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Understanding the Selection of Direct Expansion (DX) Coils for Both Cooling and Heating

The need to heat without the use of onsite fossil fuels (i.e. electrification of heat) has become an urgent initiative as the built environment focuses on decarbonization. Paramount to these goals is the broader use of heat pumps. But to maximize the use of mechanical heating, we must understand how to select direct expansion (DX) coils for both cooling and heating operation.

This Engineers Newsletter will introduce a simplistic approach for the equipment selection process to address the needs of a system that must heat as-well-as cool. We will start with some basic refrigeration and heat pump theory, and then build upon these topics to provide guidelines on DX coil selection. And since most variable refrigerant flow (VRF) systems are capable of both cooling and heating operation, we will extend the discussion throughout to address DX coils that will be utilized in a VRF system.

The Refrigeration Cycle

In its simplest form, a refrigeration cycle requires four components: an evaporator to absorb heat, a compressor to raise the pressure of the refrigerant, a condenser to reject heat, and an expansion device to lower the pressure so that the cycle can begin anew (Figure 1).

There are a number of compressor and fan control options available to modify the capacity of a system, but this newsletter will focus on the indoor coil. The indoor coil will function as the evaporator in an air-conditioning split system or as both the evaporator (during cooling mode) and the condenser (in heating mode) in a heat pump split system.

As we discuss indoor coil selection, we will cover several important parameters that describe the state of the refrigerant throughout the refrigeration cycle. We can illustrate these parameters—and the refrigeration cycle as a whole—in a number of ways, but the most common is by using a pressure-enthalpy or p-h graph. A p-h graph cleanly shows the rise and fall of pressure necessary for the expansion process, as well as the heat content (enthalpy) at each point in the cycle (Figure 2).

Figure 1. Components of a refrigeration cycle

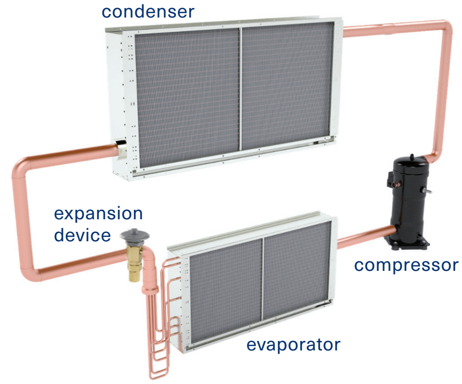
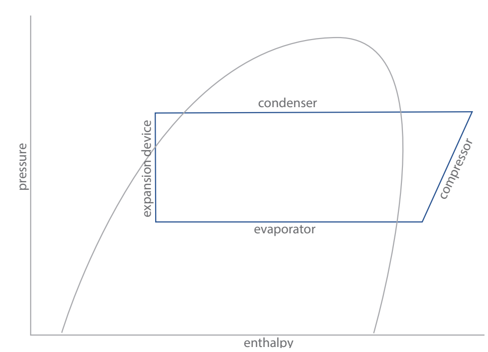


Figure 2. Typical refrigeration cycle on a p-h diagram



The terms "refrigerant coil" and "DX coil" tend to be used interchangeably. The "refrigerant" qualifier might be obvious, but *direct expansion* warrants some additional explanation.

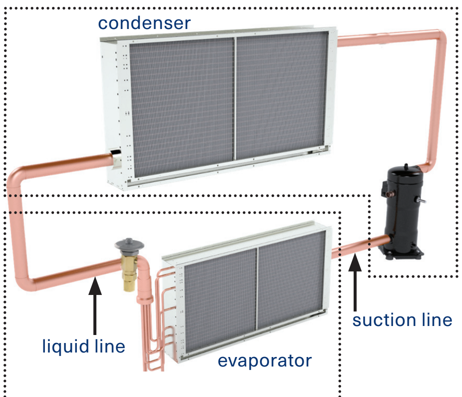
"Direct" simply means we are transferring heat to and from the refrigerant directly. An "indirect" refrigeration system would use an intermediate fluid like water or glycol. "Expansion" indicates the key phenomenon of the refrigeration cycle: a volatile refrigerant (one that can easily evaporate at normal temperatures) will evaporate and expand to produce a cooling effect.

Although we generally represent the refrigeration cycle on a pressure-enthalpy graph, a pressure-volume graph looks similar in that the volume—like the enthalpy—will steadily increase in the saturation region inside the evaporator. A notable difference is that the refrigerant will also expand through the expansion device and will be compressed through the compressor.

