

keystone of system performance ... Cooling-Coil Heat Transfer

from the editor...

What criterion do you use to evaluate cooling-coil performance? Do you select cooling coils based on face velocity? Pressure drop? Maybe it's simply a matter of cost. Regardless of which criterion you typically use, you may not be giving coil selection the engineering attention that it deserves.

This EN briefly reviews the pivotal role of chilled-water cooling coils. It also identifies ways to increase heat-transfer capacity and considers the implications for the rest of the system. Along the way, you'll learn that exploiting coil efficiency can trim unnecessary cost from the HVAC system.

The cooling coil is a critical component of air conditioning. Decisions made to select a coil (Figure 1) impact the initial investment as well as the costs of installing, providing, and maintaining thermal comfort.

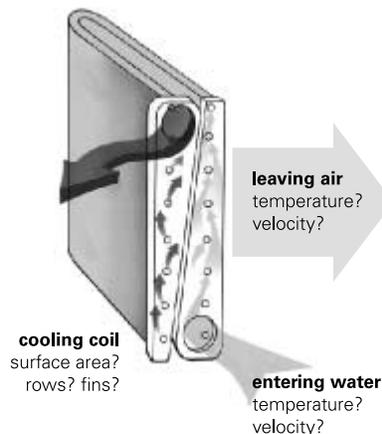
As an example, the amount of material in the coil—fins, tubes, overall size—determines the coil's initial cost; more material requires a larger outlay of capital. The size of the cooling coil also dictates the air handler's weight and footprint: the larger the coil, the larger the air handler must be to house it. A larger air handler may also require a

larger mechanical room (reducing rentable/usable floor space), adversely affect service access, or compromise the arrangement of ductwork and piping.

Because the cooling coil is an integral part of the air distribution system, its geometry—size, number of rows, fin spacing, and fin profile—contributes to the airside pressure drop and affects the sound power level of the fans. (Fan power needed to circulate air through the duct system may warrant extra sound attenuation at the air handler.)

Cooling coils are an integral part of the chilled water system, too. The extent to which coils raise the chilled water temperature dramatically affects both capital investment in chilled water piping and pumping power. Coil performance can even influence the efficiency of the chiller!

Figure 1. Key decisions for coil selection



Dynamics of Heat Transfer

Chilled-water cooling coils are finned-tube heat exchangers consisting of rows of tubes (usually copper) that pass through sheets of formed fins (usually aluminum). As air passes through the coil and contacts the cold fin surfaces, heat transfers from the air to the water flowing through the tubes.

Physically, cooling coils mark the intersection between the air distribution system and the chilled water system. Functionally, coils serve as "bridges" that permit the exchange of airside loads for chilled water loads. Improving the design of the "bridge" allows it to handle more "traffic"—that is, to transfer more heat. Better heat transfer creates opportunities to refine air and chilled water distribution in ways that best balance capital investment and life-cycle costs.

The following equation quantifies the heat-transfer process:

$$Q = U \times A \times LMTD$$

where,

Q = amount of heat transferred, Btu/hr (W)

U = heat-transfer coefficient, Btu/hr•ft²•°F (W/m²•°K)

A = effective surface area for heat transfer, ft² (m²)

$LMTD$ = log-mean temperature difference across the coil surface, °F (°C)

Increasing any one of these variables (heat-transfer coefficient, surface area, or log-mean temperature difference) results in more heat transfer and ultimately improves the life-cycle value of the cooling coil.

You may think that the realm of heat-transfer technology belongs exclusively to research engineers in white lab coats. In fact, the engineer who designs the HVAC system significantly influences heat-transfer performance simply by determining the coil selection criteria.

To understand how various design decisions affect coil efficiency, let's examine each variable individually.

