AIR CONDITIONING AND REFRIGERATION
Journal
The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers

Issue : October-December 2002

Selecting Cooling Coils without Proprietary Software

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When I started work in the HVAC field fresh out of engineering college, PCs were not commonly used in India and software programs for selecting cooling coils were rare. That was 18 years ago. Today, most large manufacturers of coils have sourced their selection software from foreign principals and this is used to select and quote for cooling coils to suit their or their customer's requirements.

There are, however, several consultants and contractors specialising in HVAC work that do not have ready and immediate access to such proprietary software. This article is meant to help them make a selection using engineering tables (based on cumbersome heat transfer equations). I have used them when I started working in this field and I have continued to use them till today. The actual performance of cooling coils in the field after installation has been satisfactory, and as desired.

Types of Coils

There are direct expansion (DX) coils and chilled water coils. Some coil manufacturers fabricate coils from 5/8 inch OD copper tubes, others from ½ inch copper tube and still others use 3/8 inch tubes. Selection of the tube size is a matter of manufacturer's choice and market demand. Price, as always, plays a major part in the tube size selection.

The selection method that I follow is for5/8 inch tubes.

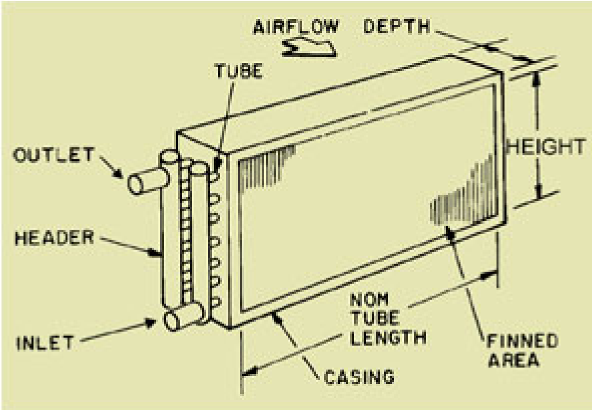

Figure 1 : Chilled water coil construction

Coil Construction and Geometry

In a coil, copper tubes are arranged parallel to one another, either in staggered pattern or non-staggered pattern, along the length 'L' of the coil. A staggered pattern is more commonly used. For 5/8 inch tubes, the triangular pitch is 1.75 inch or 1.5 inch. For ½ inch tubes it is 1.25 inch and for inch tubes it is 1 inch.

Plate or ripple fins are used to enhance the heat transfer area. Thus the primary surface area (outside area of bare copper tubes) is enhanced greatly by adding a secondary area of fins. The total area including fins is called "outside surface area," for use in the calculations, in this article.

The cross-section (L x H) across which air flows is called the face area or the finned area. Thus L is finned length and H is fin height.

Fins are arranged perpendicular to the tubes. Fin spacing varies between 8 and 14 fins per inch of tube.

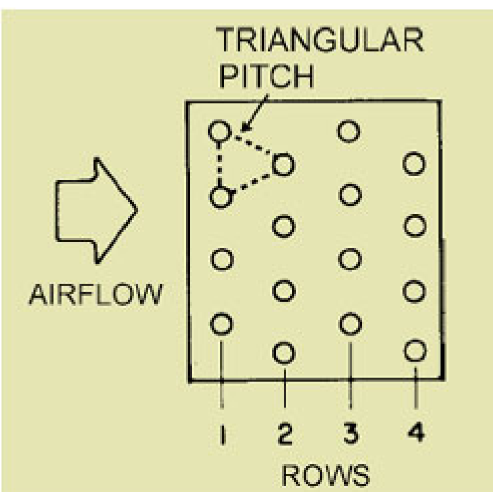

Figure 2 : A 4-row coil with a 4-tube face. Note that tubes are staggered in adjacent rows

Average air velocity across the face area is called coil face velocity or simply face velocity. Thus

$$\text{Face velocity (fpm)} = \frac{\text{Dehumidified air flow (cfm)}}{\text{Face area (sq.ft.)}}$$

The number of rows of copper tubes in the direction of air flow is termed as depth of coil (rows deep). Coils with 3,4,6 or 8 rows are commonly used.

Refrigerant or chilled water enters the first row and leaves the coil from the last row. A coil in which chilled water or refrigerant is supplied to all the tubes in the first row (also referred to as tubes high or tubes in face) is called a maximum or full circuit coil. Thus a typical coil of 17.5 inch height which has 10 tubes in face (based on 1.75 inch pitch) will have a maximum of 10 circuits.