Split System Overview

The refrigeration components that make up an air conditioner or a heat pump can come packaged together in a single unit, or they can be "split" with equipment located in two or more places (see Figure 3). The latter is generally referred to as a "split system". When an indoor coil is split away from the other components, additional effort is needed to properly select the components to match an indoor coil with an outdoor unit (ODU).

Figure 3. Split air-conditioning system boundaries (cooling mode shown)



A split system consists of three primary components:

- Indoor unit: the evaporator coil and expansion device in an air-conditioning system, or the condenser coil during heating operation
- ODU: the compressor and the condenser coil in an air-conditioning system, or the evaporator coil and expansion device during heating operation
- Line set: The liquid and suction lines, and any additional components that transport refrigeration between the indoor and the outdoor unit

All three components have an impact on split system performance. In addition to the indoor and outdoor units (where the four required components of any refrigeration cycle are located) the line set affects the balance point as it will introduce what's known as "line loss". The line loss can vary depending on factors like length and riser height. Line loss is ultimately pressure loss and will result in slight deviations to the points illustrated on an idealized p-h chart.

Note that the term "split system" is generically used for a number of approaches from a traditional 1-to-1 split system to a many-to-many VRF split system. In any case, we can simplify the concept by stating that heat is absorbed in any coil acting as an evaporator and heat is rejected in any coil acting as a condenser.

Heat Pump Overview

A heat pump is a system that can heat via mechanical means (a compressor) with electricity as the energy input. It accomplishes this by essentially reversing the refrigeration cycle. Some of the heat produced in a heat pump is generated (via heat of compression), but most of the heat is "pumped" from a lower energy state to a higher energy state. Air at any ambient temperature contains heat, and a direct expansion refrigeration cycle is utilized to move or "pump" that heat around. This can be accomplished by lowering the pressure of the refrigerant enough to absorb heat from the outside air, and then raising it enough to reject that heat usefully to the indoor air.

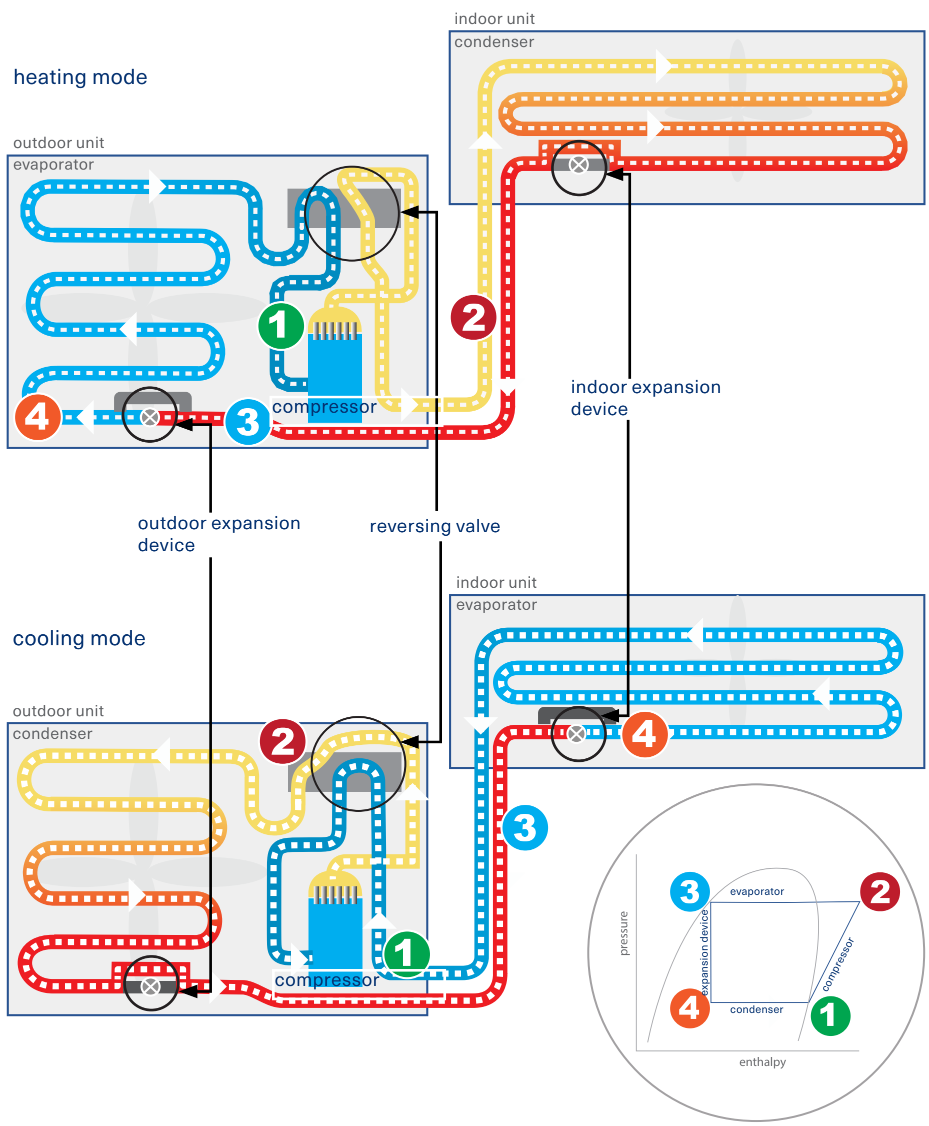
A heat pump requires both a heat source and a heat sink. With a balanced split system, these needs can be easily met. But to meet the needs of a variety of building types, we often must pair a variety of airside devices—and by extension, coils—with a variety of ODUs.

