Determining Real Time Performance of Residential AC Systems

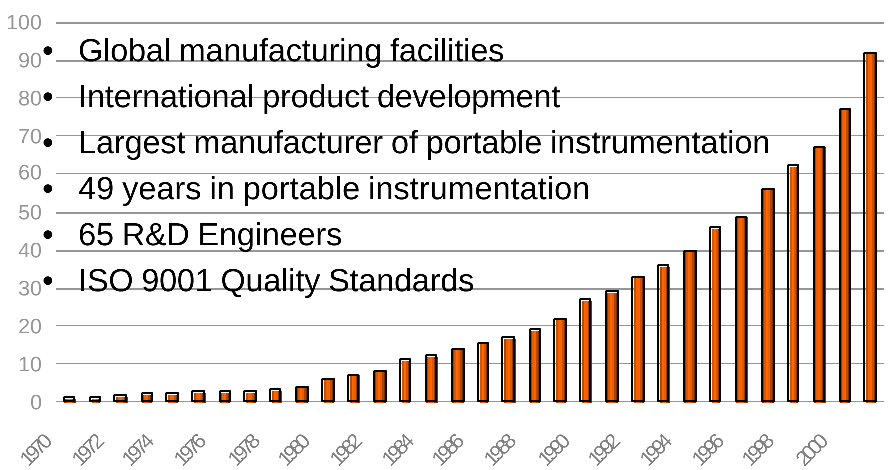
Presented at the RESNET Conference
San Antonio, TX
February 28, 2006

Bill Spohn
testo, Inc.

25 years
Testo Inc.

testo Worldwide

- Global manufacturing facilities
- International product development
- Largest manufacturer of portable instrumentation
- 49 years in portable instrumentation
- 65 R&D Engineers
- ISO 9001 Quality Standards



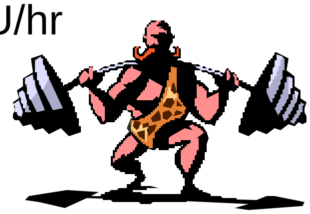
testo USA

- Headquartered in Flanders, NJ
- Dedicated technical support staff
- Coast-to-Coast Sales Support
- Fully staffed service facility prompt service and repair
- Fully stocked warehouse (3 to 5 day delivery)
- Available through HVAC/R Distributors across North America

Defining Performance

- Cooling tons
  - As designed by the manufacturer
  - As specified by the dealer/installer
  - As purchased by the consumer

- 1 ton cooling = 12,000 BTU/hr



Industry increments

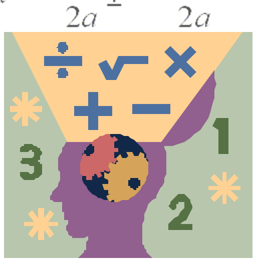
1 ton	12,000 BTUh	012
1.5 ton	18,000 BTUh	018
2 ton	24,000 BTUh	024
2.5 ton	30,000 BTUh	030
3 ton	36,000 BTUh	036
3.5 ton	42,000 BTUh	042
4 ton	48,000 BTUh	048
5 ton	60,000 BTUh	060

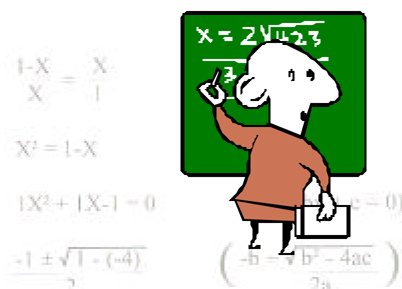
Calculating cooling capacity

$$x = -\frac{b}{2a} \pm \sqrt{\frac{b^2 - 4ac}{4a^2}}$$

$$x = -\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{\sqrt{4a^2}}$$

$$x = -\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a}$$





$$\text{LHS} = I_{k+1} = \frac{2k+1}{2(k+1)} \times \frac{(2k)!}{(k!)^2} \times \frac{\pi}{2^{2k}}$$

$$= \frac{2k+2}{2(k+1)} \times \frac{2k+1}{2(k+1)} \times \frac{(2k)!}{(k!)^2} \times \frac{\pi}{2^{2k}}$$

$$= \frac{(2k+2)!}{((k+1)!)^2} \times \frac{\pi}{2^{2(k+1)}},$$

Calculating cooling capacity

Don’t Panic

It’s as easy as

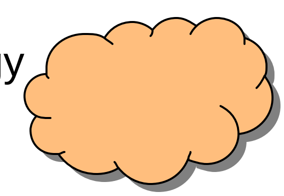
1 Measure

2 Look up

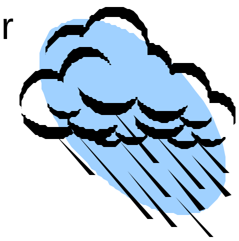
3 Calculate

Airflow Basics

- Air is the energy transfer medium in residential A/C systems
- Air has mass (weight)
- Air has sensible thermal energy
  - Measured by air temperature
- Air has **latent** thermal energy
  - Vaporization energy for humidity in air
- Airflow is measured in cubic feet per minute (**CFM**)