If the supply is given to alternate tubes in face, we get a half-circuit coil with 5 circuits as against 10 circuits. The U-bends at the end of the tubes can be arranged, at the time of manufacturing, to obtain the number of circuits desired. See **Figure 3** for full and half circuit coils with 4 tube face.

Initial Estimate

From air conditioning load calculations, one can pick up some key values such as the dehumidified air flow (cfm), the total load (ton) and calculate dehumidified cfm/ton. This value gives a very useful clue to quickly estimate the coil cost when one is making a sales proposal. Having understood the terms such as face area, face velocity and depth of coil, **Table 1** can be used to estimate coil size.

Table 1 : Estimating coil size based on cfm/ton

Dehumidified cfm/ton	Coil face velocity fpm	No. of rows
600	500	3
500	500	4
400	400	4
300	300	6
200	200	8

Face velocity is restricted to 500 fpm to avoid carryover of condensate from the coil. The value of 500 fpm is very commonly used for coil sizing and it works very well for cfm/ton in the range of 500 to 600. If cfm/ton ratio falls below 500, (this generally happens when room sensible heat factor goes below 0.8 due to high room latent load) a 4-row coil at 500 fpm becomes inadequate. A 5-row coil is not very common. Hence by lowering face velocity, a 4-row deep coil can be selected at 400 fpm, when cfm/ton is about 400. As cfm/ton ratio reduces further, 6-row or 8-row coils have to be selected. This situation is encountered when the occupancy and/or fresh air components are high.

Thus based on the face area and number of rows, a quick coil estimate can be done.

While actually sizing the coil, the initial assumption of face velocity may have to be changed to arrive at an acceptable selection. Thus the procedure is required to be repeated with a new value of face velocity. This is known as iteration.

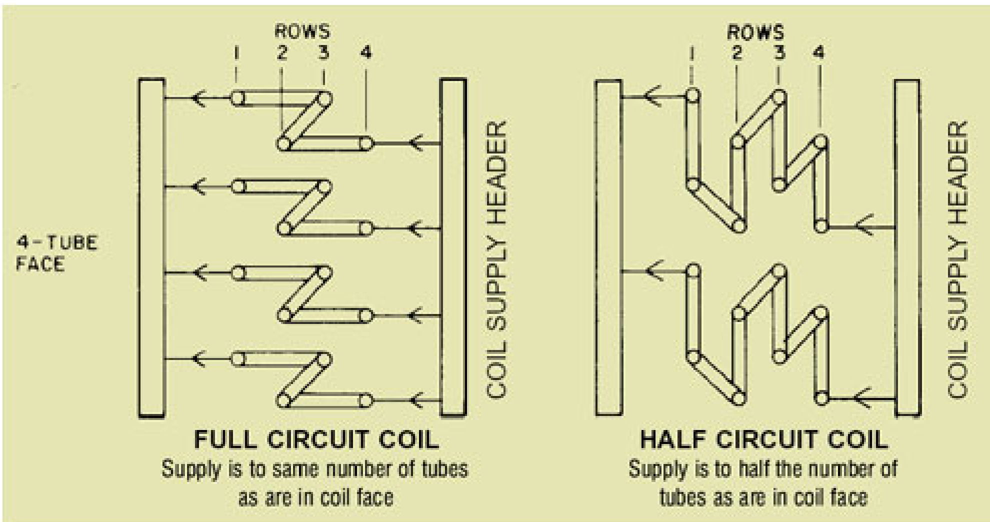

Figure 3 : Full circuit and half circuit four row coils with 4-tube face. Note that tubes are staggered in adjacent rows.

Final Selection Procedure

A. Data required

For sizing the coil, the following data is required from the heat load calculations.

- Room DB temperature/Return air DB temperature (F)
- Fresh air DB temperature (F)
- Dehumidified air quantity (cfm)
- Fresh air quantity (cfm)
- Grand sensible heat factor (GSHF)
- AC load (ton)
- Apparatus dew point ADP (F) (This denotes the average outside surface temperature of the coil.)

