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Cooling Coils

Understanding the factors that influence their design and selection

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In the October-December 2002 issue of the Journal, the focus was on cooling coils, their selection and maintenance.

As a continuation of the same theme, I could not resist an urge to cover some more information compiled for the benefit of readers, which I am sure will help them to understand the working of cooling coils.

Basic Working

The air cooling coil with Direct Expansion uses a thermostatic expansion valve and these coils are used in the majority of comfort air conditioning applications mostly, below 100 tons capacity. DX coils are also used in refrigeration applications like product coolers for cold storages and blast freezers as well as in industrial cooling equipment.

Figure 1: A typical DX air cooling coil

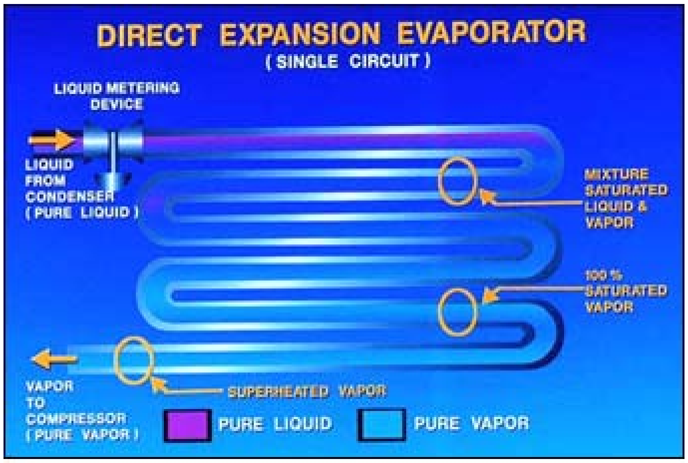

Figure 2 : Different stages of refrigerant evaporation inside a DX cooling coil

If we look at the basic refrigeration cycle and the part played by an evaporator, the function of the evaporator to take heat into the system from the surrounding atmosphere.

The refrigerant entering the coil is a low pressure, low temperature mixture of saturated liquid and vapour. As the refrigerant mixture gradually travels towards the outlet of the coil, the liquid, while absorbing heat gets converted into vapour, and at the outlet, the entire refrigerant is in the form of superheated gas .

The refrigerant flow and the superheat is controlled by the thermostatic expansion valve. The superheat ensures that the compressor is protected, at all varying load conditions, from liquid entering the compressor and thereby preventing it from damage.

In direct expansion evaporators, once the saturated mixture of liquid and gas enters a circuit, it only flows in one direction, towards the outlet and no re-circulation possible, which only happens in flooded evaporators.

The distributor and length of feeder pipes ensure equal distribution of liquid/vapour mixture being fed to each circuit. This ensures that the lower portion of the coil does not get flooded with liquid and the upper portion with a higher proportion of gas, making it less effective. The lengths of feeder pipes are therefore adjusted for equal pressure drop in each circuit.

In order to get optimum performance from the cooling coil, we try to ensure that maximum proportion of liquid enters the evaporator inlet with minimum proportion of vapour. This is essential, since it is the latent heat, which while converting liquid refrigerant into vapour absorbs a large amount of heat from the surroundings. The heat absorbed by the vapour is insignificant.

The proportion of liquid to vapour can be increased by sub-cooling the liquid before it enters the expansion valve, so that at the evaporator entry, less flash gas is formed.

Similarly, to utilize the coil more effectively, we should have liquid refrigerant upto the end of the coil, instead of providing some area of the end section of the coil to superheat the refrigerant. We however provide this superheat section as a trade-off, to protect the compressor from the possibility of liquid entry to the compressor. The electronic expansion valve, which can work on very low superheat settings allows more coil length to be used for liquid refrigerant, compared to a conventional expansion valve, and thus improves coil performance.

Having covered some of the basics , we shall now look at the factors which influence the selection of coils and affects the performance.

Factors Under Designers Control

The general equation for determination of coil capacity is

$Q = U \times A \times \Delta T$

where

U = overall heat transfer coefficient

A = coil surface area (this is not the same as coil face area)

ΔT= temperature difference between room air and coil .

The design/manufacture and the selection of a suitable coil, for the required application, are two distinct areas and we shall now, first look at the factors which can be influenced by the coil designer and the manufacturer.

The overall heat transfer coefficient “U” is determined by the designer and the application engineer has no control over it.

