

Compressor Technology / Type and its Impact on GWP

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Chapter 2: Test Description

Chapter 3: Results & Conclusions

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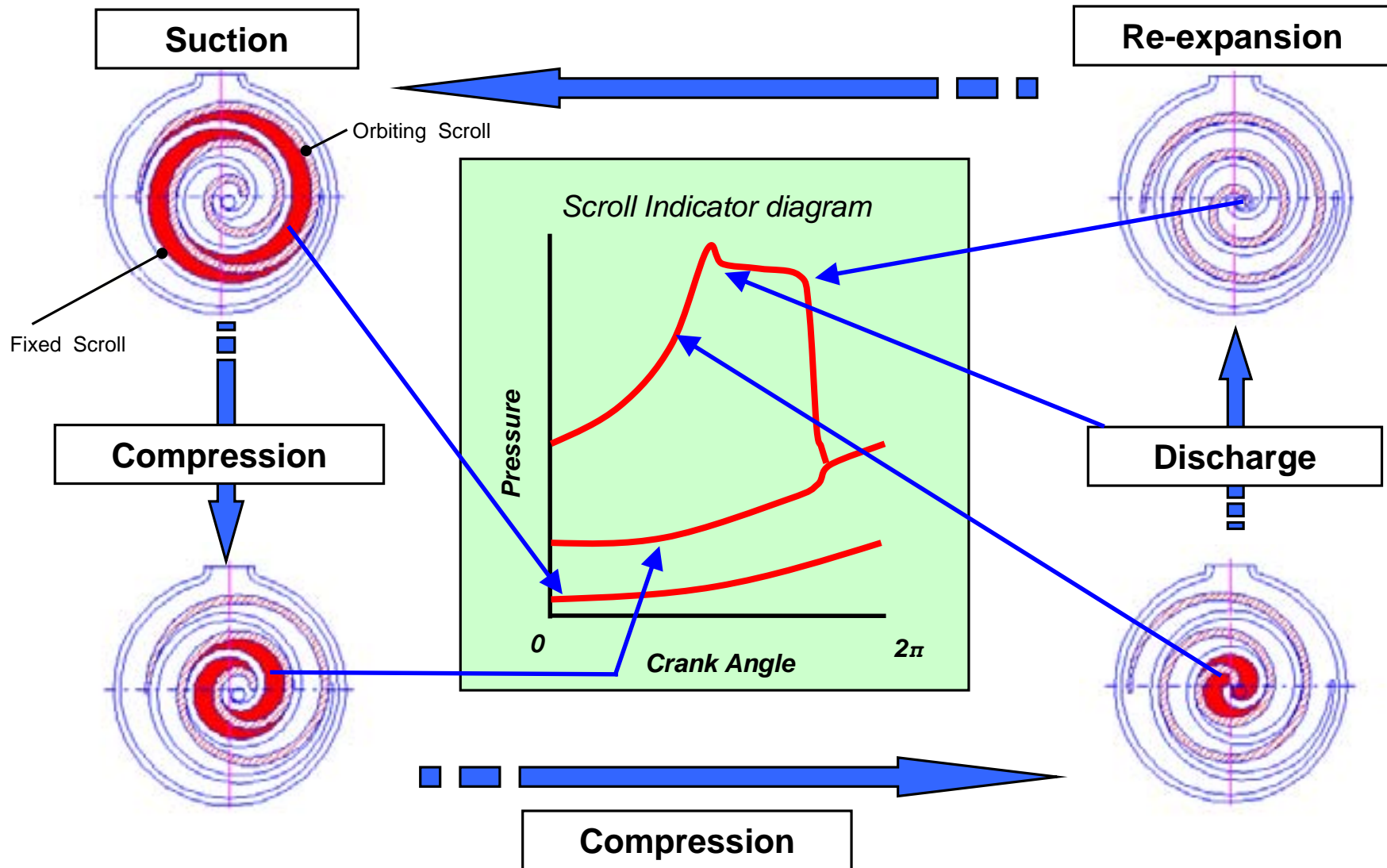
Compressor Technology / Type and its Impact on GWP

Introduction

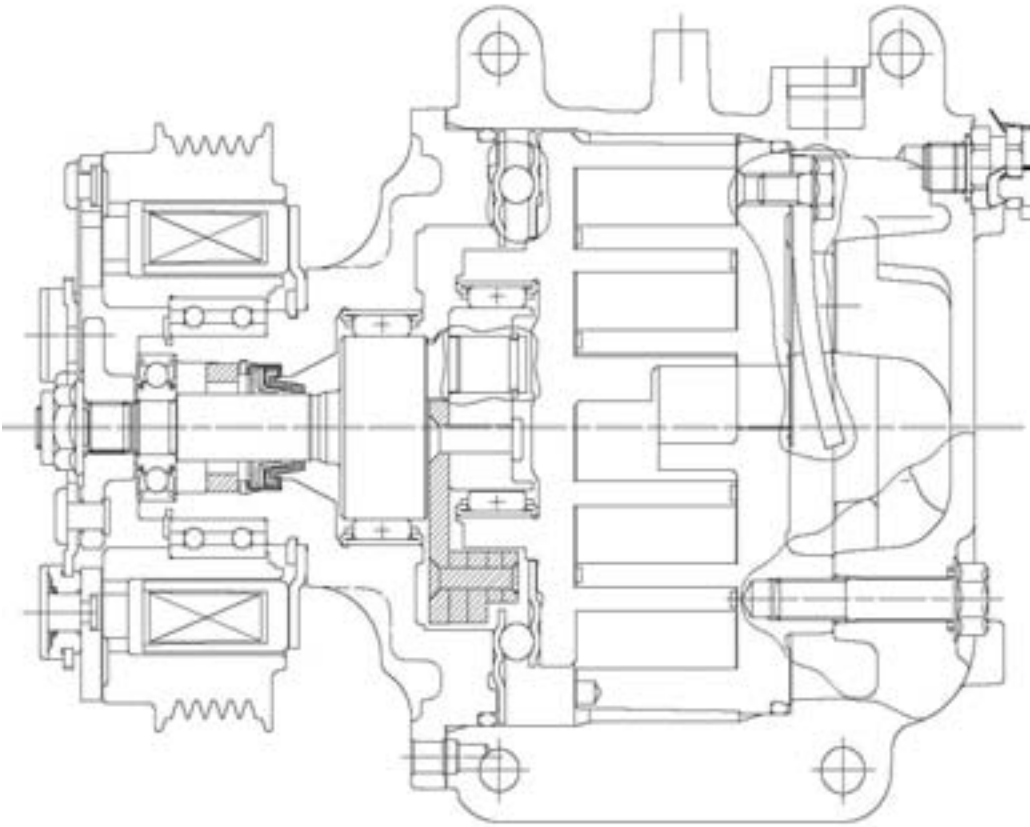
Several Compressor Technologies were evaluated for their impact on vehicle power consumption. All evaluations were conducted on a system calorimeter consistent with IMAC test conditions. Annualized Energy Consumption values were calculated based on the established IMAC weighting factors.

Sanden Scroll Compressors TRSA09 (w/o Oil Separator) & TRSE07 (w/ Oil Separator) were compared vs. Fixed Swash Plate (w/ Oil Separator) Compressor and Internally Variable Swash Plate (w/ Oil Separator) Compressor.

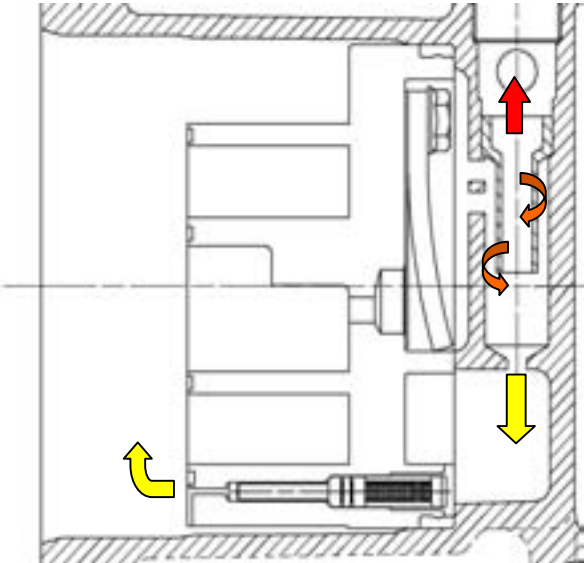
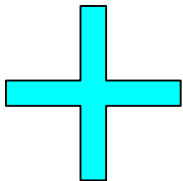
Introduction - Scroll Compression Process



Introduction - TRSA/E Cross Sectional View



TRSA



Oil Separator → TRSE

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Setup & Test Conditions

Data Management

Charge Determination

TXV Confirmation

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Chapter 4: Further Analysis – Beyond IMAC

