Research which Explains and Quantifies Humidity Problems at Part-Load

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Seminar 3
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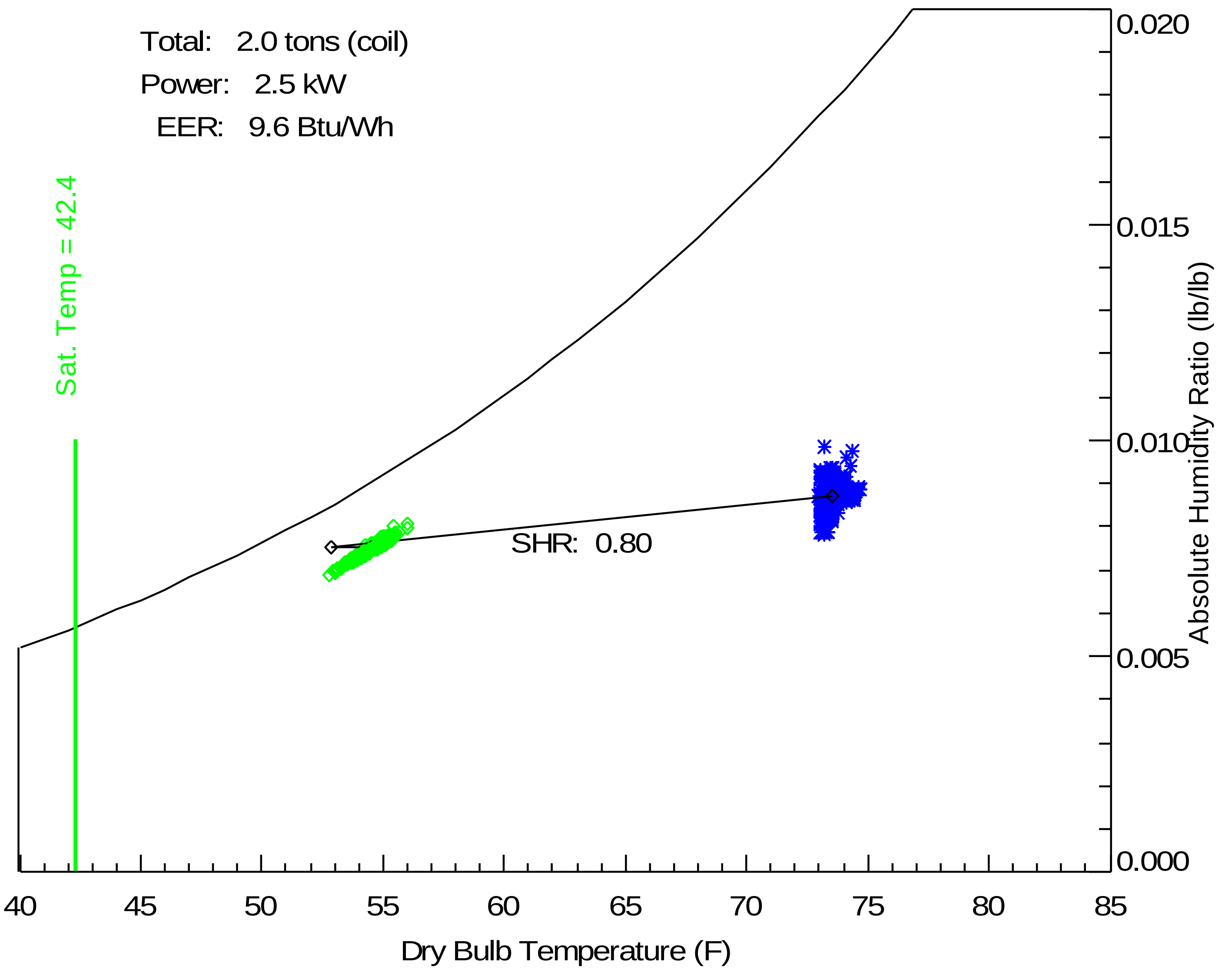
Overview

- Unitary air conditioners (AC) at steady state conditions
  - Off-design and full load performance are different
- Part-load dehumidification performance
  - Cyclic operation degrades latent capacity
  - Constant and “auto” fan control mode
- Show impact of latent degradation on space humidity levels
- What about chilled water coils?

Steady-State AC Performance

- Cooling coil performance is well understood at steady-state conditions
  - Evaporator coils provide both sensible and latent cooling (i.e., moisture removal or dehumidification)
  - **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)