Some of the factors that influence coil design are :

1. Tube diameter- 5/8",1/2", 3/8" or 7 mm
2. Tube spacing and arrangement
3. Coil circuiting
4. Fin thickness, fin material and configuration–either plain/corrugated, slitted, etc.
5. Material of construction of coil and fins and its thermal conductivity etc.

The coil manufacturer publishes coil ratings based on the parameters he has considered in his design. While designing the coil, his main objective is to reduce resistance to heat transfer.

The heat transfer coefficient on the air side can be increased by increasing the ratio of external to internal area or by increasing the airside heat transfer coefficient.

The air-side heat transfer coefficient can be increased by increasing the air velocity over the coil.

Effect of Velocity Increase

Figure 3 indicates that as the velocity increases, the coil capacity increases. However, the point to be noted is that the rate of increase is less at higher face velocities, as can be seen from the reduced slope of the coil performance line.

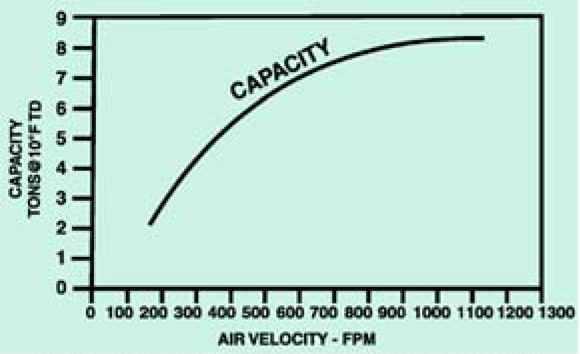

Figure 3 : Effect of air velocity increase on capacity

It should also be kept in mind that, increasing velocity means more air quantity (cfm). Coil performance alone as published by the manufacturer, is therefore not enough and we need to take into account both the components i.e. coil and fan performance to assess the net result.

Overall Performance of Fan & Coil Combination

The fan laws indicate that the fan horse power increases as the cube of the velocity increase. As can be seen from **Figure 4**, after a particular velocity the net effect, in fact, is a capacity loss, since the motor heat input more than offsets the gain in coil capacity.

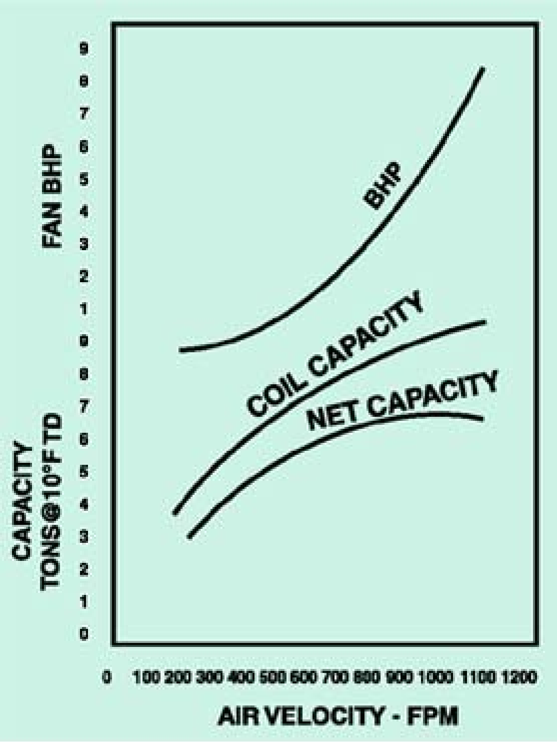

Figure 4 : Performance of fan and coil combination

Effect of Increasing Heat Transfer Area

Increasing the external surface area is the most common approach to improving coil performance. Once the tube is selected (either plain or internally grooved) the internal area gets fixed, where as the external area can be increased by adding fins of various designs and increasing the number of fins per unit length.

This also needs very careful consideration, since, as the ratio of secondary to primary surface area increases, the effectiveness per square foot of area decreases. Conversely, lower the ratio, for the required performance, the more effective the surface per square foot of area.

As can be seen from **Figure 5**, of an air-cooled condenser coil, the surface nearest to the refrigerant tube has the maximum efficiency , since the TD (temperature difference) is the highest. As we move away from the center, the fins become less and less efficient since they tend to approach surrounding air temperatures.

