Component Models for Residential HVAC System Energy Calculations

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Overview

- Model Structure
- The Data
- The Model
- Parameter Estimation
- Evaluation
  - Compare to other models
  - Availability of data

Approach

- Develop core steady state models for air conditioner and heat pump based on *available* data
- Adjust core model performance
  - Data fits
  - Part load performance
  - Charge degradation
- Focus here on AC model

Core AC Data Requirements

Inputs	Outputs
Outdoor coil entering air temperature Outdoor coil entering air humidity Outdoor coil airflow rate Indoor coil entering air temperature Indoor coil entering air humidity Indoor coil airflow rate Operating mode Parameters and physical characteristics	Indoor coil leaving air temperature Indoor coil leaving air humidity Total cooling capacity Sensible cooling capacity Compressor power Indoor fan power Outdoor fan power

System Model Structure

Inputs	Outputs
Total load Sensible load System control characteristics Fan model inputs Core AC model inputs Degraded performance parameters Simulation parameters	Fan model outputs Core AC model outputs AC energy consumption Indoor fan energy consumption Outdoor fan energy consumption AC run-time Fan run-times

Data Source: ARI Rating Data

- More than 90% of units certified by ARI
- Efficiency and capacity from one or two test conditions (can't obtain test data)
- Net ratings
- Only capacity and SEER published by ARI
- More info often reported by manufacturers

Data Source: Performance Maps

- Performance at up to 150 different operating conditions
- Often don’t match ARI data
- Performance maps “filled in” by models
- Technical literature often unavailable
- Typos or questionable values?

Availability of ARI Rating Data in Technical Literature

Air Conditioners

Manufacturer	SEER	Total Capacity	Sensible Capacity	Power (or COP, EER, EIR)	Indoor Airflow	Indoor Fan Power	Outdoor Airflow	Outdoor Fan Power	Compressor Model Number
A	X	X		X			X		
B	X	X	X	X					
C	X	X		X			X	X	
D	X	X			X		X		
E	X	X	X	X	X		X		
F	X	X		X	X	X		X	
G	X	X	X	X	X		X		

Heat Pumps

Manufacturer	HSPF	Capacity	Power (or COP, EER, EIR)	Indoor Airflow	Indoor Fan Power	Outdoor Airflow	Outdoor Fan Power	Compressor Model #
A	X	X	X			X		
B	X	X	X					
C	X	X	X			X	X	
D	X	X		X		X		
E	X	X	X	X		X		
F	X	X	X	X	X		X	
G	X	X	X	X		X		

Condenser Model

- Effectiveness-NTU model
- Key assumption: $T_{ref,cond} = T_{SDT}$
- Adjust UA as airflow changes

$$\frac{UA}{UA_{rated}} = \left(\frac{Q}{Q_{rated}} \right)^{n}$$

Evaporator Model

- Effectiveness-NTU model
  - Enthalpy-based to calculate total capacity
  - Temperature-based to calculate sensible capacity
- Key assumption: $T_{ref,evap} = T_{SST}$
- Adjust UA as airflow changes

Compressor Model

- Empirically and statistically based model

$$\frac{\dot{m}_{R22}}{\dot{m}_{R22,rated}} = M_1 + M_2 SST + M_3 SDT + M_4 SST^2 + M_5 (SST)(SDT) + M_6 SDT$$
$$+ M_7 SST^3 + M_8 (SDT)(SST^2) + M_9 (SST)(SDT^2) + M_{10} SDT^2$$

$$\frac{P}{P_{rated}} = P_1 + P_2 SST + P_3 SDT + P_4 SST^2 + P_5 (SST)(SDT) + P_6 SDT^2$$
$$+ P_7 SST^3 + P_8 (SDT)(SST^2) + P_9 (SST)(SDT^2) + P_{10} SDT^3$$

- Rated conditions:

Operating parameter	Value
Saturated evaporator temperature	45°F
Saturated condenser temperature	130°F
Superheat at compressor inlet	20°F
Subcool at expansion device inlet	15°F