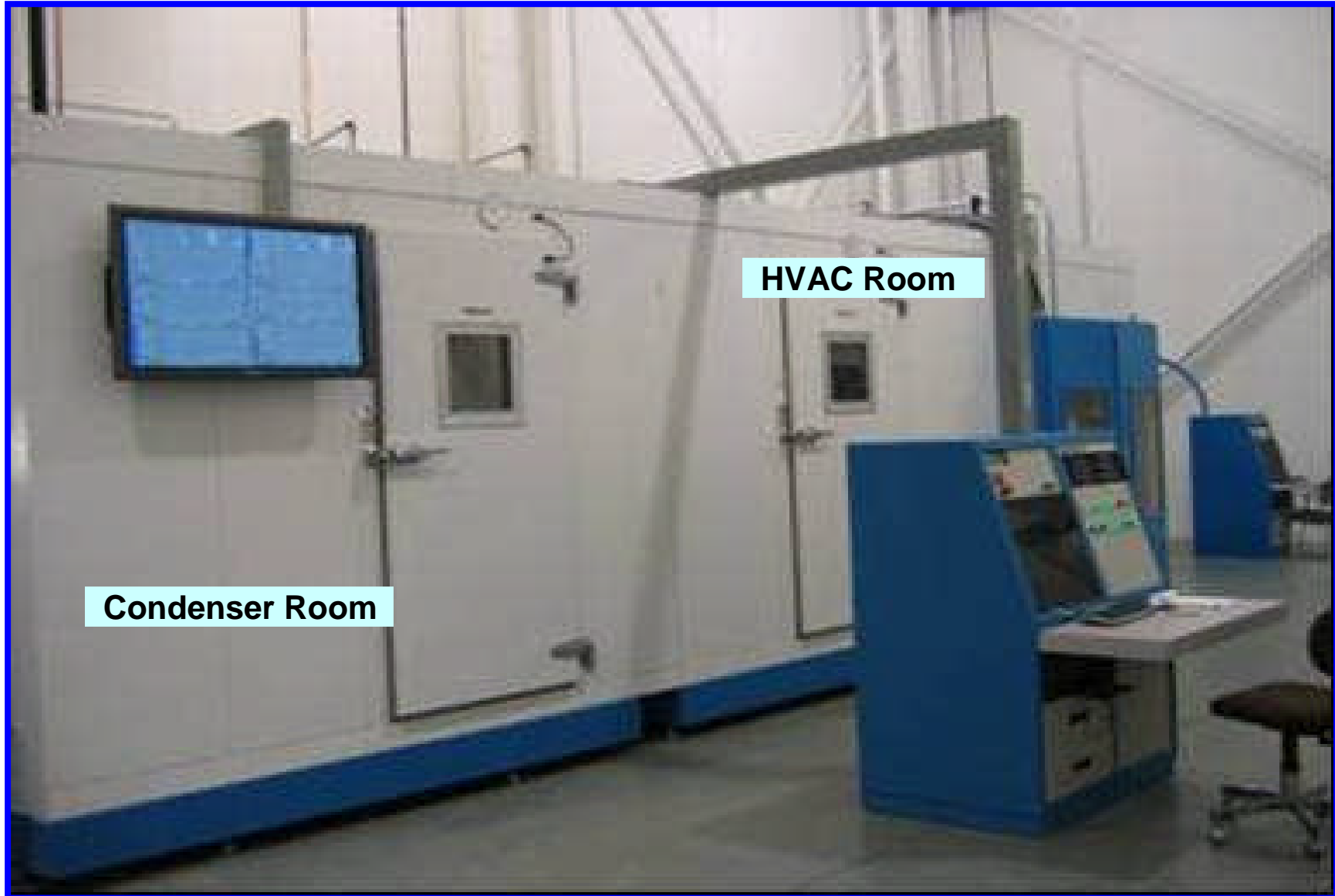
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Test Setup - Component Information

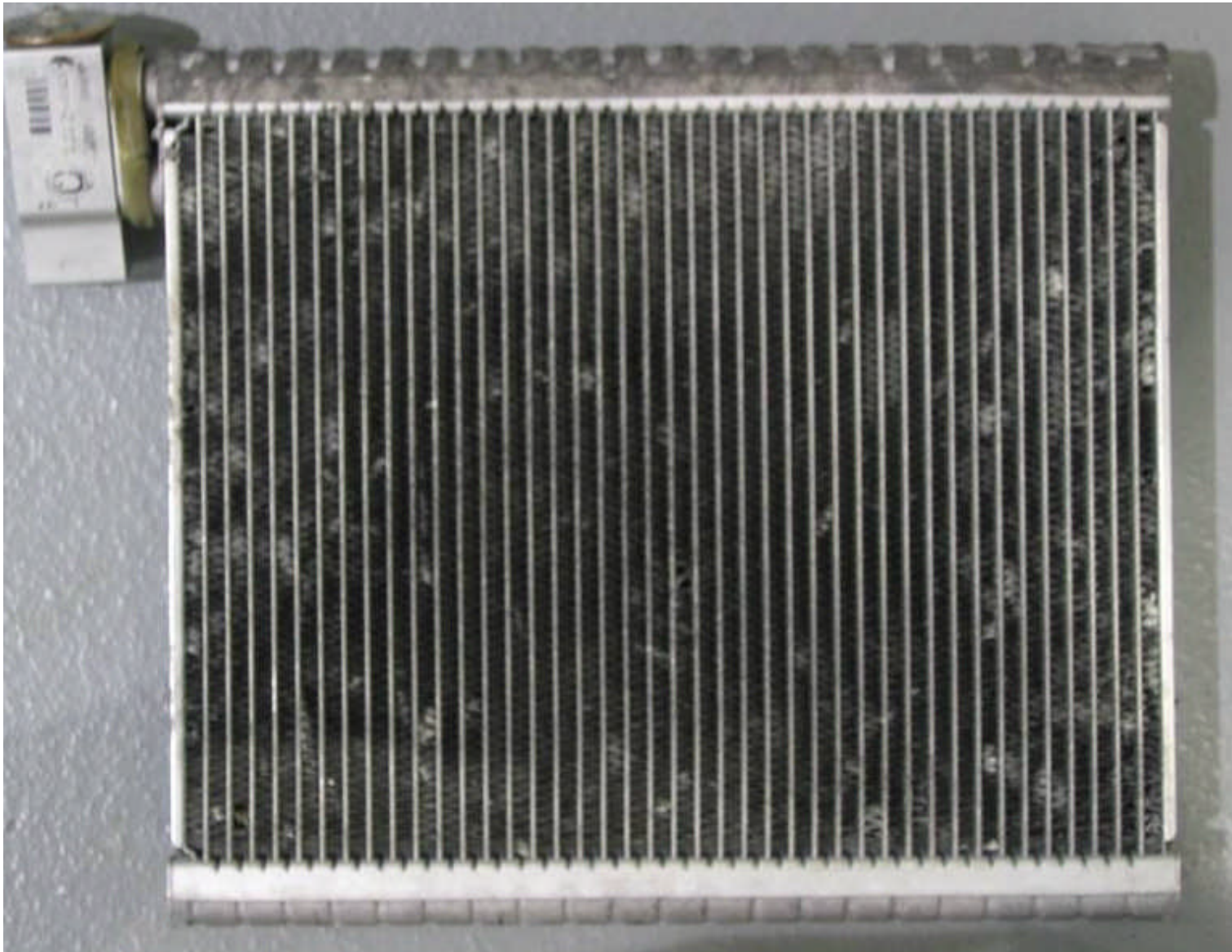
Production system with the latest condenser and evaporator technologies (i.e. micro-channel type) was chosen for the evaluation.

Components	Description
Evaporator	Micro-Channel 42 tubes 286mm Height / 280mm Length / 41mm Depth
Condenser	Micro-Channel, IRD 79 tubes 520mm Height / 630mm Length / 15mm Depth
TXV	1.0 ton, cross charge
Compressors	
Sanden TRSE07	Fixed disp. scroll w/ oil separator (77 cc)
Sanden TRSA09	Fixed disp. scroll (86 cc)
“D” IVD14	Internally variable disp. Swash plate w/ oil separator (135 cc max)
“A” FD17	Fixed disp. swash plate w/ oil separator (177 cc)

Test Setup – System Bench



Test Setup – System Bench



Test Setup - Instrumentation and Data Sampling

List of data Channels

Refrigerant Side

- Compressor inlet pressure & temperature
- Compressor outlet pressure & temperature
- TXV inlet pressure & temperature
- Evaporator outlet pressure & temperature
- Refrigerant oil circulation rate (O.C.R.)
- Refrigerant mass flow rate

Air Side

- Supply air temperature & humidity (evap. and cond.)
- Supply air mass flow (for both evap. and cond.)
- 3 thermocouple-grid at HVAC module outlet nozzle
- Temperature / Humidity combo sensor at the center of HVAC module outlet nozzle

Other

- Compressor speed
- Compressor drive torque & speed
- Blower voltage
- Clutch voltage

Data Sampling Rate	
Steady State	Every 5 sec for 10 mins.
Cycling Test	Every 0.1sec for <i>Shaft torque, RPM, Clutch voltage HVAC out air temp. & humidity</i>
	Every 5 sec for other channels
All data recorded over a period of 10 mins.	

