Understanding Dehumidification Performance at Part Load in Commercial Applications

ASHRAE Region V CRC
August 12, 2005

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DOE/NETL Project #DE-FC26-01NT41253

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Overview

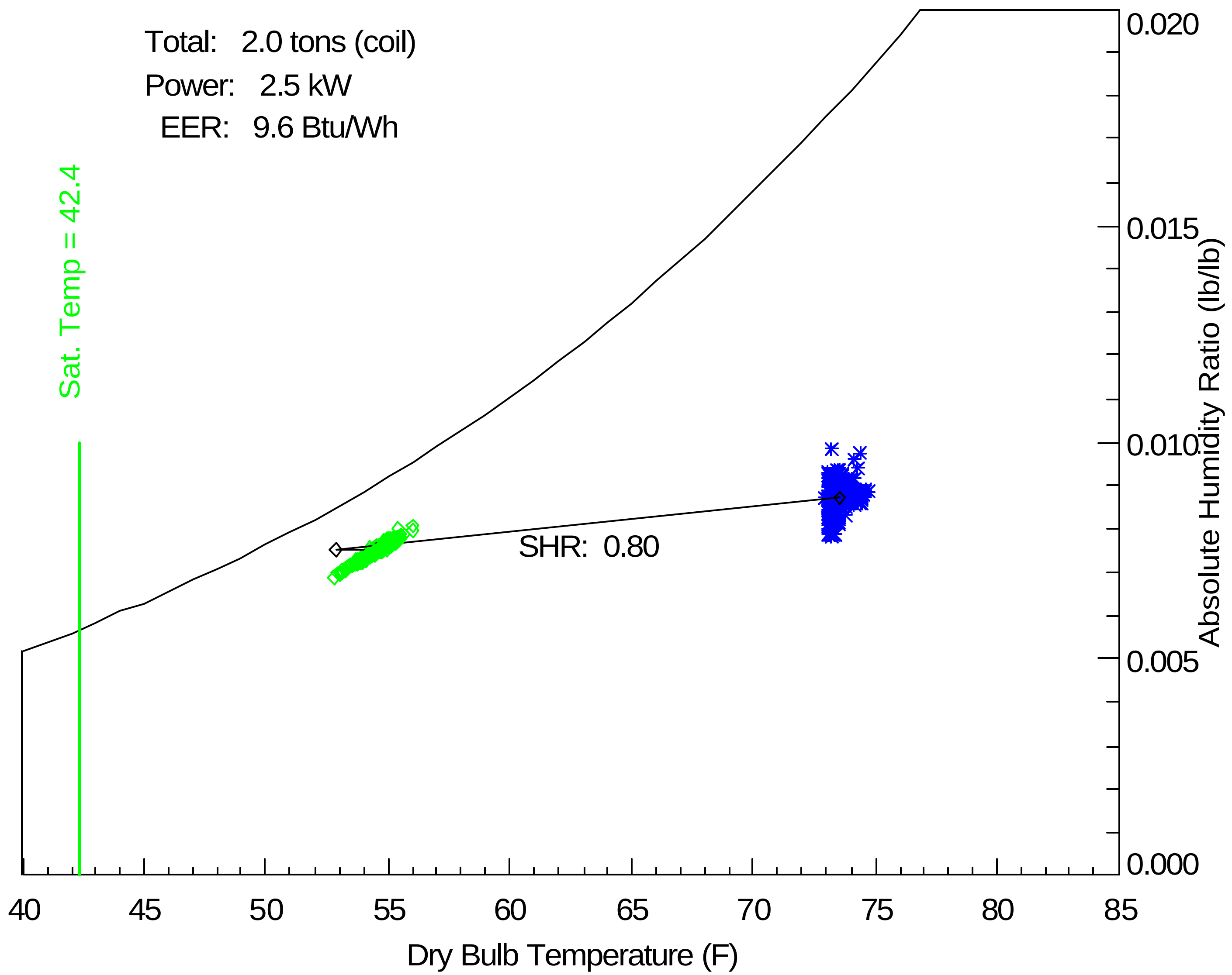
- DOE Research Project Results
  - field tested various commercial and residential cooling systems
  - detailed laboratory tests of DX and CHW coils
  - Findings: latent capacity degrades at part load conditions

- Implications for equipment manufacturers & design engineers?
  - Calcs at sensible or latent design conditions are not enough
  - Staging is key

Steady-State Cooling Coil Performance

- Cooling coil performance is well understood at steady-state conditions
  - Coils provide both sensible cooling and moisture removal (latent cooling)
  - SHR: *sensible heat ratio*…..fraction of total cooling that is sensible
  - Colder coil surfaces remove more moisture
  - Reduced air flow provides more moisture removal (for DX coils)
  - Higher condenser/outdoor temperatures increase SHR

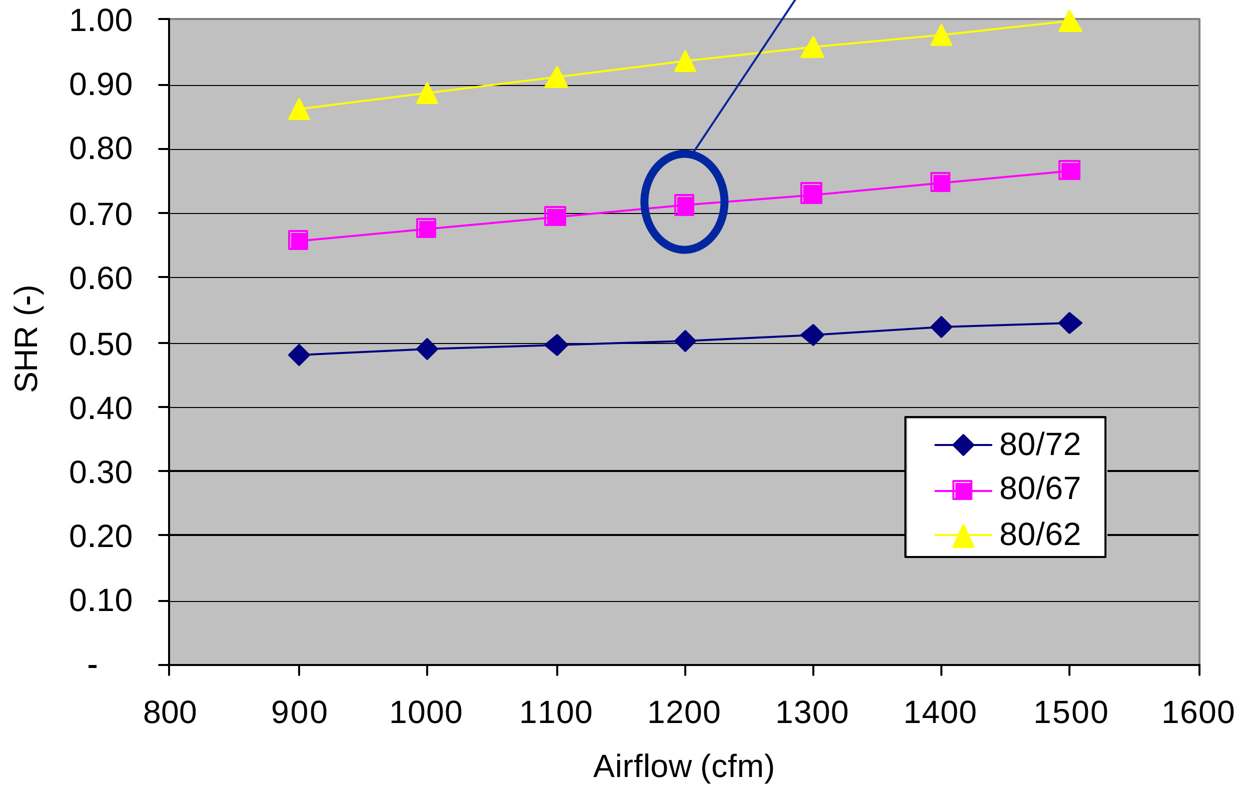
Typical AC Coil Performance



Catalog Data for 3-ton RTU

- SHR is decreases with…
  - Lower air flow cfm/ton
  - Higher WB (actually RH)