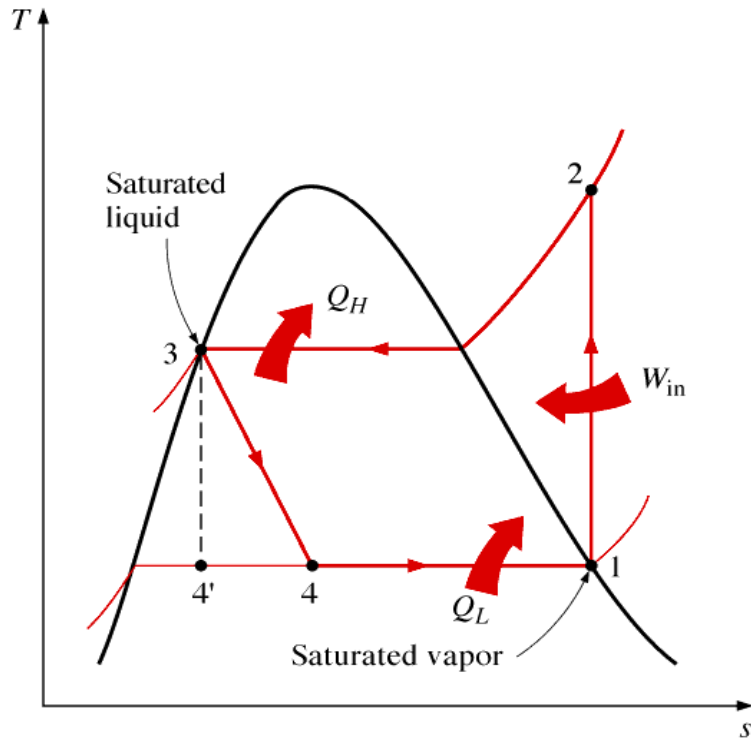
System Model

$$h_1 = h_{SST,X=1} + C_{p,SST,X=1}\Delta T_{SH}$$

$$h_2 = h_1 + \frac{f_{COMP2REF} \cdot P}{\dot{m}_{R22}}$$

$$h_3 = h_4$$

$$h_4 = h_{SDT,X=1} - C_{p,SDT,X=0}\Delta T_{SC}$$



$$q_{tot,evap} = \dot{m}_{R22}\left(h_1 - h_4\right)$$

$$q_{tot,cond} = \dot{m}_{R22}\left(h_2 - h_4\right)$$

$$P = \frac{\dot{m}_{R22}\left(h_2 - h_1\right)}{f_{COMP2REF}}$$

Component Model Adjustments

- Part-load adjustment
- Frosting/defrosting adjustment
- Refrigerant charge adjustment

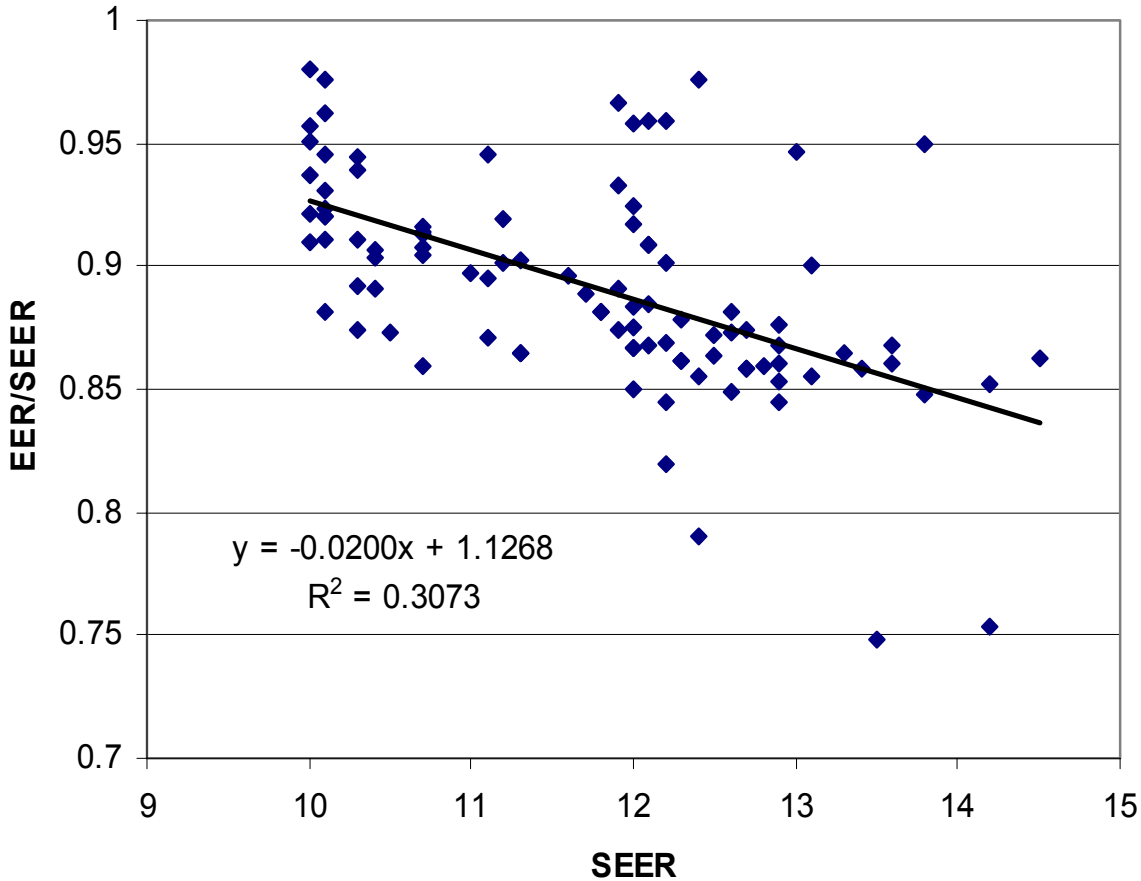
AC Data Requirements

Inputs (at ARI conditions)	Outputs
Evaporator airflow rate Condenser airflow rate Total cooling capacity Sensible cooling capacity Compressor power Compressor mass flow rate at standard compressor test conditions Compressor power at standard compressor test conditions Normalized compressor mass flow rate coefficients Normalized compressor power coefficients	UA_{cond} $UA_{int,evap}$ $UA_{ext,evap}$

