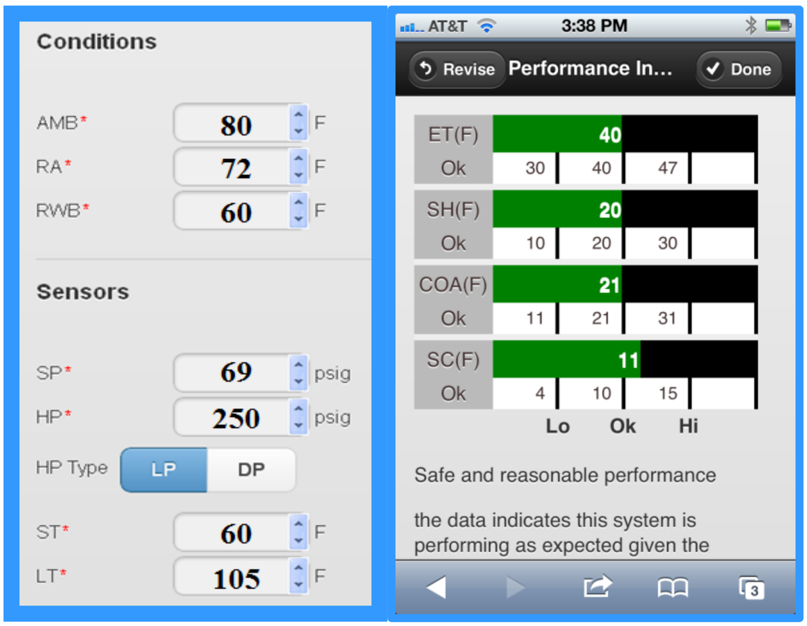
Residential Quality Maintenance Unitary Air Conditioner Fault Detection & Diagnostics

ET Project Number: ET11PGE5261



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ABBREVIATIONS AND ACRONYMS

ACCA	Air Conditioning Contractors of America
ANSI	American National Standards Institute
ATS	PG&E Applied Technology Services
CEC	California Energy Commission
EM&V	Evaluation Measurement and Verification
FDD	Fault Detection and Diagnostics
FDSI	Field Diagnostic Services, Inc.
HEEMS	HVAC Energy Efficiency Maintenance Study (Reference 1)
HVAC	Heating, Ventilation and Air Conditioning
MMMF	Multiple Metric / Multiple Fault protocol
PIER	Public Interest Energy Research
PG&E	Pacific Gas and Electric Company
QM	Quality Maintenance
PDA	Personal Digital Assistant
RCA	Refrigerant Charge and Airflow (or Adjustment)
Title-24 or T24	CEC Building Energy Efficiency Standards for Residential and Non-Residential Buildings

FIGURES

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EXECUTIVE SUMMARY

Quality Maintenance (QM) of residential heating ventilation and air-conditioning (HVAC) systems is defined by ANSI/ACCA Standard 4 (ACCA4)[1]. To implement the standard, a technician needs to take measurements and do the analysis necessary to perform fault detection and diagnostics (FDD). In support of QM, a multiple metric / multiple fault (MMMF) protocol is set forth. The required accuracies of instruments used to make measurements to calculate refrigeration system performance metrics are established. These were used to choose a commercially-available software tool for development into a native software technician tool that runs on popular mobile smart devices such as phones and tablets.

PROJECT GOAL

The project goal is to support the transformation of the residential HVAC market to be QM based using ACCA4 by providing technicians the FDD methodology needed to service existing unitary air conditioning systems.

PROJECT DESCRIPTION

Evaluation Measurement and Validation (EM&V) studies on Refrigerant Charge and Airflow or Adjustment (RCA) identified issues of measurement uncertainty and improper service procedures that result in misdiagnosis and incorrect actions by the technician to the detriment of system performance. To address the identified problems, a matrix of metrics and faults was developed and used as the basis for selecting the FDD method that on which to build the technician software tool SAMobile by Field Diagnostic Services Inc. (FDSI)[2] for ACCA4 implementation.

PROJECT FINDINGS/RESULTS

SAMobile was developed and issued to contractors and their technicians participating in the PG&E Residential HVAC QM program in May 2012. A list of instruments meeting the accuracy requirements of the QM program was included in the program manual in September 2011. Subsequent experience shows that the software tool supports technicians in the performance of QM. As of the end of 2012, software usage is ramping up and undergoing improvements and fixes that technicians and program implementers have requested. The movement from smart phones to tablets by contractors and technicians is supported and will facilitate ease of use by technicians and interactions with customers.

PROJECT RECOMMENDATIONS

1. Constant improvement is necessary in software. SAMobile is being improved with feedback from users and this will need to continue. As ACCA4 is revised, the software will need to be updated.

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[1] Air Conditioning Contractors of America, Standard Number: ANSI/ACCA 4 Maintenance of Residential HVAC Systems – 2007 https://www.acca.org/store/product.php?pid=268

[2] https://www.fielddiagnostics.com/products/samobile

2. Laboratory work is needed to provide instrumentation accuracy assessments that will allow program implementers to improve the lists of qualified instruments. There are two parts to accurate measurements: sensor and instrument calibrated accuracy, and accuracy of field measurements. The calibrated accuracy is bench test based. Field measurement accuracy is based on the protocols followed by the technician such as the placement of temperature sensors. Laboratory work is needed to further refine analysis of multiple faults commonly found in existing systems.

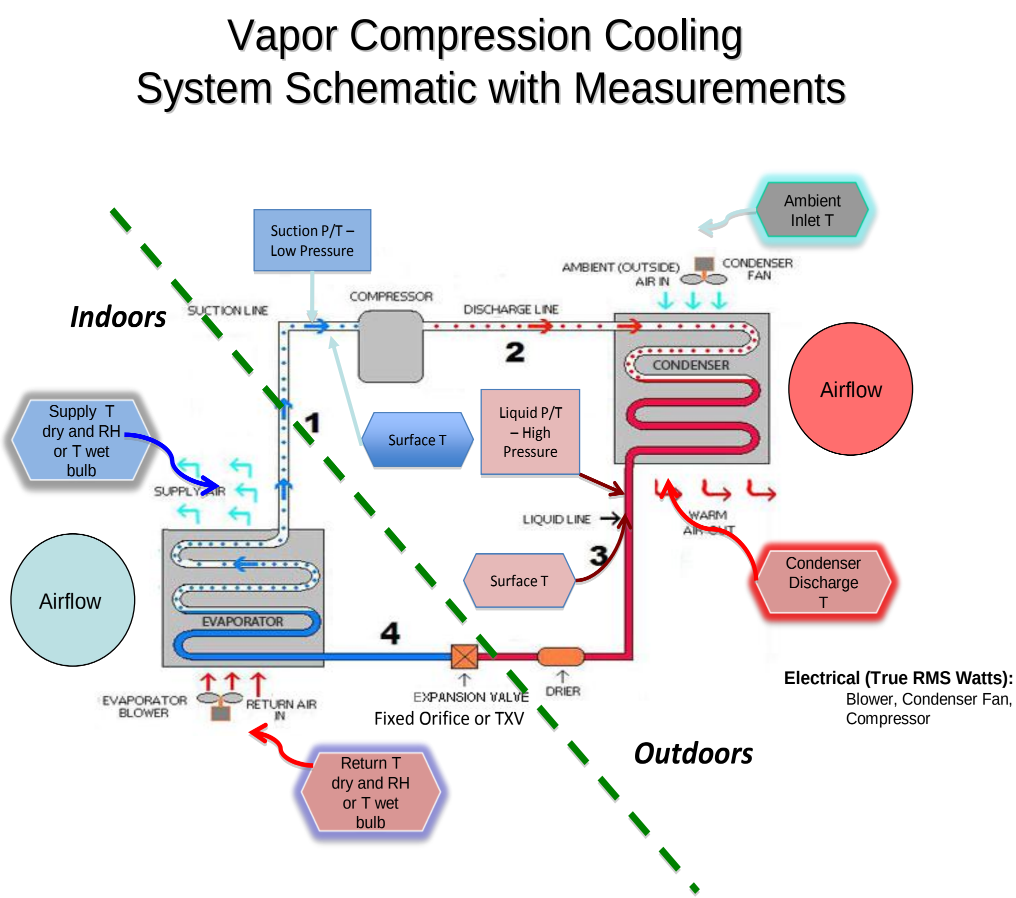

FIGURE 1. UNITARY AIR CONDITIONING CYCLE[3]

[3] Hunt, HEEMS P.10

INTRODUCTION

Market transformation and energy efficiency can be achieved with a utility rebate program that is based on HVAC contractors and taken to customers by QM contractors. This project addresses one of the key technical barriers to success. The simple paper-based checklist used by technicians cannot cover all of the items on the ACCA4 checklist, and there is no way to manually do the refrigeration system Fault Detection and diagnostics (FDD). Customers are coming to expect a higher level of service in all of their dealings. Service businesses generate professional looking reports for customers who buy tires, get an oil change, have car maintenance performed, etc. These can be hard copy, but more and more are electronic files that are emailed to the customer. SAMobile provides a path to upgrading HVAC service work.