B. Assumptions

To start with, the following assumptions will have to be made • Face velocity (fpm), based on **Table 1**

- Chilled water entering and leaving temperature (EWT and LWT) for chilled water coil or
- Temperature of refrigerant in the evaporator coil. (Tref)
- Number of circuits (1 ton/ circuit for " coil) • Bypass factor

In an ideal coil, we can expect 100 % heat transfer efficiency. Air passing over such a coil will leave the coil at a temperature equal to the ADP. But due to limitations in the coil construction and geometry, some air leaves the coil without getting fully cooled and dehumidified, as if a certain portion of air is bypassing the coil. The coil inefficiency is expressed as a fraction of air bypassing the coil, or the “bypass factor”. Face velocity and depth of coil have a large influence on “bypass factor”. The condition of air leaving the coil is the mixture condition of fully treated air at ADP and bypass air at the inlet condition.

We generally assume bypass factor (BF) in air conditioning load calculations. The same value can be assumed for the initial selection. The assumption can be reviewed based on the result of the initial selection (remember iteration?)

Coil geometry

1. Copper tube 5/8" OD, 22G thick, 1.5" triangular pitch,staggered from row to row
2. Aluminium fins - 8 fpi, 1.3" wide per row
3. Outside surface 22 sqft./row/face area
4. Inside surface 1.2 sqft /row/face area
5. Outside to inside surface area ratio R = 18.3
6. Metal resistance r_m=0.025 (hr.sqft.F) per Btu

The metal resistance of bare pipe surface (no fins) is so small as to be of any significance compared to the normal values of other resistances to heat transfer in a coil. With fins, most of the heat must pass through the small fin section. Actual value of metal resistance for common air conditioning coils in the normal range of use is from about 0.005 to 0.03 (hr.sqft.F) per Btu, depending on the thickness and material of fins. It is not constant for different fluid conditions. But for making the selection procedure simpler, it is considered to be near-enough constant.

C. The basic equation

The equation for determining the number of rows required is as under :

$$\text{No. of rows required} = \frac{\text{Tons} \times 12000}{\text{U} \times \text{LMTD} \times \text{face area} \times \text{outside surface area per face area per row}} \quad (1)$$

where

U = overall heat transfer coefficient [Btu/(hr.sqft.F.row)]

LMTD = Log (to the base e) mean temperature difference.

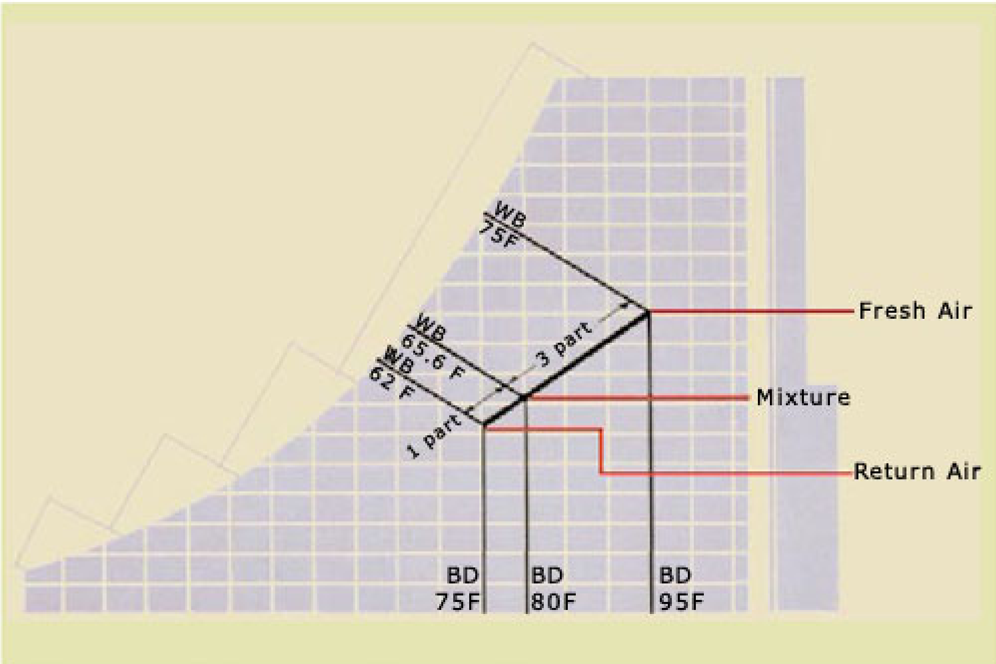

Figure 4 : Mixture of FA and RA on a psychrometric chart

D. To calculate LMTD

1. Calculate DB temperature of mixture of return air and fresh air entering the coil.

   $$DB_{(mix)} = \frac{DB_{(RA)} \times \text{RA cfm} + DB_{(FA)} \times \text{FA cfm}}{\text{Dehumidified air cfm}}$$

   (Dehumidified air = Return air + Fresh air) See **Figure 4**.

