

APPLICATION NOTES



Application Note 2012:

Proper Design of CITY MULTI® VRF Air Source Heat Pump Systems for Heating in Low Ambient Conditions

Design engineers must be aware of the industry's best practices when designing VRF Heat Pump systems for climate zones that commonly experience ambient conditions below 20° F. These best practices ensure a system meets heating needs, and provides the desired performance and comfortable interior building conditions for the occupants. CITY MULTI® "R2-", "Y-", "Hyper-heating Y-" and "S-" Series air-source heat-pump systems use the temperature differential between refrigerant and ambient air to provide conditioning to a space. Therefore, adhering to best practices is especially important in designing CITY MULTI® systems for low ambient conditions.

Scope of Discussion

The CITY MULTI® VRF product line contains both air cooled and water cooled equipment. Depending on the requirements of the space, either single mode or simultaneous heating and cooling can be provided. The scope of this document discusses proper design of the CITY MULTI® "R2", "Y", and "S" Series condensing units to provide heating in low ambient conditions. This document provides an overview on the initial steps engineers should perform when designing VRF Heat Pump systems for low ambient heating. Determining operating conditions and choosing the best system for a location will be discussed, and then factors unique to designing a variable refrigerant flow (VRF) heat pump system will be detailed.

Not included in this discussion is the H2i™ Hyper Heating Series product line which provides increased low ambient heating performance. Please contact your local Mitsubishi CITY MULTI® sales representative to learn more about the Hyper Heating Series.

Determining Operation Conditions

When designing an HVAC system for low ambient heating, it is important that engineers perform the heat loss load calculation to determine the heating block load for a building or a space based on anticipated operating conditions. Properly determining outdoor ambient conditions to which the condensing unit will be exposed is essential for equipment selection. Design engineers establish ambient conditions for a project based on several factors such as published climate data, experience, and the desires of the client. The most commonly used resource for climate information is the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) database. ASHRAE has used the database information to establish recommended outdoor design temperatures for locations throughout the world.

In locations with high elevations, extreme cold, or other conditions, however, engineers will often choose a design condition based on their experience. It is not uncommon for engineers designing for a project in Boston, Massachusetts to use 0°F DB even though the ASHRAE 99.6% design condition is 7°F DB. In Montana, Idaho, and Utah, engineers frequently use -20°F DB as the design condition.

Capacity Adjustment for Air Source Equipment

An engineer who is considering the use of air source equipment to provide heating must understand the effect of ambient temperature on the available equipment capacity. The rated heating capacities of air-source heat pump systems are established by testing the equipment at 47°F DB and 43°F WB outside air temperature which is based on the AHRI standard. The

design condition used to establish the heating block load is typically lower than the rated condition. As the design condition temperature decreases, the available heating capacity will also decrease. This equipment capacity reduction is a percentage of the AHRI tested capacity. To determine the available heating capacity of an air source heat pump at actual design conditions, a chart similar to Figure 1 should be consulted. As an example, an engineer using a desired heating operation set point of 70°F DB with a 10°F WB heating design condition would have a 66% heating capacity factor. If the engineer intended to use a condensing unit with 188,000 Btu nominal heating capacity (PUHY-P168TSHMU), he would have 124,000 Btu as the available heating capacity at design conditions before factoring in piping length and defrost capacity reductions. Both of these derates must be included as well and will be discussed further within the document. Mitsubishi Electric HVAC has optimized the design of the CITY MULTI® VRF Heat Pump systems to provide increased low ambient capacity when compared with traditional air source equipment.

PUHY-		P168TSHMU	P192TSHMU
Nominal Heating Capacity	kW	55.1	58.6
	BTU/h	188,000	200,000
Input	kW	14.73	15.38

PUHY-		P216TSHMU	P240TSHMU
Nominal Heating Capacity	kW	66.8	70.3
	BTU/h	228,000	240,000
Input	kW	18.42	19.07

PUHY-		P168YSHMU	P192YSHMU
Nominal Heating Capacity	kW	55.1	58.6
	BTU/h	188,000	200,000
Input	kW	14.73	15.38

PUHY-		P216YSHMU	P240YSHMU
Nominal Heating Capacity	kW	66.8	70.3
	BTU/h	228,000	240,000
Input	kW	18.42	19.07

