What Can 13,000 Air Conditioners Tell Us?

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ABSTRACT

Performance data on more than 13,000 air conditioners on residential and commercial buildings in California have been gathered over the last two years. These measurements were collected via a computer expert system used by HVAC field technicians during routine installation, repair, and maintenance visits. The data provide an extensive picture of the condition of air conditioning (AC) units, their operating and performance parameters, the indoor conditions of the buildings they cool, and many other factors.

This paper presents an analysis of these data. It provides answers to a number of questions of interest to program planners and evaluators, such as: What is the distribution of refrigerant charge on AC units? Are air conditioners with certain types of refrigerant metering devices more prone to improper charge adjustment? Is airflow through the evaporator coil of air conditioners a problem on residential or commercial systems? What are the humidity conditions within these buildings? Are there differences in humidity conditions between residential and commercial buildings? And do indoor humidity conditions vary by climate zone?

Given this new information, assumptions about residential and commercial AC performance and efficiencies can be updated and more accurate predictions or evaluations can be made.

Introduction

Incorrect airflow[1] and refrigerant charge level[2] compromise the energy efficiency of AC systems, causing them to operate below their designed efficiency and capacity. The average performance of residential air conditioners is at least 17% below design performance—the equivalent of a 12 SEER air conditioner operating at 10 SEER (Proctor and Downey 1999). Field surveys indicate if charge and airflow were corrected within achievable limits in residential AC systems, seasonal efficiencies would increase an average of 16% (Neme et. al. 1999). Effects on peak efficiency are also significant. Previous studies have found newly installed air conditioning systems also experience problems with refrigerant charge and airflow (Blasnik et. al. 1995, Blasnik et. al. 1996). Even units that are installed correctly develop charge and airflow problems over time. Low airflow is attributable to many factors including closed registers, low fan speed, duct design, coil fouling, and others. Incorrect charge levels are due mainly to servicing and sometimes to leaks in the refrigerant system. In response, the California Energy Commission included compliance guidelines addressing charge and airflow parameters in new and retrofit

[1] Defined herein as less than 350 cfm per nominal ton.
[2] Defined herein as more than 5% different from manufacturer's correct charge as defined by their charge diagnostic method.

residential energy and efficiency (Title 24) standards that took effect in 2001 (California Energy Commission 2001).

Studies have also shown extensive problems with HVAC equipment installations, maintenance, and service on commercial air conditioning systems. A 1999 study of commercial rooftop units performed for the Sacramento Municipal Utility District (Proctor 2000) showed that the majority of the units had refrigerant charge and air flow problems at least comparable to the problems documented in residential systems. The Center for Energy Use and the Environment study of commercial rooftop units found that only 28% were correctly charged (Hewitt et al. 1992)

Proctor Engineering Group, Ltd. (PEG) has developed CheckMe!® , a computer and human expert system (CHEX) for central air conditioning designed to ensure that both refrigerant charge and airflow through the evaporator coil are properly tested and correctly adjusted. Since 1998, through application of CheckMe!® in routine HVAC maintenance and installation procedures, data on the operating characteristics of more than 13,000 HVAC systems in California have been compiled. CheckMe!® ensures accuracy by automatically screening input data for out-of-range and suspect values. As a result, this data set is one of the most extensive and accurate collections of information on residential and commercial AC systems currently available.

The purpose of this analysis was to extract valuable information about residential and commercial AC systems in California, including refrigerant charge and airflow problems, system performance, and return air characteristics of the buildings in which the systems are installed.

Methods

Data Collection

Data for this study were compiled from January 2000 to mid February 2002 using the CheckMe!® system. These data contain both residential and small commercial air conditioning systems. The CheckMe!® system enhances the AC tune-up process used by field technicians during installation, service, repair, or maintenance visits. Data inputs include AC equipment type and operating conditions (including evaporator coil entering and exiting temperatures, and appropriate refrigerant temperatures and pressures) as well as customer, contractor, and technician information. Based on the input, CheckMe!® assesses AC performance in accordance with the manufacturer's recommended airflow and charge specifications. Output includes an analysis of refrigerant charge and airflow, recommended efficiency measures to optimize equipment performance, and customer education information.