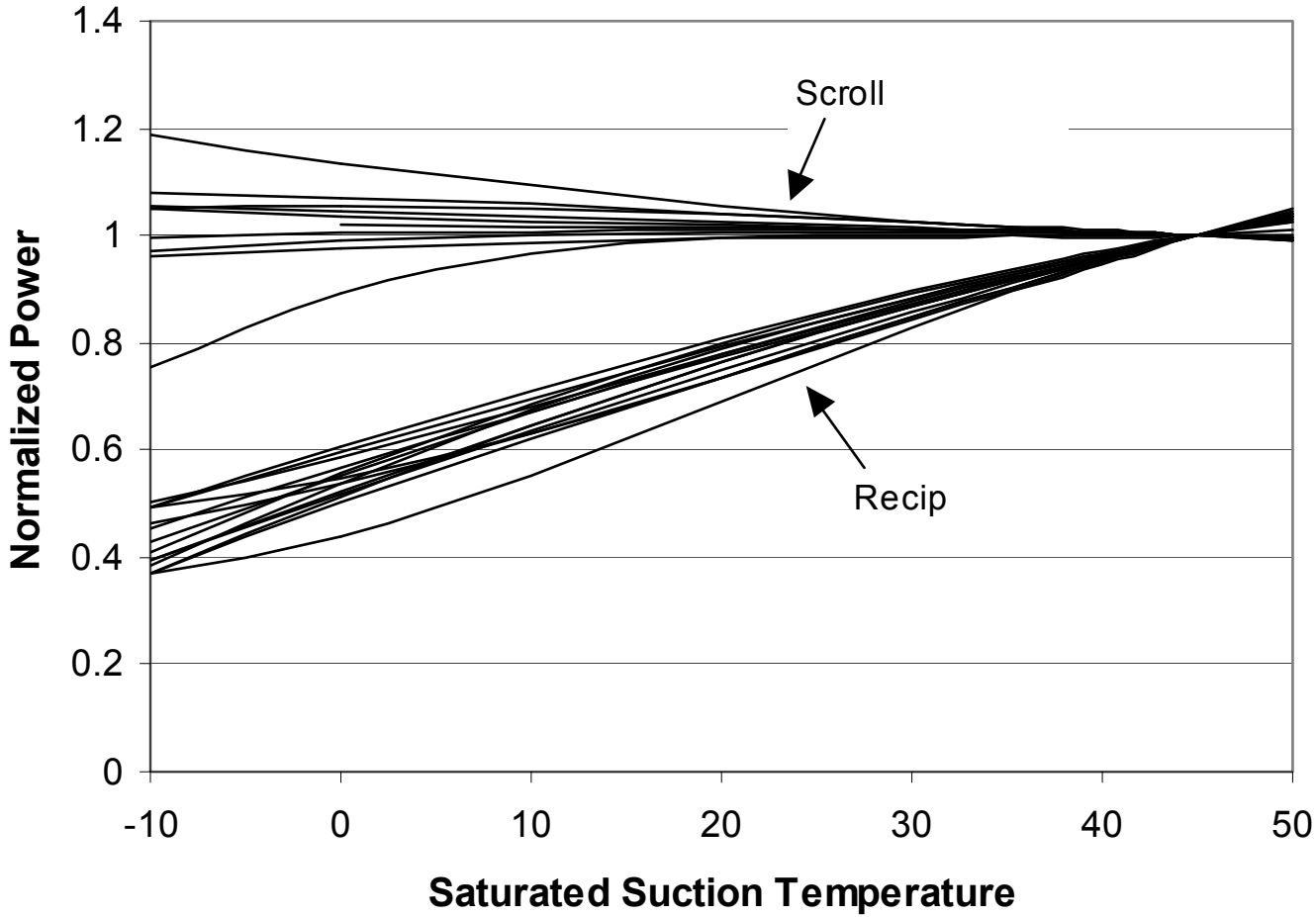
Parameter Identification

- Use ARI rating data and run Component Model “backward” to get UAs
- Same UAs used at all operating conditions
  - Modify for airflow rate
- Use defaults if ARI rating data are missing