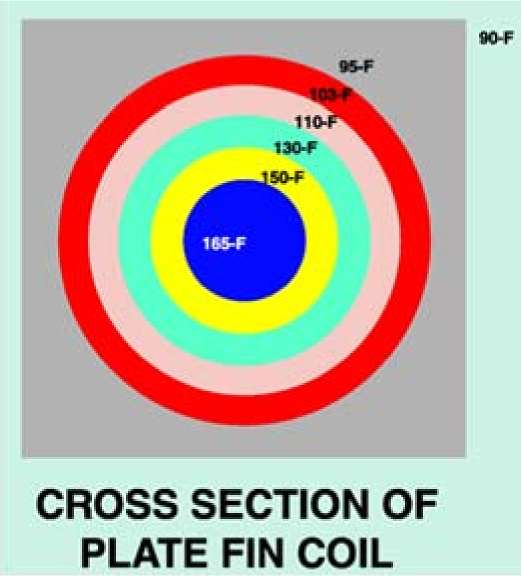

Figure 5 : Fin temperature of a condenser coil from the tube outwards.

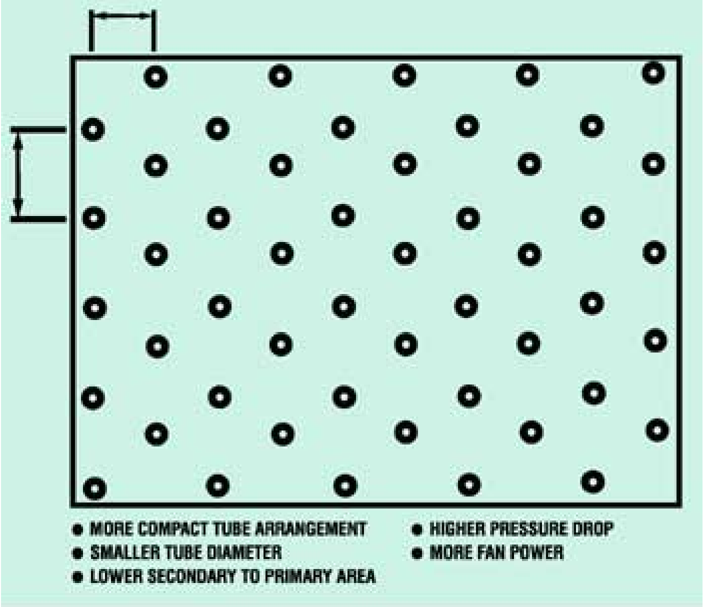

Figure 6 : Effect of using smaller diameter tubes

More primary area means more bare coil area and this is more advantageous compared to a coil having more secondary (fin) area and less tubing.

The bare pipe coil is therefore the most efficient, however, cost and space limitation considerations have to be taken into account and the coil therefore is made more compact by reducing the primary area and increasing the secondary area.

When comparing coils of various manufacturers, for the same duty conditions, one should therefore compare the primary area provided and not the total surface area, and the supplier who gives more primary coil area will be providing a more efficient coil, assuming all other parameters are equal.

Substituting plain tubes with grooved tubes, without changing the number of tubes can also increase the primary area.

Effect of Using Smaller Diameter Tubes

As can be seen from **Figure 6**, more primary area for the available face area is possible by reducing the tube diameter, thereby packing the tubes more compactly (lower secondary to primary area ratio). The drawback however, is that the more compact the coil, higher the air-side pressure drop, resulting in more fan power to deliver the same air quantity.

We shall now study some other characteristics with the help of a psychrometric chart.

In most air conditioning applications, cooling is the primary goal where as removal of moisture from the air is an associated process.

Effect of More Face Area

When two similar coils are compared, the coil having more face area has the higher refrigeration capacity. For the coil having a higher face area, the leaving temperature of air will also be lower and such a coil will lower the moisture content further than the smaller face area coil

Effect of Increasing Number of Rows

As the number of rows of coil increases for the same face area, or the coil is deeper, lower will be the air leaving temperature and moisture content. The refrigeration capacity also increases. As can be seen from **Figure 8**, it is also obvious that each successive row of tubes is less efficient and less effective. This means less moisture removal or less temperature drop is to be expected from, say the 5th or 6th row compared to the first or second row.