Test Conditions

IMAC test matrix & annual weighting factors

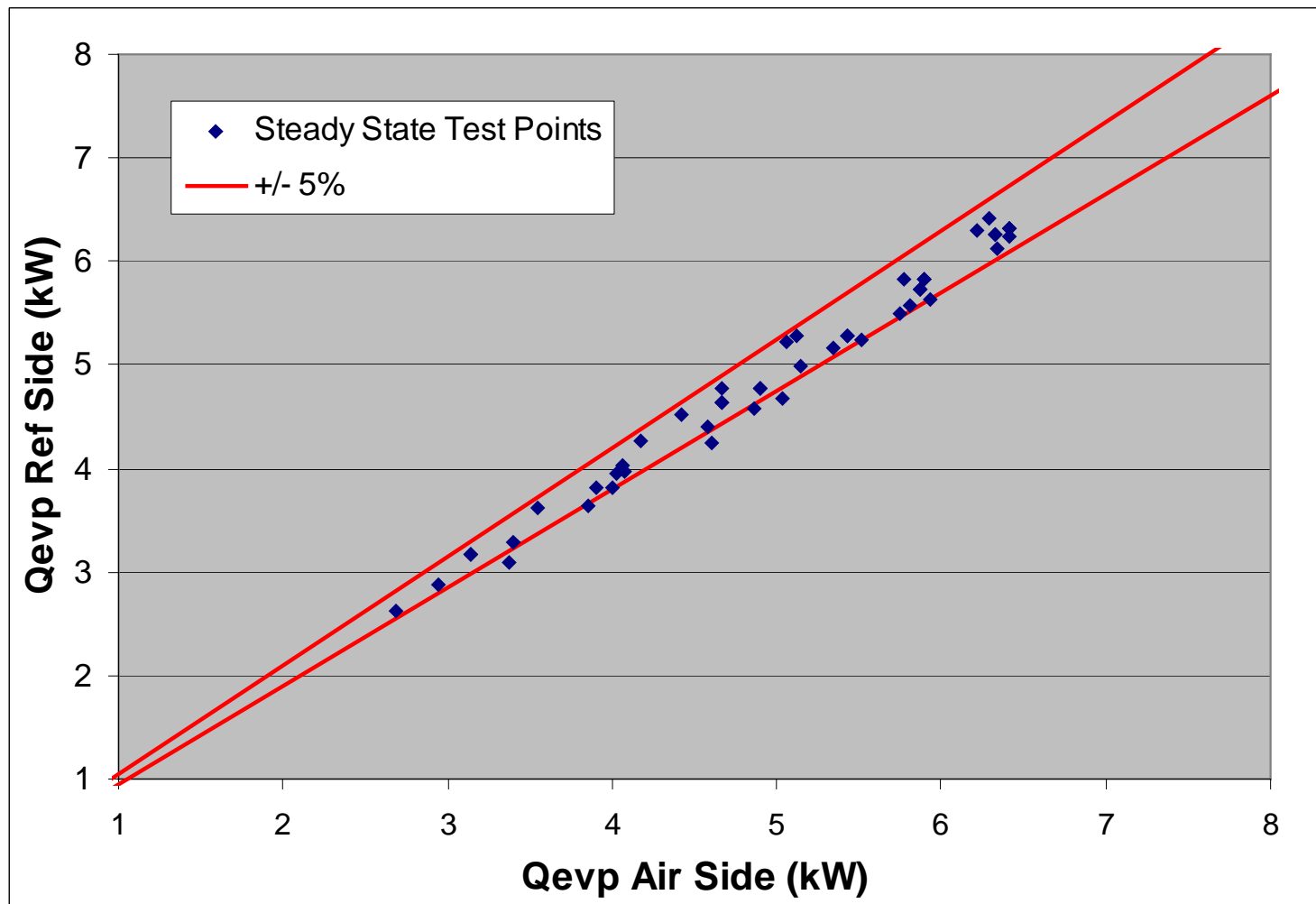
Test#	Comp speed	Cond Air Temp	Cond Air flow	Evap Air Temp	Evap Air R H	Evap Airflow	IMAC Weighting	
	RPM	°F	SCFM	°F	%	SCFM	Climate wt.	RPM Wt
I45	900	113	725	95	25	230	0.2%	17.0%
L45	1500	113	1460	95	25	275	0.2%	43.0%
M45	2500	113	2260	95	25	275	0.2%	35.0%
H45	4000	113	2260	95	25	275	0.2%	5.0%
I35a	900	95	725	95	40	230	3.8%	17.0%
L35a	1500	95	1460	95	40	275	3.8%	43.0%
M35a	2500	95	2260	95	40	275	3.8%	35.0%
H35a	4000	95	2260	95	40	275	3.8%	5.0%
I25a	900	77	725	77	80	190	37.9%	17.0%
L25a	1500	77	1460	77	80	127	37.9%	43.0%
M25a	2500	77	2260	77	80	127	37.9%	35.0%
H25a	4000	77	2260	77	80	127	37.9%	5.0%
I15	900	59	725	59	80	127	46.2%	17.0%
L15	1500	59	1460	59	80	85	46.2%	43.0%
M15	2500	59	2260	59	80	85	46.2%	35.0%
H15	4000	59	2260	59	80	85	46.2%	5.0%

Data Management Highlights

Item	Description
Cooling Capacity Match	Using average speed ratio. <u>Fixed compressor</u> : Clutch cycled to match capacity
Average speed ratio	Average of required speed ratios to meet cooling capacity at I35a, L35a and M35a
Steady State Data	Average over a 10 minute period
Clutch cycling data	Integration of data (of full on-off cycles only) over a 10 minute period.
Oil Circulation rate	Real Time Measurement
Refrigerant side Qevp	Corrected with real-time oil circulation data (steady state only)
Power consumption	Corrected for belt power consumption
COP	Using Qevp calculated from air side

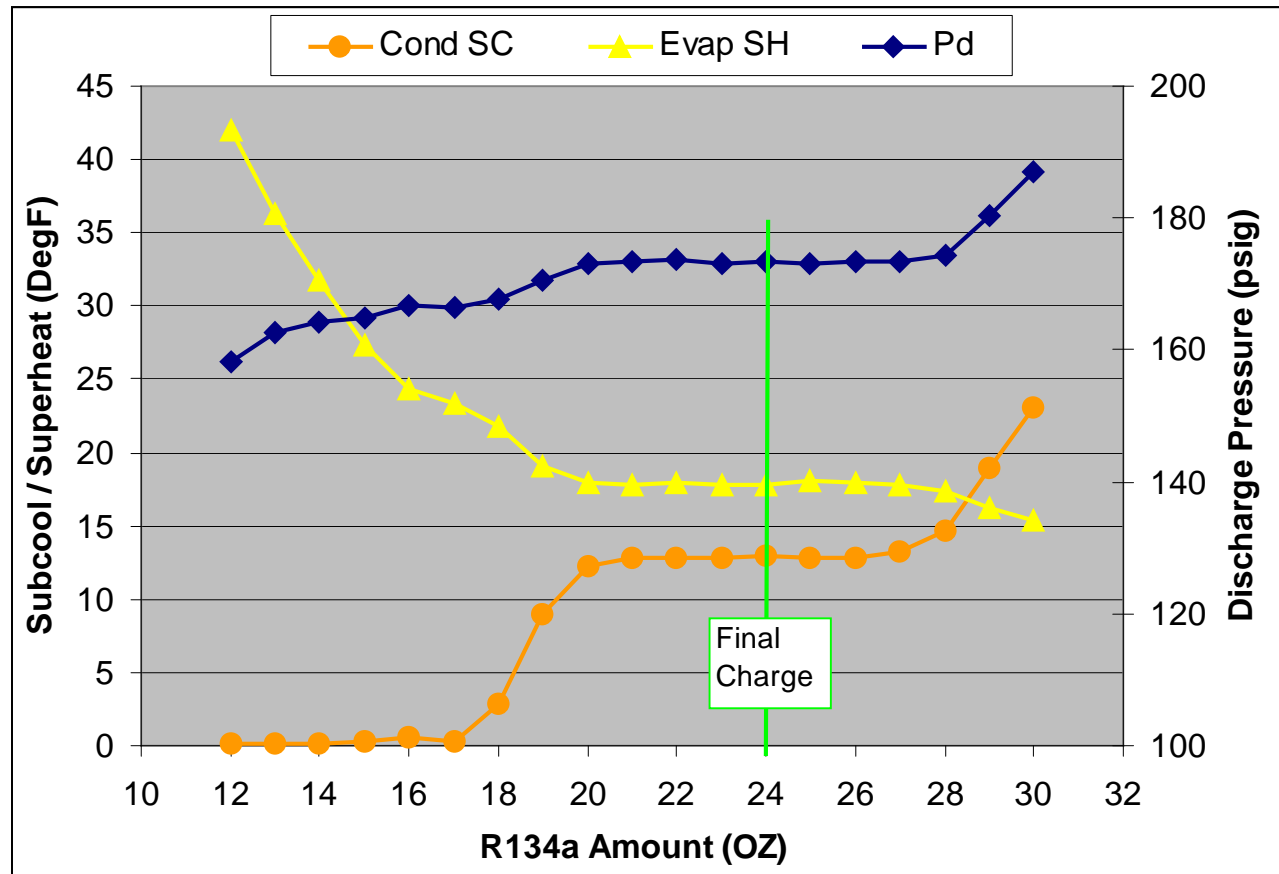
Data Management: Equipment Validation

Refrigerant & air side energy balance is within +/- 5%.