Default Parameter Example

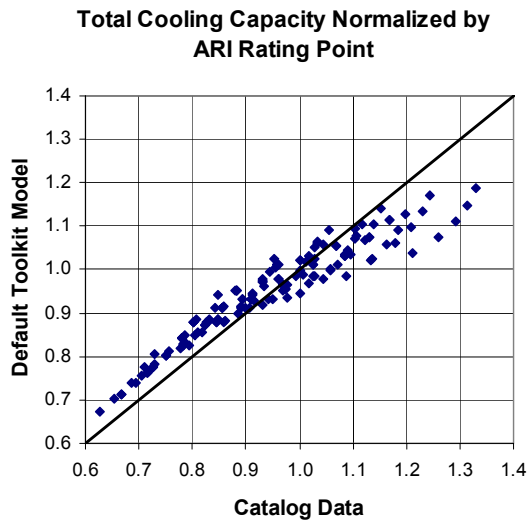


Default Parameter Example

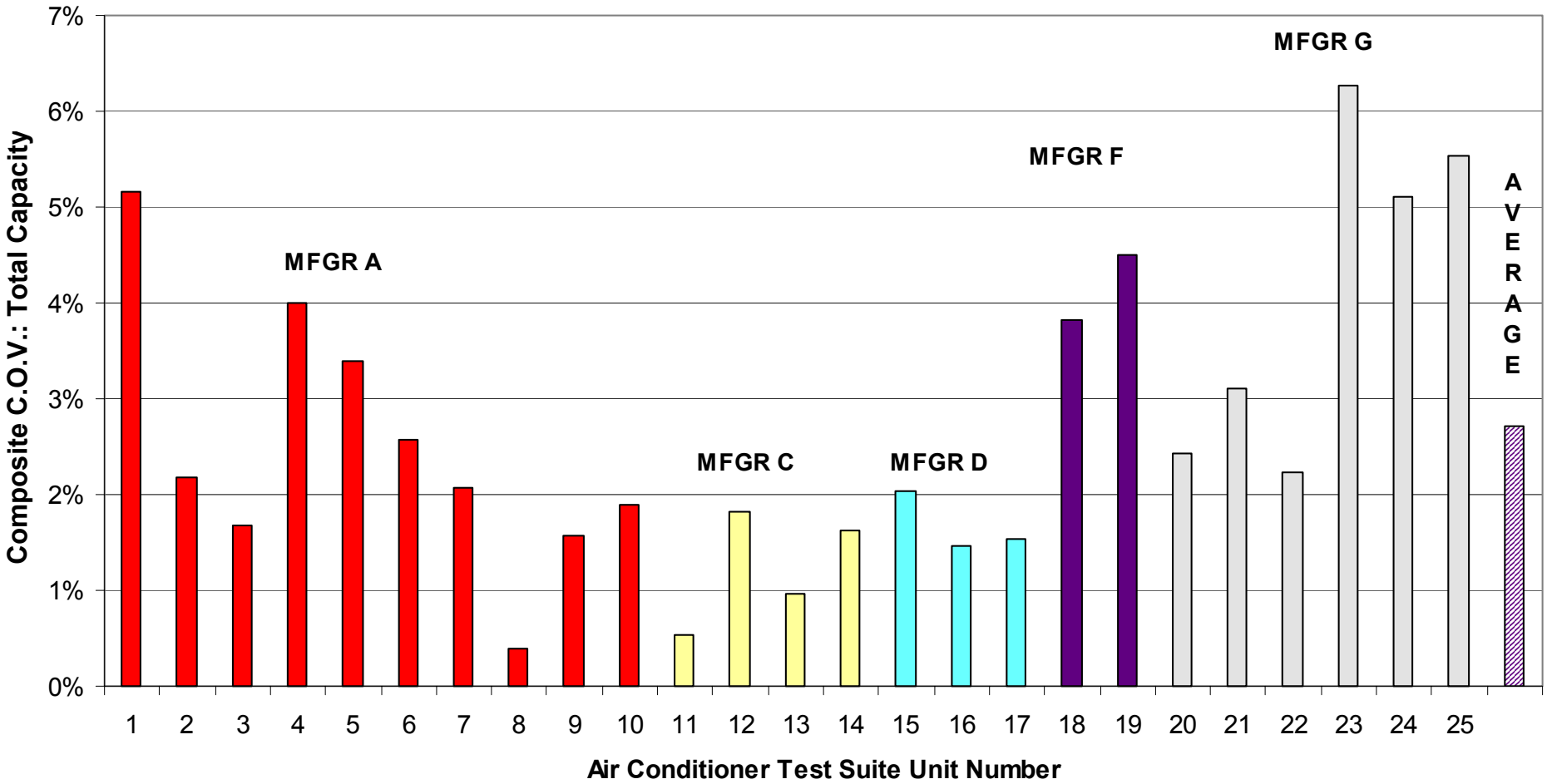


The Test Suite

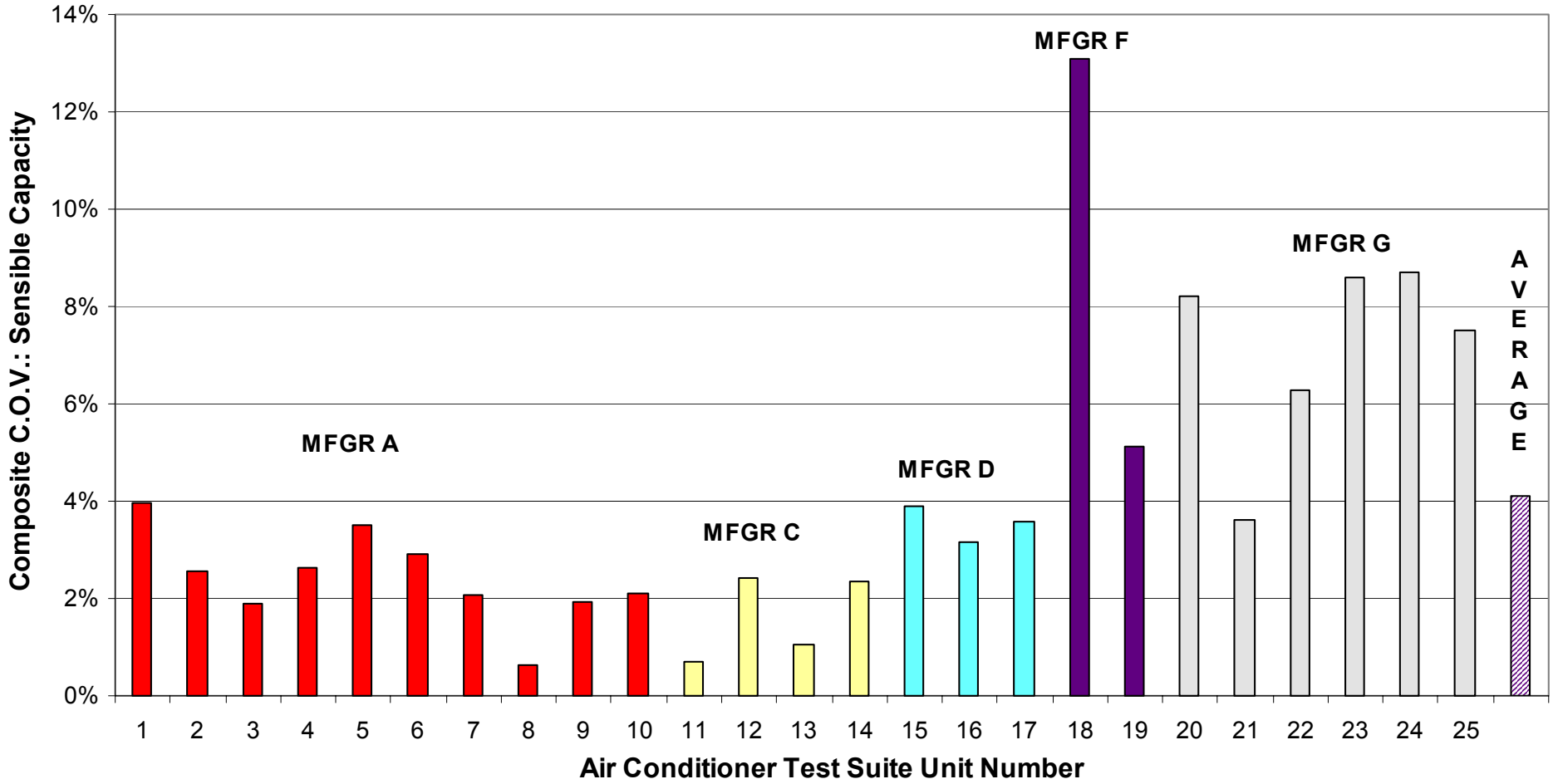
- Purpose: For model evaluation
- 13 air conditioners and 9 heat pumps
  - 5 split-system manufacturers
  - 2 compressor manufacturers
  - 2 types of compressors (scroll and recip)
  - Range of 10 –15.5 SEER and 6.8 –8.0 HSPF
  - 1 ½ -5 tons
  - R-22 and R-410a
  - Orifice and TXV
  - Single-speed and two-speed
- Coefficient of Variation



