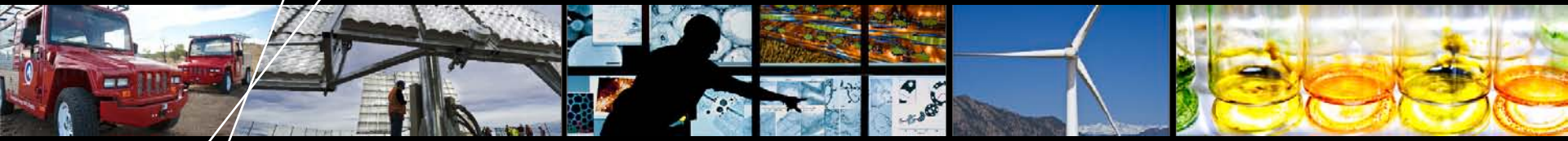
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Improving Air-Conditioner and Heat Pump Modeling



Building America Stakeholders Meeting

Jon Winkler

March 2, 2012

Simple Question

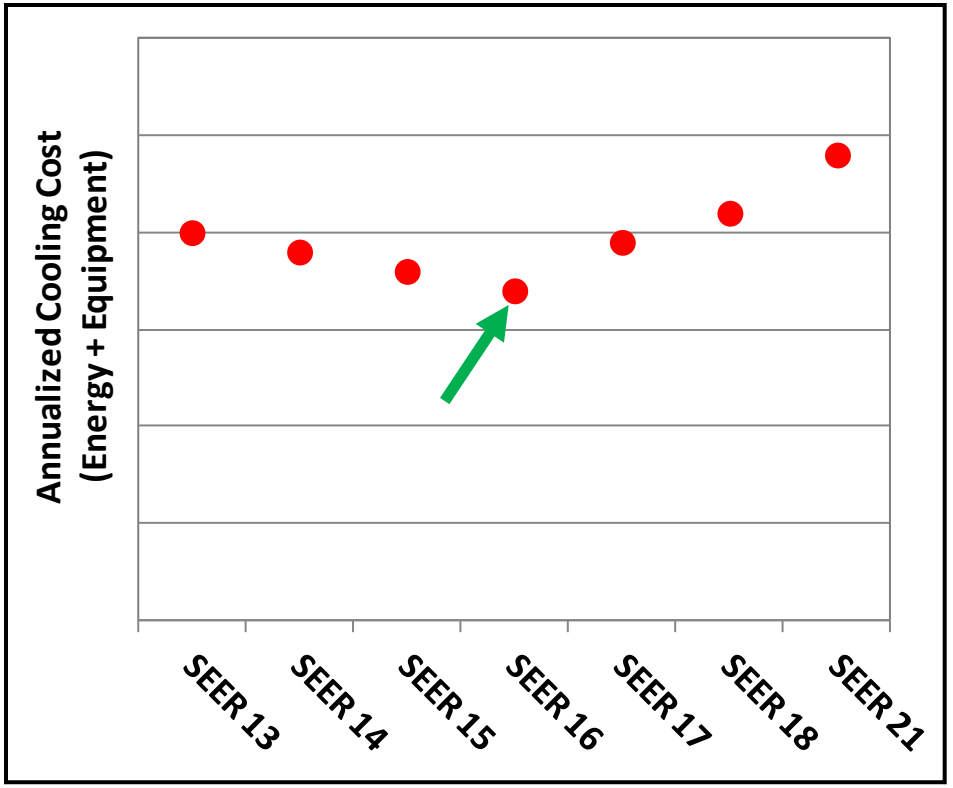
- **How do you recommend the most cost-effective A/C?**

Solution

Whole-House Simulation Tool

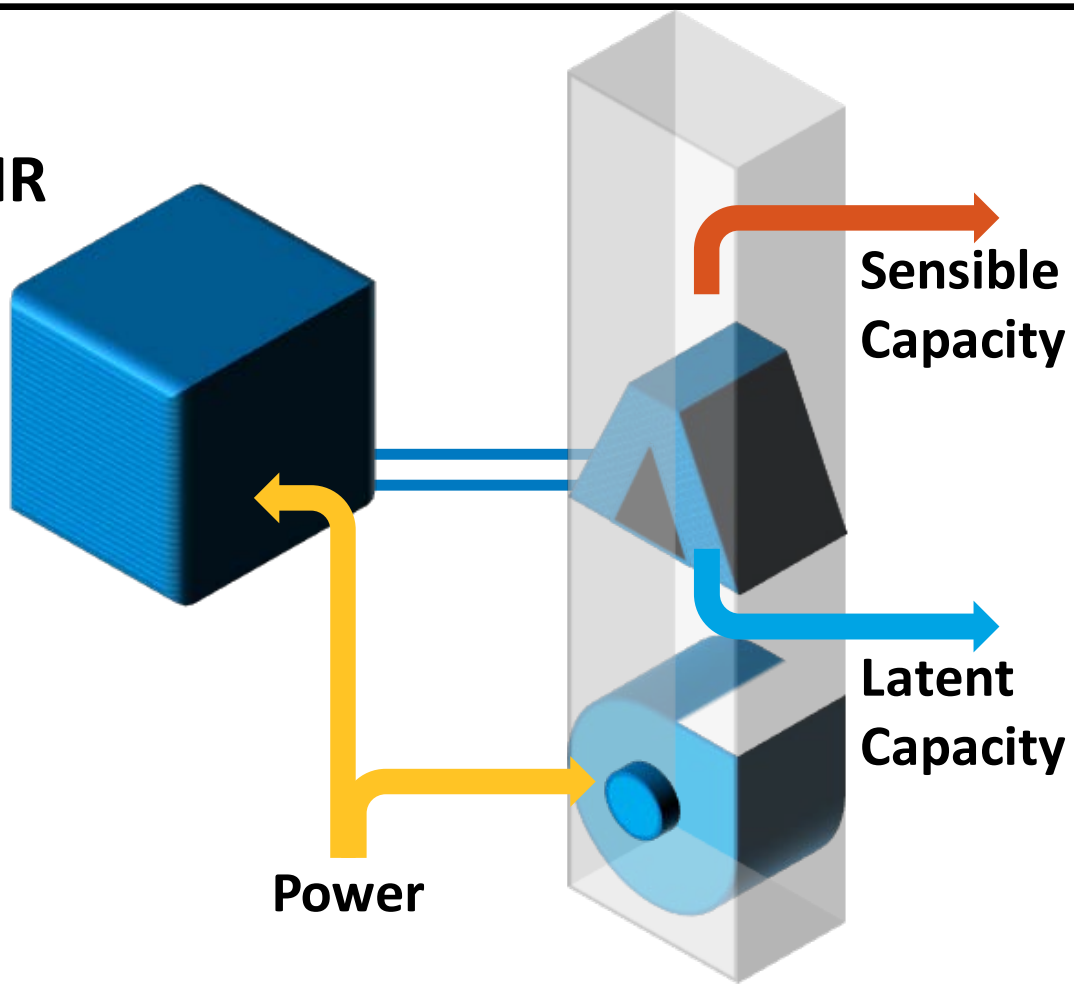
A/C Information

- SEER 13
- SEER 14
- SEER 15
- SEER 16
- SEER 17
- SEER 18
- SEER 21



Background

- **Power, capacity and SHR vary with:**
  - Outdoor temperature
  - Entering wetbulb
  - Air mass flow rate
  - Part load ratio