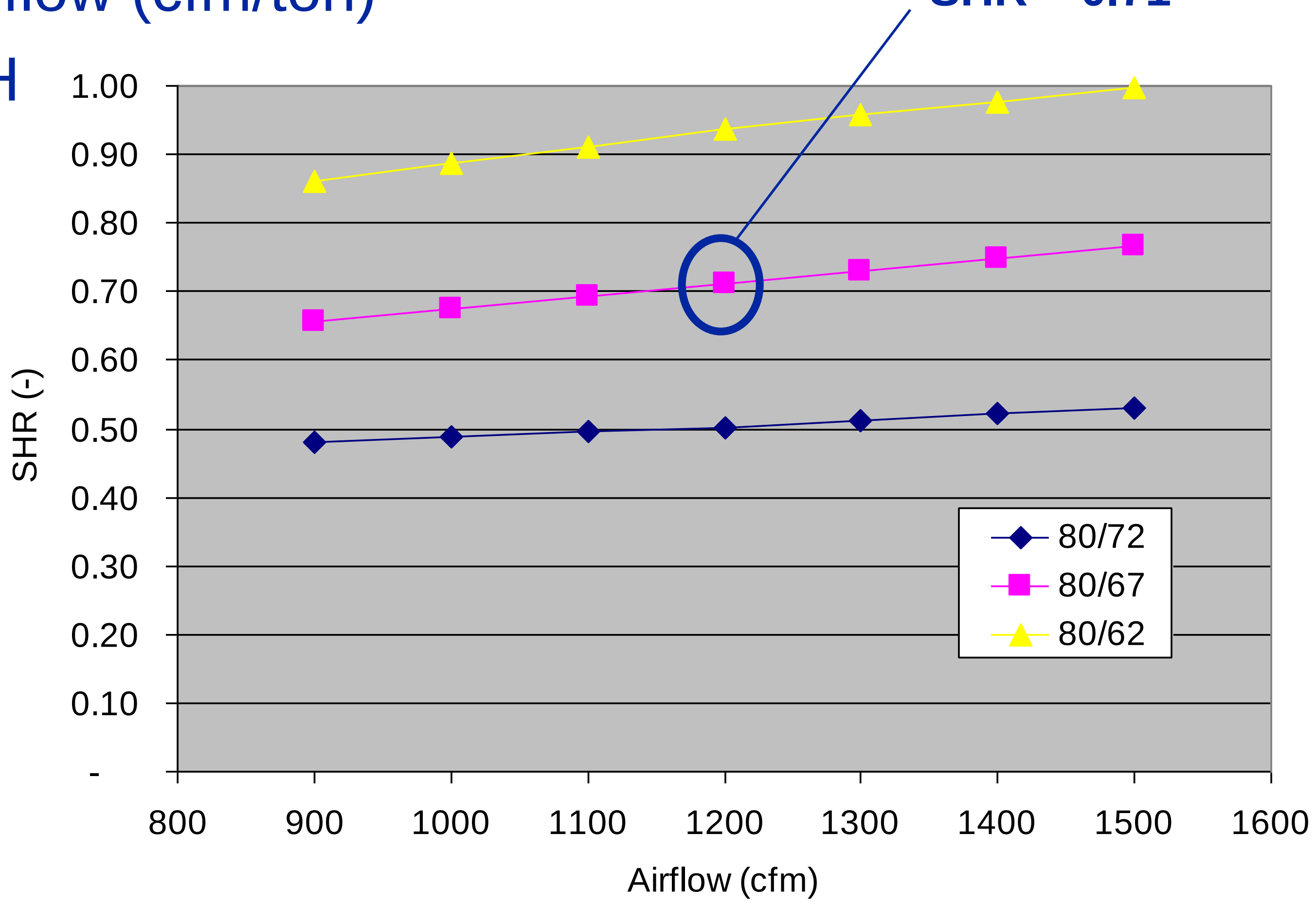
Typical AC Coil Performance



Catalog Data for 3-ton RTU

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

Nominal Rating Point: SHR ~ 0.71



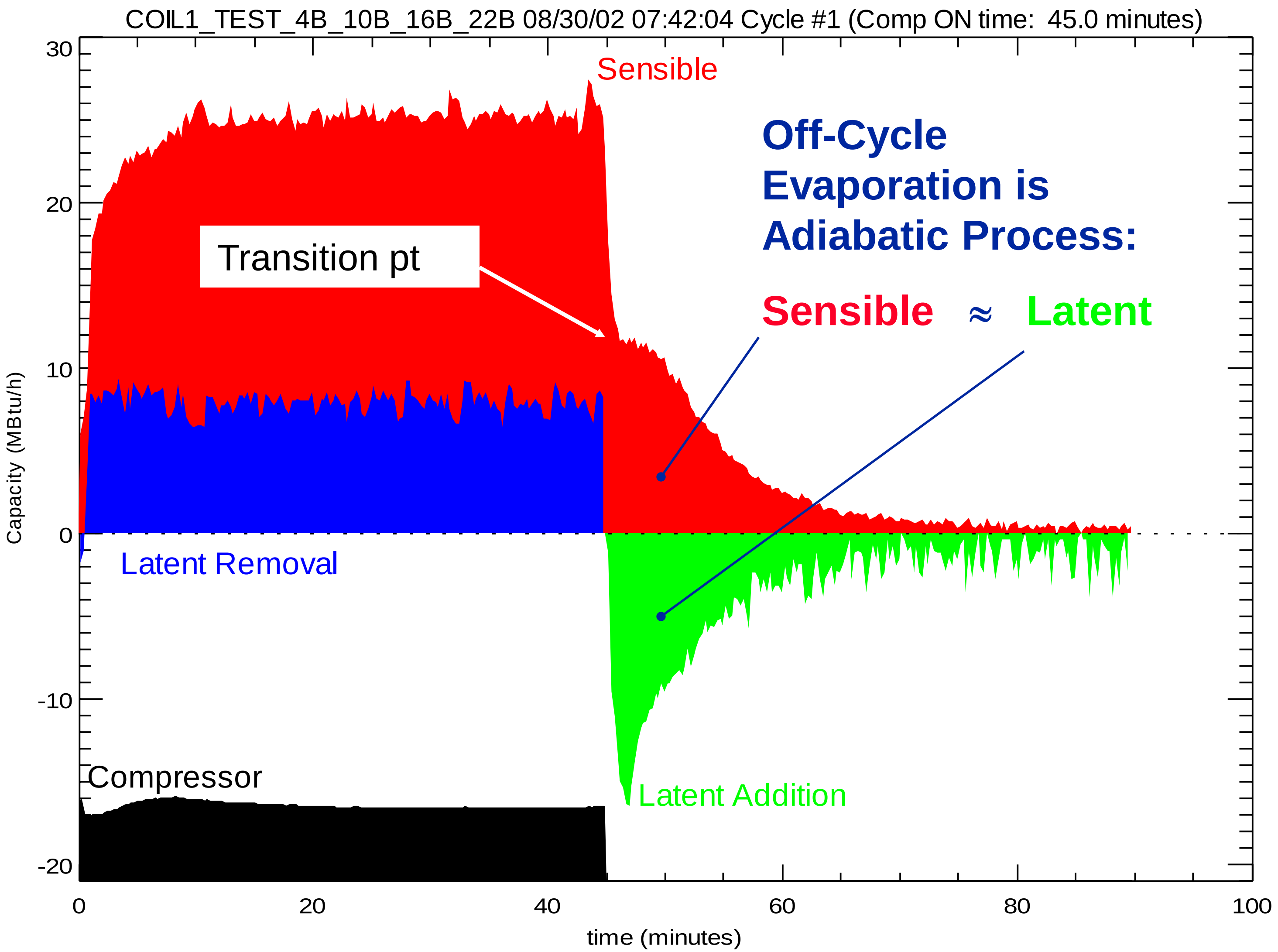
Part Load Latent Degradation

- Compressor cycles ON and OFF based on a space thermostat
- The runtime fraction is longer when cooling loads are greater