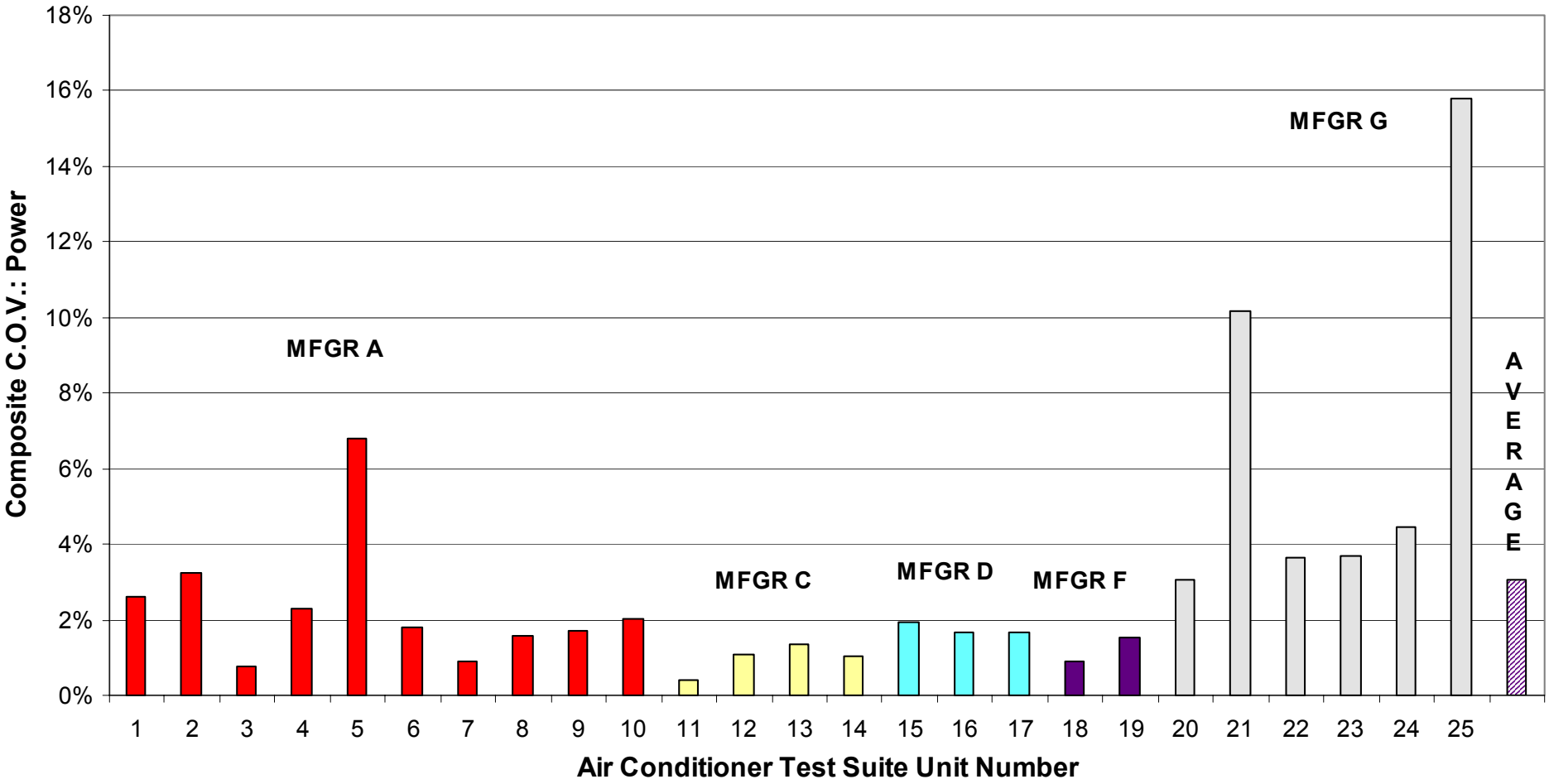
AC Test Suite Evaluation: Total Capacity