Data Verification

Field technicians trained to measure equipment performance in a prescribed, consistent manner collect all data input to the system. By way of a toll-free telephone service, the technician reports the initial performance measurements to a trained operator. The CheckMe!® operator inputs the data to the Computer and Human Expert System (CHEX).

At this stage, any out-of-range or suspect values are automatically rejected or questioned. If necessary, the operator transfers the call to a field-experienced expert who offers immediate assistance. These steps ensure the accuracy of the collected and analyzed information . If repairs are required, measurements are taken after the repair. The post repair data are analyzed while the technician is still at the site to ensure repair efficacy and optimum equipment efficiency.

Data Cleaning

Data are post-processed to find incidents where the technicians are "gaming the system" – providing numbers that make it through the expert system that are not actually the measured numbers from the air conditioners in question. A computer process that looks for patterns in the data detects these incidents. Twelve factors are evaluated in the process and compared against the statistical probability that the patterns will occur randomly. When a technician produces repeated patterns that have less than a 0.1% chance of random occurrence, the technician is decertified and their data are removed from the data set. Further information on this process is contained in Buckley (2002).

Refrigerant Charge Diagnosis

While there are manufacturer's approved methods of diagnosing refrigerant levels, they are rarely used. Less than 5% of the technicians trained in the CheckMe!® program even claimed to use these methods prior to the training. Unfortunately, most technicians have gotten into the habit of looking at the refrigerant gauge and using a "rule of thumb" to estimate proper charge (e.g. "You should have 70 PSIG on the low side and less than 275 PSIG on the high side[3].").

Two types of refrigerant metering devices are used on residential and commercial AC systems. The CheckMe!® protocol uses different manufacturer's methods[4] for testing refrigerant charge, depending on the metering device. The two primary methods are superheat and subcooling.

Fixed metering devices (non-TXV). Fixed metering devices (e.g. fixed orifices) are the most common in both residential and commercial air conditioners. CheckMe!® uses the superheat method for these systems. Superheat is the difference between the suction line temperature and the evaporator saturation temperature. The target superheat varies with outdoor ambient conditions and the load on the evaporator coil (Carrier Corporation 1994). An abbreviated table of target superheat values is displayed in Table 1.

[3] There are hundreds, perhaps thousands of such rules of thumb for refrigerant charging.

[4] For air conditioners manufactured by Lennox Corporation, subcooling is used for fixed metering devices and approach is used for TXV devices. Lennox Approach is the difference between the temperature of the air entering the condenser coil and the liquid line temperature.

Table 1. Target Superheat

Condenser Air Dry-Bulb Temperature (°F)	Return Air Wet-Bulb Temperature (°F)													
	50	**52**	**54**	**56**	**58**	**60**	**62**	**64**	**66**	**68**	**70**	**72**	**74**	**76**
55	8.8	11.5	14.2	17.1	20.0	23.1	26.2	29.4	32.4	35.1	37.7	40.2	42.7	45.0
60	7.0	9.8	12.6	15.4	18.2	21.0	23.8	26.6	29.6	32.4	35.1	37.8	40.4	42.9
65	-	7.0	10.0	12.9	15.8	18.5	21.2	23.8	26.7	29.7	32.5	35.3	38.1	40.8
70	-	-	6.4	9.7	12.7	15.7	18.4	20.9	23.9	27.0	30.0	33.0	35.9	38.7
75	-	-	-	5.6	9.2	12.4	15.3	18.0	21.1	24.3	27.5	30.6	33.7	36.7
80	-	-	-	-	-	8.7	12.0	15.0	18.3	21.7	25.0	28.3	31.6	34.8
85	-	-	-	-	-	-	8.5	11.9	15.5	19.0	22.6	26.0	29.5	32.9
90	-	-	-	-	-	-	-	8.8	12.8	16.5	20.1	23.8	27.5	31.1
95	-	-	-	-	-	-	-	5.6	10.0	13.9	17.8	21.6	25.5	29.4
100	-	-	-	-	-	-	-	-	7.3	11.4	15.4	19.5	23.6	27.7
105	-	-	-	-	-	-	-	-	-	8.8	13.1	17.4	21.7	26.0
110	-	-	-	-	-	-	-	-	-	6.4	10.8	15.3	19.9	24.4
115	-	-	-	-	-	-	-	-	-	-	8.6	13.3	18.1	22.9