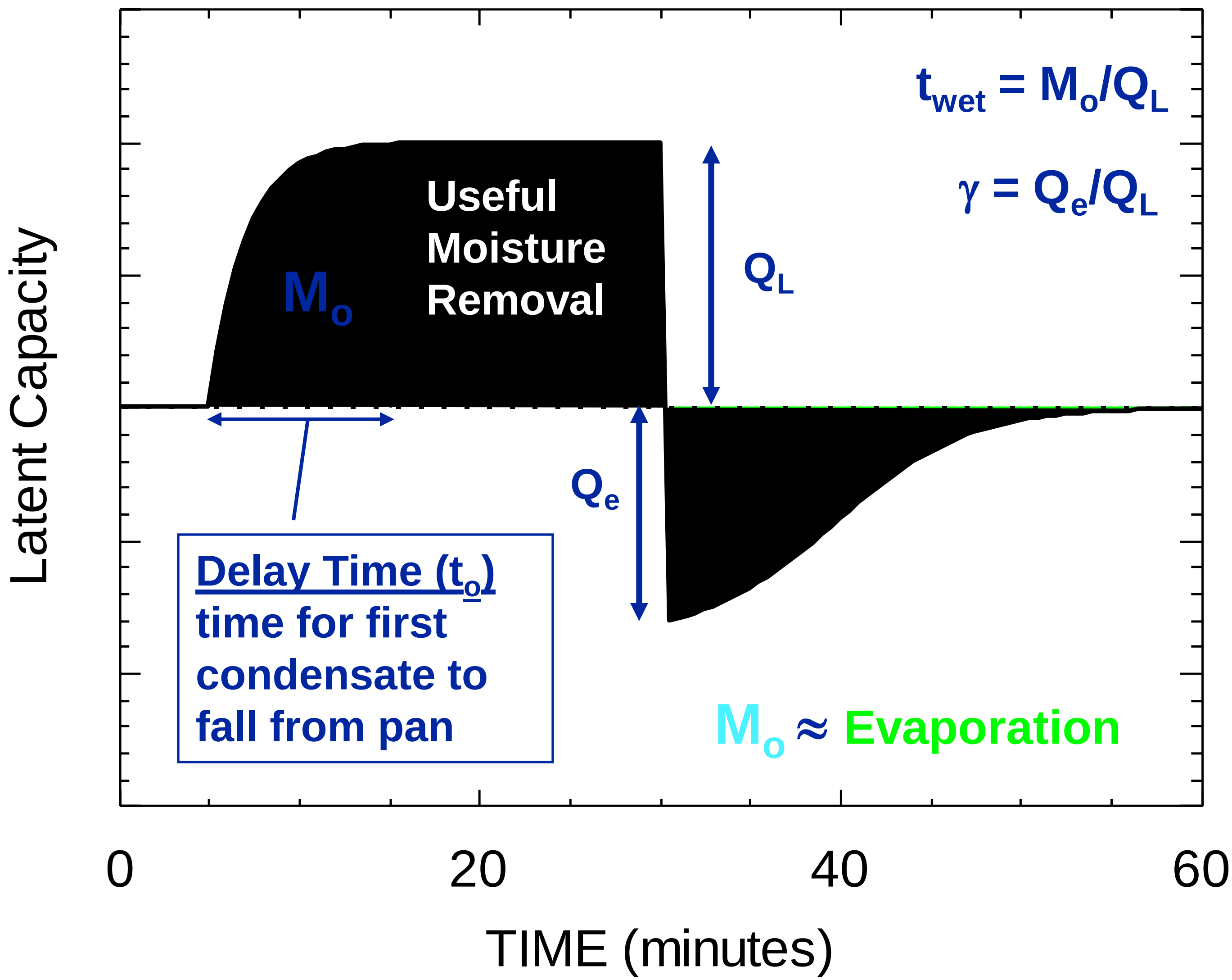
$$RTF = \frac{ON}{(ON + OFF)}$$

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

Sensible and Latent Capacity With Continuous Supply Air Fan Operation



Latent Degradation Concepts

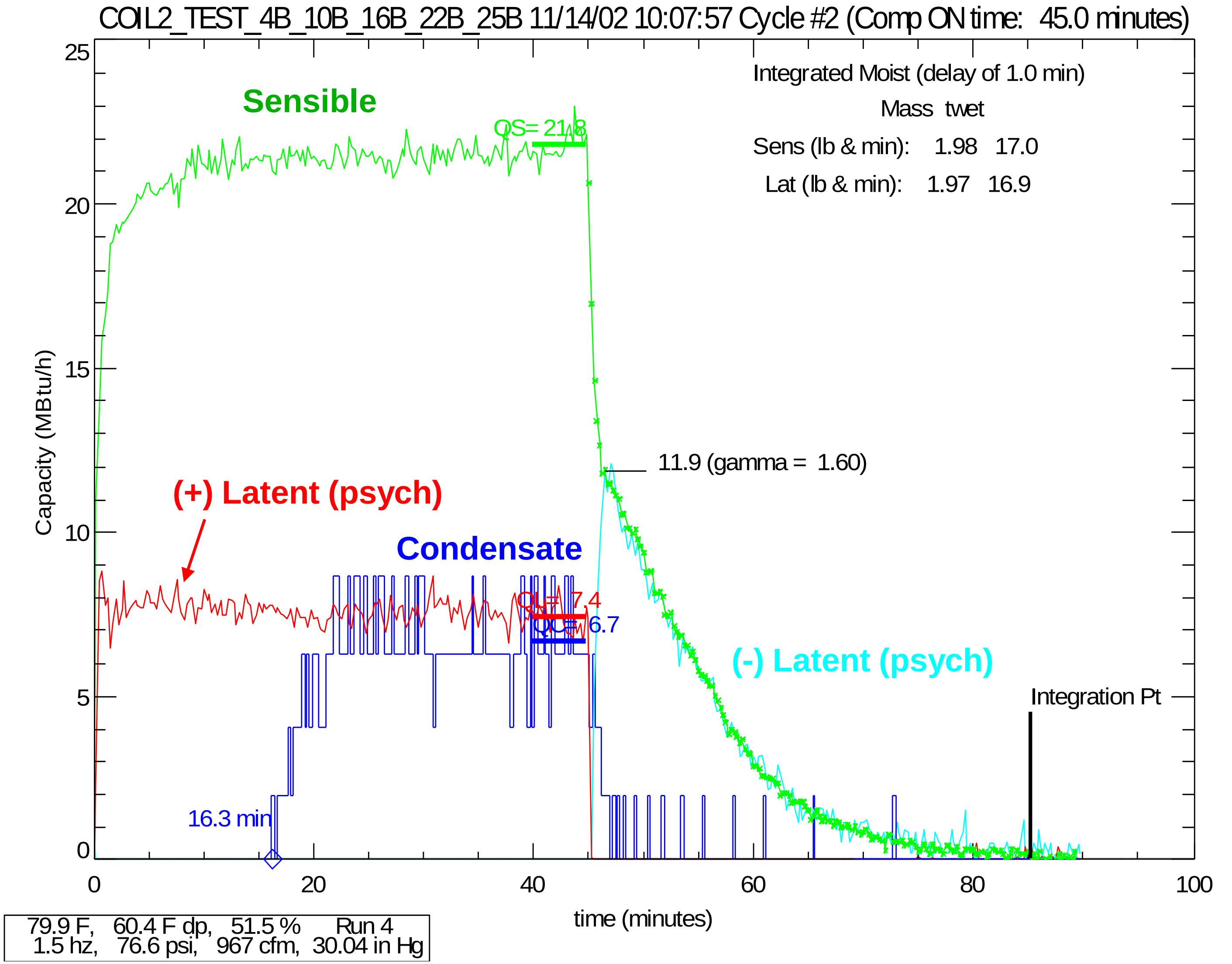


Theoretical LHR Degradation Model

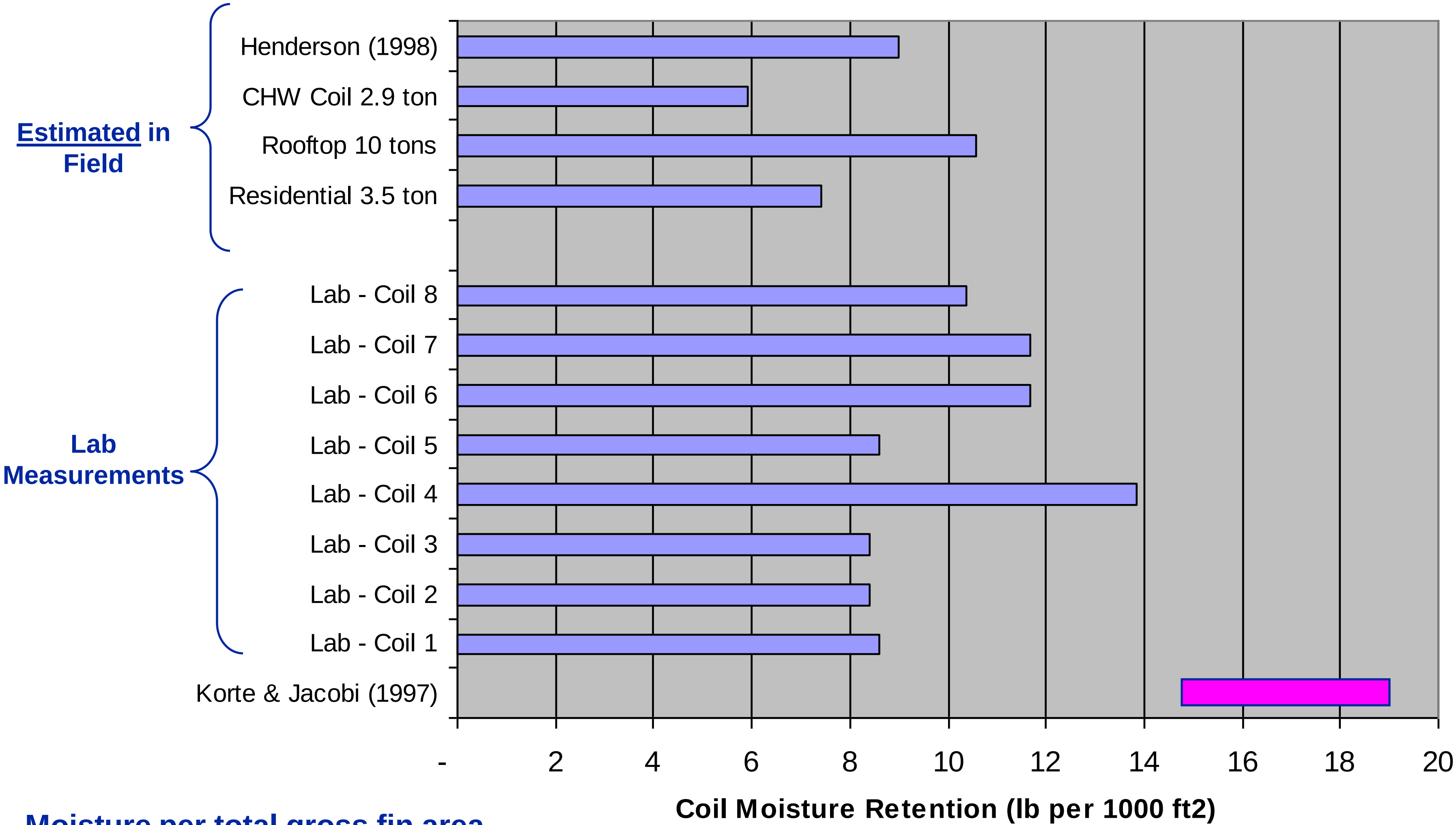
- Borrowed approaches used to develop part-load efficiency degradation function for SEER test procedure (C_d approach)
- Used same part-load assumptions (C_d):
  - AC at startup described by a time constant
  - Cycling rate driven by thermostat curve
- Additional latent assumptions:
  - Coil surfaces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