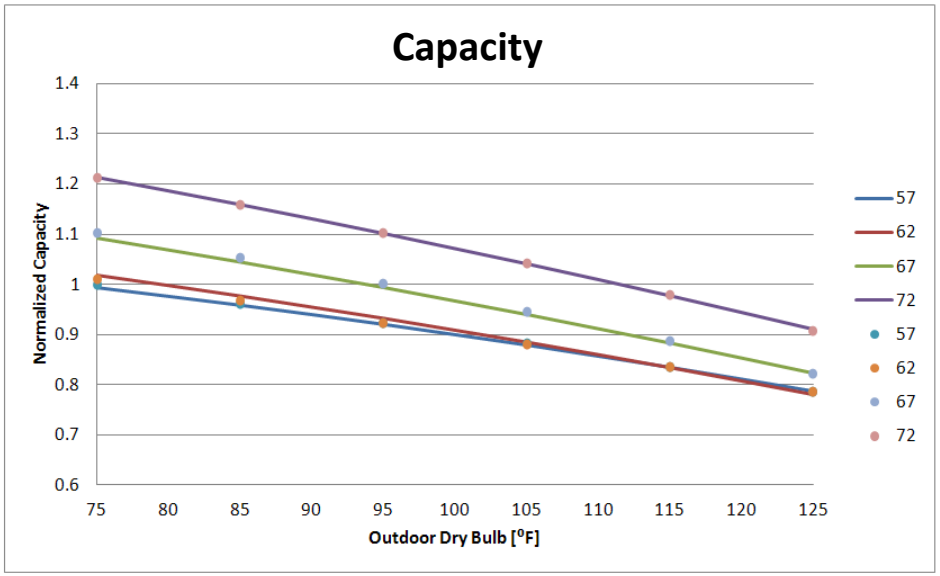


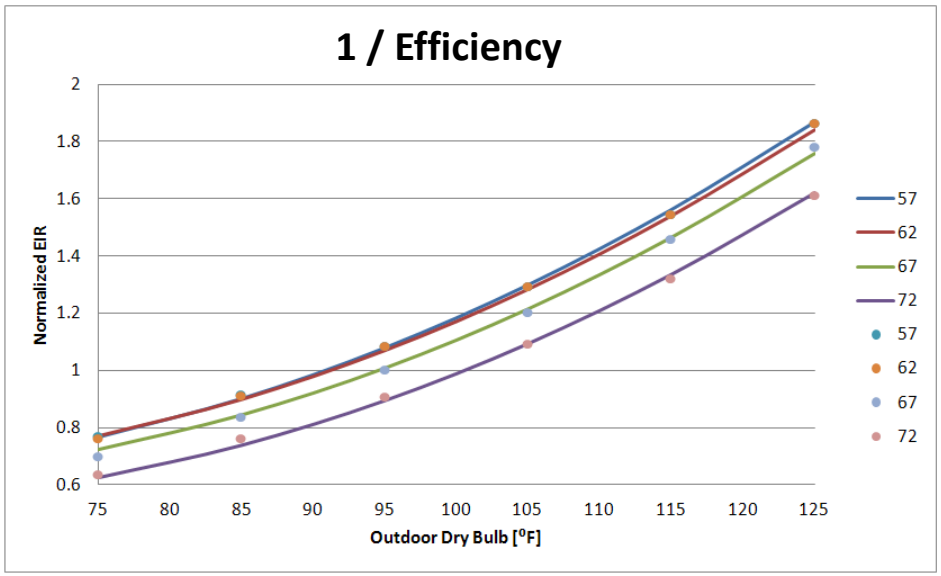
- **How to accurately and easily model A/C performance?**

Background: Model Development

- **A/C modeling utilizes two types of input**
  - Rated values (capacity, efficiency, etc.)
  - Performance curves

$$y = a + b \times EWB + c \times EWB^2 + d \times ODB + e \times ODB^2 + f \times ODB \times EWB$$





Background: Manufacturer's Data

EVAPORATOR AIR		CONDENSER ENTERING AIR TEMPERATURES °F (°C)											
		75 (23.9)			85 (29.4)			95 (35)			105 (40.6)		
CFM	EWB °F (°C)	Capacity MBtuh		Total System KW**	Capacity MBtuh		Total System KW**	Capacity MBtuh		Total System KW**	Capacity MBtuh		Total System KW**
		Total	Sens‡		Total	Sens‡		Total	Sens‡		Total	Sens‡	
875	72 (22.2)	34.32	17.27	1.96	32.83	16.71	2.19	31.24	16.13	2.44	29.59	15.54	2.71
	67 (19.4)	31.45	21.21	1.96	30.06	20.64	2.18	28.59	20.05	2.43	27.04	19.44	2.71
	63 (17.2)††	29.35	20.58	1.96	28.04	20.00	2.18	26.66	19.40	2.43	25.19	18.78	2.70
	62 (16.7)	28.82	25.13	1.95	27.56	24.55	2.18	26.24	23.94	2.43	24.86	23.29	2.70
	57 (13.9)	28.00	28.00	1.95	26.98	26.98	2.18	25.89	25.89	2.43	24.74	24.74	2.70
1000	72 (22.2)	34.88	18.05	2.01	33.32	17.49	2.23	31.66	16.90	2.48	29.96	16.30	2.76
	67 (19.4)	31.98	22.49	2.01	30.53	21.91	2.23	29.00	21.31	2.48	27.40	20.68	2.75
	63 (17.2)††	29.88	21.78	2.00	28.51	21.19	2.23	27.07	20.58	2.48	25.55	19.95	2.75
	62 (16.7)	29.44	26.90	2.00	28.16	26.29	2.23	26.81	26.81	2.48	25.62	25.62	2.75
	57 (13.9)	29.10	29.10	2.00	28.01	28.01	2.23	26.85	26.85	2.48	25.62	25.62	2.75
1125	72 (22.2)	35.27	18.78	2.06	33.67	18.21	2.28	31.96	17.61	2.53	30.22	17.01	2.81
	67 (19.4)	32.36	23.68	2.05	30.87	23.10	2.28	29.29	22.50	2.53	27.66	21.88	2.80
	63 (17.2)††	30.25	22.90	2.05	28.84	22.31	2.28	27.36	21.70	2.52	25.82	21.07	2.80
	62 (16.7)	30.02	28.49	2.05	28.84	28.84	2.28	27.62	27.62	2.52	26.32	26.32	2.80
	57 (13.9)	29.99	29.99	2.05	28.84	28.84	2.28	27.62	27.62	2.52	26.32	26.32	2.80