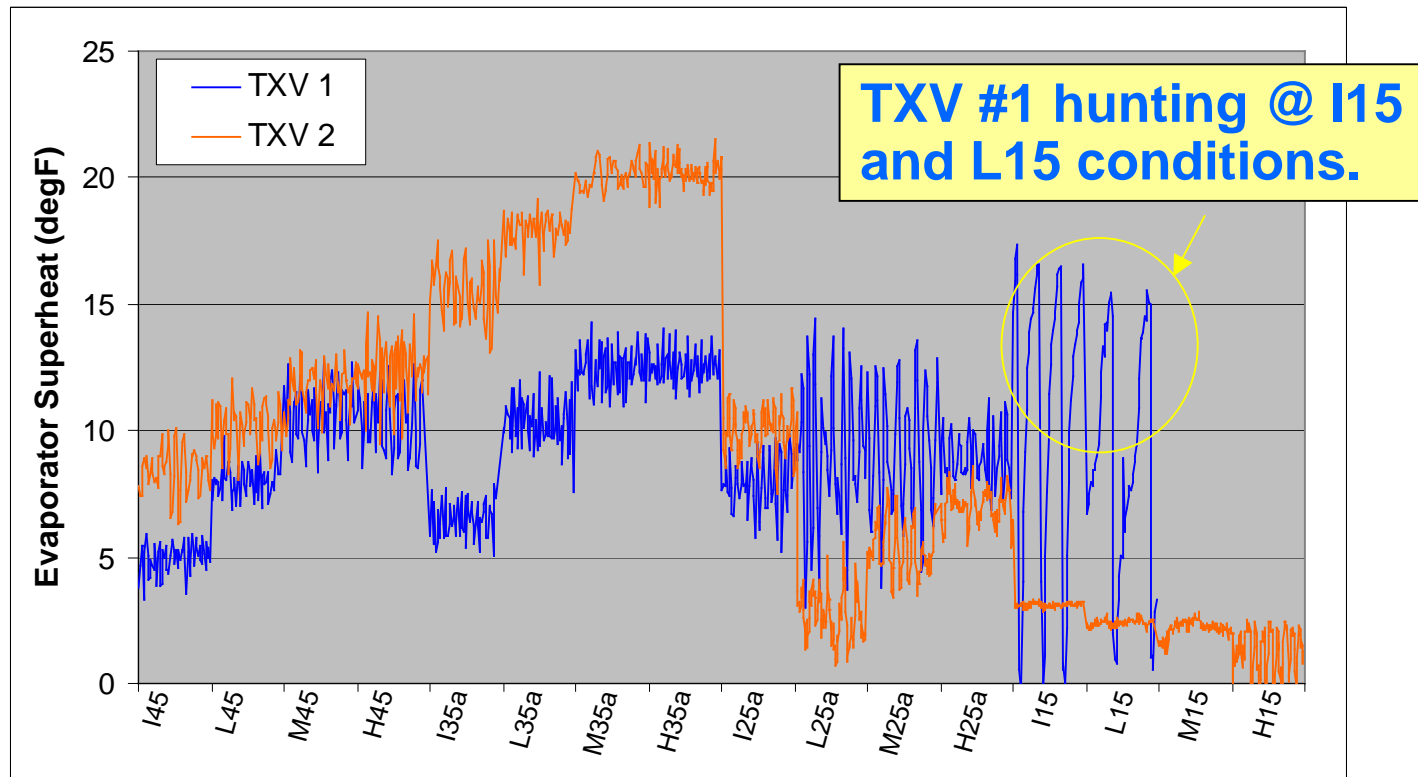
Refrigerant Charge Determination

- L35a condition.
- Final charge amount: center point of the subcooling plateau.
- Same charge amount used for all compressors.



TXV Confirmation / Selection

- Two TXV's were compared, both from production systems:
 - TXV #1: System charge, 1.5 ton
 - TXV #2: Cross Charge, 1.0 ton
- TXV #2 was selected because:
 - It didn't hunt with variable compressors at low load conditions.
 - Its superheat at higher loads was also in normal ranges.



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TRSE07 & TRSA09 vs. A FD17

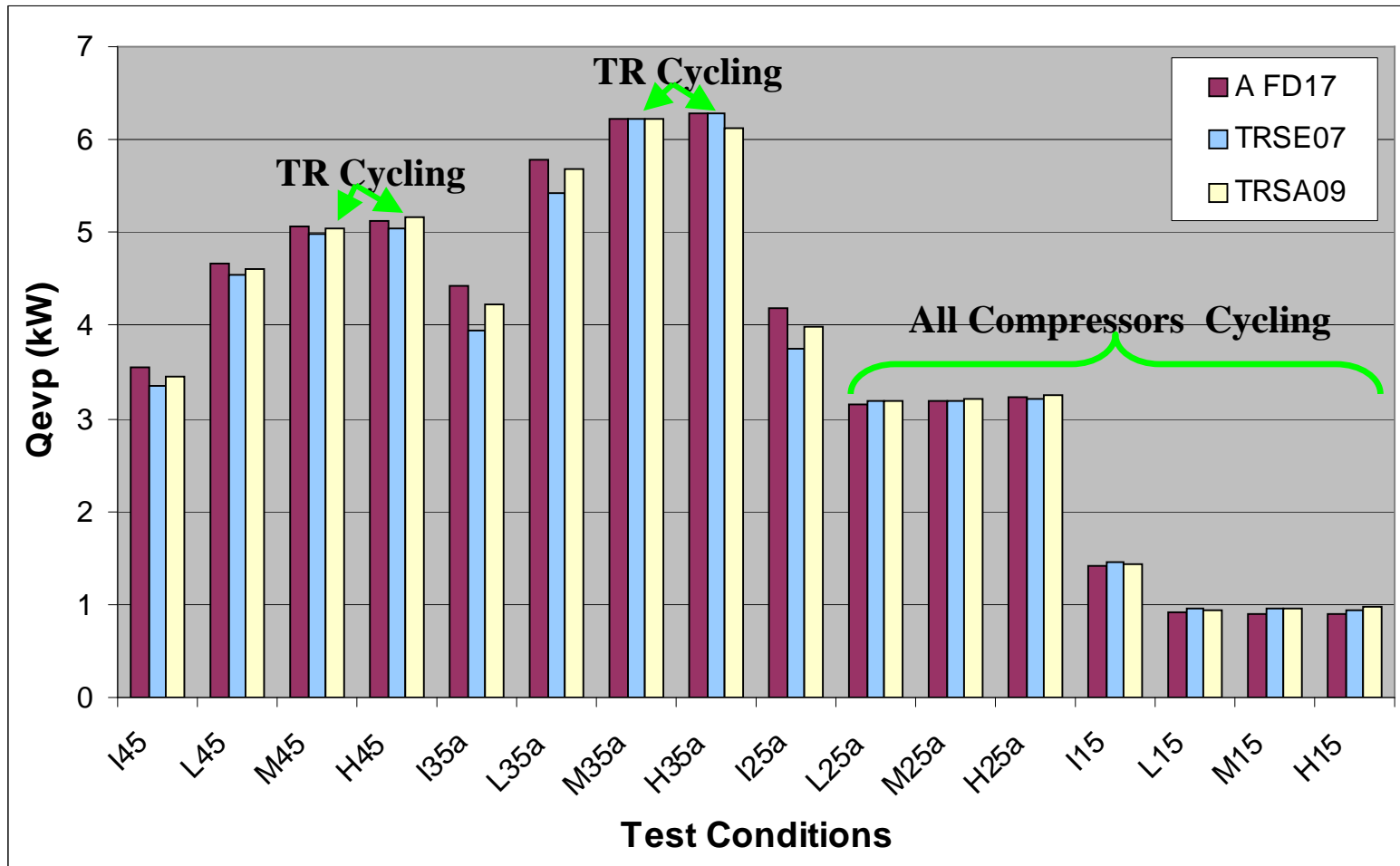
TRSE07 & TRSA09 vs. D IVD14

Conclusions

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Results - TRSE07 & TRSA09 vs. A FD17