Nominal Rating Point: SHR ~ 0.71



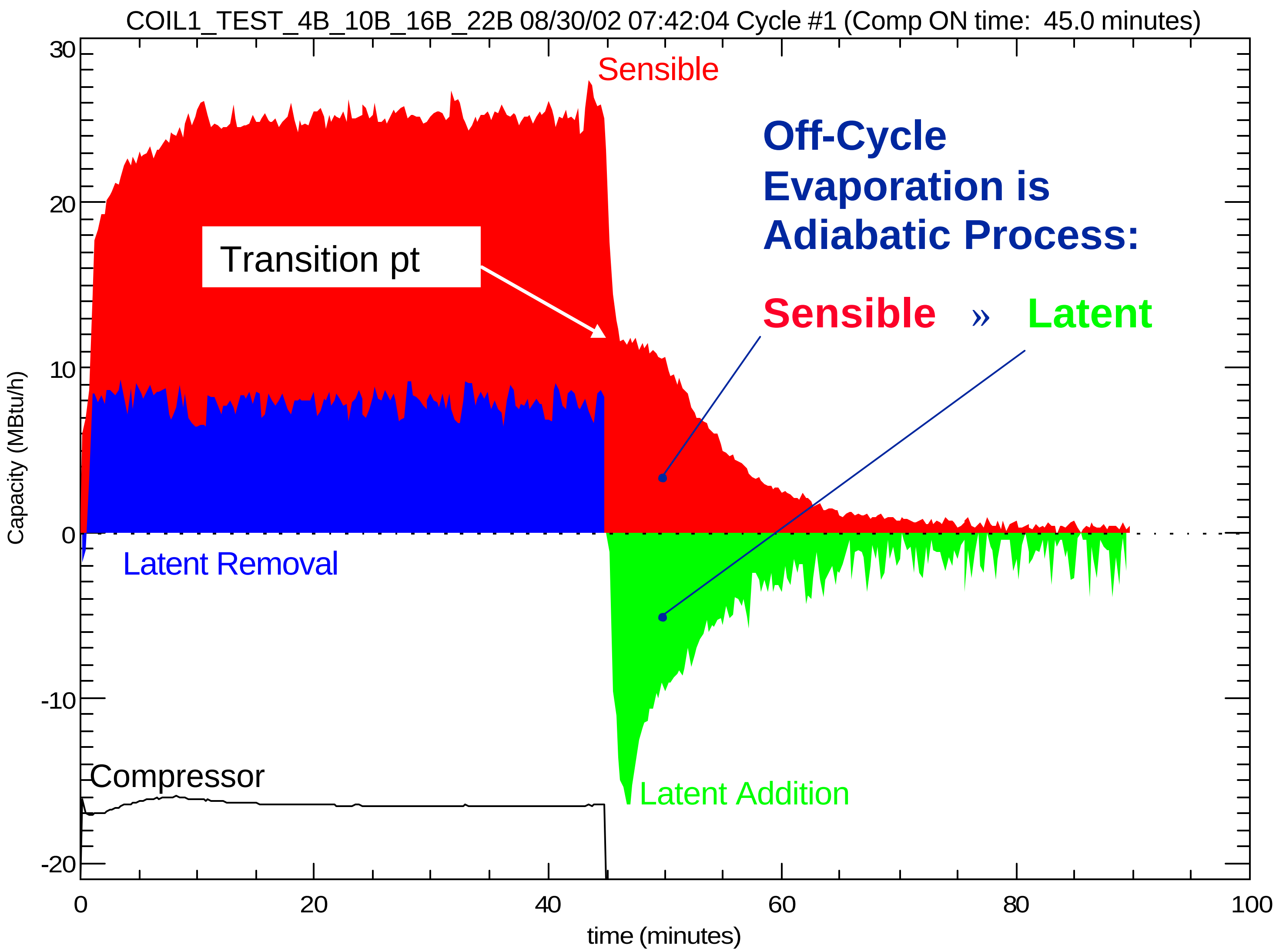
DX Part Load Performance

- AC cycles compressor ON and OFF based on a space thermostat
- The portion of time the coil operates (i.e., the runtime fraction) is longer when cooling loads are greater

$$RTF = \frac{ON}{(ON + OFF)}$$

- How do sensible and latent capacity vary under cyclic conditions?

Sensible and Latent Capacity With Continuous Supply Air Fan Operation



Sensible Heat Ratio (SHR) vs Efficiency Debate

- Some in the industry assert that high efficiency AC have lowered SHRs
  - ARI studies of industry test data have shown steady-state SHRs remain near 0.75 …. unchanged from the past

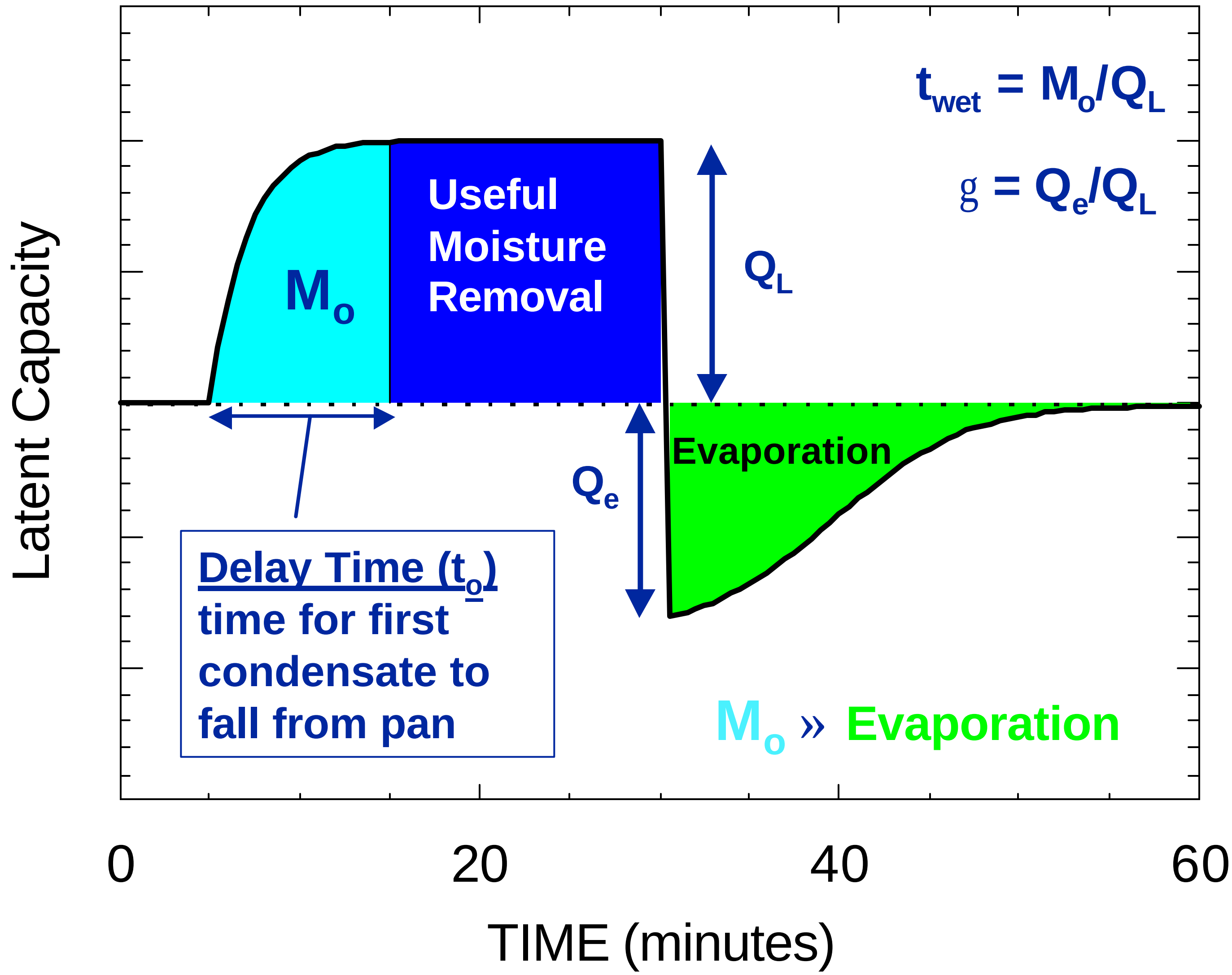
- Part-load latent degradation may explain some of this disconnect
  - newer equipment may use larger coils and lower suction temperatures to achieve the same SHR
  - steady-state performance is unchanged….but part-load characteristics may be affected

Lab & Field Test Results

&

Eng. Model Development

Latent Degradation Concepts

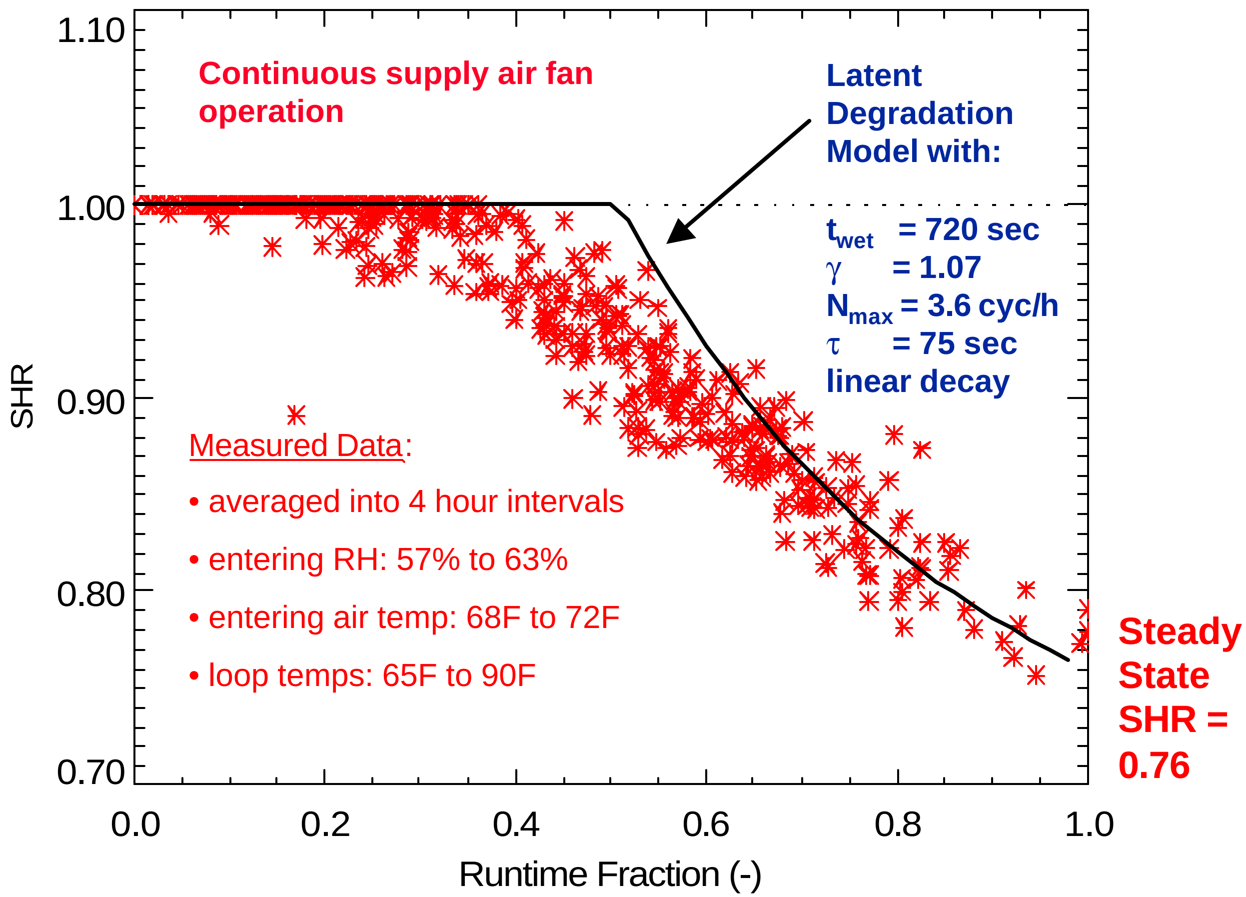


LHR Degradation Model

- Borrowed approaches used to develop part-load efficiency degradation function for SEER test procedure
- Used same part-load assumptions (C_d):
  - AC at startup described by a time constant
  - Cycling rate driven by thermostat curve
- Additional latent assumptions:
  - Coil surfaces hold a fixed amount of moisture (M_o)
  - Off-cycle coil is like an evaporative cooler