Starting with the requirement of delivering to the technician immediate feedback for FDD, a smart device of some type must be used. In early generations of this type of tool, personal digital assistants (PDAs) were used; and while they function adequately, they have limited display options and do not integrate into this and future generations of mobile devices using various operating systems. Thus, the SAMobile tool was developed as a native application that operates at customer sites without being connected to the Internet. When the technician does have access to the web remotely or at the office at the end of the day, the work is "synced" over the web. Any updates to the software are transmitted when the device is "synced". A web based portal is provided that has extensive reporting and quality control capabilities.

The instrumentation accuracy requirements were reviewed in light of the HEEMS report and the lab work by PG&E's Applied Technology Services. In addition a number of popular instruments were reviewed. As a result minor adjustments were made in requirements.

Since this project started, a California Energy Commission (CEC) Public Interest Energy Research (PIER) funded project with the New Buildings Institute has retained Purdue University Herrick Labs to review FDD tools. An early draft reviewed the RCA method used in the CEC Building Energy Efficiency Standards (commonly referred to as Title 24) found that:

> A case study was conducted in which the RCA protocol was evaluated. It was found to perform poorly, with unacceptable levels of *False Alarms*, regardless of the threshold used to differentiate faulted from unfaulted performance. [4]

It may be possible that FDD for new systems that are correctly installed can be simplified as is done by Title 24 because the heat exchangers (condenser on high side and evaporator on low side)are new and clean. But to assume that quality installations occur is not realistic. Another PIER study[5] found significant installation problems that give credence to the concern that a new system can and often will have multiple faults making it necessary to use multiple metrics to make an accurate diagnosis.

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[4] Personal communication of early draft report Summer 2012

[5] Proctor, *Efficiency Characteristics and Opportunities for New California Homes*. California Energy Commission. Publication number: CEC-500-2012-062

The scope of this project is to support the implementation of ACCA4 by PG&E. There are many questions that remain and additional lab and field work is needed. With the support from this project and other efforts the Residential HVAC QM program has been successfully launched and as of December 2012 is making steady progress.

BACKGROUND

Central forced-air vapor-compression refrigeration cooling became standard practice in the 1980s even in areas that previously had no cooling or had direct evaporative cooling. From the beginning Original Equipment Manufacturers (OEM) provided detailed installation instructions that were not rigorously followed. In residential dwellings split systems dominate. As shown in Figure 1 there is an Indoors and Outdoors part of the system. In a packaged unit both are in one sheet metal box that is roof or ground mounted. In a split system, the indoor coil is mounted to receive the airflow from the furnace or air handler blower. In a heat pump system, the same refrigerant heat exchanger provides either heating or cooling and is often with the blower in an air handler. In the field there are a large (insulated, cold suction line) and small (warm liquid line) copper tube forming a refrigerant line set. The technician brazes the tubing at each end to the evaporator and condenser coils. This is not a simple task and requires a number of steps all of which must be performed correctly. Refrigerant leakage, tubing obstruction, non-condensing vapor, and debris can be introduced which become faults immediately.

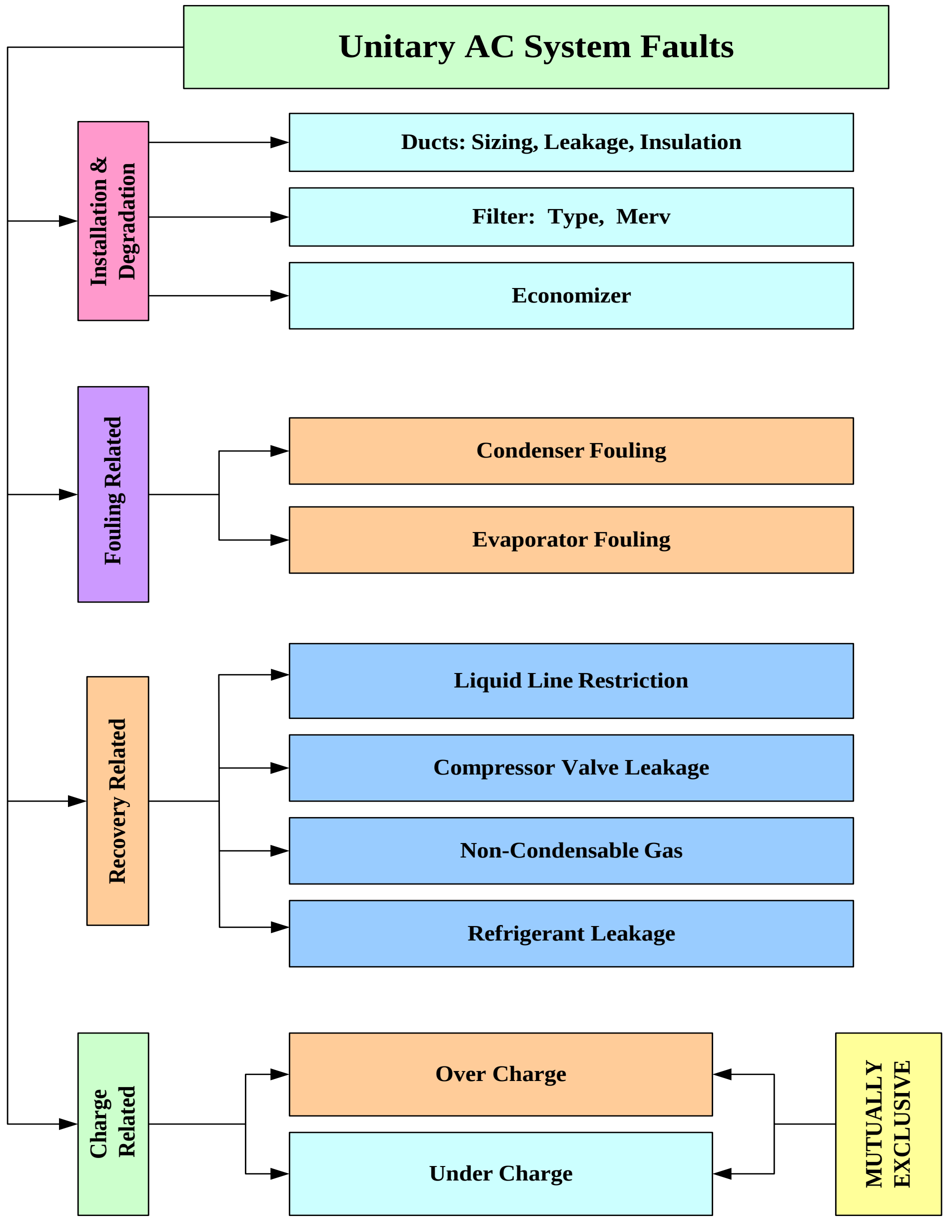

FIGURE 2 FAULTS[6]

Going from top to bottom in Figure 2 are the different faults that can occur. Some are present from the beginning due to incorrect installation practices many of which are in violation of Title 24. Fouling develops to a greater or lesser extent based on local conditions. Faults that require recovery of refrigerant, repairs, and then recharging can take the better part of a day and are therefore expensive. Compressor degradation occurs naturally over years of operation. But others are there in the beginning. Charge faults from over charging are from misdiagnosis of the charge required in the initial installation but can also be from technicians “topping off” the charge during maintenance visits. Under charging can be from inadequate charging at time of installation, or refrigerant release during maintenance, or from leakage.

