

Laboratory Measurements of Residential HVAC Installation and Maintenance Faults

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Session Title: Magnitude of the Problem



Fault Detection Diagnosis and Repair of Residential HVAC Systems
10 September 2013 – Davis, CA

Learning Objectives

- Explain how non-condensables and refrigerant restrictions enter an air conditioning system
- Distinguish non-condensables, refrigerant over charge, low airflow, and condenser coil blockage
- Describe how to prevent non-condensables and restrictions from entering an air conditioning system
- Distinguish restrictions from charge faults
- Describe how refrigerant over/under charge, non condensables, and restrictions reduce efficiency
- Opinions expressed in this presentation are those of the authors and do not reflect views of the US Department of Energy or Building America

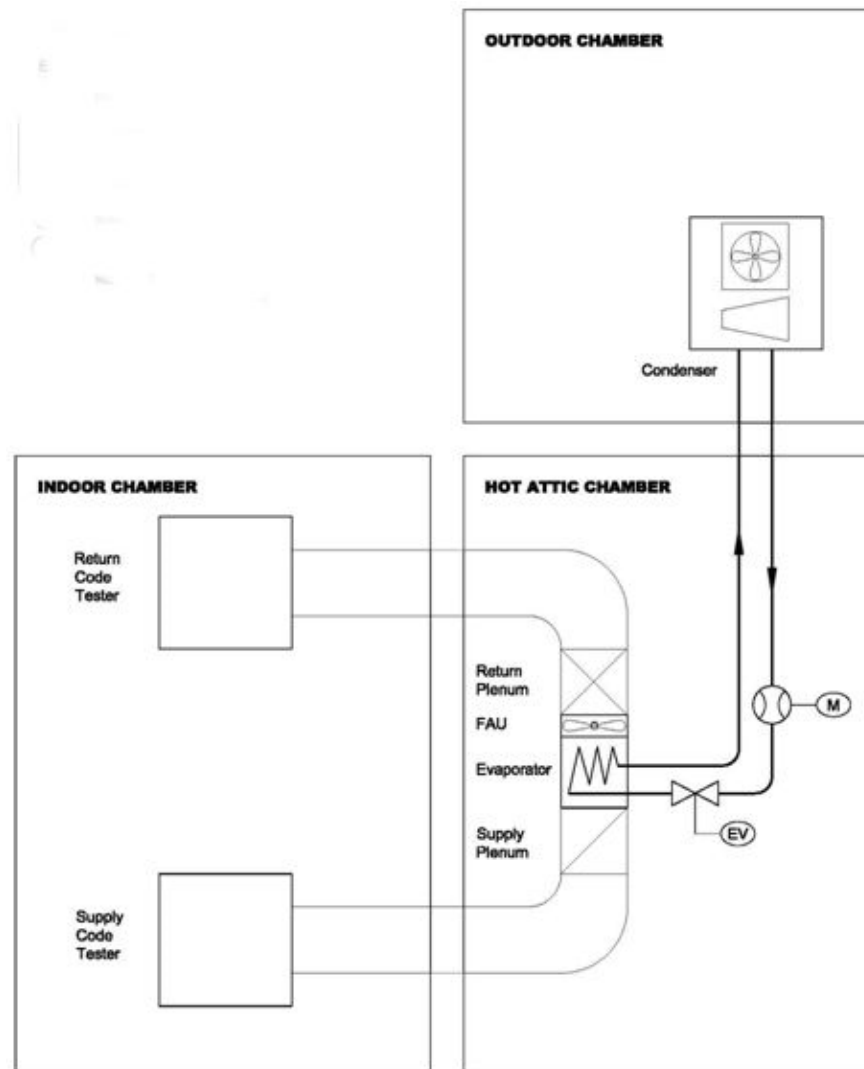
Introduction

- Residential and commercial HVAC uses 30% of peak electricity demand, 13% of total electricity, and 44% of total gas (US EIA)
- 2002 Hewlett Foundation study indicates HVAC installation and maintenance is one of the largest economically achievable opportunities for efficiency savings
- ASHRAE Paper 8631 provides tests of HVAC installation and maintenance faults for a new 3-ton split-system 13-SEER air conditioner using R-22