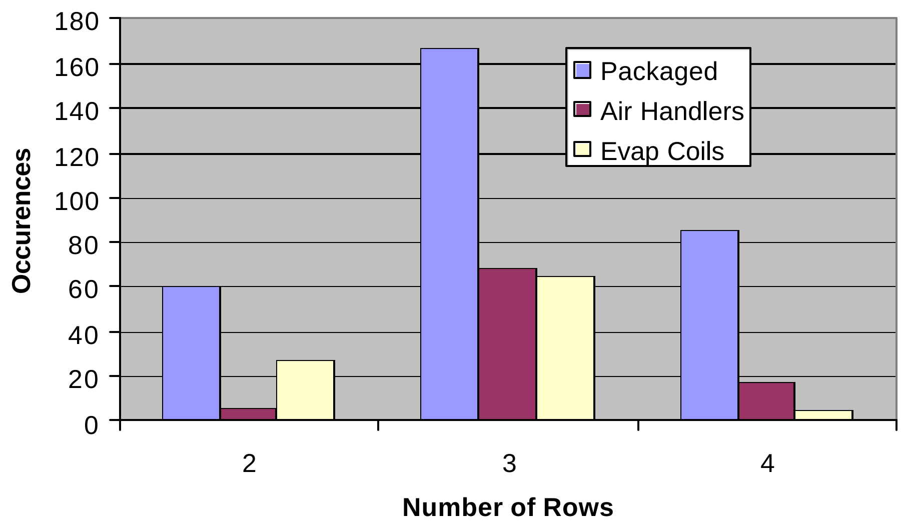
Comparing LHR Model to Field Tests

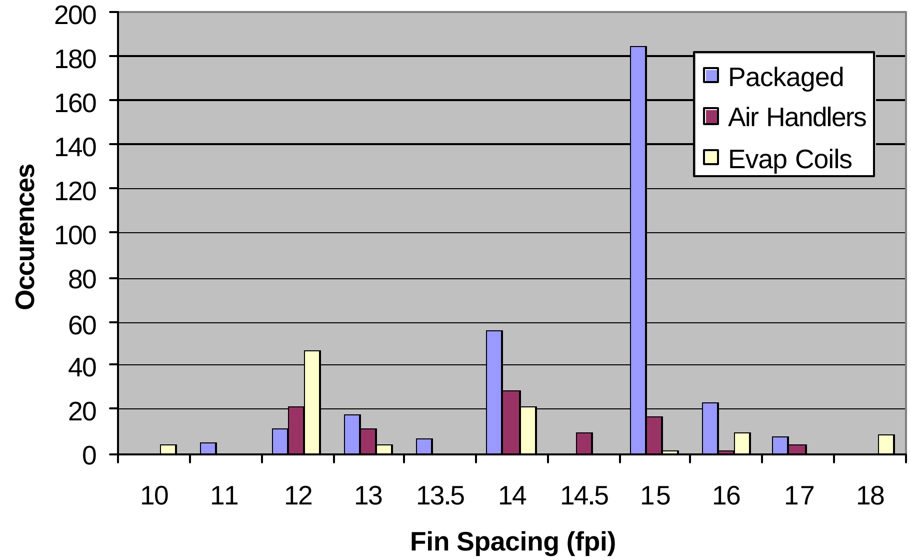
- Henderson (1998) compared the model results to field data collected on a 3-ton residential geothermal heat pump



Equipment Survey

- Reviewed specifications for 500 commercial and residential AC units
- Goal was to determine
  - range of common coil geometries
  - Variation by equipment type
- Typical DX AC coil is 3-rows, 15 fpi





Field Testing

- Six field test sites were recruited:

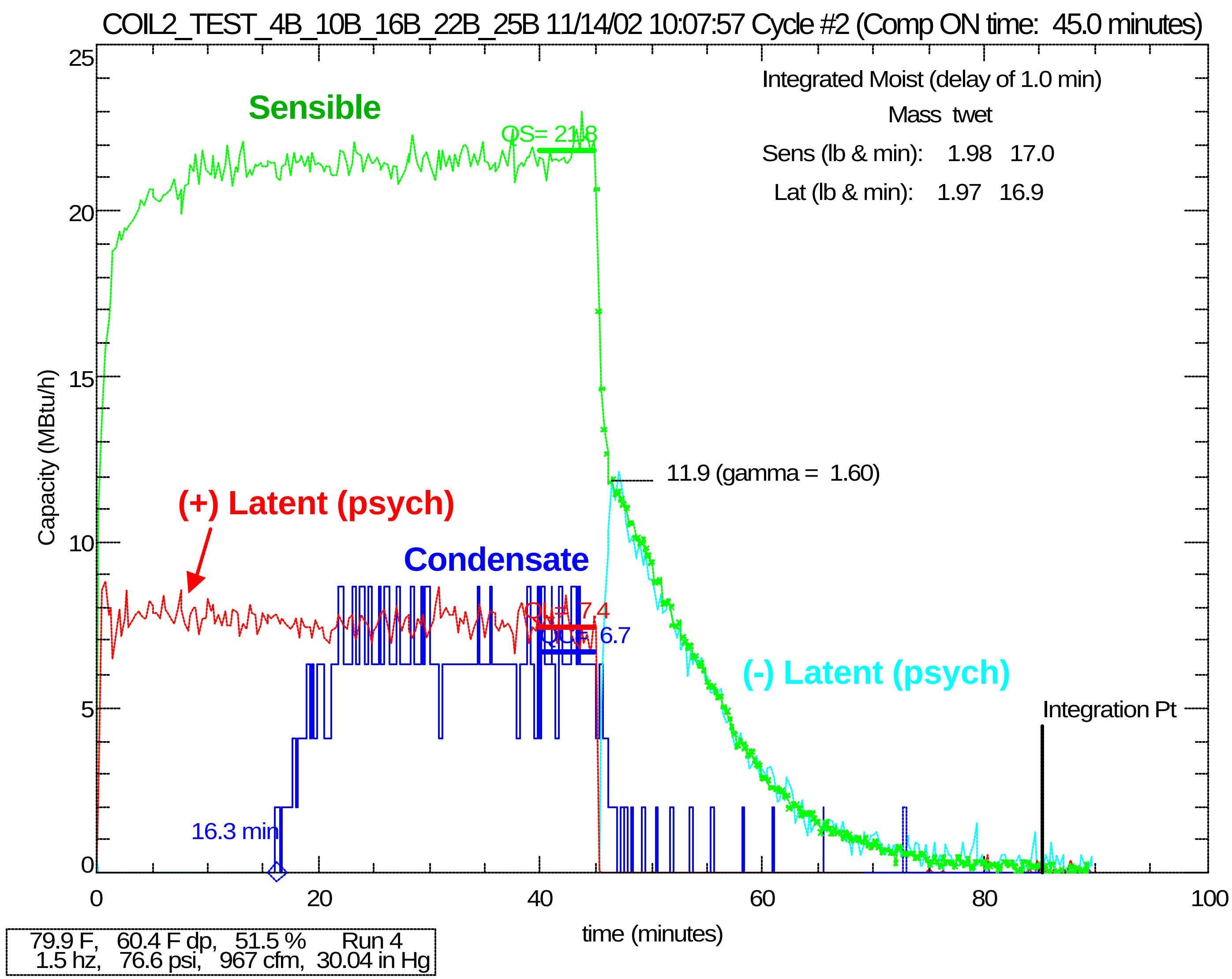
  Residential (5 units at 4 sites)

  - 5-ton single-speed residential DX system in Connecticut
  - Two single-speed DX units (2.5-ton and 3-ton) at a Virginia residence
  - 3.5-ton residential DX system in Florida (single-speed condensing unit with variable speed air handler)
  - 3-ton residential DX system in Florida (two-speed condensing unit with variable speed air handler)

  Commercial (3 units at 2 sites)

  - 10-ton commercial rooftop DX unit in Boston (2 stage)
  - Commercial constant-air-volume chilled water coil in Florida (3 ton)
  - Commercial variable-air-volume chilled water coil in Florida (7 ton)