Henderson & Rengarajan (1996)
Shirey, Henderson, & Raustad (2006)

Results from Laboratory Testing



Lab + Field: Retained Moisture

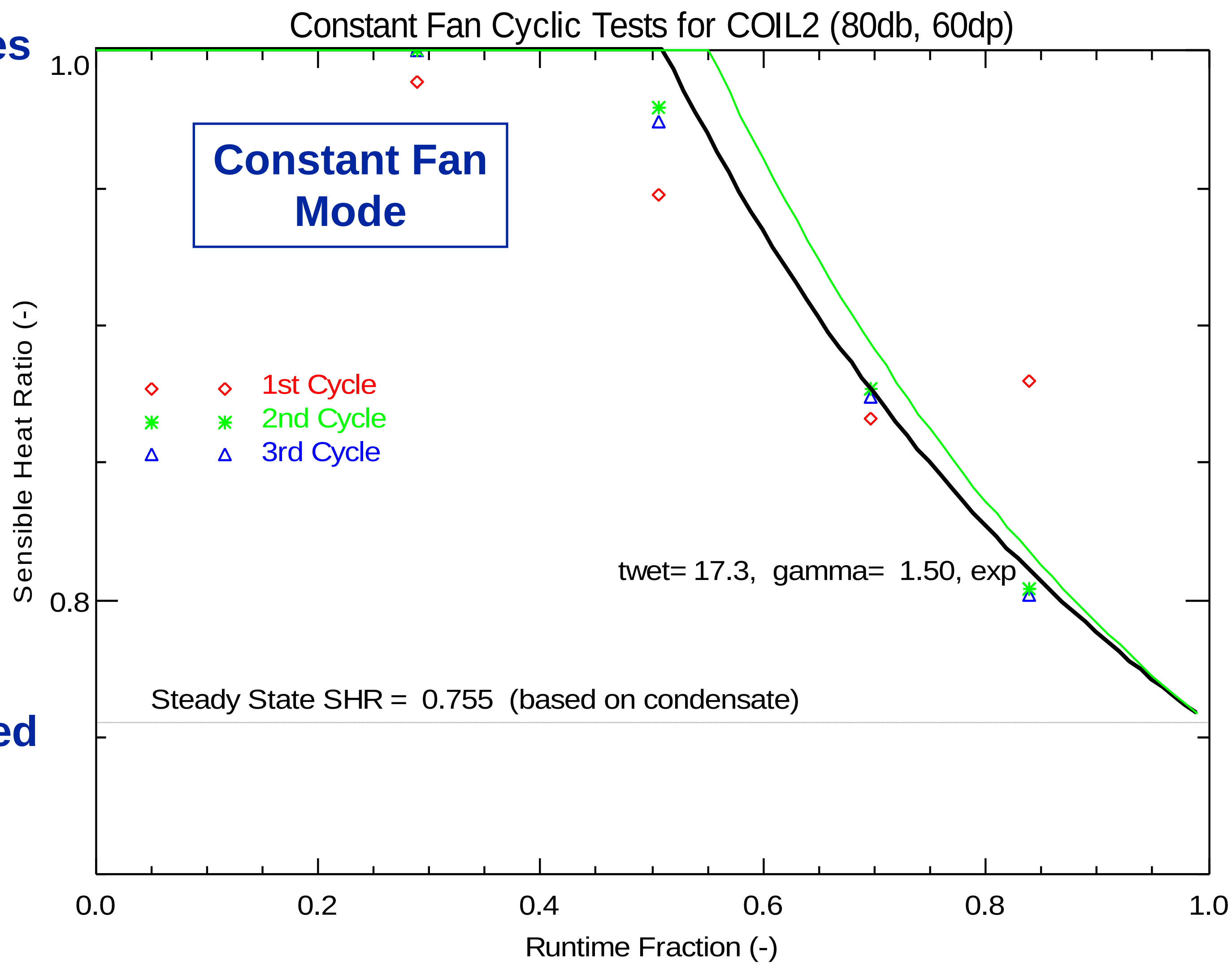


Moisture per total gross fin area
(gross area = face area x depth x fin spacing x 2)

Comparing Model to Laboratory Testing

LHR Model matches measured data at nominal entering conditions

(80F db, 67F wb)