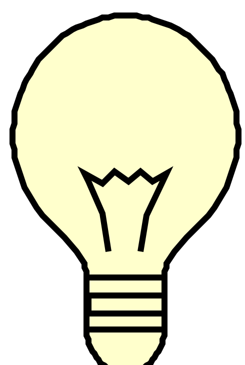


Humidity Basics



- Humidity is water trapped in a vapor state in air
- Energy must be added to get more water into a vapor state
- Energy is released when the water changes back from vapor to liquid
- Enthalpy is a measure of the total heat in a substance (both sensible and latent)
- Humidity travels from high to low

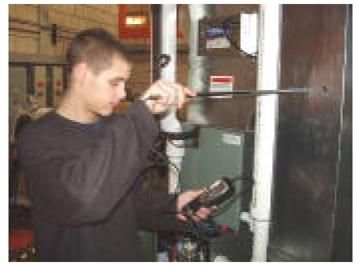
Obvious things



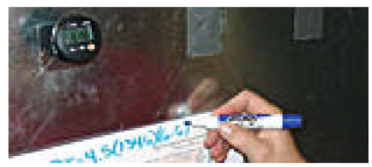
- Think clean
  - Filters
  - Coils
  - Blower wheel
- Think tight
  - No leaks downstream of measurement location

STEP 1: Measure

- Airflow - CFM
  - in the return



- Entering and leaving wet bulb
  - Over the cooling coil
  - Allows you to get the enthalpy (total energy) change



STEP 2: Look up

- Find change in enthalpy (? h) from wet bulb measurements
- Using a table, chart or program

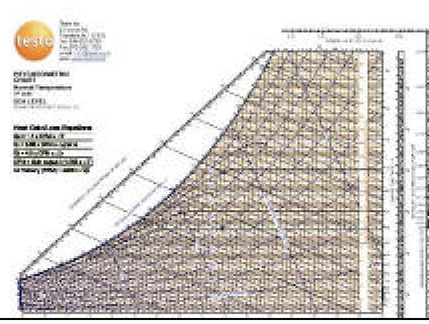
ET BULB EMPER-ATURE

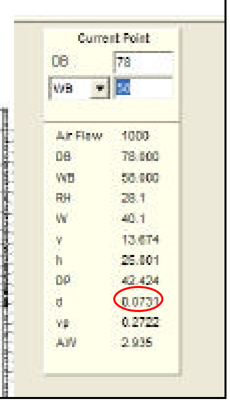
ENTHALPY CHART

WET BULB TO ENTHALPY CONVERSION

Wet bulb temperature in tenths of a degree Fahren

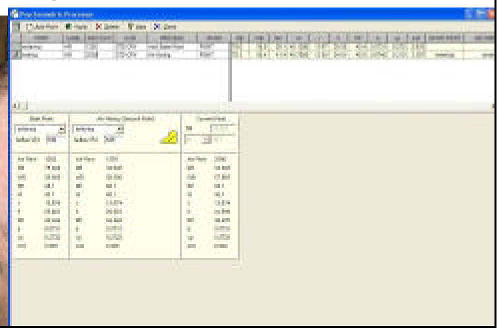
	.0	0.1	0.2	0.3	0.4	0.5	0.6
35	12.97	13.01	13.05	13.10	13.14	13.18	13.23
36	13.40	13.45	13.49	13.53	13.58	13.62	13.67
37	13.85	13.89	13.93	13.98	14.02	14.07	14.11
38	14.30	14.34	14.39	14.43	14.48	14.52	14.57
39	14.75	14.80	14.84	14.89	14.94	14.98	15.03
40	15.21	15.26	15.31	15.36	15.40	15.45	15.50
41	15.69	15.73	15.78	15.83	15.88	15.92	15.97
42	16.16	16.21	16.26	16.31	16.36	16.41	16.45
43	16.65	16.70	16.75	16.80	16.85	16.90	16.95
44	17.14	17.19	17.24	17.29	17.34	17.39	17.45
45	17.65	17.70	17.75	17.80	17.85	17.90	17.95
46	18.16	18.21	18.26	18.31	18.37	18.42	18.47
47	18.68	18.73	18.79	18.84	18.89	18.94	19.00
48	19.21	19.26	19.32	19.37	19.43	19.48	19.53
49	19.75	19.81	19.86	19.92	19.97	20.03	20.08
50	20.30	20.36	20.41	20.47	20.53	20.58	20.64
51	20.86	20.92	20.98	21.04	21.09	21.15	21.21
52	21.44	21.49	21.55	21.60	21.66	21.72	21.78
53	22.02	22.06	22.12	22.09	22.24	22.30	22.36
54	22.62	22.68	22.74	22.80	22.86	22.92	22.98
55	23.22	23.28	23.34	23.40	23.46	23.52	23.58
56	23.84	23.90	23.96	24.03	24.09	24.15	24.21
57	24.48	24.53	24.59	24.66	24.72	24.79	24.85
58	25.12	25.18	25.25	25.32	25.38	25.45	25.51
59	25.78	25.85	25.91	25.99	26.06	26.12	26.19
60	26.46	26.53	26.60	26.67	26.74	26.81	26.88