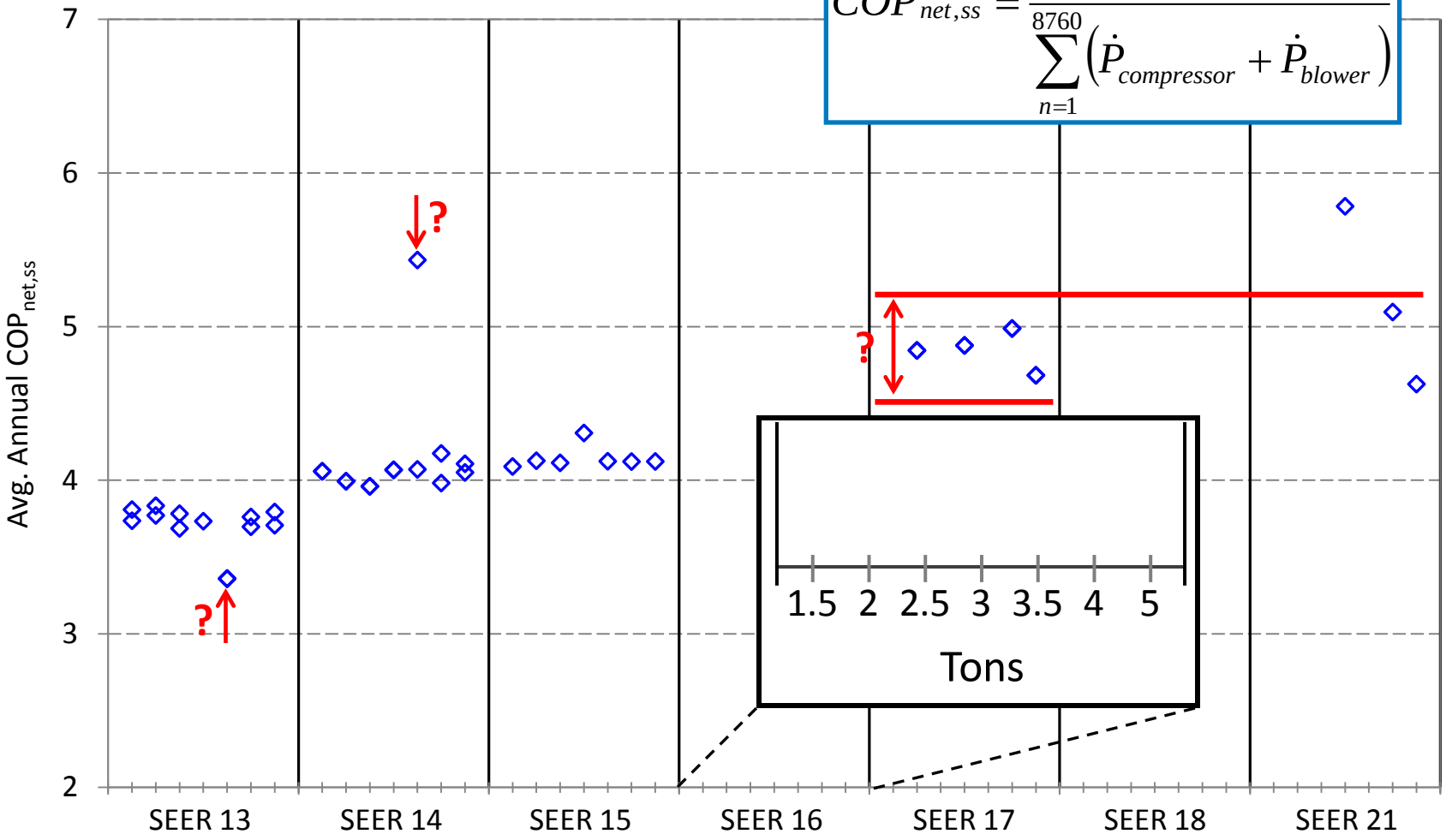
Simulation study:

- **5 leading manufacturers (76% of the market)**
- **450+ air-conditioners and heat pumps**
- **SEER 13 – 21**

Results: Specific A/C Units

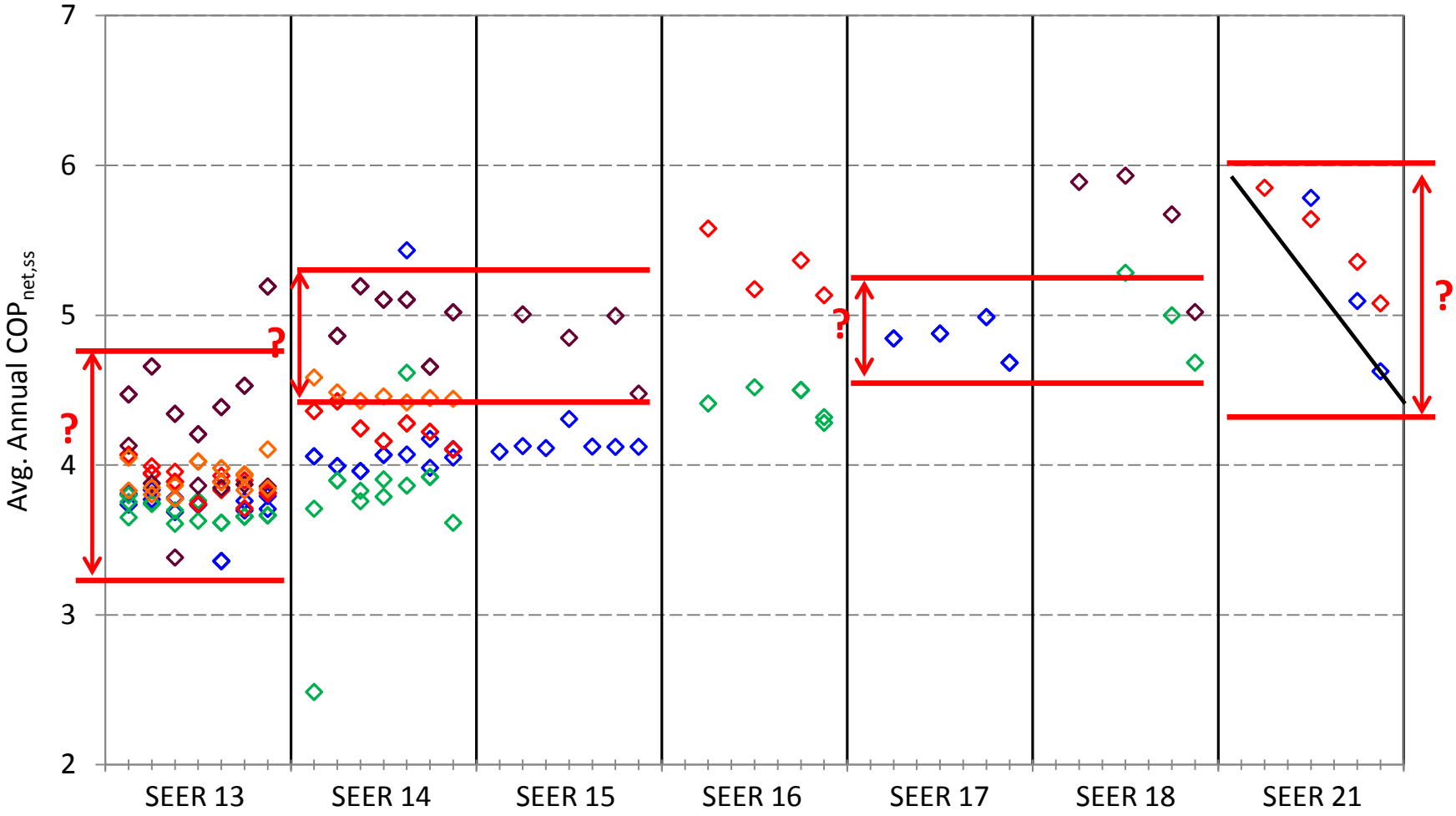
Houston: 2,500 ft² IECC 2009

$$\overline{COP}_{net,ss} = \frac{\sum_{n=1}^{8760}\left(\dot{Q}_{DX} - \dot{P}_{blower}\right)}{\sum_{n=1}^{8760}\left(\dot{P}_{compressor} + \dot{P}_{blower}\right)}$$