[6] Hunt, *HEEMS*, p. 11

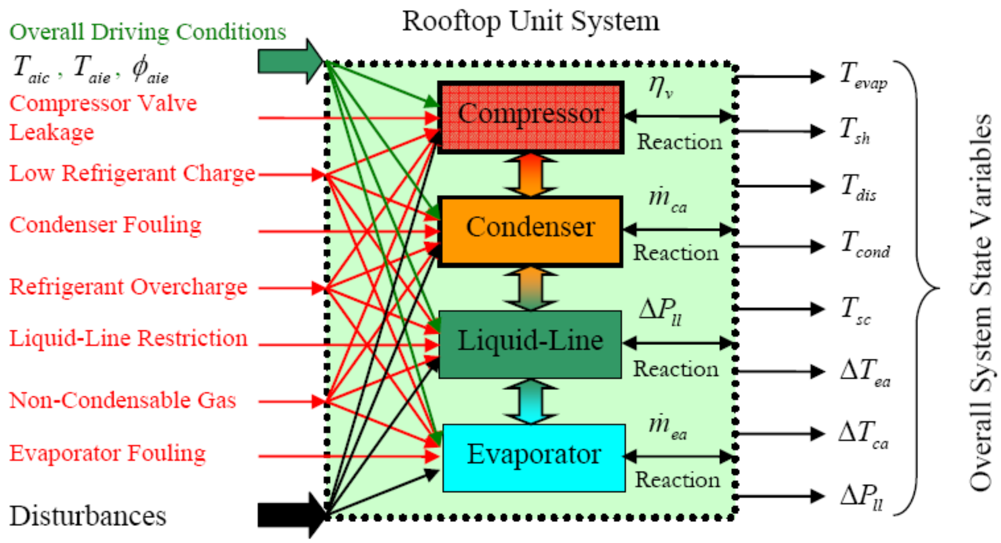

FIGURE 3. FAULT INTERACTIONS[7]

Figure 3 displays the complex interaction between the faults and the system and the system metrics. This visual makes it clear that simple manual methods will not perform the analysis needed. Even with computer algorithms faults present in ways that require an iterative process that rules out first things first. Thus a diagnostic result will contain multiple possible causes. SAMobile requires that the technician measure and enter into the software seven (7) variables using instrumentation that is readily available to technicians. In the last 5 years high quality, reasonably priced, digital devices have made it possible for technicians to make better measurements.

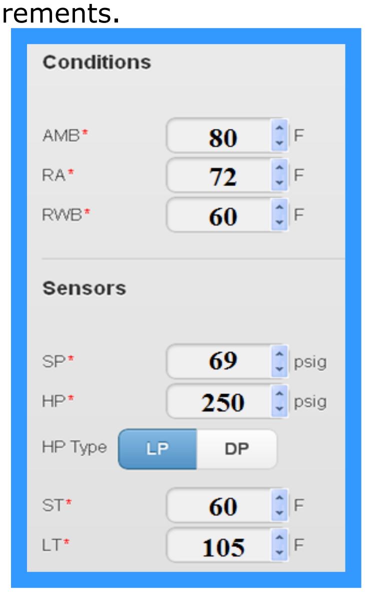

FIGURE 4. REFRIGERANT SYSTEM SERVICE FIELD MEASUREMENTS – SAMOBILE SCREEN SHOT

After adequate airflow of 350 cfm/ton or more is established the technician measures 7 variables shown in Figure 4. It is important that accuracy is achieved although field

[7] H. Li, *Unified FDD,* 2004, p. 51

accuracy cannot be as good as what is achieved in the lab. To add to the complexity the accuracy of the measurement when made on operating equipment must be known. Figure 5 is the table from the PG&E Residential HVAC QM program Contractors Manual.

Residential QM Measurement Accuracy & Calibration

9/7/2011

Measured Variables	Units	Accuracy Specification	Calibration Interval
Supply Air (Dry Bulb)	F	±1.8	Single Point – Weekly Multiple Point – Monthly
Return Air (Dry Bulb)	F	±1.8	Single Point – Weekly Multiple Point – Monthly
Outside Air (Dry Bulb)	F	±1.8	Single Point – Weekly Multiple Point – Monthly
Supply Air (Wet Bulb)	F	±1.8	Single Point – Weekly Multiple Point – Monthly
Return Air (Wet Bulb)	F	±1.8	Single Point – Weekly Multiple Point – Monthly
Suction Line (Dry Bulb)	F	±1.8	Single Point – Weekly Multiple Point – Monthly
Liquid Line (Dry Bulb)	F	±1.8	Single Point – Weekly Multiple Point – Monthly
Suction Pressure	PSIG	±1.0	Weekly
Discharge Pressure	PSIG	±3.0	Weekly
Duct Static pressure – Supply/Return	IWC	±0.02	Check zero before use Monthly Check
Static pressure – Evaporator Coil Inlet/Outlet	IWC	±0.02	Check zero before use Monthly Check
Static pressure – Filter Inlet/Outlet	IWC	±0.02	Check zero before use Monthly Check
Condenser Fan Volts (RMS)	% of reading	±3.0	Annually

Residential QM Measurement Accuracy & Calibration 9/7/2011			
Measured Variables	**Units**	**Accuracy Specification**	**Calibration Interval**
Condenser Fan Amps (RMS)	**% of reading**	**±3.0**	Annually
Compressor Fan Volts (RMS)	**% of reading**	**±3.0**	Annually
Compressor Fan Amps (RMS)	**% of reading**	**±3.0**	Annually
Blower Motor Volts (RMS)	**% of reading**	**±3.0**	Annually
Blower Motor Amps (RMS)	**% of reading**	**±3.0**	Annually
Charging Scale	**% of reading**	**±0.5**	Annually
CO sensor for Natural Gas Appliance Test (NGAT)	**PPM**	**±5**	Annually

TABLE 1. ACCURACY AND CALIBRATION CRITERIA

Table 1 was adapted from *HEEMS*[8] with minor changes to reflect the tools that are available to technicians. The resulting uncertainty in the four metrics of system performance is in Table 2. With probes that meeting the accuracy criteria about a three degree range around the measurement is expected. But using specifications from commonly used Contractor Instruments the range more than doubles.

Refrigerant System Metric °F	Accuracy Criteria Instruments	Contractor Instruments
Evaporating Temperature (ET)	± 1.40	± 3.20
Superheat (SH)	± 1.52	± 3.54
Condensing Over Ambient (COA)	± 1.70	± 4.21
Subcooling (SC)	± 1.70	± 4.21

[8] *HEEMS,* p. 56

TABLE 2. MEASUREMENT UNCERTAINTY[9]

It would be logical that an instrument and probe could be chosen that meets the criteria in Table 1 by referring to catalogue data but the data is both inconsistent and incomplete. What is needed is more research and the involvement with stakeholders such as manufacturers of HVAC instrumentation to give the true accuracy of the probes when used in the field. As a first step, Robert Davis[10] performed a bench test to assess the different surface temperature probes used to measure the temperature of refrigerant both liquid and vapor. A simple apparatus was set up to provide water circulating thorough copper tubing at a known temperature.

