COLMAC COIL Manufacturing Inc.

Technical Bulletin

By Bruce I. Nelson, P.E., President, Colmac Coil Manufacturing, Inc.

COMPARING AIR COOLER RATINGS – PART 2: Why DTM Ratings Cost You Money

Summary

As explained in a previous article, manufacturers of refrigeration evaporators publish ratings based on either average ”room” temperature difference (DTM), or air on temperature difference (DT1). Compared to DT1 ratings, the DTM rating method results in evaporator selections which are undersized for the cooling load and will cause the system to operate with lower than expected suction temperatures. This article calculates the energy efficiency penalty resulting from selecting evaporators using DTM ratings, and puts the benefit of reduced power consumption when using DT1 ratings in terms of incremental return on investment (IROI). Depending on the room temperature and type of compression system (single or 2-stage) the IROI when using DT1 ratings can be as high as 156%, a simple payback of as short as 8 months!

Background

In a previous article (Nelson 2010), two commonly used methods for rating refrigeration air coolers (evaporators), DT1 and DTM, were defined and quantified. DT1 and DTM refer to two different definitions of the difference between air temperature and evaporating temperature used to select an evaporator for a given cooling load.

DT1 = Air On Temperature – Evaporating Temperature
DTM = Average (“Room”) Air Temperature – Evaporating Temperature

The effect of including latent cooling on ratings and evaporator selection was also discussed and explained.

It was shown that using DTM ratings allows the selection of air coolers which have less surface area compared to air coolers selected using DT1 ratings for the same cooling load and temperature difference. As with many things in life, “If something sounds too good to be true, it is too good to be true!”. If coolers selected using DTM ratings have less surface area than DT1 coolers, then it follows that DTM rated coolers will operate with a lower suction temperature than DT1 rated coolers for the same cooling load.

This article, as a continuation of the previous discussion, quantifies exactly how much lower the operating suction temperature will be with DTM coolers and how much the system operating costs will increase as a result.

Room Air Temperature Gradient and DTM

DTM evaporator ratings assume a room air temperature gradient which is equal to the air temp change through the evaporator coil. Put another way, DTM assumes there is no (zero) mixing of the air leaving the evaporators with the room air. This is a false assumption which never occurs with ceiling hung air coolers discharging air from fans into the refrigerated space.
The cooled air leaving an evaporator is termed a non-isothermal jet of air. Air distribution in rooms created by jets of various configurations and aspects has been studied for some time (ASHRAE 2009, Li et al 1993). While air change effectiveness is very difficult to predict precisely, the air throw, spread, fall, and entrainment ratio of free air jets can be estimated using various formulas.

The final air temperature gradient in a refrigerated room will ultimately be determined by the effective mixing of the cooled air leaving the evaporators with the room air. Over the length of a free air jet, the amount of mixing that takes place can be quantified by calculating the entrainment ratio.

©2016 Colmac Coil Manufacturing, Inc.

At a distance of 25 to 100 fan diameters from the point of discharge, the entrainment ratio for a horizontal free air jet can be determined using the following formula:

$$\frac{Q_x}{Q_0} = \frac{2X}{K_c\sqrt{A_0}} \qquad (1)$$

Where

$Q_x = Total\ airflow\ rate\ at\ distance\ X\ from\ face\ of\ the\ outlet$
$Q_0 = Airflow\ rate\ measured\ at\ the\ outlet$
$X = Distance\ from\ face\ of\ the\ outlet$
$K_c = Centerline\ velocity\ constant\ determined\ by\ testing$
$A_0 = Jet\ discharge\ area$

Using equation (1) we can estimate the temperature gradient in a refrigerated space knowing only the air temperature change through the evaporator(s), the length of the room, and the number and diameter of the evaporator fans.

Example:

Two evaporators are ceiling hung in a cold storage room which is 36 m long. Each evaporator has 3 x 762 mm diameter fans.