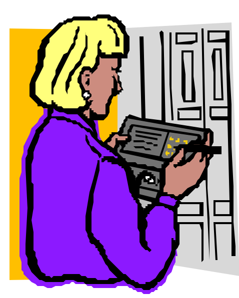
STEP 3: Calculate

- Capacity calculation
  - BTUh = 4.5 x CFM x ?h
  - Tons = BTUh/12,000
- Manually or with program



Corrections
(fixed orifice systems)

- Extended Refrigerant Line
- Voltage Correction
- Indoor Airflow Correction
- Indoor Temperature Correction



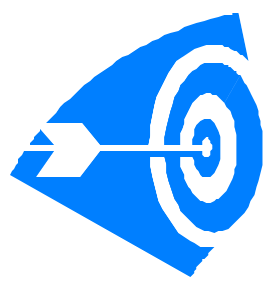
Giving a grade

- A CONCEPT:
  - a system that is putting out more than 90% of rated capacity is a PASS
  - a system that is putting out between than 75% and 90% of rated capacity is suspect
  - a system that is putting out less than 75% of rated capacity is a FAIL

Need more study to determine the definition of these ranges and comparison to other methods and measuring technologies.

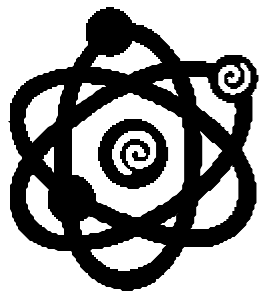
Accuracy of measurements

- Quarter a ton of cooling (3,000 BTU/hr)
  - 1 ºF wet bulb
  - 62.5 CFM



Impact of Technology

- Rotating vane not affected by
  - Air density
  - Humidity
  - Temperature
- Humidity Sensor
  - Capacitive ceramic
  - In the duct
    - Extendable probe available (t-435)
  - Quick response



Energy Star on Air Flow

- Essential for comfort
  - 70% of systems tested are operating at less than 350 cfm/ton (ideal is 400 cfm/ton)
  - Annual savings of 8% possible
- Technician verifies system is flowing at 400cfm/ton (or cfm specified by manufacturer) during full-speed testing
  - Systems incapable of 350 cfm/ton or greater must be corrected by improving ducts or would not qualify

Considering an ENERGY STAR
CAC/ASHP Specification
for 2006

Measure CFM

testo 416 Mini Vane

- Airflow in under 3 minutes
- Full duct traverse assures accuracy
- Ultra Low mass rotating vane
- Precision jewel bearings
- Excellent durability and chemical resistance.
- No air density correction required.

testo 416 Mini Vane

- Non-invasive measurement
- Excellent repeatability
- Forgiving to operator error
- Guaranteed performance with a

  Two year warranty

Measuring Wet Bulb

testo 605 H2

- Accurate measure of initial and final wet-bulb is required with 1/10th of a degree resolution
- 605 uses a high accuracy reliable sensor
- Only instrument designed to make measurements in the duct
- Low cost and easy to use
  - Single button operation
- Extendable probe available in t-435

Energy Star on proper charge.

Refrigerant Charge

- **Essential to maintain capacity**
  - **Improper charge can lead to premature compressor failure**
  - **Up to 41% systems undercharged, 33% overcharged**
  - **Average savings of 12.5% with proper charge**
- **Adjusted by technician in accordance with manufacturer's instructions**
  - **Systems with more than ±3° deviation in subcooling from manufacturer's spec would not qualify**

Considering an ENERGY STAR CAC/ASHP Specification for 2006

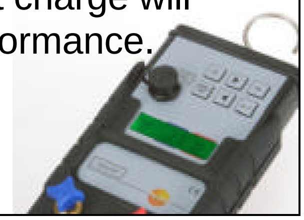
Refrigerant Charge

System charge is critical

Charging by superheat and subcooling is the most accurate method of charging.

– Superheat (Fixed) verifies evaporator performance
– Subcooling (TXV) assures adequate refrigerant for proper metering device operation with a TXV.