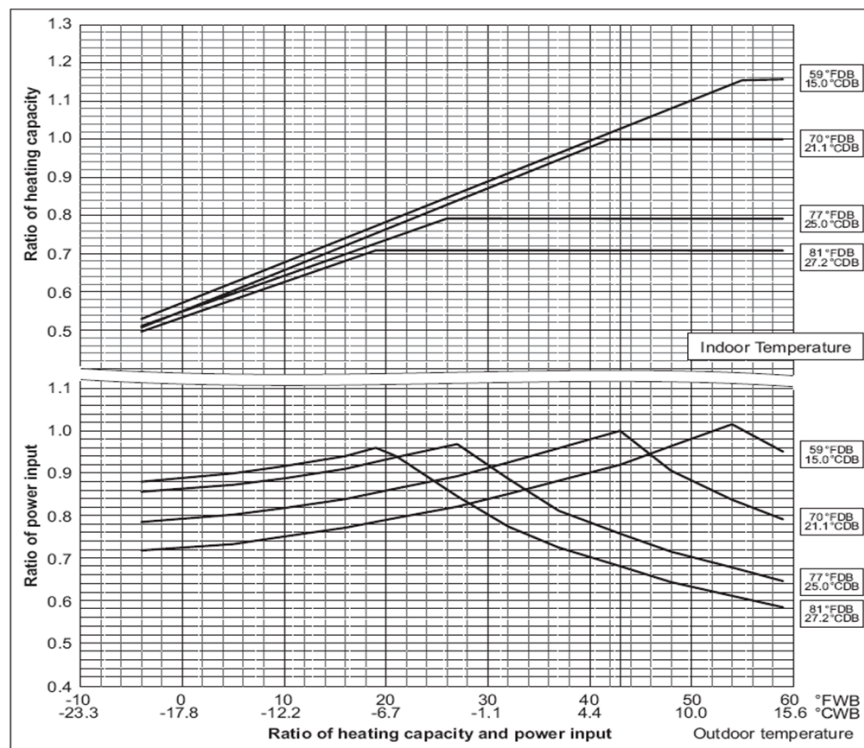


Figure 1. Heating Capacity Reduction Chart for CITY MULTI® Y-Series PUHY-P168~240T/YSHMU Condensing Units.

Choosing an HVAC System

Once the heating block load has been determined, an engineer must decide what type of equipment is best for the project. In today's market, there are many options that provide heat to a structure: air-source or water-source heat pumps; electric-resistance heating systems; fuel oil, natural gas, or propane furnaces; boiler systems that create hot water and steam using multiple power sources, and more. Other factors are also evaluated when choosing an equipment option:

- Is the project a new or existing structure,
- Initial costs,

- Maintenance costs,
- Equipment availability,

And the factor that has garnered the most attention in recent years,

- Energy efficiency costs

Comparing Energy Efficiency Costs—What are the Btus per Dollar?

When the engineer has determined several viable heating options for a project, a cost per unit of energy study should be conducted to further reduce the choices. Various fuel sources provide different amounts of energy per unit of measure which is generally considered a fixed value. HVAC products have established efficiencies associated with the equipment's actual operation which are typically not dependant on temperature. By performing a simple calculation with these known values, an engineer can easily determine the Btu per dollar for a given combination of equipment and fuel type. Some commonly used system types with their associated efficiencies are shown in Table 1.

Table 1. Comparing the Cost Per Btu and Related Efficiencies of Different Fuel Types

Fuel Type	Btu/Unit	Energy Cost	Equipment Efficiency	Btu/Dollar
Kerosene (No. 1 Fuel Oil)	134,000/gallon	\$2.89/gallon	0.85	39,412
Burner (No. 2 Fuel Oil)	140,000/gallon	\$2.18/gallon	0.85	54,587
Electricity	3,413/kWh	\$0.15/kWh	1.00	22,753
Natural Gas	100,000/therm	\$1.20/therm	0.9	75,000
Propane	91,600/gallon	\$2.24/gallon	0.85	34,759

A graphical representation of the BTU/Dollar values from Table 1 in relation to outdoor temperature is a flat line. The Btu/dollar for air-source heat pumps is not a flat line, however. As previously demonstrated in Figure 1, the heating capacity for an air-source heat pump will decrease as the outdoor temperature decreases. As such, the measured efficiency or ratio of heating capacity to energy input, commonly referred to as the Coefficient of Performance (COP), will also decrease. Table 2 illustrates COP and Btu/dollar for a CITY MULTI® Y-Series PUHY-P168YSHMU condensing unit at different outdoor temperatures.

