Compressor Technology / Type and its Impact on GWP

Sanden International (U.S.A.) Inc.

Presented by : Jacob Bayyouk

SAE 8th Alternate Refrigerant Systems Symposium

July 17 – 19, 2007 Scottsdale, Arizona

Contents

Contents

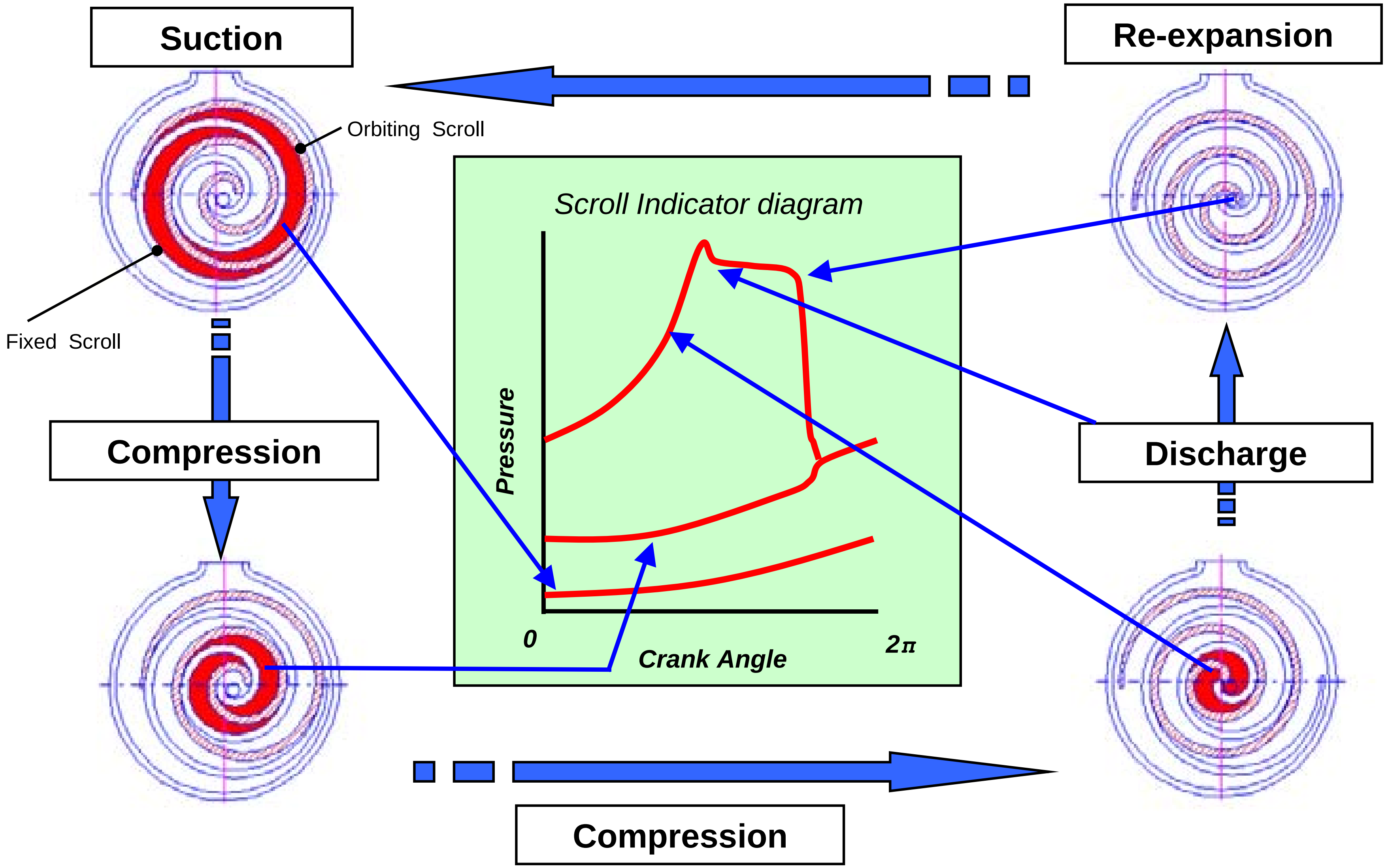
Compressor Technology / Type and its Impact on GWP