Any charge other than the correct charge will negatively affect system performance.



Thank you!

Bill Spohn

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13 SEER
So, what is the big deal?

Higher Efficiency:
- New federal regulation will make it illegal to manufacture systems rated below 13 SEER

Larger Equipment:
- Systems will be about 30% larger, Increased efficiency comes largely at the cost of increased surface area.

More TXV's:
- Higher efficiency systems require better evaporator control.

Larger size is the least of your concern

The BIG deal is!

Matched components:

– Systems must be listed in the ARI directory

Increased importance of charging:

– Proper charge is imperative to get guaranteed energy efficiency, capacity, and system reliability.

– A few ounces of refrigerant changes everything!!!!!

Critical airflows:

– Airflow directly effects efficiency, capacity, and creature comfort.

– Proper airflow across the evaporator is critical to achieve efficiency ratings.

Need for Change

Proper appliance setup is required for:

– Comfort

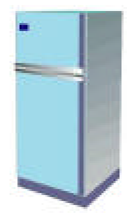
– Capacity

– Guaranteed Efficiency

– Equipment Longevity

What do we have today?

- High rate of system failure
- Unnecessary warranty claims
- Poor system performance
- Loss of confidence (consumer and technician)
- High utility bills
- Call-backs
- Dissatisfied customers
- A chain of events leading to a mess!



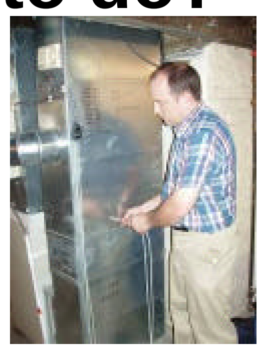
Why don't techs make good measurements?

- Not enough time
- Can't get the same results twice
- Equipment works without proper set-up
  - Although it never works right
- No idea what to measure.
- Have never been instructed how and why!

It is time to change!!

- If we always do..
- what we’ve always done..
- we’ll always get..
- what we’ve always got!

What do we need to do?



- Design properly
- Install properly
- Performance test
- Keep the system sealed!!!

testo

We are not alone!

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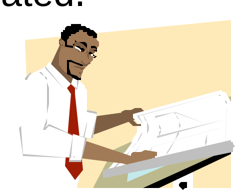
System Design

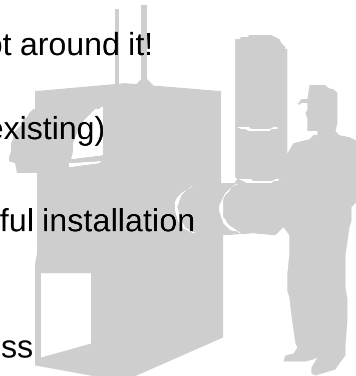
- Components must be matched and rated.
  - Matched condenser and evaporator
  - Correct air handler
  - Proper type of metering device
  - Correctly sized and insulated line set



- Duct systems must be properly designed and sealed and insulated when required.
  - Duct leakage causes reductions in capacity, efficiency, and comfort.
    - Proper sealing can yield energy savings on average of 17%

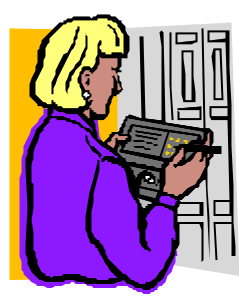
Install Properly

- Air handling
  - Air through the evaporator; not around it!
  - Proper duct design
  - Duct system testing (New or existing)
- Refrigeration system
  - Proper line set sizes and careful installation
  - Braze connections
  - Purge with nitrogen
  - Evacuate to 500 microns or less
  - Proper charge



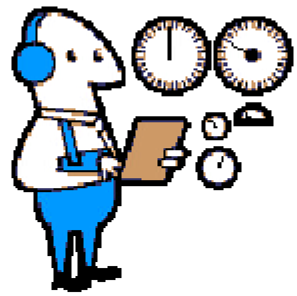
Performance testing

- Think clean
  - Filter, blower & coils
- Verify appliance operation
  - Cooling capacity
- Verify system operation
  - Delivery



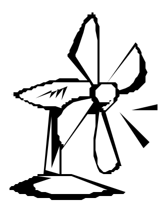
It all comes down to one thing…. Making measurements

- In any work that involves:
  - Engineering
  - Design verification
  - Installation
  - Service
  - Factory support



- The goal is to deliver
  - the designed efficiency and capacity
  - the performance that the customer purchased (13+ SEER)
  - the reliability promised (manufacturer & dealer)

Airflow



- Airflow must ALWAYS be set at the appliance first!
  - Airflow is critical to system performance
  - Refrigerant charging requires proper airflow
  - Set to a nominal 400 CFM/Ton for A/C
  - Set to 450 CFM/Ton for heat pumps

Always refer to manufacturer's specific instructions

After the airflow has been set at the appliance NEVER adjust it to change system characteristics!