Table 2. COP and Btu/Dollar for a CITY MULTI® PUHY-P168YSHMU Unit at Varying Outdoor Temperatures

Temperature (°F)	Calculated COP	Btu/Dollar
0	2.60	59,255
5	2.81	63,834
10	3.01	68,505
15	3.15	71,781
20	3.34	76,100
25	3.57	81,243
30	3.50	79,561
35	3.70	84,216
38	3.82	86,885
40	3.74	85,112
43	3.74	85,112
45	3.90	88,658
50	4.25	96,718

Figure 2 combines and graphically displays data from Tables 1 and 2. As demonstrated, the Btu/dollar for many HVAC system types remains constant regardless of outside temperature but for heat pump systems, the Btu/dollar fluctuates.

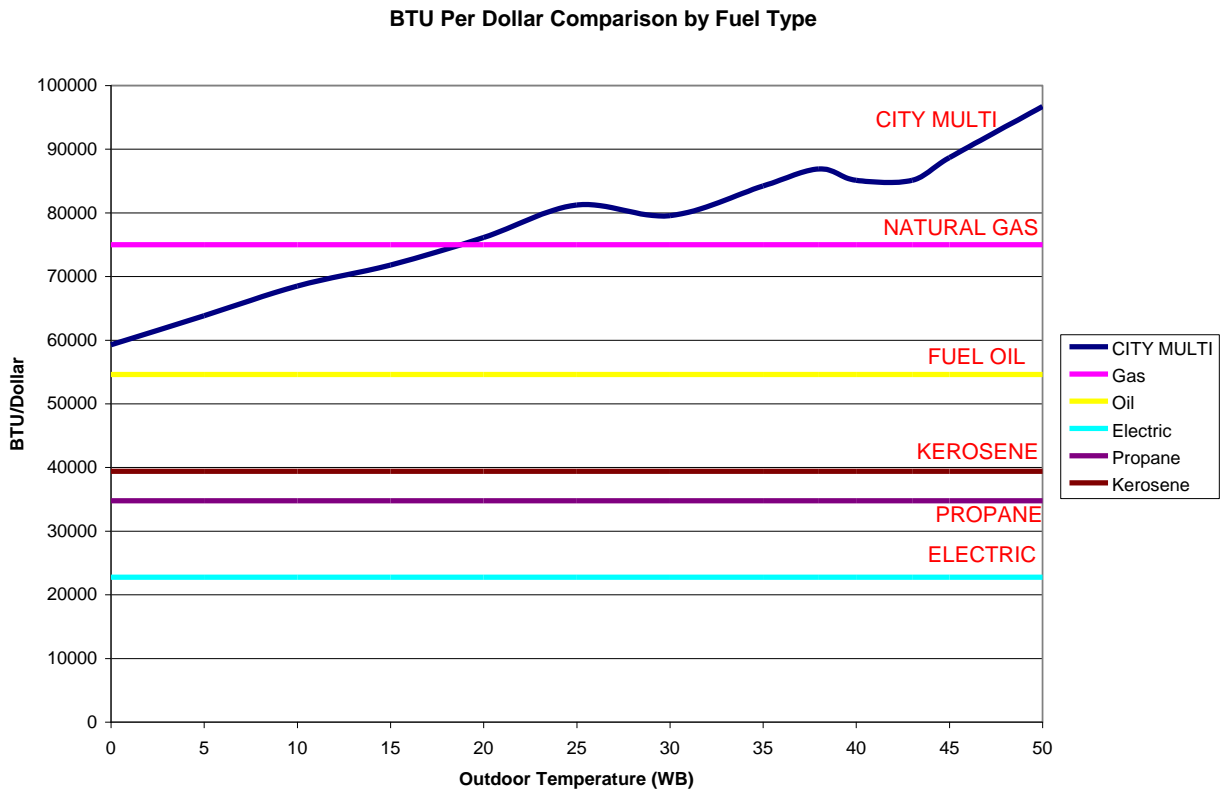


Figure 2. Btu/Dollar Comparison by Fuel Type

Special Considerations When Designing VRF Heat Pump Systems

Heat Pumps, Auxiliary Heat, and Upsizing

As shown in Figure 2, VRF heat pump systems provide more heating per dollar than other HVAC system types above 20°F WB. From a “cost of energy” standpoint, an engineer would use a heat pump to provide heating down to 20°F WB, the “changeover point,” and then switch to a gas-fired unit for auxiliary heat.