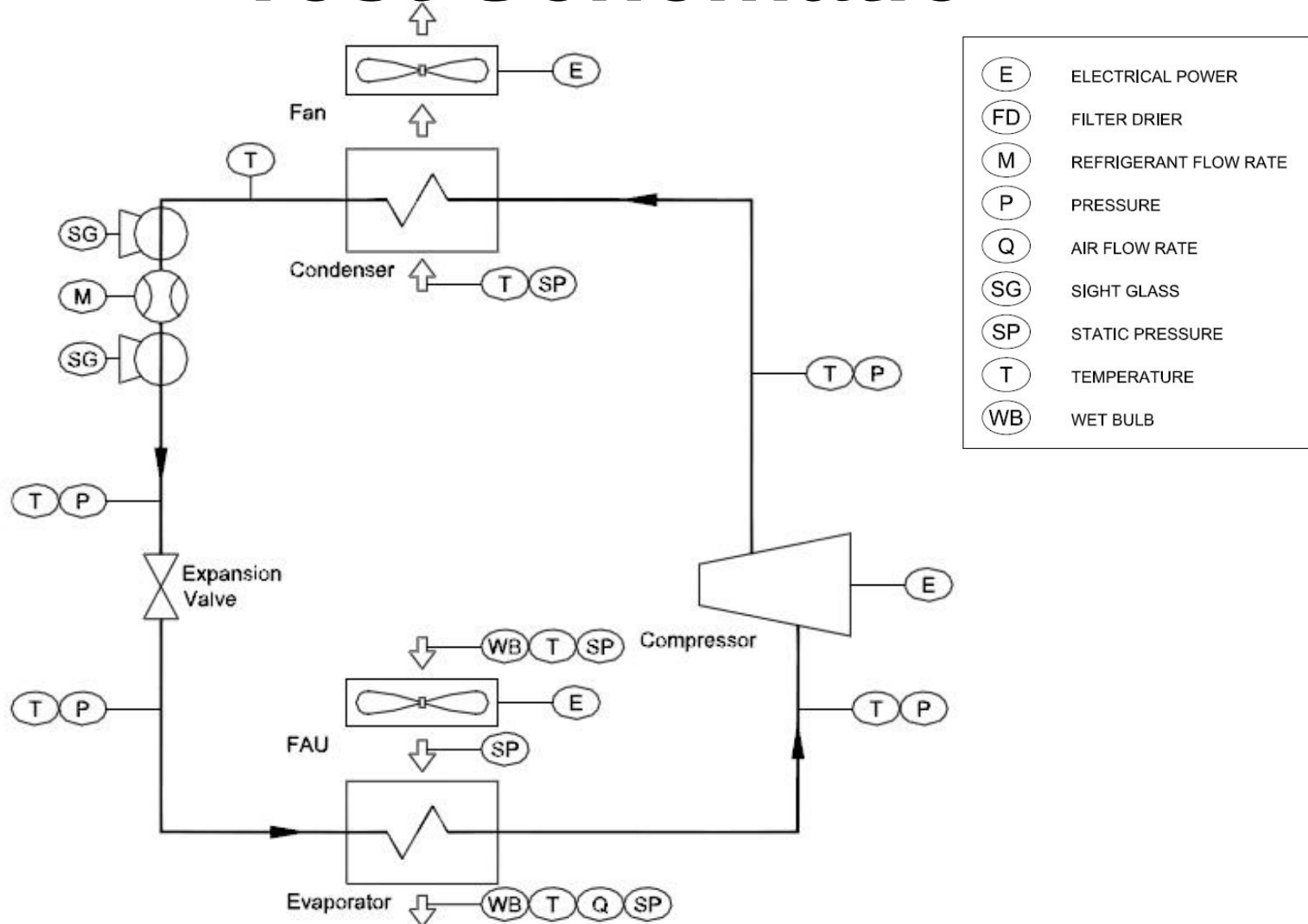
Overview of Tests

- Test equipment set up in 3 chambers to simulate ARI 210/240 indoor and outdoor conditions and hot attic conditions
- Laboratory test results are provided for HVAC faults that occur due to installation and maintenance deficiencies and degradation
- Tests for following faults: uninsulated TXV sensing bulb, low airflow, ducts/equipment in hot attic, evaporator coil blockage, duct leakage, condenser coil blockage, improper refrigerant charge, non-condensables, and restrictions

