract or reject heat to exhausted air. Optimization of the hot water plant and air handling units control can be studied to further analyze potential energy savings.

The current design achieves the design objectives and requirements set forth by various standards, building codes, and the owner. However, further analysis into other viable design options can be explored to allow El Centro to exceed these minimum requirements. These ideas will be presented further in Part II: Proposed Redesign.

Part II: Proposed Redesign

Current Design

The rooftop air handling units seem to be oversized and exceed the minimum requirements for heating, ventilation, and air conditioning. It seems that smaller air handling units could be appropriate that would consume less energy. Upon further investigation and after discussions with the design engineer, it was found that the rooftop air handling units are oversized according to ASHRAE 62.1 because the Chicago Building Code is unique in that it requires a certain amount of air be supplied to a space, regardless of the loads required. It also requires that supply air contain at least 1/3 outdoor air fraction regardless of the occupancy type. The CBC does allow for demand ventilation control which would apply to some of the classrooms and lecture halls in the building.

Alternatives Considered

Several alternatives were considered for the redesign of NEIU's El Centro mechanical system. Factors taken into account during the decision making process include cost, energy savings, system controllability, building codes, and climate. Options that were considered to redesign the system are listed below:

- Chilled Beam installation, including a chiller plant
- DOAS in accordance with a VRV system
- Building Envelope Investigation
    - Decrease the amount of glass because the curtain wall is so large
    - Use a glass with a lower u-value.
- Heat Recovery
- Ground coupled heat pump

Ultimately, it was decided that none of the above design alternatives will be implemented next semester. A detailed description of the depth and breadths that will be studied for this thesis project can be found below.

Mechanical Depth

Chicago Building Code Analysis

This project was designed using the 2012 Chicago Building Code (CBC). The CBC is unique in that it requires a certain amount of supply air to the space, regardless of what the heating and cooling loads require. This forces equipment to be larger, and therefore more expensive. In the last few years with the improvement of thermal envelopes and lighting efficiencies, the difference between the load required supply air and the CBC required supply air has increased. For example, it was found that from the TRACE Model built in Technical Report 2, Art Classroom A304 required 0.56 cfm/sf to cool the space. However, according to the CBC, art classrooms must have a minimum supply air of 1.5 cfm/sf. This is a nearly 300% increase than what standard codes require across the country. However, according to the CBC, the total supply air is allowed to be lower if the system is capable of measuring and maintaining CO_2 levels in occupied spaces, which El Centro does. The CBC table requiring these air flows can be found in the appendix at the end of this report.

Both RTU's were sized to supply 38,000 cfm of supply air each. I believe that these RTU's can be sized somewhere in the neighborhood of 20,000 - 25,000 cfm of supply air if the building was located outside of Chicago and did not conform to the dated CBC. Another unique requirement of the CBC is that it requires a minimum of 1/3 of all supply air be outside air. This requirement also often exceeds ASHRAE 62.1 requirements and is more stringent than other codes across the country. This leads to equipment being oversized and for buildings in Chicago to consume more energy than their counterparts in different cities.

Resizing Equipment Savings

I would like to resize the air handling units to not comply with the CBC, but instead comply with the IBC/IMC which is in line with ASHRAE 62.1 and 90.1 requirements. Savings that are associated with smaller air handling units include, but are not limited to, equipment first cost, energy savings, less structural steel, and smaller ductwork. Resizing the RTU's and the main ductwork will be good design experience and will be an interesting analysis of the Chicago Building Code.

Carbon Emission Reduction

Cost and energy savings associated with complying and not complying with the CBC will be compared and analyzed. Pollution emission reduction will also be analyzed. Chicago is a city with 2.7 million residents and is the third largest city in the United States. It is believed that buildings account for about 40% of all energy consumed in the United States. Although my analysis will focus on energy reduction for El Centro, a study can be conducted to look into the impacts on a grand scale if Chicago was to update their building code and change the mechanical HVAC system sections to be more in line with other codes across the country.

There will most likely not be any alternative design aspects for the mechanical system because than the values for cost and energy savings by not complying with the CBC will be altered. The purpose of this depth will be to explore how wasteful the CBC can cause mechanical systems to be.

Breadths

Structural Breadth

Since there will most likely be a significant decrease in the size of the roof top air handling units, some of the steel on the roof will have to be reframed to appropriately support the load. There will be a material and cost analysis conducted to see how much less steel can used and how much money can be saved by using a smaller frame to support the RTU's. The AISC Steel Construction Manual will be utilized for the calculations and sizing.

Electrical Breadth

The power to the new roof top air handling units is likely to be decreased, although the buildings electrical arrangement will remain the same. Electrical equipment for the RTUs such as conductors, circuit boards, and conduit may need to be resized according to the new horsepower and/or load amps associated with the RTUs. The main power delivery line into the building may be able to decrease in feeder size. The National Electric Code will be utilized for the calculations and sizing.

Tools and Methods

Load and Energy Simulation

The loads and energy usage of El Centro will be calculated using Trane TRACE 700. A model was developed for Technical Report 2 for this purpose as well, but shortcuts were taken because of time constraints (such as not angling the curtain wall even though it is not perpendicular to the ground). The model will be improved to more accurately represent the actual design of the building. This will lead to more accurate load and energy consumption results. Excel spreadsheets will be utilized further to calculate and compare supply air required by ASHRAE and supply air required by the Chicago Building Code.

Masters Coursework

Several aspects of 500-level Architectural Engineering coursework will be incorporated into this thesis project. Centralized Heating Production and Distribution Systems (AE 558) will help aid in calculating the emissions produced by the mechanical system. Content from Building Automation and Control Systems (AE 555) will help to appropriately re-size the rooftop air handling units to minimally optimize energy consumption.

Part III: Proposed Redesign Analysis

Depth Study 1: Rooftop Air Handling Unit Resize

Overview Research

Northeastern Illinois University's new building El Centro is located within the city limits of Chicago. Therefore it must conform to the 2012 Chicago Building Code (CBC). The CBC's mechanical section is unique in that it requires the system to supply a certain amount of total air, regardless of what the load is. 1/3 of this required supply air must be taken from the outdoors, regardless of the type of space the air is supplying. This often leads to stricter ventilation requirements than what is required by ASHRAE 62.1. Most codes across the United States reference the International Building Code (IBC) and International Mechanical Code (IMC). The IBC and IMC have the same ventilation requirements of ASHRAE 62.1.

Ventilation Requirements

The total supply air required by the CBC is allowed to be reduced if the system employs a way of monitoring and maintaining CO_2 levels, which El Centro does. However, the total required outdoor air supplied per space remains the same. It was found that the CBC requires about 30% more outside air than the IMC requires. The CBC outdoor air requirements were taken off of the ventilation schedule in the construction documents. Please see Table 21 below for a summary of these results. The calculations for the IBC/IMC required outdoor air can be found in the appendix.

System	CBC	IBC/IMC	% Saved
	Req'd OA (CFM)	Req'd OA (CFM)	
RTU-1 Total	9260	5761	37.79%
RTU-2 Total	10890	8292	23.86%
System Total	20150	14053	30.26%

Table 20 – CBC vs. IMC Ventilation Requirements

Load Analysis

A TRACE model was developed using block loading techniques to calculate the new loads associated with lowering the ventilation requirements. According to the TRACE model, the cooling load is reduced by about 9%. The heating load reduction was negligible. Refer to Table 22 for a summary of these results.

System	CBC		IBC/IMC	
	Cooling (Tons)	Supply Air (CFM)	Cooling (Tons)	Supply Air (CFM)
RTU-1	93	20,700	84	20,700
RTU-2	97	22,100	89	22,100
Total	190	42,800	173	42,800
		% Diff.	*-9.10%*	*0%*

Table 21 – Cooling Load Analysis

New RTU Selection

The new rooftop air handling units were selected from a variety of packaged units provided by Carrier. RTU-1 and RTU-2 have a cooling load of 84 and 89 tons respectively. Since these loads are so close to each other, identical RTUs will be chosen that have a capacity of 90 tons. Ultimately, the model number from Carrier 48D09061 was chosen. See the figure below for denotations.

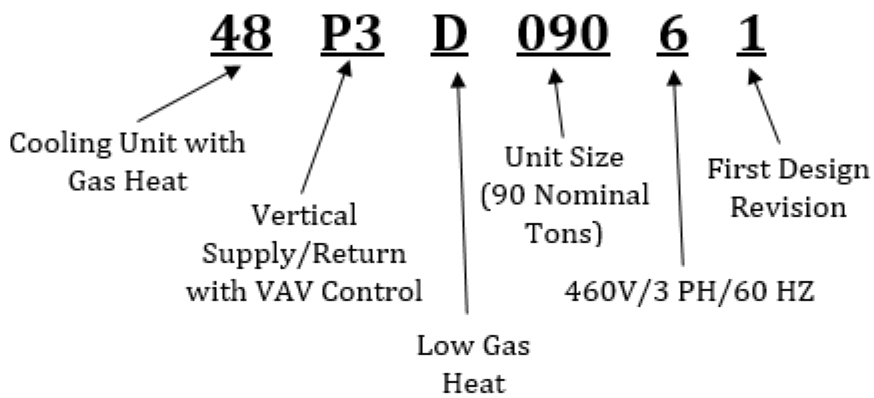


Figure 18 – Carrier Model Number Denotations

Note that a low gas heat option was chosen over a high gas heat option (527 MBH vs 790 MBH gas heat output respectively). Since these air handling units are only heating the air to 55°F year round for ventilation purposes, the low heat option is appropriate. See the calculation below.

$$q\left(\frac{BTU}{hr}\right) = 1.10 * Q(CFM) * \Delta T(°\text{F})$$

$$where\ \Delta T = T_s - T_{ma} = 0.3(-10°\text{F}) + 0.7(70°\text{F}) = 9°\text{F}$$

$$q = 1.10 * (34{,}000\ CFM) * (9°\text{F}) = 336{,}600\frac{BTU}{hr}$$

$$q = 337\ MBH\ \leq 527\ MBH\ ✓$$

Note: Carrier's free e-catalog program "Applied Rooftop Builder" was utilized for the RTU selection. The maximum cooling supply air this unit is capable of is 34,000 CFM. A summary of the loads and capacities associated with these RTUs can be found below.

Tag	Area Served	Cooling		Supply Air		Heating	
		Peak Load (tons)	Capacity (tons)	Peak Load (CFM)	Capacity (CFM)	Peak Load (MBH)	Capacity (MBH)
RTU-1	1st A&B, 2nd B	84	90	20,700	34,000	337	527
RTU-2	2nd A, 3rd A&B	87	90	22,100	34,000	337	527

Table 22 – RTU Peak Loads and Capacities Summary

Fan Selection

In the engineer's original design, two AF fans were chosen for both supply and return. In my redesign, I will only use one supply fan and one return fan. Carrier provides two options for fans in this type of air handling unit: Forward Curved Centrifugal Fans (FC) or Airfoil Fans (AF). The AF fan was selected over the FC fan because it is more efficient. FC fans are typically lower cost than AF, but since this is a large packaged rooftop unit, the AF fan is more appropriate although it has a higher first cost because of its greater efficiency. Please see the table below for energy input comparisons of the two types of fans in this particular application.

Fan Type	Total Supply (CFM)	Input Power (BHP)	Speed (rpm)
Housed FC	34,000	42.9	592
Housed AF	34,000	36.7	1432

Table 23 – Fan Selection Comparison

The FC fan requires 42.9 brake horsepower (BHP) while the AF fan requires 36.7 BHP. The AF fan was chosen because it requires about 15% less power than the FC fan. As stated previously, each RTU will house one supply fan and one return fan. Please refer to the table below for more information about the fans in each RTU.

Fan Type	Wheel Type	Qty.	E.S.P. (in. wg)	T.S.P. (in. wg)	Flow (CFM)	BHP	HP	Speed (RPM)	V/PH/Hz
Supply	AF	1	1.00	2.33	34000	36.7	40	1432	460/3/60
Return	AF	1	0.5	0.5	30000	23.1	25	1141	460/3/60

Table 24 – Misc. Fan Data

The following figures are representations of each type of fan. In the cross section, you can clearly see the difference in the types of blades associated with each fan. TRANE provided the figures below.

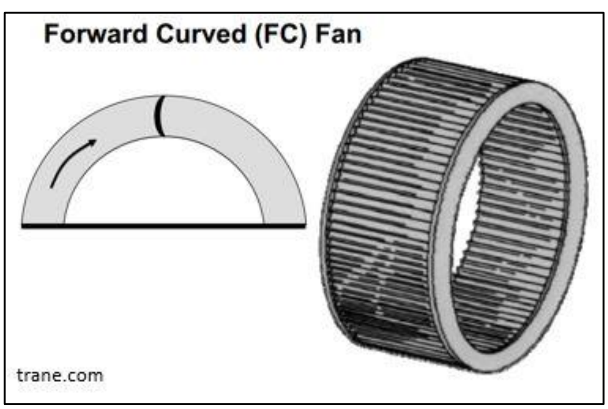


Figure 19 – FC Fan Profile

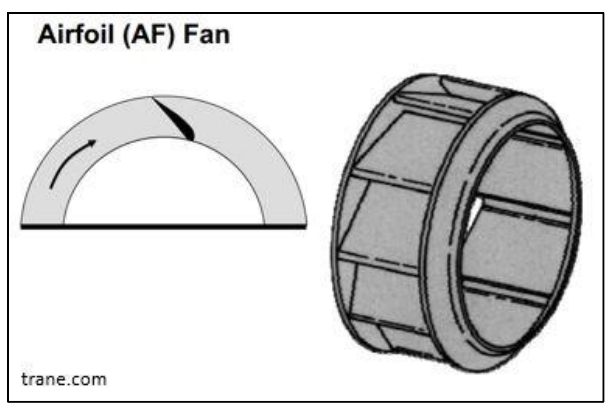


Figure 20 – AF Fan Profile

First Cost Savings

RS Means Mechanical Cost Data 2015 was used to estimate the cost of each RTU (100 ton RTU for the CBC and 90 tons RTU for the IBC/IMC). Please refer to the table below.

Applicable Code	RTU Size	Cost (incl. O&P)	Location Factor	Adjusted Cost	Qty. of RTUs	Total Cost
Baseline (CBC)	105 ton cooling	$252,000	113.6%	$286,272	2	$572,544
New (IBC/IMC)	90 ton cooling	$225,500	113.6%	$256,168	2	$512,336

Table 25 – RTU Cost Data

Total Amount Saved	$60,208
Percentage Saved	10.5%

As you can see from the table above, the total cost of furnishing and installing two 90 ton packaged rooftop units is about $512,000. This is $60,000 less than a 105 ton RTU (required by the CBC). Note that cost data for a 100 ton packaged RTU was not available in RS Means, so a 105 ton unit was used instead.

New RTU Operation and Schematic

Each RTU has one supply fan and one return fan with separate VFD control for each. Both RTU's employ an economizer cycle, so the exhaust air, return air, and outside air dampers fluctuate depending on outdoor air temperature and relative humidity, as well as the demand load of the building. The minimum volume of outdoor air incorporated is about 30% of the total supply air.

The rooftop air handling units combine the return conditioned air and outdoor air to get mixed air. The mixed air then passes through the filter (prefilter MERV-7 & final filter MERV-13). Then the air is drawn through the direct expansion (DX) cooling coil by the supply fan. Note that the air cooled condensing unit which is included in the packaged RTU serves the DX cooling coil. The air then passes through the modulating indirect natural gas fired burner which is used during the heating season. A final supply air temperature and duct static pressure are measured to ensure necessary conditions are met. Please refer to Figure 15 below for a schematic of each RTU.

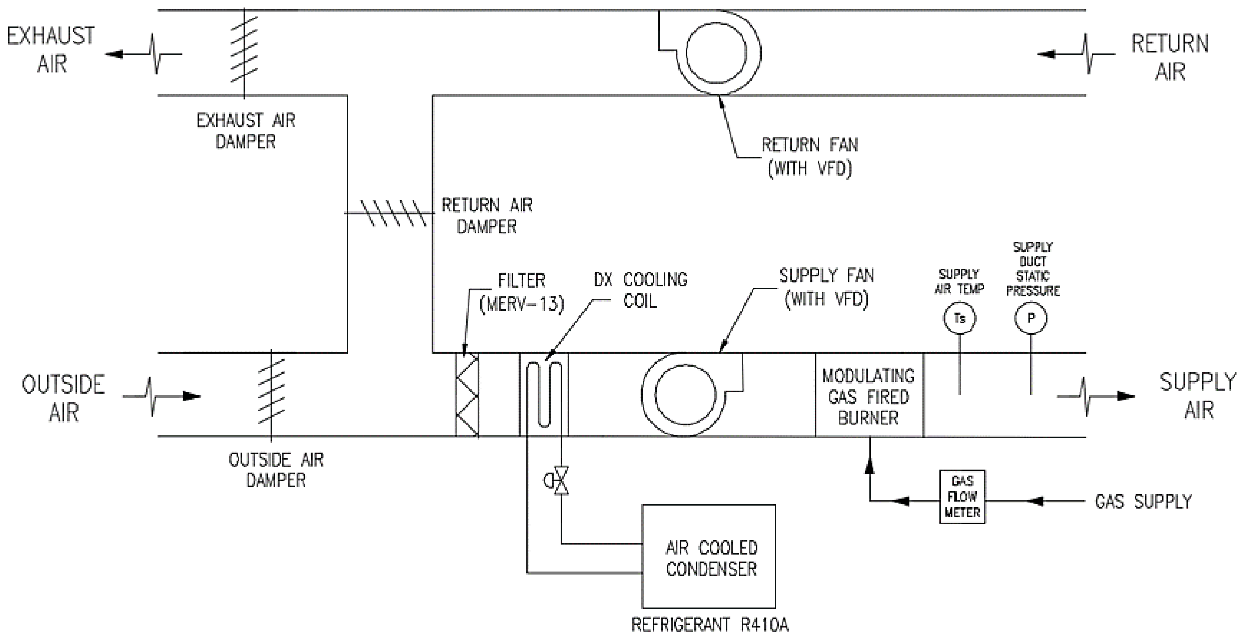


Figure 21 – New RTU Schematic

Main Ductwork Resize

The main supply duct is designed to handle the maximum capacity of the RTU which is 38,000 CFM and a friction head loss of (0.08 in. wg.)/(100 ft of duct). Upon further investigation, the main ductwork will not be resized to be smaller because in doing so, the fan power increase. This is because a smaller diameter duct will result in a higher ΔP. See the following equation below.

$$Fan\ Power\ (hp) = \frac{\dot{Q}(cfm) * \Delta P * in.wg}{6300}$$

Depth Study 2: Energy and Emission Comparisons (CBC vs. IMC)

Overview Research

Since the system requires less ventilation when complying to the IMC rather than the CBC, energy savings can be expected. El Centro utilizes two energy sources: electricity and natural gas. Electricity is generated on site with an 80 kW DC PV array located on the roof. Excess electricity needed on site will be drawn off the grid and provided by the local utility company: Commonwealth Edison (ComEd). Excess electricity created on site can be exported to the grid and sold to ComEd (measured by a two way electric meter). Natural gas service for El Centro will be provided by a pipeline from the Peoples Gas Company. Peoples Gas delivers its products through some 2,000 miles of pipelines in Chicago. Natural gas will be provided to both indirect gas fired air handling units, both boilers, and the domestic water heater.

Utility Costs

An average yearly energy cost was used during the first semester to calculate the yearly energy costs associated with the systems in El Centro. Average monthly utility rates for the site were provided by the engineer and will lead to more accurate representation of operational costs for El Centro. Electricity is more expensive in the warmer months because there is more demand. Natural Gas is more expensive in the summer months because there is less demand for it. Please see the table and figure below for average commercial monthly utility rates for Chicago below.

Month #	Month	Data Year	Electricity ($/kWh)	Natural Gas $/Therm
1	Jan	2013	$0.0758	$0.6870
2	Feb	2013	$0.0793	$0.6730
3	Mar	2013	$0.0780	$0.7040
4	Apr	2012	$0.0836	$0.7650
5	May	2012	$0.0855	$1.0370
6	Jun	2012	$0.0794	$1.0620
7	Jul	2012	$0.0815	$1.2040
8	Aug	2012	$0.0825	$1.1800
9	Sep	2012	$0.0828	$1.0030
10	Oct	2012	$0.0800	$0.8300
11	Nov	2012	$0.0801	$0.7510
12	Dec	2012	$0.0775	$0.7280

Table 26 – Average Monthly Utility Rates

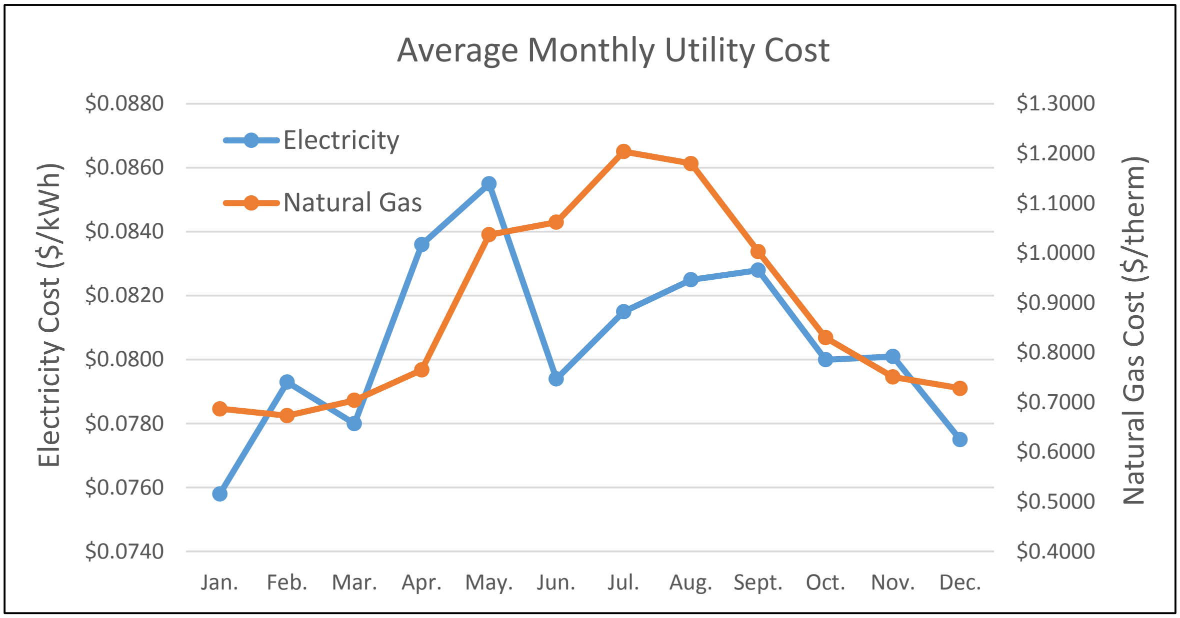


Figure 22 – Average Monthly Utility Rates Graph

As you can see in the graph above, utility rates fluctuate throughout the year.