Given:
Air temperature change through the evaporator(s): 3 deg C
Assume a centerline velocity constant of 4.5, which is typical for fans with wire fan guards

Calculated:
Total fan discharge area per evaporator: 3 x 0.46 sq m per fan = 1.37 sq m

Assuming the average entrainment ratio for the room will be found at half the distance to the back wall, a distance of 36 / 2 = 18 m will be used.

$$Average\ Entrainment\ Ratio = \frac{2\ x\ 18}{4.5\ x\ \sqrt{1.37}} = 6.8$$

Since the entrainment ratio indicates the amount of air mixing that will take place in the room, the average room temperature gradient will be approximately equal to the air temperature change through the evaporator divided by the average entrainment ratio.

$$Average\ Room\ Temp\ Gradient = \frac{Temp\ Change\ Through\ Evaporator}{Average\ Entrainment\ Ratio} = \frac{3}{6.8} = 0.4\ \text{deg}\ C$$

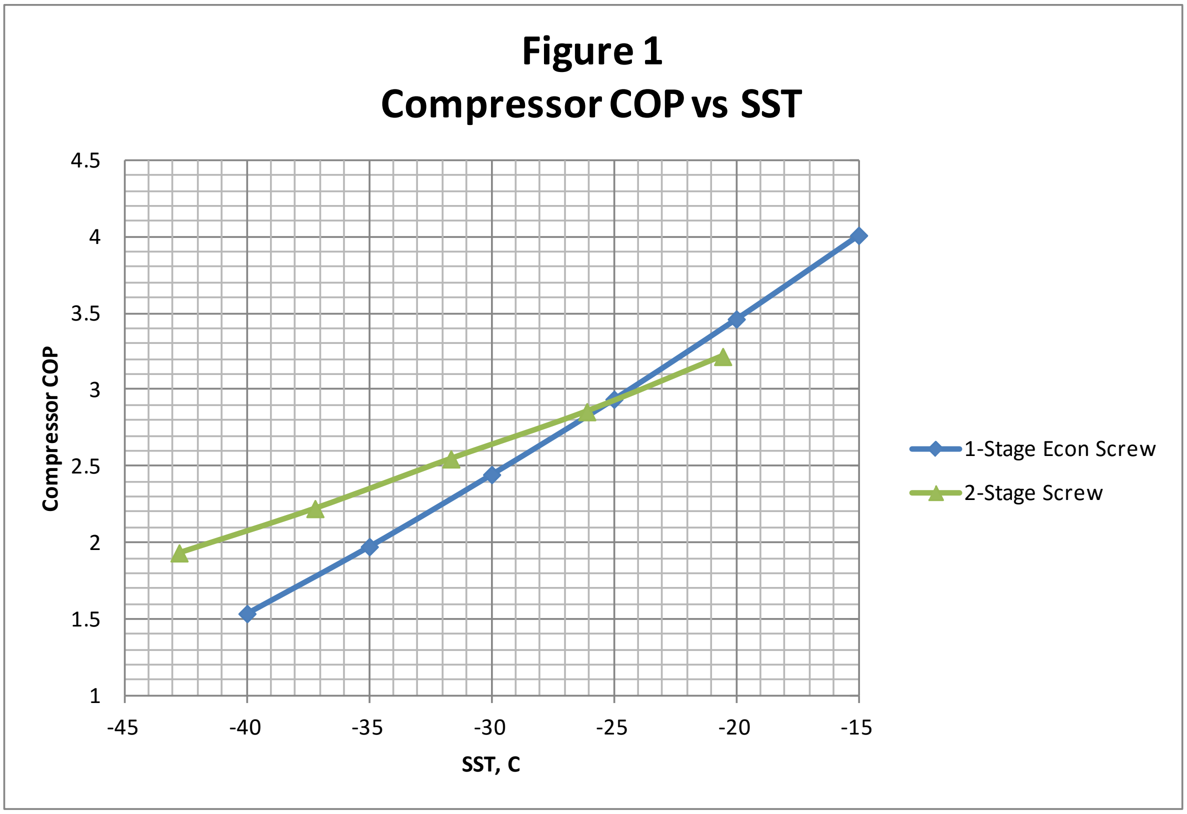
The above analysis clearly shows that the DTM assumption that room temperature gradient is equal to the air temperature change through the evaporator, is NOT valid.