Introduction

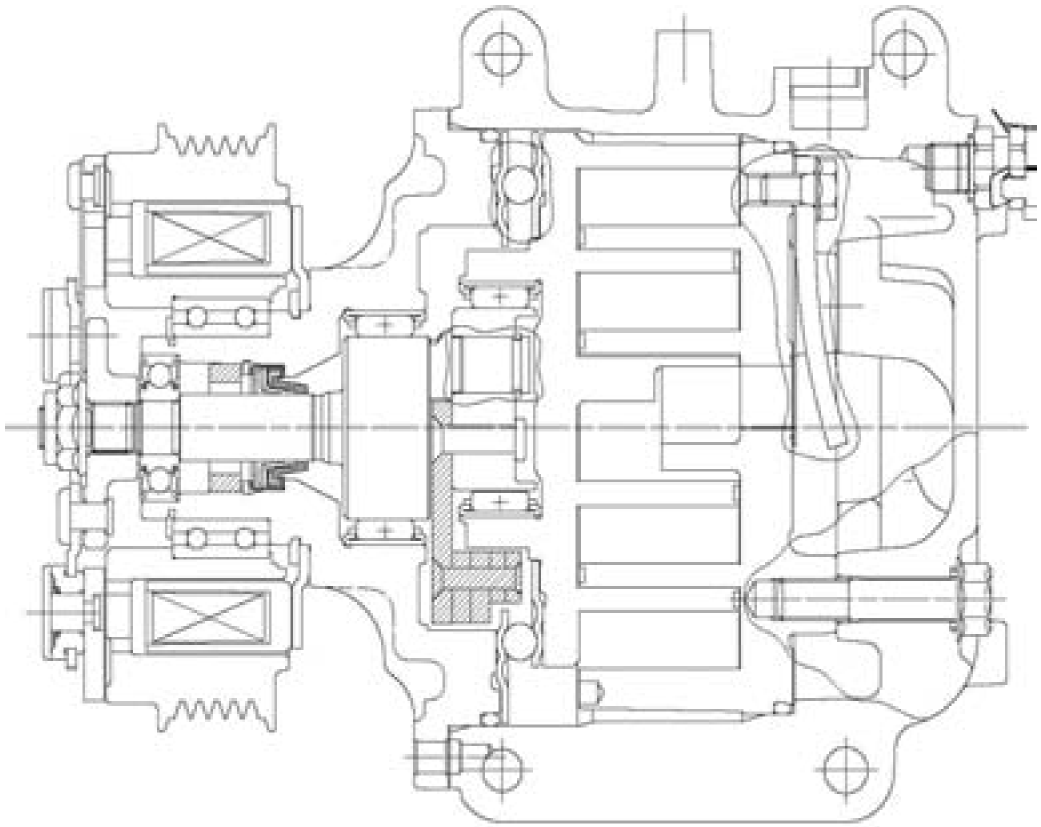
Several Compressor Technologies were evaluated for their impact on vehicle power consumption. All evaluations were conducted on a system calorimeter consistent with IMAC test conditions. Annualized Energy Consumption values were calculated based on the established IMAC weighting factors.

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.

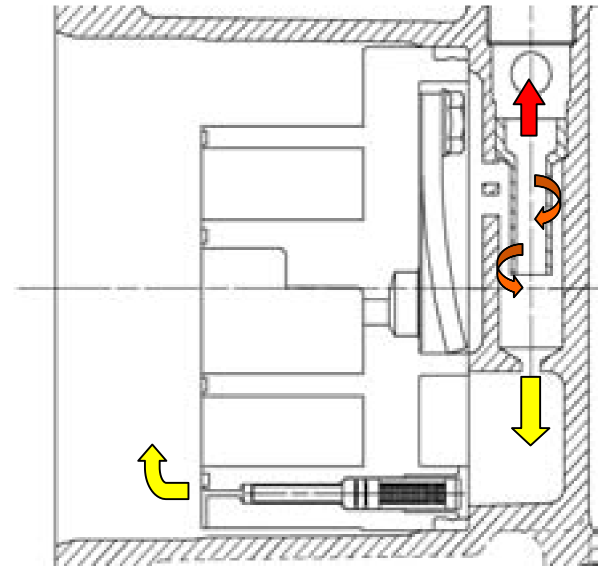
Introduction - Scroll Compression Process