Total Utility Consumption

Below is a table that summarizes the total building utility usage per month for El Centro.

Month	CBC			IBC/IMC		
	Elec Used (kWh)	NG Used (therms)	Total Fuel Cost	Elec Used (kWh)	NG Used (therms)	Total Fuel Cost
Jan.	47,653	3,230	$5,831	48,012	2,464	$5,332
Feb.	42,833	2,013	$4,751	43,149	1,464	$4,407
Mar.	47,971	1,341	$4,686	47,998	1,012	$4,456
Apr.	51,416	321	$4,544	52,299	308	$4,608
May.	67,751	22	$5,816	67,914	21	$5,828
Jun.	77,829	0	$6,180	76,169	0	$6,048
Jul.	82,507	0	$6,724	80,446	0	$6,556
Aug.	85,721	0	$7,072	83,348	0	$6,876
Sept.	70,043	3	$5,803	69,186	3	$5,732
Oct.	59,409	192	$4,912	60,625	186	$5,004
Nov.	46,192	854	$4,341	46,175	727	$4,245
Dec.	47,579	1,627	$4,872	47,710	1,231	$4,594
Total	**726,904**	**9,603**	**$65,532**	**723,031**	**7,416**	**$63,686**
			% Saved	0.54%	29.49%	2.90%

Table 27 – Total Monthly Building Utility Usage

From the table above you can clearly see that there are minimal savings in electricity usage when complying with the IBC/IMC rather than the CBC (0.54% savings). There are significant savings in natural gas usage however (nearly 30%). The electricity usage peaks during the summer months and the natural gas usage peaks during the winter months. This is because the cooling plant utilizes electricity to operate and the boilers utilize natural gas. Please refer to the bar graphs below that represent the monthly utility usage of electricity and natural gas when El Centro complies with either code.

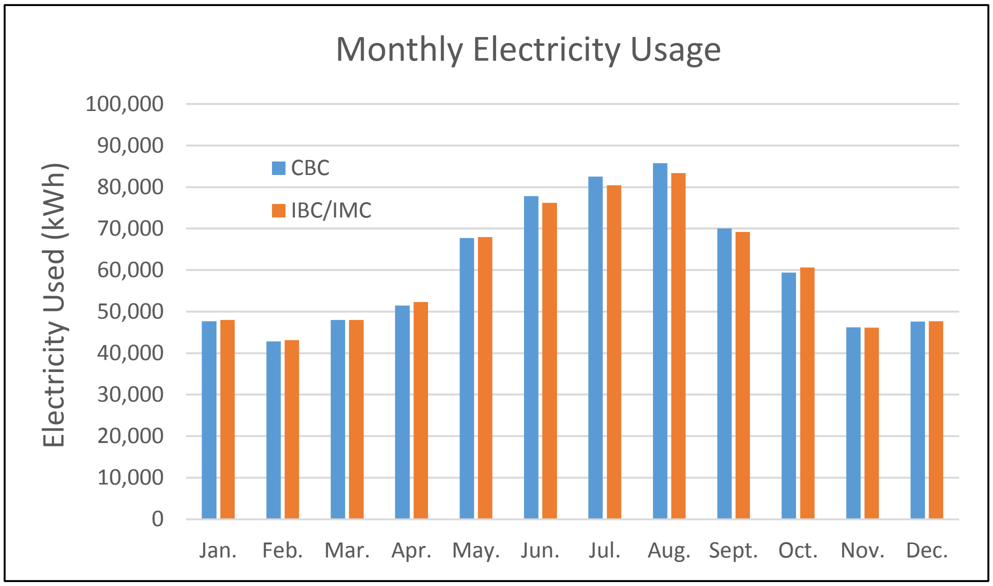


Figure 23 –Monthly Electricity Usage

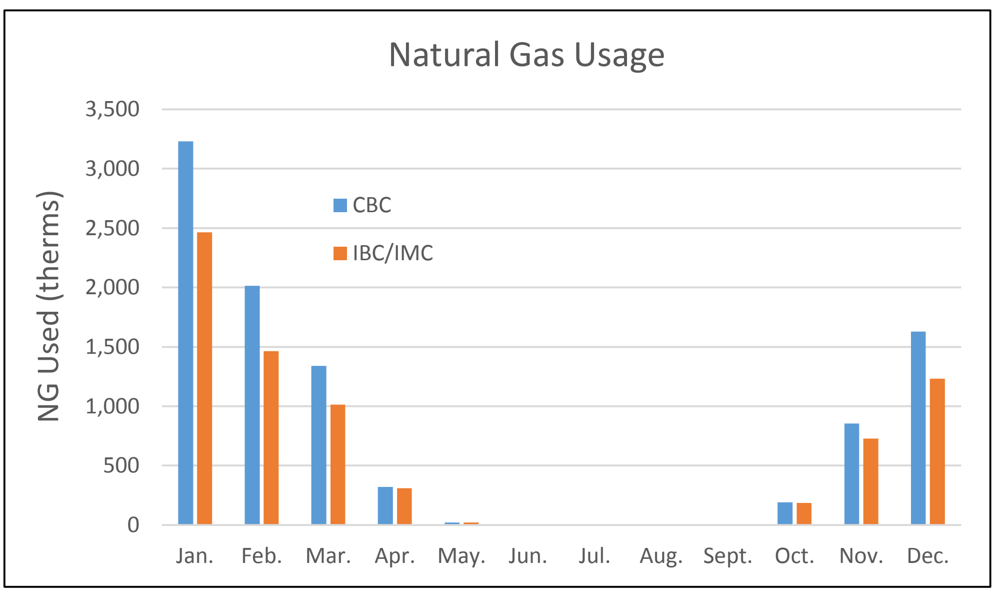


Figure 24 –Monthly Natural Gas Usage

The figure below represents the monthly energy cost savings when complying with IBC/IMC in lieu of the CBC. These cost savings are minimal, but are most noticeable during the winter months when significant volumes of natural gas are being saved. The total annual energy cost savings associated with the IBC/IMC are only about 3% of the baseline CBC energy costs.

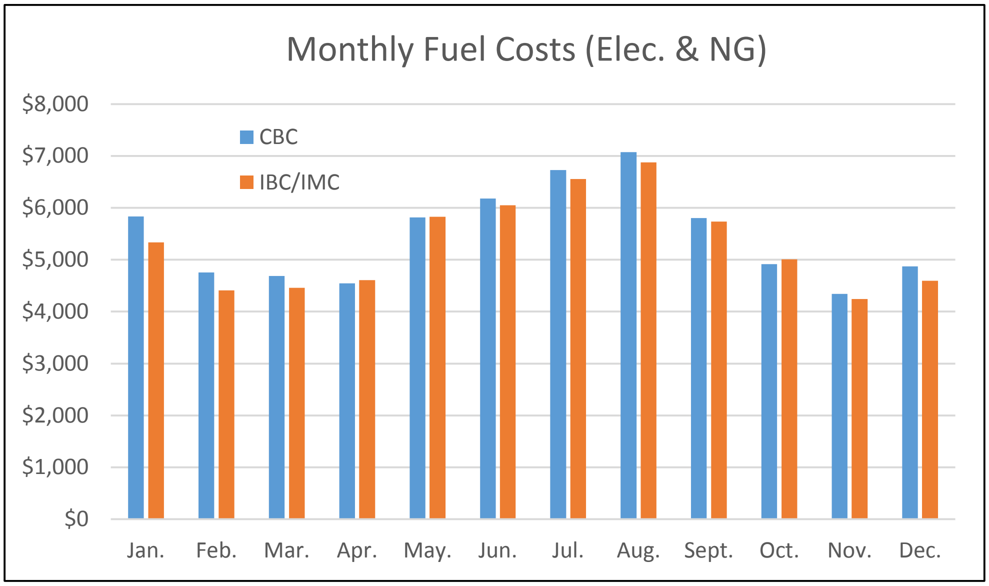


Figure 25 – Monthly Natural Gas Usage

System Energy Savings

The table below is a summary of the energy usage by the different systems within El Centro. Electricity and natural gas usage were both converted to kBtu/year so they are in the same units of energy. Notice that the largest user of energy in the building is the lighting followed by heating for each applicable code. On the next page in Table 29, the total energy per year is broken down into kBTU/SF/yr. 4 kBTU/SF can be saved per year at El Centro if the IBC/IMC was followed instead of the CBC.

Building System	CBC		IBC/IMC	
	Total Energy Used (kBtu/yr)	% of Total Building Energy	Total Energy Used (kBtu/yr)	% of Total Building Energy
Heating	976,350	28.2%	757,755	23.5%
Cooling	448,996	13.0%	432,986	13.4%
Auxiliary	369,150	10.7%	371,932	11.5%
Lighting	1,324,987	38.3%	1,324,987	41.1%
Receptacle	339,038	9.8%	339,038	10.5%
Total	*3,458,521*	*100%*	*3,226,698*	*100%*

Table 28 – System Energy Usage

Code	Total Energy (kBTU/yr)	Total Energy per SF (kBTU/SF/yr)
CBC	3,458,521	63
IBC/IMC	3,226,698	59
Energy Saved	231,823	4
% Saved	6.7%	6.7%

Table 29 – Total Building Energy Usage

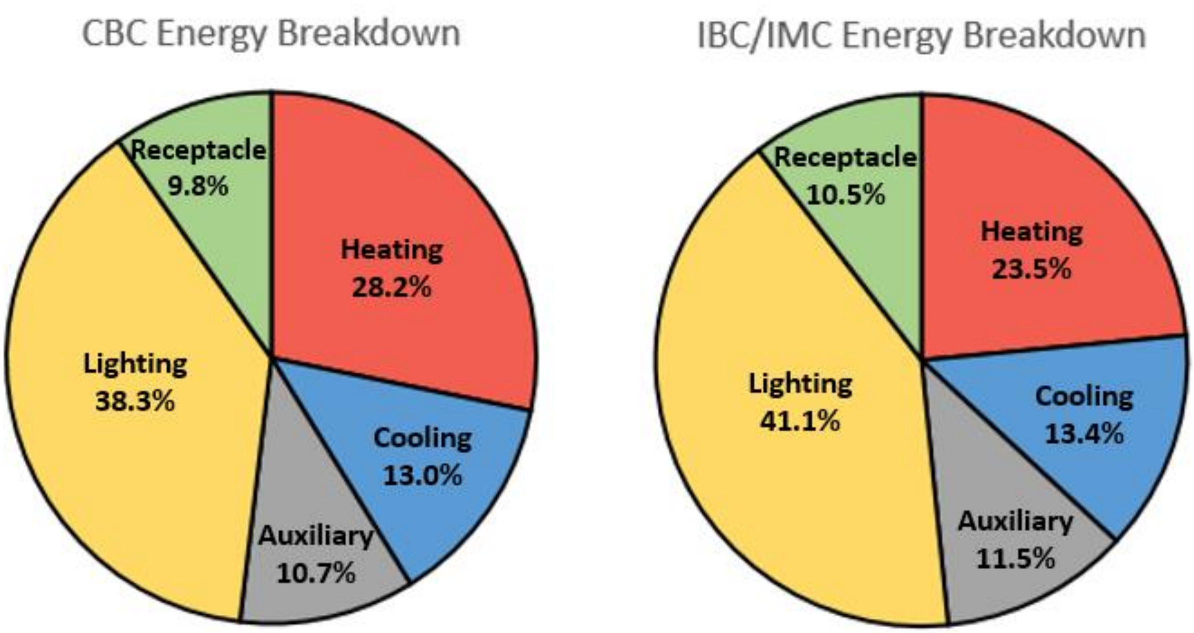


Figure 26 – System Energy Breakdown Comparison

The figures above represent the energy breakdown within the building for each code. The most noticeable difference is the reduction in heating energy used (28.2% for the CBC vs. 23.5% for the IBC/IMC). At about 40% of the buildings total energy usage, lighting makes up the largest user of energy in the building for both codes. It is high because there are a lot of interior classrooms in El Centro with no exterior walls or windows. These spaces have much higher lighting requirements than corridors and the corridor happens to get most of its light from the curtain wall that encloses the building.

The total amount electricity saved by the cooling plant when applying the IBC/IMC is only about 3.5% when compared to the CBC. The total amount of natural gas saved by the heating plant is about 22%. The reason that the heating plant saves so much more energy than the heating plant is because of the number of degree days. There are 6311 heating degree days (HHD 65F) in Chicago vs. only 842 cooling degree days (CCD 65F). Please see the appendix in the back of this report for the data provided by ASHRAE.

The reason HHD is so much greater than CCD is because of the ΔT. The average winter temperature in Chicago is about 25°F while the average summer temperature is about 85°F. See below.

$$\Delta T = |T_{RA} - T_{OA}|$$

$$\Delta T_{cooling} = |75°\text{F} - 85°\text{F}| = 10°\text{F}$$

$$\Delta T_{heating} = |70°\text{F} - 25°\text{F}| = 45°\text{F}$$

Emission Comparison

Most of the emission savings associated with complying with the IBC/IMC over the CBC is the natural gas being saved for heating purposes. The total CO_{2e} (carbon dioxide pollutant equivalent) emissions for the CBC is about 1.39 million pounds per year and for the IBC/IMC is 1.36 million pounds. This equates to a total annual pollutant savings of about 2.4% if complying with the IBC/IMC in lieu of the CBC.

Code	Pollutant	Electricity		Natural Gas		Total
		lb/kWh	lbs.	lb/MCF	lbs.	(lbs pollutant/year)
CBC	CO_{2e}	1.74	1,273,668	123	118,080	1,391,748
	CO_2	1.64	1,200,469	122	117,120	1,317,589
	NO_x	0.003	2,196	0.111	107	2,303
IBC	CO_{2e}	1.74	1,266,904	123	91,229	1,358,134
	CO_2	1.64	1,194,094	122	90,487	1,284,581
	NO_x	0.003	2,184	0.111	82	2,267
		% Saved (CO_{2e})	0.53%		22.74%	2.42%

Table 30 – Annual Emissions

Depth Study 3: City of Chicago Study

Overview

The city of Chicago is the third largest city in the country, after New York and Los Angeles. Since it has one of the largest building stocks in the country, and the world, it would be interesting to see how much potential energy and pollutant emissions would be saved if every building's mechanical system was designed to comply with the IBC/IMC rather than the CBC. Please see the table below to see where Chicago ranks for the number of skyscrapers in relation to the rest of the world's major cities. Note that a skyscraper is defined as a building that is at least 150 meters tall (492 feet).

Rank	City	Country	No. of Skyscrapers
1	Hong Kong	China	302
2	New York City	United States	235
3	Dubai	United Arab Emirates	148
4	Shanghai	China	126
5	**Chicago**	**United States**	**115**
6	Tokyo	Japan	112
7	Chongqing	China	94
8	Guangzhou	China	93
9	Shenzhen	China	83
10	Singapore	Singapore	79

Table 31 – International City Skyscraper Count

Chicago Climate Action Plan

The Chicago Climate Action Plan (CCAP) is Chicago's climate change alleviation and adaptation strategy that was created in September 2008. The CCAP has an ultimate goal of reducing Chicago's greenhouse gas emissions by 80 percent below 1990 levels by the year 2050, with an intermediate goal of 25 percent below 1990 levels by 2020.

The Chicago Action Plan Consists of Five Strategies:

- **Energy Efficient Buildings (30%)**
- Clean & Renewable Energy Sources (34%)
- Improved Transportation Options (23%)
- Reduced Waste & Industrial Pollution (13%)
- Adaptation

The plan calls for the Energy Efficient Building Strategy to account for 30% of greenhouse gas reductions. The plan expects for over 50% of all buildings in Chicago to undergo a retrofit. I believe that upgrading the city Energy Code and CBC can affect these retrofits significantly.

Energy Savings Estimation

Chicago currently has upwards of 23,000 commercial, institutional, and industrial buildings which includes government, office buildings, schools, hospitals, corner grocery stores, etc. according to a recent report of the Chicago Climate Action Plan. It is hard to estimate the total square footage of all of these buildings because they vary so much. For instance, the Willis Tower (formerly the Sears Tower) is 4.5 million square feet, while NEIU El Centro is only 55,000 square feet.

In the 2014 City of Chicago Building Energy Benchmarking Report, it is estimated that Chicago buildings spends $3 billion a year on energy. I calculated that NEIU will spend about $65,000 a year for energy for El Centro. This is equates to about $1.20/SF/yr. Using these numbers, an estimated square footage for the commercial building stock in Chicago can be roughly calculated. Note that some buildings such as hospitals require more energy per SF, but other buildings such as office buildings require less energy per SF when compared with El Centro. See the table below provided by the DOE for energy use intensities (EUIs) in the city of Chicago in 2009.

Building Type	kBTU/ft^2/yr
Large Office	43
Medium Office	48
Small Office	51
Warehouse	24
Stand-alone Retail	81
Strip Mall	85
Primary School	65
Secondary School	76
Supermarket	195
Quick Service Restaurant	657
Hospital	148
Outpatient Facility	271
Small Hotel	80
Large Hotel	138
Mid-Rise Apartment	47
NEIU El Centro*	**62**

Table 32 – Energy Use Intensities in Chicago in 2009
****Calculated by TRANE Trace***

As you can see from the table above, El Centro lands somewhere in the middle of the EUIs at 62 kBtu/ft^2/yr. But since El Centro is a university type building with varying spaces such as classrooms, offices, laboratories, and lounges it is somewhat representative of the diverse Chicago building stock. See the calculation below for an equivalent total Chicago building stock square footage using the cost per square foot for energy of El Centro and the total cost of energy for the buildings of Chicago.

$$Total\ Equivalent\ Square\ Footage\ of\ Commercial\ Building\ Stock\ in\ Chicago =$$

$$\frac{3{,}000{,}000{,}000\,\frac{\$}{yr}}{1.20\,\frac{\frac{\$}{ft^2}}{yr}} = 2{,}500{,}000{,}000\ ft^2$$

Using 2.5 billion square feet of equivalent building stock in Chicago, energy and pollutant savings can be calculated if all of the city's commercial buildings conformed to the IBC/IMC instead of the CBC. To do this, El Centro's energy and pollutant savings on a square foot basis will be utilized.

I estimated that El Centro can save up to 2.9% of money spent on energy if it conformed to the IBC/IMC instead of the CBC. If all the buildings in Chicago had mechanical systems designed for the IBC/IMC, there is a potential savings of $87 million per year. Note that this is assuming that all buildings have a potential economic savings of 2.9% associated with their mechanical system. Please see the table below.

Total Amount Chicago Spends on Building Energy ($)	Potential Savings (%)	Potential Savings ($)
$3 billion	2.90%	**$87 million**

Table 33 – Economic Impact

El Centro saved 6.7% in total building energy. Most of this energy was saved through the natural gas saved for the heating plant. Chicago could potentially save 10.4 billion kBtu/year assuming a 6.7% energy savings. Please see the table below.

Total Amount of Energy Used by Chicago Buildings (kBtu/year)	Potential Savings (%)	Potential Savings ($/year)
155 billion kBtu	6.70%	**10.4 billion kBtu**

Table 34 – Potential Energy Savings

Pollutant Savings

El Centro saves about 2.42% of pollutant savings. Assuming that the buildings of Chicago can save this much, there is a potential savings of 765,000 tons of CO_{2e} per year. This would be equivalent to taking 184,000 cars off the road each year. Please see the equation below for the method used to calculate the amount of CO_2 cars produce:

$$\frac{12{,}000\ driven\ miles\ per\ year\ (average)}{25.5\ miles\ per\ gallon\ (average)} = 471\ gallons\ per\ year\ (average)$$

$$471\ gallons\ per\ year\ x\ 17.68\,\frac{lbs.CO_2}{gallon} = \mathbf{8320\ lbs.CO_2\ per\ car\ per\ year}$$

Unit	Total Pollutants Produced by Chicago Buildings (CO_{2e}/year)	Potential Savings (%)	Potential Savings (CO_{2e}/year)
lbs. CO_{2e}/year	63 billion lbs.	2.42%	**1.5 billion lbs.**
tons CO_{2e}/year	31.6 million tons	2.42%	**765,000 tons**
Equivalent of Cars on the Road per year	7.6 million cars	2.42%	**184,000 cars**

Table 35 - Pollutant Savings

Mechanical Depth Conclusions

The savings in the peak cooling load and heating load associated with complying to the IBC/IMC ventilation requirements instead of the CBC are low (9% for cooling and negligible for heating). This allowed for slightly smaller RTUs to be specified for this project. But for other projects, smaller equipment may not be available to be specified because the next size piece of equipment may have too low of a capacity since the peak cooling and heating load savings are so low.

The energy saved associated with complying with the IBC/IMC is mostly through the natural gas savings because the number of HDD is so much greater than CDD. Overall, the energy savings are small at 6.7% per year which results in about $2,000 per year being saved on energy costs`. The pollution saved is about 2.42%.

