Cooling Coils: A Comparison of Dehumidification Performance

Summary

The conditioning of air occurs at the cooling coil. Obviously, the coil is the center of the air-conditioning process, so one would imagine that much would be studied and written about the performance of coils. A quick review of recent trade journals at almost any instant in time will prove this assumption wrong. The cooling coil is the component that today's manufacturers have most compromised in the name of cost savings.

For climate zones that are humid, it is important that the cooling coil be able to dehumidify the airstream. This ability is initially defined by how "cold" the coil can be. As important as that is, the part-load performance is often just as important as the full load values. Even for dryer climates, dehumidification can be important for conference rooms, training rooms, school classrooms, and similar occupancies.

Today, packaged equipment is utilized for the majority of air-conditioning applications. Packaged equipment is pre-designed by the manufacturer, so a system designer has limited control over factors that are important to the process. Most packaged equipment is not designed to effectively dehumidify when the application is more than a light-duty challenge. It does not have to be this way! Sadly, instead of improving past packaged equipment designs, American manufacturers have chosen to import equipment designs from other countries where designs are optimized for indoor conditions much different that ours.

This paper will endeavor to explain the three major cooling coil types in simple terms, with additional details coming in further papers.

Chilled Water Coils

Chilled water coils perform best when dehumidification is important.

A chilled water coil is unquestionably the best coil to condition air. It can be sized and selected to provide the optimal performance for given conditions (tubes, rows, fins, etc.). By using chilled water (or any fluid), optimal part-load performance is present as well.

Chilled water is typically distributed at temperatures of 42 to 48 degrees, but most often at 45 degrees. Design return water temperatures are often 55-58 degrees. We will use 55 to make the math simple.

The airside heat transfer across a coil at full load is defined by the equation:

$$Q_{100\%} = CFM \times 1.08 \times \Delta T_{AIR}$$

If a VAV system is present (it usually is), then at 50% load and airflow:

$$Q_{50\%} = (0.50) \times CFM \times 1.08 \times \Delta T_{AIR}$$

Of significance here is that the airflow is reduced proportionately to the load, leaving the airside delta-T constant. This is important and desirable, as a low leaving air temperature is necessary to maintain some level of dehumidification capacity within the system.

Of equal significance, the water-side performance encourages proper air conditioning as well. The water-side heat transfer across a coil at full load is defined by the equation:

$$Q_{100\%} = GPM \text{ x } 500 \text{ x } \Delta T_{WATER}$$

Given the previously mentioned VAV system, at part load:

$$Q_{50\%} = 0.50 \text{ x } GPM \text{ x } 500 \text{ x } \Delta T_{WATER}$$

This equation is possible because a control valve can vary the water flow through the coil. Today, pressure independent controls ensure this. So, like the air side, a constant delta-T is maintained across the water system. This is optimal for the chiller operation and efficiency, but it also maintains a constant average water temperature across the coil. This translates to a constant average coil surface temperature, even at part load, which is helpful.

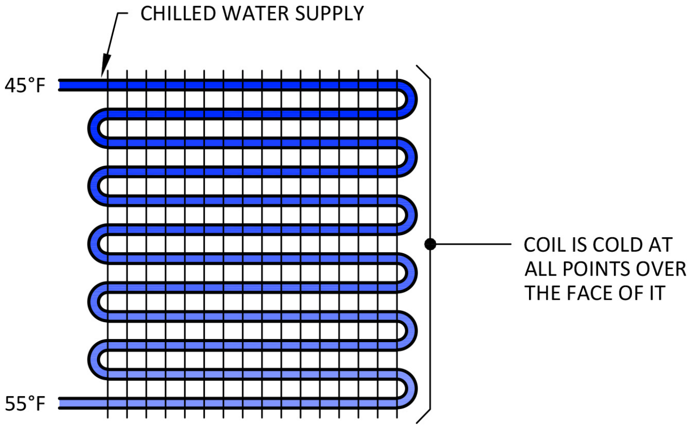

Figure 1 - Chilled Water Coil Illustration

So, it is relatively easy to see that a chilled water coil performs admirably and efficiently when conditioning air, especially when dehumidification is required.

Traditional Direct Expansion (DX) Coils

The term “traditional” is used here to describe a single refrigerant coil that is provided refrigerant by a single compressor-condenser, whether as a prepackaged unit or a split unit. Traditional units utilize cycling, or on-off control in order to address part-load capacity.

A DX coil is very similar to a chilled water coil in many aspects. They have similar components and properties (i.e.tubes, fins, rows, etc.). However, the heat transfer medium is not water, but a refrigerant liquid that changes state within the coil tubes to a gas. This change of state brings heat transfer with it and allows the airflow across the coil to be conditioned.