Test Chamber



Test Schematic



Test Set-up

- Tests conducted at AHRI-certified laboratory
- Prior to charging with refrigerant, system was pressurized to 300 psig with nitrogen and held for 60 minutes to absorb moisture and check for leaks
- Vacuum pump was used to evacuate system to below 500 micron mercury (μHg) vacuum held for 30 minutes

Baseline Tests

Description	EER* _A	Impact	SEER*	Impact
AHRI Rating	11.2	-	13.0	-
No FAU, HS-TXV copper bulb/strap, ducts/evap in 80F/67F	11.3	0.5%	12.6	-3%
FAU, HS-TXV stainless-steel bulb/strap, ducts/evap in 80F/67F	10.7	-5%	11.9	-9%
Above + ducts/evap in 118F hot attic	9.5	-16%	9.2	-29%

Multiple Fault non-TXV Tests

Description	EER* _A	Impact	SEER*	Impact
FAU, non-TXV, ducts/evap in conditioned space	10.5	NA	10.8	NA
Above + hot attic 118F, 50' line set	9.4	-11%	8.9	-18%
Above + 25% low airflow, 10% undercharge, 30% duct leak, 50% condenser coil blockage	4.4	-54%	2.94	-67%

TXV Sensing Bulb Tests

Description	EER* _A	Charge Diagnostic
Correct charge, insulated bulb	-	Correct
Correct charge, uninsulated	-2%	False undercharge
+10% charge, uninsulated	-4%	False undercharge
+20% charge, uninsulated	-7%	False undercharge
+30% charge, uninsulated	-12%	False correct charge
+40% charge, uninsulated	-17%	Slight overcharge

Airflow Tests

- Airflow tests with proper refrigerant charge
- Low airflow from 250 to 350 cfm/ton reduces EER* by 3 to 12%
- Low airflow down to 250 cfm/ton does not cause false undercharge diagnostics
- Airflow below 250 cfm/ton can cause false over charge diagnostics due to icing of evaporator coil