Because of the mixing effect of the entrainment ratio, evaporators selected using DTM ratings will be undersized for the load and will operate with a suction temperature that is lower than expected in order to achieve the design cooling capacity.

Using the DT1 rating method, on the other hand, assumes there is complete mixing of the air in the refrigerated space. Put another way, DT1 conservatively assumes an infinite entrainment ratio and therefore no room air temperature gradient. While this is not absolutely true, it is much closer to reality and results in operating suction temperatures much closer to design compared to evaporators selected using DTM ratings.

©2016 Colmac Coil Manufacturing, Inc.

The next sections examine the increase in operating costs resulting from the lower operating suction temperatures required by DTM rated evaporators compared to DT1 rated evaporators.



Effect of Suction Temperature on Energy Consumption

For a given fixed condensing temperature, all compressors lose efficiency as suction pressure falls. With ammonia, the Coefficient of Performance (COP) falls approximately 2.0 to 3.6% for every 1 deg C reduction in suction temperature (Stoecker 1998). Figure 1 shows compressor COP vs suction temperature for typical single stage and 2-stage screw compressor systems at a condensing temperature of 29.4 deg C (85 deg F). Below about -25 deg C (-13 deg F) suction temperature, 2-stage compression systems operate with higher COP compared to single stage compression with economizing (Jekel 2008).

As explained in the previous section, evaporators selected using DTM ratings will cause the system to operate at a lower than expected suction temperature compared to evaporators selected using DT1 ratings. Using the relationships shown in Figure 1 along with fundamental evaporator capacity relationships we can determine how much additional power will be consumed by system compressors when evaporators are selected based on DTM ratings.

Power Consumption Comparison DTM Vs DT1

Two sets of evaporators having the same total airflow rate will be selected for the same cooling load and temperature difference, one on the basis of DTM and the other on the basis of DT1, to answer the questions:

1. What will the difference in actual operating suction temperatures be between DTM and DT1 evaporators?
2. What will be the resulting difference in compressor power consumption?
3. What incremental return on investment benefit will result from selecting evaporators using DT1 ratings instead of DTM ratings?

Assumptions:

- Total Cooling Load: 352 kW (100 TR)
- Temperature Difference, TD: 6.67 deg C (12 deg F)
- Sensible Heat Ratio: 1.0 (all sensible cooling)
- Saturated Condensing Temperature: 29.4 deg C (85 deg F)
- Airflow Rate: 302,308 m3/h (177,930 cfm)

©2016 Colmac Coil Manufacturing, Inc.

- Specific Heat of Air: 1.005 kJ/kg K (0.24 Btu/lbm F)
- Cost of Electricity: $0.15/kWh
- Price of DT1 Rated Evaporators: $1,600/kW C
- Air in the room is fully mixed. i.e. Zero or very little room temperature gradient

Based on the above, the following calculations were made for a range of air temperatures and shown in Tables 1 and 2 below:

Air Density:
$$\rho_a = 1.225\ x\ \frac{(273.15 + 15)}{(273.15 + T_0)} \quad (2)$$

Rated DTM Air On Temp:
$$T_{on\ DTM} = T_0 + \frac{\dot{q}}{2\ x\ \frac{Q}{3600}\ x\ \rho_a\ x\ C_p} \quad (3)$$

Rated DTM Air Off Temp:
$$T_{off\ DTM} = T_{on\ DTM} - \frac{\dot{q}}{\frac{Q}{3600}\ x\ \rho_a\ x\ C_p} \quad (4)$$

Rated DTM Suction Temp:
$$T_{evap\ DTM} = T_0 - TD \quad (5)$$

DTM Effectiveness:
$$\varepsilon = \frac{T_{on\ DTM} - T_{off\ DTM}}{T_{on\ DTM} - T_{evap\ DTM}} \quad (6)$$