The economic, energy, and pollutant savings for El Centro are quite small when looking at it at a micro level. But looking at the potential savings for the entire city of Chicago if it were update its mechanical section of the building code are substantial. The potential impact is:

- $87 million in energy savings per year
- 10.4 billion kBtu in energy savings per year
- 765,000 tons of CO_{2e} saved per year (equivalent to taking 184,000 cars off the road)

Breadth Study 1: Structural

Overview

The new RTU's have a smaller operating weight and footprint than the existing design, so there is an opportunity for steel savings. The new design utilizes RTUs that each have air cooled condensing units built into them. Therefore, extra steel that was required for the separate air cooled condensing units in the existing design is no longer needed. Please refer to the figure below for clarification.

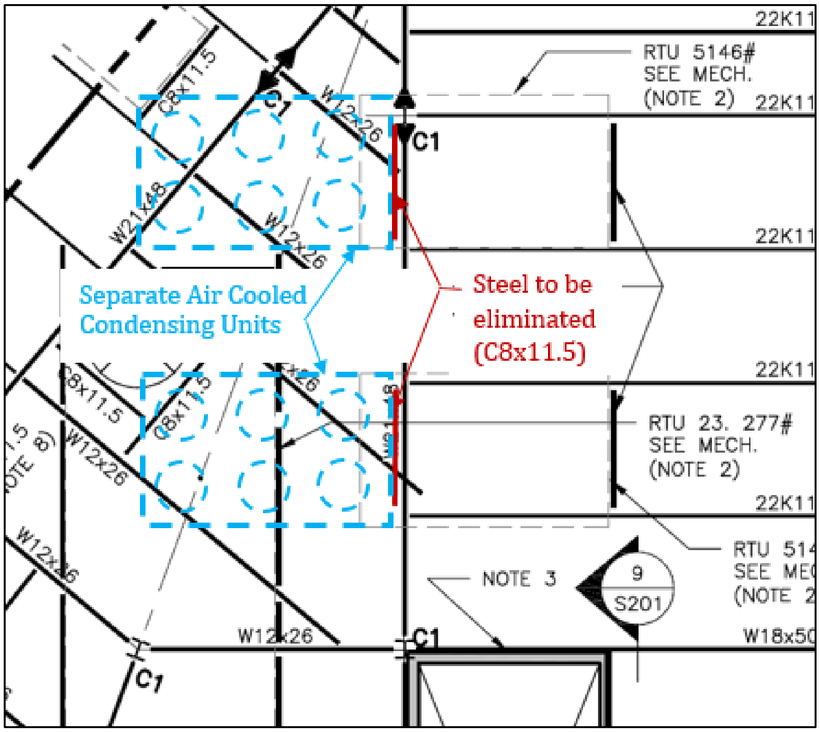


Figure 27 – Existing Partial Structural Roof Plan with Separate ACU's (Courtesy of Construction Documents)

Rooftop Air Handling Units

The new designed RTUs have a significant decrease in their operating weight when compared to the existing RTUs. The RTU's also have a smaller footprint, because they are not as long or as wide. Please refer to the table below.

Unit	CBC Operating Weight (lbs)	IBC/IMC Operating Weight (lbs)
RTU-1	23277	11054
RTU-2	26380	11054

Table 36 – RTU Operating Weight

See the next page for a partial structural roof plan that displays the downsize in footprints of the RTU's when comparing the old design to the new design.

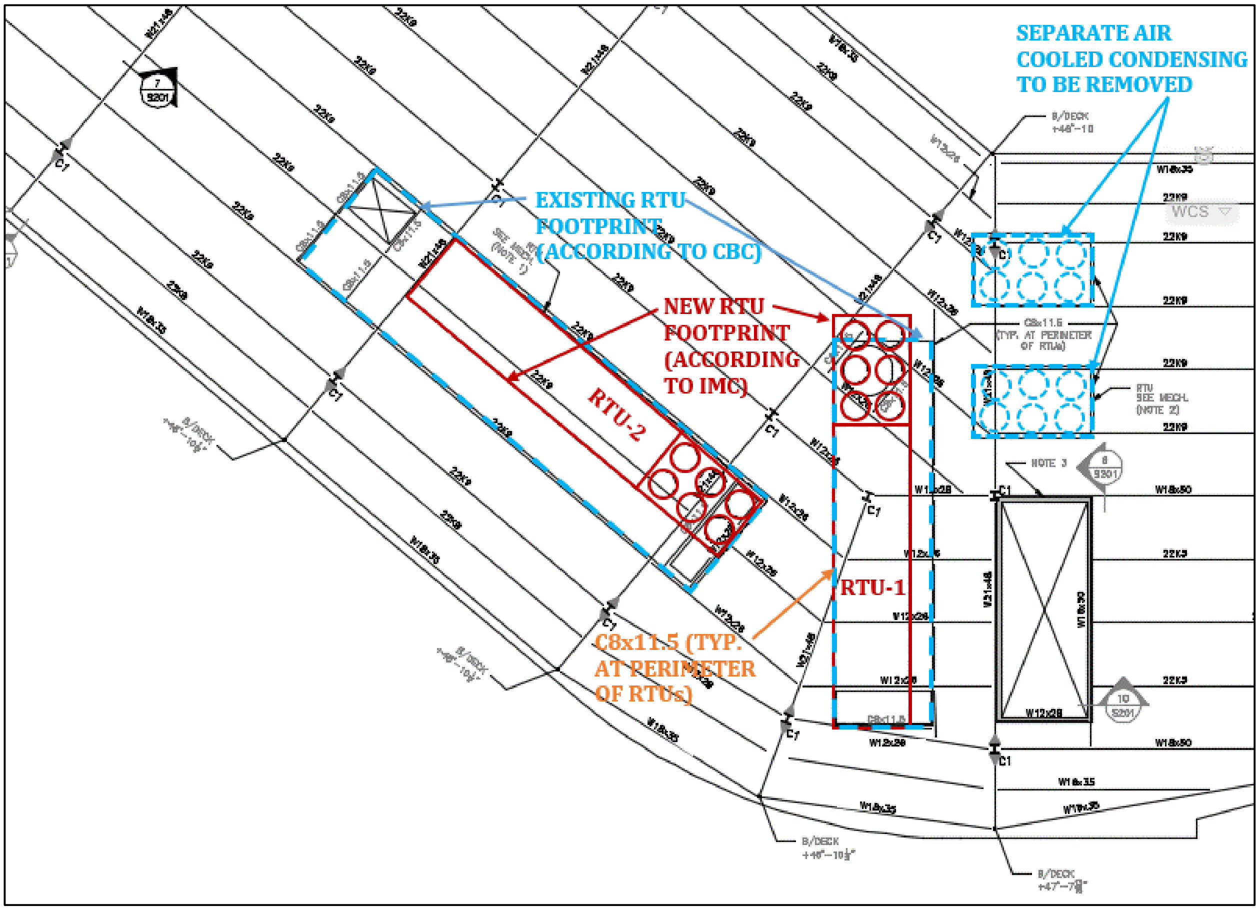


Figure 28 – Partial Structural Roof Plan with RTU footprints (Courtesy of Construction Documents)

Structural Gravity Loads

Since the new RTUs sized according to IMC weigh less and have a smaller footprint, the steel supporting them is able to be reduced. The table below illustrates the loads associated with structurally supporting the roof

Load Type	Material	Weight (psf)
Dead Load	PVC Roof	10
	1/2" Cover Board	2
	R-30 Insulation Board	2
	Galvanized Metal Deck	2
	Misc. (lights, duct, PV array, etc.)	10
Live Load or Snow Load	Live Load	20
	Snow Load	25
Total	***Dead Load***	***26***
	Snow Load	***25***

Table 37 – Roof Loads

The new steel beams will be sized according to the Load and Resistance Factor Design Method (LRFD):

$$Load\ Combination \quad 1.2D + 1.6(L_r or\ S\ or\ R)$$

Where D = Dead Load
L_r = Roof Live Load
S = Snow Load
R = Rain Load

Because the snow load is greater than the roof live load, the snow load controls.

$$1.2(26\ psf) + 1.6(25\ psf) = 71\ psf\ factored\ load$$

RTU-2 Analysis

The newly sized RTU-2 was is located in the same place as the existing design. The figure below shows the location and the few variations in the layout of the steel. The beams below are the original sizes associated with the original RTU-2. The beams highlighted in red will be structurally analyzed to ensure they can support the new loads and to see if the girders and joists can be reduced. The point loads in green are the loads associated with the new RTU-2 and they are already factored (1.2D).

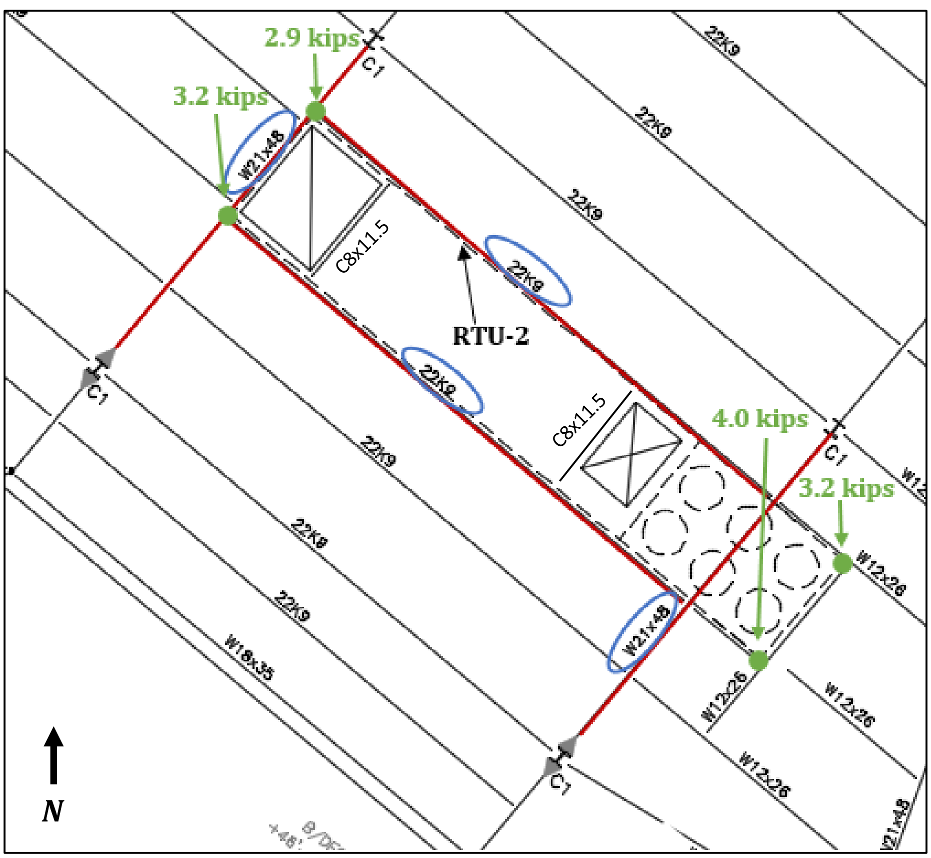


Figure 29 – New Steel Framing Plan for RTU-2 (Courtesy of Construction Documents)

West W21x48 Analysis

The west W21x48 will be analyzed because it supports a greater load than the east W21x48 because it has a larger tributary width. (36 feet as opposed to 26 feet). The following figure is beam diagram that depicts the loading. 2.9 kips and 3.2 kips are the point loads associated with RTU-2.

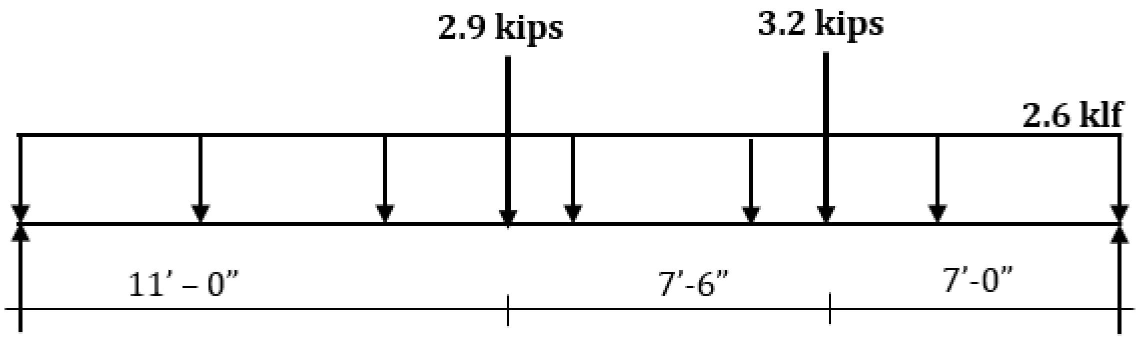


Figure 30 – Beam Loading Diagram

The beam diagram can be simplified so that the moment can be easily calculated. See the following figure.

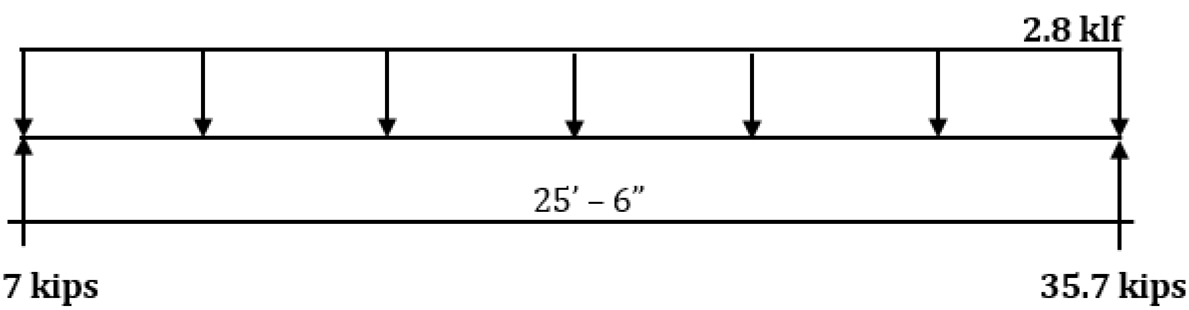


Figure 31 – Simplified Beam Loading Diagram

Mid Span Moment $$M = \frac{wl^2}{8} = \frac{(2.8\ klf)(25.5\ ft)^2}{8} = 228\ kip - ft$$

Max Deflection $$\Delta \leq \frac{L}{240} = \frac{25.5\ ft * 12\frac{in}{ft}}{240} = 1.275\ in.$$

$W21x44\ (I_x = 843)$ $$\Delta = \frac{5wl^4}{EI} = \frac{5\left(233.3\frac{lb}{in}\right)(306\ in)^4}{384(30 * 10^6\frac{lb}{in^2})(843\ in^4)} = 1.053\ in.\ ✓$$

(Max M = 358 kip-ft) ✓

The maximum moment occurs at the beam's midspan and is 228 kip-ft. The maximum deflection for this beam is 1.275 inches. A beam size of W21x44 can support this load (max allowable moment of 358 kip-ft and a deflection of 1.053 in. under these loading conditions). The beam size is decided by the maximum deflection, because the shear force is insignificant, and smaller beams can support this moment, but fail the deflection criteria. This is a slight decrease in girder size compared to the W21x48 used to support the heavier RTU. This means that both W21x48 beams can be reduced to W21x44. Please refer to the Z_x tables in the appendix for reference.

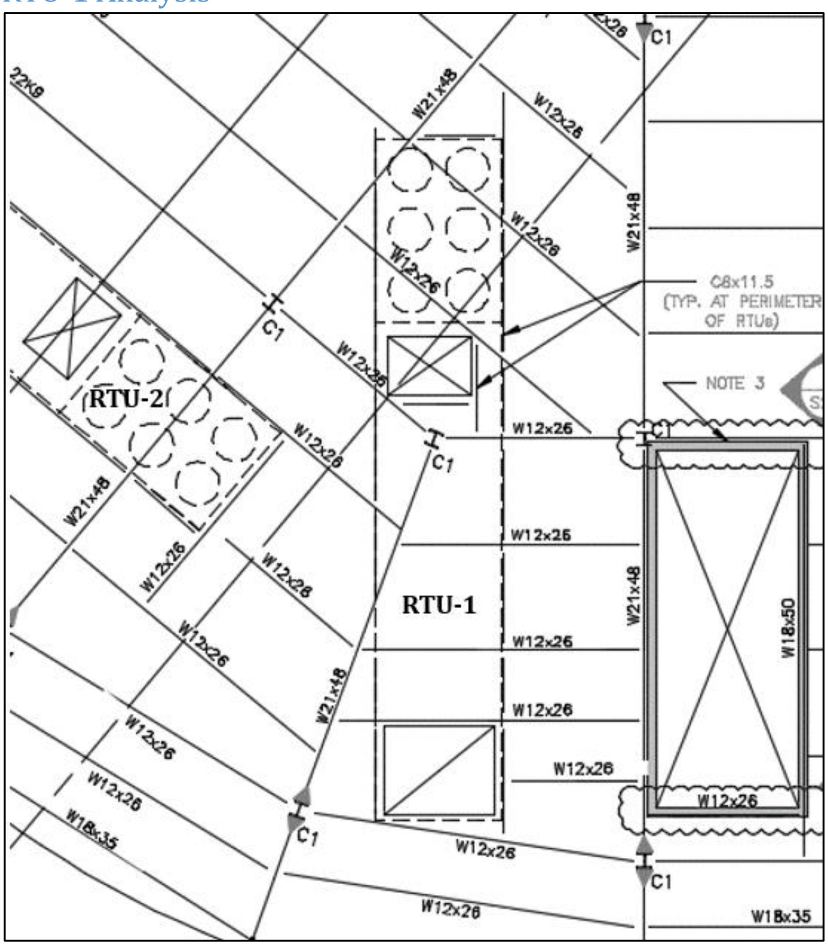
Steel Joist 22K9 Analysis

Each 22K9 being analyzed in Figure 16 support the same loads and have the same span length of 36 ft. The joists have a tributary width of 6.75 ft.

$$w_u = (6.75\ ft) * (71\ psf) = 479\ plf$$

A 22K9 joist that spans 36 ft can support a factored load of 516 plf. This joist can be reduced to a 26K7 but due to the increased depth of the joist, it cannot be reduced. Please refer to the appendix for the economy table of open web steel joists, K-series.

RTU-1 Analysis



The framing around RTU-1 will not be reduced because it is being supported by W12x26 girders and beams. This is already a small size beam, and is more than adequate in supporting the current loads. Since RTU-1 has reduced in weight, it is safe to assume that the same beam/girder layout can support the new size. The structural engineer of record for the project does not use any beams smaller than W12x26, so they will not be reduced. This can be for a variety of reasons such as previous design knowledge and experience.

Figure 32 - New Steel Framing Plan for RTU-1

Reduced Structural Steel Cost Savings

Cost Data for Structural Steel was taken from RS Means Facilities 2015. It is estimated that about $2,776 can be saved if the smaller RTU's are implemented. The main cost difference comes from the reduced length of C8x11.5 members needed. The C8x11.5 beams frame the perimeter of each RTU, and since the IBC/IMC RTUs are smaller and the separate air cooled condensing units do not need to be framed for the new design, this length is able to be reduced significantly. Please see the table below for a summary of these results.

Beam Size	CBC Length (ft)	IBC/IMC Length (ft)	Cost ($/LF) (incl O&P &loc.)
C8x11.5	151	124	$83.68
W21x44	0	51	$84.21
W21x48	51	0	$94.34
Total Cost	**$17,447**	**$14,671**	
Savings:		***$2,776***	

Table 38 – Structural Steel Cost Savings

Structural Breadth Conclusions

There are steel savings associated with the new RTU selection. However, this is a result of using a different strategy in specifying the equipment. In the new design, packaged RTUs were chosen that include condensing units, while in the existing design they were separate. Choosing a different manufacturer as the original design also resulted in a smaller footprint and operating weight of the equipment. So by using a different design strategy, the steel was able to be used.

This steel savings was not in relation to having smaller equipment sized based off of the IBC/IMC. The equipment, when designed to IBC/IMC instead of CBC, in other buildings may be able to be minimally resized but it will most likely not have an impact on a reduction of steel because the operating weights will be nearly identical. For example, the 100 ton packaged RTU from carrier is only a mere 20 lbs. heavier than the 90 ton packaged RTU.

Breadth Study 2: Electrical

Overview

In the existing design, the separate air cooled condensing units are wired directly to the main switchboard of the building. The RTUs are served by a mechanical panel, which in turn is served by the main switchboard. Since in the new design, the condensing units are included with the packaged RTU, this wiring can be eliminated. The new design still employs a separate mechanical panel, but the panel needs to be larger to accommodate the larger load of the packaged RTU which includes the condensing units.

Branch Wiring and Feeder Tables & Conduit Calculations

In the new design, the branch wiring to the condensing units can be removed. Please refer to the table below for the new branch size wiring to the roof top units and the accompanying conduit calculation.