Introduction - TRSA/E Cross Sectional View



TRSA



Oil Separator → TRSE

Contents

Test Setup - Component Information

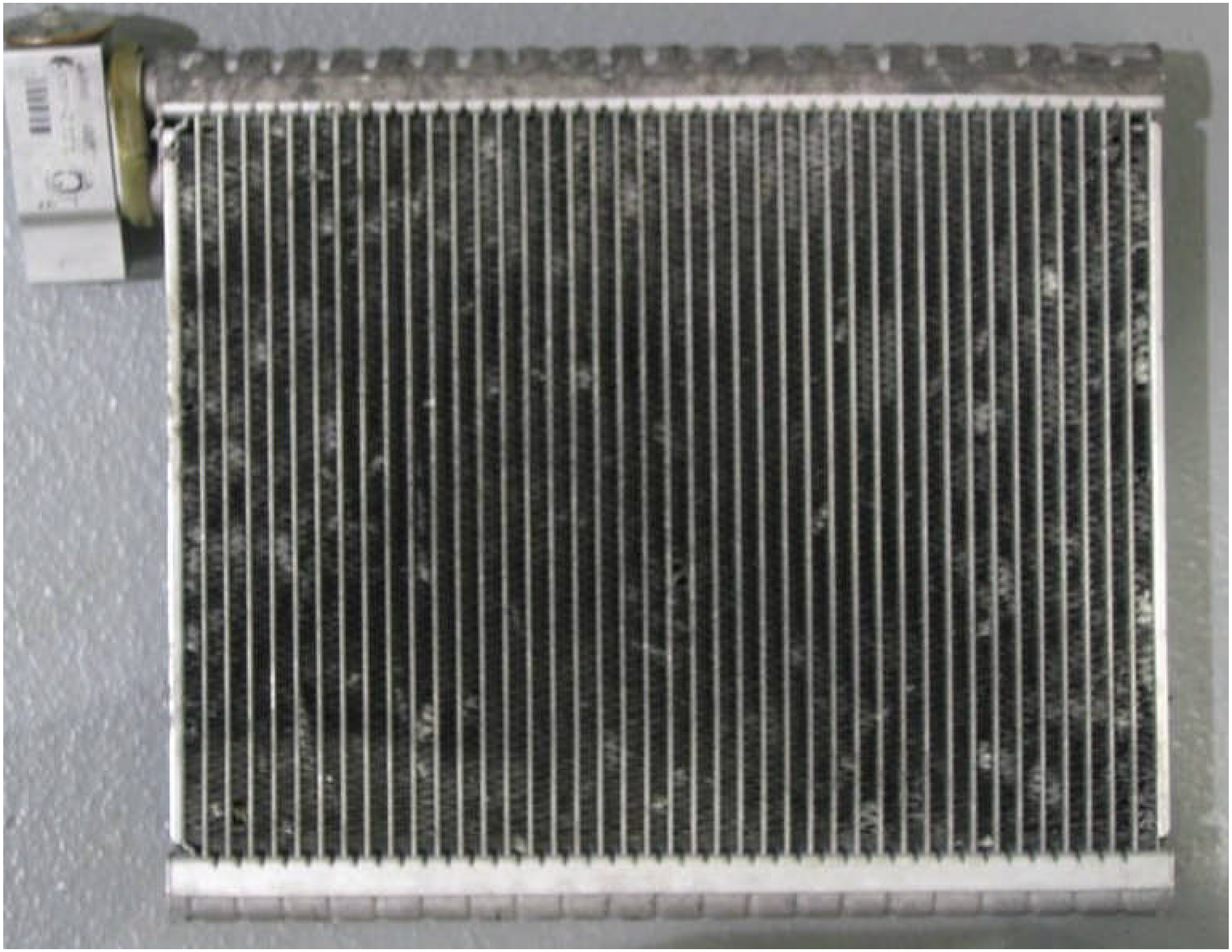
Production system with the latest condenser and evaporator technologies (i.e. micro-channel type) was chosen for the evaluation.