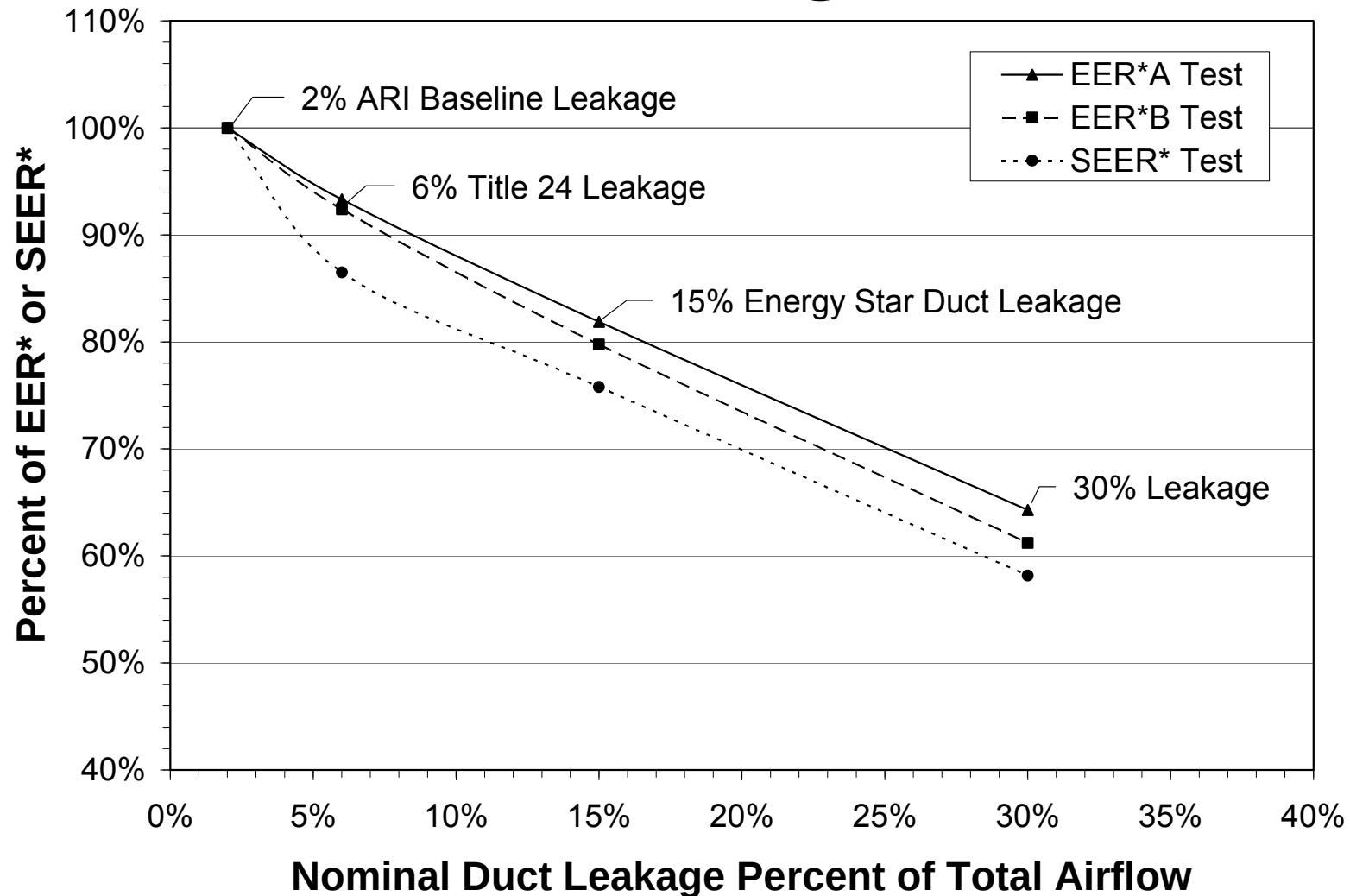
Evaporator Blockage Tests

- Non TXV with 50% evaporator blockage reduces airflow by 16%, EER* by 4.6%, and causes false overcharge diagnostics
- With 11% charge removal delta superheat within $\pm 5^{\circ}\text{F}$, but EER* is reduced by 7.2%
- TXV with 50% blockage reduces airflow by 15% and EER* by 4.2%, but charge diagnostics are okay (delta SC within $\pm 3\text{F}$)

Duct Leakage Tests

- 6% duct leakage per California Energy Commission building standards reduces EER* by 7% and SEER* by 14%
- 15% duct leakage per Energy Star[®] reduces EER* by 18% and SEER* by 24%
- 30% duct leakage common of many US homes reduces EER* by 36% and SEER* by 42%

Duct Leakage Tests



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Condenser Coil Blockage

Description	EER*%	kW %	Diagnostic
Base non-TXV Hot Attic	NA	NA	Correct charge
50% Condenser Coil Blockage	-6%	7%	False overcharge
80% Condenser Coil Blockage	-30%	27%	False overcharge

Refrigerant Charge Tests

- TXV *overcharge* of 10-40% reduces EER* by 4-17% and increases kW by 5-18%
- TXV undercharge of 10-40% reduces EER* by 4-56% and kW by 3-12%
- Non-TXV *overcharge* of 10-40% reduces EER* by 4-9% and increases kW by 4-9%
- Non-TXV undercharge of 10-40% reduces EER* by 21-66% and reduces kW by 5-13%

Non-Condensable Tests

- Non-TXV with 0.3% nitrogen impacts EER* by -18%, SEER* by -19%, and kW by +8%
- Non-TXV with 1% nitrogen impacts EER* by -21% and power by +25%
- Non-TXV evacuation with vacuum pump containing dirty oil impacts EER* by -38% and power by +22%
- TXV with 0.3% nitrogen impacts EER* by -12%, SEER* by -13%, and power by +6%