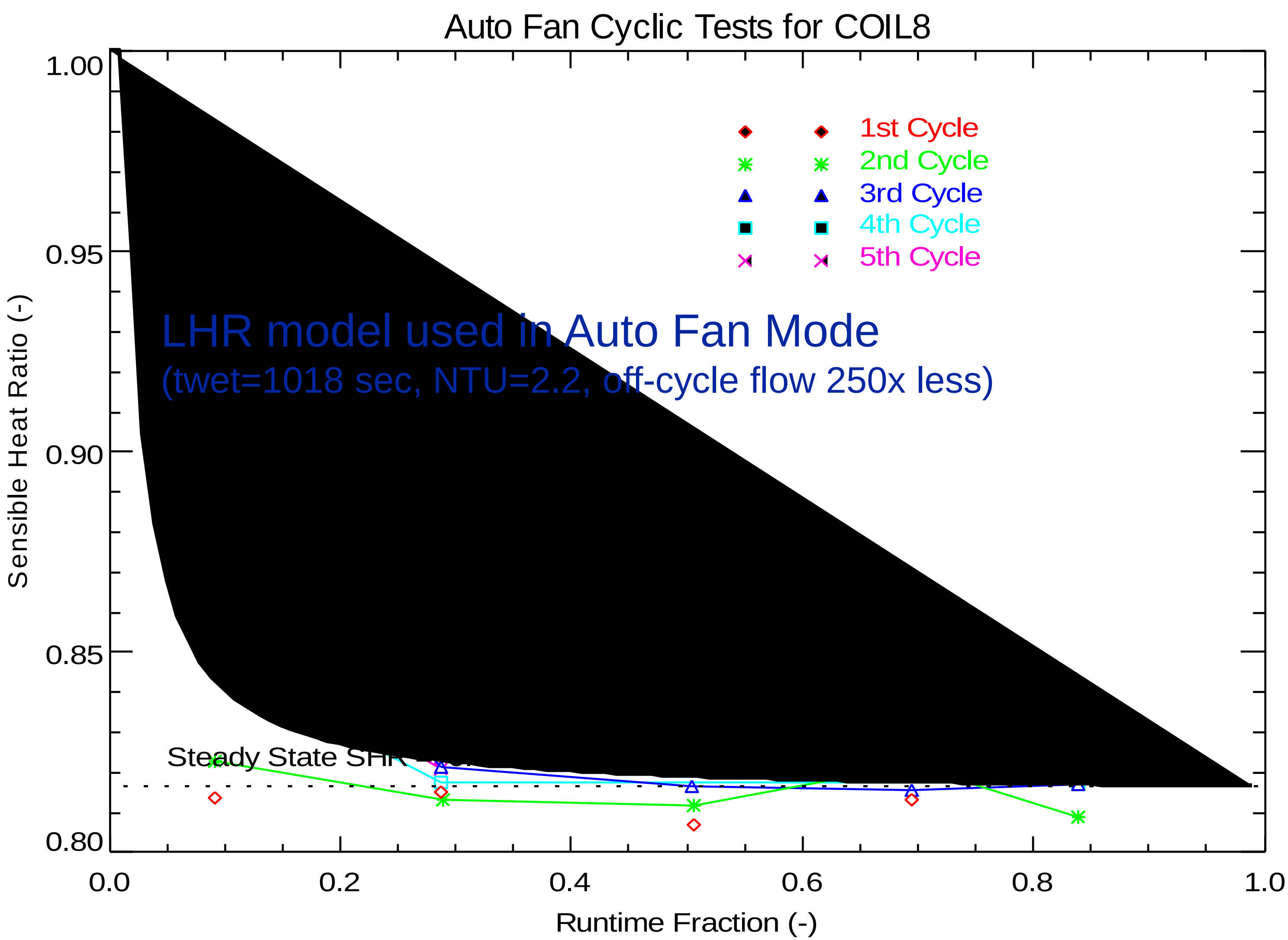


Laboratory results from DOE-sponsored testing at FSEC

Shirey, Henderson, & Raustad (2006)

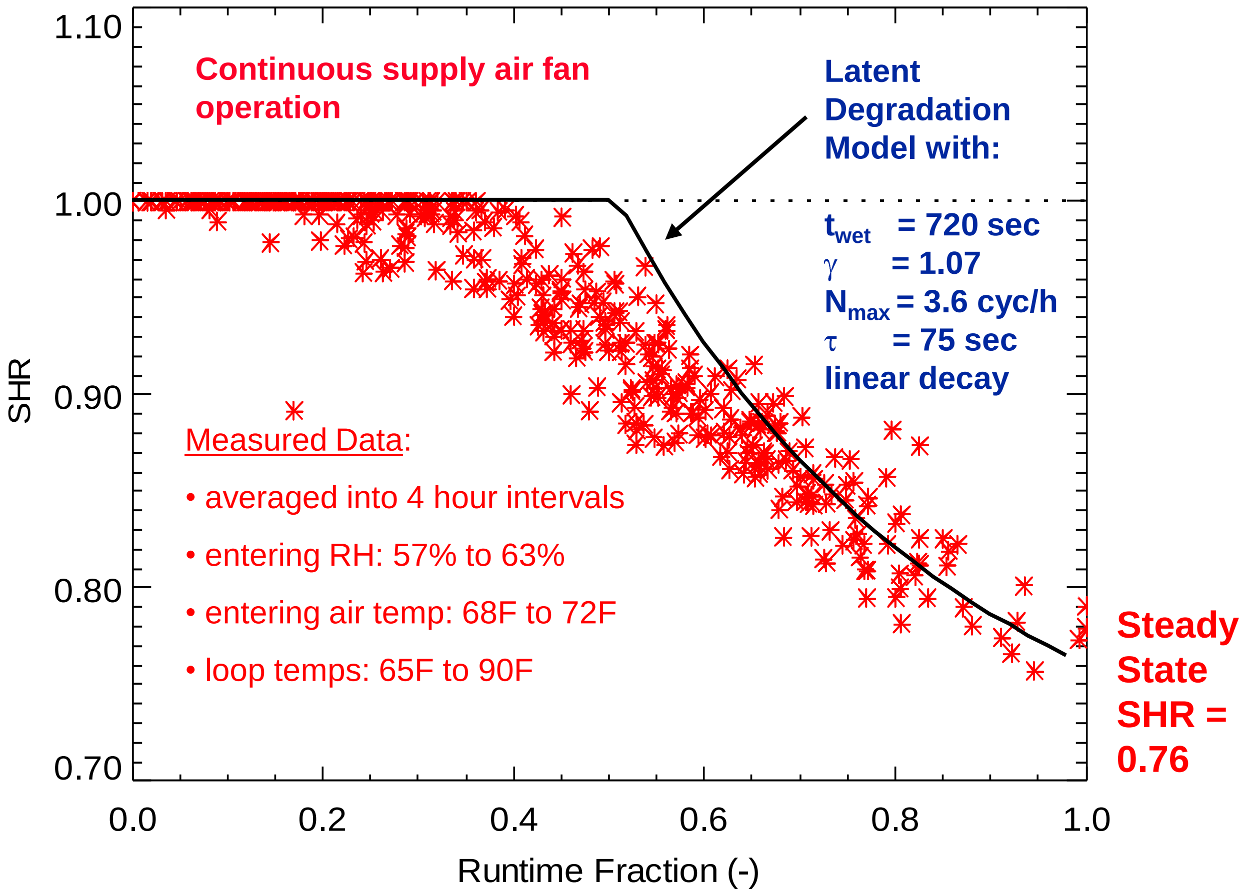
Laboratory Testing – SHR Degradation

AUTO Fan Mode (fan cycles with compressor)



Comparing LHR Model to Field Tests

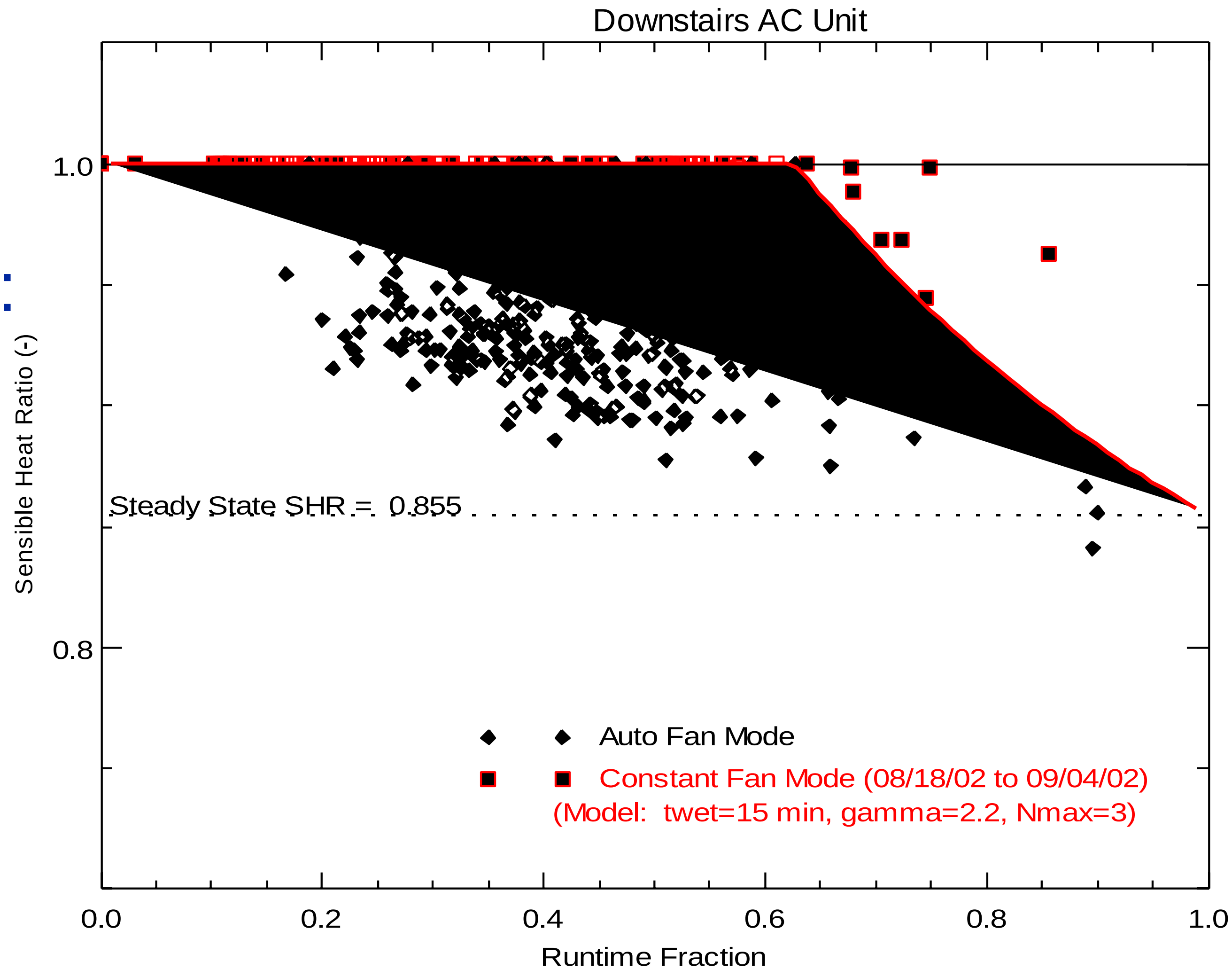
- Henderson (1998) compared the model results to field data collected on a 3-ton residential geothermal heat pump