Appliance and System Performance

If the airflow is correct…….

And the refrigerant charge is correct……

The system capacity should be correct……..

Benchmarking system performance assures your customer is getting the designed BTUh!!!

If you don’t measure, how can you ever know???

We need to use modern technology

- Benchmarking equipment requires lab accurate tools
- Field instruments are available with lab accuracy
- With new technology, and tools comes new and **quicker** and methods

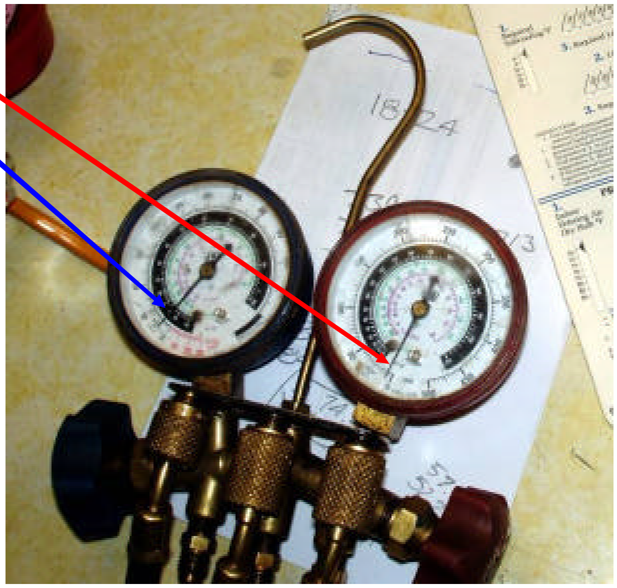
Analog inaccuracies

- Gauge design (ca. 1850's)
  - Gauge accuracy (3/2/3)
  - Repeatability
  - Construction
- Errors
  - Human errors (parallax or fluttering
  - Calculation errors
  - Calibration errors
- Procedures or lack thereof
- Just about beer can cold?

Discharge 5 PSI off

Suction 5 PSI off

How many systems were charged like this???



Frick **Temperature/Pressure Chart** Frick

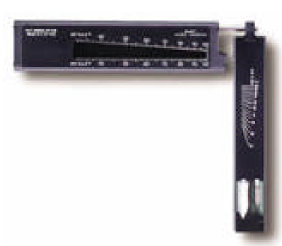
Temp °F	R-717	R-22	R-507A	Temp °F	R-717	R-22	R-507A	Temp °F	R-717	R-22	R-507A
	Refrigerant Code				Refrigerant Code				Refrigerant Code		
-60	18.7"	11.9"	5.8"	12	25.5	34.8	48.5	42	61.4	71.5	93.4
-55	16.7"	9.2"	2.2"	13	26.4	35.8	49.8	43	62.9	73.0	95.2
-50	14.4"	6.1"	0.9	14	27.4	36.8	51.0	44	64.5	74.5	97.0
-45	11.8"	2.7"	3.1	15	28.3	37.8	52.2	45	66.1	76.1	98.9
-40	8.8"	0.6	5.5	16	29.3	38.8	53.5	46	67.6	77.6	100.8
-35	5.5"	2.6	8.2	17	30.3	39.9	54.8	47	69.3	79.2	102.7
-30	1.7"	4.9	11.1	18	31.3	40.9	56.1	48	70.9	80.8	104.6
-25	1.2	7.5	14.3	19	32.4	42.0	57.4	49	72.6	82.4	106.6
-20	3.5	10.2	17.8	20	33.4	43.1	58.8	50	74.3	84.1	108.6
-18	4.5	11.4	19.3	21	34.5	44.2	60.1	55	83.2	92.6	118.8
-16	5.6	12.6	20.9	22	35.5	45.3	61.5	60	92.6	101.6	129.7
-14	6.7	13.9	22.5	23	36.6	46.5	62.9	65	102.8	111.3	141.3
-12	7.8	15.2	24.1	24	37.7	47.6	64.3	70	113.8	121.5	153.6
-10	9.0	16.5	25.8	25	38.8	48.8	65.8	75	125.5	132.2	166.6
-8	10.2	17.9	27.6	26	40.0	50.0	67.2	80	138.0	143.7	180.3
-6	11.5	19.4	29.4	27	41.2	51.2	68.7	85	151.4	155.7	194.8
-4	12.8	20.9	31.3	28	42.4	52.4	70.2	90	165.5	168.4	210.2
-2	14.2	22.4	33.2	29	43.7	53.7	71.7	95	180.6	181.9	226.4
0	15.6	24.0	35.2	30	44.9	54.9	73.3	100	196.7	196.0	243.5
1	16.4	24.8	36.2	31	46.1	56.2	74.8	105	213.9	210.8	261.6
2	17.1	25.7	37.3	32	47.4	57.5	76.4	110	231.8	226.4	280.6
3	17.9	26.5	38.3	33	48.7	58.8	78.0	115	251.0	242.8	300.7
4	18.7	27.4	39.4	34	50.0	60.2	79.6	120	271.1	260.0	321.9
5	19.5	28.3	40.5	35	51.4	61.5	81.3	125	292.5	278.1	344.3
6	20.3	29.1	41.6	36	52.7	62.9	82.9	130	314.9	297.0	367.8
7	21.1	30.0	42.7	37	54.1	64.3	84.6	135	338.8	316.8	392.6
8	22.0	31.0	43.8	38	55.5	65.7	86.3	140	363.5	337.5	418.7
9	22.8	31.9	45.0	39	57.0	67.1	88.1	145	390.2	359.1	446.3
10	23.7	32.8	46.2	40	58.4	68.6	89.8	150	417.4	381.7	475.3
11	24.6	33.8	47.3	41	59.2	70.0	91.6	155	447.0	405.4	505.8