System	Equipment	V/PH/Hz	FLA	MOCP	kVA	Wire (Copper) (THWN)	Ground (Copper)	Conduit (EMT)
Existing	RTU-1	460/3/60	149	150 A	124	(4) #2/0	#6	2"
	RTU-2	460/3/60	149	150 A	124	(4) #2/0	#6	2"
	CU-1	460/3/60	227	250 A	189	(4) 350 kcmil	#4	3 1/2"
	CU-2	460/3/60	227	250 A	189	(4) 350 kcmil	#4	3 1/2"
New	RTU-1	460/3/60	257	300 A	214	(4) 300 kcmil	#4	**2 1/2"**
	RTU-2	460/3/60	257	300 A	214	(4) 300 kcmil	#4	**2 1/2"**

Table 26 – Existing and New Branch Wire Sizing for RTUs

$$[300\ kcmil] \quad 0.4608\ in^2 * 4 = 1.8432\ in^2$$
$$[\#4] \quad 0.0824\ in^2 * 1 = \underline{0.0824\ in^2}$$
$$1.9256\ \text{in}^2$$ ∴ use **2 ½" Conduit**

System	Panel Label	Equipment Served	Voltage	FLA	kVA	MOCP	Feeder Size (Copper, THWN, EMT)
Existing	DPM3-1	RTU-1 & RTU-2	480/277	298	248	600 A	(2) sets: 4-350 kcmil, #1/0 Grd, 3 1/2" C
New	DPM3-1	RTU-1 & RTU-2	480/277	514	428	800 A	(3) sets: 4-300 kcmil, #2 Grd, **2 1/2" C**

Table 27 – Existing and New Feeder Sizing for RTUs

$$[300\ kcmil] \quad 0.4608\ in^2 * 4 = 1.8432\ in^2$$
$$[\#2] \quad 0.1158\ in^2 * 1 = \underline{0.1158\ in^2}$$
$$1.959\ \text{in}^2$$ ∴ use **2 ½" Conduit**

Simplified One Line Diagrams

Below there are two figures that show simplified one-line electrical arrangement diagrams to the RTU equipment located on the roof and visually summarizes the tables on the previous page. It is important to note that in the existing design, separate wiring was run from the main switchboard of the building directly to the condensing units. In the new design, this wiring can be eliminated because they are included with the packaged RTU. The mechanical panel serving the RTUs needs to be a larger size, but these costs would be offset by the eliminated separate CU wiring.

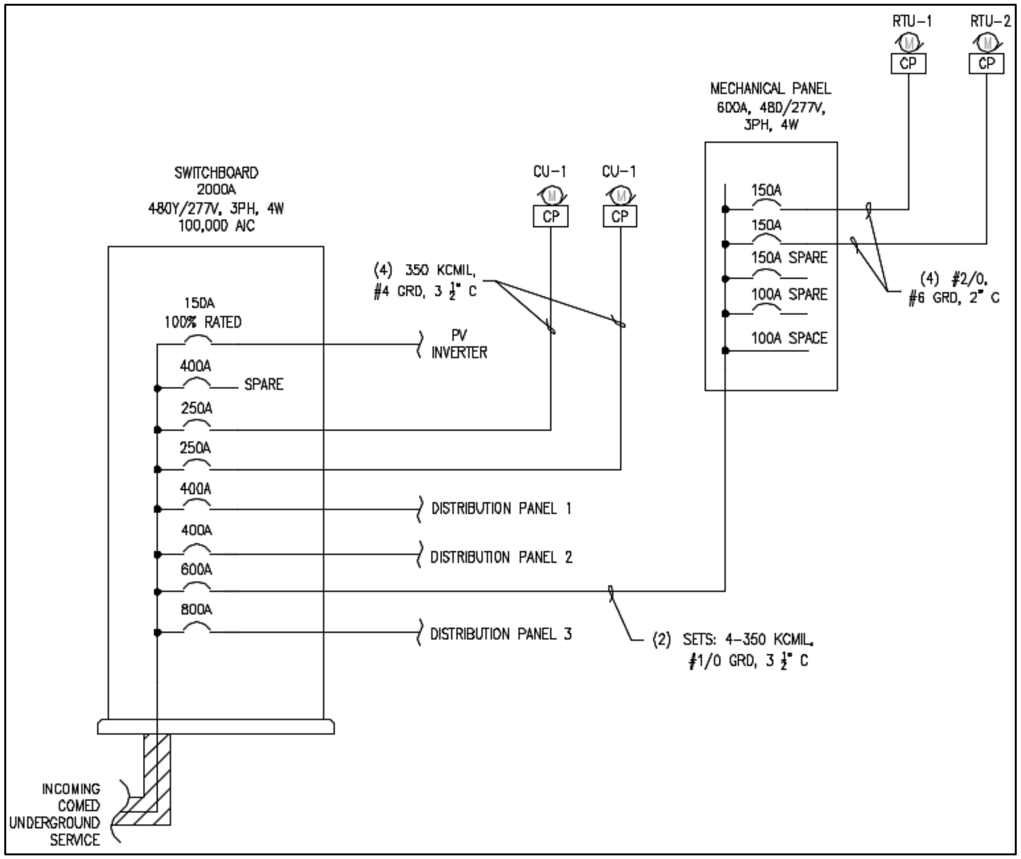


Figure 20 – Existing One-Line Diagram to CUs & RTUs

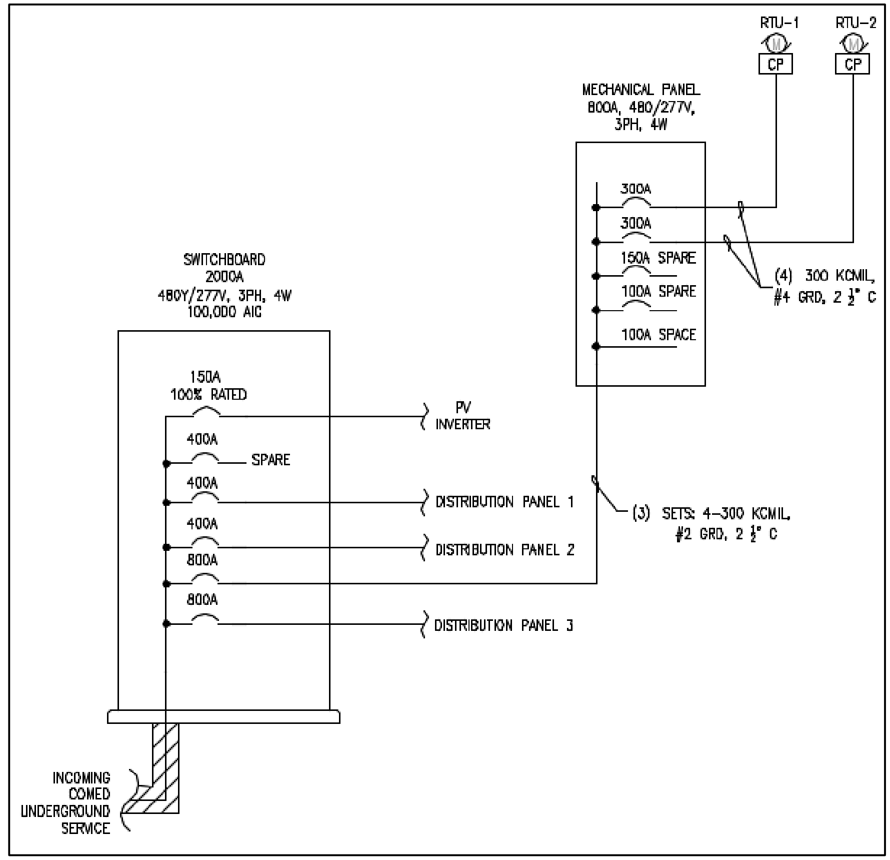


Figure 21 – New One-Line Diagram to RTUs

Electrical Breadth Conclusions

There are electrical installation and material savings associated with the new design. This, however, is because of the same reason for the structural savings. A different mechanical design strategy was used by choosing a packaged RTU with included condensing units. This allowed the electrical wiring to be reduced by having only one run of wires from the main switchboard to each RTU, rather than a run to each RTU and the each separate CU.

There would likely be no electrical cost savings when designing to the IBC/IMC instead of the CBC. This is because the mechanical power requirements differing between the two approaches are very small. For example, the 90 ton RTU from Carrier requires 257 amps while the 100 ton RTU requires 269 amps.

Masters Coursework

Several aspects of masters coursework was incorporated into this report. Knowledge obtained in AE 555 (Building Automation and Control Systems) was used to help choose an appropriate air handling unit. The class also provided vital information to understand and draw an accurate RTU operation schematic as well.

Knowledge obtained in AE 558 (Centralized Heating Production and Distribution Systems) was used to help in calculating the amount of pollutant emissions produced by El Centro. It also provided important information regarding potential emission savings for the entire city of Chicago if it were to update its building code.

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Appendices

Appendix A: Mechanical Depth Resources

1. 2012 Chicago Building Code Ventilation Requirements
2. Ventilation Calculations (CBC vs. ASHRAE 62.1/IMC)
3. Carrier Packaged RTU Product Cut Sheet
4. Carrier E-Catalog RTU Builder Results
5. ASHRAE 90.1 RTU EER Requirements
6. ASHRAE Fundamentals Chicago Weather Conditions

Appendix B: Structural Breadth Resources

1. I-Beam Z_x Tables
2. K-Series Open Web Steel Joists

Appendix C: Electrical Breadth Resources

1. NEC 2011 Table 310.104(A)

18-28-403 Mechanical Ventilation.

18-28-403.1 Source of air supply.

The air supply for every ventilation system, either natural or mechanical, shall be taken from out of doors, except in the following situations:

Exceptions:

1. Recirculation. When air is supplied by a mechanical ventilating supply system, a portion of the code required air supply may be recirculated, provided the system is equipped with such devices for control of temperature and dust content in the spaces to be ventilated and that the conditions of the air so supplied, (except as to temperature) are substantially the same as though all of the supply air were taken from out-of-doors. Under such conditions, not less than thirty-three and one-third percent of the Code requirements shall be taken from out-of-doors by the mechanical ventilating supply system; and sixty-six and two-thirds percent of the code requirements may be recirculated air, plus any additional air volume of system design capacity in excess of code requirements.

2. When air is supplied by a mechanical ventilating supply system which is not equipped with devices prescribed in paragraph 1, then only such portions of the air volumes of the system design capacity in cfm that exceed the total code requirements in cfm may be recirculated during the time of room occupancy. The air intake and all equipment and ducts shall be so arranged that all of the code required air supplied by the system can be taken from outside, with provisions made for release or exhaust of such air to the atmosphere.

3. Prohibited exhaust. No air exhausted from bath, toilet, urinal, or similar room, lavatory, locker, coat room, kitchen, boiler room, or rooms of similar use in which such air might be contaminated by smoke, gases, or dust which might be noxious, dangerous, or detrimental to health shall be recirculated at any time; except that air exhausted from locker and coat rooms or kitchens may be recirculated when unoccupied.

18-28-403.1.1 Air reduction to actual load.

For Variable Air Volume (VAV) systems, the amount of air delivered to any given space shall be allowed to be reduced to track the load in the space provided that the minimum amount of air delivered to the space is not less than 1/3 of the code required air supply.

18-28-403.1.2 Demand ventilation.

The amount of outside air delivered by a mechanical supply system may be reduced during operation below the quantities listed in Table 18-28-403.3 if the system is capable of measuring and maintaining CO2 levels in occupied spaces no greater than 1000 ppm. The system capacity shall be greater than or equal to the ordinance requirements.

18-28-403.1.3 Systems with water economizers.

If a system is equipped with a Water Economizer in accordance with the Chicago Energy Conversion Code, the amount of outside air delivered by the mechanical air handling system shall be no less than 1/3 of the code-required supply air. The area of the outside air intake shall be sized so that at least 1/3 of the code-required supply air can be taken from outdoors at velocities not in excess of 1,000 feet per minute (304.8 mpm) through the free area. The remaining air may be supplied by a recirculating air system if the system is equipped with devices to control temperature and dust content. The total quantity of air delivered to the space shall be 100 percent of the code-required air.

18-28-403.2 Structural requirements of a mechanical system.

Any system which conveys ventilation air shall be designed and installed in accordance with Article 6, Duct Systems.

18-28-403.3 Ventilation requirements.

See Table 18-28-403.3, Ventilating Requirements.

Table 18-28-403.3
Ventilating Requirements*

* S = Mechanical Supply; E = Mechanical Exhaust From Room; RO = Relief Opening; NR = No Requirement; NV = Natural Ventilation; Vent opening = percentage of floor area.

	Vent Opening Percent of Floor Area		Mechanical Ventil. CFM/SF		
Room Purpose	**Less Than**	**Not Less Than**	**S, Supply**	**E, Room Exhaust**	**Remarks**
Correctional					
Cell rooms		4	0	0	
	4		1.2	1.2	
Dry Cleaners/Laundries					
Dry Cleaning		4	0	4	See 18-28-403.3.3
	4		1.5	4	
Laundries (Residential for less than 30 units)		4	0	0	
	4		0	1	
Laundries serving general public			1.5	1.5	See 18-28-403.3.3
Linen Rooms			0.5	0.5	
Education					
Music Rooms		4	0	0	
	4		1.5	0.75	
Class Rooms/Auditoriums		4	0	0	
	4		1.5	0.75	
Cooking Rooms for Instruction only		4	0	1.5	
	4		1.0	1.5	
Libraries/Reading Rooms		4	0	0	
	4		1.2	0.6	
Food and Beverage Service					
Cafeterias/Food Courts		4	0	0	
	4		1.5	2.0	
Public Dining Rooms - no cooking equipment		4	0	0	
	4		1.5	1.5	
Public Dining Rooms - with cooking equipment		4	0	2	
	4		1.5	2	
Grills		1	0	2	
	1		1.5	2	
Kitchen, public		3	0	4	See Note 5.
	3		1.2	4	
Lounges/Bars		4	0	0	
	4		1.0	1.5	

Room Purpose	Vent Opening Percent of Floor Area		Mechanical Ventil. CFM/SF		Remarks
	Less Than	Not Less Than	S, Supply	E, Room Exhaust	
Health Care					
Anesthesia Storage Rooms			1.2	1.2	See Note 5.
Autopsy Rooms			1.5	3.0	See Note 5.
Doctor's - Dentist exam rooms		4	0	0	
	4		0.6	0.3	
Delivery Rooms/Birthing Rooms			2.0	1.0	
Intensive Care			2.0	1.0	No recirculation within room.
Morgues			1.5	3.0	See Note 5.
Nurseries			2.0	1.0	
Operating Rooms			2.0	1.0	No recirculation within room.
Patient Rooms		4	0	0	May exhaust through toilet room.
	4		0.3	0.3	
Physiotherapy		4	0	0	
	4		0.6	0.3	
Recovery Rooms			1.0	1.0	No recirculation within room.
Sterilizing Equipment Rooms			1.6	1.6	No recirculation within room. See Note 5.
Treatment Rooms			0.6	0.3	
X-Ray operator's rooms			0.6	0.3	
Hotels, Motels and Dormitories					
Banquet Halls/Assembly Pre-function			2.0	1.5	
Hotels (Lobby)		4	0	0	
	4		1.0	NR	
Sleeping Rooms		4	0	0	May exhaust through toilet room.
	4		0.3	0.3	
Foyers except the above			0	0	
Sleeping Rooms (Dormitories)		4	NV	NV	See Chapter 13-172 Light and Ventilation.
Offices					
Lunch Rooms - no cooking		4	0	0	
	4		1.5	1.5	
Offices and computer rooms		4	0	0	
	4		0.6	0.3	
Entrance lobby		4	0	0	
	4		1.0	NR	

Supply Unit	**Exhaust Unit**	Room #	Room Name	Occupancy Type	ASHRAE 62.1 SECTION 6.2 (IBC/IMC)						CBC	Extra CBC Req'd OA vs. IBC/IMC
					A_z Floor Area ft^2	R_a CFM/ft^2	Pop. Dens. pers./ft^2	P_z Zone Pop.	R_p CFM/ pers.	Total OA (CFM)	Total OA (CFM)	
-	-	A101	VESTIBLE	CORRIDOR	300					0	0	0
RTU-1	RTU-1	A102	LOBBY	BREAK ROOM	2695	0.06	25.0	67.38	5.00	499	2095	1596
RTU-1	RTU-1	A103	RECEPTION	OFFICE	246	0.06	30.00	7.38	5.00	52	50	-2
RTU-1	RTU-1	A104	RECEPTION OFFICE	OFFICE	100	0.06	5.00	0.50	5.00	9	15	7
	-	ST001	STAIR	STAIR	271					0	0	0
RTU-1	RTU-1	A106	COMPUTER LAB	COMPUTER ROOM	1089	0.06	4.00	4.36	20.00	152	665	513
RTU-1	RTU-1	A107	CORRIDOR	CORRIDOR	1364	0.06	0.00	0.00	0.00	82	105	23
RTU-1	RTU-1	A108	RESOURCE ROOM	LIBRARY	1097	0.06	10.00	10.97	5.00	121	440	319
RTU-1	RTU-1	A109	BREAK ROOM	BREAK ROOM	134	0.12	25.00	3.35	7.00	40	70	30
RTU-1	RTU-1	A111	STORAGE	STORAGE INACTIVE	96					15	15	0
	TEF-1	A112	MEN'S TOILET	TOILET ROOM	245					0	0	0
	TEF-1	A113	WOMEN'S TOILET	TOILET ROOM	245					0	0	0
RTU-1	EF-9	A114	ELEC RM	STORAGE INACTIVE	45					0	0	0
RTU-1	RTU-1	A115	WORK ROOM	LIBRARY	154	0.12	10.00	1.54	17.00	45	65	20
RTU-1	RTU-1	A116	STORAGE	STORAGE INACTIVE	222					50	50	0
	-	ST003	STAIR	STAIR	313					0	0	0
RTU-1	RTU-1	B101	CONSULTATION ROOM	OFFICE	59	0.06	5.00	0.30	5.00	5	20	15
RTU-1	RTU-1	B102	CONSULTATION ROOM	OFFICE	59	0.06	5.00	0.30	5.00	5	20	15
RTU-1	RTU-1	B103	CONSULTATION ROOM	OFFICE	55	0.06	5.00	0.28	5.00	5	20	15
RTU-1	RTU-1	B104	CONSULTATION ROOM	OFFICE	59	0.06	5.00	0.30	5.00	5	20	15
RTU-1	RTU-1	B105	CONSULTATION ROOM	OFFICE	65	0.06	5.00	0.33	5.00	6	20	14
RTU-1	RTU-1	B106	FACULTY ROOM	OFFICE	2223	0.06	5.00	11.12	5.00	189	235	46
RTU-1	RTU-1	B107	PRIVATE OFFICE	OFFICE	110	0.06	5.00	0.55	5.00	9	25	16
RTU-1	RTU-1	B108	PRIVATE OFFICE	OFFICE	110	0.06	5.00	0.55	5.00	9	25	16
RTU-1	RTU-1	B109	PRIVATE OFFICE	OFFICE	110	0.06	5.00	0.55	5.00	9	25	16
RTU-1	RTU-1	B110	PRIVATE OFFICE	OFFICE	110	0.06	5.00	0.55	5.00	9	25	16
RTU-1	RTU-1	B111	PRIVATE OFFICE	OFFICE	110	0.06	5.00	0.55	5.00	9	25	16
RTU-1	RTU-1	B113	PRIVATE OFFICE	OFFICE	131	0.06	5.00	0.66	5.00	11	25	14
RTU-1	RTU-1	B114	PRIVATE OFFICE	OFFICE	106	0.06	5.00	0.53	5.00	9	25	16
RTU-1	RTU-1	B115	PRIVATE OFFICE	OFFICE	106	0.06	5.00	0.53	5.00	9	25	16

RTU-1	RTU-1	B116	PRIVATE OFFICE	OFFICE	106	0.06	5.00	0.53	5.00	9	25	16
RTU-1	RTU-1	B117	CORRIDOR	CORRIDOR	1078	0.06	0.00	0.00	0.00	65	80	15
	-	B118	MECHANICAL ROOM	STORAGE INACTIVE	652					0	0	0
	TEF-2	B119	FAMILY RESTROOM	TOILET ROOM	60					0	0	0
	TEF-2	B120	JC	JANITOR'S CLOSET	53					0	0	0
RTU-1	RTU-1	B121	CLOSET	STORAGE INACTIVE	44					10	10	0
RTU-1	RTU-1	B122	CORRIDOR	CORRIDOR	518	0.06	0.00	0.00	0.00	31	40	9
	-	ST002	STAIR	STAIR	271	0.00	0.00	0.00	0.00	0	0	0
RTU-1	RTU-1	B123	RESOURCE CENTER	LIBRARY	1171	0.12	10.00	11.71	17.00	340	470	130
RTU-1	RTU-1	B124	BIKE ROOM	STORAGE INACTIVE	115					20	20	0
RTU-1	RTU-1	B125	FIRE PUMP	STORAGE INACTIVE	115					0	0	0
RTU-1	EF-7	B126	RECYCLING ROOM	STORAGE ACTIVE	439	0.12	0.00	0.00	0.00	53	75	22
RTU-1	-	B127	ELEC RM	STORAGE INACTIVE	276					25	25	0
	EF-6	B128	SHOWER	SHOWER ROOM	47					0	0	0
	EF-10	B129	CYLINDER STORAGE	STORAGE INACTIVE	18					0	0	0
	-	B130	WATER METER VAULT	STORAGE INACTIVE	37					0	0	0
RTU-2	RTU-2	A201	LECTURE ROOM	CLASSROOM	1491	0.06	65.00	96.92	7.50	816	750	-66
RTU-2	RTU-2	A202	CLASSROOM II	CLASSROOM	728	0.06	65.00	47.32	7.50	399	500	101
RTU-2	RTU-2	A203	LOBBY	CORRIDOR	1096	0.06	0.00	0.00	0.00	66	85	19
	-	ST001	STAIR	STAIR	271						0	0
RTU-2	RTU-2	A204	CLASSROOM II	CLASSROOM	905	0.06	65.00	58.83	7.50	495	540	45
RTU-2	RTU-2	A205	CLASSROOM II	CLASSROOM	873	0.06	65.00	56.75	7.50	478	535	57
RTU-1	RTU-1	A206	CORRIDOR	CORRIDOR	932	0.06	0.00	0.00	0.00	56	70	14
RTU-2	RTU-2	A207	CLASSROOM III	CLASSROOM	675	0.06	65.00	43.88	7.50	370	405	35
RTU-2	RTU-2	A208	CLASSROOM III	CLASSROOM	652	0.06	65.00	42.38	7.50	357	400	43
RTU-1	RTU-1	A209	CORRIDOR	CORRIDOR	917	0.06	0.00	0.00	0.00	55	70	15
RTU-2	RTU-2	A210	ELEC. RM	STORAGE INACTIVE	96					0	200	200
RTU-2	EF-5	A211	IT ROOM	STORAGE INACTIVE	412					0	30	30
	TEF-1	A212	MEN'S TOILET	TOILET ROOM	322					0	0	0
	TEF-1	A213	WOMEN'S TOILET	TOILET ROOM	327					0	0	0
	-	ST003	STAIR	STAIR	218					0	0	0
RTU-1	RTU-1	B201	CLASSROOM II	CLASSROOM	896	0.06	65.00	58.24	7.50	491	535	44
RTU-1	RTU-1	B202	CLASSROOM II	CLASSROOM	896	0.06	65.00	58.24	7.50	491	535	44