An ODU designed to operate as a heat pump will look similar to an ODU setup to operate as an air conditioner. The primary difference is that the ODU will include two additional components (Figure 4):

- a reversing valve, and
- an additional outdoor expansion device

The reversing valve is used to reverse the refrigeration cycle so that heat can be "pumped" from the outdoor air to the indoor air. The additional expansion device is necessary to protect the compressor and maintain a stable level of superheat inside the outdoor coil.

Figure 4. Reversible refrigeration cycle (heat pump) in heating and cooling modes



Cooling Mode Performance Parameters

The following parameters need consideration to accurately predict the performance of a DX coil that is used as an evaporator coil:

- Liquid temperature entering the expansion device
- Saturated suction temperature (SST)
  - Also known as *low-side pressure* or *suction pressure*
- Target superheat

These parameters can be illustrated on a p-h graph as shown in Figure 6. Note that the liquid temperature entering the expansion device will be much higher than the temperature at the start of evaporation process (the SST).

Cross plotting for cooling

To select the components of a traditional split system for cooling, both the ODU and the evaporator need to be evaluated at a point of balance for the system. This balance point occurs where the capacities of the two portions of the system match, at the same (evaporator) saturated suction temperature.

To evaluate the balance point manually, without the aid of a software tool, we use a process known as "cross plotting". This involves first locating a plot of ODU capacity as a function of saturated suction temperature, often at a variety of ambient temperatures. Most ODU manufacturers will provide such a graph in catalogs or selection programs.

The system designer then superimposes an evaporator curve on the ODU graph. To obtain the values needed to plot an evaporator curve, coil performance is needed for at least two conditions (assuming a linear evaporator curve). Assuming all other variables remain the same (air conditions, physical coil properties, etc.), the end result will be two intersecting lines with opposing slopes as shown in Figure 7.

But we must also account for something known as "line loss". The line loss is an estimate of the increase in the SST as a result of pressure drop in the suction line. The term "loss" is used here as the increase in SST reduces the amount of heat that can be absorbed from the evaporator. So the SST that's used for coil selection is actually the saturated suction temperature from the ODU plot PLUS the line loss (Figure 8).

But there are better ways to evaluate performance. Using software models for both the ODU and the evaporator, the balance point can be found without the need for the extra steps described above.