Source: California Energy Commission 2001

There are limitations to what the superheat method can detect. The combinations of outside conditions and indoor conditions in the lower left-hand corner of the above table produce a target superheat less than 5°F. When this occurs, substantial undercharge can be detected (a substantially undercharged air conditioner will have an actual superheat over 10°F). In that situation refrigerant can be added until the superheat drops to less than 10°F. However when the target superheat is less than 5°F overcharge cannot be detected with superheat alone. A total of 698 of the 13,258 tests in this study (5%) were tested when the target superheat was less than 5°F and the actual superheat was less than 10°F.

The superheat method is less friendly to the HVAC technician than the method used for Thermostatic Expansion Valves (see below). As time elapses during the charge adjustment procedure, the conditions both outside and inside the building can change and must be re-measured, making the target superheat a "moving target".

Thermostatic expansion valves (TXV). Recently manufactured, higher efficiency AC units typically have a thermostatic expansion valve (TXV). The TXV modulates based on outdoor conditions and system load. For TXV systems, CheckMe!® uses the subcooling method. Subcooling is the difference between the condenser saturation temperature and the liquid line temperature. The target subcooling value is often provided by the manufacturer (Carrier Corporation 1994). Unfortunately, many TXV systems are not marked with target subcooling information. Under these conditions technicians use a default target subcooling.

Airflow Diagnosis

Airflow is rarely tested in either residential or small-commercial AC systems. The CheckMe!® protocol uses the temperature split method as promulgated by Carrier Corporation (Carrier Corporation 1994). This method provides a quick check to see if airflow is likely to be outside a reasonable lower limit. The technician performs the test simultaneous with testing the charge using one of the methods described above. The technician measures the dry-bulb temperature drop across the evaporator coil and the return plenum wet-bulb temperature using a thermocouple probe with a wet wick.

The temperature split method is a qualitative airflow indicator that fits easily into technicians' standard diagnostic tests. The method is based on the fact that the air conditioner has a cooling capacity limited by its design. Given that limitation the temperature split (drop) across the evaporator coil is given by the formula: Temperature Split °F = Sensible Capacity btuh / (1.08 x cfm).

Given this relationship only low airflow will give higher than expected temperature split. The generally accepted limit for low airflow is 3°F above the expected temperature split. Examination of the above equation also shows that lower than expected temperature split will be caused by either higher than expected airflow (unlikely) or low sensible capacity.

A condensed Maximum Temperature Split Table is displayed in Table 2. It is derived from the Carrier Corporation charging procedures and their required superheat calculator (Carrier Corporation 1994, 1986). The table shows the upper limit of temperature split (3°F above the expected temperature split). Under the most common conditions temperature splits above this value will indicate airflows below 350 cfm per ton (between 360 cfm and 300 cfm per ton for condenser air entering temperatures between 85°F and 105°F).

