

REGIONAL AIR CONDITIONERS: WHAT DOES THE HARDWARE HAVE TO TELL US?

*Jim Crawford, Director of Regulatory Affairs, Trane,
Tyler, Smith County, Texas*

Abstract. In many parts of the world, the principal form of a heat pump is an air-to-air air conditioner. Alternatively, the principal function of air-to-air heat pumps in many parts of the world is comfort cooling. There is a widely-held opinion that the basic design of an air conditioner should be tailored to the climate. This notion has considerable support in some quarters in the United States among those who contend that there ought to be different designs for dry and humid climates. This paper will examine the published performance data for a typical single package air-to-air air conditioner for a range of indoor and outdoor conditions with particular attention to the way in which the performance changes in response to changes in indoor and outdoor relative humidity. The relationships elicited through this investigation will be generalized to demonstrate trends that might be expected in any air-to-air air conditioner, and the way in which those trends are influenced by the ambient conditions.

Key Words: *air conditioner, air-to-air, humidity, performance, cooling*

1 INTRODUCTION

There is a widely-held opinion that the basic design of an air conditioner should be tailored to the climate. This notion has considerable support among those who contend that there ought to be different designs for dry and humid climates. In this paper, published performance data for a typical single package air-to-air air conditioner is examined over a range of indoor and outdoor conditions. Particular attention is given to the way in which the performance does, or does not, change in response to changes in outdoor and indoor relative humidity. The relationships disclosed by this investigation are generalized to illustrate trends that should be expected in any air-to-air air conditioner, and the way in which those trends are influenced by the ambient conditions. Some of these trends may be counter-intuitive.

2 EXAMPLE HARDWARE AND ITS PERFORMANCE DATA

The data examined in this paper are the published performance data on a typical single-package air conditioner. This configuration was selected to eliminate the variable of matching a split system outdoor unit with an appropriate indoor unit. In examining the data, the goal is to elicit some general rules about air conditioner performance. Thus, the focus is on **how** the unit operates in response to changing indoor and outdoor conditions. A later paper may examine **why** the unit operates this way, with emphasis on some of what might be unexpected trends.

The data that describes the performance of the unit are presented in Table 1. The data come from Product Data for a typical unit with a nominal capacity of three tons [10.55 kW] and a nominal EER of 12 [COP of 3.55]. This data will be analyzed to ferret out relationships that are general. For the most part, the generality of these relationships will not be demonstrated. It is hoped that the generality will be evident once discussed.

Table 1; Cooling Performance of a Typical Single-Package Air Conditioner

	A	B	C	D	E	F	G	H
1	OD	ID	Total Capacity kBtu/hr	Sensible Capacity in kBtu/hr at entering Dry Bulb Temperature				Total Power
2				72°F	75°F	78°F	80°F	kW
3	DB	WB						
4	85°F	59°F	34.7	23.4	28.1	32.7	34.7	2.9
5		63°F	36.2	21.4	25.6	30.0	32.8	2.92
6		67°F	39.0	18.5	22.2	25.9	28.3	2.97
7		71°F	42.1	15.3	18.4	21.5	23.5	3
8	95°F	59°F	32.2	22.4	26.9	31.4	32.2	3.22
9		63°F	33.6	20.5	24.7	28.8	31.5	3.24
10		67°F	36.2	17.7	21.3	24.8	27.2	3.29
11		71°F	39.1	14.7	17.7	20.6	22.5	3.32
12	105°F	59°F	29.8	21.3	25.6	29.8	29.8	3.53
13		63°F	31.0	19.6	23.5	27.4	30.0	3.55
14		67°F	33.4	16.9	20.3	23.6	25.8	3.61
15		71°F	36.1	14.0	16.8	19.6	21.4	3.64
16	115°F	59°F	27.3	20.1	24.2	27.3	27.3	3.84
17		63°F	28.5	18.5	22.2	25.9	28.3	3.87
18		67°F	30.7	15.9	19.2	22.3	24.4	3.93
19		71°F	33.1	13.2	15.9	18.5	20.3	3.97

The columns of Table 1 are:

- A Outdoor Dry Bulb Temperature in Degrees F.
- B Indoor Wet Bulb Temperature in Degrees F.
- C The total Cooling Capacity in kBtu/Hr.
- D-G The sensible Cooling Capacity in kBtu/Hr.
- H The Total Input Power in kW.