Figure 6. Cooling mode performance parameters

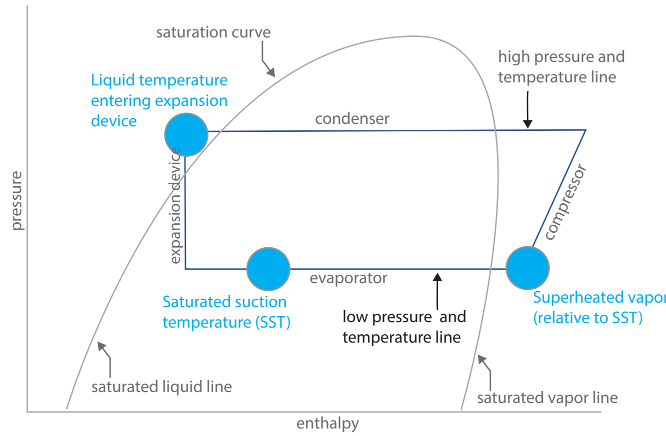
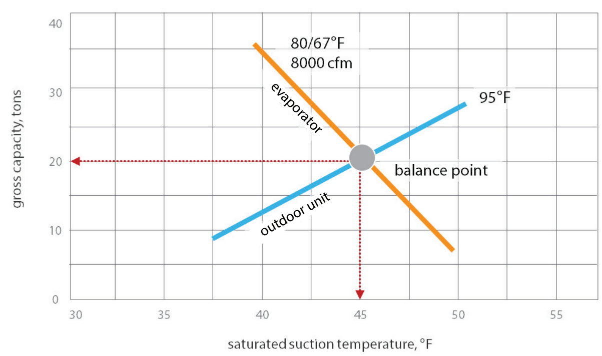


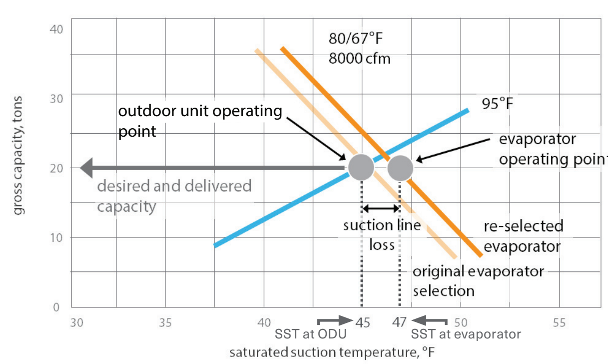
Figure 7. Cross plot of evaporator coil and ODU curves in cooling mode



To learn more about cross plotting, and how to visualize system response based on a number of changing situations, refer to Trane *Engineers Newsletter* volume 48-4 (ADM-APN072-EN). Effects covered include:

- Coil size
- Airflow changes
- Changes in entering air temperature
- Refrigeration capacity reduction methods

Figure 8. Evaporator coil and ODU operating points including line loss



Cross plotting for a VRF system

The selection of a VRF system is considerably different and cross plotting is not normally necessary. A VRF system has many additional components which provide these systems with greater flexibility. This includes variable speed compressors, variable speed condenser fans, and the system controls required to maintain fixed or predictable variance in SST. Thus, it is not necessary to determine a balanced operating point for a VRF system.

This flexibility also makes it much easier to design systems consisting of one ODU and many indoor units (one-to-many) or even a network of ODUs connected to many indoor units (many-to-many).

Heating Mode Performance Parameters

Similar to a coil operating in the cooling mode, there are a number of parameters that must be evaluated for a DX coil when used as a heating (condenser) coil:

- Hot gas temperature
- Saturated discharge temperature (SDT)
  - Also known as *condensing temperature*
  - Also known as *head pressure* or *high-side pressure*
- Target subcooling
- Heat available

These parameters (except heat available) can again be illustrated on a p-h graph as shown in Figure 9. Note that the hot gas temperature will be much higher than the temperature at the start of the condensing process (the SDT). Also, target subcooling is a relative value which represents the difference between the temperature entering the expansion device and the SDT. Since most of the heat rejection occurs along a line of constant temperature and pressure, the most important of these—in the context of coil selection—is SDT.

These parameters are similar to those used in cooling mode but note the addition of a new parameter: *heat available*. Unlike in cooling mode, where the coil is *absorbing* heat from the air, in heating mode it's necessary to *reject* a certain amount of heat in the condenser to complete the refrigeration cycle. Thus, the heat available from the ODU is needed to determine the amount of heat to be rejected (or is available for useful heating) in the indoor unit.

Cross plotting for heating

Cross plotting for heating works much the same way as cross plotting for cooling, the difference being a balance point based on the SDT with heating capacity in lieu of the SST with cooling capacity.

However, this exercise is generally not performed for a number of reasons, one being limited availability of a curve plotting SDT with heating capacity. Instead, it is recommended that a software tool be used to properly predict the heating capacity of a split system.

Outdoor unit performance

ODUs are generally sized based on their cooling performance at a relatively high design point (95°F ambient). Heating performance can be much lower, and nominal heating capacity is often based on a very mild or somewhat mild design point: 47°F ambient or 17°F ambient respectively.