Table 2. Maximum Temperature Split

Return Air Dry–Bulb (ºF)	Return Air Wet-Bulb (ºF)												
	50	**52**	**54**	**56**	**58**	**60**	**62**	**64**	**66**	**68**	**70**	**72**	**74**
70	23.9	23.6	23.1	22.5	21.7	20.7	19.5	18.2	16.7	14.9	13		
72	24.9	24.7	24.2	23.6	22.8	21.8	20.6	19.3	17.7	16	14.1	12	
74	26	25.8	25.3	24.7	23.9	22.9	21.7	20.4	18.8	17.1	15.2	13.1	
76	27.1	26.9	26.4	25.8	25	24	22.8	21.5	19.9	18.2	16.3	14.2	11.9
78	-	-	27.5	26.9	26.1	25.1	23.9	22.5	21	19.3	17.4	15.3	13
80	-	-	-	28	27.2	26.2	25	23.6	22.1	20.4	18.5	16.4	14.1
82	-	-	-	-	28.2	27.2	26.1	24.7	23.2	21.5	19.6	17.5	15.2
84	-	-	-	-	-	28.3	27.2	25.8	24.3	22.5	20.6	18.6	16.3

Source: California Energy Commission 2001. Upper limit of temperature split

The above table is based on the estimated sensible capacity of the air conditioner based on the return wet and dry bulb temperatures. Since that sensible capacity estimate does not take into account the condenser air entering temperature, it is designed to provide a wide range of acceptable values. The acceptable values of temperature split are widened by the uncertainty in whether the measured temperature split is truly representative of the average temperature split of all the airflows through the coil and whether the unit is properly charged with refrigerant. The temperature split method works best with technicians who know its limitations and are diligent at obtaining representative temperatures as well as repeating the measurements when the refrigerant charge is correct. The temperature split method can also be improved through more sophisticated estimation of the sensible capacity that includes the effect of the condenser air entering temperature and correcting the algorithms for return dry bulb and wet bulb temperatures[5]. Improved estimates exist and were originally used in early

[5] See Temperature Split Discussion section.

versions of the CheckMe!® system[6]. In order to conform to the new California Title 24 regulations and the manufacturers' recommendations this data set has been analyzed using the standard temperature split method as defined in the Title 24 Standards (California Energy Commission 2001).

There are at least two methods that provide more accurate measurements of airflow across the evaporator coil. These are the Duct Blaster® method and the Trueflow™ method (The Energy Conservatory 2001a, 2001b). The authors prefer both of these methods because they measure the flow immediately up or downstream of the coil. The Trueflow™ method is the easier of the two, but the measuring device is only recently available.

When either of two methods above is used to measure the airflow an average of 70% of the units show airflow below 350 cfm per ton (Neme et al. 1999). The temperature split method used here on the other hand identifies only 21% of the units as having low airflow. This is not a direct comparison on the same units. Since more accurate methods find a 70% failure rate, we estimate that the best the temperature split method can do is spot 30% (21%/70%) of the units with airflow below 350 cfm per ton. A further discussion of the temperature split method as it now exists is in the Temperature Split Discussion section.

System Considerations

Since its initial introduction in 1998, use of CheckMe!® has increased markedly, from about 200 test runs in its first year to more than 6,000 test runs between September 2001 and February 2002. This increase is due in large part to contractor incentive programs sponsored by the California Energy Commission (CEC) and several California electric utilities (Table 3). The CEC incentive program began on August 31, 2001 and is scheduled to run through September 30, 2002. That program will address more than 12,000 residential and 18,000 light commercial AC systems.

HVAC contractors have begun using CheckMe!® on systems that do not qualify for inclusion in an incentive program. These non-program related system tests account for about 4% of the systems in this analysis.

Table 3. CheckMe! Units and Associated Incentive Programs

Program Sponsor	Residential	Commercial	Number of systems in this study
California Energy Commission	1,728	3,130	4,858
Utility sponsored programs	6,629	1,199	7,828
Non-program Contractor Use	516	56	572
Total	8,873 (67%)	4,385 (33%)	13,258

Source: CheckMe! Data Base 2002

[6] Further improvements are possible using these data.

System Characteristics

Beginning October 2001 the CheckMe!® program began collecting make, model number, and capacity information. These data provide an initial estimate of the characteristics within the database.
Table 4 shows the capacity distribution of units treated since the capacity data has been collected.