Field Testing – SHR Degradation

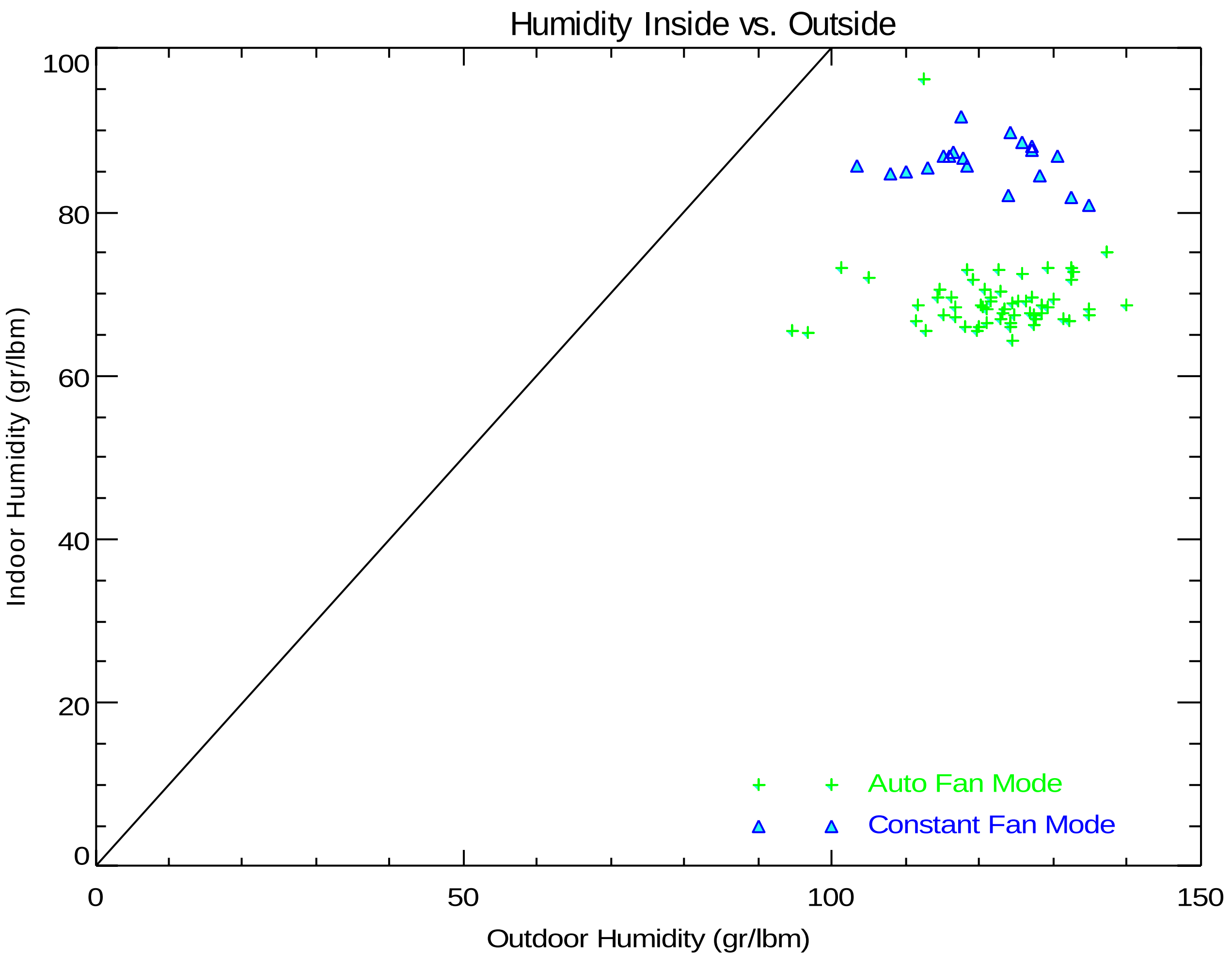
Same AC system with different fan control modes:

Significant AUTO fan degradation!



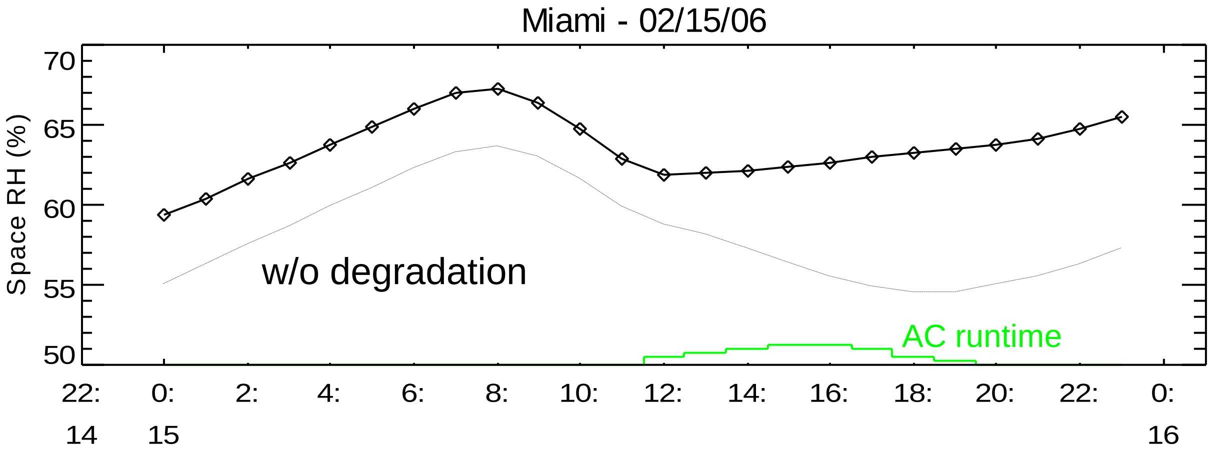
Space Humidity – ***Impact of Constant Fan***