Actual DTM Air On Temp:
$$T'_{on\ DTM} = T_0 \quad (7)$$

Actual DTM Air Off Temp:
$$T'_{off\ DTM} = T'_{on\ DTM} - \frac{\dot{q}}{\frac{Q}{3600}\ x\ \rho_a\ x\ C_p} \quad (8)$$

Actual DTM Suction Temp:
$$T'_{evap\ DTM} = T'_{on\ DTM} - \frac{T'_{on\ DTM} - T'_{off\ DTM}}{\varepsilon} \quad (9)$$

Actual DT1 Air On Temp:
$$T_{on\ DT1} = T_0 \quad (10)$$

Actual DT1 Air Off Temp:
$$T_{off\ DT1} = T_{on\ DT1} - \frac{\dot{q}}{\frac{Q}{3600}\ x\ \rho_a\ x\ C_p} \quad (11)$$

Actual DT1 Suction Temp:
$$T_{evap\ DT1} = T_{on\ DT1} - TD \quad (12)$$

DTM Power Used:
$$PU_{DTM} = 365\frac{days}{y}x\ 24\frac{h}{day}\ x\ \frac{\dot{q}}{COP_{DTM}} \quad (13)$$

DT1 Power Used:
$$PU_{DT1} = 365\frac{days}{y}x\ 24\frac{h}{day}\ x\ \frac{\dot{q}}{COP_{DT1}} \quad (14)$$

DT1/DTM Price Ratio:
$$PR = \frac{T_{on\ DTM} - T_{evap\ DTM}}{TD} \quad (15)$$

©2016 Colmac Coil Manufacturing, Inc.

DT1 Price Premium: $$PP = (PR - 1)\ x\ \frac{\$1600/(kW/C)\ x\ \dot{q}}{TD} \tag{16}$$

DT1 v DTM Simple Payback: $$SPB = \frac{PP}{(PU_{DTM} - PU_{DT1})\ x\ \$0.15/kWh} \tag{17}$$

Incremental Return on Investment: $$IROI = \frac{1}{SPB}\ x\ 100 \tag{18}$$

TABLE 1					
SINGLE STAGE (ECONOMIZED) POWER CONSUMPTION COMPARISON					
Room Temp, C	-12.2	-17.8	-23.3	-28.9	-34.4
Room Temp, F	10	0	-10	-20	-30
Air Density, kg/m3:	1.35	1.38	1.41	1.45	1.48
Rated DTM Air On, C:	-10.7	-16.3	-21.9	-27.4	-33.0
Rated DTM Air Off, C:	-13.8	-19.3	-24.8	-30.3	-35.9
Rated DTM SST, C:	-18.9	-24.4	-30.0	-35.6	-41.1
Rated DTM SST, F:	-2.0	-12.0	-22.0	-32.0	-42.0
DTM Effectiveness:	0.38	0.37	0.36	0.36	0.35
Actual DTM Air On, C:	-12.2	-17.8	-23.3	-28.9	-34.4
Actual DTM Air Off, C:	-15.3	-20.8	-26.3	-31.8	-37.3
Actual DTM SST, C:	-20.4	-26.0	-31.5	-37.0	-42.5
Actual DTM SST, F:	-4.8	-14.7	-24.7	-34.6	-44.5
DTM COP (29.44C SCT):	3.42	2.84	2.30	1.80	1.33
Actual DT1 Air On, C:	-12.2	-17.8	-23.3	-28.9	-34.4
Actual DT1 Air Off, C:	-15.3	-20.8	-26.3	-31.8	-37.3
Actual DT1 SST, C:	-18.9	-24.4	-30.0	-35.6	-41.1
Actual DT1 SST, F:	-2.0	-12.0	-22.0	-32.0	-42.0
DT1 COP (29.44C SCT):	3.58	3.00	2.44	1.93	1.44
DTM Power Used, kWh/y:	901,854	1,083,296	1,337,619	1,714,718	2,319,003
DT1 Power Used, kWh/y:	860,264	1,027,953	1,260,360	1,600,079	2,133,436
Savings/y, $:	$6,239	$8,302	$11,589	$17,196	$27,835
DT1/DTM Price Ratio:	1.23	1.23	1.22	1.22	1.21
DT1 Cooler Cost, $ / (kW/C):	$1,600	$1,600	$1,600	$1,600	$1,600
DT1 Price Premium, $:	$19,482	$19,067	$18,652	$18,238	$17,823
DT1 Simple Payback, y:	3.12	2.30	1.61	1.06	0.64
DT1 Incremental ROI, %/y:	32.0%	43.5%	62.1%	94.3%	156.2%