2. Calculate DB temperature of air leaving the coil :

   $DB_{(lvg\ air)} = DB_{(mix)} - (1-BF)(DB_{(mix)} - ADP)$

   BF = Bypass factor

3. Calculate LMTD

   for DX coil :

   $GTD = DB_{(mix)} - T_{ref}$

   $LTD = DB_{(lvg\ air)} - Tref$

   For chilled water coil :

   $GTD = DB_{(mix)} - LWT$

$$LTD = DB_{(lvg\ air)} - EWT$$

$$LMTD = \frac{GTD - LTD}{\log_e \frac{GTD}{LTD}}$$

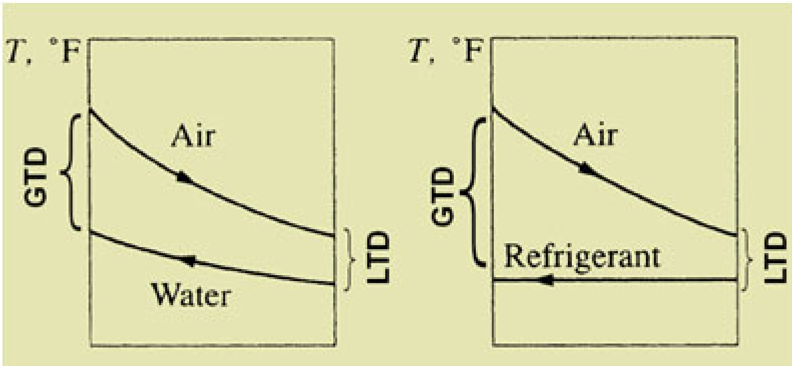

Figure 5 : Temperature gradients across cooling coils

E. To calculate U - value

The overall U-value is calculated using the following equation.

$$\frac{1}{U} = \frac{1}{K_o} + r_m + \frac{R}{K_i} \qquad (2)$$

The overall heat transfer coefficient 'U' depends on the following factors.

Table 2[1] : Boiling refrigerant coefficient k_i (for direct expansion in coils)

Refrigerant flow tons/circuit	Tube OD (inch) 5/8"
0.8	250
1.0	325
1.2	400
1.5	500

Table 3[1] : Heat transfer coefficients k_i for water inside tubes

Water velocity (fps)	Inside tube dia 0.6"
1	230
2	400
3	550

4	720
6	1000
8	1250

1. **Inside film coefficient k_i**

   Experimental data is available for chilled water and refrigerant. Please refer to **Table 2** and **Table 3**

   k_i for chilled water coil.

   1.1 Calculate water flow :

   $$\text{Water flow(USgpm)} = \frac{\text{Ton} \times 12000}{500 \times (\text{LWT} - \text{EWT})}$$

   1.2 Calculate water velocity through tube.

   $$\text{WV (fps)} = \frac{\text{waterflow} \times 1.2 \text{ fps}}{\text{No. of circuits}}$$

   1.3 Calculate k using **Table 3**

   For DX assume 1 ton/circuit to start with and read k_i from **Table 2**

2. **Metal resistance :**

   For the selected coil geometry the metal resistance is 0.025 hr.sqft.F/Btu

3. **Outside film coefficient – k_o.**

   Outside film coefficient k_o depends on face velocity and grand sensible heat factor.

   Refer to **Table 4**

Table 4[1] : Outside film coefficient (for dry coil)

Coil face velocity fpm	k_o Btu/hr.sqft.F
100	4.1
200	6.3
300	8.0
400	9.6
500	11.0
600	12.3

For wet coil (GSHF < 1) the value of k_o is calculated as under :

$$k_o = \frac{k_o \text{ (dry coil)}}{\text{GSHF}}$$

The overall U-value can now be calculated using Equation (2)

F. Calculating the coil face area :

$$\text{Coil face area (sq.ft)} = \frac{\text{Dehumidified air quantity (cfm)}}{\text{face velocity (fpm)}}$$

G. Calculating the number of rows of coil :

Calculate the number of rows required using Equation (1)

The assumption of bypass factor can be verified using **Table 5** based on the number of rows required as calculated above.