Table 4. Air Conditioner Nominal Nameplate Capacity Distribution

AC Nominal Capacity Bin (btuh) 12,000 btuh = 1 ton	Residential Percentage	Commercial Percentage
0-12000	0	0.6
12001-24000	11.3	12
24001-30000	12	10.8
30001-36000	25.3	14.5
36001-42000	12.8	7.4
42001-48000	24	15.8
48001-54000	0.7	0.6
54001-60000	13.3	22.6
60001-72000	0.6	4
72001-84000	0	3
84001-96000	0	1.5
96001-120000	0	4.9
120001-240000	0	2.7

Source: CheckMe! Data Base 2002

System Repair Data

The 13,258 residential and light commercial AC systems in this analysis were tested between January 2000 and mid-February 2002. Of the 8,873 residential systems tested, 5,776 (65%) required repairs. Of the 4,385 light commercial systems tested, 3,100 (71%) required repairs. After repairs were attempted, systems were retested to determine whether repairs had been successful. A summary of system test and repair totals appears in Table 5.

Table 5. System Test and Repair Totals

	Systems	Systems in Need of Repair	Repairs Attempted (% of needed)	Successful Repairs (% of attempted)
Residential	8,873	5,776 (65%)	4,280 (74%)	3,924 (92%)
Commercial	4,385	3,100 (71%)	2,469 (80%)	2,257 (91%)
Total	13,258	8,876 (67%)	6,749 (76%)	6,181 (92%)

Source: CheckMe! Data Base 2002

A total of 5,776 or 65% of residential systems were identified as needing a correction to refrigerant charge or airflow, or both. Unsuccessful repairs were generally attributable to low evaporator airflow problems that could not be immediately corrected.

Problems with Refrigerant Charge

Initial diagnostic tests on 13,258 units showed 57% of the systems were outside specification for refrigerant level. Table 6 summarizes system charge and repair information for these data.

Table 6. System Charge Condition and Repair

	Systems	Systems identified in need of charge repair	Charge repairs attempted (% of needed)	Charge Corrected (% of repairs attempted)	Charge Improved (% of repairs attempted)
Residential	8,873	4955 (56%)	3955 (80%)	3650 (92%)	222 (6%)
Commercial	4,385	2642 (60%)	2221 (84%)	1931 (87%)	259 (12%)
Total	13,258	7597 (57%)	6176 (81%)	5581 (90%)	481 (8%)

Source: CheckMe! Data Base 2002

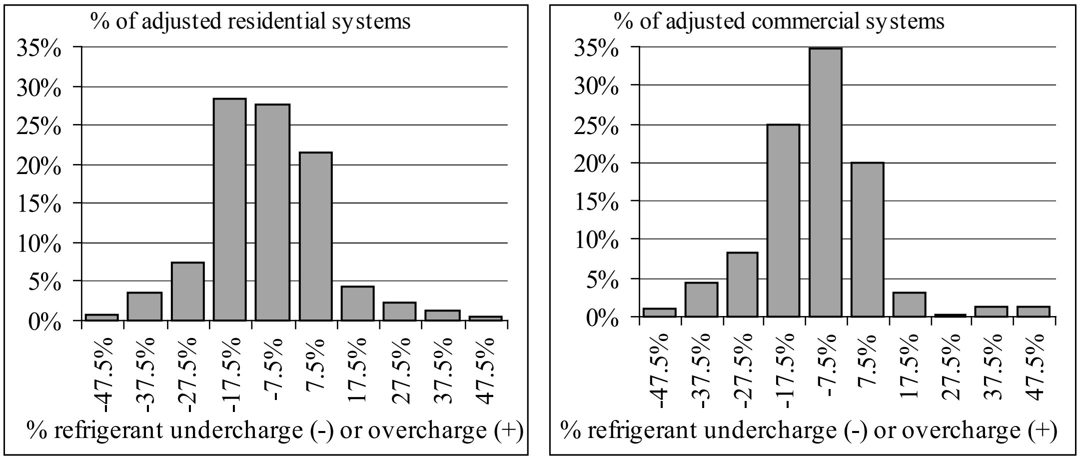
Overall 57% of the systems were positively identified as in need of repair to bring the refrigerant level within specification. The systems in need of repair include 504 fixed metering device systems that were tested under conditions where the target superheat was less than 5°F[7]. These systems showed excessive superheat indicating undercharge. Four hundred and eighty one of these systems had refrigerant added sufficient to bring their superheat to less than 10°F.