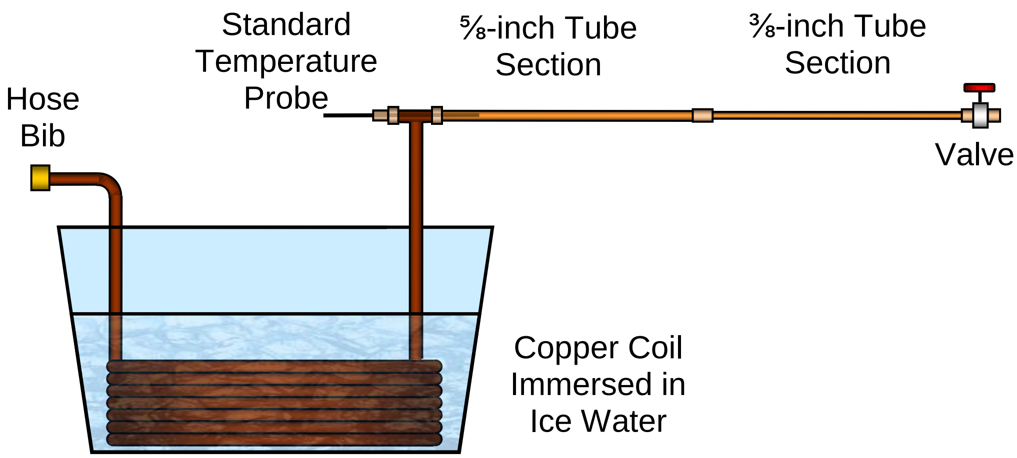

FIGURE 5. SCHEMATIC TEST SETUP[11]

Eleven (11) probes were assessed after being purchased from sources used by HVAC technicians. For each probe six (6) scenarios were run. The results are displayed in Figure 8 as a percent difference from the known temperature of the circulating water. It is instructive to note only in the case of the low temperature tap water (green bars, 4th from the left in each set of five) that the required 1.8 F is met if they are calibrated. From this it can be inferred that measurements of liquid line temperatures can meet the accuracy criteria. Measuring the ice bath water with probes that are not covered with insulation (red and pink bars, 1st and 2nd from the left in each set of five) presents difficulties that need to be addressed. The addition of insulation over the probes (blue bars, 3rd and 4th from the left) improved accuracy some of the most popular probes but still the accuracy criteria is not met. It was also found that the time each probe takes to have a steady reading varies widely to the point that it could impact the procedures of the technician.

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9 Adapted from *HEEMS*, p. 53

10 Davis, *Experimental Analysis of Tube Surface Temperature Measurements,* ATS Report #:491-07.6, 2007. Report embedded in Appendices

11 Davis, *Experimental*, p. 6

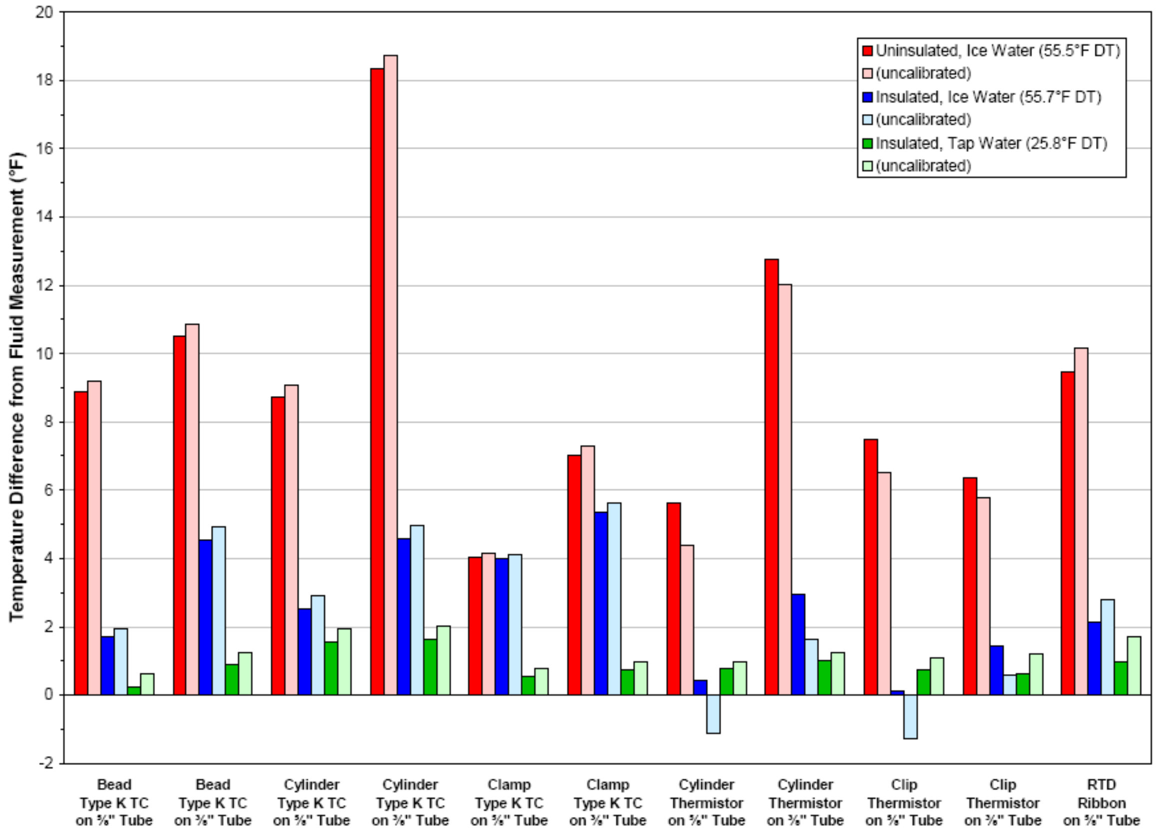

FIGURE 6. PIPE SURFACE-TO-FLUID TEMPERATURE DIFFERENCE[12]

The conclusion drawn from this work is that the lab work must be done to fully understand what is possible in the field with instruments and probes that technicians can buy and use reliably. Bench testing is a good start but testing on equipment operating in test chambers is needed. From this work best practices for probe placement, attachment, and insulation need to be developed. It is possible that the result will be that uncertainty levels will be closer to those in the "Contractor" column in Table 2.

Another problem area is calibration. Contractors and technicians rarely if ever calibrate instruments. Some will calibrate refrigeration gages using a service tank of refrigerant that has been stored at a fairly constant temperature. But sending instruments off to a calibration lab is not normal practice. Instruments and probes are used out of the box and then out of the bucket or tool bag where they are subjected to rough handling. Contractor bench top calibration protocols and equipment need to be developed and available at price points that are "reasonable." Until these research and testing projects are done the assessment of refrigeration system faults must be done with the knowledge of the uncertainty in the measurements. This leads to programs needing to take a whole HVAC system approach so that the customer is benefitted even if some of the measures are not optimized from a laboratory perspective.

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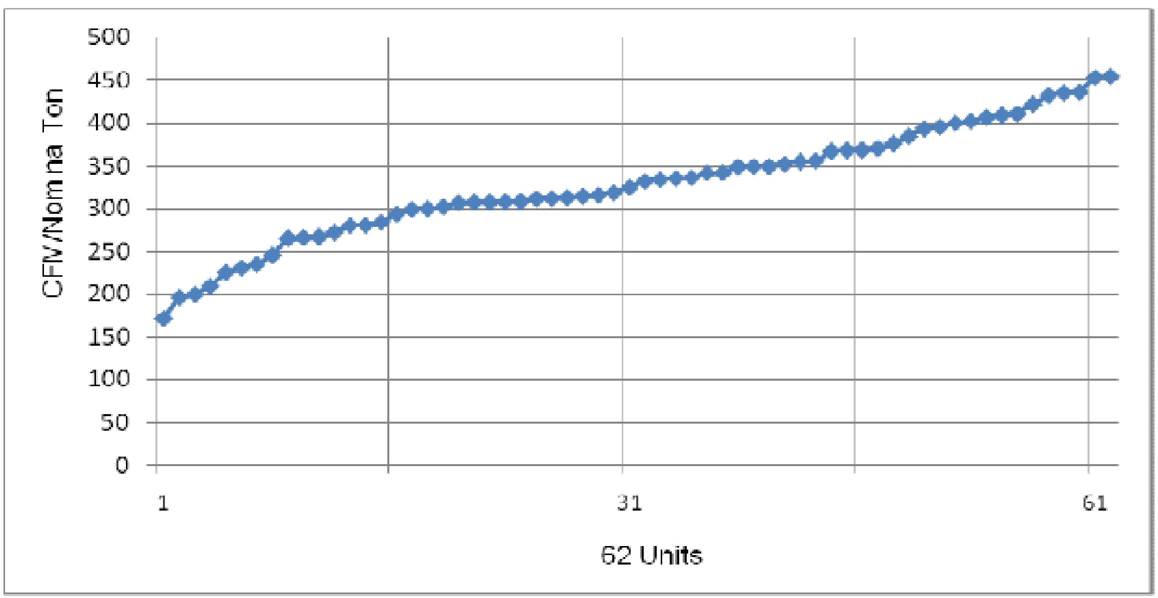
[12] Davis, *Experimental*, p.11