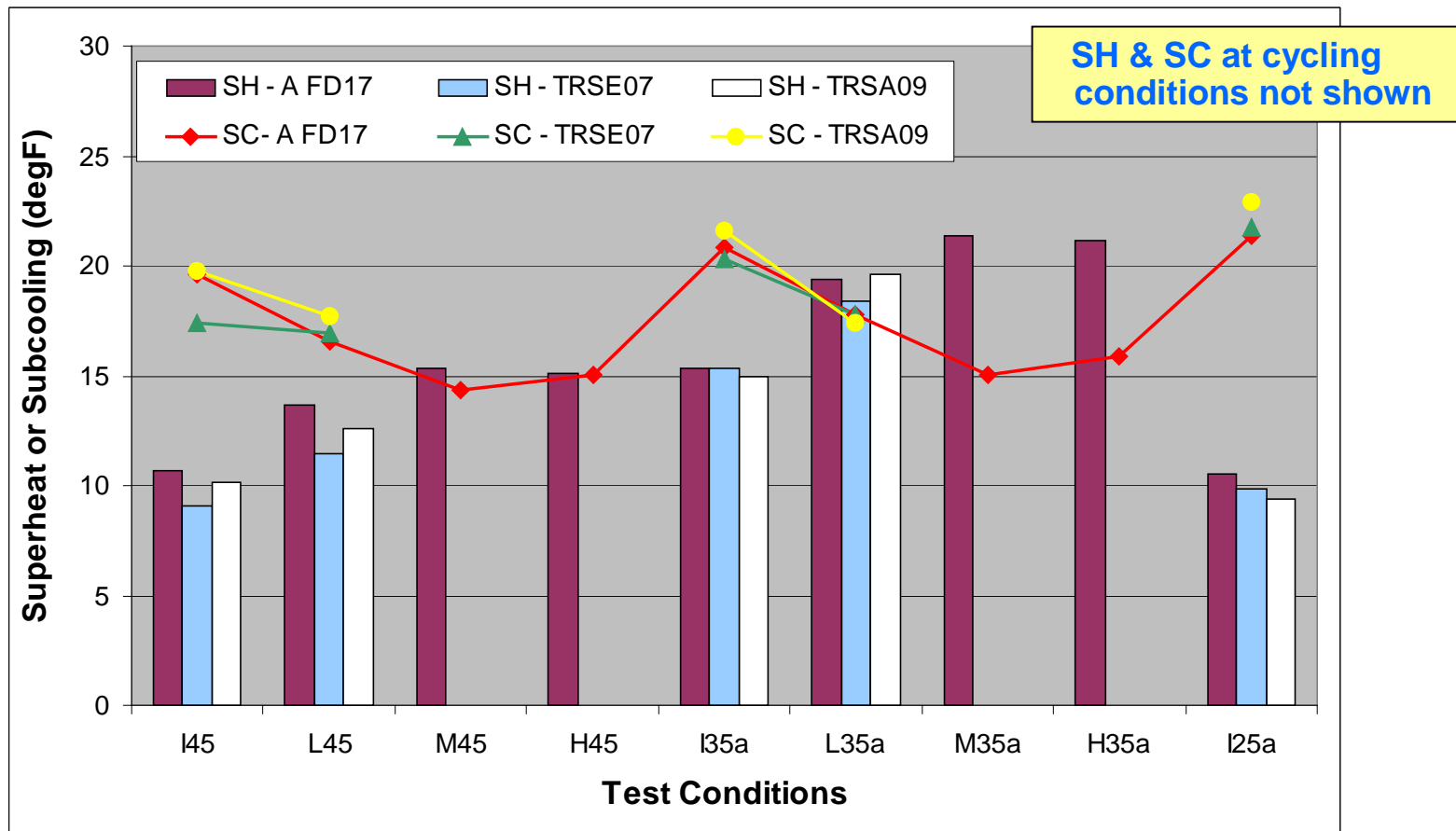


Matched Cooling Capacity



Results - [TRSE07 & TRSA09](#) vs. A FD17

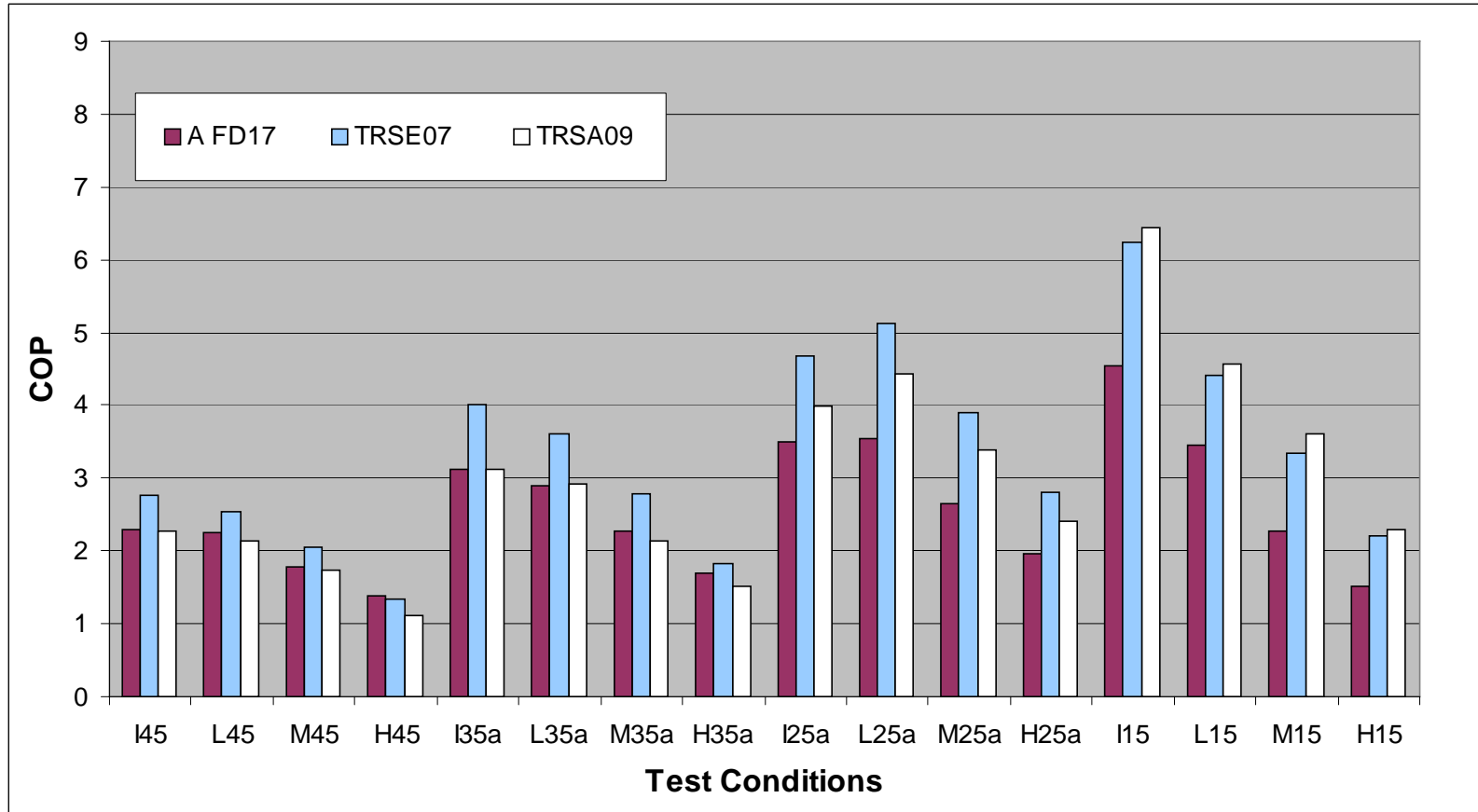
Superheat and Subcooling Comparison



Superheat and sub cooling are similar, indicating same system characteristics for all compressors

Results - TRSE07 & TRSA09 vs. A FD17

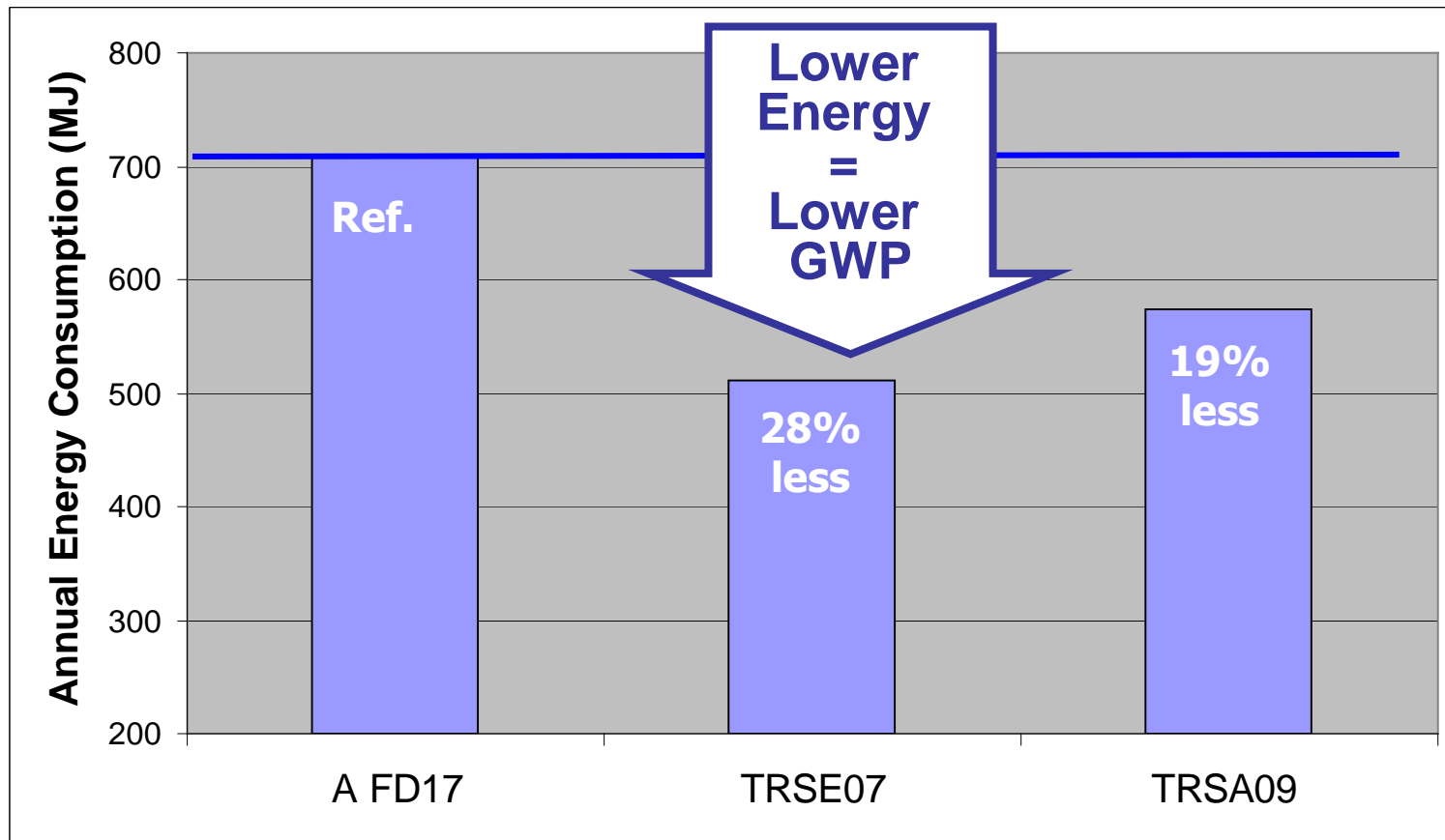
COP Comparison



Over all TRSA09, TRSE07 COP are higher than A FD17 particularly at low / mild load conditions.