RTU-1	RTU-1	B203	CORRIDOR	CORRIDOR	1061	0.06	0.00	0.00	0.00	64	80	16
RTU-1	RTU-1	B204	CLASSROOM II	CLASSROOM	906	0.06	65.00	58.89	7.50	496	540	44
RTU-1	RTU-1	B205	CLASSROOM II	CLASSROOM	906	0.06	65.00	58.89	7.50	496	540	44
RTU-1	RTU-1	B206	CORRIDOR	CORRIDOR	1170	0.06	0.00	0.00	0.00	70	90	20
RTU-1	RTU-1	B207	CLASSROOM III	CLASSROOM	747	0.06	65.00	48.56	7.50	409	415	6
RTU-1	RTU-1	B208	CLASSROOM III	CLASSROOM	747	0.06	65.00	48.56	7.50	409	415	6
	TEF-2	B209	FAMILY RESTROOM	TOILET ROOM	60					0	0	0
	TEF-2	B210	JC	JANITOR'S CLOSET	61					0	0	0
RTU-1	RTU-1	B211	CLOSET	STORAGE INACTIVE	128					0	20	20
RTU-1	RTU-1	B212	CORRIDOR	CORRIDOR	623	0.06	0.00	0.00	0.00	37	50	13
	-	ST002	STAIR	STAIR	271					0	0	0
RTU-1	RTU-1	B213	CLASSROOM II	CLASSROOM	975	0.06	65.00	63.38	7.50	534	600	66
RTU-1	RTU-1	B214	TUTORING ROOM	OFFICE	76	0.06	5.00	0.38	5.00	6	35	29
RTU-1	RTU-1	B215	TUTORING ROOM	OFFICE	81	0.06	5.00	0.41	5.00	7	35	28
RTU-1	RTU-1	B216	TUTORING ROOM	OFFICE	82	0.06	5.00	0.41	5.00	7	35	28
RTU-1	RTU-1	B217	RESOURCE CENTER	LIBRARY	787	0.12	10.00	7.87	17.00	228	315	87
RTU-2	RTU-2	A301	SEMINAR	OFFICE	421	0.06	5.00	2.11	5.00	36	160	124
RTU-2	RTU-2	A302	SEMINAR	OFFICE	430	0.06	5.00	2.15	5.00	37	160	123
RTU-2	RTU-2	A303	STUDENT LOUNGE	BREAK ROOM	1952	0.06	25.00	48.80	5.00	361	980	619
RTU-2	RTU-2	ST001	STAIR	STAIR	271	0.00	0.00	0.00	0.00		0	0
RTU-2	RTU-2/EF-1	A304	ART CLASSROOM	CLASSROOM	900	0.18	20.00	18.00	0.18	165	465	300
RTU-2	RTU-2	A305	VENDING	STORAGE ACTIVE	505	0.12	0.00	0.00	0.00	61	85	24
RTU-2	RTU-2	A306	CORRIDOR	CORRIDOR	712	0.06	0.00	0.00	0.00	43	55	12
RTU-2	RTU-2	A307	MUSIC ROOM	CLASSROOM	631	0.06	65.00	41.02	7.50	345	395	50
RTU-2	RTU-2	A308	CLASSROOM III	CLASSROOM	608	0.06	65.00	39.52	7.50	333	395	62
RTU-2	RTU-2	A309	CORRIDOR	CORRIDOR	676	0.06	0.00	0.00	0.00	41	55	14
RTU-2	RTU-2	A310	ELEC. RM	STORAGE INACTIVE	90					0	10	10
RTU-2	RTU-2	A311	CLOSET	STORAGE INACTIVE	346					0	55	55
	TEF-1	A312	MEN'S TOILET	TOILET ROOM	322					0	0	0
	TEF-1	A313	WOMEN'S TOILET	TOILET ROOM	327					0	0	0
RTU-2	RTU-2	ST003	STAIR	STAIR	217					0	0	0
RTU-2	RTU-2	A314	SEMINAR	STORAGE INACTIVE	278	0.06	65.00	18.07	7.50	152	650	0
RTU-2	RTU-2	A316	ELEV CLOSET	STORAGE INACTIVE	20					0	0	0

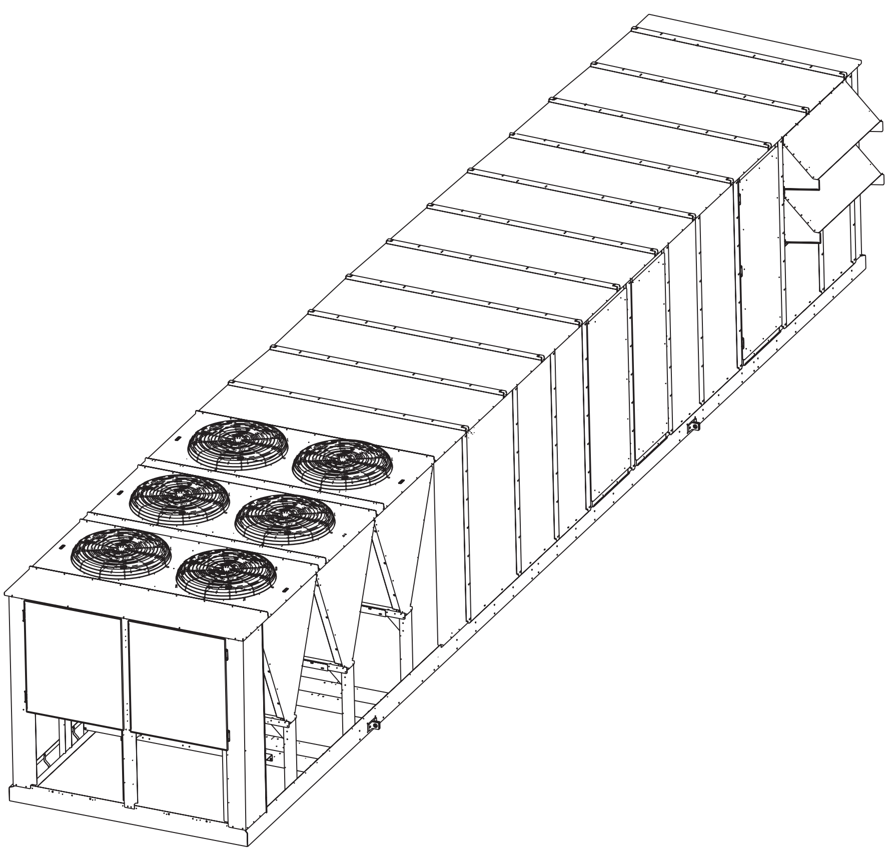
RTU-2	EF-4	B301	CHEM CLOSET	STORAGE INACTIVE	127					50	50	0
RTU-2	EF-3	B302	PREP ROOM	STORAGE INACTIVE	333					60	60	0
RTU-2	RTU-2	B303	EQUIPMENT CLOSET	STORAGE ACTIVE	116	0.12	0.00	0.00	0.00	14	20	6
RTU-2	RTU-2/EF-2	B304	WET LAB	LABORATORY	1368	0.18	25.00	34.20	10.00	588	505	-83
RTU-2	RTU-2	B305	DAMP LAB	LABORATORY	1121	0.18	25.00	28.03	10.00	482	505	23
RTU-2	RTU-2	B306	CORRIDOR	CORRIDOR	1061	0.06	0.00	0.00	0.00	64	80	16
RTU-2	RTU-2	B307	CLASSROOM II	CLASSROOM	896	0.06	65.00	58.24	7.50	491	535	44
RTU-2	RTU-2	B308	CLASSROOM II	CLASSROOM	896	0.06	65.00	58.24	7.50	491	535	44
RTU-2	RTU-2	B309	CORRIDOR	CORRIDOR	1183	0.06	0.00	0.00	0.00	71	90	19
RTU-2	RTU-2	B310	STORAGE	STORAGE INACTIVE	337					0	0	0
	TEF-2	B311	FAMILY RESTROOM	TOILET ROOM	60					0	0	0
	TEF-2	B312	JC	TOILET ROOM	61					0	0	0
RTU-2	RTU-2	ST002	STAIR	STAIR	271					0	0	0
RTU-2	RTU-2	B314	CORRIDOR	CORRIDOR	628	0.06	0.00	0.00	0.00	38	50	12
RTU-2	RTU-2	B315	CLASSROOM	CLASSROOM	862	0.06	65.00	56.03	7.50	472	580	108
RTU-2	RTU-2	B316	CLASSROOM I	CLASSROOM	1221	0.06	65.00	79.37	7.50	668	750	82
	RTU-2	B316	ELEV CLOSET	STORAGE INACTIVE	20					0	0	0
RTU-2	RTU-2	B319	CLOSET	STORAGE INACTIVE	208					250	250	0

Product Data

WeatherMaster®
48/50P2,P3,P4,P5030-100
Single-Package Gas Heating/Electric Cooling Rooftop Units and Electric Cooling Rooftop Units with Optional Electric Heat with *Comfort*Link Controls and Puron® Refrigerant (R-410A)

30 to 100 Nominal Tons

WeatherMaster®



Carrier's 48/50P Series commercial packaged rooftops offer:

- Puron® refrigerant (R-410A)
- Novation® heat exchanger technology with microchannel coil
- scroll compressors
- digital scroll compressor option
- constant volume (CV)
- staged air volume (SAV™)
- variable air volume (VAV)
- vertical supply/return units
- horizontal supply/return units
- flexible chassis and plenum options
- optional return fan/modulating power exhaust
- optional high-capacity modulating power exhaust
- staged gas control option for supply air tempering
- optional modulating gas heat
- hydronic heat option
- high-capacity evaporator coil
- optional airfoil fan
- Humidi-MiZer® adaptive dehumidification option

Features/Benefits

Carrier's 48/50P commercial packaged unit offers design flexibility, quality, reliability, interoperability and *Comfort*Link controls.

*Comfort*Link controls

Factory-installed *Comfort*Link controls provide the capability for free standing operation or may be linked with a more extensive system. Factory-installed and programmed BACnet* communication capability provides simple integration with the building HVAC system (e.g., terminal devices), an i-Vu® Open control system or a BACnet building automation system.

Puron®
the environmentally sound refrigerant

Model number nomenclature

48P2,P3,P4,P5 UNITS

48 P2 D 030 6 1 Option Code

48 – Cooling Unit with Gas Heat

Configuration
- **P2** – Vertical Suppy/Return, CV/SAV ComfortLink Controls
- **P3** – Vertical Supply/Return, VAV ComfortLink Controls
- **P4** – Horizontal Suppy/Return, CV/SAV ComfortLink Controls
- **P5** – Horizontal Suppy/Return, VAV ComfortLink Controls

Heat and Chassis Options
- **–** – Low Gas Heat, Humidi-MiZer® System
- **A** – High Gas Heat, Humidi-MiZer System
- **B** – Low Gas Heat, Stainless Steel
- **C** – High Gas Heat, Stainless Steel
- **D** – Low Gas Heat
- **E** – High Gas Heat
- **F** – Low Staged Gas Heat, Stainless Steel, Humidi-MiZer System
- **G** – High Staged Gas Heat, Stainless Steel, Humidi-MiZer System
- **H** – Low Staged Gas Heat, Stainless Steel
- **J** – High Staged Gas Heat, Stainless Steel
- **K** – Low Modulating Gas Heat, Stainless Steel
- **L** – High Modulating Gas Heat, Stainless Steel
- **M** – Low Gas Heat, Stainless Steel, Humidi-MiZer System
- **N** – High Gas Heat, Stainless Steel, Humidi-MiZer System
- **P** – Low Gas Heat, Stainless Steel, Extended Chassis
- **Q** – High Gas Heat, Stainless Steel, Extended Chassis
- **R** – Low Gas Heat with Extended Chassis
- **S** – High Gas Heat with Extended Chassis
- **W** – Low Staged Gas Heat, Stainless Steel, with Extended Chassis
- **X** – High Staged Gas Heat, Stainless Steel, with Extended Chassis
- **Y** – Low Modulating Gas Heat, Stainless Steel, Humidi-MiZer System
- **Z** – High Modulating Gas Heat, Stainless Steel, Humidi-MiZer System
- **2** – Low Modulating Gas Heat, Stainless Steel, with Extended Chassis
- **3** – High Modulating Gas Heat, Stainless Steel, with Extended Chassis

Factory Options
See note below

Design Revision Level
- **0** – Initial Release
- **1** – First Revision

Voltage Options
- **1** – 575-3-60
- **5** – 208/230-3-60
- **6** – 460-3-60

Unit Size – Nominal Tons

030 – 30	**060** – 60
035 – 35	**070** – 70
040 – 40	**075** – 75
050 – 50	**090** – 90
055 – 55	**100** – 100

LEGEND

CV — Constant Volume
SAV™ — Staged Air Volume
VAV — Variable Air Volume

NOTE: Because of the large number of options and the many resulting combinations, the Applied Rooftop Builder software must be used to generate the 8-digit option code for the unit model number. Refer to the software for the different choices for unit factory-installed options. Once all of the options have been selected, the software will generate the correct code. Unit options and accessories are listed in the Options and Accessories section on page 29.

50P2,P3,P4,P5 UNITS

50 P2 D 030 6 1 Option Code

50 – Cooling Unit with Electric heat

Configuration
- **P2** – Vertical Suppy/Return, CV/SAV ComfortLink Controls
- **P3** – Vertical Supply/Return, VAV ComfortLink Controls
- **P4** – Horizontal Suppy/Return, CV/SAV ComfortLink Controls
- **P5** – Horizontal Suppy/Return, VAV ComfortLink Controls

Heat and Chassis Options
- **-** – No Heat
- **A** – Low Electric Heat
- **B** – Medium Electric Heat
- **C** – High Electric Heat
- **D** – No Heat, Humidi-MiZer System
- **E** – Low Electric Heat, Humidi-MiZer System
- **F** – Medium Electric Heat, Humidi-MiZer System
- **G** – High Electric Heat, Humidi-MiZer System
- **H** – No Heat with Discharge Plenum
- **J** – No Heat with Discharge Plenum, Humidi-MiZer System
- **P** – No Heat with Discharge Plenum and Extended Chassis
- **R** – No Heat with Extended Chassis
- **S** – Low Electric Heat with Extended Chassis
- **T** – Medium Electric Heat with Extended Chassis
- **V** – High Electric Heat with Extended Chassis
- **W** – No Electric Heat with Extended Chassis and Hot Water Coil
- **Y** – No Electric Heat with Discharge Plenum, Extended Chassis and Hot Water Coil
- **Z** – Low Electric Heat, Humidi-MiZer with SCR Control
- **2** – Medium Electric Heat, Humidi-MiZer with SCR Control
- **3** – High Electric Heat, Humidi-MiZer with SCR Control
- **4** – Low Electric Heat, with Extended Chassis with SCR Control
- **5** – Medium Electric Heat, with Extended Chassis with SCR Control
- **6** – High Electric Heat, with Extended Chassis with SCR Control

Factory Options
See note below

Design Revision Level
- **0** – Initial Release
- **1** – First Revision

Voltage Options
- **1** – 575-3-60
- **2** – 380-3-60
- **5** – 208/230-3-60
- **6** – 460-3-60

Unit Size – Nominal Tons

030 – 30	**060** – 60
035 – 35	**070** – 70
040 – 40	**075** – 75
050 – 50	**090** – 90
055 – 55	**100** – 100

LEGEND

CV — Constant Volume
SAV — Staged Air Volume
SCR — Electronic Fan Speed Controller
VAV — Variable Air Volume

NOTE: Because of the large number of options and the many resulting combinations, the Applied Rooftop Builder software must be used to generate the 8-digit option code for the unit model number. Refer to the software for the different choices for unit factory-installed options. Once all of the options have been selected, the software will generate the correct code. Unit options and accessories are listed in the Options and Accessories section on page 29.

Quality Assurance

Certified to ISO 9001

UNIT DESIGN AIRFLOW LIMITS

UNIT SIZE	UNIT TYPE	MINIMUM COOLING CFM	MAXIMUM CFM
030	48P2,P3,P4,P5 Low Heat	6,000	15,000
	48P2,P3,P4,P5 High Heat	6,000	15,000
	50P2,P3,P4,P5	6,000	15,000
035	48P2,P3,P4,P5 Low Heat	7,000	15,000
	48P2,P3,P4,P5 High Heat	7,000	15,000
	50P2,P3,P4,P5	7,000	15,000
040	48P2,P3,P4,P5 Low Heat	8,000	20,000
	48P2,P3,P4,P5 High Heat	8,000	20,000
	50P2,P3,P4,P5	8,000	20,000
050	48P2,P3,P4,P5 Low Heat	9,000	20,000
	48P2,P3,P4,P5 High Heat	9,000	19,500
	50P2,P3,P4,P5	9,000	20,000
055	48P2,P3,P4,P5 Low Heat	10,000	25,000
	48P2,P3,P4,P5 High Heat	10,000	25,000
	50P2,P3,P4,P5	10,000	25,000
060	48P2,P3,P4,P5 Low Heat	12,000	30,000
	48P2,P3,P4,P5 High Heat	12,000	30,000
	50P2,P3,P4,P5	12,000	30,000
070	48P2,P3,P4,P5 Low Heat	14,000	30,000
	48P2,P3,P4,P5 High Heat	14,000	30,000
	50P2,P3,P4,P5	14,000	30,000
075	48P2,P3,P4,P5 Low Heat	15,000	30,000
	48P2,P3,P4,P5 High Heat	15,000	30,000
	50P2,P3,P4,P5	15,000	30,000
090	48P2,P3,P4,P5 Low Heat	17,000	40,000
	48P2,P3,P4,P5 High Heat	17,000	37,000
	50P2,P3,P4,P5	17,000	40,000
100	48P2,P3,P4,P5 Low Heat	20,000	44,000
	48P2,P3,P4,P5 High Heat	20,000	37,000
	50P2,P3,P4,P5	20,000	44,000

NOTE: Refer to Application Data section for more information concerning minimum operating airflow in Cooling mode.

TWO-STAGE GAS HEATING CAPACITIES — 48P2,P3 UNITS
(Natural Gas on All Units and LP Gas on 030-100 Low Heat and 030-100 High Heat Units)

UNIT 48P2,P3	GAS INPUT (1000 Btuh)		EFFICIENCY (%)	OUTPUT CAPACITY (1000 Btuh)		TEMP RISE (F)	AIRFLOW (Cfm)	
	Stage 1	Stage 2		Stage 1	Stage 2		Min	Max
030-050 Low Heat	244	325	81.0%	197	263	10-40	6,094	20,000
030-050 High Heat	488	650	81.0%	395	527	25-55	8,864	19,259
055-070 Low Heat	488	650	80.7%	393	525	10-40	12,142	30,000
055-070 High Heat	731	975	80.7%	590	787	20-50	14,571	30,000
075-100 Low Heat	488	650	80.9%	394	526	10-40	12,172	44,000
075-100 High Heat	731	975	80.4%	588	784	20-50	14,517	36,292

LEGEND

LP — Liquid Propane

NOTES:
1. Ratings are approved for altitudes to 2000 ft. At altitudes over 2000 ft, ratings are 4% less for each 1000 ft above sea level.
2. At altitudes up to 2000 ft, the following formula may be used to calculate air temperature rise:

$$\Delta t = \frac{\text{maximum output capacity}}{1.10 \text{ x air quantity}}$$

3. At altitudes above 2000 ft, the following formula may be used:

$$\Delta t = \frac{\text{maximum output capacity}}{(.24 \text{ x specific weight of air x } 60)\ (\text{air quantity})}$$

4. Minimum allowable temperature of mixed air entering the heat exchanger during half-rate (first stage) operation is 35 F. There is no minimum mixture temperature limitation during full-rate operation.
5. Temperature rise limits: see table.
6. On VAV (variable air volume) applications set the zone terminals to provide minimum unit heating airflow as indicated in the table upon command from Heat Interlock Relay (HIR) function.