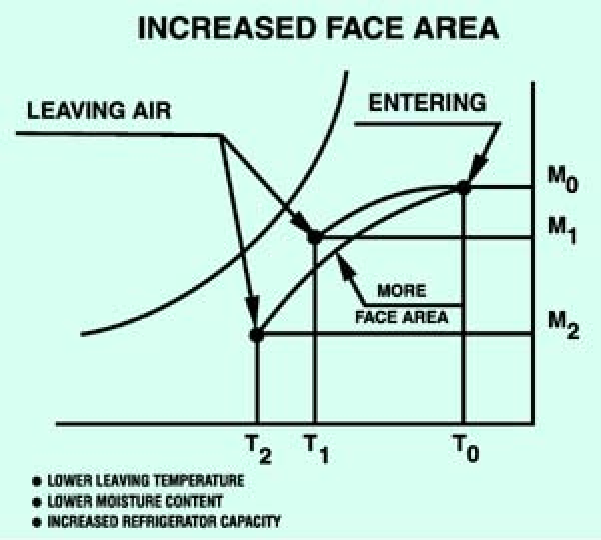

Figure 7 : Effect of more face area on capacity

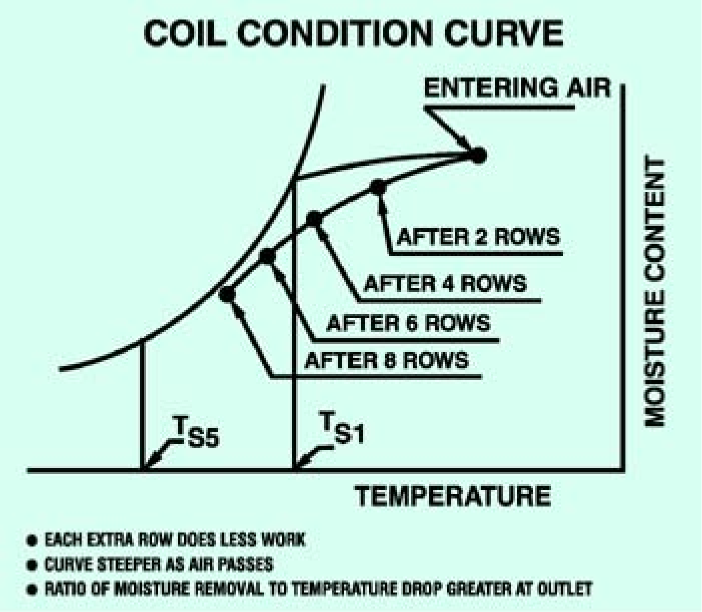

Figure 8 : Effect of increasing number of rows

The greatest rate of heat transfer is where the air is entering the coil, since at the entry condition, the moisture content and the temperature is highest. As the air temperature curve approaches the saturation line, the curve becomes steeper, indicating that the ratio of moisture removal to temperature drop is greatest at the last row or at the exit of the coil. Such coil designs with more rows are used in cold rooms, blast freezers or in low temperature applications.

Coils with a large face area and lower number rows, with very high air quantities, are preferred for applications where we do not need the moisture to be separated from air, like in grape storage rooms, where high humidity needs to be maintained to prevent weight loss. Such coils with less rows are also used where it is predominantly a sensible cooling application. In both such cases the objective is to get the psychrometric chart process line flatter to avoid more moisture separating from the air.

Effect of Fin Spacing

Closer fin spacing also lowers the coil condition curve, similar to the one with face area increase. Refrigeration capacity also increases. However, closer fins means a higher pressure drop across the coil, resulting in decrease in air quantity or increase in fan horse power for the same air quantity. See **Figure 9**.

In the case of condenser coils, choking with dirt increases, when fin density increases and needs frequent cleaning. In case of coils used for low temperature applications, the defrosting becomes difficult, if the coils have closer fin spacing.

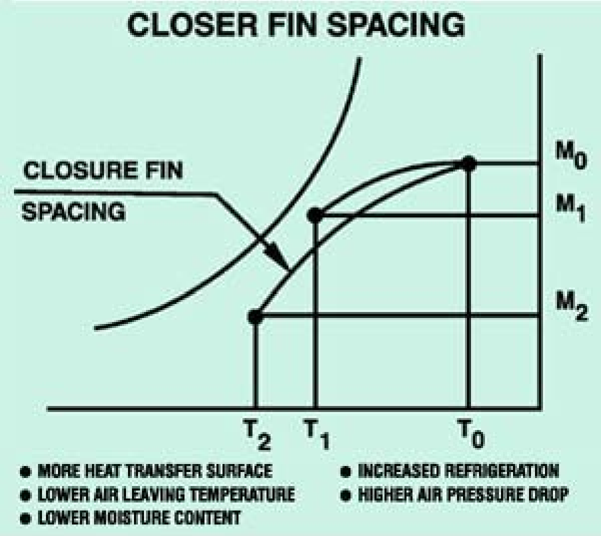

Figure 9 : Effect of closer fin spacing

Effect of Increase in Air Flow

Higher air flow will raise the coil condition curve, which means the air outlet temperature will be higher compared to the coil subjected to a lower air flow. The refrigeration capacity however increases, because air flow rate increases in greater proportion than decrease in enthalpy. Q ∝ cfm x ΔH where ΔH is the enthalpy difference. See **Figure 10**.