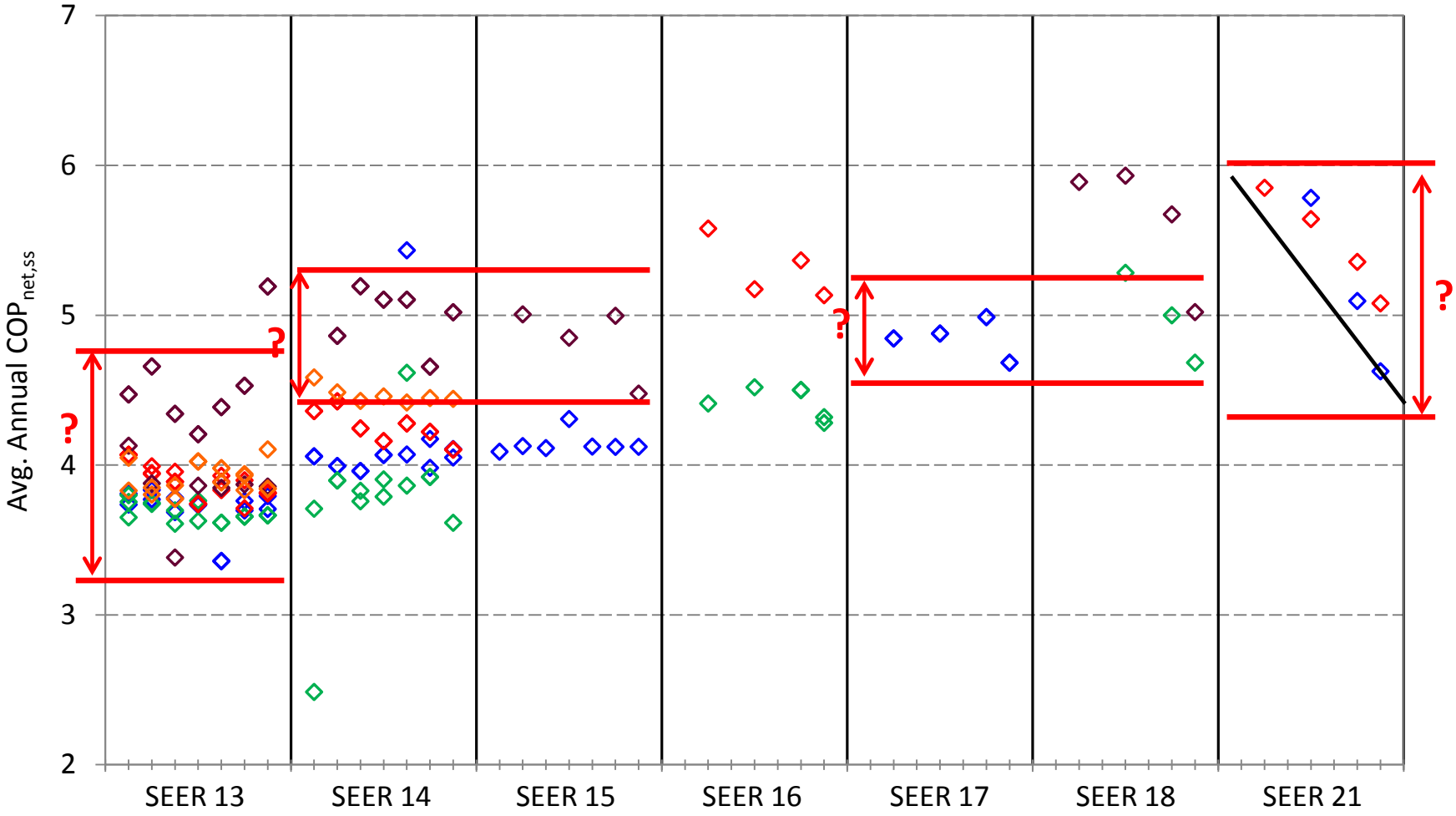
Results: Specific A/C Units

Houston: 2,500 ft^2 IECC 2009



Results: Specific A/C Units

Question #1: What leads to the variation in average annual COP?