Log-mean temperature difference

$$Q = U \times A \times LMTD$$

Arguably the most effective way to improve heat-transfer performance is to increase the log-mean temperature difference (LMTD). In the context of a chilled-water cooling coil, LMTD describes the difference between the temperatures of the air passing across the coil fins and the water flowing through the coil tubes:

$$LMTD = \frac{TD_2 - TD_1}{\ln(TD_2/TD_1)}$$

where,

TD_1 = leaving-air and entering-water temperature difference at the coil, °F (°C)

TD_2 = entering-air and leaving-water temperature difference at the coil, °F (°C)

One way to increase LMTD is to supply the coil with colder water. (See "Low-Flow Coil Performance," p. 3.)^{1,2}

¹ Schwedler, M., PE, "How Low-Flow Systems Can Help You Give Your Customers What They Want," *Engineers Newsletter* 26 no. 2 (1996).

² Trane, "The Low Dollar Chiller Plant," *Engineers Newsletter Live* videotape APP-APV001-EN (1999).

Heat-transfer coefficient

$$Q = U \times A \times LMTD$$

Also called *U-factor* or *thermal transmittance*, the heat-transfer coefficient describes the overall rate of heat flow through the coil. Three factors determine this rate:

- **Airside film coefficient** describes the "barrier" (resistance to heat transfer) between the passing air stream and the fin surfaces
- **Waterside film coefficient** describes a similar "barrier" between the inside surfaces of the copper tubes and the circulating fluid
- **Thermal conductance** describes the rate at which heat flows through the aluminum fins and copper tubes of the coil

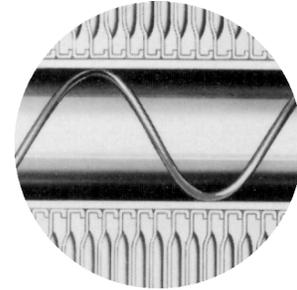
System designers can do little to affect thermal conductance, but they wield considerable control over the film coefficients. How? By specifying **velocities** for the air and fluid that pass through the cooling coil. Increasing the rate of airflow reduces heat-transfer resistance on the air side of the cooling coil. Likewise, increasing the water velocity reduces the waterside resistance to heat transfer.

Fin geometry can improve the overall heat-transfer coefficient, too, by lessening the airside film coefficient. Like velocity, fin geometry can be specified as part of the design of the HVAC system. For comfort-cooling applications, coil fins are usually stamped into waveforms resembling

Figure 2. Typical geometries for coil fins



Figure 3. Typical turbulator



corrugated cardboard (Figure 2). These waveforms create turbulence in the passing air stream, which lessens the resistance to heat transfer. More exaggerated waveforms produce more turbulence.

Turbulent water flow, like turbulent airflow, also reduces resistance to heat transfer. And, like fin geometry, it can become an important criterion for coil selection. Waterside turbulence can be created by metal ribbons or helical wires (Figure 3) inside the tubes. Called **turbulators**, these devices create eddies as the water flows across them.

Both methods of improving the heat-transfer coefficient (increased velocity and turbulence) create higher pressure drops, which can mean additional fan or pump power.

Coil surface area

$$Q = U \times A \times LMTD$$

The third determinant of heat transfer is the coil's surface area. Typically, **fin spacing** for comfort heating or cooling ranges from 80 to 168 fins per foot. Spacing the fins closer together multiplies the surface area by permitting more fins per linear unit. Although the airside pressure drop may increase, adding fins extends the available surface area without affecting the overall size of the coil.

Adding **rows** of tubes also increases the heat-transfer surface area. Most coils are constructed with same-end connections, so rows are usually added in pairs. The weight and cost of the coil increase accordingly, but the airside pressure drop may not. (Wider fin spacing often accompanies the decision to add rows.)

The best way to extend the surface area for heat transfer is to decrease the **face velocity** of the coil, that is, *face area relative to airflow*:

$$\text{face velocity} = \frac{\text{airflow}}{\text{face area}}$$

Face velocity can be reduced in one of two ways: by increasing the size of the coil or (paradoxically) by reducing

the required airflow. Selecting a physically larger coil increases the initial investment in the coil and the air handler, and may also enlarge the air-handler footprint... seldom desirable outcomes. So, how can we reduce the required airflow without sacrificing coil capacity?