AC Test Suite Evaluation: Sensible Capacity



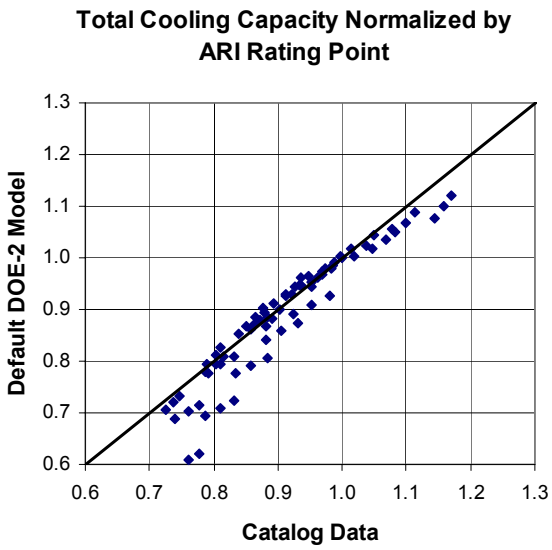
AC Test Suite Evaluation: Power

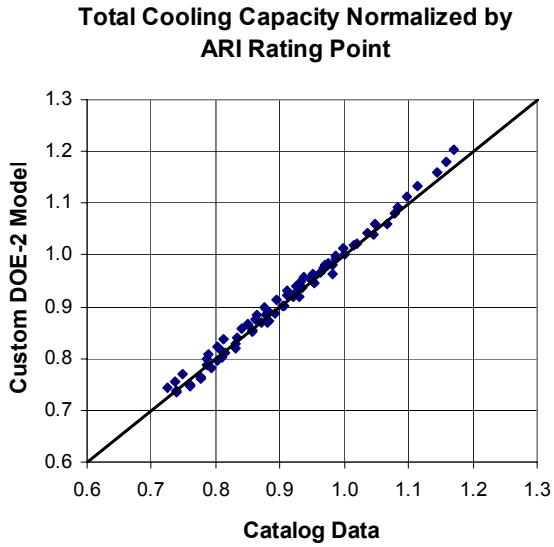


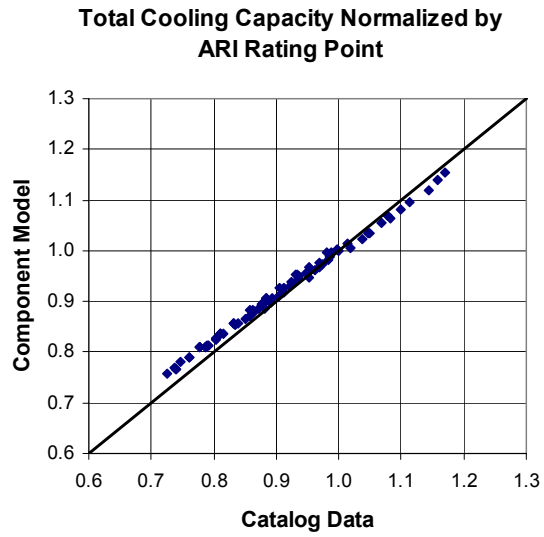
Model Comparison

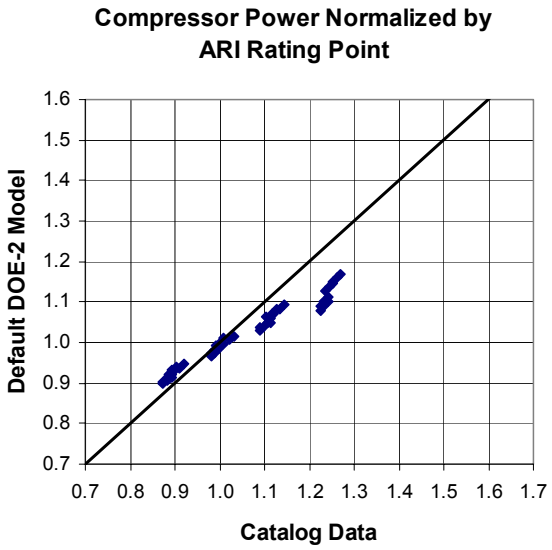
- Compare to DOE-2 curve fits
  - Default curve fit
  - Custom curve fit to performance map
- Use data from performance map to develop custom curve fits
  - Different amounts of data depending on manufacturer
  - Test data set same as regression data set