As shown in Figure 10. A heat pump will produce much lower capacities at lower outdoor (ambient)temperatures. This occurs for two primary reasons:

1. air will have lower heat content at lower ambient temperatures
2. the compressor mass flow rate decreases due to the increasing refrigerant specific volume at lower temperatures

As a result, regions subject to coil frosting will see a reduction to integrated heating capacities during defrost cycles.

Another consideration is that all heat pumps will have a minimum operating temperature. Many traditional outdoor units will shut off mechanical heating near or just below 0°F. Others, particularly VRF outdoor units, can operate down to even lower temperatures.

Figure 9. Heating mode performance parameters

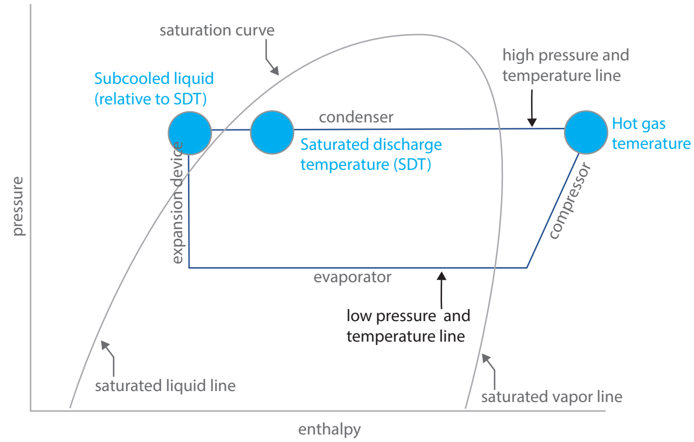
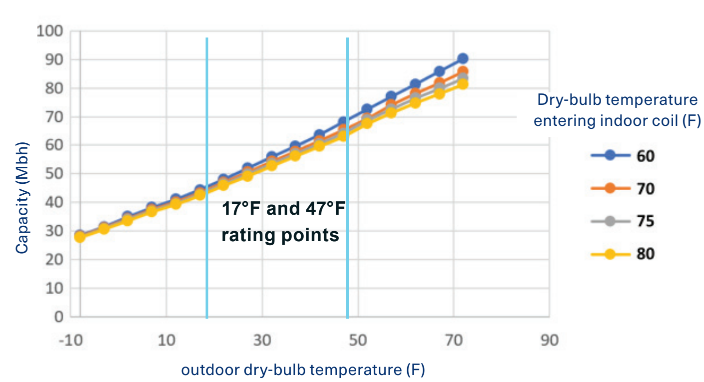


Figure 10. ODU heating performance (6T example)



Recommended Selection Method

Selecting a DX coil for both cooling and heating might seem complicated, but we can simplify the process down to just a few steps:

1. Select the coil and ODU based on design day cooling requirements
    - Use a cross plot or ideally, an electronic selection tool.
2. Compare the heating performance output from an electronic selection tool with the design day heating requirements.
3. If the output heating performance is insufficient, return to Step 1 and select a larger ODU

This process assumes the goal is to maximize the use of mechanical heating. To increase the amount of mechanical heating a unit can provide, it is recommended to use a larger ODU. Be careful: an oversized unit could have poor humidity control during cooling or result in excessive compressor cycling. To mitigate these issues, consider a unit with dehumidification control (e.g., hot gas reheat) and/or a variable capacity refrigeration system.

In lieu of selecting a larger ODU, an alternative would be to determine the ambient temperature where auxiliary heat should be enabled. The auxiliary heat can then be sized to handle the deficiency.

Selecting coils for VRF applications

When heating in addition to cooling is desired, a VRF system is often considered. A VRF system can operate as a heat pump as well as a heat recovery system to provide simultaneous heating and cooling.

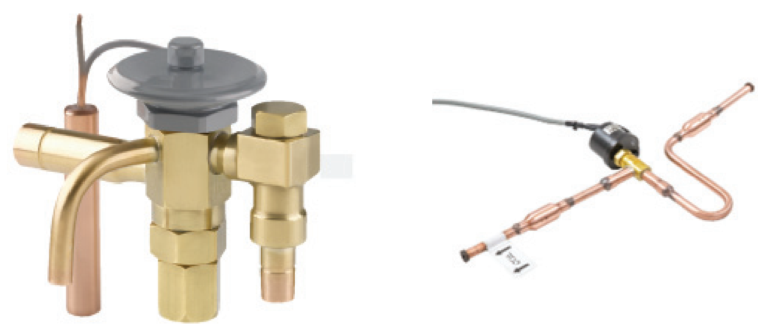
In lieu of a thermostatic expansion valve (TXV), VRF units often utilize an electronic expansion valve (EXV) to monitor entering and leaving conditions of both the refrigerant and the indoor air stream (Figure 11). This additional monitoring can result in some unique parameter values, coil design criteria, and control considerations relative to a traditional split system:

- The default VRF parameters differ:
    - The liquid temperature entering the expansion device will be much lower (e.g., 80°F vs. 115°F)
    - The subcooling temperature will be much higher (e.g., 27°F vs. 10°F)
    - The SST and SDT parameters will depend on outdoor ambient temperature, line length, and/or ODU model
- Coil volume, refrigerant pressure drop, and refrigerant velocity must fall within specific ranges
- Controls will limit discharge air temperature:
    - Discharge air temperature control vs. zone temperature control will have different limits
    - The heat available from the ODU will also determine an upper limit

As mentioned earlier, cross plotting is not needed for a VRF system. But we can extend our simplified method to include VRF coils:

1. Select coil and ODU based on design day cooling requirements
2. Obtain heat available from the ODU, and run coil heating performance
3. Compare the output heating performance with the design day heating requirements
4. If the output heating performance is insufficient, return to Step 1 and select a larger ODU

Figure 11. Expansion valves



thermostatic expansion valve (TXV)

electronic expansion valve (EXV)

Application Considerations

When a DX coil is to be used for both cooling and heating, the system designer should be aware of several application considerations.

Higher working pressures

DX coils offered in air handlers and terminal devices are typically designed to function as an evaporator, which operates on the low pressure side of the refrigeration system. Many coils are capable of operating at both the low and high pressure sides of the refrigeration system, but tube diameter and tube wall thickness options may be limited.

VAV operation

The effects of varying airflow need to be considered for a system in heating. For example, many electrical components may be limited to a maximum operational temperature. Supply fan motors tend to determine this upper limit with a maximum high temperature as low as 104°F. Low and/or high voltage control box locations might also be a factor. To account for these constraints, the equipment may be limited in turndown, or controlled to revert to constant volume airflow during heating mode. Other systems might include controls to limit discharge air temperature. In any case, the system should be carefully selected to ensure leaving air temperatures do not exceed upper limits for the components included in the air handler.

Auxiliary heat and dual-fuel (hybrid)

It is common to size an auxiliary heater to handle the full design day heating load in the unlikely event the heat pump malfunctions. In many jurisdictions, a dual-fuel (hybrid) system can be provided where the auxiliary heater utilizes gas as a fuel source. A dual-fuel unit will require a separate gas hookup, and a gas heat exchanger rated for dual fuel. When done properly, the electrical connection size may not need to be increased.

In other jurisdictions, electric resistance heat may be necessary. In this case, the electrical connections will need to factor in both the mechanical heating and the electrical resistance heating simultaneously (during defrost for example).

Electricification of heating could mean converting all forms of energy used to heat a building to electricity, minimizing fossil fuels as a source of energy, or some combination of both practices. A dual-fuel unit is a useful tool for this purpose as it will supplement heat pump operation only when necessary, while providing an early step for future electrification goals and requirements.

Defrost

All heat pump systems will need to periodically enter a defrost cycle when outdoor conditions cause frosting of the outdoor coil. When an outdoor unit is in defrost, the indoor evaporator coil operates in cooling mode and quick drops in indoor space temperature can be expected.

Some units may simply shut off the indoor fan during defrost. In others, auxiliary heat is used to warm up the cold air coming off the evaporator coil. If the indoor fan remains energized, a quick acting auxiliary heater should be energized and set to a minimum position/stage (50 percent minimum recommended).

Conclusion

Electrification of heating using heat pumps is further enabling building decarbonization goals. Matching a split indoor DX coil with an ODU can be simplified using a similar approach for both cooling and heating (Figure 12). This EN suggested a simplified selection method that starts with cooling and doubles back to verify performance for heating. If simultaneous heating and cooling is a goal, consider the unique selection characteristics inherent with a Variable Refrigerant Flow (VRF) system.

By Dustin Meredith, Trane. To subscribe or view previous issues of the Engineers Newsletter visit trane.com. Send comments to ENL@trane.com.

Figure 12. Traditional split system, air handling coil and variable refrigerant flow outdoor unit

split system

coil

outdoor VRF unit

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