The EER is the ratio of the value in column C divided by the value in column H. At 85°F outdoor dry bulb and 59°F indoor wet bulb, the EER is (34.70kBtu/Hr) / 2.90 kW = 11.97. The COP would be 11.97 / 3.412 = 3.5.

Units of Measure

Apologies to the international audience for the use of Imperial units. These are the units in which the equipment ratings are published. Fortunately, The lessons to be learned are in terms of the relationships not in terms of the values of the numbers nor the units of measure.

3 FIRST ORDER LESSONS

At this point, we should note the first important characteristic of air-source vapor-compression air conditioners:

i. The total capacity and efficiency [COP] of an air source air conditioner are determined by the outdoor dry bulb temperature and the indoor wet bulb temperature.

Alternatively, the total capacity and efficiency are independent of the outdoor wet bulb and the indoor dry bulb temperatures.

Being independent of the outdoor wet bulb is largely attributable to the fact that no condensation or evaporation of the moisture in the outdoor air takes place at the condenser. Thus, the effect of the moisture in the outdoor air is limited to a slight variation in the specific heat of the air passing over the condenser.

The dew point of the outdoor air on a typical day might be in the range of 50 to 70°F [10 to 21.1°C]. This corresponds to a moisture content of 0.008 to 0.016 #H₂O/# Air [Which is numerically identical to the corresponding measure in kgH₂O/kgAir.]. The associated differences in specific heat of the air are not zero, but are not of practical significance.

At the evaporator [indoors], the wet bulb temperature correlates closely with the total heat content of the air [i.e., the sum of the sensible and latent heat of the indoor air]. Examining columns B, C and H of Table 1, two important observations can be made:

ii. For a given outdoor temperature, the higher the heat content of the indoor air, the greater the total cooling capacity of the air conditioner.

iii. For a given outdoor temperature, the higher the heat content of the indoor air, the greater the efficiency [COP] of the air conditioner.

These are both rather counter-intuitive. A more intuitive observation is that:

iv. For any indoor air heat content, the higher the outdoor air temperature, the lower the cooling capacity and the lower the system efficiency [COP].

In fact, the efficiency drops rather rapidly as the outdoor temperature rises because the capacity decreases and the power consumption increases as the outdoor temperature increases. This is directly attributable to increases in the condensing temperature with increasing outdoor air temperature.

Figure 1 illustrates the efficiency trends reflected in points iii and point iv. Note that the COP increases by almost 2:1 as the conditions are changed from an indoor wet bulb temperature of 59°F at 115°F outdoors to the indoor wet bulb temperature 71°F at 85°F outdoors.