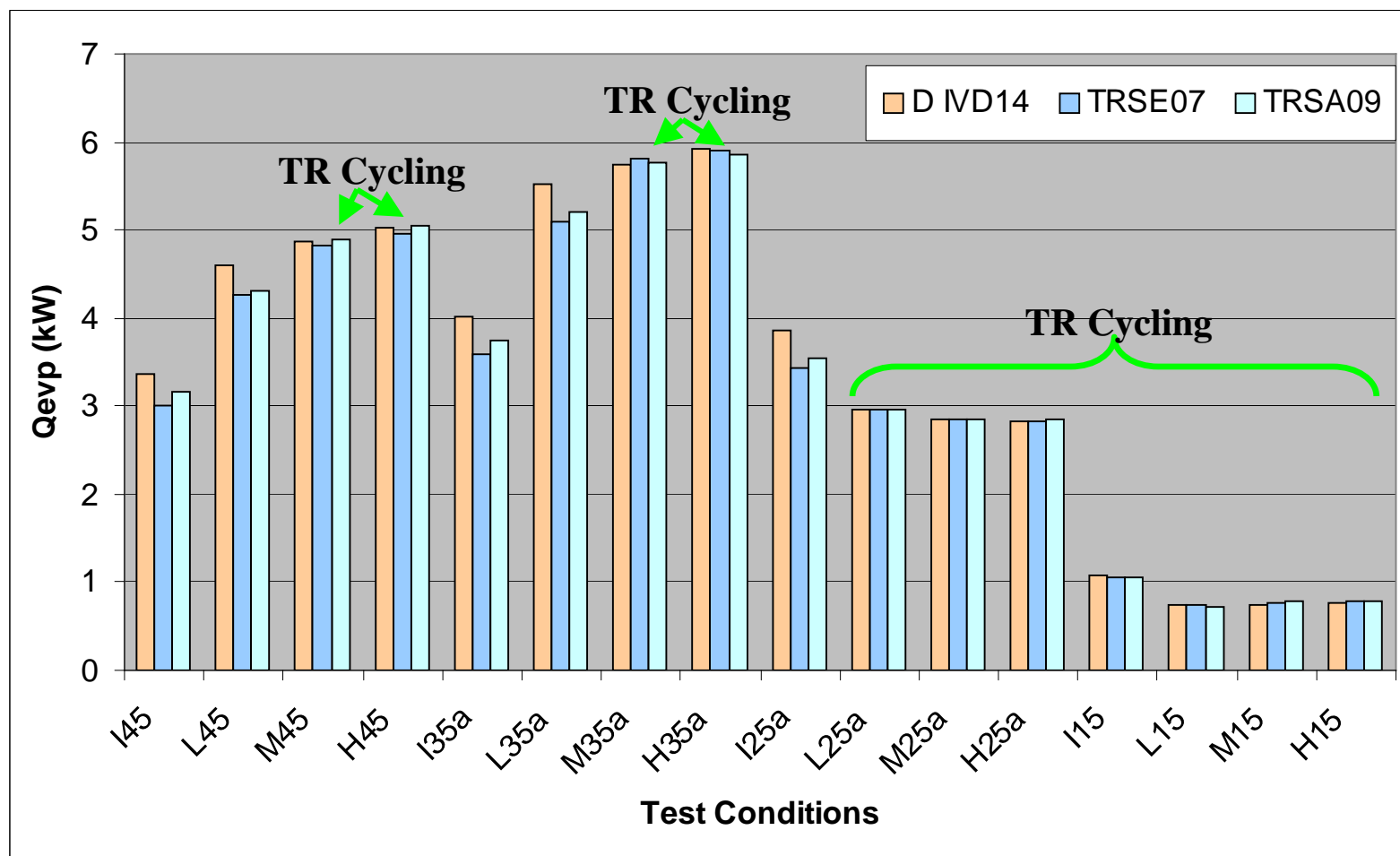
Results - [TRSE07 & TRSA09](#) vs. A FD17

Annualized Energy Consumption



TR compressors energy consumption is significantly less (lower GWP) than A FD17

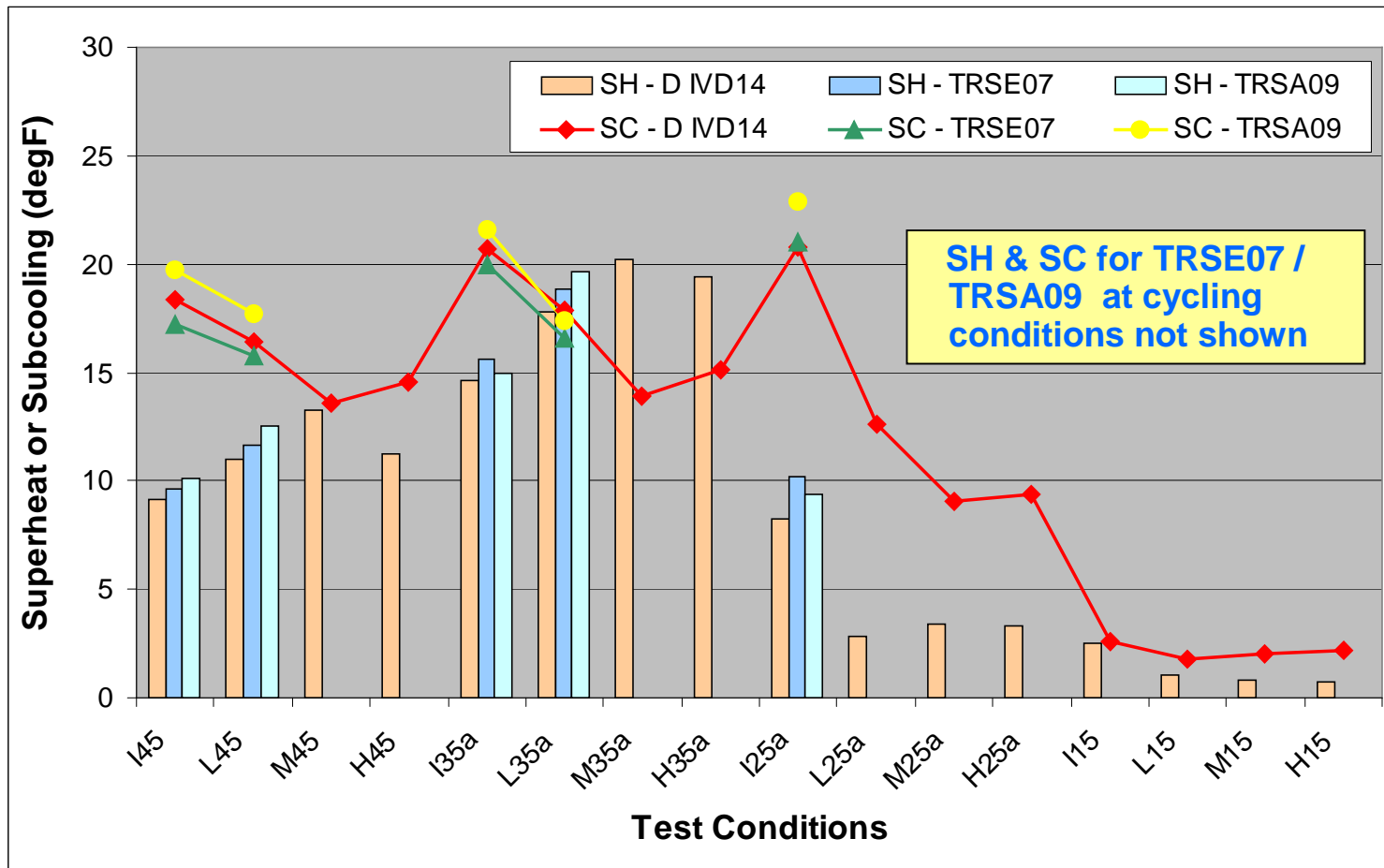
Results - [TRSE07 & TRSA09](#) vs. D IVD 14