MULTIPLE METRIC MULTIPLE FAULT (MMMF) FDD

Low airflow in a central forced air ducted HVAC systems is a common problem. When it is low enough the coil can become a block of ice but is most cases reduced capacity is the problem. Sensible cooling (lowering of the dry bulb temperature) capacity can be reduced to the point that the customer calls for service reporting that the system is running but it is hot inside. The Original Equipment Manufacturer (OEM) minimum airflow is 350 cfm/ton of rated capacity. In a study for the CEC PIER program with 79 housing built to meet Title 24 standards the mean was 322 cfm/ton for systems that had not been in use for very long. A plot of data from 61 dwellings shows that more than half have low airflow. Without the use of good filters that are changed on a regular bases the starting airflow will drop significantly.

Figure 10: Cooling System Airflow



Source: Rick Chitwood

FIGURE 7. RANGE OF CFM/TON[13]

A refrigerant charge adjustment can be done that matches the charge to low airflow which results in the equipment operating at reduced capacity. The direct measurement of airflow is subject to uncertainty and difficult to do correctly. The Residential HVAC Quality Maintenance employs an Airflow Correction measure than combines filter capacity, return duct size, supply duct size, duct sealing, duct insulation and static pressure drop maximum through furnace or air handler. The MMMF software tool then uses the combination of four (4) metrics to help the technician diagnose an airflow volume problem. This diagnosis also serves to assess whether or not the coils are clean. A fouled condenser coil will display as a high pressure side fault and will be detected. The condenser coil may look clean especially

[13] Proctor, *Efficiency Characteristics and Opportunities,* p. 29

if water is sprayed in the direction of airflow and yet still be fouled. A fouled evaporator coil will usually not pass the maximum static pressure since it is most common to find a blanket of debris covering the coil.

A matrix of faults and diagnostics was developed from a wide variety on industry sources and set as the goal for MMMF software. No fault has just one variable that diagnoses the problem. When multiple faults are present then complexity and confusion rise. "High" and "Low" are relative to the range of allowed values. The expected range of each variable and metric is dependent on refrigerant type, type of refrigerant metering device, efficiency of the system, and the driving conditions under which it operates. This requires the use of software to empower the technician to act correctly.

Fault	Suction Pressure	Liquid Pressure	Condensing Over Ambient	Superheat TXV	Superheat Fixed Orifice	Subcooling TXV	Subcooling Fixed Orifice	Compressor Watts/Amps
Refrigerant Overcharge	High	High	High	Low	Low	High	High	High
Refrigerant Undercharge	Low	Low	Low	High	High	Low	Low	Low
Condenser Dirty Coil, Low Airflow, etc.	High	High	Low	Low	Low	Low	Low	High
Evaporator Dirty, Low Airflow, Dirty Filter, etc.	Low	Low	Low	Low	Low	High	High	Low
Liquid Line Restriction - clogged filter-drier, crimped line, orifice blocked, orifice too small, etc.	Low	Low	Low	High	High	High	High	Low
TXV Overfeed sensor bulb attachment and/or insulation, leaking valve seat	High	High	High	Low	N/A	Low	N/A	High
TXV Underfeed Sensor charge lost, movement frozen	Low	Low	Low	High	N/A	High	N/A	Low
Inefficient compressor	High	Low	High	High	High	High	Low	High
Non-Condensible in System	High	High	High	High	Low	Low	Low	High

TABLE 3. MATRIX OF FAULTS AND DIAGNOSTICS

EVALUATION WITH LABORATORY TEST DATA

Robert Davis has conducted tests on unitary HVAC equipment with and without faults being introduced at the PG&E ATS laboratory. These are embedded in the Appendices of this report. SAMobile runs were made to explore its MMMF FDD response to the data from 212 test runs.

Variables Tested at PG&E ATS HVAC Lab

Refrigerant	Expansion Device	Ambient Temperature °F	Return Dry Bulb	Return Wet Bulb	Charge	Airflow cfm/ton
R-22	Fixed	82	80	67	120%	450
R-410a	TXV	95		63	110%	400
		105			100%	350
		115			90%	250
					80%	200
					70%	
					60%	

TABLE 4. VARIABLES TESTED[14]

The focus of testing SAMobile is the data that combines the faults of incorrect charge and airflow. These were the major faults identified in 2001. Data from each of the laboratory runs were entered manually into SAMobile just as a technician would do and the outputs recorded.

The Residential HVAC QM program requires that the Airflow measure be completed before refrigerant charge can be assessed. This requires that corrections be made to bring airflow up to 350 cfm/ton based on the application of ACCA Manual D and Manual T procedures. The result will not be precise but allows the cfm/ton lab runs of 350 and higher to be considered as ones which SAMobile can be judged on for its practicality. A second program decision was to respect the lack of field measurement certainty and not expect charging to be known within 10% of the correct. The often referenced chart from Robert Davis reproduced as Figure 8) shows charge has the most impact when it is more than 20% low. High charge can damage equipment but has less of an impact on efficiency. Fixed orifice equipped systems are much more sensitive to charge levels but at the 20% from correct levels the results are within the uncertainty of field measurements.

[14] Airflow values are rounded to 50 cfm increments to simplify reporting without degradation of the testing of SAMobile

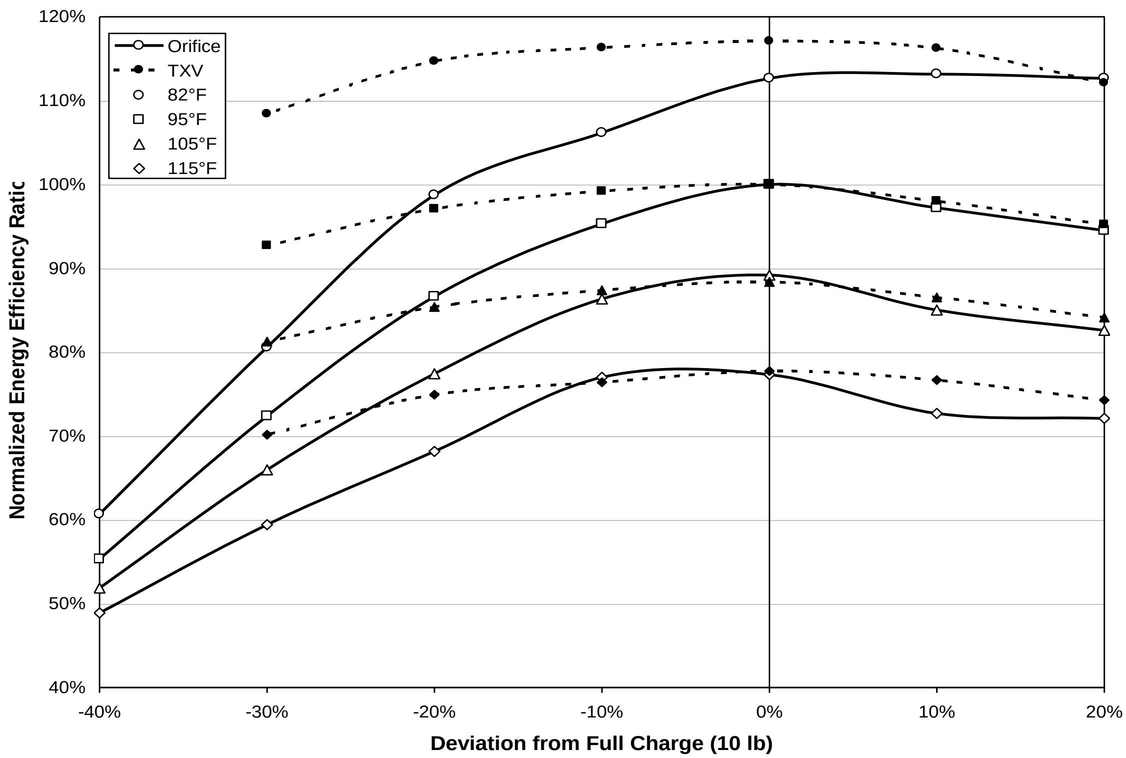


FIGURE 8. CHARGE AND AMBIENT TEMPERATURE IMPACTS ON EER[15]

An important feature of a diagnostic program is the directions given on the smart phone, tablet, or other device running the program.