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)

SAE®

Test Setup – System Bench

Test Setup – System Bench



Evaporator

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** ***Shaft torque,*** ***RPM,*** ***Clutch voltage*** ***HVAC out air temp. & humidity*** **Every 5 sec for other channels** **All data recorded over a period of 10 mins.**

Test Conditions

IMAC test matrix & annual weighting factors

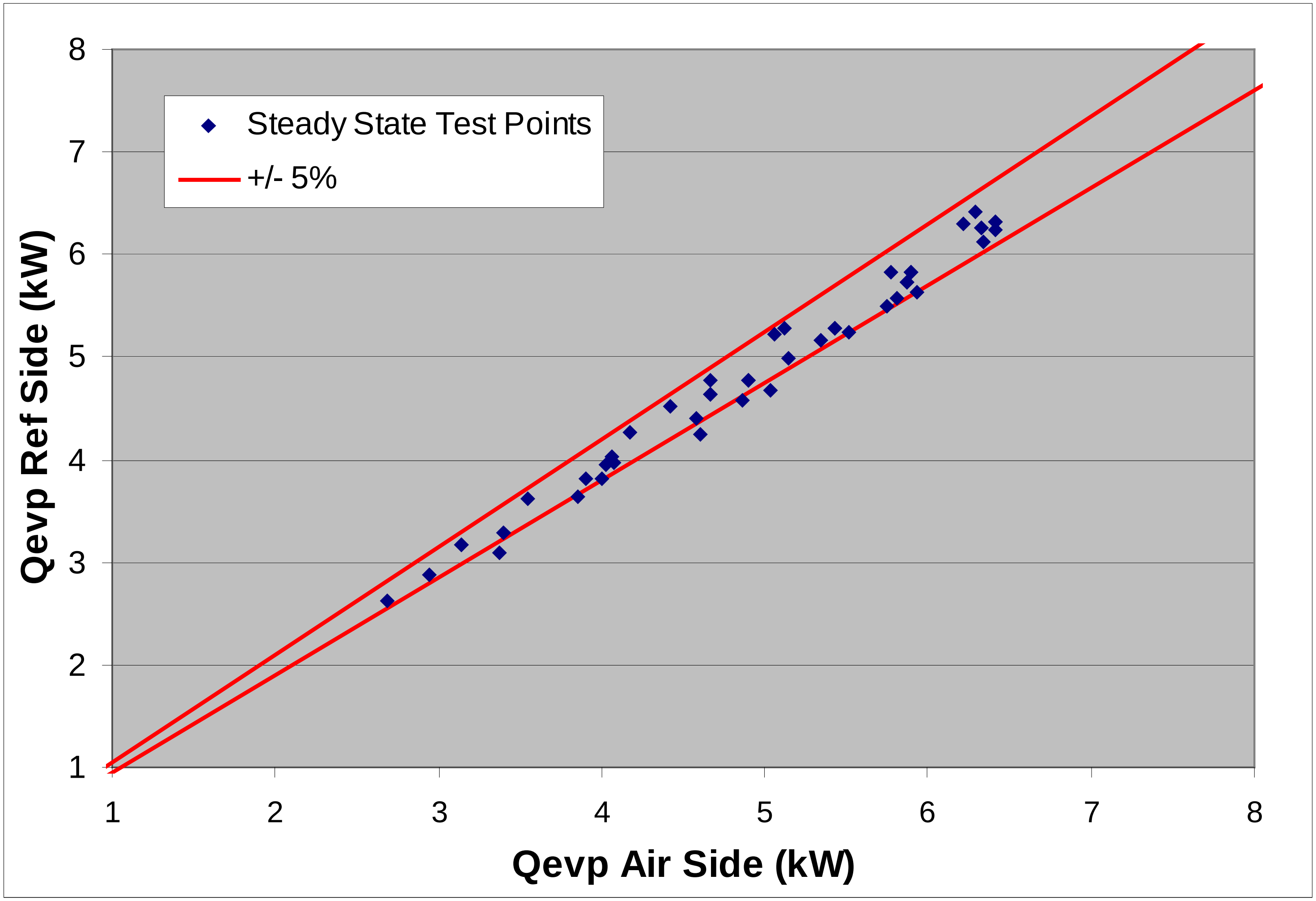
Test#	Comp speed	Cond Air Temp	Cond Air flow	Evap Air Temp	Evap Air R H	Evap Airflow	IMAC Weighting	
	RPM	ºF	SCFM	ºF	%	SCFM	Climate wt.	RPM Wt
I45	900	113	725	95	25	230	0.2%	17.0%
L45	1500	113	1460	95	25	275	0.2%	43.0%
M45	2500	113	2260	95	25	275	0.2%	35.0%
H45	4000	113	2260	95	25	275	0.2%	5.0%
I35a	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. Fixed compressor: 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