©2016 Colmac Coil Manufacturing, Inc.

TABLE 2 2-STAGE POWER CONSUMPTION COMPARISON					
Room Temp, C	-12.2	-17.8	-23.3	-28.9	-40.0
Room Temp, F	10	0	-10	-20	-40
Air Density, kg/m3:	1.35	1.38	1.41	1.45	1.51
Rated DTM Air On, C:	-10.7	-16.3	-21.9	-27.4	-38.6
Rated DTM Air Off, C:	-13.8	-19.3	-24.8	-30.3	-41.4
Rated DTM SST, C:	-18.9	-24.4	-30.0	-35.6	-46.7
Rated DTM SST, F:	-2.0	-12.0	-22.0	-32.0	-52.0
DTM Effectiveness:	0.38	0.37	0.36	0.36	0.34
Actual DTM Air On, C:	-12.2	-17.8	-23.3	-28.9	-40.0
Actual DTM Air Off, C:	-15.3	-20.8	-26.3	-31.8	-42.8
Actual DTM SST, C:	-20.4	-26.0	-31.5	-37.0	-48.0
Actual DTM SST, F:	-4.8	-14.7	-24.7	-34.6	-54.5
DTM COP (29.44C SCT):	3.42	2.89	2.56	2.24	1.70
Actual DT1 Air On, C:	-12.2	-17.8	-23.3	-28.9	-40.0
Actual DT1 Air Off, C:	-15.3	-20.8	-26.3	-31.8	-42.8
Actual DT1 SST, C:	-18.9	-24.4	-30.0	-35.6	-46.7
Actual DT1 SST, F:	-2.0	-12.0	-22.0	-32.0	-52.0
DT1 COP (29.44C SCT):	3.58	3.00	2.65	2.32	1.75
DTM Power Used, kWh/y:	901,854	1,065,634	1,204,661	1,376,579	1,816,120
DT1 Power Used, kWh/y:	860,264	1,027,953	1,164,475	1,328,353	1,756,369
Savings/y, $:	$6,239	$5,652	$6,028	$7,234	$8,963
DT1/DTM Price Ratio:	1.23	1.23	1.22	1.22	1.21
DT1 Cooler Cost, $ / (kW/C):	$1,600	$1,600	$1,600	$1,600	$1,600
DT1 Price Premium, $:	$19,482	$19,067	$18,652	$18,238	$17,408
DT1 Simple Payback, y:	3.12	3.37	3.09	2.52	1.94
DT1 Incremental ROI, %/y:	32.0%	29.6%	32.3%	39.7%	51.5%

Conclusions

The author has examined two commonly used rating methods for refrigeration evaporators, DTM and DT1. The following conclusions are based on the results of the discussion:

1. The DTM rating method assumes an air entrainment ratio of 1, that is to say, the room air temperature gradient equals to the air temperature change through the evaporator coil. This is a fundamentally flawed assumption and results in an artificially high assumed temperature difference between air on temperature and evaporating temperature.
2. Because of the artificially high assumed temperature difference, evaporators selected using DTM ratings will have less surface area and will cost less than evaporators selected using DT1 ratings.
3. Because DTM ratings result in undersized evaporator selections, the operating system suction temperature will be lower than expected. This results in greater compressor power consumption compared to evaporators selected using DT1 ratings.
4. Selecting evaporators based on DT1 ratings avoids the DTM power consumption penalty and results in significant energy savings due to higher operating suction temperatures. In the examples given, the beneficial DT1 Incremental Return on Investment (IROI) for the single stage compression case ranged from 32% to 156% per year. For the 2-stage compression case, the DT1 IROI ranged from 32% to 52% per year.