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

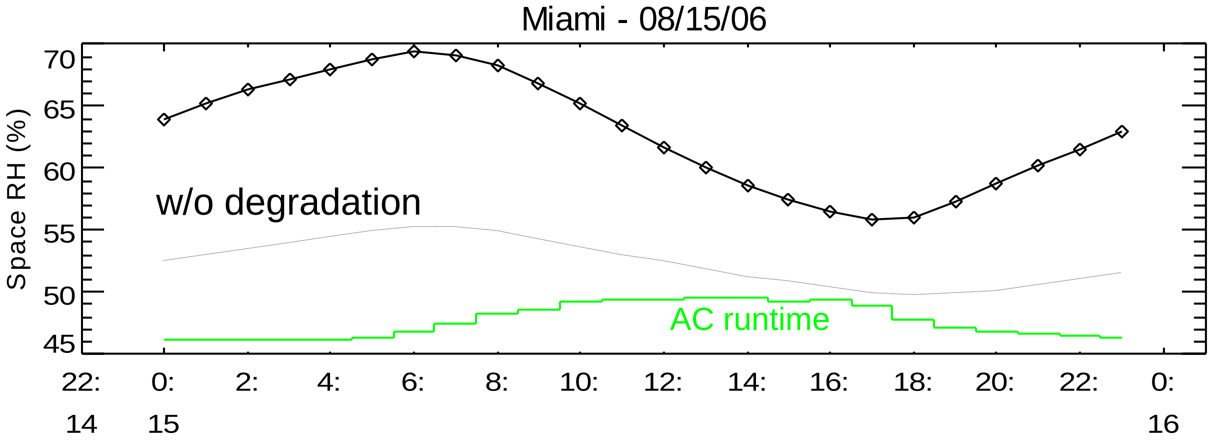


Simulating the Impact of Latent Degradation with the LHR Model

- Simulation models that consider latent degradation predict 10 to 15% higher RH

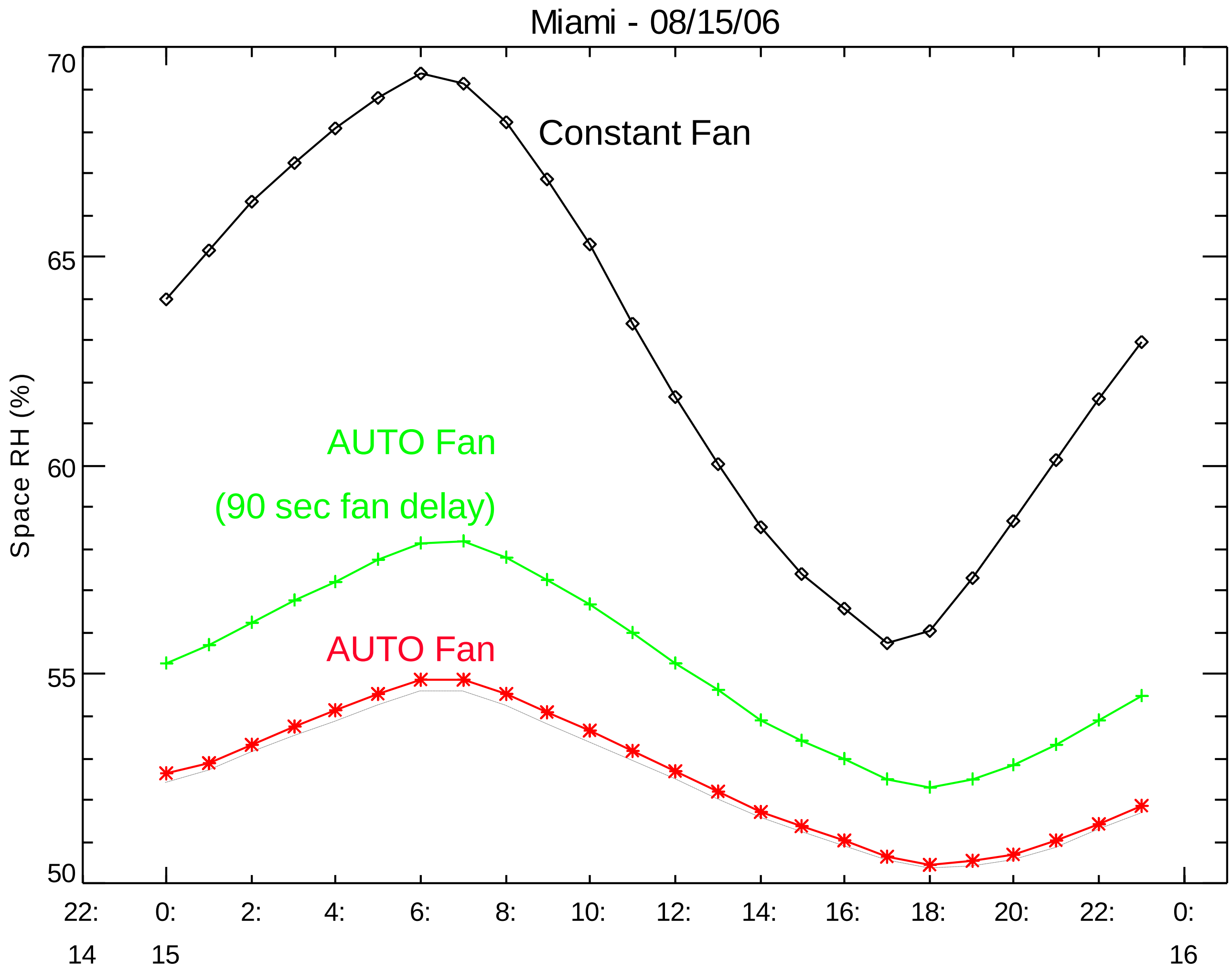


- Constant Fan Operation (HERS Reference House, Miami)



***Space Humidity** – Impact of Fan Control*

- Large penalty for constant fan operation
- Even small delays have an impact



Annual Results for Miami

Description		Hours above 60% RH (hrs)	AC Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Total HVAC Electric Use (kWh)
No Latent Degradation	CONST Fan	1,636	2,473	5,921	3,434	9,355
Latent Degradation	CONST Fan	7,283	2,089	5,165	3,434	8,598
No Latent Degradation	AUTO Fan	1,458	2,174	5,216	862	6,078
Latent Degradation	AUTO Fan	1,583	2,166	5,201	859	6,061
1.5 min "fan delay" time	AUTO Fan	2,854	2,096	5,075	948	6,023