The PUHY-P168YSHMU VRF heat pump example unit has approximately 143,000 Btu/h available for heating at 20°F WB. The engineer would recalculate the heating block load at 20°F WB to determine the heating block load at changeover point. The engineer would determine both the difference in peak load at the heating design condition and the changeover point, and then would analyze the area’s weather bin data, available from ASHRAE, to find the number of operating hours below the changeover point. Table 3 displays the bin hour information for several locations.

Table 3. Bin Hour Information for Selected United States Cities.

Location	ASHRAE 99.6% Design Condition for Heating	Bin Hours Below Changeover Point	Percentage of hours below changeover point in Calendar Year
Washington, DC	+15°F	225	3
Worcester, MA	0°F	681	8
Denver, CO	-3°F	507	6
Helena, MT	-18°F	1003	11

For Helena, MT where the outdoor ambient condition often drops below the -4°F minimum operating temperature for CITY MULTI® condensing units, the engineer would automatically include auxiliary heat. For all other locations, a second analysis should be performed to determine if a larger sized heat pump can meet the maximum heating load at the design condition, or if auxiliary heat needs to be included. Table 4 illustrates the maximum and changeover point heating loads for Washington, Worcester, and Denver, and the recommended outdoor unit size for each.

Table 4. Maximum and Changeover Point Heating Loads

Location	Max. Heating Load	Changeover Point Heating Load	Nominal Tonnage Difference	Condensing Unit Size-Max. Heating Load	Condensing Unit Size-Changeover Point Heating Load	Nominal Tonnage Difference
Washington, DC	216,500	197,030	1.6	PUHY-P312YSHMU	PUHY-P264YSHMU	4
Worcester, MA	275,842	197,030	6.5	(2) PUHY-P192YSHMU	PUHY-P264YSHMU	10
Denver, CO	287,664	197,030	7.5	(2) PUHY-P192YSHMU	PUHY-P264YSHMU	10

At this point, costs would be prepared that compared the upsized CITY MULTI® outdoor unit and whatever auxiliary heat was determined most appropriate based on the energy cost study discussed in the previous section. If CITY MULTI® is chosen to provide 100% of the heating capacity, the engineer can apply the appropriate temperature derate and choose the equipment size necessary to meet the heating block load. If adding auxiliary heat is the best option, find the changeover point to maximize the efficiencies of both systems.

Properly Sizing the Indoor Units

The engineer must understand that temperature derate applies to the indoor units of a VRF heat pump system as well. To follow the example presented in the “Determining the Condenser Unit Size” section, an engineer using a desired heating operation set point of 70°F DB with a 10°F WB heating design condition would have a 66% heating capacity factor. A space located in a building requires 11,100 Btu/h to meet the heating load, and a wall-mounted unit has been specified (see Table 5 for examples).

Table 5. Specifications of Four PKFY Indoor Units

Model			PKFY- P06NBMU-E	PKFY- P08NBMU-E	PKFY- P12NHMU-E	PKFY- P15NHMU-E
Power source			1-phase 208/230V 60Hz			
Cooling capacity (Nominal) *1	BTU / h		6,000	8,000	12,000	15,000
	kW		1.8	2.3	3.5	4.4
	Power input	kW	0.03	0.03	0.03	0.03
	Current input	A	0.15	0.15	0.30	0.30
Heating capacity (Nominal) *2	BTU / h		6,700	9,000	13,500	17,000
	kW		2.0	2.6	4.0	5.0
	Power input	kW	0.03	0.03	0.03	0.03
	Current input	A	0.15	0.15	0.30	0.30

Utilizing the heating capacity factor in a quick calculation reveals that the PKFY-P12NHU-E only has an 8,910 Btu heating capacity, but the PKFY-P15NHMU-E can provide an 11,220 Btu heating capacity at 10°F WB. The 15,000 Btu/h unit meets the load, but only by 100 Btu/h. Before finalizing on such a “close” sizing, the engineer should analyze a couple more issues

- How accurate is the load calculation,
- What is the effect of defrost and line length,
- How vital is maintaining set point to this space

Ventilation Air Requirements

Engineers must follow all ventilation air code requirements, regardless of the climate. Whether the project is located in humid, hot, coastal Georgia or in the extreme cold of the Montana mountains, the ventilation air load must be accounted for.