Physical data — 48 series units (cont)

48P2,P3,P4,P5075-100

BASE UNIT	48P2,P3,P4,P5075		48P2,P3,P4,P5090		48P2,P3,P4,P5100	
NOMINAL CAPACITY (tons)	75		90		100	
OPERATING WEIGHT (lb)	Standard Chassis	Extended Chassis	Standard Chassis	Extended Chassis	Standard Chassis	Extended Chassis
Base Unit						
Low Heat	9065	9615	9665	10,215	9685	10,235
High Heat	9195	9745	9795	10,345	9815	10,365
With Economizer						
Low Heat	9595	10,145	10,195	10,745	10,215	10,765
High Heat	9725	10,275	10,325	10,875	10,345	10,895
COMPRESSORS	Scroll					
Quantity...Type	2...ZP182/2...ZP182		3...ZP154,3...ZP154		3...ZP154,3...ZP182	
Oil Charge (oz) per Compressor	110		110		110	
Number of Refrigerant Circuits	2		2		2	
REFRIGERANT	R-410A					
Operating Charge (lb), Ckt 1/Ckt 2						
Standard Evaporator Coil	39.5/42.0		50.4/51.3		50.8/52.8	
Standard Evaporator with Humidi-MiZer® System	39.5/54.4		50.4/69.1		50.8/70.6	
Alternate High-Capacity Evaporator Coil	49.0/50.0		61.5/62.9		59.3/62.8	
Alternate High-Capacity Evaporator with Humidi-MiZer	49.0/62.4		61.5/80.7		59.3/80.6	
CONDENSER COILS	Aluminum Novation® Heat Exchanger with Microchannel Coils					
Quantity	4		6		6	
Total Face Area (sq ft)	106.7		160.0		160.0	
EVAPORATOR COILS						
Quantity	2					
Total Face Area (sq ft)	61.5					
Refrigerant Feed Device...No. per Circuit	TXV...2					
Standard Evaporator Coils						
Rows...Fins/in.	4...15		4...15		4...15	
Fin Type	Double Wavy		Double Wavy		Double Wavy	
Tube Type	Cross Hatched		Cross Hatched		Cross Hatched	
Alternate, High-Capacity Evaporator Coils						
Rows...Fins/in.	6...16		6...16		6...16	
Fin Type	Double Wavy		Double Wavy		Double Wavy	
Tube Type	Cross Hatched		Cross Hatched		Cross Hatched	
HEATING SECTION	Low Heat	High Heat	Low Heat	High Heat	Low Heat	High Heat
Number of Heat Exchangers	2	3	2	3	2	3
Input (MBtuh)	650	975	650	975	650	975
Output (MBtuh) (Vertical/Horizontal)	526/520	784/780	526/520	784/780	526/520	784/780
Temperature Rise Range (F)	10-40	20-50	10-40	20-50	10-40	20-50
Efficiency (%) (Vertical/Horizontal)	81/80	81/80	81/80	81/80	81/80	81/80
Burner Orifice Diameter						
Quantity (in. ...drill no.)	7 (.1285...30)	7 (.1285...30)	7 (.1285...30)	7 (.1285...30)	7 (.1285...30)	7 (.1285...30)
Manifold Pressure (in. wg)	3.5	3.5	3.5	3.5	3.5	3.5
Line Pressure (in. wg) (Min...Max)	5.0...13.0	5.0...13.0	5.0...13.0	5.0...13.0	5.0...13.0	5.0...13.0
Number of Gas Valves	2	3	2	3	2	3
CONDENSER FAN	Propeller Type					
Quantity...Diameter (in.)	4...30		6...30		6...30	
Nominal Cfm	39,000		58,000		58,000	
Motor Hp (ea)...rpm	1.0...1140		1.0...1140		1.0...1140	
STANDARD SUPPLY FAN	Forward Curved Centrifugal 36 x 30 in.					
Nominal Cfm	30,000		36,000		40,000	
Maximum Allowable Cfm	30,000		36,000		40,000	
Maximum Allowable Rpm	680		680		680	
Shaft Diameter at Pulley (in.)	1 11/16		1 11/16		1 11/16	

STANDARD SUPPLY-FAN MOTOR AND DRIVE	(Any motor available on any unit)			
Motor Hp	30	40	50	60
Motor Frame Size	S268T	S324T	S326T	S364T
Efficiency at Full Load (%)	93.6	94.5	94.5	95.4
Fan Pulley Pitch Diameter (in.)	18.5	18.5	18.5	18.5
Motor Pulley Pitch Diameter (in.)	5.3	5.7	6.5	7.1
Resulting Fan Rpm	501	539	615	672
Belts Quantity...Type	3...5VX1320	4...5VX1320	4...5VX1320	4...5VX1320
Center Distance Range (in.)	47.88-45.01	47.64-44.76	47.42-44.52	47.42-44.52

ALTERNATE, AIRFOIL FAN	48P2,P3,P4,P5075	48P2,P3,P4,P5090	48P2,P3,P4,P5100
	Airfoil		
Nominal Airflow (cfm)	30,000	36,000	40,000
Maximum Allowable Airflow (cfm)	30,000	36,000	40,000
Maximum Allowable Wheel Speed (rpm)	1846	1846	1846
Shaft Diameter at Pulley (in.)	2 11/16	2 11/16	2 11/16

ALTERNATE SUPPLY-FAN MOTOR AND DRIVE	(Any motor available on any unit)				
Motor Hp	30	40	50	60	75
Motor Frame Size	S268T	S324T	S36T	S364T	365T
Efficiency at Full Load (%)	93.6	94.5	94.5	95.4	95.4
Fan Pulley Pitch Diameter (in.)	9.7	10.2	8.9	8.9	10.8
Motor Pulley Pitch Diameter (in.)	7.5	8.7	8.1	8.7	11.1
Resulting Fan Rpm	1353	1493	1593	1711	1799
Belts Quantity...Type	2...5VX1150	2...5VX1180	3...5VX1150	3...5VX1150	3...5VX1230
Center Distance Range (in.)	42.96...45.82	42.96...45.57	42.96...45.57	42.45...45.35	42.45...45.35

LEGEND

MBtuh — Btuh in Thousands
TXV — Thermostatic Expansion Valve

*See page 22 for high-capacity power exhaust information. See Power Exhaust Fan Drive Data table on page 28 for more information.

48P2,P3,P4,P5075-100 (cont)

BASE UNIT	48P2,P3,P4,P5075	48P2,P3,P4,P5090	48P2,P3,P4,P5100
OPTIONAL POWER EXHAUST*	Centrifugal, 18 x 15 in. (Any motor available on any unit.)		
Quantity...Motor Hp	2...5	2...7.5	2...10
Motor Frame Size	184T	213T	215T
Efficiency at Full Load (%)	89.5	91.7	91.7
Fan Pulley Pitch Diameter (in.)	10.6	10.6	10.6
Motor Pulley Pitch Diameter (in.)	4.5	5.0	5.6
Shaft Diameter at Pulley (in.)	$1^{7}/_{16}$	$1^{7}/_{16}$	$1^{7}/_{16}$
Resulting Fan Rpm	740	820	920
Maximum Allowable Rpm	1000	1000	1000
FILTERS			
Standard Efficiency Throwaway (Standard)			
Quantity...Size (in.)	12...20 x 25 x 2, 12...20 x 20 x 2	12...20 x 25 x 2, 12...20 x 20 x 2	12...20 x 25 x 2, 12...20 x 20 x 2
30% and 65% Pleated (Optional)			
Quantity...Size (in.)	12...20 x 25 x 2, 12...20 x 20 x 2	12...20 x 25 x 2, 12...20 x 20 x 2	12...20 x 25 x 2, 12...20 x 20 x 2
OUTSIDE AIR SCREENS			
Standard Hood (25%) Quantity...Size (in.)	4...25 x 16 x 1, 2...20 x 16 x 1	4...25 x 16 x 1, 2...20 x 16 x 1	4...25 x 16 x 1, 2...20 x 16 x 1
OPTIONAL ECONOMIZER FILTER	Aluminum Frame, Permanent		
Quantity...Size (in.)	12...16 x 25 x 1, 2...16 x 20 x 1	12...16 x 25 x 1, 2...16 x 20 x 1	12...16 x 25 x 1, 2...16 x 20 x 1

LEGEND

MBtuh — Btuh in Thousands
TXV — Thermostatic Expansion Valve

*See page 22 for high-capacity power exhaust information. See Power Exhaust Fan Drive Data table on page 28 for more information.

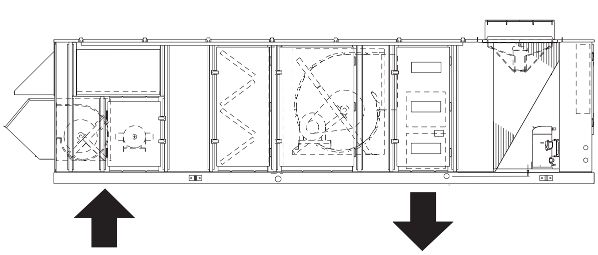
Options and accessories (cont)

ITEM	OPTION*	ACCESSORY†	SPECIAL ORDER**
CONTROLS			
Controls Expansion Module (CEM)	X	X	
BACnet Communication	X		
System Pilot™ Interface		X	
Touch Pilot™ Interface		X	
Navigator™ Display		X	
Return Air CO_2 Sensor		X	
CO_2 Space Sensor		X	
Return Air Smoke Detector		X	
Return and Supply Air Smoke Detectors Installed			X
Filter Switch		X	
Fan Status Switch (requires CEM)		X	
T-55 Space Temperature Sensor with Override		X	
T-56 Space Temperature Sensor with Override and Set Point Adjustment		X	
Space Temperature Sensor with CO_2 Override		X	
Space Temperature Sensor with CO_2 Override and Set Point Adjustment		X	
MODBUS Carrier Translator		X	
LonWorks Carrier Translator		X	
INDOOR FAN AND MOTOR			
Bypass on IFM VFD	X		
Airfoil Fan (sizes 075-100 only)	X		
PACKAGING			
Domestic	X		
Export	X		
MISCELLANEOUS			
Digital Compressor	X		
Refrigeration Service Valves	X		
Replacable Core Filter Drier	X		
Extended Chassis	X		
14-in. Roof Curb		X	
Condenser Section Roof Curb (sizes 070-100 only)		X	
Security Grille (sizes 070-100 only)	X		
Low Ambient Control	X	X	
Extended Lube Lines			X
Access Door Retainers			X
Horizontal Supply / Vertical Return			X
Vertical Supply / Horizontal Return			X
Low Outdoor Sound	X		
Low Compressor Sound		X	

Chassis arrangements (48 Series units)

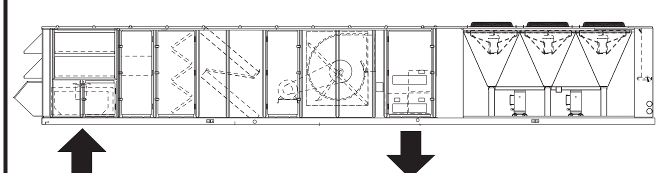
Standard length chassis with vertical discharge — The standard, compact, vertical discharge arrangement is provided with a bottom, return-air opening, straight-through air path, and horizontal discharge into the heating section with bottom supply air outlet. Ductwork is attached to accessory roof curb. These units are available with factory-installed optional power exhaust or barometric relief packages in conjunction with factory-installed optional economizers.

STANDARD CHASSIS



Vertical discharge with optional return fan — This vertical discharge arrangement adds a factory-installed return fan and VFD. Return air enters through the bottom opening upstream of the return fan and follows a straight-through path to the supply fan and into the heating section, where it exits through the bottom supply air outlet. Ductwork is attached to the accessory roof curb.

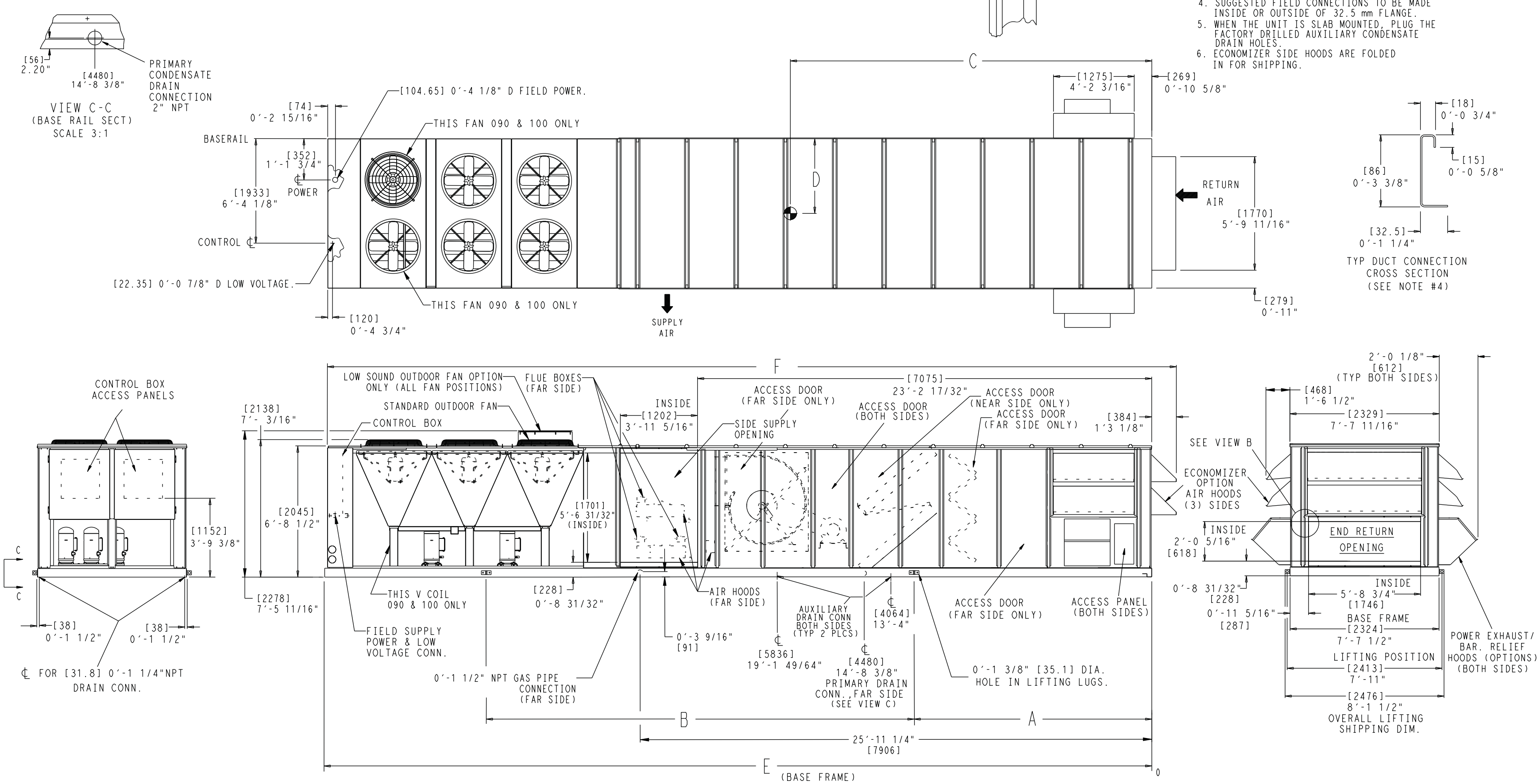
OPTIONAL RETURN FAN



48P4,P5075-100 UNITS

UNIT SIZE	WEIGHT LBS.	WEIGHT KGS.	A MM	A FT.IN.	B MM	B FT.IN.	C MM	C FT.IN.	D MM	D FT.IN.	E MM	E FT.IN.	F MM	F FT.IN.
075 LOW HEAT	10665	4838	3544	11′-7 1/2"	6495	21′-3 11/16"	6429	21′-1 1/8"	1021	3′-4 3/16"	11378	37′-3 5/16"	11762	38′-7 1/16"
090 LOW HEAT	11265	5110	3544	11′-7 1/2"	6495	21′-3 11/16"	6628	21′-8 15/16"	1054	3′-5 1/2"	12555	41′-2 5/16"	12939	42′-5 7/16"
100 LOW HEAT	11285	5119	3544	11′-7 1/2"	6495	21′-3 11/16"	6603	21′-7 15/16"	1054	3′-5 1/2"	12555	41′-2 5/16"	12939	42′-5 7/16"
075 HIGH HEAT	10795	4897	3544	11′-7 1/2"	6495	21′-3 11/16"	6462	21′-2 7/16"	1021	3′-4 3/16"	11378	37′-3 5/16"	11762	38′-7 1/16"
090 HIGH HEAT	11395	5169	3544	11′-7 1/2"	6495	21′-3 11/16"	6657	21′-10 1/16"	1054	3′-5 1/2"	12555	41′-2 5/16"	12939	42′-5 7/16"
100 HIGH HEAT	11415	5178	3544	11′-7 1/2"	6495	21′-3 11/16"	6637	21′-9 5/16"	1054	3′-5 1/2"	12555	41′-2 5/16"	12939	42′-5 7/16"

NOTES:
1. DIMENSIONS IN [ ] ARE IN MILLIMETERS.
2. ⊕ UNIT WEIGHT AND CENTER OF GRAVITY INCLUDES ECONOMIZER, LARGEST INDOOR FAN MOTOR AND HIGH CAPACITY EVAPORATOR COIL.
3. UNIT CLEARANCES
   TOP - DO NOT RESTRICT CONDENSER FANS
   CONTROL BOX END - 6′-0"
   SIDES - 6′-0" (EXCEPT POWER EXHAUST UNITS 10′-0")
   ECONOMIZER END - 6′-0"
   FOR SMALLER SERVICE AND OPERATIONAL CLEARANCES, CONTACT CARRIER APPLICATION ENGINEERING DEPARTMENT.
4. SUGGESTED FIELD CONNECTIONS TO BE MADE INSIDE OR OUTSIDE OF 32.5 mm FLANGE.
5. WHEN THE UNIT IS SLAB MOUNTED, PLUG THE FACTORY DRILLED AUXILIARY CONDENSATE DRAIN HOLES.
6. ECONOMIZER SIDE HOODS ARE FOLDED IN FOR SHIPPING.

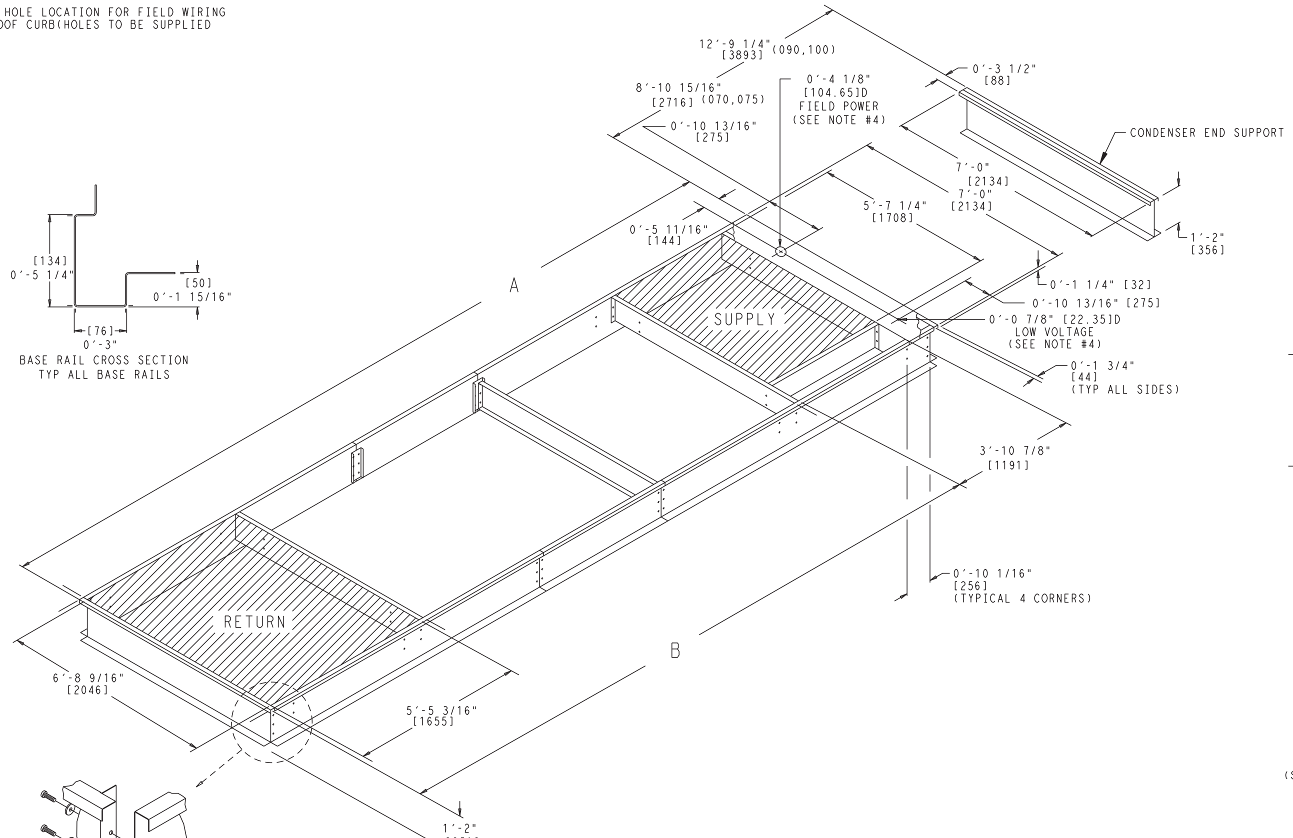


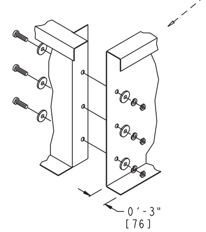
This section details six examples of the P Series large rooftop unit. To determine dimensions for the appropriate unit for your application, refer to the Applied Rooftop Builder software.

United Technologies
Carrier

ROOF CURB — SIZES 070-100

NOTES:
1. ROOF CURB ACCESSORY IS SHIPPED DISASSEMBLED.
2. ROOF CURB: 14 GA.[VA03-56] STL.
3. DIMENSIONS IN [ ] ARE MILLIMETERS.
4. SUGGESTED HOLE LOCATION FOR FIELD WIRING THROUGH ROOF CURB(HOLES TO BE SUPPLIED BY FIELD).





(CORNER CONNECTIONS AND SPLICE PLATE CONNECTIONS)

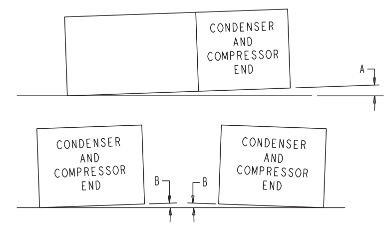
UNIT TYPE	DIMENSION	UNIT SIZE 070	UNIT SIZE 075,090,100
50P VERTICAL SUPPLY & RETURN	A B	24'-5 1/16" 19'-5 9/16"	27'-9 11/16" 22'-10 3/16"
50P VERTICAL SUPPLY & RETURN W/EXTENDED CHASSIS	A B	26'-6 1/4" 21'-6 3/4"	29'-10 7/8" 24'-11 3/8"
48/50P VERTICAL & HORIZONTAL SUPPLY & RETURN W/EXTENDED PLENUM	A B	27'-9 11/16" 22'-10 3/16"	27'-9 11/16" 22'-10 3/16"
48/50P VERTICAL & HORIZONTAL SUPPLY & RETURN W/EXTENDED CHASSIS & PLENUM	A B	29'-10 7/8" 24'-11 3/8"	29'-10 7/8" 24'-11 3/8"

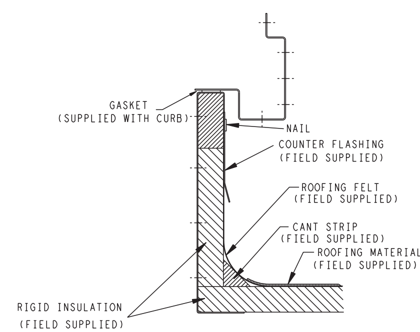
DIMENSIONS (degrees and inches)

A		B	
DEG.	IN.	DEG.	IN.
1.0	2.0	.50	.75

UNIT LEVELING TOLERANCES

*From edge of unit to horizontal.