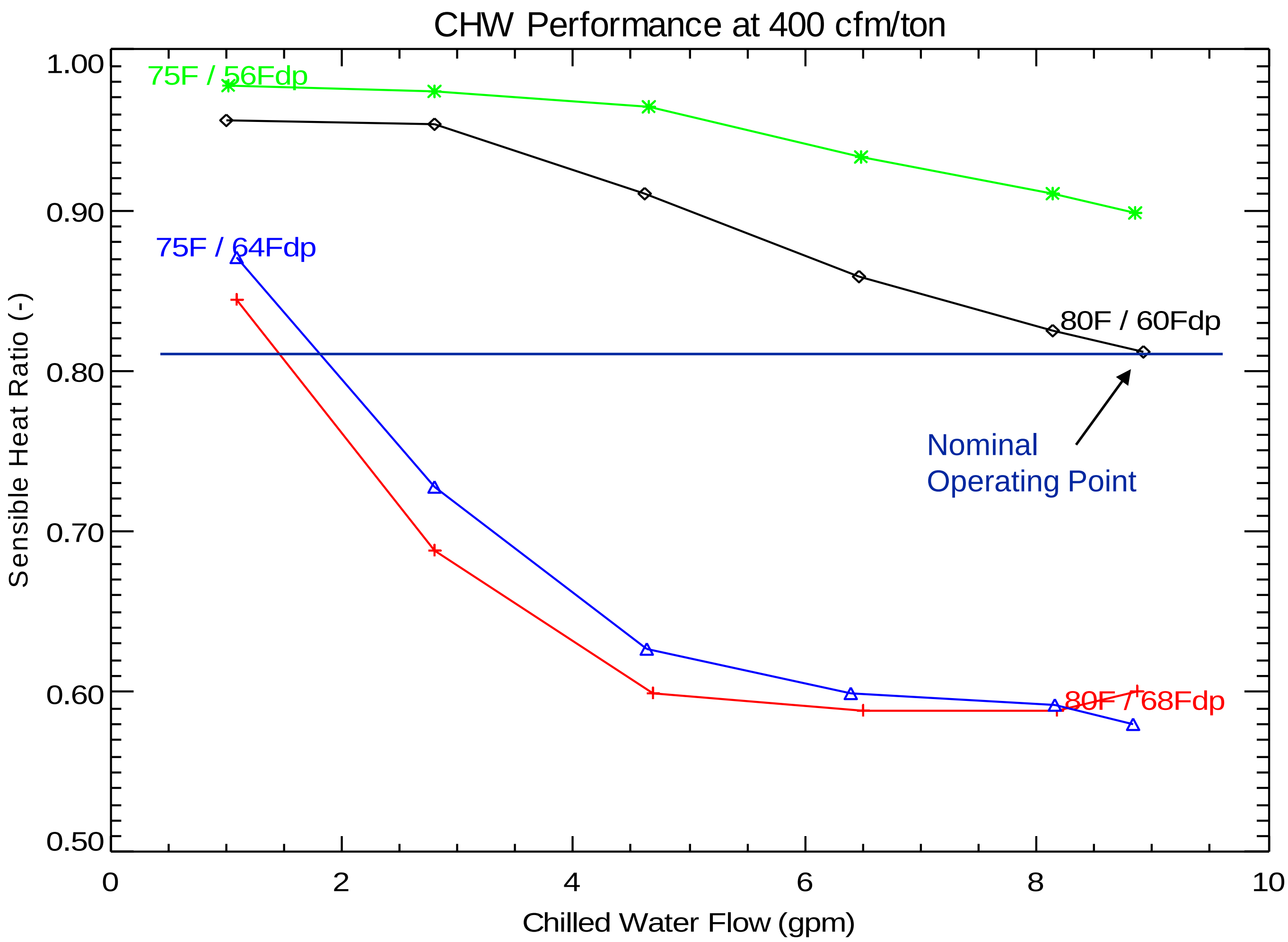
Notes: Constant Vent/Infiltration, with Duct Leaks

2000 sq ft HERS reference house
(duct leakage, ACH=0.356, 75°F)

Chilled Water Coil Latent Performance

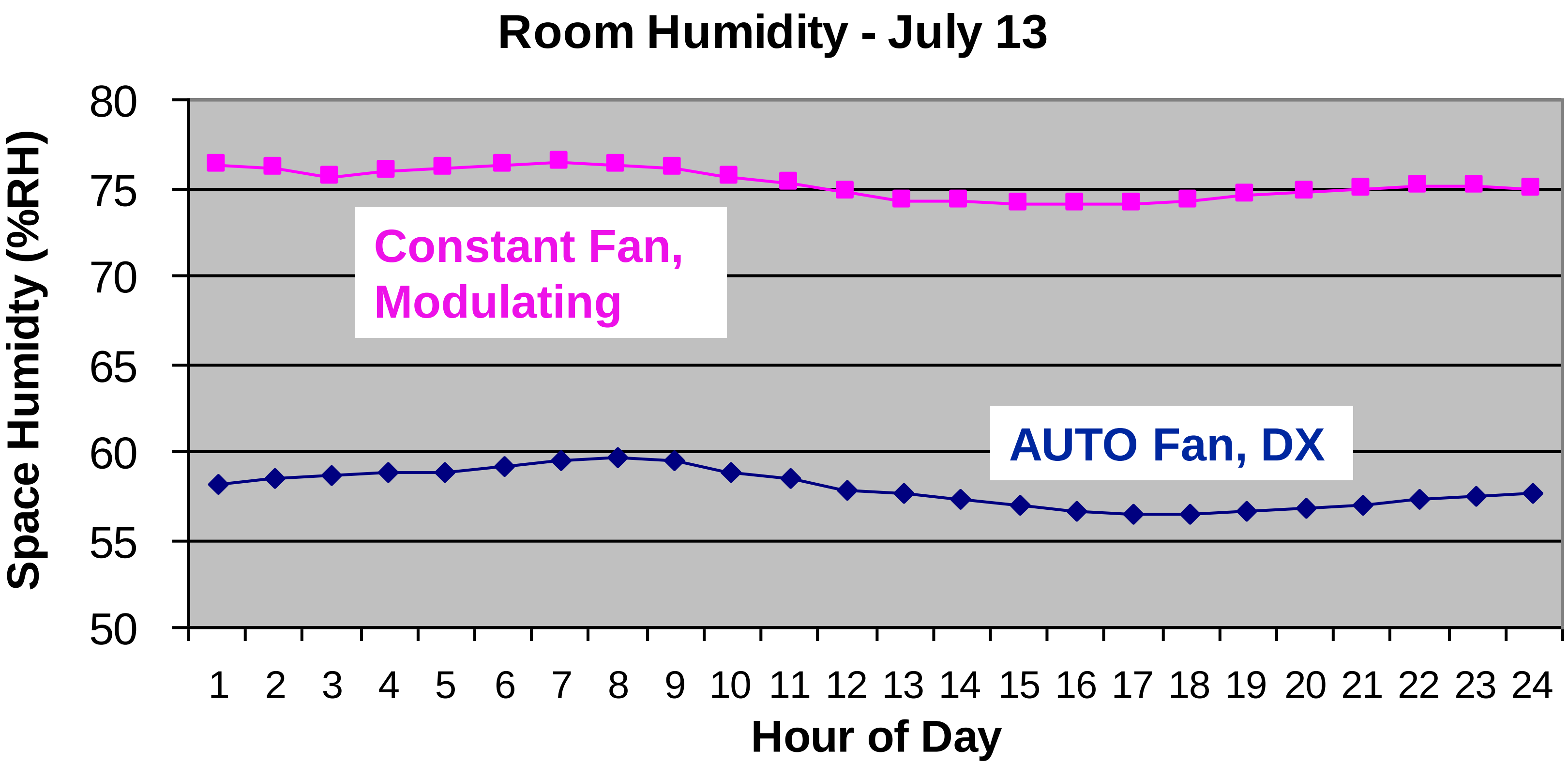
Chilled water coils behave similar to direct expansion (DX) coils …..even though they are controlled differently

- **gpm varies to provide capacity**



Impact on Space Humidity Levels

Modulating CHW Coil



TRNSYS Model of Hotel Room with Modulating Chilled Water Coil in Hawaii

Summary

- Latent degradation occurs when ACs operate at part load
  - Moisture evaporates from coil during off cycle
  - As a result, the net SHR approaches 1 at part load conditions
- Latent degradation is most prevalent with constant fan operation
  - Dehumidification capacity disappears below half load
  - Still some degradation in AUTO fan mode
  - Short fan delays have a significant impact
- Chilled water coils have similar part load performance
  - Latent capacity disappears faster than sensible capacity at lower chilled water flow rates
- Models have been developed to predict these impacts
  - Impacts on space humidity are typically 10 to 15% RH