CITY MULTI® indoor units have a minimum temperature range at which return air can enter the coils. As such, in locations where systems must be designed for heating, some type of preheating must be incorporated to ensure an acceptable mixed air temperature. The choice on whether to use a full enthalpy energy recovery ventilator such as a LOSSNAY® unit, or some other form of preheat should be based on a financial analysis. If preheating is included, the engineer should recalculate the mixed air condition to reflect the preheating, because this will affect the maximum heating load which the terminal equipment must handle.

Diversity

A CITY MULTI® VRF heat pump system can be designed to take advantage of the “diversity” inherently present in a building. Diversity is generally considered a representation of shifting building loads throughout the day. Diversity is commonly created by changing solar loads, varying people loads, and heat generated from office equipment and lights. Diversity allows the engineer to connect more indoor unit capacity than the condenser unit can provide. In some systems, the diversity could be upwards of 20%. When sizing a CITY MULTI® system based on heating block load, however, diversity becomes very important.

Peak cooling load commonly occurs on a mid-afternoon in July or August, often when the building is at maximum operation and the load profile matches the anticipated diversity. Peak heating load, however, occurs at a very different time, usually in the middle of the night. As such, any available diversity is minimal. In a heating-dominant climate, the connected indoor unit capacity should be very close to 100% of the condenser unit’s capacity, unless the engineer has strong data to indicate otherwise.

Defrost Operation

All air-source heat pumps must switch into defrost mode when certain conditions are present. The defrost cycle for CITY MULTI® condenser units has been designed so that both its frequency and time have been minimized, but during defrost mode, CITY MULTI® systems stop the heating operation completely. Therefore, the engineer must design to handle any heating needs during defrost, especially in building zones with an exterior exposure.

CITY MULTI® indoor unit fans can be set to turn off when the system is in defrost mode. In fact, in heating dominant loads, it is recommended that the fans are turned off during defrost heating, unless a duct mounted heating source is in place.

Design Tool Software

How does an engineer ensure that all of the appropriate capacity reductions are included in the design calculations? Mitsubishi Electric’s Design Tool was developed to aid in designing CITY MULTI® projects. The engineer creates the entire CITY MULTI® system; outdoor and indoor

design conditions are also input. The output will then display the actual capacity of each component of the system based on piping length, defrost operation, and any other derates. This ensures the indoor units meet the peak load for each space, and the condenser unit has the capacity to meet the building load.

Heating Design Guidelines

Some general guidelines the engineer should always consider when designing a VRF heat pump system are:

- 1- Minimize connected capacity to near 100%. Very little diversity exists when maximum heating capacity is needed.
- 2- Consider using auxiliary heat sources whenever the ambient condition is below 10°F. An energy cost and equipment first cost comparison is the most reliable way of making the proper decision.
- 3- Input all designs into the Design Tool software with accurate conditions and piping lengths to verify available capacities of indoor units.
- 4- Preheat outside air as needed to create a 55°F minimum mixed air condition to lower heating load on indoor equipment. A Lossnay® ERV can be utilized to recover energy from an exhaust air stream for preheating.
- 5- Have indoor unit fans shut off when the LEV is at minimum position unless utilizing a downstream duct heater.
- 6- Use room mounted sensors to control space temperature especially in units which incorporate outside air.
- 7- Utilize the outdoor temperature method for controlling auxiliary heat to ensure that the space temperature does not drop beyond a comfortable point for occupants.
- 8- Consider using an integrated temperature component which can energize supplemental heat in case of system error.
- 9- Consider placing the outdoor unit in an enclosed space to minimize affects of low ambient conditions. The designer must account for the necessary airflow needed by the condenser unit.

Summary

CITY MULTI® VRF heat pump systems are viable options for low ambient heating. Utilizing proper design considerations ensures the system will provide the needed heating capacity to maintain a comfortable space. Please contact your local Mitsubishi Electric HVAC sales person for assistance if you should have any further questions about the CITY MULTI® VRF system.