YORK Refrigeration YORK INTERNATIONAL 100 CV Ave., Waynesboro, PA 17268 • 717-762-2121 www.frickcold.com

testo

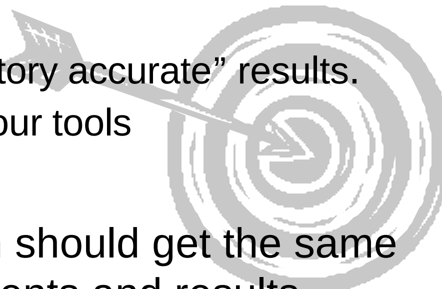
Thermometers and Psychrometers

- Thermometers
  - Sensor tolerances
  - Measurement technique
  - Sensor drift
- Sling Psychrometers
  - Proper air velocity
  - Distilled water
  - Low resolution
  - "Speed reading"



Why does equipment fail???

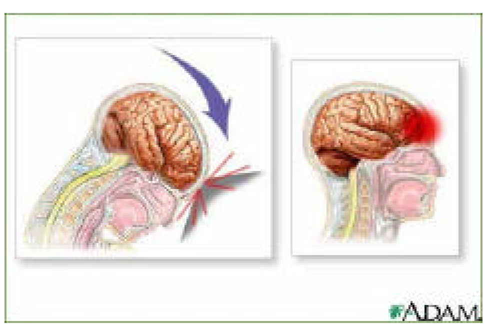
- Our test instruments and techniques do not measure up
  - We can't get "factory accurate" results.
  - We cannot trust our tools



Tech after tech should get the same measurements and results….

How often do you think that happens?

Insanity: Doing the same thing over and over, each each time expecting a different result.



There is a better way to:

- Make correct measurements the right way without hurting your frontal lobe.
- Get lab accurate results in the field.
- Get the job done right the first time in *less* time.
- Guarantee the efficiency and capacity you have been selling.

REMEMBER
There are no theories in HVAC/R!

- Air conditioning is made of scientific facts
  - Repeatable
  - Universal
  - Well proven
  - Understandable
  - Provable
  - And you can do it!
- Measurements are made to prove facts!

System Design

- Measurements on their own mean nothing without knowledge of the design operation
- ARI Design conditions
  - What's your "design temperature"?

Appliance Commissioning vs. System Commissioning

- Too often technicians repair the appliance instead of the system.
- Symptoms at the appliance often indicate problems elsewhere in the system.
- It is imperative we teach system commissioning and not just appliance start-up.
- Airflow and refrigerant charge are two of the most common misunderstood and improperly adjusted parameters in our industry
- **How are you addressing the problem?**

Accurate Instruments are Important!

- Problems inherent with instrumentation lead to misdiagnoses.
- Technician after technician should get the same measured results.
  - Technicians should be able to make equipment operate in the field as well as it did in the lab!!! (You need lab accurate instruments to do it!!!)

Achieving Proper Charge:
523 Refrigeration System Analyzer

- A digital window into AC/R systems
  - Superior accuracy
  - Greater speed
  - Real-time calculations
  - All-in-one tool
  - Confidently charge at low ambient temps
  - Graphic capabilities

DEALER DESIGN AWARDS

NEWS | SILVER

TestoKool 523

- Displays:
  - High/Low pressure
  - Evaporating & Condensing temperatures
  - Calculates superheat or subcooling in real time
- Works with all refrigerants (except ammonia)
- 2-way manifold with sight glass

TestoKool 523

- Advanced features & benefits
  - Datalogs / monitors system
  - Powerful PC analysis software
  - Refrigerant upgrades off the ‘net
  - Pressure-Leak test mode
  - Easy precision charging
  - Confidently charge at low ambient

Digital does it better!