Improving Coil Performance

Lowering the supply air temperature reduces the amount of air required for sensible cooling and saves fan energy.³ From our review of the heat-transfer equation, we know that: less airflow

³ Eppelheimer, D., "Cold Air Makes Good Sense," *Engineers Newsletter* 29 no. 2 (2000).

increases airside film resistance, which reduces heat-transfer coefficient U ; and requires colder air, which decreases $LMTD$ (Figure 4, p. 4).

To compensate for the negative effects on coil performance that accompany less airflow, we must find a way to increase U (heat-transfer coefficient) and/or A (surface area). In other words, we must select a cooling coil with better-than-average heat-transfer characteristics.

Increase U . Recall that turbulent flow reduces the film resistance to heat transfer. Choosing a fin configuration with a more pronounced waveform and/or adding turbulators inside the coil tubes will improve the heat-transfer coefficient.

Increase A . Any additional increase in heat-transfer capacity must be achieved by physically increasing the available surface area; that is, by:

- Adding rows
- Adding fins
- Increasing the physical size of the coil (which will increase the initial costs of the coil, air handler, and airside accessories)

For example, the HVAC design for a 400,000 ft², seven-story office building includes blow-through air handlers (one per floor) with chilled water coils and variable-volume air distribution. Originally, the design conditions required each air handler to deliver 55,385 ft³/min of 55°F air. Figure 5 (p. 4) summarizes the results of a study that evaluated the benefit of supplying colder, 52°F air. Neither the air handlers nor the waterside design conditions were altered.

Reducing the coil face ΔT velocity from 552 ft/min to 469 ft/min and increasing the number of fins per foot from 124 to

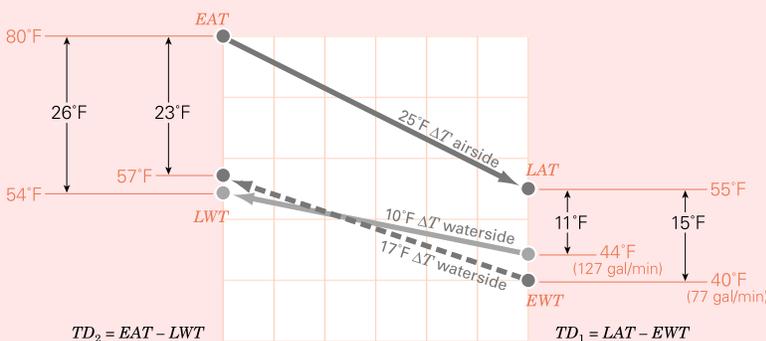
"Low-Flow" Coil Performance

Two objectives underlie the design of virtually every HVAC system: lower first cost and lower energy (life-cycle) cost. These goals are largely responsible for the growing popularity of "low-flow" chilled water systems. "Low-flow" designs provide required cooling capacity by using less water at colder temperatures, essentially trading an increase in chiller energy consumption for a greater reduction in pumping costs.

How does reduced water flow affect the performance of the cooling coil? An understanding of thermodynamics and the

heat-transfer equation, $Q = U \times A \times LMTD$, tells us that less water flow through the coil tubes reduces heat-transfer coefficient U (waterside resistance to heat transfer increases). But as the graph below illustrates, the log-mean temperature difference ($LMTD$) increases because the entering water temperature is *colder*.