[15] Davis, ATS 491-01.4, p. 22

FIGURE 9. SCREENSHOTS FROM SAMOBILE

On the left is an example screenshot showing a properly charged system showing **green** bars which appears as message "1" in the table below. On the right is an extremely undercharged system which has message "2B" displayed and shows **red** bars.

The menu of SAMobile diagnostic messages encountered when analyzing the 212 lab tests is:

Number	Message	Text
1	1	ACCEPTABLE/No repair needed: Safe and reasonable performance because the data indicates this system is performing as expected given the conditions entered. No further system diagnostics are required.
2	1A	ACCEPTABLE/No repair needed: Safe and reasonable performance because the data indicates this system is performing as expected given the conditions entered. No further system diagnostics are required. It is not recommended to adjust the SH to less than 5F.
3	1B	ACCEPTABLE/No repair needed: Safe and reasonable performance because the data indicates this system is performing as expected given the conditions entered. No further system diagnostics are required. It is not recommended to adjust the SH to the goal value.
4	2	DANGER/Leak Check and Repair: Add charge because this is a fixed orifice unit with high superheat.
5	2A	DANGER/Leak Check and Repair: Add charge because this is a fixed orifice unit with high superheat. It is not recommended to reduce the SH to less than 5F.
6	2B	DANGER/Leak Check and Repair: Add charge because this is a fixed orifice unit with high superheat and low subcooling.
7	2C	DANGER/Leak Check and Repair: Add charge because this is a fixed orifice unit with high superheat and low subcooling. It is not recommended to reduce the SH to less than 5F.
8	2D	DANGER/Leak Check and Repair: Add charge because this is a fixed orifice unit with a cold evaporator and high superheat.
9	2E	DANGER/Leak Check and Repair: Add charge because this is a fixed orifice unit with a cold evaporator and high superheat. It is not recommended to reduce the SH to less than 5F.
10	3	ALERT/Leak Check and Repair: Add charge because this is a TxV unit with low subcooling.
11	3A	ALERT/Leak Check and Repair: Add charge, if decreasing superheat can be tolerated (difficult diagnosis) because this is a TxV unit with low subcooling and superheat is already below the goal value and will decrease more if charge is added.
12	4	DANGER/Recover Charge: Recover charge because this is a fixed orifice unit with low superheat.
13	4A	DANGER/Recover Charge: Recover charge because this is a fixed orifice unit with a low superheat and high subcooling.
14	5	ALERT/Recover Charge: Recover charge because this is a TxV unit with high subcooling.
15	5A	DANGER/Recover Charge: Recover charge because this is a TxV unit with high subcooling.
16	6	DANGER/Tune up low side: Low-side heat transfer problem because this is a TxV unit with low ET and SH is less than goal. Consider increasing indoor airflow by replacing filters, cleaning fan, cleaning evap coil, adjusting fan belt, and/or opening registers.
17	6A	DANGER/Tune up low side: Cold evaporator with no obvious single explanation because evaporator temperature is low. Cold Evaporators are caused by either low charge, low-side heat transfer problem or liquid line restriction. There are other simultaneous issues clouding a single clear explanation.

TABLE 5. DIAGNOSTIC MESSAGES FROM SAMOBILE

A total of 72 diagnostic messages are possible which include items such as “measurements do not make physical sense” and “unfavorable test condition”. These have been developed to guide technicians in doing their work.

Fixed Orifice R-22 Tests

It is common to find residential systems with R-22 and fixed orifice expansion devices. Starting with 100% charge and 400 cfm/ton with four ambient temperatures and two return wetbulb temperatures the technician should the message "1" in Table 5. This is the case even though the EER measured in the lab varied from 12 to 7.5 showing the impact of ambient temperatures from 82 to 115 F.

Run #	Refrigerant	Expansion Device	Charge Level	Airflow (cfm/ton)	Outdoor Temp	Indoor Wet Bulb	Message	EER (Btu/wh)
29	R-22	Fixed	100%	400	82	67	1	12.0
30	R-22	Fixed	100%	400	95	67	1	11.0
31	R-22	Fixed	100%	400	105	67	1	10.0
32	R-22	Fixed	100%	400	115	67	1B	8.0
33	R-22	Fixed	100%	400	82	63	1	11.6
34	R-22	Fixed	100%	400	95	63	1	10.0
35	R-22	Fixed	100%	400	105	63	1	8.7
36	R-22	Fixed	100%	400	115	63	1	7.5
37	R-22	Fixed	100%	450	95	67	1	11.2
38	R-22	Fixed	100%	350	95	67	1	9.9
39	R-22	Fixed	100%	250	95	67	4	9.1
40	R-22	Fixed	100%	450	95	63	1	10.5
41	R-22	Fixed	100%	350	95	63	1	9.1
42	R-22	Fixed	100%	250	95	63	1B	8.1

TABLE 6. LAB RUNS FOR FIXED ORIFICE R-22 FULL CHARGE

When airflow is varied from 350 to 450 cfm/ton a message "1" is delivered. The exception is the case of the outdoor temperature being 115 when a "1B" message is given to assure the technician that despite a metric being out of range no change should be made.

The low airflow of 250 cfm/ton generates a "1B" when the return air is dry which puts a lower thermal load on the evaporator coil producing a low superheat. In the case of the same 250 cfm/ton with more humid return air the evaporator coil has even lower superheat and message "4" is displayed warning the technician to take action. The QM program implements Airflow Correction prior to doing the Refrigeration Service to minimize low airflow situations. It is significant that this new system with a correct charge, clean heat exchangers, new compressor, and lab grade installation works over a wide range of airflow conditions. The EER is reduced to 7.5 but the system is in working order.

Run #	Refrigerant	Expansion Device	Charge Level	Airflow (cfm/ton)	Outdoor Temp	Indoor Wet Bulb	Message	EER (Btu/wh)
1	R-22	Fixed	120%	400	82	67	4A	12.0
2	R-22	Fixed	120%	400	95	67	4A	10.0
3	R-22	Fixed	120%	400	105	67	1	9.0
4	R-22	Fixed	120%	400	115	67	1B	8.0
5	R-22	Fixed	120%	400	82	63	4A	11.1
6	R-22	Fixed	120%	400	95	63	1B	9.5
7	R-22	Fixed	120%	400	105	63	1B	8.4
8	R-22	Fixed	120%	400	115	63	1B	7.1
9	R-22	Fixed	120%	450	95	67	4A	10.5
10	R-22	Fixed	120%	350	95	67	4A	9.3
11	R-22	Fixed	120%	250	95	67	4	8.5
12	R-22	Fixed	120%	450	95	63	1B	9.9
13	R-22	Fixed	120%	350	95	63	1B	8.8
14	R-22	Fixed	120%	250	95	63	1B	8.1
15	R-22	Fixed	110%	400	82	67	1	12.0
16	R-22	Fixed	110%	400	95	67	4A	10.0
17	R-22	Fixed	110%	400	105	67	1	9.0
18	R-22	Fixed	110%	400	115	67	1B	8.0
19	R-22	Fixed	110%	400	82	63	4A	11.4
20	R-22	Fixed	110%	400	95	63	1B	9.6
21	R-22	Fixed	110%	400	105	63	1B	8.3
22	R-22	Fixed	110%	400	115	63	1B	7.2
23	R-22	Fixed	110%	450	95	67	4A	10.9
24	R-22	Fixed	110%	350	95	67	4A	9.4
25	R-22	Fixed	110%	250	95	67	4	8.7
26	R-22	Fixed	110%	450	95	63	1B	10.0
27	R-22	Fixed	110%	350	95	63	1B	8.7
28	R-22	Fixed	110%	250	95	63	1B	7.9

TABLE 7. LAB RUNS FOR FIXED ORIFICE R-22 OVERCHARGE

As shown in Figure 8 overcharged systems do not impact efficiency to the degree that undercharging does. But overcharged systems put stress on the compressor and if liquid returns from the evaporator coil the compressor can be heavily damaged. At very high temperatures system will utilize the overcharge as shown by the "1" and "1B" messages. It is not recommended that refrigerant charge testing be done above 100 F. At lower temperatures "4" and "4A" are shown telling the technician that an overcharge exists and needs attention.