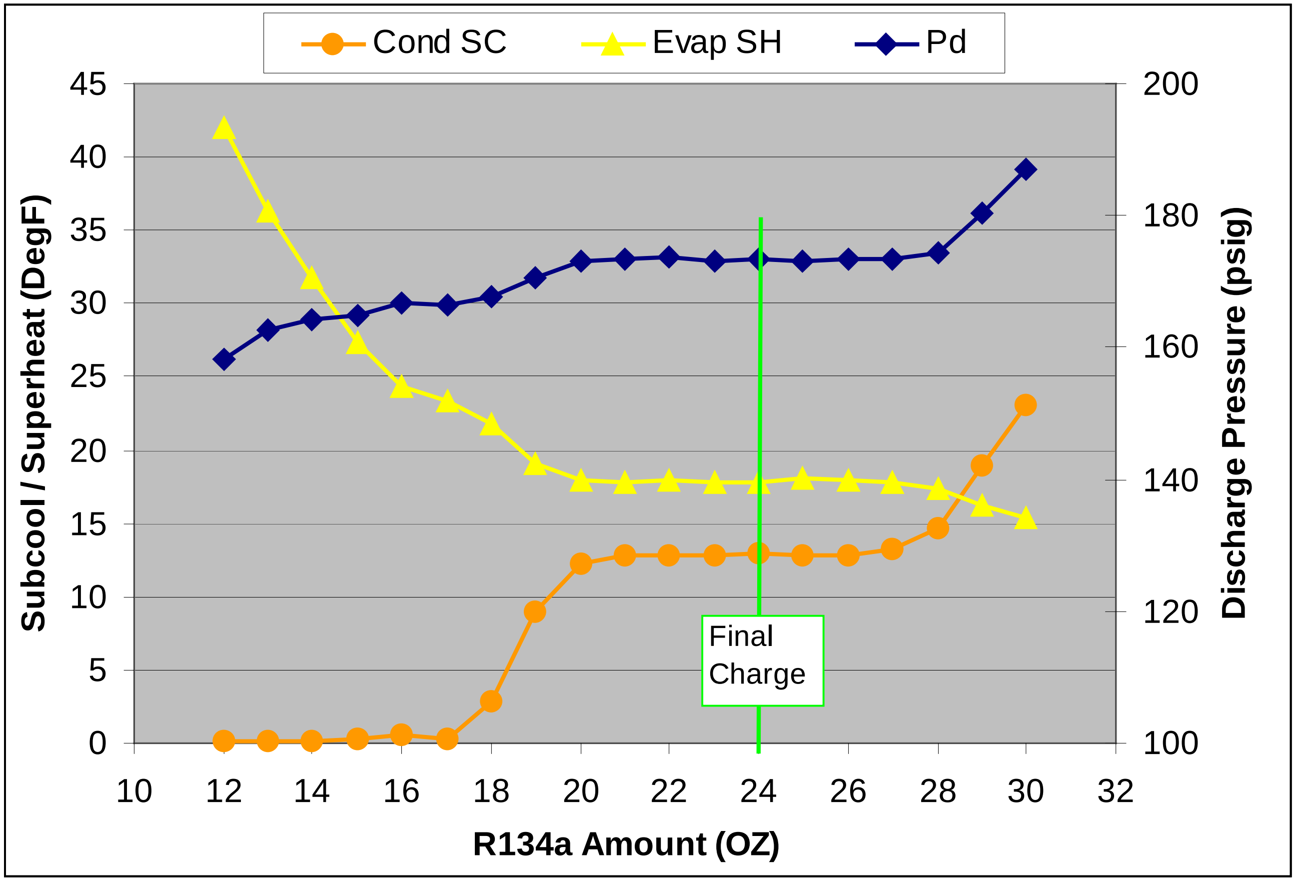
Data Management: Equipment Validation

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