©2016 Colmac Coil Manufacturing, Inc.

Nomenclature

$A_0 = Jet\ discharge\ area, m^2$
$IROI = Incremental\ return\ on\ investment, \%/y$
$K_c = Centerline\ velocity\ constant\ determined\ by\ testing, dimensionless$
$PP = DT1\ price\ premium, \$$
$PR = \frac{DT1'}{DT1}\ price\ ratio, dimensionless$
$PU_{DT1} = DT1\ power\ consumption, {kWh}/{y}$
$PU_{DTM} = DTM\ power\ consumption, {kWh}/{y}$
$\dot{q} = Cooling\ load, kW$
$Q = Evaporator\ airflow\ rate, {m^3}/{h}$
$Q_0 = Airflow\ rate\ measured\ at\ the\ outlet, {m^3}/{h}$
$Q_x = Total\ airflow\ rate\ at\ distance\ X\ from\ face\ of\ the\ outlet, {m^3}/{h}$
$\frac{Q_x}{Q_0} = Entrainment\ ratio$
$SPB = DT1\ vs\ DTM\ simple\ payback, y$
$T_0 = Room\ air\ temperature, C$
$TD = Air\ minus\ evaporating\ temperature\ difference, C$
$T_{on\ DT1} = Actual\ DT1\ air\ temperature\ entering\ the\ evaporator, C$
$T_{off\ DT1} = Actual\ DT1\ air\ temperature\ leaving\ the\ evaporator, C$
$T_{evap\ DT1} = Actual\ DT1\ evaporating\ (suction) temperature, C$
$T_{on\ DTM} = Rated\ DTM\ air\ temperature\ entering\ the\ evaporator, C$
$T_{off\ DTM} = Rated\ DTM\ air\ temperature\ leaving\ the\ evaporator, C$
$T_{evap\ DTM} = Rated\ DTM\ evaporating\ (suction) temperature, C$
$T'_{on\ DTM} = Actual\ DTM\ air\ temperature\ entering\ the\ evaporator, C$
$T'_{off\ DTM} = Actual\ DTM\ air\ temperature\ leaving\ the\ evaporator, C$
$T'_{evap\ DTM} = Actual\ DTM\ evaporating\ (suction) temperature, C$
$X = Distance\ from\ face\ of\ the\ outlet, m$
$C_p = Air\ specific\ heat\ capacity, {kJ}/{kg\ K}$
$\varepsilon = Evaporator\ effectiveness, dimensionless$
$\rho_a = Air\ density, {kg}/{m^3}$

Bibliography

ASHRAE 2009. 2009 ASHRAE Handbook - Fundamentals. *American Society of Heating Refrigerating and Air-Conditioning Engineers.* Atlanta, GA. Chap. 20, pp 20.5-6.

Jekel, T.B., Reindl, D.T. 2008. “Single or Two-Stage Compression”, *ASHRAE Journal*, Aug 2008, pp 46-51.

Nelson, B. 2010. “Refrigeration Air Cooler Rating Methods”. *ASHRAE Journal*, Aug 2010, pp 24-28

Li, Z.H., Zhang, J.S., Zhivov, A.M., Christianson, L.L. 1993. “Characteristics of Diffuser Air Jets and Airflow in the Occupied Regions of Mechanically Ventilated Rooms – A Literature Review”. *ASHRAE Transactions* 99(1): 1119-1127.

Stoecker, W.F. 1998. 1. *Industrial Refrigeration Handbook.* NY: McGraw-Hill Publishers

For more information, please contact Colmac Coil Manufacturing, Inc.
mail@colmaccoil.com | (800) 845-6778 | (509) 684-2595
P.O. Box 571, Colville, WA. 99114-0571 | www.colmaccoil.com

© 2016 Colmac Coil Manufacturing, Inc.

©2016 Colmac Coil Manufacturing, Inc.