What Causes Non-Condensables

- Final assembly of split-systems requires evacuation to 240 microns held at or below 500 microns for 5 minutes prior to charging
- Non-condensables caused by improper evacuation and contaminated hoses
- Non-condensables increase condensing pressures, temperatures and power, reduce capacity, and cause compressor failure

Restriction Tests

- Restrictions cause coil freezing, reduce capacity, increase run time and energy use
- non-TXV restriction (20% increase in high-low pressure difference) impacts EER^*_A by -30%, EER^*_B by -45%, $SEER^*$ by -35%, power by -3% similar to undercharge
- TXV restriction (20% increase in high-low pressure difference) impacts EER^*_A by -36%, EER^*_B by -55%, $SEER^*$ by -59%

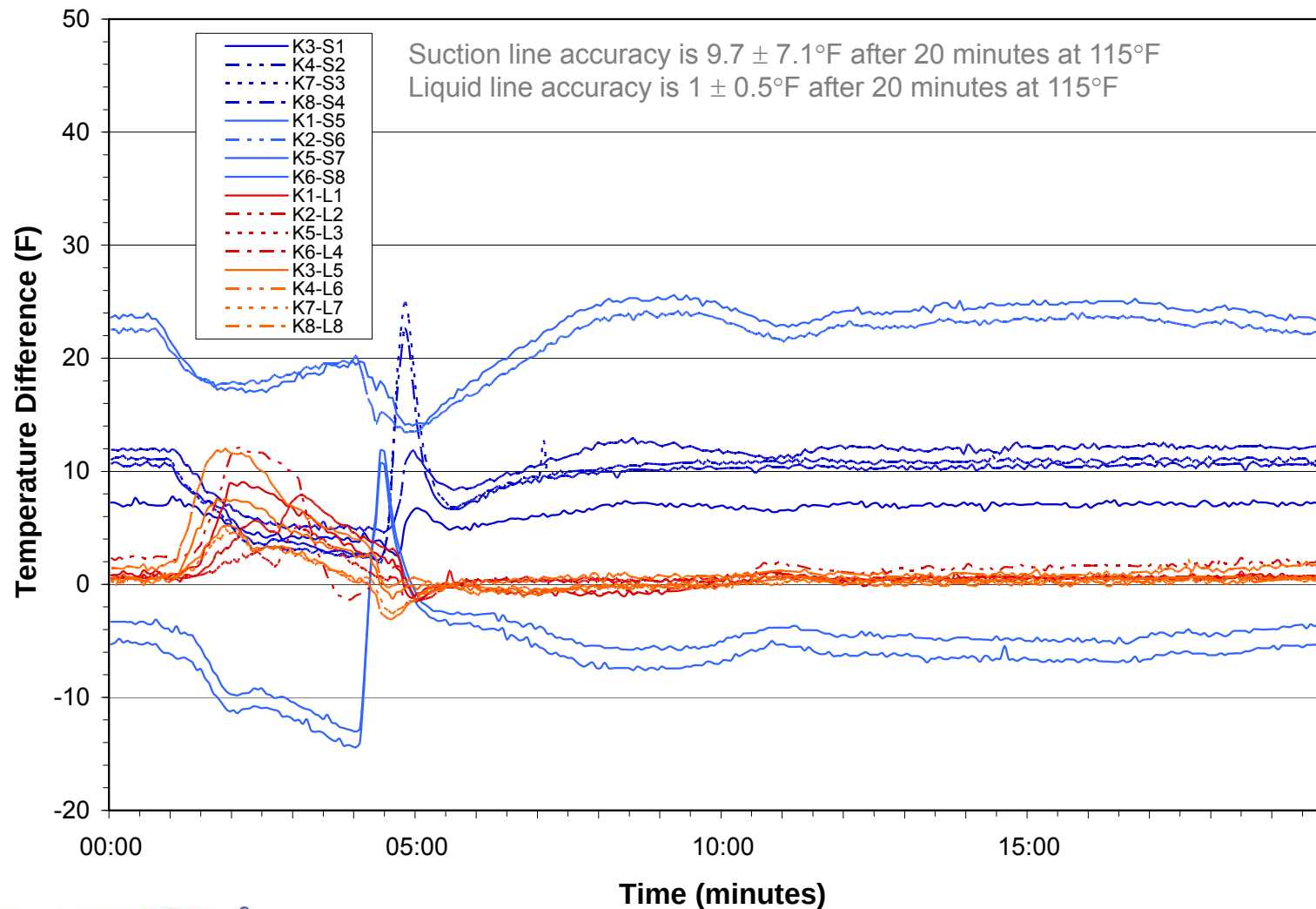
What Causes Restrictions

- Moisture, copper particles, flux, brazing residue, and particulates cause damage to compressors, clog screens, metering devices, or filter driers
- Moisture combines with oil and refrigerant to form corrosive acid and sludge causing refrigerant restrictions
- Restrictions can also be caused by oil logged refrigerant flooding compressor, wax buildup in valve from wrong oil, or sludge from byproducts of compressor burnout