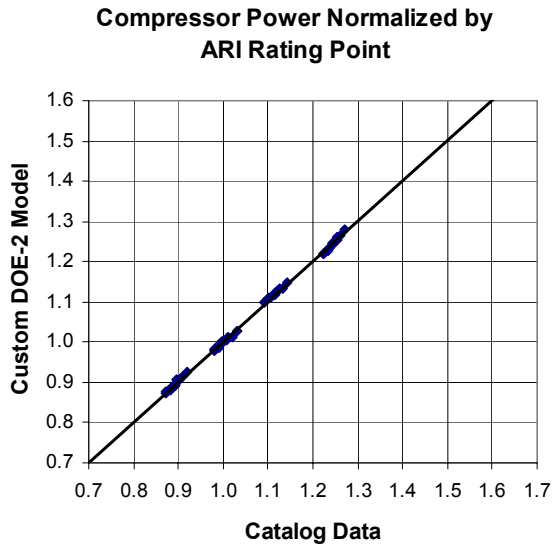
Typical Scatter Plots

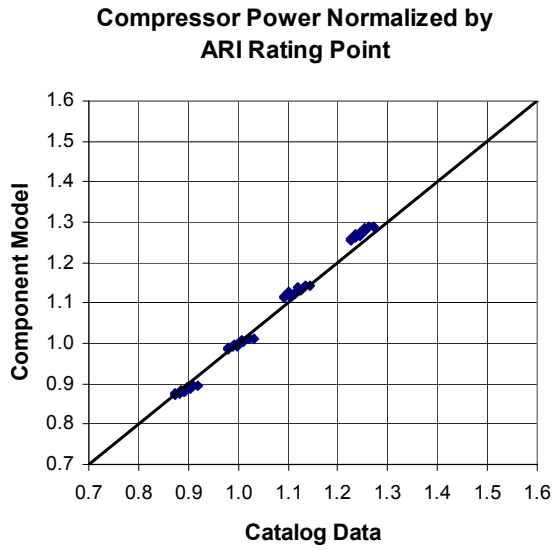




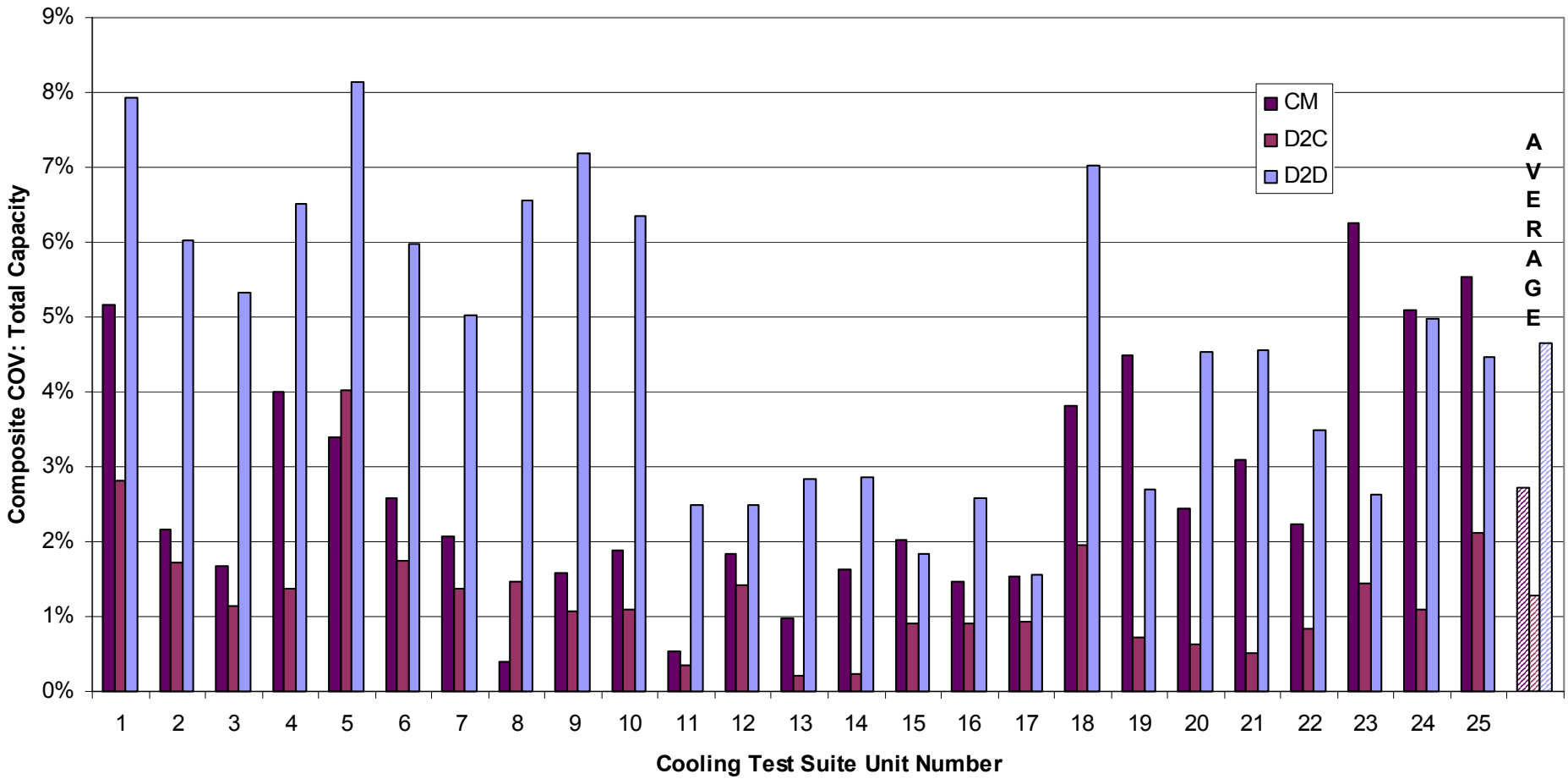




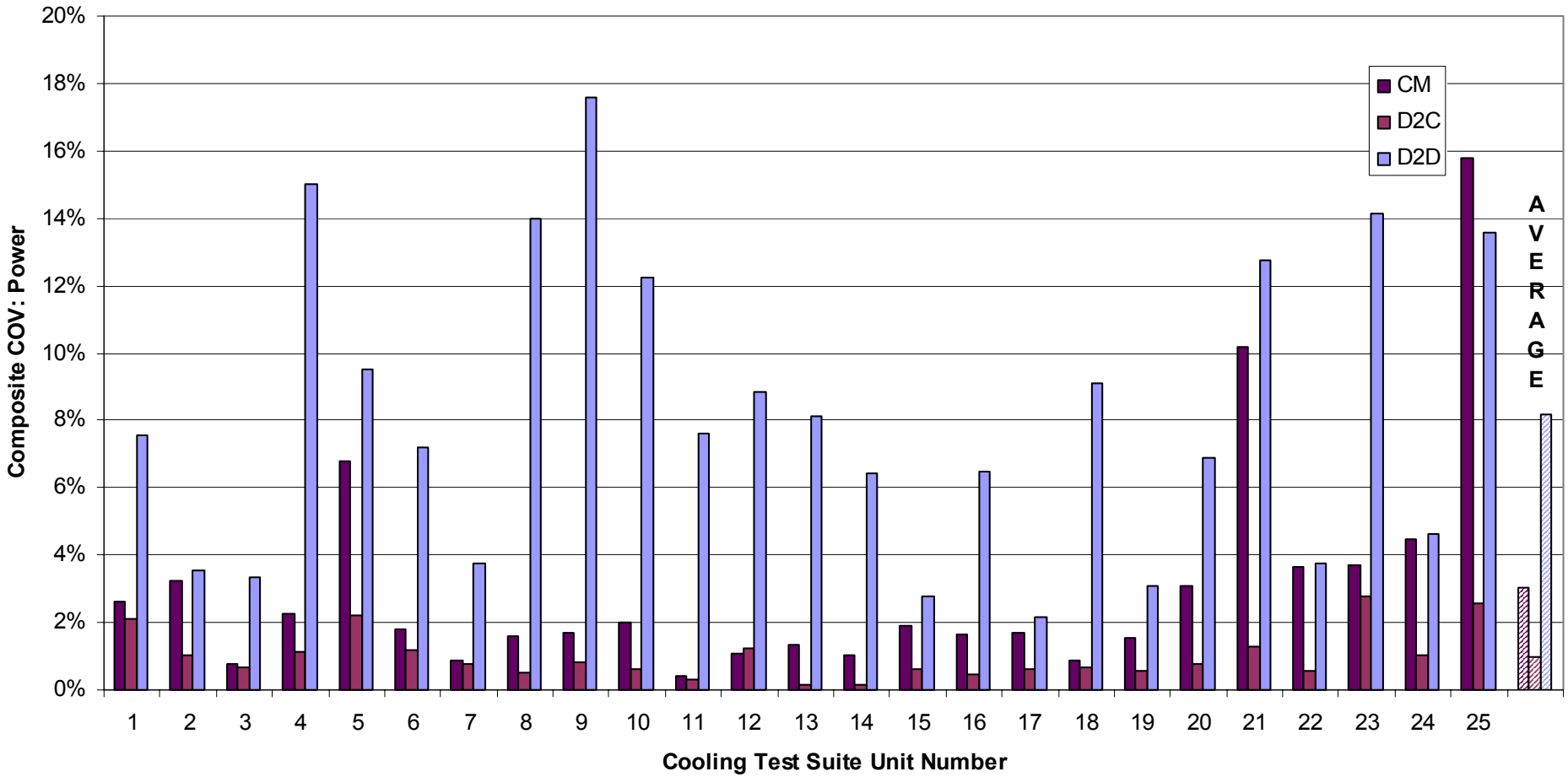




AC Model Comparison: Total Capacity

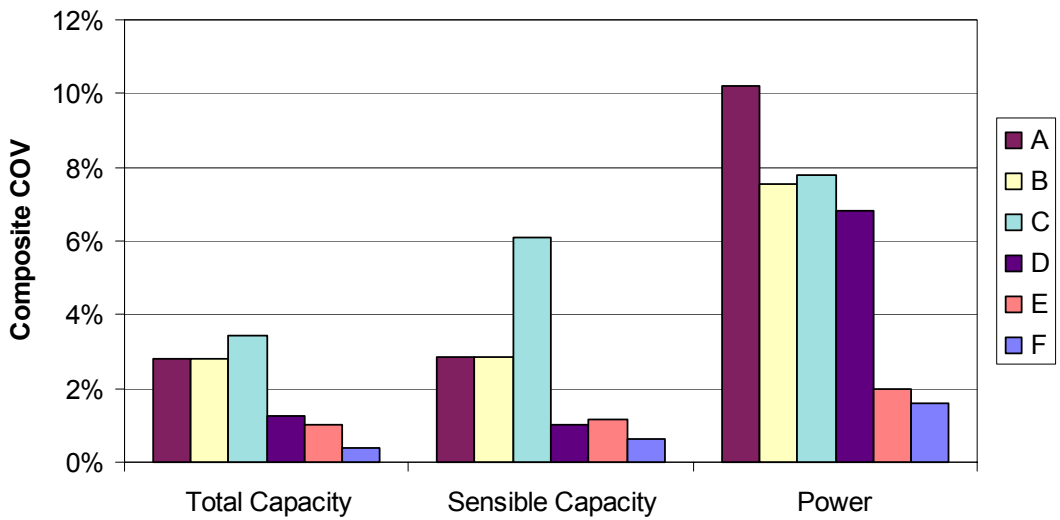


AC Model Comparison: Power



Effects of Data Availability

Data Availability Scenario	SEER	Total Capacity	Sensible Capacity	Power (or COP, EER, EIR)	Indoor Airflow	Outdoor Airflow	Type of Compressor	Compressor Model Number
A	X	X						
B	X	X		X				
C	X	X	X	X				
D	X	X	X	X	X	X		
E	X	X	X	X	X	X	X	
F	X	X	X	X	X	X	X	X



Conclusions

- Component model requires only performance at ARI rating point
  - More data better
  - Fan info and type of compressor most valuable for improved performance
- Performance nearly as good as polynomial fit to performance map
- Should performance maps be trusted?