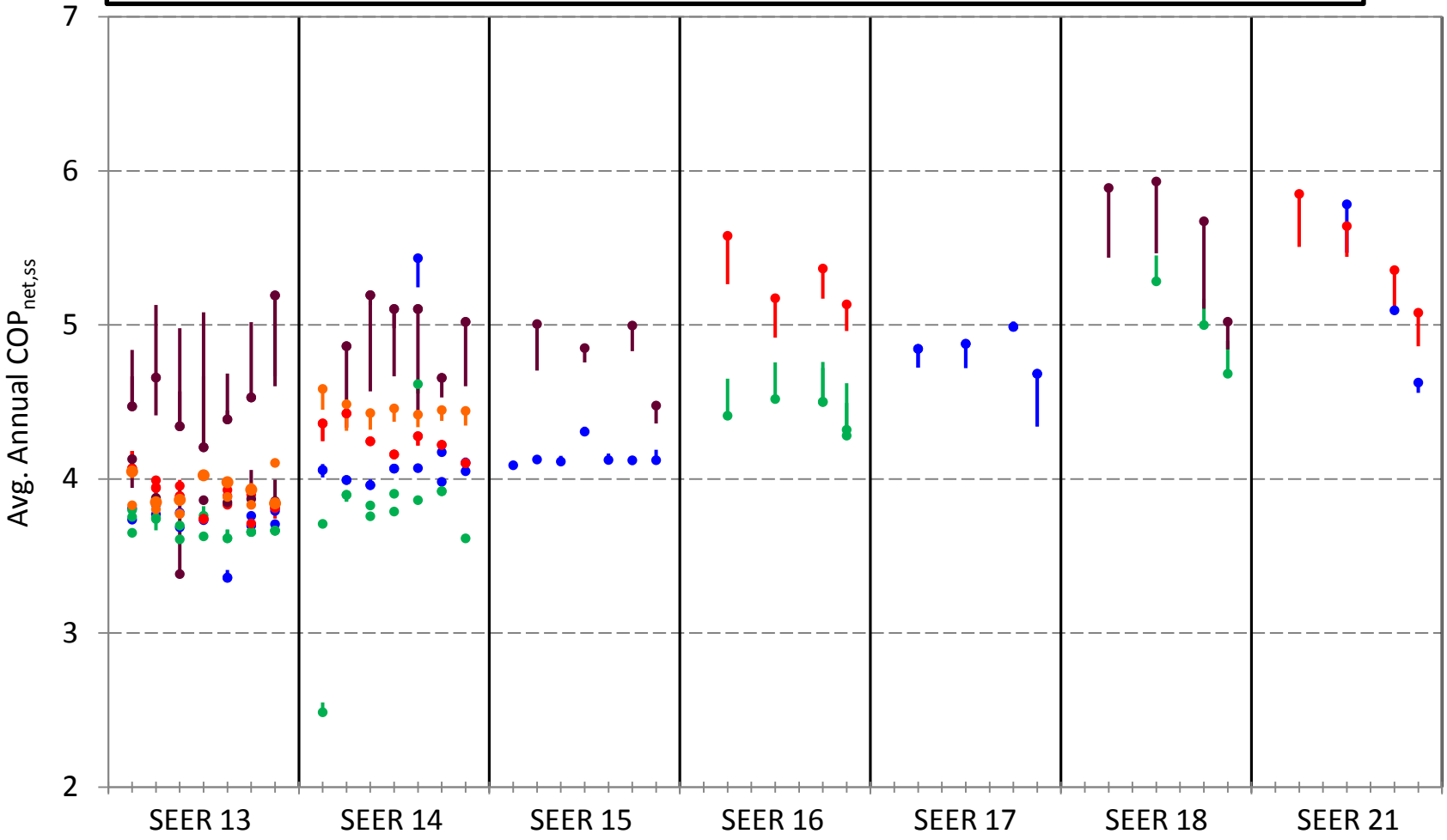


Sensitivity to Curve Inputs

- **Simulation inputs**
  - Rated values (capacity, efficiency, etc.)
  - Performance curves
- **Which type of input is leading to the observed variation?**
  - What happens if a selected set of curves are used for all simulations?

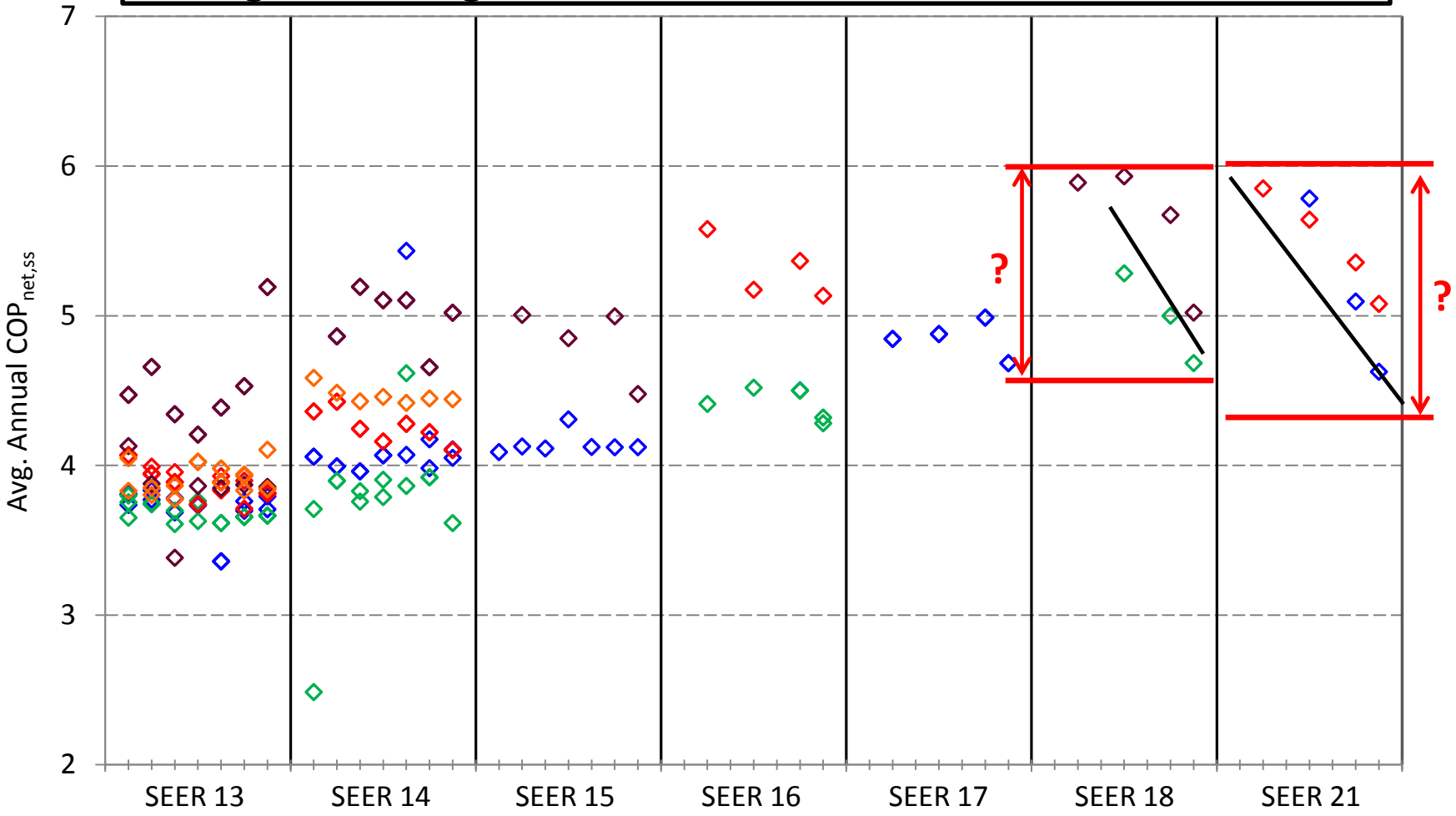
Results: Sensitivity to Curve Inputs

Conclusion #1: Annual simulation results are not highly dependent on the selected performance curves