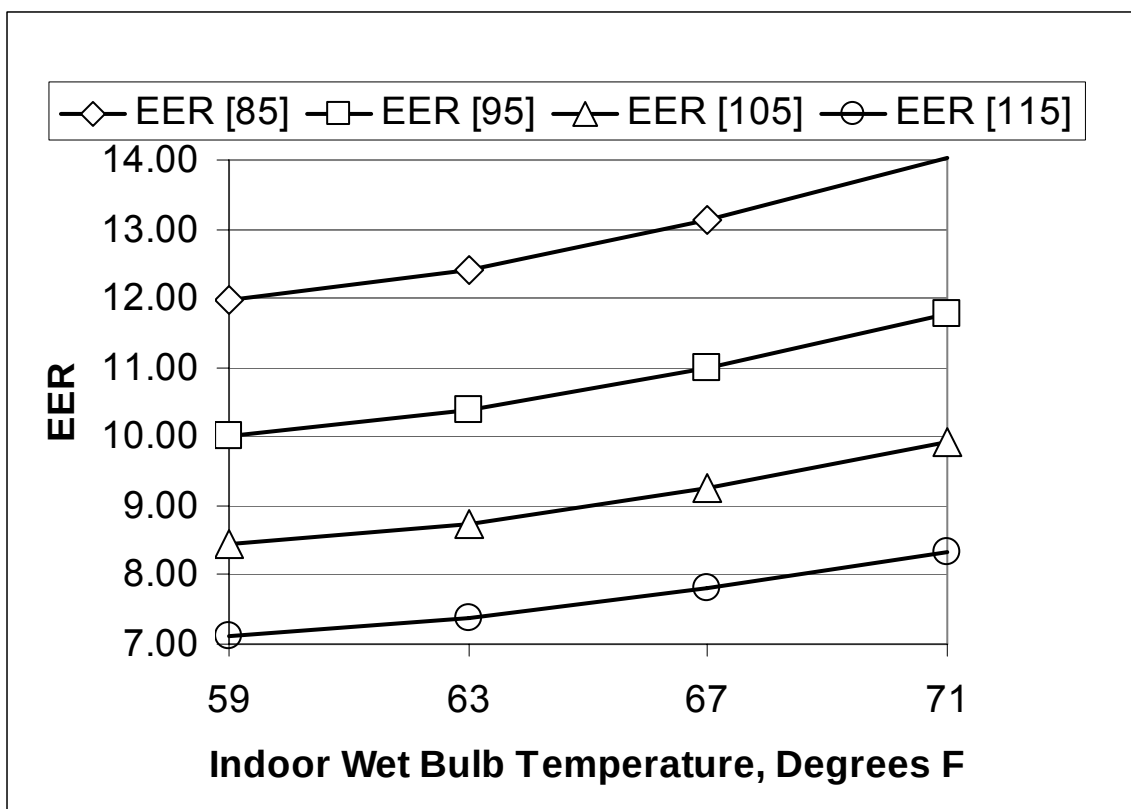


Figure 1; Efficiency As a Function of Outdoor Dry Bulb Temperature and Indoor Wet Bulb Temperature

These trends are very general, they are not dependent on the specific hardware in question. The particular values of the numbers depend on the hardware; the trends do not.

4 SECOND ORDER LESSONS --- VARIATION DUE TO INDOOR RELATIVE HUMIDITY

The indoor relative humidity plays a very important role in the performance of the unit. Before delving into this, it is import to become calibrated to the relative humidity associated with pairs of wet bulb and dry bulb temperatures of the individual cells of Table 1.

To start the investigation of humidity effects, the “wet bulb depression” [i.e., dry bulb temperature minus wet bulb temperature] is tabulated in Table 2 for the cells of the performance data in Table 1.

Table 2; Wet Bulb Depression at the Data Points

Wet Bulb	Dry Bulb Temperature, Degrees F			
	72	75	78	80
59	15	16	19	21
63	9	12	15	17
67	5	8	11	13
71	1	4	7	9

Psychrometric data sources

Psychrometric programs, tables, and charts are available from a variety of sources. There is a fair amount of variation among these. The discrepancies could be of significance in some analyses. For the present analyses, the small errors will not bias the conclusions to be drawn. The psychrometric data here is drawn from a routine available on the internet.

The wet bulb depression ranges from 1 degree in the lower left corner [low dry bulb and high wet bulb temperature] to 21 degrees in the upper right hand corner [high dry bulb and low wet bulb temperature]. The corresponding relative humidity for each cell is shown in Table 3.

Table 3; Relative Humidity at the Data Points

Wet Bulb	Dry Bulb Temperature, Degrees F			
	72	75	78	80
59	16.0%	37.9%	31.0%	27.0%
63	61.1%	51.6%	43.4%	38.5%
67	77.5%	66.4%	56.8%	51.1%
71	95.3%	82.5%	71.4%	64.9%

Examining Tables 2 and 3 together, we note that, in the range of wet and dry bulb temperatures in the tables, a wet bulb depression of 12 to 13 degrees F corresponds to a relative humidity in the range of 50%. Smaller values of the wet bulb depression indicate relative humidity greater than 50% and the need to consider dehumidification.