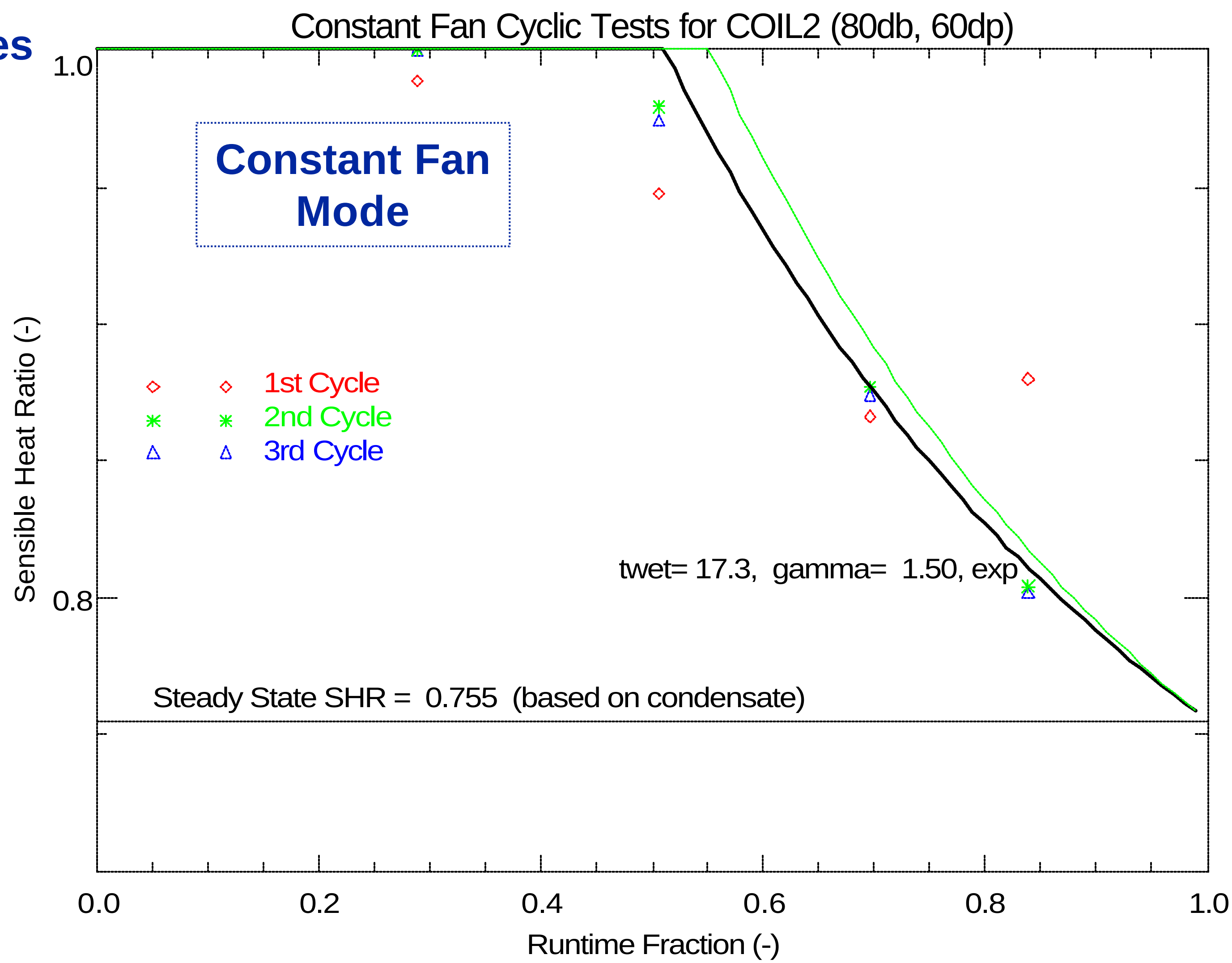
Actual Laboratory Results



Laboratory Testing – SHR Degradation

LHR Model matches measured data at nominal entering conditions

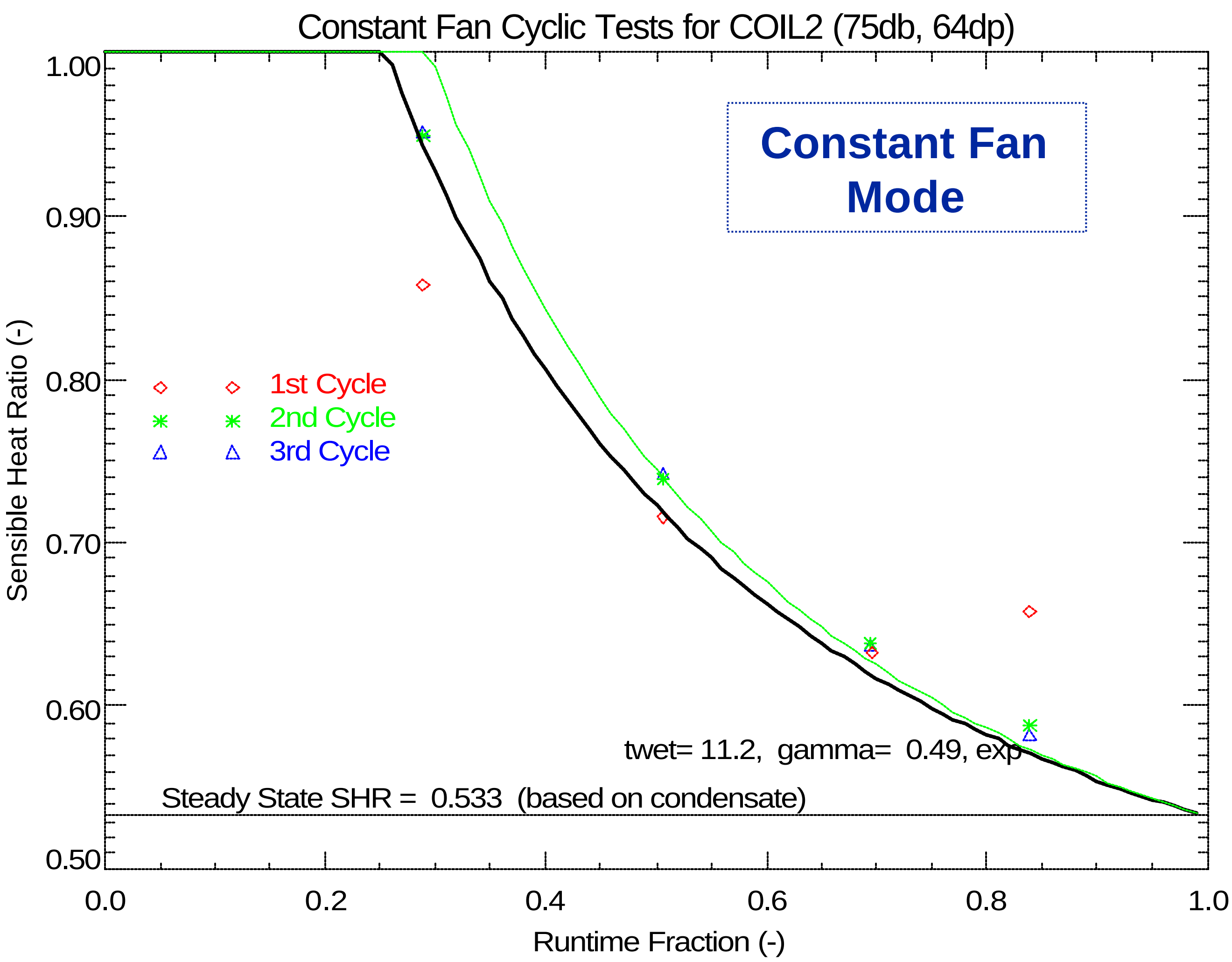
(80F db, 60.4F dp)



Laboratory Testing – SHR Degradation (cont.)

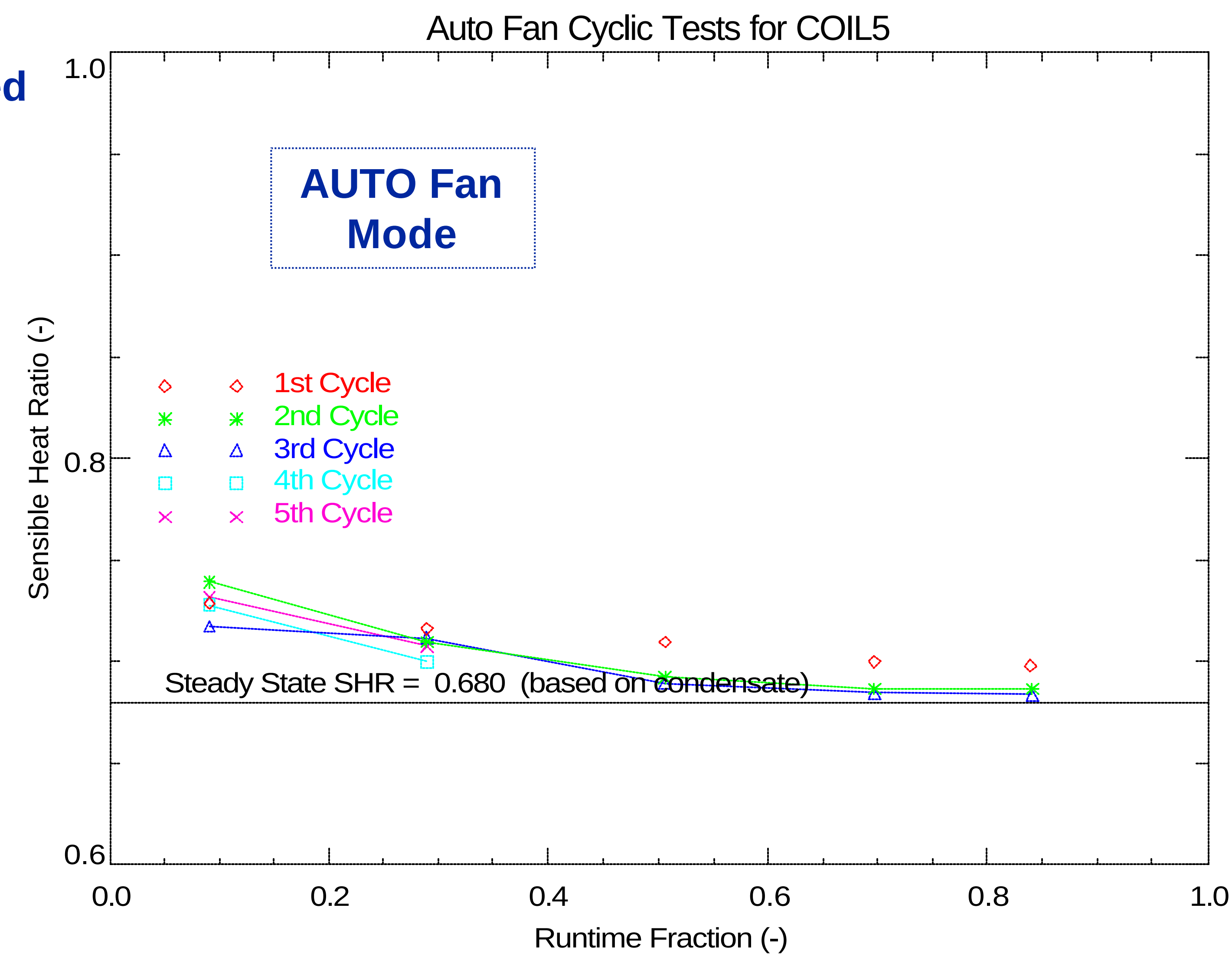
Model also matched measured data at other entering conditions!