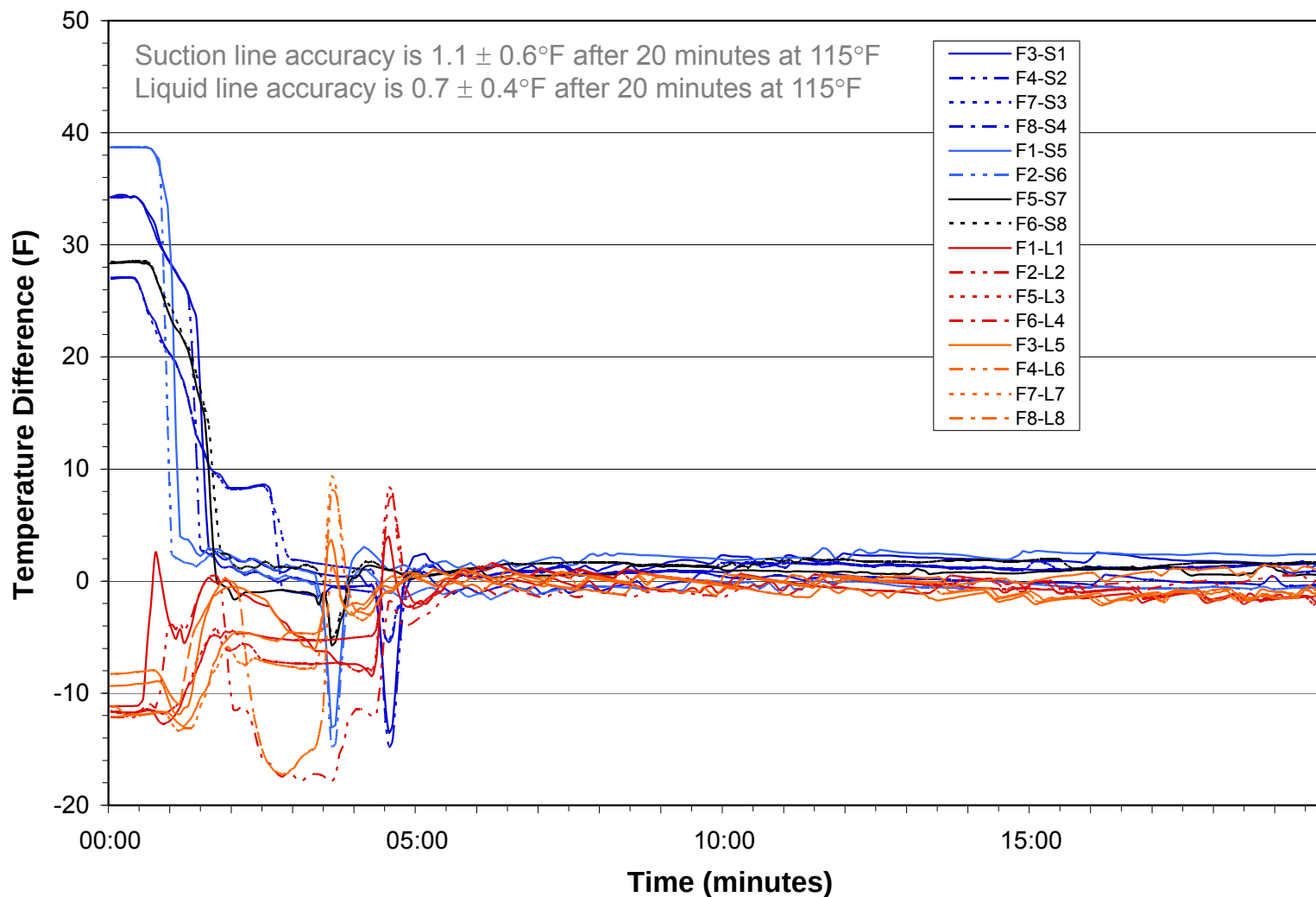
Current Standards

- California Energy Commission Standard Charge Measurement Procedure requires verification of subcooling for TXV units or verification of superheat for non-TXV units
- These simple tests can only be used to diagnose refrigerant charge faults if no other faults are present
- CEC standards do not require filter driers, methods for proper evacuation, vacuum pump maintenance, or purging hoses before connecting to Schrader valves

Cylindrical Thermistors



Type-K Clamp Probes



Measurement Instruments

- It takes 5 to 10 minutes for sensors to accurately measure temperatures
- Type-K clamp suction accuracy is $1.1 \pm 0.6^{\circ}\text{F}$ and liquid accuracy is $-0.7 \pm 0.4^{\circ}\text{F}$ at 115°F outdoor
- Other Type-K clamp suction line accuracy is $6.8 \pm 1.0^{\circ}\text{F}$ and liquid accuracy is $1 \pm 0.5^{\circ}\text{F}$ at 115°F
- Insulated cylindrical thermistor suction accuracy is $9.7 \pm 7.1^{\circ}\text{F}$, and clamp thermistor suction line accuracy is $5.4 \pm 2.1^{\circ}\text{F}$ at 115°F outdoor
- Measurement instrument standards are required

Refrigerant Test Matrix

	Low Superheat	High Superheat
Low Subcooling	TXV or TXV sensing bulb failure	Refrigerant undercharge or liquid line restriction SH, SC, EST $f(\text{OAT, SH, SC})$ or compressor valve failure (check compressor Watts)
High Subcooling	Refrigerant over charge, blocked condenser or evaporator, low airflow, or non-condensables check SH, SC, COA $f(\text{OAT, SH, SC})$	Non-condensables check SH, SC, COA thresholds or liquid line restriction SH, SC, EST $f(\text{OAT, SH, SC})$