Matched Cooling Capacity

Results - [TRSE07 & TRSA09](#) vs. D IVD 14

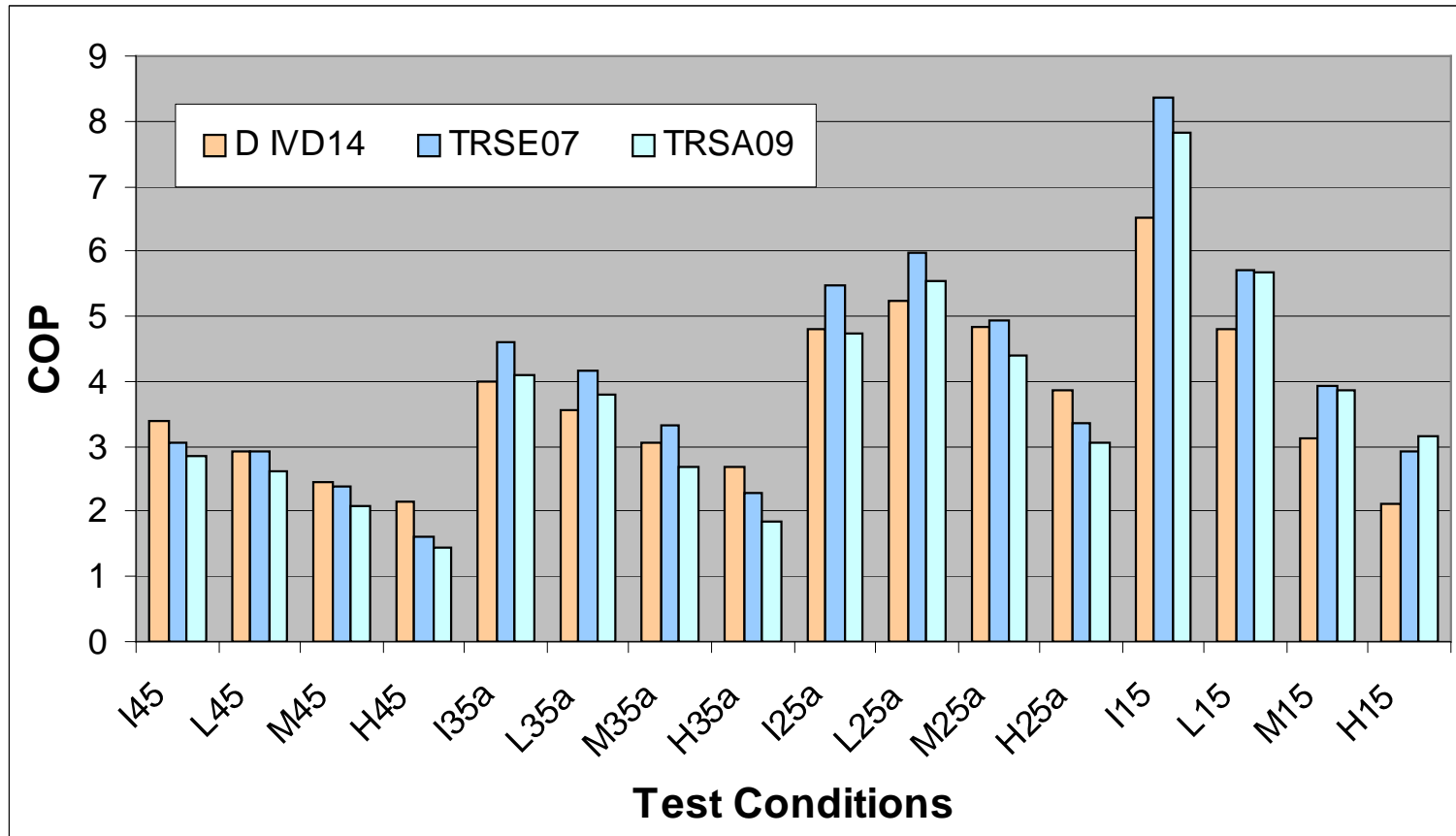
Superheat and Subcooling Comparison



Superheat and sub cooling are similar, indicating same system characteristics for all compressors

Results - [TRSE07 & TRSA09](#) vs. D IVD 14

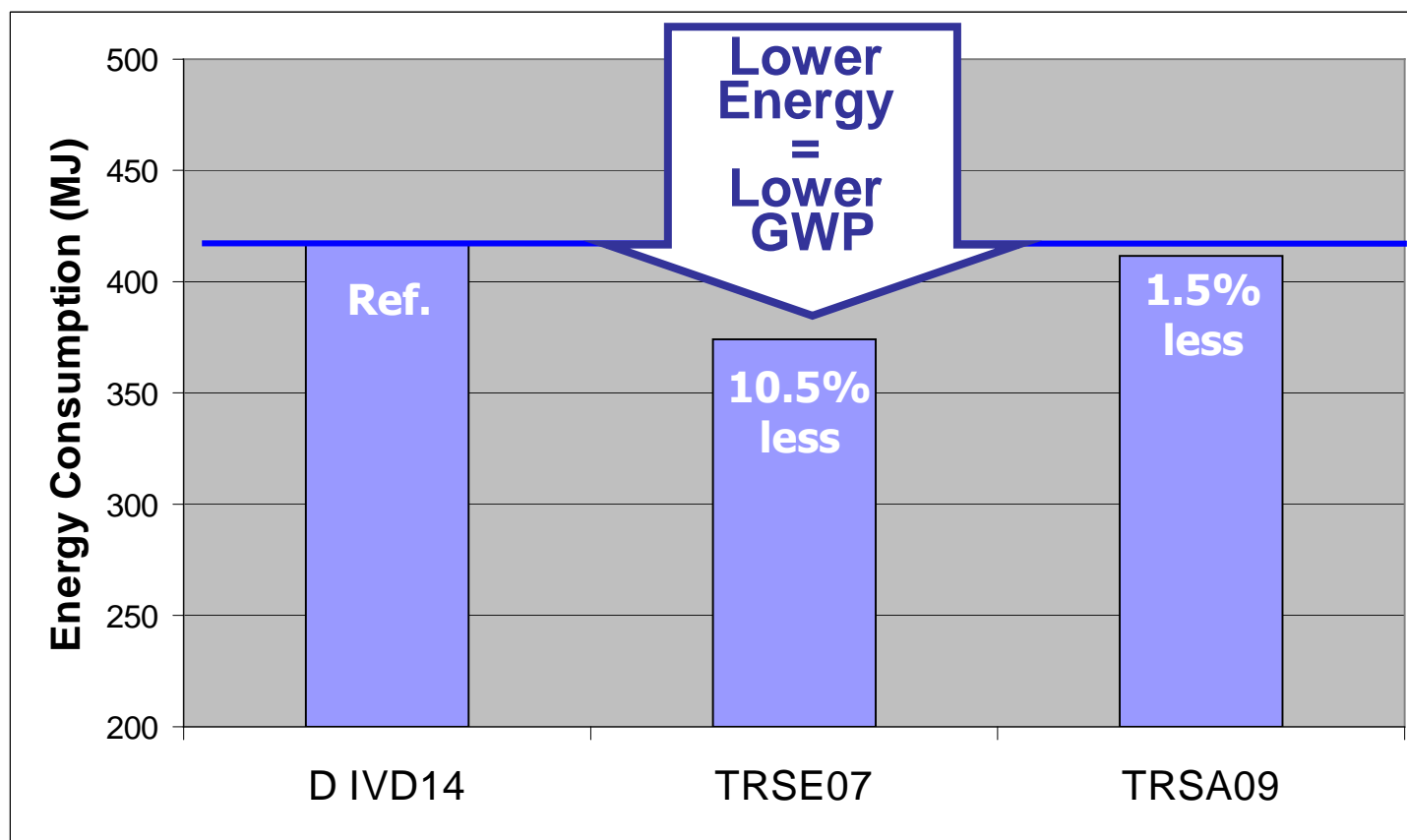
COP Comparison



TRSE07/TRSA09 COP significantly higher at low load conditions, however lower at high speed conditions (H45, H35a & H25a) partly because of engagement torque peaks during cycling

Results - [TRSE07 & TRSA09](#) vs. D IVD 14

Annualized Energy Consumption



TR compressors energy consumption is significantly less (lower GWP) than D IVD14

Conclusions

TR compressors annual energy consumption is the least among tested compressors:

- *TRSE07 annual power consumption is:*
 - 28% less than A FD17
 - 10.5% less than D IVD14.
- *Similarly, TRSA09 annual power consumption is:*
 - 19% less than A FD17
 - 1.5% less than D IVD14

Lower Energy Consumption = Lower GWP

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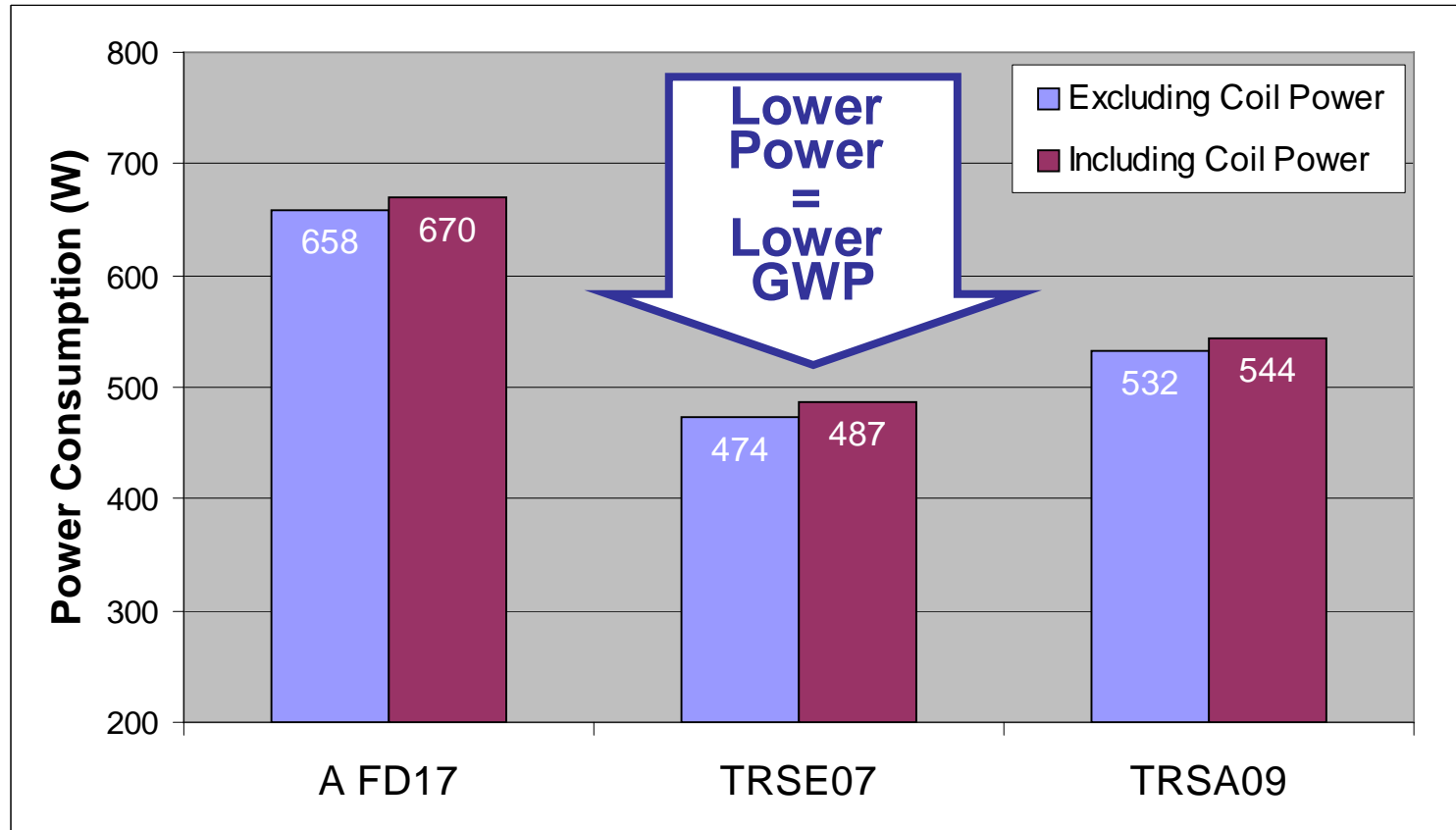
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Further Analysis – Beyond IMAC Study