- Leading to:
  - Fewer call-backs
  - Increased profitability
- A laboratory accurate instrument designed for use in the field
- Allows trending & more complex functions
- Saves time & works when you are not there
- Records without human error
- Stays in calibration
- More reliable
- Higher repeatability
- Provides accurate results for your customers
- Plus they are really cool!!!!

Why go digital?

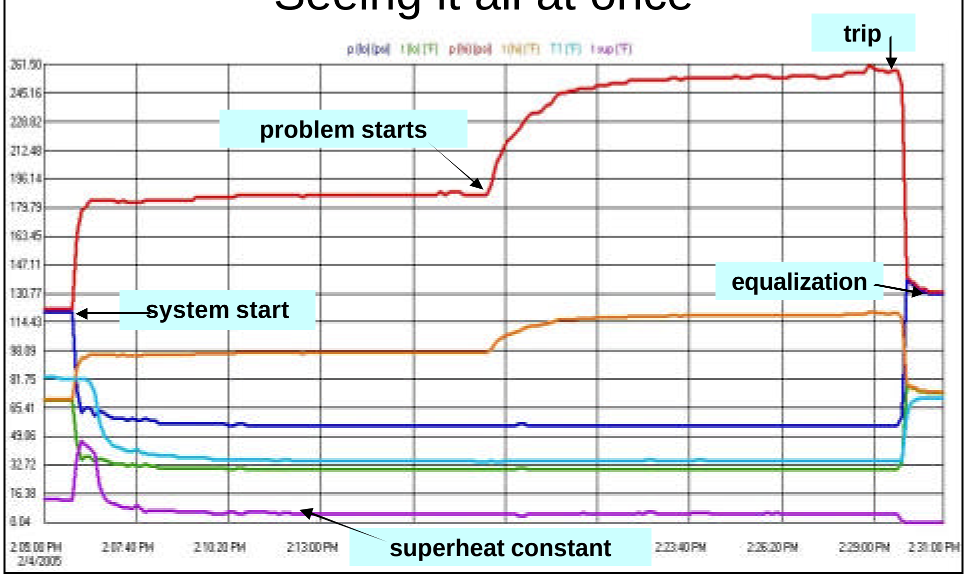
- Integrated temperature probe for superheat and subcooling
- Equipment upgrade
  - New refrigerants: Eg 410A
  - Improve your understanding of refrigeration
  - The value of a 0.5% gauge, vs. 1%, 2%, 3%
- Charge directly by superheat & subcooling
  - See what's happening, not what happened!
  - Rather than by pressures, temperatures, P/T charts

Why use a digital manifold?

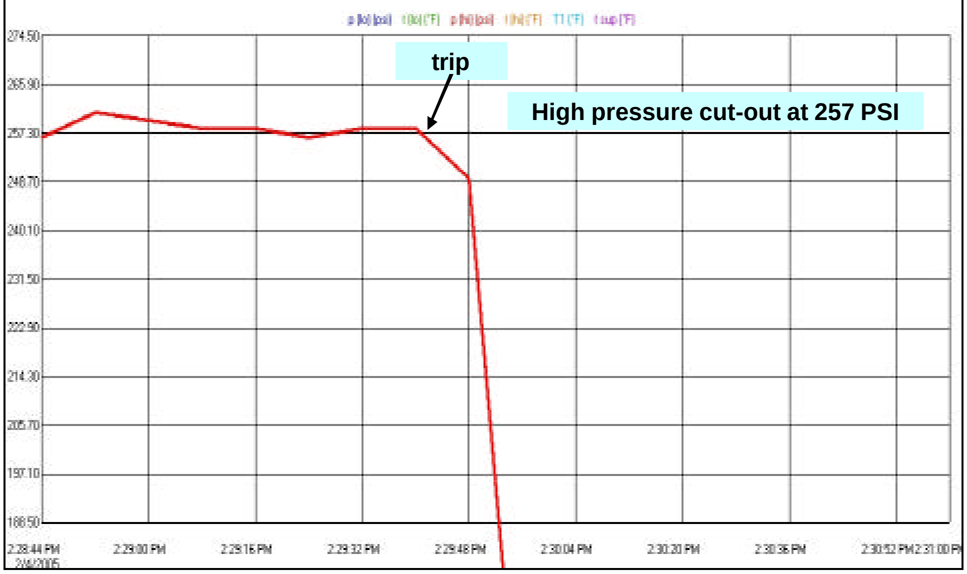
- Repeatability
- Accuracy
- Real-time calculations = real-time answers
- See “The Big Picture”
  - Suction and discharge pressures
  - Superheat and subcooling
  - Saturation temperatures
  - True operational curves
  - Run cycle info – start/stop/was it long enough