Note: Low airflow check external static pressure and/or fan amps or Watts

ACCA 4

Component	Check List	# Tasks	EE Tasks	Measures
Air Distribution	7.1	6	1	Duct leakage
Controls	7.2	6	0	Thermostat
Furnace	7.3	32	1	Airflow
Evaporator Coil	7.6	10	1	Clean Coil
Condensing Unit	7.7	14	2	RCA, Clean Coil
Fan Coil	7.8	20	""	""
Package Units	7.12	26	""	""
Evap. Coolers	7.14	15	0	Operation
Accessories	7.15	33	0	
Total		162	5	

- 3% of ACCA 4 tasks impact energy efficiency

Observations of Technicians

- 85% perform maintenance using “rules of thumb”
- 92% have issues with tools or procedures
- 50% don’t have low-loss fittings or didn’t purge hoses before attaching to Schrader valves
- 10% add contaminated refrigerant to systems or mix refrigerants in hoses or in systems
- Technicians don’t regularly change vacuum pump oil or perform proper evacuations (500 microns)
- Technicians don’t typically install liquid line driers on split or packaged systems

Conclusions

- Common installation and maintenance faults can reduce EER* by 10-55% and SEER* by 35-59%
- Standard methods cannot differentiate non-condensables from overcharge or dirty condenser and restrictions from undercharge or low airflow
- Current standards do not require filter driers, proper evacuation, vacuum pump maintenance, or purging hoses before connecting to systems
- Federal standards are required for tools, FDD, and procedures to prevent contamination and improper installation & maintenance of HVAC units

Thank you!

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