A safety margin of 5 - 10% is advisable.

Table 5 : Bypass Factors

No of rows	Coil face velocity fpm			
	300	400	500	600
2	0.225	0.274	0.314	0.346
3	0.107	0.143	0.176	0.204
4	0.052	0.076	0.099	0.120
5	0.025	0.040	0.056	0.071
6	0.012	0.022	0.032	0.042

The procedure can be repeated for:

- different value of face velocity
- different T_{ref} or EWT.
- different ΔT for chilled water

  Please refer to the example on the next page.

What if the coil geometry is different2

- More number of fins per inch. 0

$$\text{For 10 fpi, number of rows required} = \frac{\text{number of rows (8fpi)}}{1.1}$$

$$\text{For 12 fpi, number of rows required} = \frac{\text{number of rows (8fpi)}}{1.18}$$

- ½ " copper tube coil with 1.25" pitch

  The face area and number of rows arrived at by the above procedure, gives 5 - 10% extra safety. Water side pressure drop calculations will change.

- Thinner copper tube

  The data available for 22G thick coil can be used since the effect on U-value due to change in thickness of copper tube will be insignificant. Waterside pressure drop calculations will change very marginally.

Chilled water coil selection example

1. Data from heat load estimate :

Room/return air DB temp., F	75	Dehumidified air, cfm	13500
Fresh air DB temp., F	95	Fresh air, cfm	870
GSHF	0.79	ADP, F	57.0
Ton	30		

2. Assumptions :

Face velocity , fpm	500
Ent. water temp. F	44
Lvg. water temp. F	52
Number of circuits per ton	1
Bypass factor	0.1

3. Coil geometry :

1. Copper tube 5/8" OD, 22G thick , 1.5" triangular pitch, staggered from row to row
2. Aluminium fins – 8 fpi, 1.3" wide per row
3. Outside surface 22 sqft./row/face area
4. Inside surface 1.2 sqft /row/face area
5. Outside to inside surface area ratio R = 18.3
6. Metal resistance rm = 0.025 (hr.sqft.F) per Btu

4. Initial selection :

Face area , sqft	=	27.00
Assume coil size :		52.5" X 75"
Coil height, inch	=	52.5
Coil length, inch	=	75
Maximum circuits	=	35
Selected circuits	=	35

5. Selection procedure :

To calculate LMTD

DB mix., F	=	76.29	(using equation for mixture condition)
LDB, F	=	58.93	(using ADP and bypass factor)
GTD, F	=	24.29	
LTD, F	=	14.93	
LMTD, F	=	19.23	

To calculate U-value :

To calculate k_i :

Water flow, USgpm =	90	(using ton, EWT and LWT)
Water velocity, fps =	3.09	(flow in USgpm x 1.2)
k_i =	550	(from table 3)

To calculate k_o :

k_o (dry coil) =	11	(using table 4)
k_o (wet coil) =	13.9	(using formula)
r_m (metal resistance)	0.025	(based on coil geometry)

Using equation for U, we get

U =	7.7

Number of rows required :

Using ton, U value, LMTD, face area and outside surface area per row, we get

Number of rows required (8 fpi) =	4.1
Number of rows required (12 fpi) =	3.5

Selected rows (8 fpi) =	5
Safety : (%) (8 fpi)	22

Selected rows (12 fpi) =	4
Safety : (%) (12 fpi)	15

Pressure drop :

(from charts)

Velocity (fps) =	3.09
Copper roughness =	0.00006
Pressure drop , ft./100ft.	8.95
Tubes high =	35
No. of rows =	4
Number of tubes =	140
Tubes per circuit =	4

Equivalent length = (no.of tubes per ckt. x length) + (no.of tubes per ckt x 1.4)

Equivalent length, ft. =	30.6
Pressure drop, ft. =	2.7
Pressure drop, psi =	1.2

References :

1. Tested Solutions to Design Problems in Air Conditioning and Refrigeration by M. A. Ramsay. The Industrial Press 1963 (Table 2 to 4)
2. Blue Star Engineers' Handbook (Different coil geometry)
3. Voltas Engineers' Handbook (Table 5)