- **Compressor clutch coil power consumption**
- **Annualized power consumption in Watts**

Further Analysis – Beyond IMAC Study

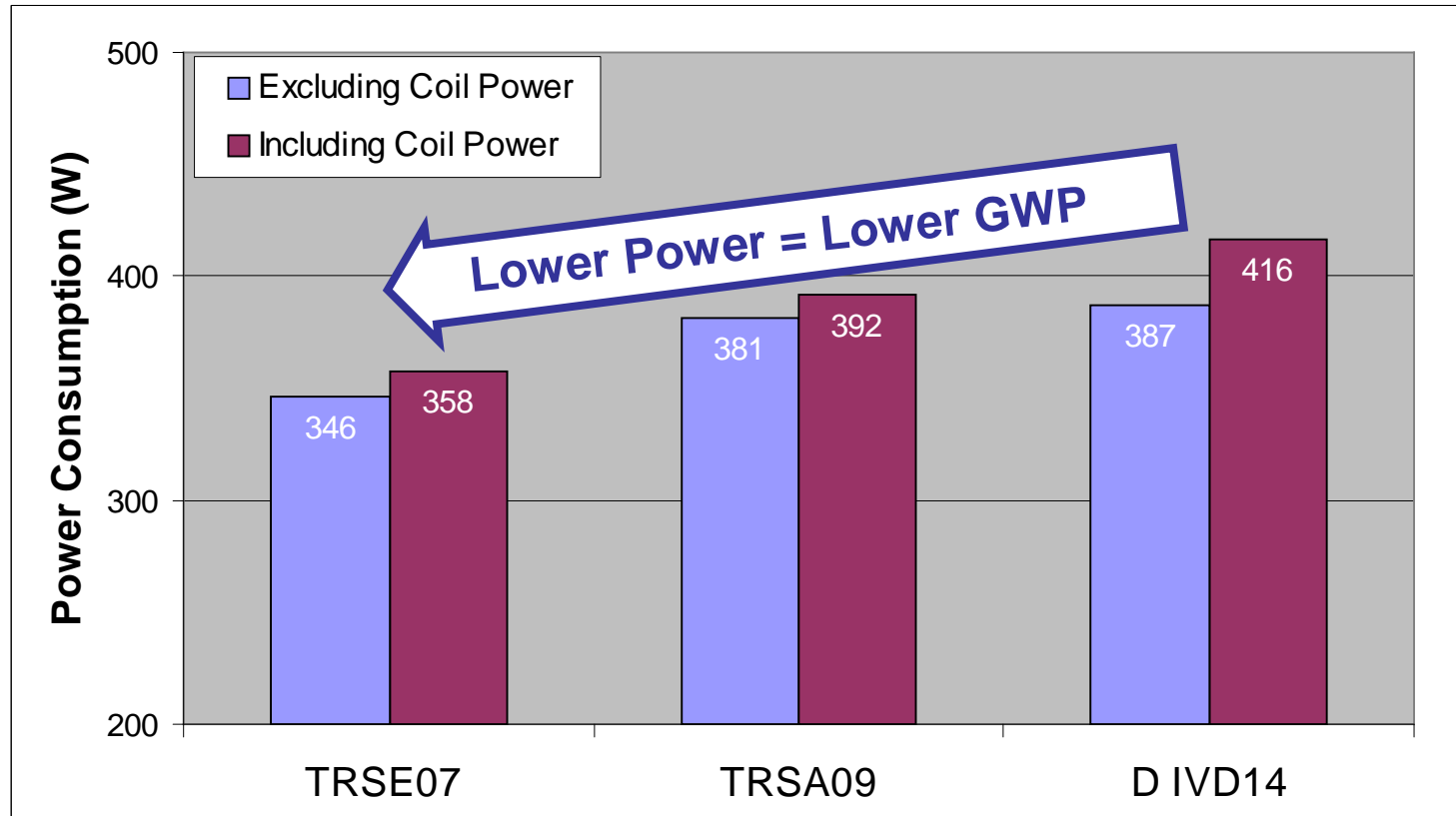
TRSE07 & TRSA09 vs. A FD17 Annualized Power Consumption in Watts (w/ & w/o clutch coil power consumption)



Coil power consumption has little impact on the overall power consumption rate.
TR compressors power consumption is significantly lower than A FD17

Further Analysis – Beyond IMAC Study

TRSE07 & TRSA09 vs. D IVD14 Annualized Power Consumption in Watts (w/ & w/o clutch coil power consumption)



Coil power consumption has little impact on the overall power consumption rate.
TR compressors power consumption is significantly lower than D IVD14

Further Analysis – Beyond IMAC Study

Conclusions

- TRSE compressor annual power consumption is significantly less than all tested compressor technologies. Including clutch coil power, *TRSE07 power consumption is:*
 - *183 Watts less than “A” Fixed Swash Plate*
 - *58 Watts less than “D” Internally Variable Swash Plate*
- **Lower Watts means:**
 - Reduced fuel consumption (higher vehicle MPG)
 - Lower GWP.

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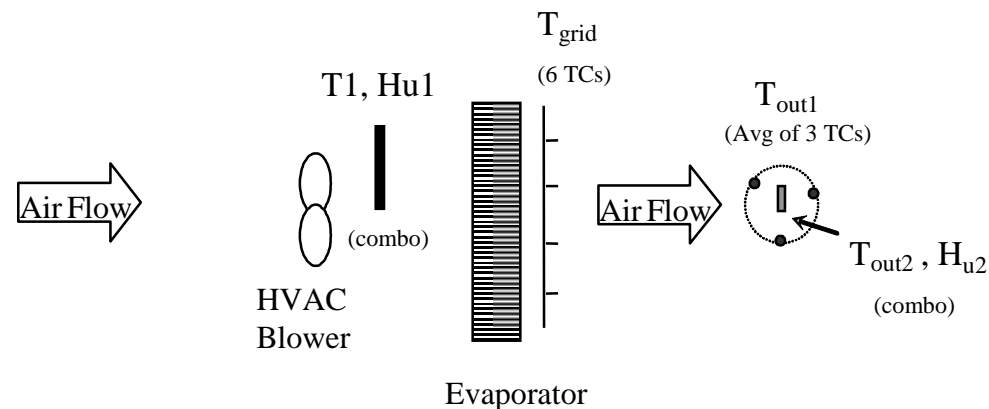
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I. Evaporator Cooling Capacity Calculations:

Q_{evp}: Air side calculations

$$\dot{Q}_{evp} = \dot{m}_a (h_{ai} - h_{ao}) + \dot{m}_w c_{pw} (T_{ai} - T_{ao})$$

- The 2nd term on the RHS represents sensible energy of condensed moisture.
- Enthalpy of air using inlet temperatures T_1 and outlet temperature T_{out1} , T_{out2} , and dew points from H_{u1} and H_{u2} (see below).
- During clutch cycling, T_{out1} , T_{out2} & H_{u2} (recorded at high sampling rate) are integrated over 10 min. of data (minus partial cycles at start / end).



Appendix

I. Evaporator Cooling Capacity Calculations:

Q_{evp}: Refrigerant side calculations

$$\dot{Q}_{evp} = \dot{m}_r (h_{reo} - h_{rei}) + \dot{m}_{oil} c_{p,oil} (T_{reo} - T_{rxi})$$

- The 2nd term on the RHS represents sensible energy change of oil.
- R134a and oil flow rates are derived from the measured mass flow rate and OCR.

Appendix

II. COP & Energy Consumption Calculation:

- Compressor power consumption

$$\dot{W}_c = 2p \cdot (\text{shaft torque}) \cdot (\text{shaft speed}).$$

Data are averaged / integrated over 10mins. (For cycling data, partial cycles at start / end are removed).

Because the torque meter is pulley mounted, the measured torque is also corrected for transmission losses.

- COP = Q_{evp} / \dot{W}_c

Only Q_{evp} calculated from air side is used for COP calculation because refrigerant side calculation is less reliable at low load conditions.

Appendix

II. COP & Energy Consumption Calculation:

- IMAC annualized energy consumption =

$$\sum_{i=1}^{i=16} (wt_{climate})_i (wt_{RPM})_i \frac{(Average Q_{evp})_i}{(COP)_i}$$

- $(Average Q_{evp})_i$ = average Q_{evap} of all compressors at i th test condition
- $wt_{climate}$, wt_{RPM} = IMAC climate and speed weighting factors