Part Number: **48P3D0906100098SLV**

Unit Refrigerant:	**R410A**	
EER (ARI 360):	**9.5**	
IEER:	**12.3**	

Shipping Dimensions

Unit Length:	**41' 2"**	
Unit Width:	**7' 8"**	
Unit Height:	**6' 11"**	
Unit Shipping Weight:	**12689**	lb

Unit

Supply/Return:	**Vertical/Vertical**	
Application Type:	**VAV**	
Voltage:	**460-3-60**	
Evaporator Type:	**Std Evap**	
Cooling Airflow:	**34000**	CFM
Altitude:	**673**	ft
Cond. Ent. Air Temp:	**91.0**	F
Ent. Air Dry Bulb:	**79.7**	F
Ent. Air Wet Bulb:	**66.7**	F
Ent. Air Enthalpy:	**31.55**	BTU/lb
Lvg. Air Dry Bulb:	**58.3**	F
Lvg. Air Wet Bulb:	**57.0**	F
Lvg. Air Enthalpy:	**24.68**	BTU/lb
Gross Cooling Capacity:	**1025.53**	MBH
Gross Sensible Clg. Cap:	**766.23**	MBH
Compressor Power:	**72.4**	kW
Coil Bypass Factor:	**0.158**	

Part Load(%) Operation

Standard Capacity Steps:	**17, 33, 50, 67, 83, 100**	

Gas Heating Data:

Heating Airflow:	**34000**	CFM
Heating Ent. Air Temp:	**51.4**	F
Gas Output:	**527**	MBH
Heating Lvg. Air Temp:	**66.2**	F
AFUE:	**81**	
Steady State Eff:	**81**	
Temp.Rise:	**14.7**	F

Supply Fan Information:

Ext.Static Pressure:	**1.00**	in wg
Low Gas Heat Loss:	**0.79**	in wg
Economizer Loss:	**0.31**	in wg
Pleated Filters Loss:	**0.23**	in wg
Selection Static Pressure:	**2.33**	in wg
Supply Fan Type:	**AF Supply Fan**	
Supply Fan RPM:	**1432**	
Supply Fan BHP:	**36.72**	BHP
Supply Fan Motor HP:	**40 Hp**	

Power Exhaust Information:

Airflow:	**30000**	CFM
Ext. Static:	**0.50**	in wg
Tot. Static:	**0.50**	in wg
Fan RPM:	**1141**	
Fan BHP:	**23.1**	BHP

Motor HP: **25 Hp**

Electrical Data

Minimum Voltage:	**414**
Maximum Voltage:	**508**
Indoor Fan Motor HP:	**40**
Indoor Fan Motor FLA:	**52**
Condenser Fan Motor Qty:	**6**
Condenser Fan Motor FLA (ea):	**3.3**
Pwr. Exhaust Fan Motor Qty:	**1**
Pwr. Exhaust Fan Motor HP (ea.):	**25**
Pwr. Exhaust Fan Motor FLA (ea.):	**34**
Power Supply MCA:	**257**
Power Supply MOCP (Fuse or HACR):	**300**
Compressor Count (A1,A2):	**3**
Compressor RLA (ea), (A1,A2):	**23.1**
Compressor LRA (ea), (A1,A2):	**150**
Compressor Count (B1,B2):	**3**
Compressor RLA (ea), (B1,B2):	**23.1**
Compressor LRA (ea), (B1,B2):	**150**

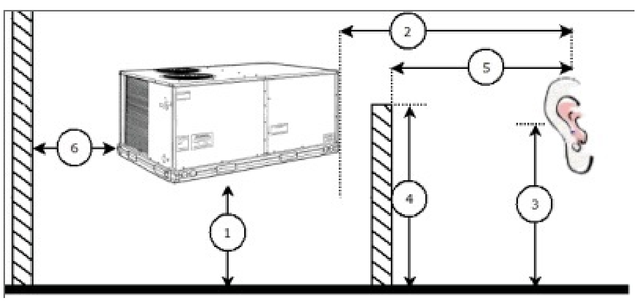
Acoustic Information

	Discharge, Lw	Inlet, Lw	Outdoor, Lw
63 Hz	103.6	95.6	74.9
125 Hz	103.6	85.6	82.0
250 Hz	102.1	83.1	88.6
500 Hz	94.2	74.2	94.2
1000 Hz	88.0	71.0	94.5
2000 Hz	82.3	71.3	92.4
4000 Hz	73.8	60.8	89.3
8000 Hz	65.4	49.4	83.7

Discharge and Inlet data represents the Supply fan only and do not include the impact of the return fan or power exhaust fans

Calculation methods used in this program are patterned after the ASHRAE Guide; other ASHRAE Publications and the AHRI Acoustical Standards. While a very significant effort has been made to insure the technical accuracy of this program, it is assumed that the user is knowledgeable in the art of system sound estimation and is aware of the tolerances involved in real world acoustical estimation. This program makes certain assumptions as to the dominant sound sources and sound paths which may not always be appropriate to the real system being estimated. Because of this, no assurances can be offered that this software will always generate an accurate sound prediction from user supplied input data. If in doubt about the estimation of expected sound levels in a space, an Acoustical Engineer or a person with sound prediction expertise should be consulted.

Advanced Acoustics



Advanced Accoustics Parameters

1. Unit height above ground: **30.0** ft

2. Horizontal distance from unit to receiver:........ **50.0** ft
3. Receiver height above ground:........................ **5.7** ft

Detailed Acoustics Information

Octave Band Center Freq. Hz	63	125	250	500	1k	2k	4k	8k	Overall
A	74.9	82.0	88.6	94.2	94.5	92.4	89.3	83.7	99.6 Lw
B	48.7	65.9	80.0	91.0	94.5	93.6	90.3	82.6	98.9 LwA
C	41.5	48.6	55.2	60.8	61.1	59.0	55.9	50.3	66.3 Lp
D	15.3	32.5	46.6	57.6	61.1	60.2	56.9	49.2	65.5 LpA

Legend

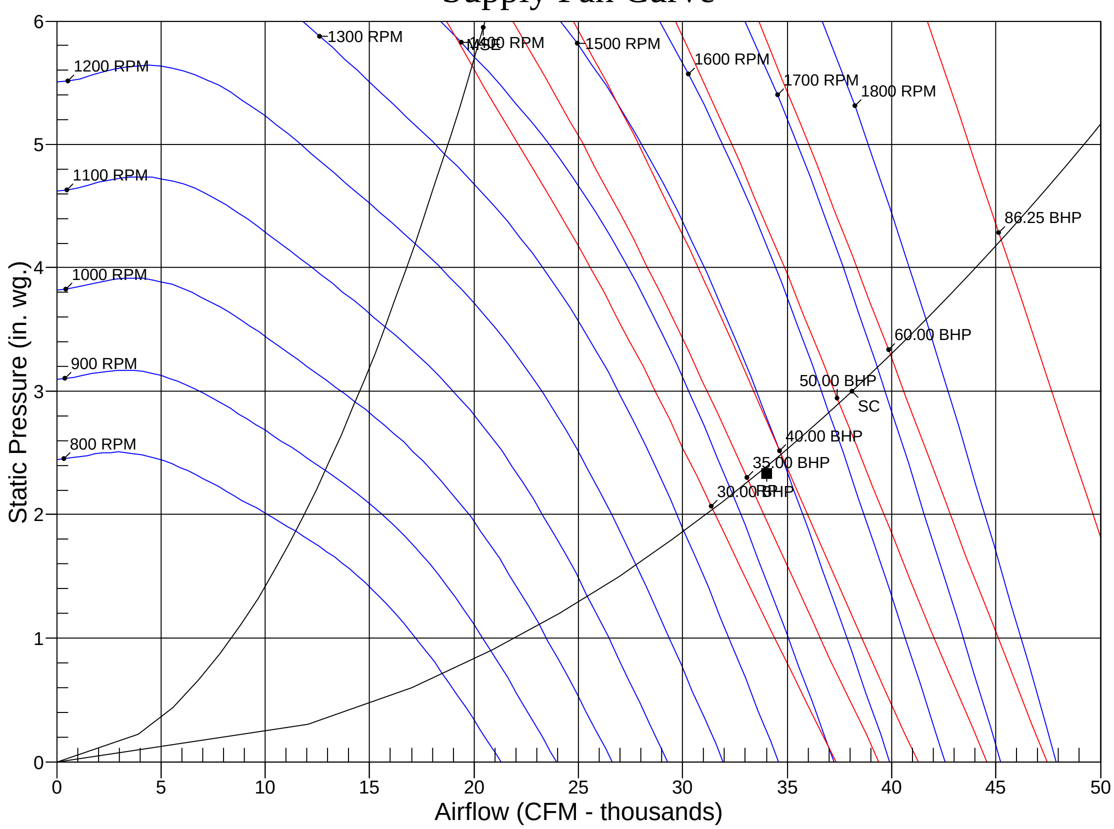
A Sound Power Levels at Unit's Acoustic Center, Lw

B A-Weighted Sound Power Levels at Unit's Acoustic Center, LwA

C Sound Pressure Levels at Specific Distance from Unit, Lp

D A-Weighted Sound Pressure Levels at Specific Distance from Unit, LpA

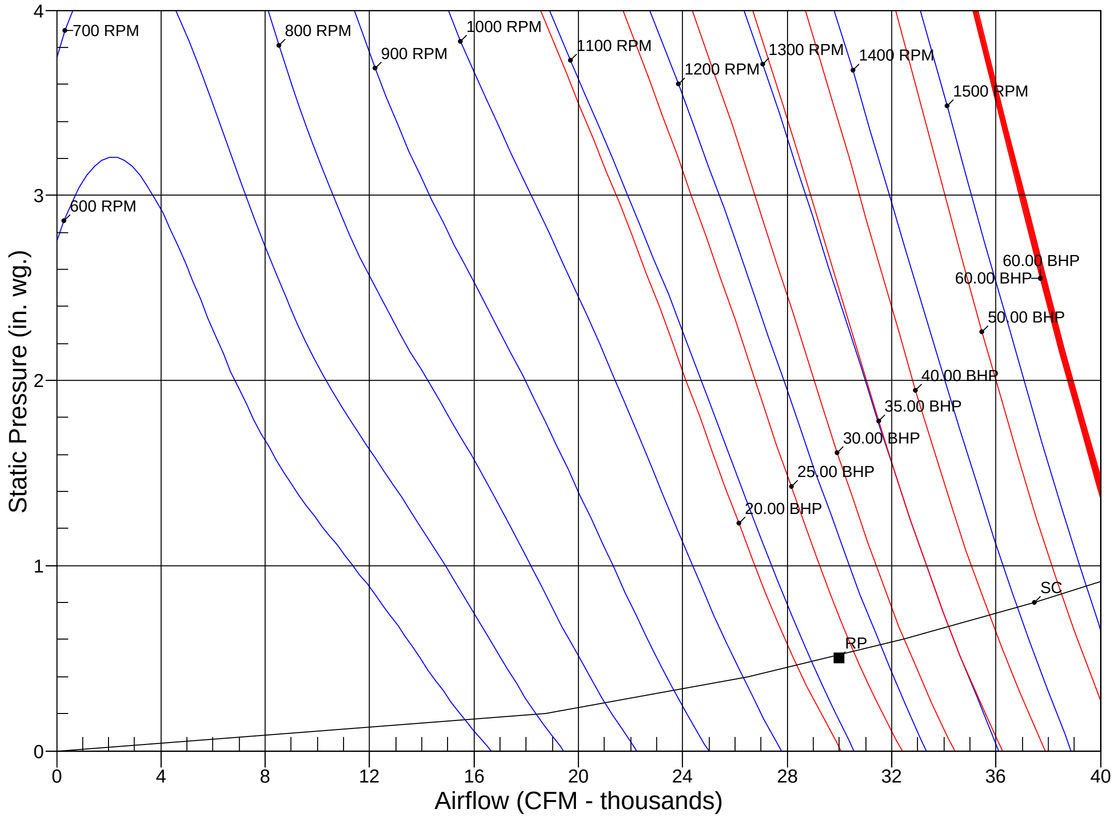
Supply Fan Curve



RPM = 1432 BHP = 36.72 Maximum RPM = 1799 Maximum HP = 75.00

SC - System Curve RP - Rated Point

Power Exhaust Fan Curve



RPM = 1141 BHP = 23.12 Maximum RPM = 1440 Maximum HP = 60.00

SC - System Curve RP - Rated Point

**TABLE 6.8.1-1 Electrically Operated Unitary Air Conditioners and Condensing Units—
Minimum Efficiency Requirements**

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency	Test Procedure[a]
Air conditioners, air cooled	<65,000 Btu/h[b]	All	Split system	13.0 SEER	AHRI 210/240
			Single package	13.0 SEER (before 1/20/15) 14 SEER (as of 1/1/2015)	
Through the wall, air cooled	≤30,000 Btu/h[b]	All	Split system	12.0 SEER	
			Single package	12.0 SEER	
Small duct high velocity, air cooled	<65,000 Btu/h[b]	All	Split System	11.0 SEER	
Air conditioners, air cooled	≥65,000 Btu/h and <135,000 Btu/h	Electric resistance (or none)	Split system and single package	11.2 EER 11.4 IEER (before 1/1/2016) 12.9 IEER (as of 1/1/2016)	AHRI 340/360
		All other	Split system and single package	11.0 EER 11.2 IEER (before 1/1/2016) 12.7 IEER (as of 1/1/2016)	
	≥135,000 Btu/h and <240,000 Btu/h	Electric resistance (or none)	Split system and single package	11.0 EER 11.2 IEER (before 1/1/2016) 12.4 IEER (as of 1/1/2016)	
		All other	Split system and single package	10.8 EER 11.0 IEER (before 1/1/2016) 12.2 IEER (as of 1/1/2016)	
	≥240,000 Btu/h and <760,000 Btu/h	Electric resistance (or none)	Split system and single package	10.0 EER 10.1 IEER (before 1/1/2016) 11.6 IEER (as of 1/1/2016)	
		All other	Split system and single package	9.8 EER 9.9 IEER (before 1/1/2016) 11.4 IEER (as of 1/1/2016)	
	≥760,000 Btu/h	Electric resistance (or none)	Split system and single package	9.7 EER 9.8 IEER (before 1/1/2016) 11.2 IEER (as of 1/1/2016)	
		All other	Split system and single package	9.5 EER 9.6 IEER (before 1/1/2016) 11.0 IEER (as of 1/1/2016)	

a. Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.
b. Single-phase, air-cooled air conditioners <65,000 Btu/h are regulated by NAECA. SEER values are those set by NAECA.

Meaning of acronyms: *Lat: Latitude, °* *Long: Longitude, °* *Elev: Elevation, ft*
DB: Dry bulb temperature, °F *WB: Wet bulb temperature, °F* *DP: Dew point temperature, °F* *HR: Humidity ratio, grains of moisture per lb of dry air* *WS: Wind speed, mph*
MCWB: Mean coincident wet bulb temperature, °F *MCDB: Mean coincident dry bulb temperature, °F* *HDD and CDD 65: Annual heating and cooling degree-days, base 65°F, °F-day*