5 APPLICATION

Referring back to Table 1, we examine the cells under the heading of Sensible Capacity at the entering dry bulb temperature. These cells, in columns D, E, F, & G, list the sensible cooling capacity of the machine at the indicated indoor and outdoor conditions. The latent capacity is, by definition:

$$\text{Latent Capacity} \equiv [\text{Total Capacity}] \text{ minus } [\text{Sensible Capacity}] \quad \text{EQ. 1}$$

In considering the cooling capacity of an air conditioner, it is common to refer to the Sensible Heat Ratio [SHR] which is the ratio of the sensible capacity to the total capacity. Alternatively, the Latent Heat Ratio [LHR] would be the ratio of the latent cooling capacity to the total cooling capacity.

$$\begin{aligned} \text{SHR} + \text{LHR} &\equiv 1.0 & \text{EQ. 2} \\ \text{LHR} &= 1.0 - \text{SHR} & \text{EQ. 2a} \end{aligned}$$

The SHR for each case is given in Table 4

Table 4; Sensible Heat Ratio, SHR

OD DB	SHR at Entering DB Temperature				
		72	75	78	80
85	59	0.67	0.81	0.94	1.00
	63	0.59	0.71	0.83	0.91
	67	0.47	0.57	0.66	0.73
	71	0.36	0.44	0.51	0.56
95	59	0.70	0.84	0.98	1.00
	63	0.61	0.74	0.86	0.94
	67	0.49	0.59	0.69	0.75
	71	0.38	0.45	0.53	0.58
105	59	0.71	0.86	1.00	1.00
	63	0.63	0.76	0.88	0.97
	67	0.51	0.61	0.71	0.77
	71	0.39	0.47	0.54	0.59
115	59	0.74	0.89	1.00	1.00
	63	0.65	0.78	0.91	0.99
	67	0.52	0.63	0.73	0.79
	71	0.40	0.48	0.56	0.61

Examining Tables 3 and 4 together illustrates an extremely important characteristic of conventional air conditioners.

v. When the air in the conditioned space has a high relative humidity, the operating point of a conventional air conditioner shifts automatically to increase the capacity of the air conditioner to remove the humidity.

This is not truly a property of the machinery, it is an intrinsic property of the psychometrics of the air conditioning process.

The higher the relative humidity, the higher the dehumidification capacity of a conventional air conditioner and conversely. This tends to dispel the notion of regional designs for hot and dry or hot and humid climate.

If the indoor wet and dry bulb conditions in Table 2 and 3 are entered into a psychrometric calculator, the indoor air dew point for each cell can be determined. This has been done and the results are presented in Table 5.

If the entering air dew point is above the coil surface temperature [or more precisely the temperature of the air leaving the coil], then the air conditioner will dehumidify along with sensible cooling.

Consider two extreme cells, those at 72°F-DB/71°F-WB and 80°F-DB/59°F-WB. In the first case [72/71] the dew point is 70.6°F, well above any reasonable coil temperature. The latent

Local Weather Effects

It has been demonstrated that an air conditioner adjusts its operating point to increase or decrease latent capacity depending on whether the relative humidity in the conditioned space is high or low. What has not been addressed is the influence of the local climate on the indoor relative humidity. To the extent that the air conditioning load is dependent on infiltration, the local climate and weather will influence the indoor relative humidity and the SHR [or LHR] required to achieve and maintain the desired indoor temperature and relative humidity. To a remarkable degree, the equipment will accommodate weather changes.

capacity under these conditions ranges from 60 to 64% of the total capacity depending on the outdoor temperature.

It is noteworthy that despite a 20°F range in outdoor temperature for this indoor condition, the LHR varies only slightly.

In the second case [80/59], the dew point is 43.1°F, well below the expected coil temperature. This is generally referred to as a "dry-coil condition". Because the dew point is well below the temperature of the coil, there will be no condensation. The relative humidity at these dry coil conditions [typically 78/59, 80/59, and 80/61] is well below 40%. Dehumidification is not needed and does not occur.

An approximate equation for sensible cooling is:

$$\Delta T = Q / (1.08 \bullet \text{CFM}) \quad \text{EQ. 3}$$

Where ΔT = Temperature difference [cooling] in degrees Fahrenheit.

Q = Sensible cooling in Btu/hr

CFM = Air flow through the coil in cubic feet per minute

The assumption here is that the specific heat of the air is constant at 0.24 Btu/#°F, and that the density is constant at 0.075#/ft³. [$0.24 \bullet 0.075 \bullet 60 = 1.08$]

Since the nominal air flow for an air conditioner is 400 cfm/ton [680 m³/Hr], it will be instructive to determine the value of ΔT for that condition.

$$\Delta T = (12,000 \text{ Btu/hr}) / (1.08 \bullet 400 \text{ cfm}) = 27.8^\circ\text{F} [15.4^\circ\text{C}] \quad \text{EQ.3a}$$

To assess the significance of this, it helps to take the indoor conditions one more step. Table 5 gives the indoor air dew point for each wet and dry bulb in the table.