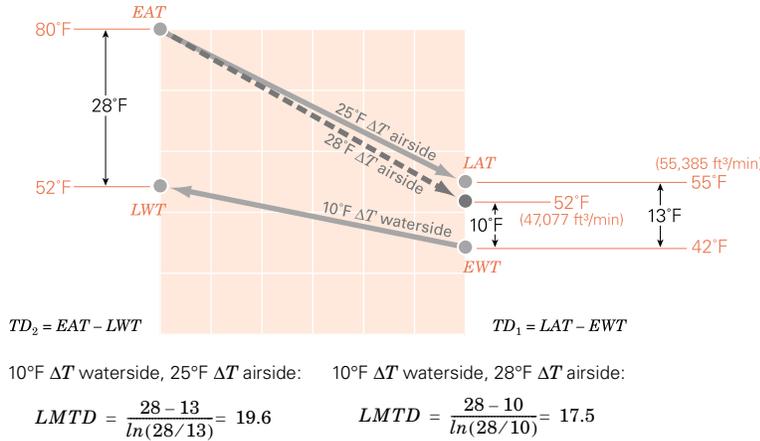
The higher $LMTD$ that accompanies low flow offsets the reduced heat-transfer coefficient. In effect, the capacity of the coil remains the same whether the water flow is 127 gal/min or 77 gal/min—*without* changing surface area A . ■



$$10^\circ\text{F } \Delta T \text{ waterside, } 25^\circ\text{F } \Delta T \text{ airside: } LMTD = \frac{26 - 11}{\ln(26/11)} = 17.4$$

$$17^\circ\text{F } \Delta T \text{ waterside, } 25^\circ\text{F } \Delta T \text{ airside: } LMTD = \frac{23 - 15}{\ln(23/15)} = 18.7$$

Figure 4. Effect of supply air temperature on log-mean temperature difference



152 provided the additional heat transfer needed to reach 52°F. Not only was the airside pressure drop less, but the lower face velocity also alleviated concerns about moisture carryover.

In this case, improving heat-transfer performance and selecting the coils based on a closer approach (TD_1) reduced the required airflow by 15 percent... and yielded annual fan-energy savings of almost \$12,000 USD.

Note: Improving coil efficiency by reducing airflow offers two benefits—it requires less fan horsepower and it reduces the cooling load (via less fan heat). Of course, cooler air may require more reheat. A detailed energy analysis should be performed to assess the economic impact on the entire HVAC system and, ultimately, on building life-cycle costs.

Closing Thoughts

$Q = U \times A \times LMTD$ reminds us of the extent to which we preordain the capital and life-cycle costs of an HVAC system. Specifying the entering water and leaving air temperatures that all cooling coils must meet not only determines the required mass of air

and water, but also the costs of moving them.

The next time that you select a coil, invest a few extra minutes to explore the LMTD effect with lower chilled water temperatures and colder supply air. You'll find that the potential benefits are simply too attractive to ignore. ■

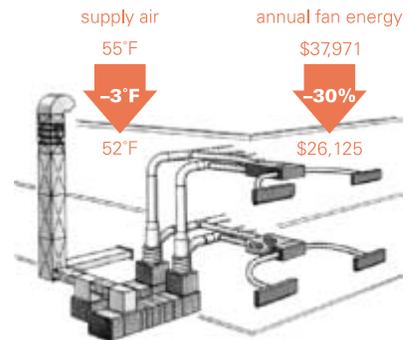
By Don Eppelheimer, applications engineer, and Brenda Bradley, information designer, Trane.

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Figure 5. Supply air temperature versus annual fan energy consumption

Design Parameters		Before	After
Coil	rows	4	4
	fin spacing	124	152 fins/ft
	face velocity	552	469 ft/min
Airside	LAT	55°F	52°F
	flow volume	55,385	47,077 ft ³ /min
	pressure drop	0.62	0.56 in. wg
Waterside	EWT	42°F	42°F
	flow volume	222	219 gal/min
	pressure drop	31.7	30.9 ft of water

LAT = leaving-coil air temperature
EWT = entering-coil water temperature



Energy savings were projected with Trane's System Analyzer™ software (version 5.08.09), and are based on a 400,000 ft² building and variable-volume air distribution.



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