(75F db, 64F dp)



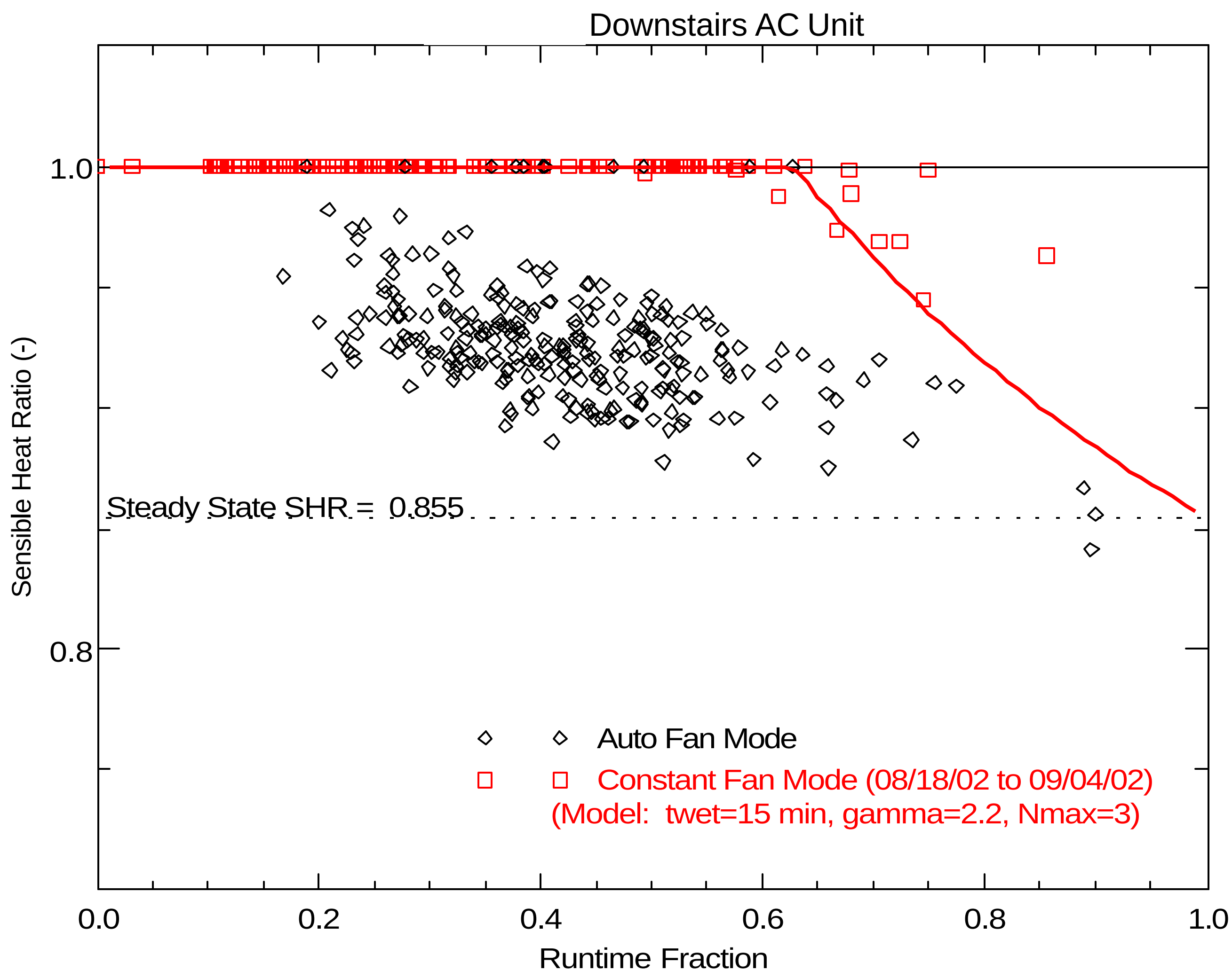
Laboratory Testing – SHR Degradation (cont.)

Coil 5 showed impact in AUTO Fan Mode!



Field Testing – SHR Degradation

Significant AUTO fan degradation!

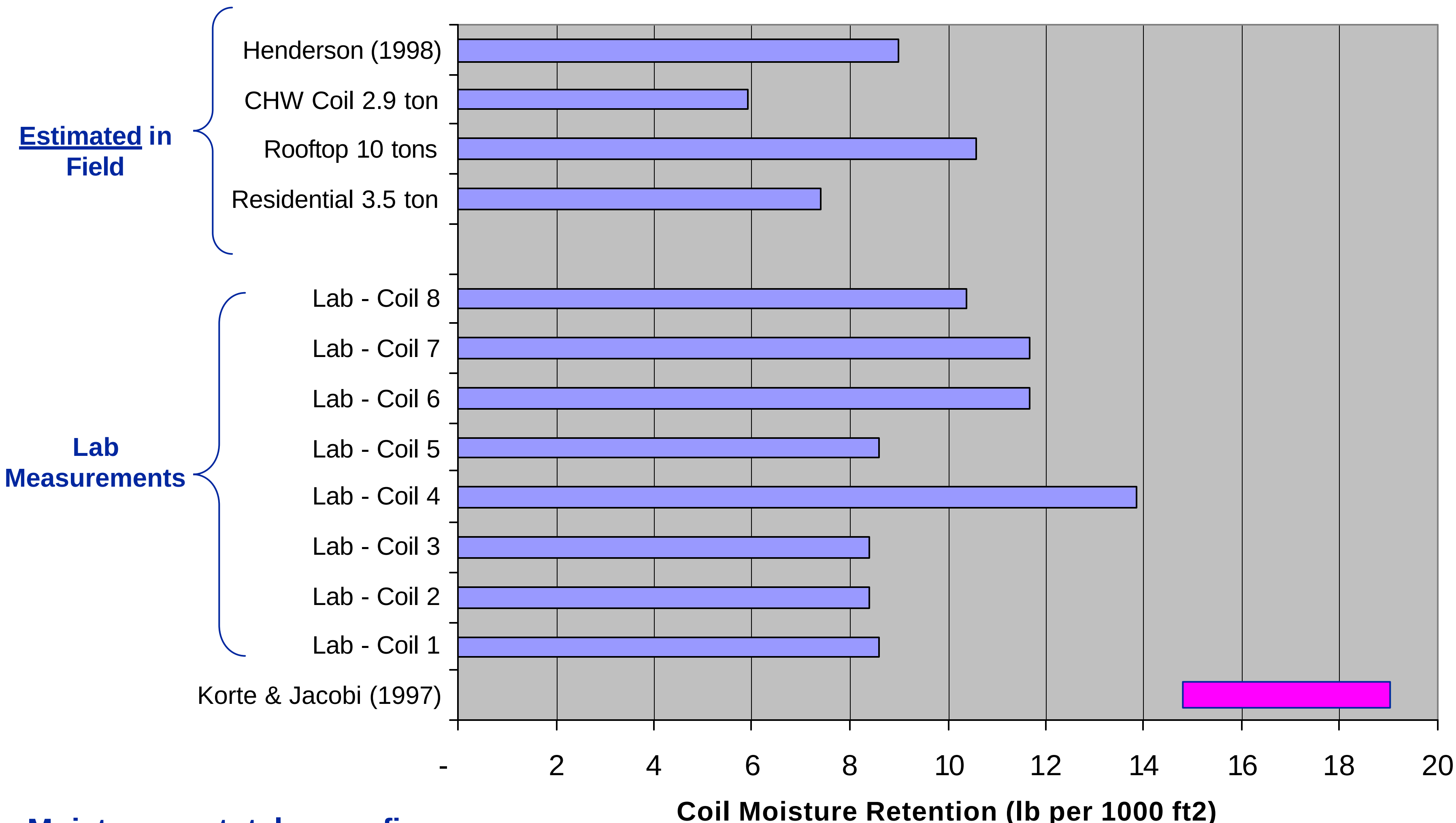


Measured Performance Parameters

	Size (tons)	Fin Surface Area (ft^2)	Retained Moisture Mass (lb)	(lb/kft^2)	Cond Delay Time (min)	t_{wet} (min)
Coil 1 (Slanted slab, 3 row, 13 fpi, plain fins, orifice)	2.9	243.8	2.1	8.6	13.5	16.5
Coil 2 – Normal Flow (A-coil, 3 rows, 15.5 fpi, lanced sine-wave fins, TXV)	2.4	237.8	2.0	8.4	16.3	17.0
Coil 2 – Low Flow (A-coil, 3 rows, 15.5 fpi, lanced sine-wave fins, TXV)	1.4	237.8	2.0	8.4	32.5	29.0
Coil 4 (vert. slab, 2 rows, 14 fpi, wavy fins, orifice)	1.8	137.4	1.9	13.8	23.5	18.5
Coil 5 (slanted slab, 4 rows, 12 fpi, wavy fins, orifice)	2.3	162.7	1.4	8.6	11.5	9.5
Coil 6 (A-coil, 3 rows, 13 fpi, wavy fins,TXV)	1.7	231.1	2.7	11.7	34.0	33.
Coil 6 – High Flow (A-coil, 3 rows, 13 fpi, wavy fins,TXV)	2.0	231.1	2.7	11.7	27.0	27.
Coil 8 – Chilled Water (vert. slab, 4 rows, 10 fpi, wavy fins,46°F CHW)	1.5	135.0	1.4	10.4	26.5	26.5