Run #	Refrigerant	Expansion Device	Charge Level	Airflow (cfm/ton)	Outdoor Temp	Indoor Wet Bulb	Message	EER (Btu/wh)
60	R-22	Fixed	80%	400	82	67	2B	11.0
61	R-22	Fixed	80%	400	95	67	2B	9.4
62	R-22	Fixed	80%	400	105	67	2B	8.0
63	R-22	Fixed	80%	400	115	67	2C	7.4
64	R-22	Fixed	80%	400	82	63	2B	10.4
65	R-22	Fixed	80%	400	95	63	2C	9.1
66	R-22	Fixed	80%	400	105	63	2C	7.9
67	R-22	Fixed	80%	400	115	63	2C	7.0
68	R-22	Fixed	80%	450	95	67	2B	10.2
69	R-22	Fixed	80%	350	95	67	2B	9.1
70	R-22	Fixed	80%	250	95	67	2B	8.3
71	R-22	Fixed	80%	450	95	63	2C	9.5
72	R-22	Fixed	80%	350	95	63	2C	8.5
73	R-22	Fixed	80%	250	95	63	2C	7.8
74	R-22	Fixed	70%	400	82	67	2D	9.0
75	R-22	Fixed	70%	400	95	67	2D	8.0
76	R-22	Fixed	70%	400	105	67	2D	7.0
77	R-22	Fixed	70%	400	115	67	2E	6.0
78	R-22	Fixed	70%	400	82	63	2D	8.6
79	R-22	Fixed	70%	400	95	63	2E	7.7
80	R-22	Fixed	70%	400	105	63	2E	6.8
81	R-22	Fixed	70%	400	115	63	2E	6.3
82	R-22	Fixed	70%	450	95	67	2D	8.2
83	R-22	Fixed	70%	350	95	67	2D	7.3
84	R-22	Fixed	70%	250	95	67	2D	6.8
85	R-22	Fixed	70%	450	95	63	2E	7.9
86	R-22	Fixed	70%	350	95	63	2E	7.3
87	R-22	Fixed	70%	250	95	63	2E	6.7
88	R-22	Fixed	60%	400	82	67	2D	7.0
89	R-22	Fixed	60%	400	95	67	2D	6.0
90	R-22	Fixed	60%	400	105	67	2D	6.0
91	R-22	Fixed	60%	400	115	67	2E	5.0
92	R-22	Fixed	60%	400	82	63	2D	6.5
93	R-22	Fixed	60%	400	95	63	2E	6.0
94	R-22	Fixed	60%	400	105	63	2E	5.5
95	R-22	Fixed	60%	400	115	63	2E	5.1
96	R-22	Fixed	60%	450	95	63	2E	6.2
97	R-22	Fixed	60%	300	95	63	2E	5.3
98	R-22	Fixed	60%	250	95	63	2E	5.2

TABLE 8. LAB RUNS FOR FIXED ORIFICE R-22 UNDERCHARGE

A wide range of under charged systems was tested. The 90% runs are not shown in Table 8 but can be found as Runs 44 to 59 in the Appendix embedded EXCEL file. Of more interest for energy efficiency is the runs with 80 to 60% of correct charge. In every case the messages are "2B" or worse telling the technician that a dangerous undercharge condition exists. Looking at the EER column low of 5.0 EER is reached at the extreme weather conditions. At the less extreme condition of 95 F outside 5.2 EER is reached. In all of the messages the technician is cautioned to check for leaks.

In conclusion SAMobile gave the technician correct fault detection and diagnostics for the commonly found cases of low air flow and incorrect charge of an R-22 system with a fixed orifice.

Thermal Expansion Valve (TXV) R-22 Tests

Figure 1: Thermostatic Expansion Valve (TXV) and Cross Section

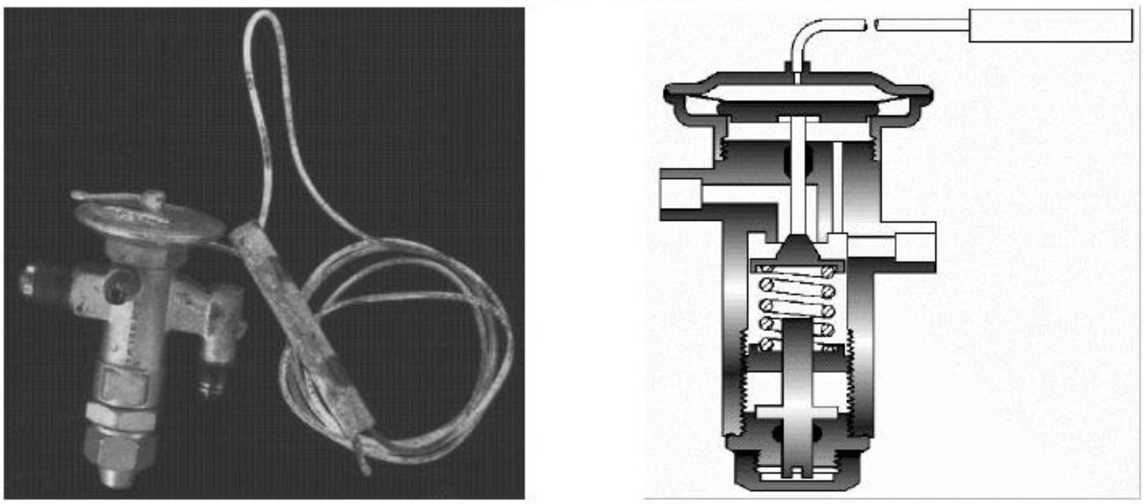


FIGURE 10. PICTURE AND CROSS SECTION OF TXV

The use of thermal expansion valves has gained in popularity in the last 2 decades as a way to achieve better efficiency as reported as Seasonal Energy Efficiency Ratio (SEER). As seen in Figure 12 TXV controlled systems are more tolerant of incorrect charge levels. We can expect that the results from SAMobile will align with this observation. A total of 83 tests (runs number 99 to 181) were run over the full range of charge and airflow combinations. Figure 11 shows the narrower range of EER values TXVs display in comparison the Fixed Orifice system which had EER values as low as 5.0.