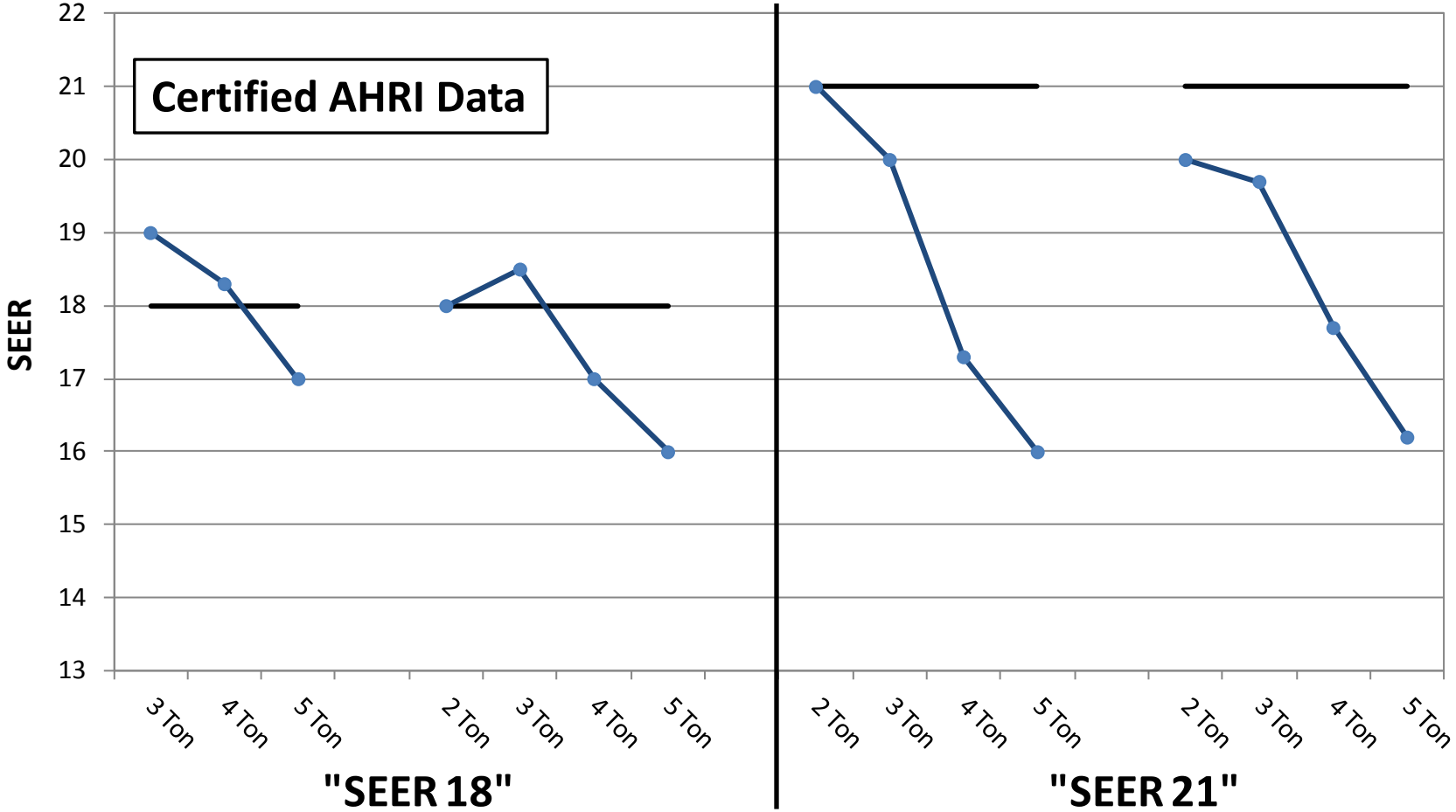


Results: Specific A/C Units

Question #2: Does the efficiency of high SEER A/C's decrease for higher tonnage units?



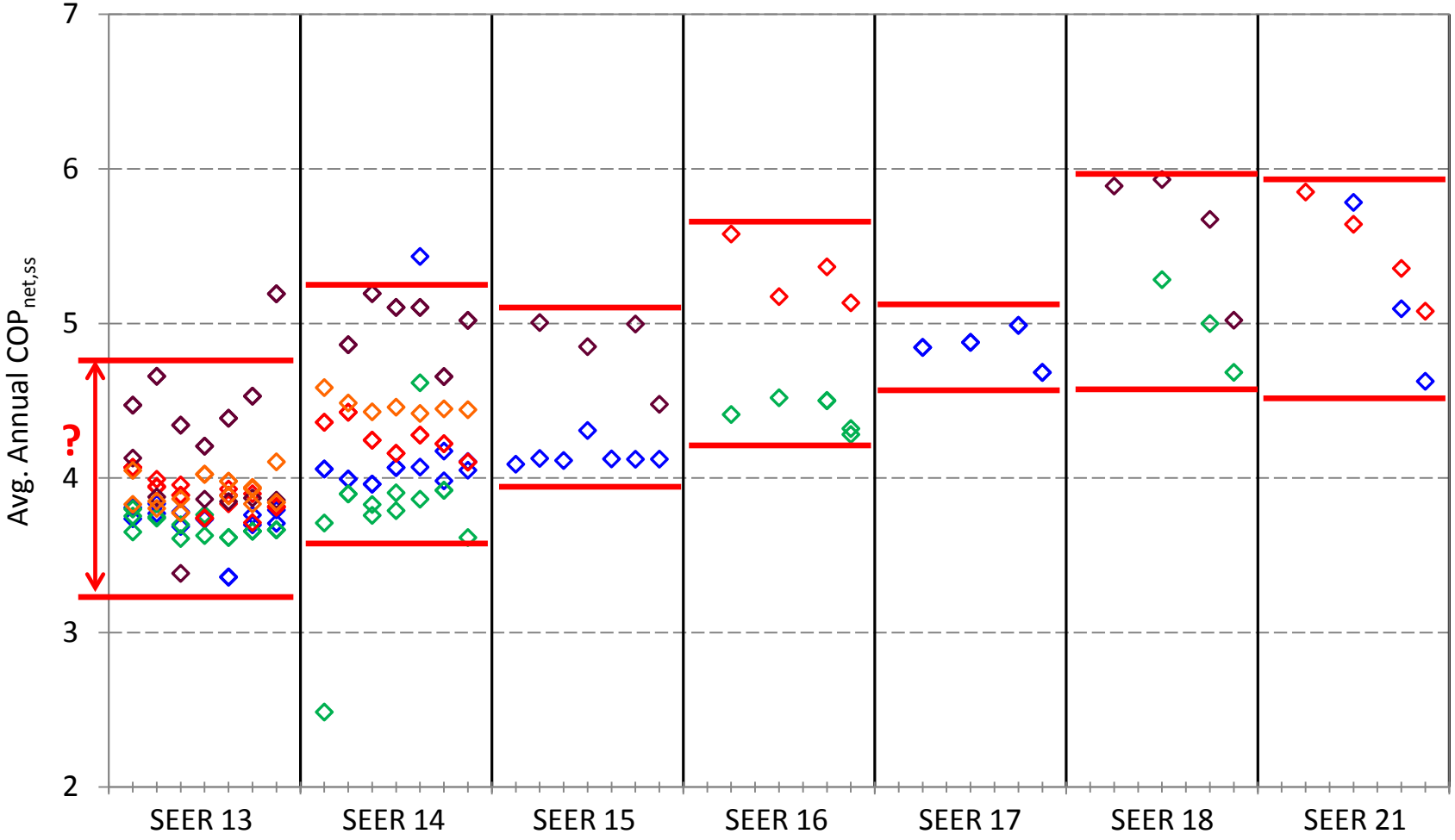
Results: SEER vs. Tonnage



Conclusion #2: SEER is highly effected by nominal tonnage for high efficiency equipment