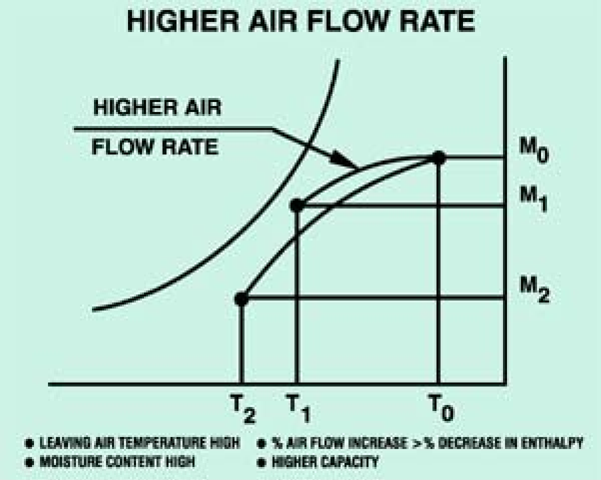

Figure 10 : Effect of higher air flow rate

By increasing airflow the heat removal will be faster and the temperatures will be more uniform in the conditioned space. Increasing air quantity, will however mean a higher fan power as well as a higher noise level.

Effect on Bypass Factor

The design of the coil also affects the bypass factor. As the air travels over the coil, if it remains in contact with the coil for a longer duration, the bypass factor reduces, which means the supply air condition is nearer to the saturation line. As the air leaving the coil is nearer to the saturation line, the required air quantity reduces. It also means that the supply air temperature is lower and air leaves in a drier condition as more moisture is removed from it.

While estimating cooling loads and air quantity, we have to assume a certain bypass factor, which depends upon the coil configuration. **Table 1** indicates the bypass factors normally taken for calculations.

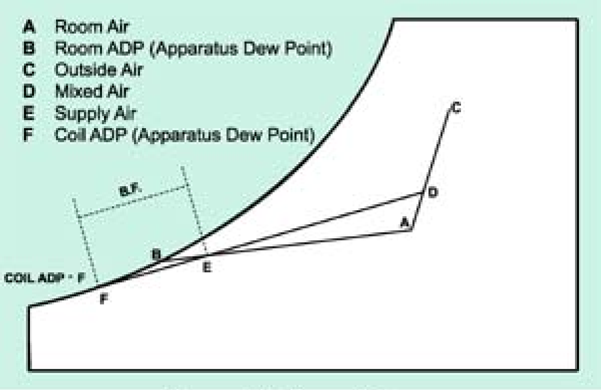

Figure 11 : Bypass Factor

Table 1 : Bypass Factor for varying coil depth

Depth of coil (rows)	8 fins per inch velocity 300-700 fpm	14 fins per inch velocity 300-700 fpm
2	0.42-0.55	0.22-0.38
3	0.27-0.40	0.10-0.23
4	0.15-0.28	0.05-0.14
5	0.10-0.22	0.03-0.09
6	0.06-0.15	0.01-0.05
8	0.02-0.08	0.00-0.02

An analysis of **Table 1** will reveal the following :

1. As the fin density increases, there is more resistance for the air to travel, and the bypass factor reduces. Increasing fin density, however, increases the condenser coil cleaning frequency and if it a cold storage coil, the defrosting takes longer. Also, as the airside pressure drop increases, the fan starts delivering lesser air quantity, or for the same air quantity consumes more power.
2. As the number of rows increase, the air remains in contact for a longer duration leading to a lower bypass factor.
3. As the velocity increases, since the air passes through the coil faster, the bypass factor increases. If we reduce the velocity below a particular point, the chances of coil freezing increase.
4. If the velocity is increased beyond a point, the increased fan horespower neutralizes the gains in capacity, which has been demonstrated in **Figure 4.**

Conclusion

The selection of a proper coil for the application requires careful consideration of many parameters and the writer has discussed some of the factors influencing coil performance.

It should also be noted, that all factors discussed above do not act independently, but the combination of one or more factors operating at a time, influence the performance of the fan and coil combination.