When charge repairs were attempted they were extremely successful (90% brought within specification and another 8% significantly improved). For systems that were undercharged when initially tested, the average amount of refrigerant added was 16 ounces. For systems that were overcharged, the average amount of refrigerant removed was just under 14 ounces.

In late October 2001, Proctor Engineering Group started gathering nameplate refrigerant charge. These data enable an estimate of refrigerant charge errors by percentage of correct charge. Figure 1 shows the distribution of charge adjustment for 405 residential units. Figure 2 shows the distribution of charge adjustment for 316 commercial units.

[7] A total of 1202 systems were tested under conditions that produced a target superheat of less than 5°F. Six hundred and ninety eight of those systems had actual superheat readings of less than 10°F and were not adjusted.

Figure 1. Refrigerant Level Errors a) Residential b) Commercial



Source: CheckMe! Data Base 2002

PEG is aware that some of the technicians who perform CheckMe!® tune-ups already have corrected the refrigerant charge prior to calling in their initial test. Examination of data patterns has revealed this tendency, and PEG is making an effort to get the technicians involved to call in their initial data as the system was originally found. As a result, the number of systems with correct charge on the initial test is overstated in this data set.

Charge Differences Between Metering Devices

Table 7 displays the distribution of metering devices in this study.

Table 7. Metering Device Distribution

	Non-TXV	TXV	Lennox TXV
Residential	82%	16%	2%
Commercial	92%	7%	1%
Total	85%	13%□	2%

Source: CheckMe! Data Base 2002

The majority of the units in the field have fixed metering devices. These units also are the most likely to be diagnosed as mischarged as shown in Table 8. TXVs are less likely to be diagnosed as mischarged. This could be because TXV units are less often mischarged, or because the subcooling diagnostic is less sensitive to charge errors than the superheat diagnostic used on non-TXV systems.

Table 8. Correct Charge on Initial Diagnosis (by Metering Device)

	Non-TXV (superheat)	TXV (subcooling)
Residential	40%	54%
Commercial	38%	53%
Total	39%	54%

Source: CheckMe! Data Base 2002

Both metering devices can be charged to within manufacturer's specifications with a reasonable amount of effort. Ninety eight percent of both TXV and non-TXV[8] systems could be charged properly when repairs were attempted.

Problems with Airflow Across the Inside Coil

Table 9 shows problems and success rates on airflow. Out of 13,258 initial tests, 2,751 (21%) residential and commercial units were diagnosed as having low airflow across the inside coil. Of the 2,751 units identified with low airflow, repairs were attempted on 2,000. Tests after the repairs showed 1,777 units had been brought to acceptable airflow levels. Dirty filters, fouled coils, dirty blower wheels, or incorrect blower speed settings usually cause low airflow. A restrictive duct system will also cause the problem. Filter replacements and opening registers are simple repairs and virtually always authorized. When the costs increase (such as adding an additional return) the authorizations for repairs decrease.

Table 9. Airflow Across the Inside Coil

	Systems Tested	Systems with Low Airflow (% of Systems)	Attempted Repairs (% of Systems with low airflow)	Successful Repairs (% of Attempts)
Residential	8,873	1,666 (19%)	1,353 (81%)	1,198 (89%)
Commercial	4,385	1,085 (25%)	647 (60%)	579 (89%)
Total	13,258	2,751 (21%)	2,000 (73%)	1,777 (89%)

Source: CheckMe! Data Base 2002

Commercial systems have more airflow problems than residential systems and the repairs are less likely to be authorized. Most commercial buildings are not occupied by the party responsible for covering the cost of the repairs making immediate approval for the repair less likely.