Notes:
1- Cooling capacity includes sensible and latent cooling at nominal conditions. Nominal conditions correspond to ASHRAE Test A test point.
2- Surface area is gross fin area (coil face area x coil depth x fin spacing x 2).
3- Condensate delay time and t_{wet} are at nominal conditions.

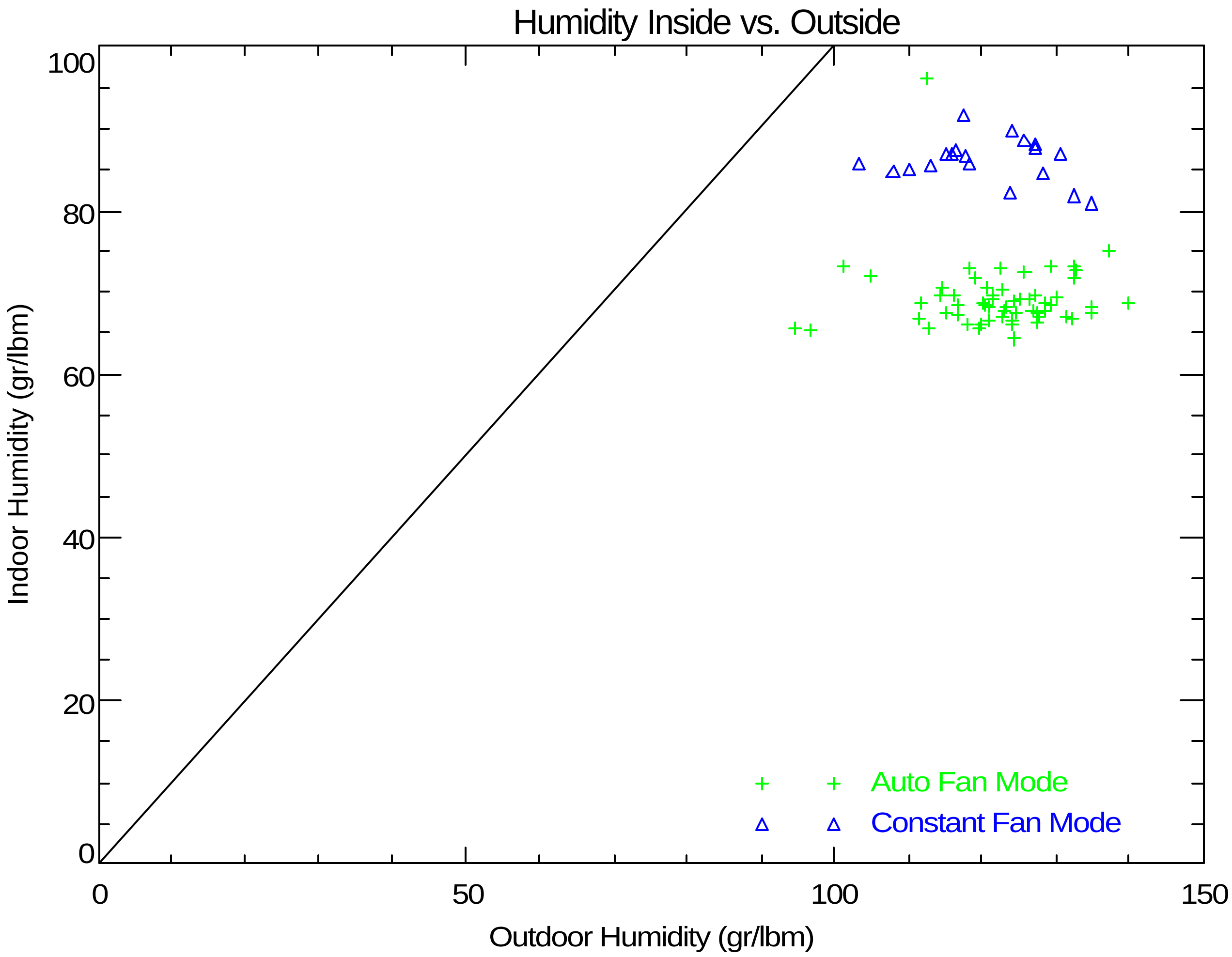
Lab + Field: Retained Moisture



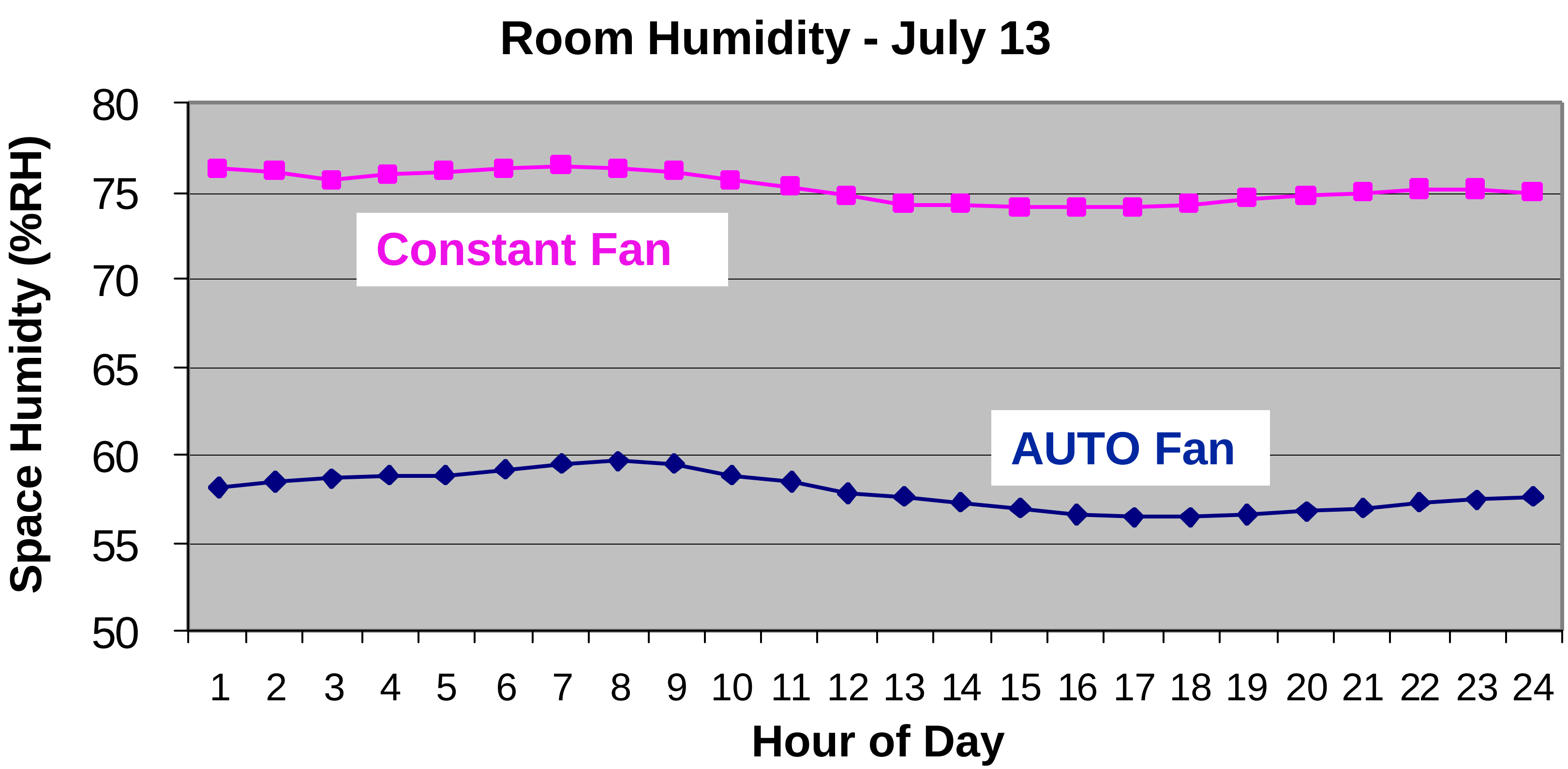
Moisture per total gross fin area
(gross area = face area x depth x fin spacing x 2)