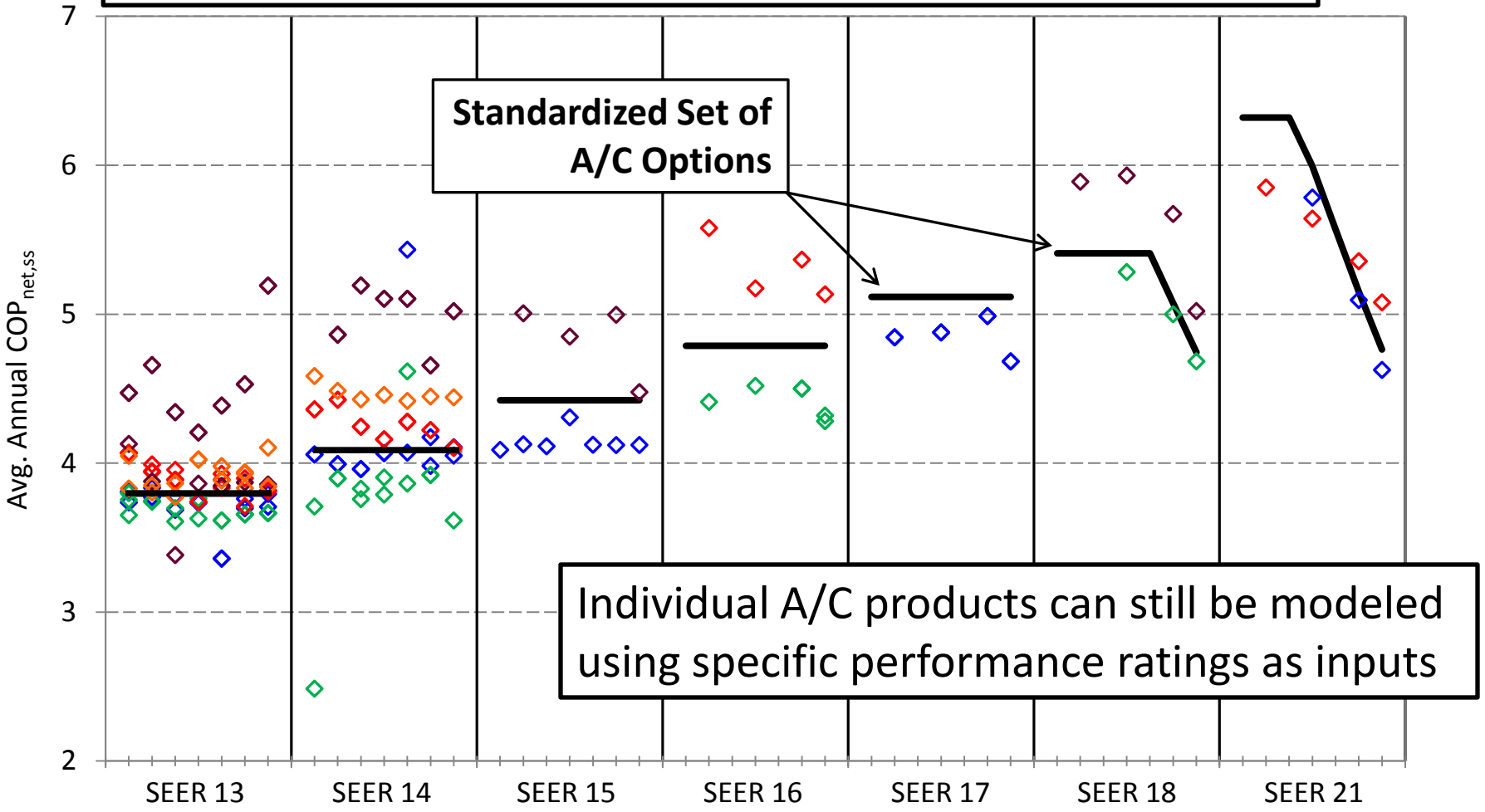
Results: Specific A/C Units

Question #3: How do we generalize A/C energy use across different SEER levels?



Results: Standardized Set of A/C Options

Conclusion #3: Develop a set of rated performance inputs for generic A/C units to be consistent across SEER levels



Conclusions

When comparing different A/C's:

1. **Specific performance curves don't really matter**
2. **Be careful of "Up to SEER…"**
3. **The rated performance data does matter and needs to be consistent**

Application: BEopt – Simplified Inputs

BEopt 1.1

Cooling EER	12.72
COOL_CAP_FT_SPEC_coefficients	1.61196622,-0.03412895,0.00044551,0.00278667,-0.00000211,-0.00008969
COOL_SH_FT_SPEC_coefficients	0.42251614,0.07360185,-0.00089453,-0.00840292,0.00001615,0.00004937
COIL_BF_FT_SPEC_coefficients	56.67437760,-1.66560721,0.01245741,0.0,0.0,0.0
COOL_EIR_FT_SPEC_coefficients	-0.68032067,0.03410170,-0.00025020,0.00559185,0.00010461,-0.00015031
COOL_EIR_FPLR_SPEC_coefficients	0.00000728,1.09852231,-0.11487027,0.01634067
COOL_CLOSS_FPLR_SPEC_coefficients	0.90949556,0.09864773,-0.00819488
COIL_BF_FFLOW_SPEC_Max	1.0
COIL_BF_FFLOW_SPEC_Min	0.0
COIL_BF_FFLOW_SPEC_coefficients	1.0, 0.0
FAN_EIR_FPLR_SPEC_coefficients	0.0, 1.0, 0.0, 0.0
SupplyKW	0.000256
CoilBF	0.100700