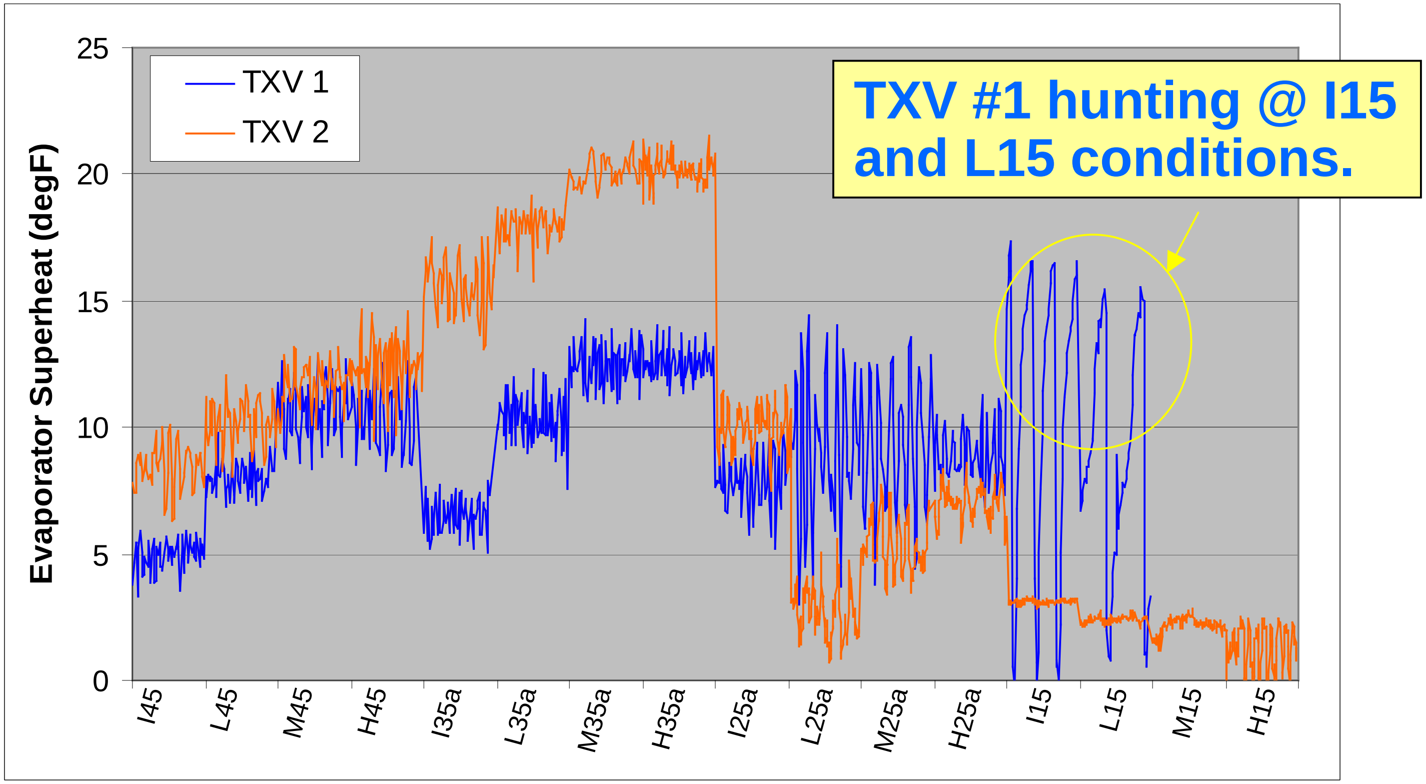
Refrigerant Charge Determination

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