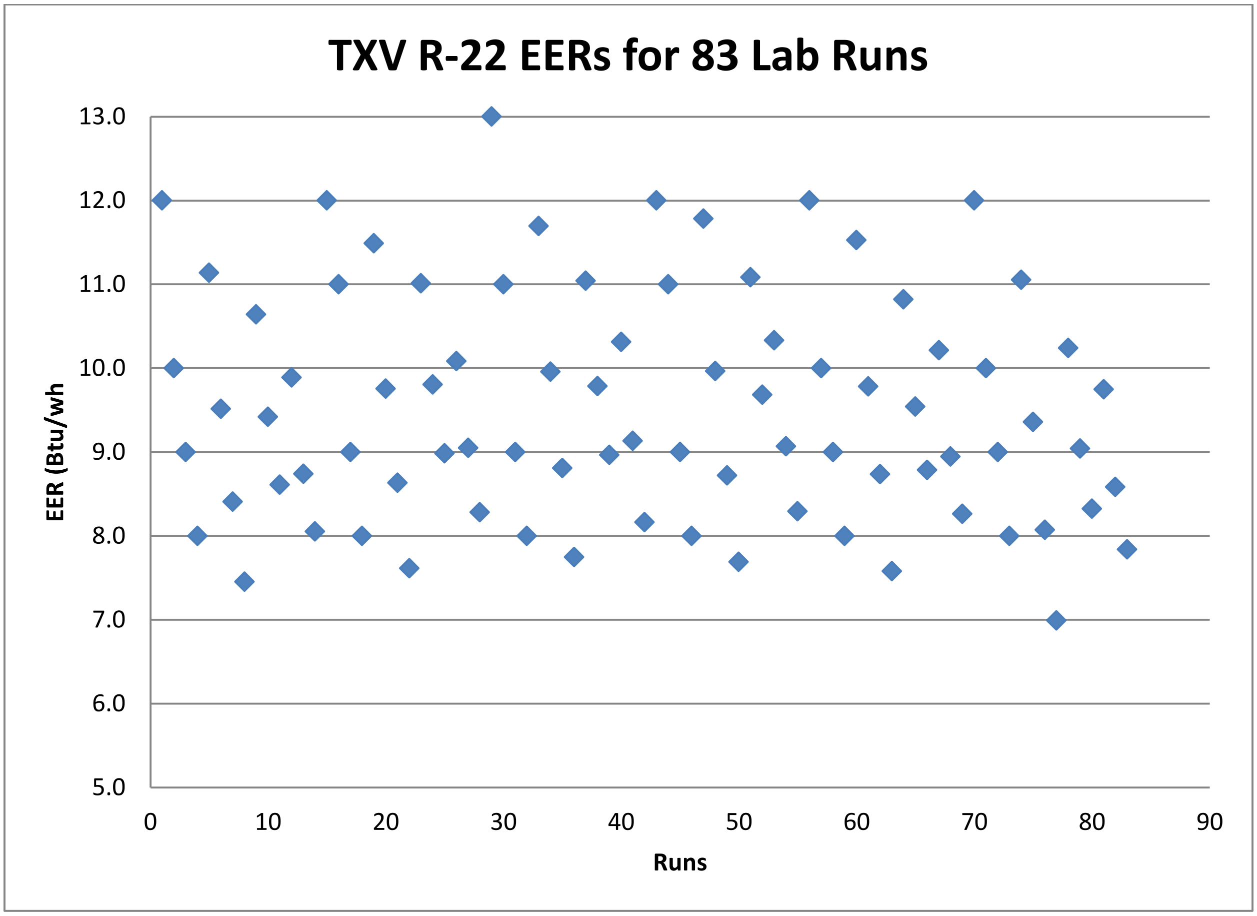


FIGURE 11. SCATTER PLOT OF TXV R-22 LAB

All but 3 of the overcharge and correct charge situations received message "1". The 3 are test numbers 135 to 137 which had Subcooling of 9 degrees which is very close to the nominal 10. The message given is "3A" which is an "ALERT" and comes with advice on how to proceed. All of the undercharge runs have either a "3" or "3A" message which is correct.

In conclusion all of the TXV R-22 runs were correctly diagnosed by SAMobile.

R-410a Tests

R-410a refrigerant has been the predominate replacement for R-22 that was phased out in 2010. It appeared earlier so there will be more systems with it than have been manufactured since 2010. Fifteen (15) tests were done with R-410a refrigerant with fixed orifice. All variables except charge were kept constant. Impacts of charge level were tested with charge from 62% to 134%.

Run #	Refrigerant	Expansion Device	Charge Level	Airflow (cfm/ton)	Outdoor Temp	Indoor Wet Bulb	Message	EER (Btu/wh)
182	R-410a	Fixed	134%	400	95	67	4	10.6
183	R-410a	Fixed	124%	400	95	67	4	10.8
184	R-410a	Fixed	120%	400	95	67	4	10.8
185	R-410a	Fixed	110%	400	95	67	1	10.8
186	R-410a	Fixed	108%	400	95	67	1	10.8
187	R-410a	Fixed	103%	400	95	67	1	10.6
188	R-410a	Fixed	100%	400	95	67	1	10.6
189	R-410a	Fixed	90%	400	95	67	2B	9.6
190	R-410a	Fixed	80%	400	95	67	2D	7.7
191	R-410a	Fixed	70%	400	95	67	2D	6.3
192	R-410a	Fixed	62%	400	95	67	2D	4.0
193	R-410a	Fixed	103%	350	95	67	1	10.6
194	R-410a	Fixed	103%	300	95	67	1	10.6
195	R-410a	Fixed	62%	350	95	67	2D	4.5
196	R-410a	Fixed	62%	300	95	67	2D	4.7

TABLE 9. FIXED ORIFICE R-410A TEST RESULTS

The messages match the conditions of the lab tests so that "4" is catching overcharge and the "2" series of messages is catching the undercharge runs.

Run #	Refrigerant	Expansion Device	Charge Level	Airflow (cfm/ton)	Outdoor Temp	Indoor Wet Bulb	Message	EER (Btu/wh)
197	R-410a	TxV	134%	400	96	67	5	10.3
198	R-410a	TxV	124%	400	95	67	1	10.7
199	R-410a	TxV	120%	400	95	67	1	10.8
200	R-410a	TxV	110%	400	95	67	1	10.9
201	R-410a	TxV	108%	400	95	67	1	11.0
202	R-410a	TxV	103%	400	95	67	1	10.8
203	R-410a	TxV	100%	400	95	67	1	10.8
204	R-410a	TxV	90%	400	95	67	3A	10.4
205	R-410a	TxV	80%	400	95	67	3A	10.0
206	R-410a	TxV	70%	400	95	67	3	9.4
207	R-410a	TxV	62%	400	95	67	3	8.0
208	R-410a	TxV	103%	350	95	67	1	10.8
209	R-410a	TxV	103%	300	95	67	1	10.6
210	R-410a	TxV	62%	350	95	67	3	7.8
211	R-410a	TxV	62%	300	95	67	3	7.9

TABLE 10. TXV R-410A TEST RESULTS

The fourteen (14) tests shown in Table 10 vary the charge level and airflow to generate results from EER of 7.9 to 11.0. The data demonstrates the way a TXV is capable of operating over a wide range of conditions. The "3" and "3A" messages capture the undercharge situations. The overcharge conditons receive "1" messages even when the charge is at 124%. As shown in Figure 8 there is no energy impact from high charge which is the focus of the QM program. SAMobile does warn the technician with "5" that there is an overcharge situation and refrigerant need to be recovered.

For all R-410a cases tested SAMobile gave the technician correct FDD information for energy efficiency improvements. In a few cases such as Row 198 in Table 10 a high charge message would be preferred. The messages displayed give guidance to the technicians who are trained to the degree that they can then iterate to solve the fault or faults.

RECOMMENDATIONS

Refrigeration Service Instrumentation, Measurement, and Calibration

- The measurement of refrigeration system variables is hampered by inaccuracy. Initial scoping lab bench testing has been done. A complete and thorough lab testing program is needed. The testing must be done on operating systems at practical locations using field methods of placement and attachment with field grade instrumentation. Concurrent measurements with low uncertainty lab grade sensors and data capture become the benchmark used to establish best practice field measurement accuracy.
- Multiple Metric Multiple Fault (MMMF) diagnostic software gives correct diagnosis but any software it needs continued testing to further refine its usefulness to the field technician.
- More laboratory testing of systems with multiple faults in scenarios found in the field is needed. Contaminated refrigerant from incorrect installation processes needs additional research.
- The MMMF software SAMobile is an appropriate technician software tool for use in HVAC Quality Maintenance programs.

APPENDICES

This embedded EXCEL file is the data set used for the assessment of SAMobile.

SAMobile Output Summary 112512.xls›   491-01.4_TXVvsOrificeReport.pdf   491-07.06_SurfaceTemperatureMeasuren   491-01.7_R410aTXVvsOrificeReport.pdf

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