“The Big Picture”

Seeing it all at once



Zoom in



Superheat Showdown

Analog

- Connect hoses to system
- Measure suction line temperature
- Measure suction pressure
- Convert to saturation temperature
- Subtract saturation temp. from measured temp.
- You now have ***one average*** Superheat reading
- Adjust charge (change parts?)
- Repeat

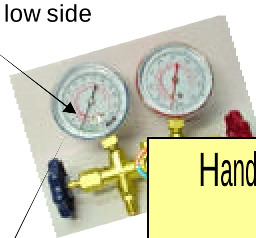
Digital

- Turn on meter
- Connect hoses to system
- Attach temperature probe and hit “enter”
- You now have ***Real-time*** Superheat heat readings

new 13 SEER (TXV) system
R-22, 8º subcooling
Correct Airflow
Low load

In the analog world

53 – 61 PSI on low side



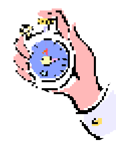
29 to 34°F line temp

Hand calculated superheat

30 -29 = 1°F

35-29 = 6°F

Reads as 30 to 35°F
On the gauge scale
(R-22)

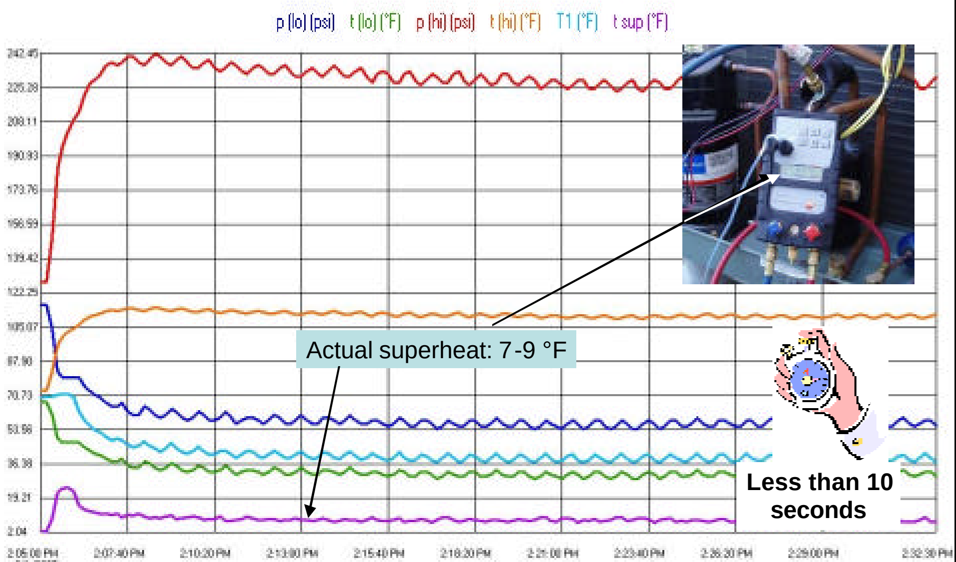


3- 5 minutes

LOW SUPERHEAT!
This looks like it could be a problem!

What is your solution?

In the digital world



Analog vs. digital

- Analog superheat Awww %@#, it wasn't a bad TXV!
  - 1 to 6 degrees – ~~**out of spec!**~~
- Real-time (digital) superheat
  - 7 to 9 degrees – OK for load condition
- The difference is the real-time readings!
  - vs. the "averaging" extremes, eyeballing the needles, and interpolating the analog readings

No technicians or systems were harmed during this testing.

It's your choice…

Waste your time and fix the problem that doesn't exist

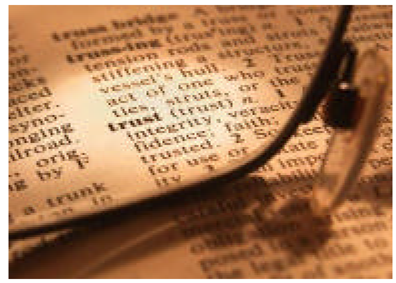
Or

Get on with the next job!

How many warranty parts to fix this one?

You can trust your digital tools

- As long as they are:
  - NIST traceable
  - Repeatable
  - Easy to work with
  - Reliable
  - Durable



Do it right, do it once!

Do it digitally!

Your keys for success in a 13 SEER world

- Testo 523 Digital Refrigeration Analyzer
- Testo 416 Mini Vane Anemometer
- Testo 605-H2 Wet-Bulb Hygrometer
- Testo 506-3 (+/-80”) Digital Manometer
- Testo Air-conditioning Applications Guide