Table 5; Dew Point Temperature for Differing Indoor Wet and Dry Bulb Temperatures

Wet Bulb	Dry Bulb Temperature, Degrees F			
	72	75	78	80
59	50.2	47.7	45.0	43.1
63	57.9	56.0	54.0	52.6
67	64.6	63.1	61.5	60.4
71	70.6	69.3	68.0	67.1

If the dew point is subtracted from the dry bulb temperature, the result is the indoor "dew point depression" which is the amount by which the indoor air entering the air conditioner would have to be depressed [cooled] in order to begin dehumidification. [i.e., dehumidification requires that the air be cooled below its dew point.]. This dew point depression is given in Table 6.

Table 6; Dew Point Depression for Differing Indoor Wet and Dry Bulb Temperatures

Wet Bulb	Dry Bulb Temperature, Degrees F			
	72	75	78	80
59	21.8	27.3	33.0	36.9
63	14.1	19.0	24.0	27.4
67	7.4	11.9	16.5	19.6
71	1.4	5.7	10.0	12.9

It is tempting to compare these values with the result of Equation 3a, but we need to remember that the total capacity depends on both the outdoor dry bulb temperature and the indoor wet bulb temperature as shown in Columns A, B, and C of Table 1. However, Table 5 does serve as a useful tool to reinforce our understanding. Looking at the two extreme cases we note that at 80/59 the dew point depression is about 25 times as great as the dew point depression at 72/71. We might infer that the first case is a dry coil case [and it is] and that the second case is one where latent cooling dominates [and it does].

Considering this table in light of EQ. 3a, we note that the maximum ΔT is less than the dew point depression for two cells and very close for 2 or 3 more. These are "dry coil" cases or cases that are nearly dry coil.

The maximum cooling potential for this specific piece of equipment, if it were all sensible, can be determined from columns A, B, and C of Table 1. This shows that, because the total capacity increases with increasing indoor wet bulb temperature, and decreases with outdoor dry bulb temperature, and the indoor air flow is constant, the maximum potential sensible cooling does the same thing.

Whether the maximum *potential* sensible cooling is realizable under a given set of conditions depends on the indoor dry bulb temperature.

vi. For any given indoor wet bulb temperature and outdoor dry bulb temperature, the higher the indoor dry bulb temperature, the higher the sensible cooling.

6 RECAPITULATION

From examination of the performance of a typical air conditioner, we have noted five very general observations about the performance of air conditioners:

- i. The total capacity and efficiency [COP] of an air source air conditioner are determined by the outdoor dry bulb temperature and the indoor wet bulb temperature.*
- ii. For a given outdoor temperature, the higher the heat content of the indoor air, the greater the cooling capacity of the air conditioner. --- So, the higher the load, the higher the capacity to handle the load.*
- iii. For a given outdoor temperature, the higher the heat content of the indoor air, the greater the efficiency [COP] of the air conditioner. --- So the higher the cooling load, the higher the efficiency with which the air conditioner serves the load.*
- iv. For any indoor air heat content, the higher the outdoor air temperature, the lower the cooling capacity and the lower the system efficiency [COP]. --- For the most part, this is an unavoidable consequence of the second law of thermodynamics.*
- v. When the air in the conditioned space has a high relative humidity, the operating point of a conventional air conditioner shifts automatically to increase the capacity of the air conditioner to remove the humidity.*
- vi. For any given indoor wet bulb temperature and outdoor dry bulb temperature, the higher the indoor dry bulb temperature, the greater the sensible cooling.*

These very general observations about the nature of an air conditioner and its operating response to the indoor and outdoor environment can serve as useful guides in investigation of the potential performance of future systems. The numbers may change, but the general trends highlighted here will not.

7 REFERENCES

Psychrometric properties <http://psychropro.homestead.com/files/>

Product Data: Trane Pub. No. 22-1783-04, 21 September 2006