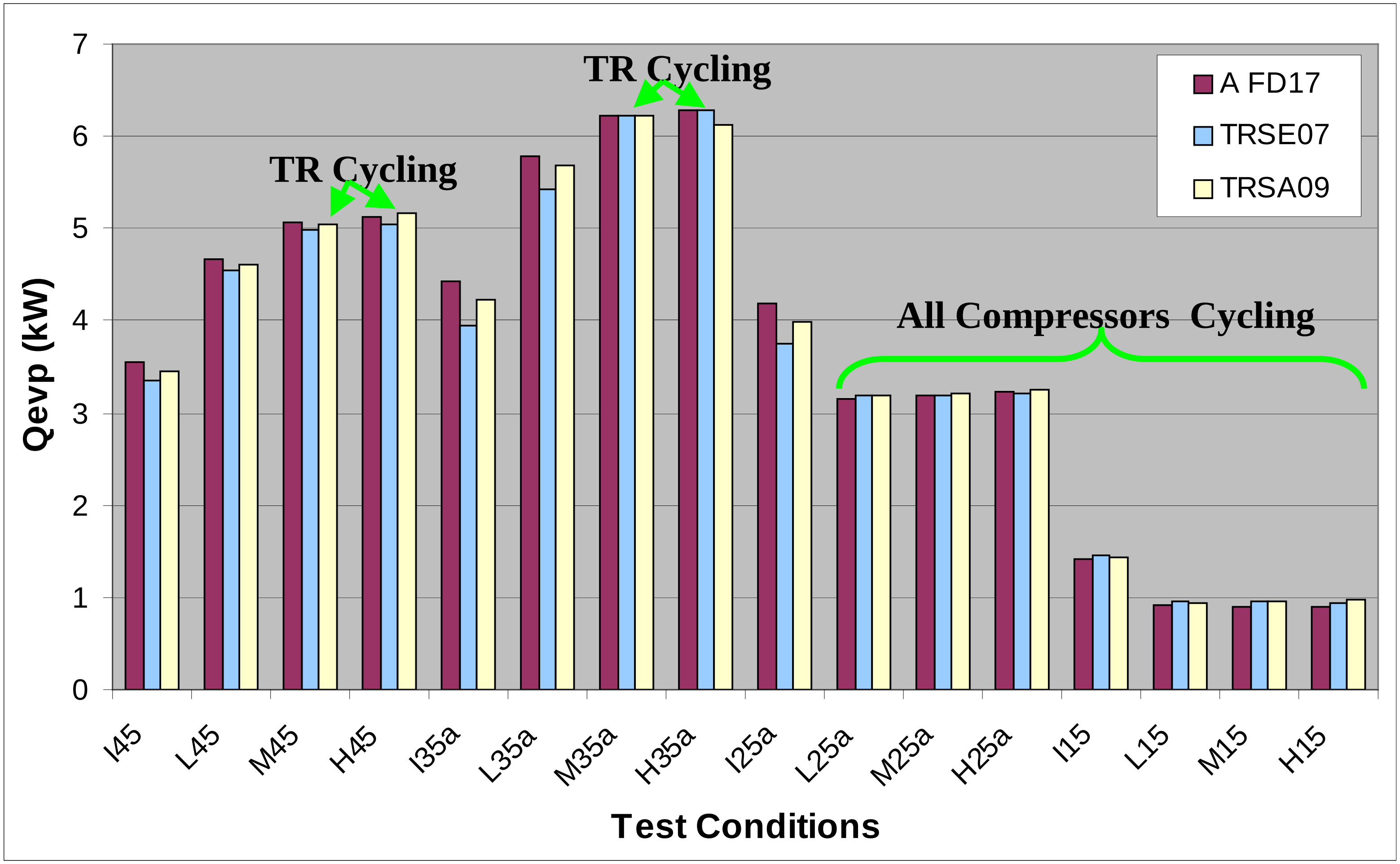
TXV Confirmation / Selection

- **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.*



Contents