Right away, the DX coil loses some efficiency compared to a chilled water coil. Because a DX coil must ensure that all liquid is evaporated before being returned to the compressor, a smaller but significant portion of the coil tubes is essentially wasted because the change of state is completed before the refrigerant travels through the entire coil. This final stage is called "superheat" and is required to ensure that no drops of liquid reach the compressor, where they would cause damage or failure.

This disadvantage of superheat may be offset by the fact that within the portion of the coil that does experience a change of state, the pressure and therefore the temperature of the fluid-gas is relatively constant and does not rise significantly as chilled water does. The temperature actually falls a small amount, as the pressure drop due to friction in the coil results in a corresponding temperature drop. This is the saturated suction temperature (SST) and coils are often (but not always) selected for a SST of 45 degrees F which is similar to entering chilled water temperatures. Since it does not rise to 55 degrees F like chilled water, the average coil surface temperature may be lower than a chilled water coil, at least for the active portion of the coil. This is a positive impact on airside cooling and especially dehumidification.

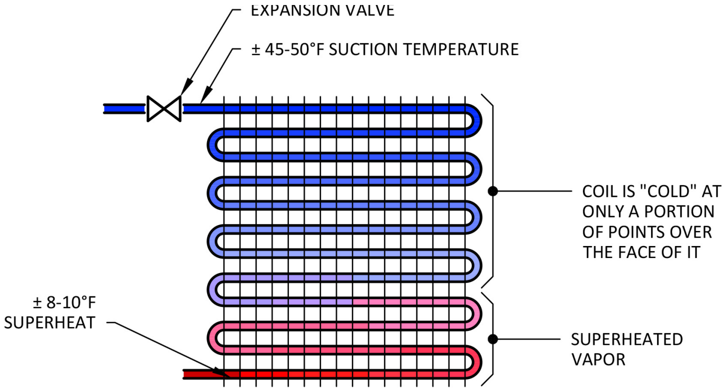

Figure 2 - Traditional Direct Expansion (DX) Coil Illustration

DX systems are "off" at part load and will not dehumidify.

A traditional DX system does not have the ability to operate at part load, at least for most packaged equipment. If the space temperature falls below the desired setpoint, the system will simply turn off, until the space temperature again rises sufficiently high enough to warrant cooling again.

The dehumidification performance of a DX coil, at peak loads, can be equal or greater than that of a chilled water coil. However, at part load, dehumidification becomes less efficient, mainly because the coil is off and not cold. This contrasts with a water coil where the coil surface is almost always cold. So, because of periodic system shutdown, the dehumidification of direct-expansion systems is somewhat less effective than chilled water.

It is interesting to note that for traditional DX systems, capacities do vary based on outside conditions and indoor loads. While coils are “selected” for a particular SST, the system SST is not really controlled in any manner. Rather, the coil superheat is regulated by a thermal expansion valve (TXV) and the rest of the system will “balance” from that point. This is a red flag that many designers do not fully grasp - the variable that is most important to system capacity is not directly controlled in any manner!

The concept of balancing is a difficult subject, but is well explained in a publication of the Trane Company. This document , *Understanding the Selection of Direct Expansion (DX) Evaporator Coils, Engineers Newsletter, Volume 48-4*, can be found on Trane’s website. Written by Paul Solberg, a long-time Trane employee, it describes how system variables change with outside temperature and indoor loads in a manner that few have in the past.

In the context of this paper, it is useful to note that the system capacity goes up as the outside temperature falls. While that might initially seem positive, it actually leaves the coil and system “oversized” at part loads, so that the system run time is further reduced.

Variable Refrigerant Flow (VRF) Coils

We previously described a traditional DX system and pointed out a compromise - the most important coil property, saturated suction temperature (SST), is not even directly controlled by the system. This leaves a system subject to missing performance goals (or certification!) because of external (but normal) influences like outdoor temperature or indoor load.

Today, manufacturers are promoting ″variable refrigerant flow (VRF)″ systems, although not a lot is being said about the way in which they operate. We will try to reduce the complexity and offer a simplified explanation.

Most of today’s VRF systems are built around individual air handlers that may, or may not be, manifolded with a number of similar units. Each VRF air handler consists of a fan and refrigerant coil, not unlike a traditional DX system. However, a VRF system will exert direct control on an electronic expansion valve instead of using a thermal expansion valve to control refrigerant superheat. This initially sounds positive, as the lack of direct control of this expansion valve was one significant drawback of a traditional DX system.

Unfortunately, the VRF industry has not chosen to control the refrigerant flow in a manner that would be consistent with control of dehumidification.

VRF coils are flawed, but because of control sequence, not coil potential.

The typical control sequence for a VRF coil is based on return temperature only. If the return (space) temperature is quite far from setpoint, then the expansion valve will be opened completely, allowing full refrigerant flow. Heat transfer follow a similar path to the traditional DX coil:

$$Q_{100\%} = CFM \times 1.08 \times \Delta T_{AIR}$$

Unlike a VAV chilled water system though, the VRF control sequence maintains constant airflow across the coil. So, at 50% load, the following equation applies:

$$Q_{50\%} = \text{CFM} \times 1.08 \times (\Delta T_{\text{AIR}} \times 0.50)$$

Simply stated, the coil temperature difference is halved. Since the space temperature is roughly constant, then the leaving air temperature will now rise from a value that might be in the mid-to-high 50's to a number that is well into the 60's. Obviously, much less dehumidification will occur.