***Space Humidity** – Impact of Constant Fan*

- Large penalty for constant fan operation
- Even for a dual-capacity AC unit



Impact on Space Humidity Levels



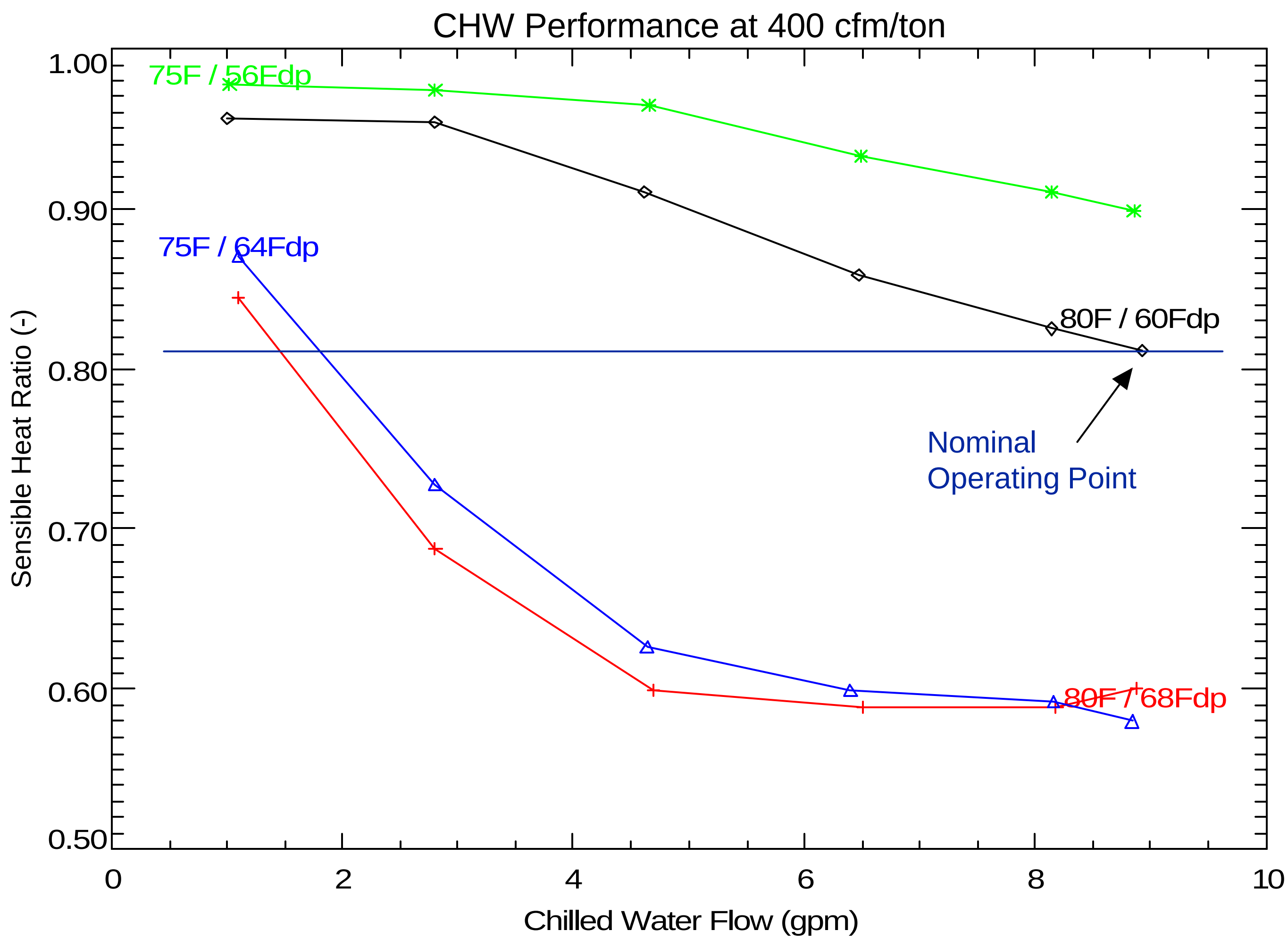
TRNSYS Model of Hotel Room in Hawaii

Chilled Water Coils

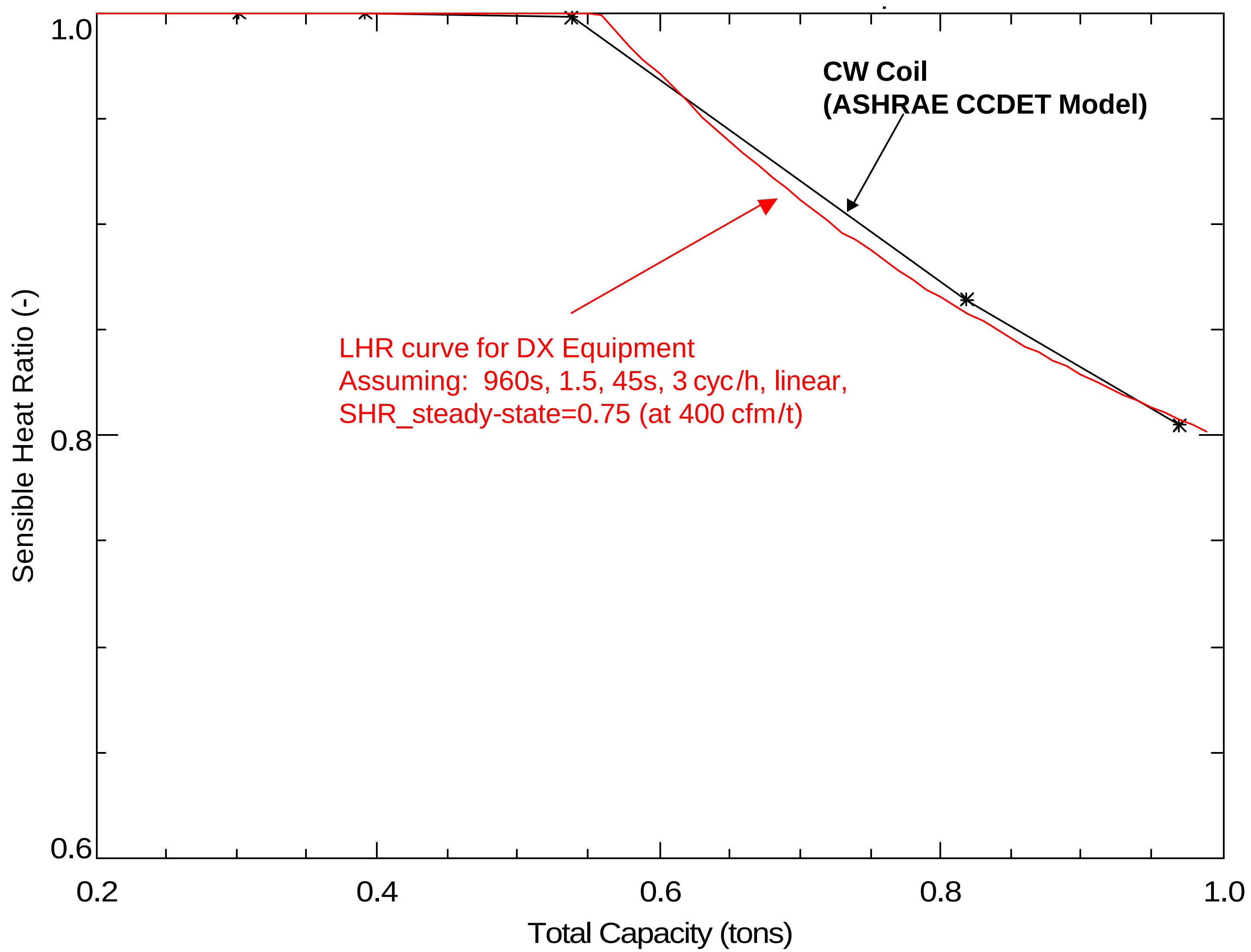
Chilled Water Coil Performance

Chilled water coils behave similar to direct expansion (DX) coils …..even though they are controlled differently

- **gpm varies to provide capacity**



Latent Degradation - CW Coils



What Can Equipment Manufacturers & Design Engineers Do?

What Control Strategies Help?

Do fan delay strategies help?

- No…not until about a 10 minute delay

Two-speed or staged capacity systems?

- Yes…increases runtime fraction (depends on coil split & fan control)

Reduced airflow during off cycle?