For both residential and commercial units if repairs are attempted they are almost 90% successful. .

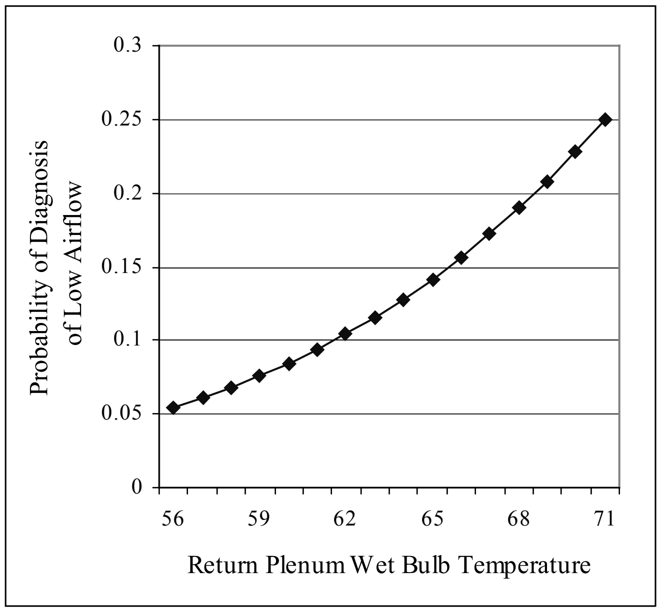
Temperature Split Discussion

There is much discussion concerning methods of measuring air handler airflow or diagnosing low evaporator airflow (Palmiter & Francisco 2000; Wray & Sherman 2001; Wray, Walker & Sherman 2002; Wray et al. 2002). The simplest method, most readily integrated into HVAC technicians standard procedure is the temperature split method. Aside from the caveats mentioned in the Airflow Diagnostics section of this paper, the analysis of the CheckMe!® data shows biases in the results when the standard temperature split table (Table 2) is used. A logistic regression of the airflow diagnostic data from the final test sets

[8] Excluding the 10% of the non-TXV units where testing could not conclusively eliminate the possibility of overcharging

where the charge has been corrected shows biases associated with the return plenum wet and dry bulb temperatures. These biases are in addition to the condenser air entering temperature bias pointed out earlier. Figure 2 illustrates one bias in the low airflow diagnostic for post repair testing[9]. Note that the unit is three times as likely to be diagnosed as having low airflow if the return plenum wet bulb temperature is 66°F compared to a return wet bulb of 56°F. The temperature split method needs to be improved through more sophisticated estimation of the sensible capacity that includes the effect of the condenser air entering temperature and correcting the algorithms for return dry bulb and wet bulb temperatures.

Figure 2. Low Airflow Diagnosis Bias



Source: CheckMe! Data Base 2002

Climate Considerations and Indoor Humidity

One of the nagging questions in analyzing the actual performance of air conditioners is scarce information about the indoor (return plenum) conditions when they operate. These data give us a unique opportunity to look at the return plenum conditions when the technician is there to test the air conditioner. These data are extensive but they cover limited geographic range. We have limited the analysis to units in California. The areas in this study have hot, dry summer climates.

These data indicate that residential systems have higher interior moisture content than commercial buildings. As shown in Table 10, the mean absolute humidity ratio in the return air is 0.0097 (lbs/lb of dry air) for residences. This translates to an indoor relative humidity of about 45% at 80°F. Corresponding data for commercial buildings shows a humidity ratio of 0.0089 (lbs/lb) which is about 41% Rh at 80°F. The lower moisture levels in commercial structures may be a reflection of commercial operations running their air conditioners when some residences do not.