Station	Lat	Long	Elev	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB				Dehumidification DP/HR/MCDB						Extreme Annual WS			Heat./Cool. Degree-Days	
						0.4%		1%		2%		0.4%		1%		0.4%			1%							
				99.6%	99%	DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	DP	HR	MCDB	DP	HR	MCDB	1%	2.5%	5%	HDD	CDD 65
VALDOSTA WB AIRPORT	30.78N	83.28W	197	27.5	30.9	95.4	77.4	93.4	76.6	91.8	76.1	80.4	89.8	79.3	88.6	78.3	148.0	83.4	77.1	142.2	82.5	17.1	14.9	13.1	1509	2532
WARNER ROBINS AFB	32.63N	83.60W	302	25.0	28.2	97.3	76.1	94.9	76.0	92.8	75.3	79.8	90.9	78.5	89.5	76.9	141.6	84.5	75.5	135.0	82.9	19.0	16.5	13.9	2135	2246
Hawaii																										*4 sites, 4 more on CD-ROM*
BARBERS POINT NAS	21.30N	158.07W	33	59.4	61.6	90.9	73.0	89.9	73.0	88.8	72.8	77.6	85.7	76.5	85.1	75.2	132.3	82.7	73.7	125.4	82.1	19.6	17.8	16.3	0	4418
HILO INTERNATIONAL AP	19.72N	155.05W	36	61.5	62.7	85.6	74.1	84.6	73.9	83.8	73.7	76.7	82.1	76.0	81.5	75.1	131.9	79.2	74.2	127.8	78.6	17.6	15.8	13.5	0	3258
HONOLULU INTL ARPT	21.33N	157.94W	16	61.2	63.3	89.9	74.0	89.1	73.6	88.2	73.4	77.2	84.8	76.3	84.2	75.0	131.3	81.3	73.9	126.3	80.6	21.8	20.0	18.7	0	4649
KANEOHE BAY MCAS	21.45N	157.77W	20	64.3	66.2	85.3	74.6	84.3	74.2	83.6	73.9	77.4	82.2	76.4	81.7	75.6	133.9	80.5	74.6	129.7	80.1	19.3	17.6	16.2	0	4297
Idaho																										*7 sites, 7 more on CD-ROM*
BOISE AIR TERMINAL	43.57N	116.22W	2867	2.7	10.5	98.1	64.2	95.0	63.1	91.9	62.1	66.3	91.7	65.0	90.0	57.8	79.4	72.2	55.5	72.8	72.3	21.8	19.0	17.1	5658	890
CALDWELL (AWOS)	43.63N	116.63W	2428	11.6	16.4	97.0	66.4	93.1	65.0	90.4	63.9	68.3	92.1	66.7	89.8	60.6	86.5	77.5	57.1	76.1	77.3	21.4	18.8	16.6	5698	638
COEUR D`ALENE(AWOS)	47.77N	116.82W	2320	6.7	11.6	91.4	62.8	88.5	62.3	84.2	60.8	65.6	86.3	63.9	83.8	57.4	76.6	70.9	55.4	71.2	69.6	22.4	18.9	16.8	6892	286
IDAHO FALLS FANNING FIELD	43.52N	112.07W	4744	-8.7	-2.4	91.7	61.4	89.4	60.8	86.3	59.8	64.9	83.6	63.2	82.2	58.9	88.5	70.9	56.6	81.5	69.2	27.2	24.3	20.7	7825	275
JOSLIN FLD MAGIC VA	42.48N	114.48W	4255	9.4	12.4	94.5	63.8	91.1	63.1	89.6	62.7	66.9	89.6	65.3	86.8	59.2	88.1	75.8	56.9	80.9	74.7	27.5	24.4	20.8	6157	700
LEWISTON NEZ PERCE CNTY AP	46.38N	117.01W	1437	10.2	17.5	97.8	65.4	94.3	64.5	90.7	63.3	67.7	92.1	66.0	89.8	59.6	80.3	72.8	57.3	73.9	72.0	20.6	17.6	14.8	5124	814
POCATELLO REGIONAL AP	42.92N	112.57W	4478	-4.9	1.3	94.4	61.8	91.3	61.1	88.3	60.2	65.4	86.5	63.7	84.4	58.9	87.7	71.2	56.3	79.7	70.6	28.1	25.0	21.9	7035	419
Illinois																										*14 sites, 6 more on CD-ROM*
AURORA MUNICIPAL	41.77N	88.47W	705	-2.0	1.4	90.8	74.4	88.4	73.5	85.7	71.8	77.7	87.2	75.9	84.3	74.8	133.9	83.2	73.0	125.6	80.9	25.9	22.8	19.8	6403	711
CAHOKIA/ST. LOUIS	38.57N	90.15W	413	9.5	14.2	93.5	77.3	91.4	76.4	90.3	76.0	80.4	90.3	78.8	89.1	77.5	145.1	85.1	75.3	134.9	83.9	20.6	18.4	16.5	4452	1396
CHICAGO MIDWAY AP	41.79N	87.75W	617	-1.6	4.3	92.1	74.9	89.6	73.3	86.5	71.9	78.0	88.3	76.2	85.4	75.0	134.1	84.3	73.0	125.5	82.2	24.4	21.2	19.2	5930	1022
CHICAGO OHARE INTL AP	41.99N	87.91W	673	-4.0	2.2	91.9	74.6	89.0	73.4	86.1	71.9	77.9	88.2	76.1	85.2	74.9	134.2	84.1	73.2	126.3	81.9	24.8	21.1	19.2	6311	842
DECATUR	39.83N	88.87W	699	-0.4	4.6	93.0	76.7	90.5	75.7	88.2	74.3	79.3	89.6	77.7	87.7	76.2	140.2	85.8	74.7	133.4	84.1	24.8	21.7	19.7	5529	1065
GLENVIEW NAS	42.08N	87.82W	653	-4.6	2.1	93.2	75.0	89.8	73.1	86.7	71.6	77.7	89.9	75.8	86.4	73.9	129.6	84.9	72.2	122.1	83.2	21.0	18.7	16.7	6227	902
MOLINE QUAD CITY INTL AP	41.47N	90.52W	594	-6.2	0.0	93.5	76.3	90.6	75.1	87.7	73.5	79.1	89.7	77.4	87.5	76.1	139.5	85.3	74.4	131.7	83.1	24.6	20.7	18.7	6141	999
PEORIA GREATER PEORIA AP	40.67N	89.68W	663	-3.6	2.3	92.7	76.5	90.1	75.3	87.4	73.8	79.3	89.0	77.7	87.0	76.5	141.4	85.0	74.9	133.9	83.2	23.8	20.2	18.3	5809	1035
QUINCY MUNI BALDWIN FLD	39.94N	91.19W	768	-2.0	3.3	93.3	76.4	90.4	75.3	87.8	74.2	78.6	89.1	77.4	87.8	75.6	137.8	84.7	74.2	131.4	83.2	24.7	21.0	19.2	5552	1100
ROCKFORD GREATER ROCKFORD AP	42.20N	89.09W	745	-8.4	-1.7	91.5	75.0	88.5	73.7	85.8	72.0	78.2	87.8	76.3	85.0	75.3	136.5	84.0	73.5	128.1	82.0	24.6	21.0	19.2	6694	779
SCOTT AFB/BELLEVILL	38.55N	89.85W	443	4.5	10.3	95.1	77.4	92.7	76.6	90.4	75.6	80.2	90.4	78.8	88.9	77.3	144.6	85.7	75.8	137.4	84.1	21.5	18.8	16.7	4638	1428
SPRINGFIELD CAPITAL AP	39.85N	89.68W	614	-2.1	4.6	92.9	76.7	90.5	75.6	88.1	74.2	79.4	89.7	77.9	87.5	76.4	140.9	85.9	74.9	134.0	84.0	24.9	21.8	19.5	5429	1135
UNIV OF ILLINOIS WI	40.03N	88.27W	774	-1.0	4.4	92.5	76.4	90.1	75.4	87.7	74.4	79.8	89.1	77.9	86.7	77.1	145.0	86.3	75.1	135.8	83.5	27.4	24.6	22.0	5657	1010
W. CHICAGO/DU PAGE	41.92N	88.25W	758	-5.4	0.6	90.5	74.9	88.1	73.8	85.1	72.0	78.3	87.3	76.4	84.7	75.3	136.5	84.4	73.4	127.6	81.6	24.5	21.0	19.0	6511	736
Indiana																										*8 sites, 1 more on CD-ROM*
EVANSVILLE REGIONAL AP	38.04N	87.54W	387	5.6	12.1	93.9	76.2	91.6	75.7	89.5	74.9	79.4	89.8	78.1	88.1	76.4	139.9	85.2	75.3	134.4	83.6	20.7	18.5	16.6	4449	1410
FORT WAYNE INTL AP	41.01N	85.21W	827	-2.6	3.8	91.1	74.4	88.4	73.1	85.7	71.7	77.6	87.0	75.9	84.1	74.8	134.5	82.8	73.2	127.4	80.9	24.6	20.8	18.8	6011	831
GRISSOM ARB	40.65N	86.15W	830	-3.9	3.4	92.4	75.8	89.4	74.8	86.7	72.9	79.2	89.0	77.3	85.9	76.3	141.8	85.5	74.5	133.2	83.1	24.9	20.6	18.4	5761	1025
INDIANAPOLIS INTL AP	39.71N	86.27W	807	-0.5	6.4	91.1	75.3	88.6	74.4	86.3	73.1	78.2	87.6	76.9	85.5	75.4	137.1	83.4	74.1	131.2	82.1	24.5	20.8	18.7	5322	1055
LAFAYETTE PURDUE UNIV AP	40.41N	86.94W	636	-2.3	4.2	92.4	75.6	90.0	74.6	87.5	73.2	78.8	88.7	77.2	86.3	75.9	138.6	84.8	74.4	131.8	82.9	23.1	20.0	18.3	5577	1003
MONROE CO	39.13N	86.62W	866	4.8	10.2	90.6	76.0	89.6	76.1	87.5	74.7	78.9	86.7	77.6	86.0	76.7	143.8	83.7	74.9	135.1	82.3	19.5	17.5	15.8	4936	1009
SOUTH BEND MICHIANA RGNL AP	41.71N	86.33W	774	-1.5	4.5	90.9	74.3	88.1	72.7	85.3	71.3	77.4	86.8	75.6	84.0	74.6	133.2	83.3	72.9	125.7	81.0	24.1	20.5	18.6	6188	810
TERRE HAUTE/HULMAN	39.45N	87.32W	574	-0.3	6.6	92.1	76.6	90.1	75.9	87.8	74.6	79.6	88.9	78.0	86.9	76.9	143.2	85.4	75.2	134.9	83.5	22.8	19.5	17.9	5194	1085
Iowa																										*9 sites, 19 more on CD-ROM*
AMES MUNI ARPT	42.00N	93.62W	955	-5.8	0.5	90.5	76.1	88.3	74.9	85.6	73.8	79.2	87.4	77.3	85.6	76.8	144.5	84.9	74.8	134.9	82.7	26.5	23.6	20.2	6388	794
ANKENY REGIONAL ARP	41.68N	93.55W	902	-5.4	0.4	94.9	75.2	91.1	74.4	88.3	73.2	77.8	89.1	76.4	87.2	74.6	133.9	84.0	73.0	126.8	82.7	20.7	18.4	16.5	5954	1063
BOONE MUNI	42.05N	93.85W	1161	-5.8	0.4	91.3	77.8	89.8	76.7	86.2	74.4	81.0	89.0	78.9	86.1	79.0	157.4	86.2	76.8	146.1	84.6	26.4	23.5	20.3	6328	894
CEDAR RAPIDS MUNICIPAL AP	41.88N	91.71W	873	-9.6	-3.9	91.6	76.0	88.6	74.6	85.7	73.0	78.6	87.4	77.0	85.6	76.2	141.4	84.3	74.3	132.2	82.2	26.3	23.2	20.2	6703	807
DAVENPORT NEXRAD	41.62N	90.58W	850	-3.4	1.3	90.3	76.2	88.1	75.4	84.4	73.1	78.5	87.0	77.1	85.2	75.4	137.5	83.5	74.5	133.2	82.7	26.4	23.6	20.4	6188	808
DES MOINES INTL AP	41.54N	93.67W	965	-6.9	-1.6	93.4	76.2	90.2	75.0	87.3	73.5	78.4	88.9	77.1	87.3	75.4	138.1	84.7	73.9	131.1	83.4	25.6	22.5	19.6	6240	1041
DUBUQUE REGIONAL AP	42.40N	90.70W	1079	-8.2	-2.6	89.3	74.8	86.3	73.3	83.5	71.2	77.6	86.0	75.5	83.1	75.1	137.3	83.1	73.2	128.3	80.6	25.6	22.8	19.9	6988	649
SIOUX CITY SIOUX GATEWAY AP	42.39N	96.38W	1102	-8.8	-3.6	93.4	75.2	90.4	74.4	87.7	73.0	78.6	88.6	77.1	87.2	75.9	140.9	84.9	73.9	131.6	83.6	28.7	25.4	22.7	6721	921
WATERLOO MUNICIPAL AP	42.55N	92.40W	879	-12.7	-6.3	91.8	75.5	88.8	73.8	86.1	72.4	78.5	87.8	76.7	85.5	75.9	140.0	84.4	74.0	130.9	82.2	26.2	23.5	20.2	7032	786
Kansas																										*10 sites, 16 more on CD-ROM*
FT RILEY/MARSHALL A	39.05N	96.77W	1063	-1.4	6.0	99.6	75.0	96.3	74.6	93.2	74.3	78.4	91.6	77.2	90.6	74.8	135.7	86.0	73.2	128.4	84.4	20.7	18.3	16.2	5051	1518
LAWRENCE MUNI ARPT	39.00N	95.22W	833	5.1	9.9	99.1	76.9	95.3	76.3	91.3	75.4	80.0	92.2	78.4	90.7	76.7	143.5	87.2	74.9	135.0	85.4	25.0	21.6	19.1	4801	1466
MANHATTAN RGNL	39.13N	96.67W	1083	2.5	8.8	99.9	75.6	97.2	75.7	93.0	74.8	78.6	93.1	77.7	91.9	74.9	136.3	85.5	73.2	128.7	83.7	24.2	20.6	18.4	5081	1456
MCCONNELL AFB	37.62N	97.27W	1358	5.2	11.6	99.9	73.2	97.0	73.4	93.5	73.1	77.5	90.6	76.4	89.2	74.2	134.5	82.5	72.8	128.0	81.9	26.4	23.6	20.6	4347	1726
OLATHE/JOHNSON CO.	38.85N	94.73W	1096	5.2	9.8	96.7	76.4	92.6	75.9	90.2	75.3	79.0	90.0	77.9	89.0	75.3	138.4	85.4	74.6	135.0	84.4	23.4	20.2	18.3	4678	1405
SALINA MUNICIPAL AP	38.81N	97.66W	1283	0.9	7.4	101.3	73.9	98.2	73.7	94.9	73.3	77.4	92.5	76.3	90.9	73.2	129.6	84.2	72.2	125.0	83.1	27.6	24.8	22.2	4847	1661
TOPEKA FORBES FIELD	38.95N	95.66W	1079	1.0	7.1	96.7	74.8	93.0	74.4	90.3	74.0	78.3	89.9	77.0	88.5	74.9	136.4	85.1	73.3	129.0	83.3	25.4	23.4	20.4	4992	1325

F_y = 50 ksi

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

Z_x

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF/Ω_b	$\phi_b BF$	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.³	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.⁴	ASD	LRFD
W21×55	126	314	473	192	289	10.8	16.3	6.11	17.4	1140	156	234
W14×74	126	314	473	196	294	5.31	8.05	8.76	31.0	795	128	192
W18×60	123	307	461	189	284	9.62	14.4	5.93	18.2	984	151	227
W12×79	119	297	446	187	281	3.78	5.67	10.8	39.9	662	117	175
W14×68	115	287	431	180	270	5.19	7.81	8.69	29.3	722	116	174
W10×88	113	282	424	172	259	2.62	3.94	9.29	51.2	534	131	196
W18×55	112	279	420	172	258	9.15	13.8	5.90	17.6	890	141	212
W21×50	110	274	413	165	248	12.1	18.3	4.59	13.6	984	158	237
W12×72	108	269	405	170	256	3.69	5.56	10.7	37.5	597	106	159
W21×48[f]	107	265	398	162	244	9.89	14.8	6.09	16.5	959	144	216
W16×57	105	262	394	161	242	7.98	12.0	5.65	18.3	758	141	212
W14×61	102	254	383	161	242	4.93	7.48	8.65	27.5	640	104	156
W18×50	101	252	379	155	233	8.76	13.2	5.83	16.9	800	128	192
W10×77	97.6	244	366	150	225	2.60	3.90	9.18	45.3	455	112	169
W12×65[f]	96.8	237	356	154	231	3.58	5.39	11.9	35.1	533	94.4	142
W21×44	95.4	238	358	143	214	11.1	16.8	4.45	13.0	843	145	217
W16×50	92.0	230	345	141	213	7.69	11.4	5.62	17.2	659	124	186
W18×46	90.7	226	340	138	207	9.63	14.6	4.56	13.7	712	130	195
W14×53	87.1	217	327	136	204	5.22	7.93	6.78	22.3	541	103	154
W12×58	86.4	216	324	136	205	3.82	5.80	8.87	29.8	475	87.8	132
W10×68	85.3	213	320	132	199	2.58	3.85	9.15	40.6	394	97.8	147
W16×45	82.3	205	309	127	191	7.12	10.8	5.55	16.5	586	111	167
W18×40	78.4	196	294	119	180	8.94	13.2	4.49	13.1	612	113	169
W14×48	78.4	196	294	123	184	5.09	7.67	6.75	21.1	484	93.8	141
W12×53	77.9	194	292	123	185	3.65	5.50	8.76	28.2	425	83.5	125
W10×60	74.6	186	280	116	175	2.54	3.82	9.08	36.6	341	85.7	129
W16×40	73.0	182	274	113	170	6.67	10.0	5.55	15.9	518	97.6	146
W12×50	71.9	179	270	112	169	3.97	5.98	6.92	23.8	391	90.3	135
W8×67	70.1	175	263	105	159	1.75	2.59	7.49	47.6	272	103	154
W14×43	69.6	174	261	109	164	4.88	7.28	6.68	20.0	428	83.6	125
W10×54	66.6	166	250	105	158	2.48	3.75	9.04	33.6	303	74.7	112

ASD	LRFD
Ω_b = 1.67	ϕ_b = 0.90
Ω_v = 1.50	ϕ_v = 1.00

[f] Shape exceeds compact limit for flexure with F_y = 50 ksi.

Z_x

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

F_y = 50 ksi

Shape	Z_x	M_{px}/Ω_b	$\phi_b M_{px}$	M_{rx}/Ω_b	$\phi_b M_{rx}$	BF/Ω_b	$\phi_b BF$	L_p	L_r	I_x	V_{nx}/Ω_v	$\phi_v V_{nx}$
		kip-ft	kip-ft	kip-ft	kip-ft	kips	kips				kips	kips
	in.³	ASD	LRFD	ASD	LRFD	ASD	LRFD	ft	ft	in.⁴	ASD	LRFD
W18×35	66.5	166	249	101	151	8.14	12.3	4.31	12.3	510	106	159
W12×45	64.2	160	241	101	151	3.80	5.80	6.89	22.4	348	81.1	122
W16×36	64.0	160	240	98.7	148	6.24	9.36	5.37	15.2	448	93.8	141
W14×38	61.5	153	231	95.4	143	5.37	8.20	5.47	16.2	385	87.4	131
W10×49	60.4	151	227	95.4	143	2.46	3.71	8.97	31.6	272	68.0	102
W8×58	59.8	149	224	90.8	137	1.70	2.55	7.42	41.6	228	89.3	134
W12×40	57.0	142	214	89.9	135	3.66	5.54	6.85	21.1	307	70.2	105
W10×45	54.9	137	206	85.8	129	2.59	3.89	7.10	26.9	248	70.7	106
W14×34	54.6	136	205	84.9	128	5.01	7.55	5.40	15.6	340	79.8	120
W16×31	54.0	135	203	82.4	124	6.86	10.3	4.13	11.8	375	87.5	131
W12×35	51.2	128	192	79.6	120	4.34	6.45	5.44	16.6	285	75.0	113
W8×48	49.0	122	184	75.4	113	1.67	2.55	7.35	35.2	184	68.0	102
W14×30	47.3	118	177	73.4	110	4.63	6.95	5.26	14.9	291	74.5	112
W10×39	46.8	117	176	73.5	111	2.53	3.78	6.99	24.2	209	62.5	93.7
W16×26[v]	44.2	110	166	67.1	101	5.93	8.98	3.96	11.2	301	70.5	106
W12×30	43.1	108	162	67.4	101	3.97	5.96	5.37	15.6	238	64.0	95.9
W14×26	40.2	100	151	61.7	92.7	5.33	8.11	3.81	11.0	245	70.9	106
W8×40	39.8	99.3	149	62.0	93.2	1.64	2.46	7.21	29.9	146	59.4	89.1
W10×33	38.8	96.8	146	61.1	91.9	2.39	3.62	6.85	21.8	171	56.4	84.7
W12×26	37.2	92.8	140	58.3	87.7	3.61	5.46	5.33	14.9	204	56.1	84.2
W10×30	36.6	91.3	137	56.6	85.1	3.08	4.61	4.84	16.1	170	63.0	94.5
W8×35	34.7	86.6	130	54.5	81.9	1.62	2.43	7.17	27.0	127	50.3	75.5
W14×22	33.2	82.8	125	50.6	76.1	4.78	7.27	3.67	10.4	199	63.0	94.5
W10×26	31.3	78.1	117	48.7	73.2	2.91	4.34	4.80	14.9	144	53.6	80.3
W8×31[f]	30.4	75.8	114	48.0	72.2	1.58	2.37	7.18	24.8	110	45.6	68.4
W12×22	29.3	73.1	110	44.4	66.7	4.68	7.06	3.00	9.13	156	64.0	95.9
W8×28	27.2	67.9	102	42.4	63.8	1.67	2.50	5.72	21.0	98.0	45.9	68.9
W10×22	26.0	64.9	97.5	40.5	60.9	2.68	4.02	4.70	13.8	118	49.0	73.4
W12×19	24.7	61.6	92.6	37.2	55.9	4.27	6.43	2.90	8.61	130	57.3	86.0
W8×24	23.1	57.6	86.6	36.5	54.9	1.60	2.40	5.69	18.9	82.7	38.9	58.3
W10×19	21.6	53.9	81.0	32.8	49.4	3.18	4.76	3.09	9.73	96.3	51.0	76.5
W8×21	20.4	50.9	76.5	31.8	47.8	1.85	2.77	4.45	14.8	75.3	41.4	62.1

ASD	LRFD
Ω_b = 1.67	ϕ_b = 0.90
Ω_v = 1.50	ϕ_v = 1.00

[f] Shape exceeds compact limit for flexure with F_y = 50 ksi.

[v] Shape does not meet the h/t_w limit for shear in AISC *Specification* Section G2.1(a) with F_y = 50 ksi; therefore, ϕ_v = 0.90 and Ω_v = 1.67.

LRFD

ECONOMY TABLE FOR OPEN WEB STEEL JOISTS, K-SERIES
Based on a 50 ksi Maximum Yield Strength - Loads Shown in Pounds per Linear Foot (plf)

Joist Designation	26K5	16K9	24K7	18K9	26K6	20K9	26K7	22K9	28K6	24K8	18K10	28K7	24K9	26K8	20K10	26K9
Depth (In.)	26	16	24	18	26	20	26	22	28	24	18	28	24	26	20	26
Approx. Wt (lbs/ft.)	9.8	10	10.1	10.2	10.6	10.8	10.9	11.3	11.4	11.5	11.7	11.8	12	12.1	12.2	12.2
Span (ft.)																
16		825 550														
17		825 526														
18		825 490		825 550							825 550					
19		825 455		825 523							825 523					
20		825 426		825 490		825 550					825 490				825 550	
21		825 406		825 460		825 520					825 460				825 520	
22		825 385		825 438		825 490		825 548			825 438				825 490	
23		825 363		825 418		825 468		825 518			825 418				825 468	
24		825 346	825 544	825 396		825 448		825 495		825 544	825 396		825 544		825 448	
25		771 311	825 520	825 377		825 426		825 474		825 520	825 377		825 520		825 426	
26	813 535	711 276	825 499	807 354	825 541	825 405	825 541	825 454		825 499	825 361		825 499	825 541	825 405	825 541
27	753 477	658 246	825 479	747 315	820 519	825 389	825 522	825 432		825 479	825 347		825 479	825 522	825 389	825 522
28	699 427	612 220	761 436	694 282	762 464	775 353	825 501	825 413	822 541	825 456	822 331	825 543	825 456	825 501	825 375	825 501
29	651 384	570 198	727 392	646 254	709 417	723 317	790 463	798 387	766 486	804 429	766 298	825 522	825 436	825 479	825 359	825 479
30	607 346	532 178	679 353	603 229	661 377	675 286	738 417	745 349	715 439	750 387	715 269	796 486	816 419	816 457	799 336	825 459
31	568 314	498 161	636 320	564 207	619 341	631 259	690 378	697 316	669 397	702 350	669 243	745 440	765 379	763 413	748 304	825 444
32	534 285	466 147	595 290	529 188	580 309	592 235	648 343	654 287	627 361	658 318	627 221	699 400	717 344	715 375	702 276	778 407
33	501 259		559 265	498 171	546 282	556 214	609 312	615 261	589 329	619 289	589 201	657 364	673 313	672 342	660 251	732 370
34	472 237		526 242	468 156	514 257	523 195	573 285	579 239	555 300	582 264	555 184	618 333	634 286	633 312	621 229	688 338
35	445 217		496 221	441 143	484 236	493 179	540 261	546 219	523 275	549 242	523 168	583 305	598 262	597 286	585 210	649 310
36	420 199		469 203	417 132	457 216	466 164	510 240	516 201	495 252	519 222	495 154	550 280	565 241	564 263	553 193	613 284
37	397 183		444 187		433 199	441 151	483 221	487 185	468 232	490 205		522 257	534 222	534 242	523 178	580 262
38	376 169		421 172		411 184	418 139	457 204	462 170	444 214	465 189		493 237	507 204	505 223	496 164	550 241
39	357 156		399 159		390 170	397 129	433 188	438 157	420 198	441 174		469 219	480 189	480 206	471 151	522 223
40	340 145		379 148		370 157	376 119	412 174	417 146	399 183	420 161		445 203	456 175	456 191	447 140	496 207
41	322 134		361 137		352 146		393 162	396 135	379 170	399 150		424 189	435 162	433 177		472 192
42	307 125		343 127		336 136		373 150	378 126	361 158	379 139		403 175	414 151	412 164		450 178
43	294 116		328 118		319 126		357 140	360 117	345 147	363 130		385 163	394 140	394 153		429 165
44	280 108		313 110		306 118		340 131	343 109	330 137	346 121		367 152	376 131	376 143		409 155
45	268 101		298 103		291 110		325 122		315 128	330 113		351 142	360 122	360 133		391 145
46	256 95		286 97		279 103		310 114		301 120	316 106		336 133	345 114	343 125		375 135
47	246 89		274 90		267 96		298 107		288 112	303 99		321 125	330 107	328 117		358 127
48	235 83		262 85		256 90		285 100		276 105	291 93		309 117	316 101	315 110		343 119
49	225 78				246 85		274 94		265 99			295 110		303 103		330 112
50	216 73				235 80		262 89		255 93			283 103		291 97		316 105
51	208 69				226 75		252 83		244 88			273 97		279 91		304 99
52	199 65				217 71		243 79		235 83			262 92		268 86		292 93
53									226 78			252 87				
54									217 74			243 82				
55									210 70			234 77				
56									202 66			226 73				

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18**	—	—	14	—	—	—	—
16**	—	—	18	—	—	—	—
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	555	665	750	470	560	630	2000

*Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).
**Refer to 240.4(D) for conductor overcurrent protection limitations.