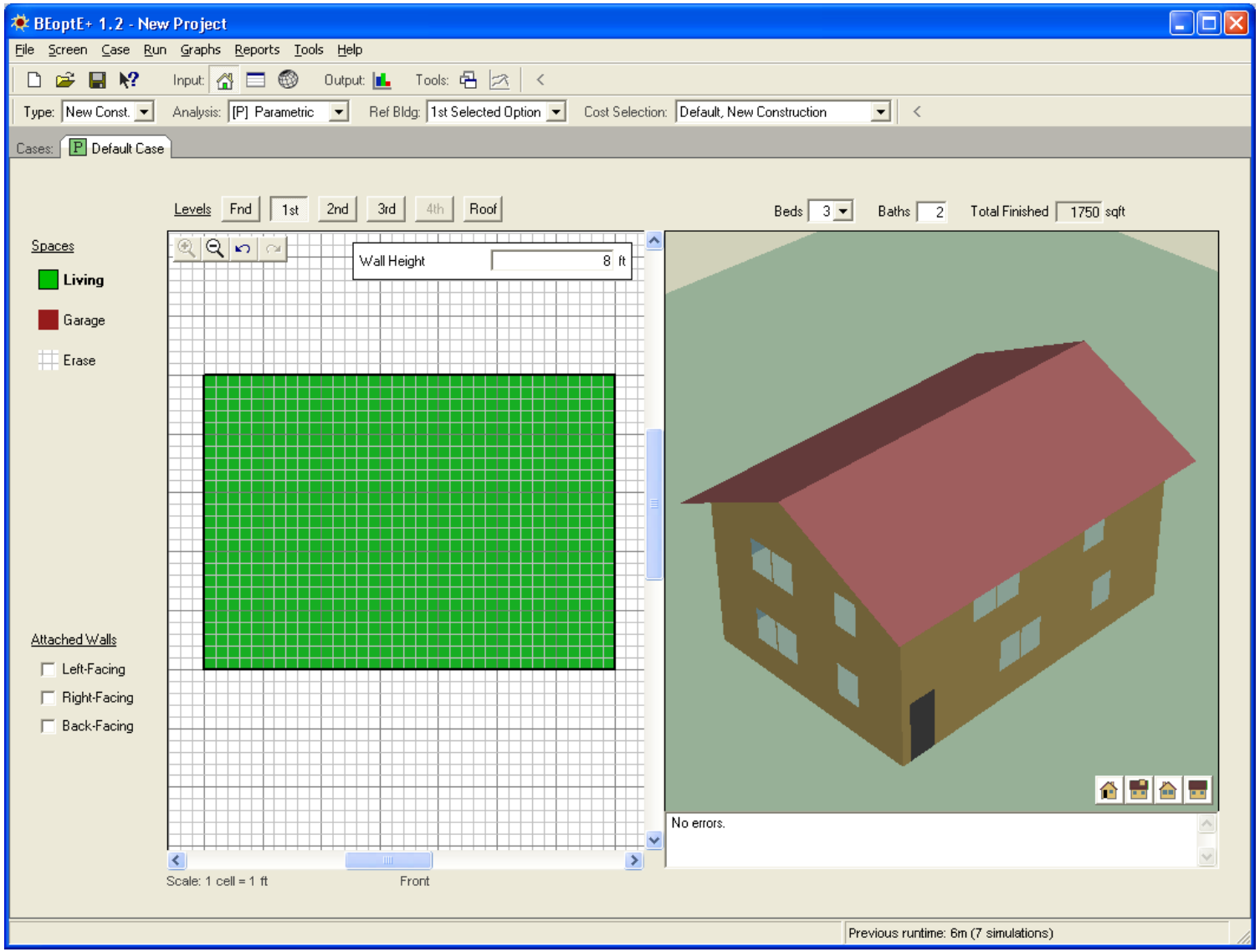
BEopt 1.2

Cooling SEER	14.0
Cooling EER	11.98
SHR	0.74
SupplyFanPower	0.365

User inputs for single stage units

- **Benefits**
  - Easily model specific make & model A/C's
  - Negligible sacrifice in accuracy/flexibility

Application: BEopt – Consistent Results



Application: BEopt – Consistent Results

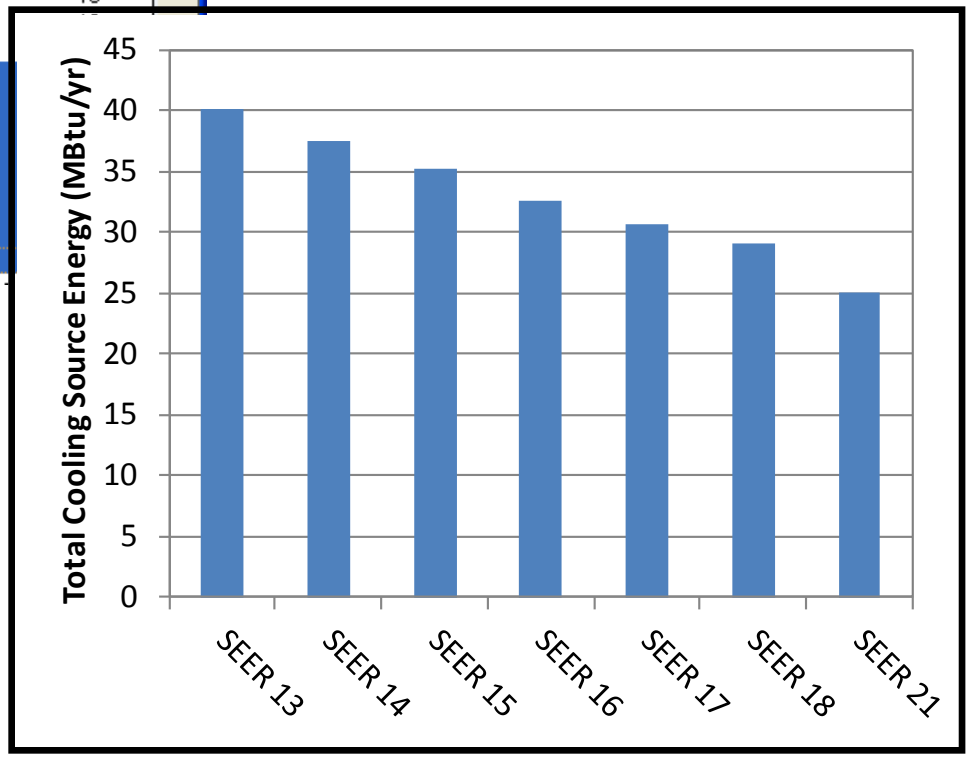
Tools:

ed Option | Cost Selection: Default, New Construction

d Graphs

Air Conditioner options	SEER	EER [kBtu/kWh]	Compressor	Lifetime [years]
1) None	NA	NA	NA	99
2) * SEER 8, 15yrs old(Seldom Maint.)	5.1	4.6	1 Stage	19
3) * SEER 8, 15yrs old (Frequently Maint.)	6.9	6.3	1 Stage	19
4) * SEER 10, 10yrs old (Seldom Maint.)	7.4	6.5	1 Stage	19
5) * SEER 10, 10yrs old (Frequently Maint.)	9.0	8.1	1 Stage	
6) * SEER 13, at wear out	13.0	11.1	1 Stage	
7) SEER 13	13.0	11.1	1 Stage	
8) SEER 14	14.0	12.0	1 Stage	
9) SEER 15	15.0	13.0	1 Stage	
10) SEER 16	16.0	13.9	1 Stage	
11) SEER 16 (2 Stage)	16.0	13.5 , 12.4	2 Stage	
12) SEER 17	17.0	14.4 , 13.2	2 Stage	
13) SEER 18	18.0	15.2 , 14.0	2 Stage	
14) SEER 21	21.0	17.7 , 15.3	2 Stage	

BEoptE+
Parametric
Simulation



Building America Gaps and Barriers

- **Gap: Analysis Methods and Tools Standing Technical Committee**
  - BA Strategic Plans: http://www1.eere.energy.gov/buildings/building_america/strategic_plan.html
- **Achievements**
  - "… it is important to continually **update** and advance **air-conditioner and heat pump modeling approaches and capabilities**."
  - "Additionally, it is important that users can **easily enter specific air-conditioners into building simulation software** (such as BEopt) in order to compare specific manufactured units not included in built-in component libraries."

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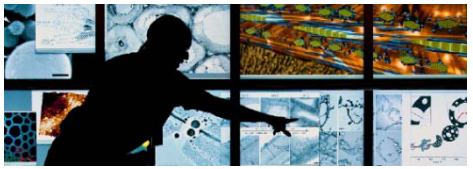

Thanks!

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