Another perspective on the process is that at part load, a smaller amount of refrigerant is being metered through the expansion valve. The coil is essentially oversized at this point. This results in the refrigerant evaporating very quickly and only using very small portion of the coil for the process. The rest is subjected to superheat, where it accomplishes little to no dehumidification.

A VRF coil loses its ability to dehumidify very quickly as load falls. Even more problematic is that most systems rarely operate at full load. Since the system is at a constant part load condition, dehumidification is simply not available in significant quantities. From a project standpoint, a VRF coil should not be utilized any time that moisture removal is important, at least in humid climate zones. This would include applications that include people, fresh air, and infiltration.

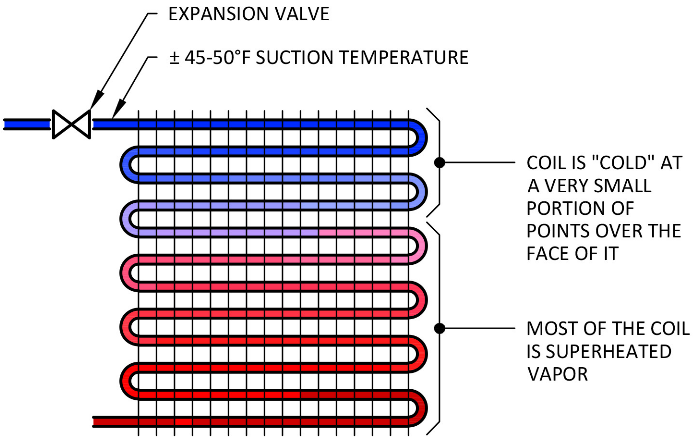

Figure 3 - Variable Refrigerant Flow (VRF) Coil Illustration

A VRF coil is only effective for DH at near full load conditions. Dehumidification depends on a cold coil, but the coil is not going to be cold enough for that at part load, which is where a system operates most of the time

Saturated suction temperature (SST) defines dehumidification potential.

For a given coil, variable flow or not, the coil SST is the variable that will define dehumidification ability. This value will be very close to the coil's apparatus dewpoint (ADP) or average surface temperature, at least for the portion of the coil that avoids superheat. Sadly, the saturated suction temperatures that result in some VRF systems are fairly high, limiting dehumidification even at full load. Further, the limited number of coil rows that exist on most VRF indoor units result in coil bypass factors that limit DH performance even further. While VRF systems could possibly include deeper coils (more rows), manufacturers have not offered these options. As is the case with most packaged equipment options, low cost is over emphasized over adequate dehumidification and overall system efficiency.

VRF coils, at least for most manufacturer's systems, should not be considered where dehumidification is an important part of the design. Manufacturers have chosen control sequences and coil configurations that do not promote it, so one should assume that a VRF coil is only effective for sensible cooling only.

Indoor conditions in Asia are different than those in America!

Today, almost all VRF systems on the market have been designed and are manufactured in Asia. It is interesting to note that customs in that part of the world are to condition interior spaces to 28º C (84º F) instead of the 75º F that is prescribed in the USA. These are design/code values. Reality is that most occupants set their thermostats to 26º C (79º F) in Asia, while Americans set theirs closer to 72º F.

It should be pointed out that Asian-designed systems do have the ability to maintain lower humidity levels at the indoor temperatures that they are designed for in Asia. Their application to interior spaces that are maintained at the lower American temperatures is compromised at best, and simply wrong at worst.

VRF technology for America should be engineered to take advantage to variable speed fan motors and reduce airflow at part loads. By so doing, the coil's ability to dehumidify would be maintained. VRF systems, including their coils, should be designed to condition spaces at temperatures that Americans are accustomed to. It is unclear why American manufacturers lack the ability to design such systems, but perhaps that will occur in the near future.

Conclusion

It should surprise no one that chilled water coils dehumidify well at all conditions of part and full load. They have a long history of good service within buildings with humidity challenges.

Traditional DX coils have long been known to be a step less effective than chilled water coils. However, equipment right-sizing seems to limit problems. Still, overall performance is less effective and the process of right-sizing can be more complex than it might seem, especially for high occupancy type applications like classrooms, theaters, and churches/auditoriums.

VRF systems should not be considered for applications that require dehumidification. While a coil can be sized for dehumidification (they rarely are), its performance at part load will quickly degrade and lose any capacity it once had.

applied
engineering

405 Erin Drive
Knoxville, TN 37919
www.appeng.com

For more information:
Contact: Jack Hopkins, P.E. Principal