[9] The same biases are shown in the initial tests and tests where the refrigerant charge has not been corrected.

Table 10 shows the return plenum absolute humidity ratios in the initial tests, which is after at least 15 minutes of run time. This table makes no distinction with respect to the outdoor conditions at the time of test.

Table 10. Average Indoor Humidity Ratios by California Climate Zone

California Climate Zone	Residential Mean Humidity Ratio (lbs/lb dry air)	Number of Residential Systems Tested	Commercial Mean Humidity Ratio	Number of Commercial Systems Tested
6	0.0097	237	0.0096	175
7 *	0.0100*	971	0.0092*	462
8 *	0.0104*	332	0.0098*	116
9	0.0094	2093	0.0091	853
10 *	0.0098*	3175	0.0088*	1197
12	NA	None	0.0084	397
13 *	0.0094*	391	0.0088*	520
14	0.0076	102	0.0077	92
15	0.0095	855	0.0099	82
All Zones Combined *	0.0097*	8156	0.0089*	3894

* Statistically significant difference between residential and commercial humidity ratios at the .05 level.
California Climate Zone Descriptions (California Energy Commission 1998)
Source: CheckMe! Data Base 2001

The next table, Table 11, is restricted to units that had both initial and final tests within the same condenser air entering temperature bin. The initial tests are all conducted after at least 15 minutes of run time. The second tests are conducted after repairs and after an additional 15 minutes of run time.

Table 11 shows an expected drop in return temperatures and humidity ratios due to the operation of the air conditioner during the repair and test sequence. When testing above 75°F, residential humidity ratios always average above 0.01 lbs. per lb. of dry air. This level was higher than our expectation. It is also notable that the return temperatures rise as the outdoor temperatures rise.

Conclusions

- Contractors are willing to put forth the effort necessary to make sure air conditioning systems are operating within manufacturers' refrigerant charge specifications, once they are taught to do it correctly and are held to an easy means of checking their work.
- 65% of the residential systems tested required repairs.
- 71% of the light commercial systems tested required repairs.
- 57% of the systems were outside specification for refrigerant level.

Table 11. Return Plenum Humidity and Temperature by Condenser Air Entering Temperature

Condenser Air Temp Bin		Residential Units		Commercial Units	
		Initial Test	Second Test	Initial Test	Second Test
71°F - 75°F	Humidity Ratio (lbs per lb)	0.0098	0.0096	0.0093	0.0092
	Return Plenum Dry Bulb °F	70.93	70.35	71.67	71.05
	Number of Units	643	643	402	402
76°F - 80°F	Humidity Ratio	0.0103	0.0101	0.0093	0.0092
	Return Temp.	73.44	72.81	73.65	72.72
	N units	651	651	362	362
81°F- 85°F	Humidity Ratio	0.0104	0.0103	0.0095	0.0094
	Return Temp.	74.75	74.07	75.43	74.47
	N units	449	449	267	267
86°F - 90°F	Humidity Ratio	0.0107	0.0105	0.0094	0.0093
	Return Temp.	76.94	76.22	77.23	76.51
	N units	363	363	172	172
90°F - 95°F	Humidity Ratio	0.0106	0.0103	0.0098	0.0097
	Return Temp.	78	77.13	77.19	76.4
	N units	172	172	100	100
96°F - 100°F	Humidity Ratio	0.0101	0.01	0.0095	0.0096
	Return Temp.	79.69	78.4	78.85	77.61
	N units	107	107	54	54
All Above	Humidity Ratio	0.0103	0.0101	0.0094	0.0093
	Return Temp.	74.15	73.47	74.34	73.52
	N units	2385	2385	1357	1357

Source: CheckMe! Data Base 2002

- Above 76 degrees outdoor temperature, residential humidity ratios average above 0.01 lbs. per lb. of dry air.
- The current temperature split method of identifying units with low airflow is flawed and should be revised to eliminate biases associated with the conditions at the time the measurements are made.

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