- Yes…would minimize off cycle evaporation

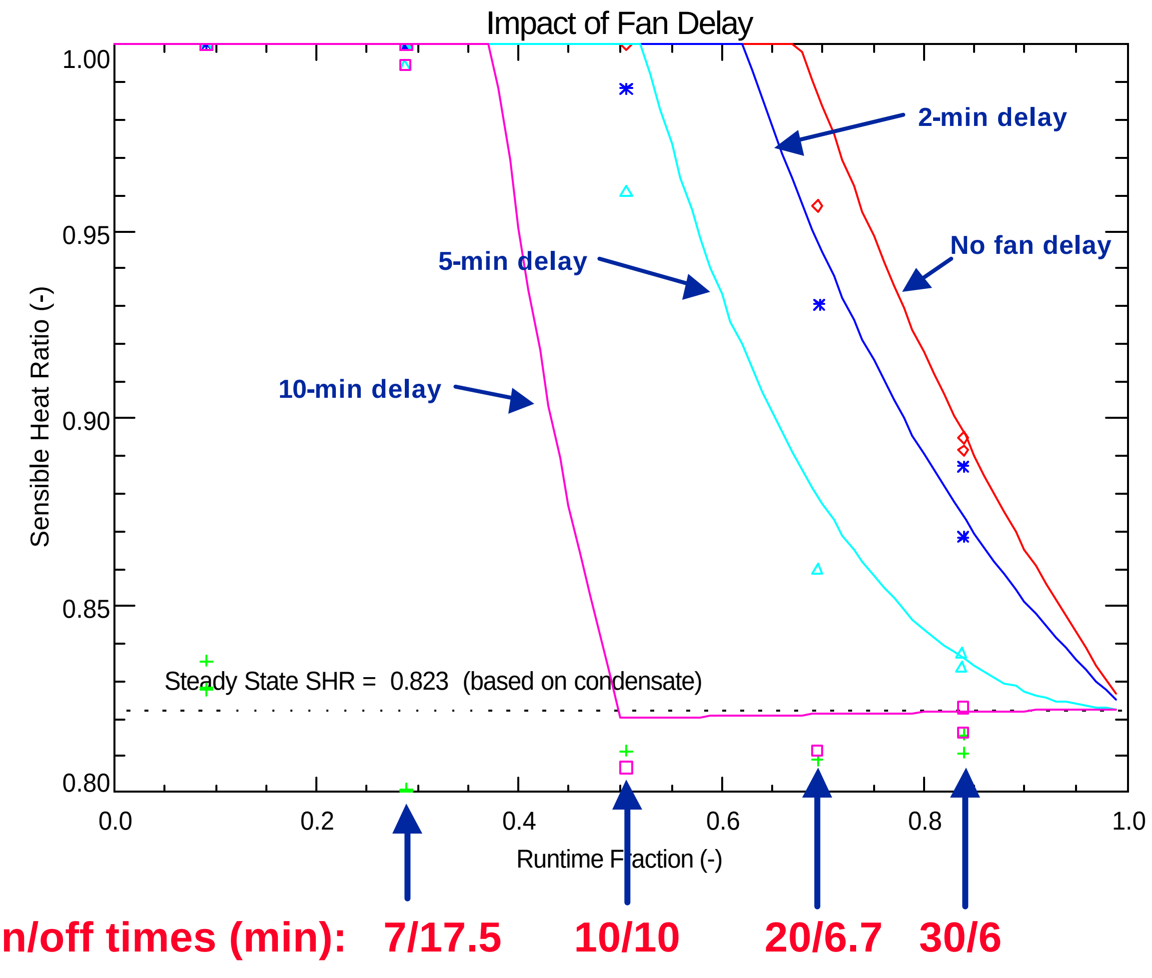
Cycle the fan with the compressor?

- Yes…whenever possible

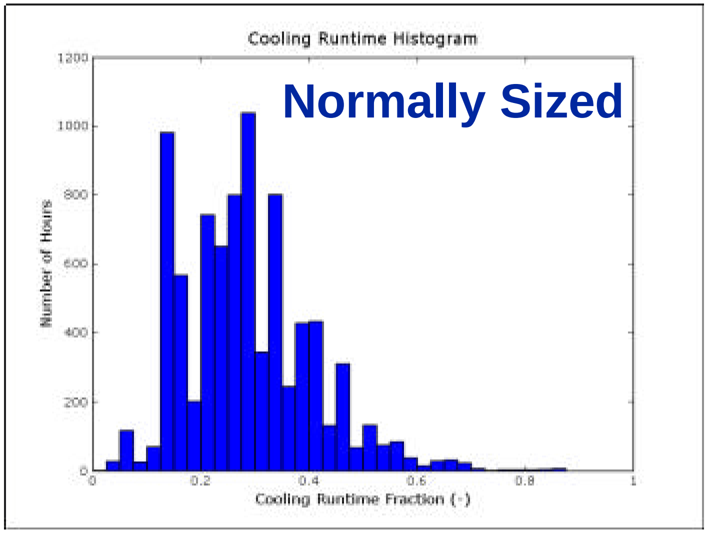
Impact of Fan Delay

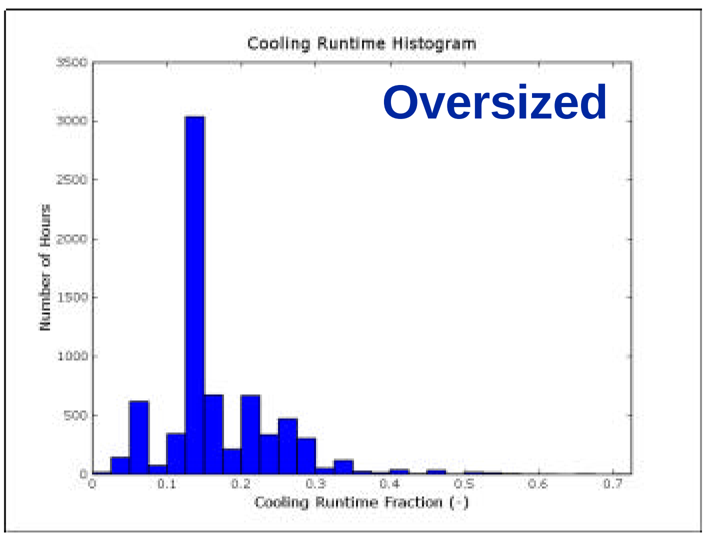
- **Fan was turned off for 2-, 5-, and 10-minutes after the cooling cycling to "*allow moisture to drain from the coil*".**

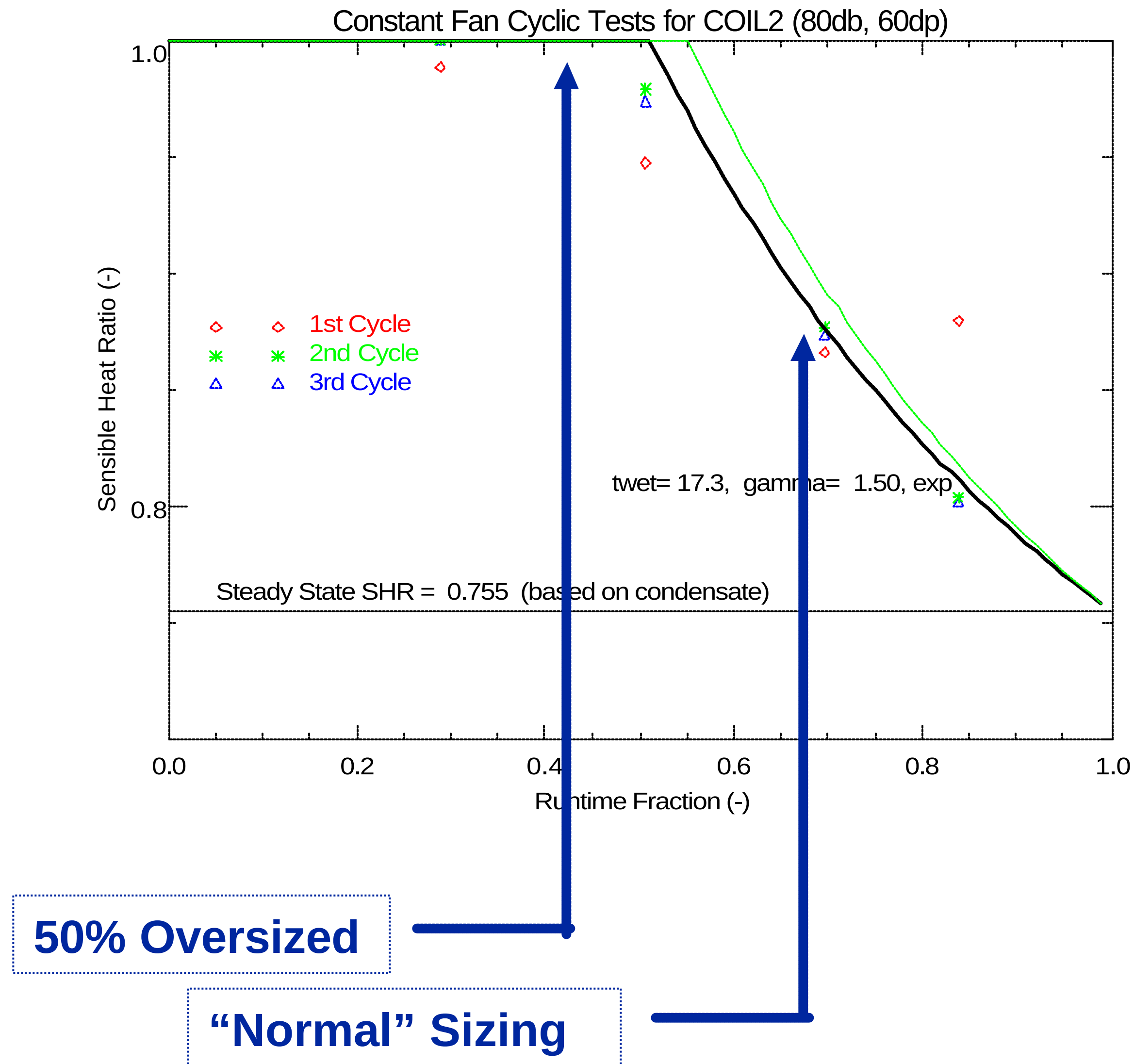
- **No significant "drainage" occurs**



Impact of Proper AC Sizing







Impact of Equipment Staging

- Specify 2-Stage RTUs
  - Most RTUs spend majority of operating time at less than 50% runtime…with no latent capacity
  - Continuous operation in first stage provides more latent removal at part load..assuming face-spilt coils
- Operate in continuous fan only when required
  - Consider cycling fan with compressor when ventilation is not required
  - Consider using lower air flow rate when cooling is off

Summary

- It takes 10 to 30 minutes after startup for moisture removal to begin
- A typical coil holds ½ to 1 lb per ton
- With constant fan, latent removal disappears below half load
- Chilled water coils have similar part load performance
- To maintain latent capacity
  - Cycle fan with the compressor (when possible)
  - Slow the fan down during off cycle
  - Add more capacity stages