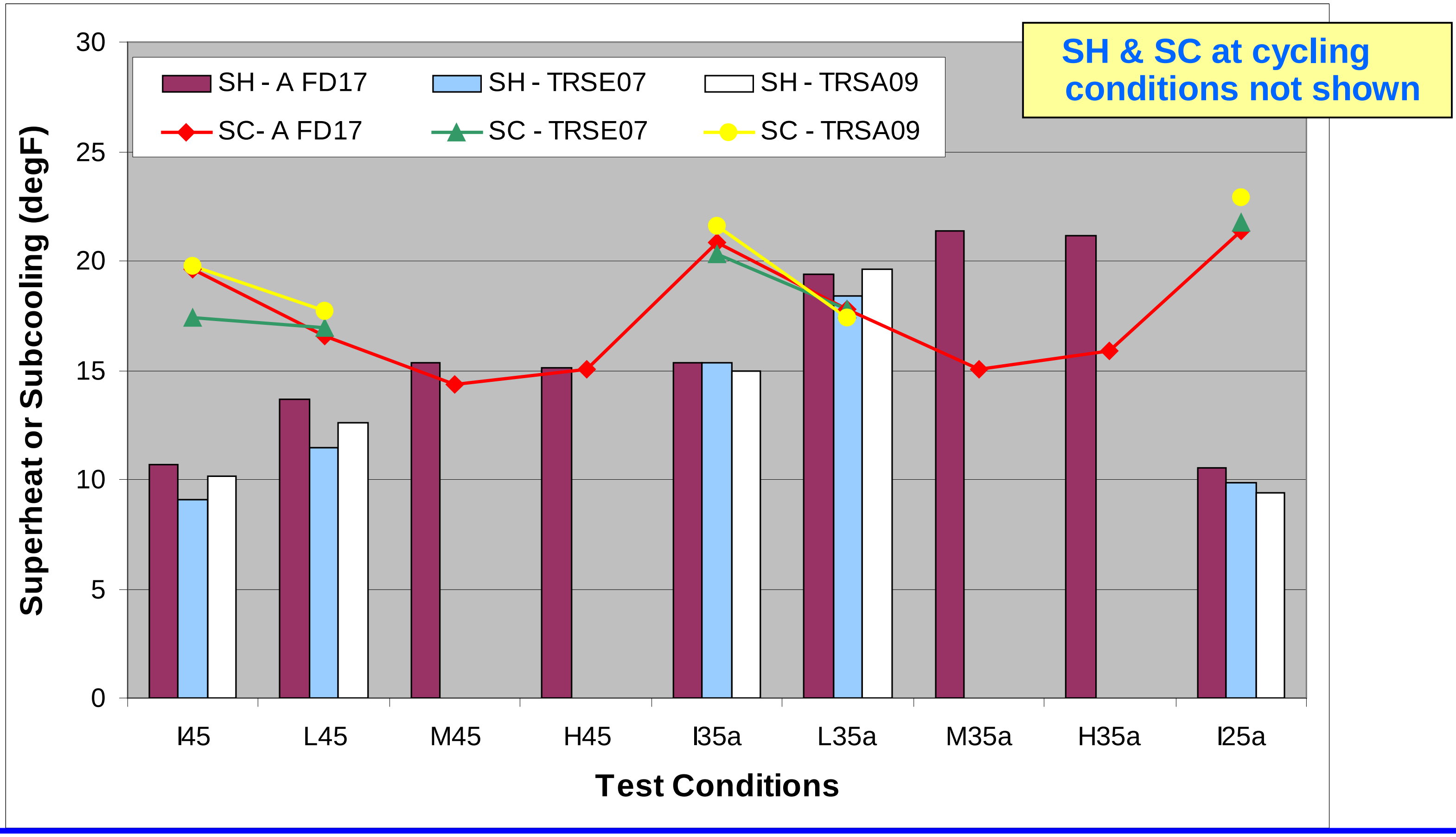
Results - TRSE07 & TRSA09 vs. A FD17



Matched Cooling Capacity

Results - TRSE07 & TRSA09 vs. A FD17

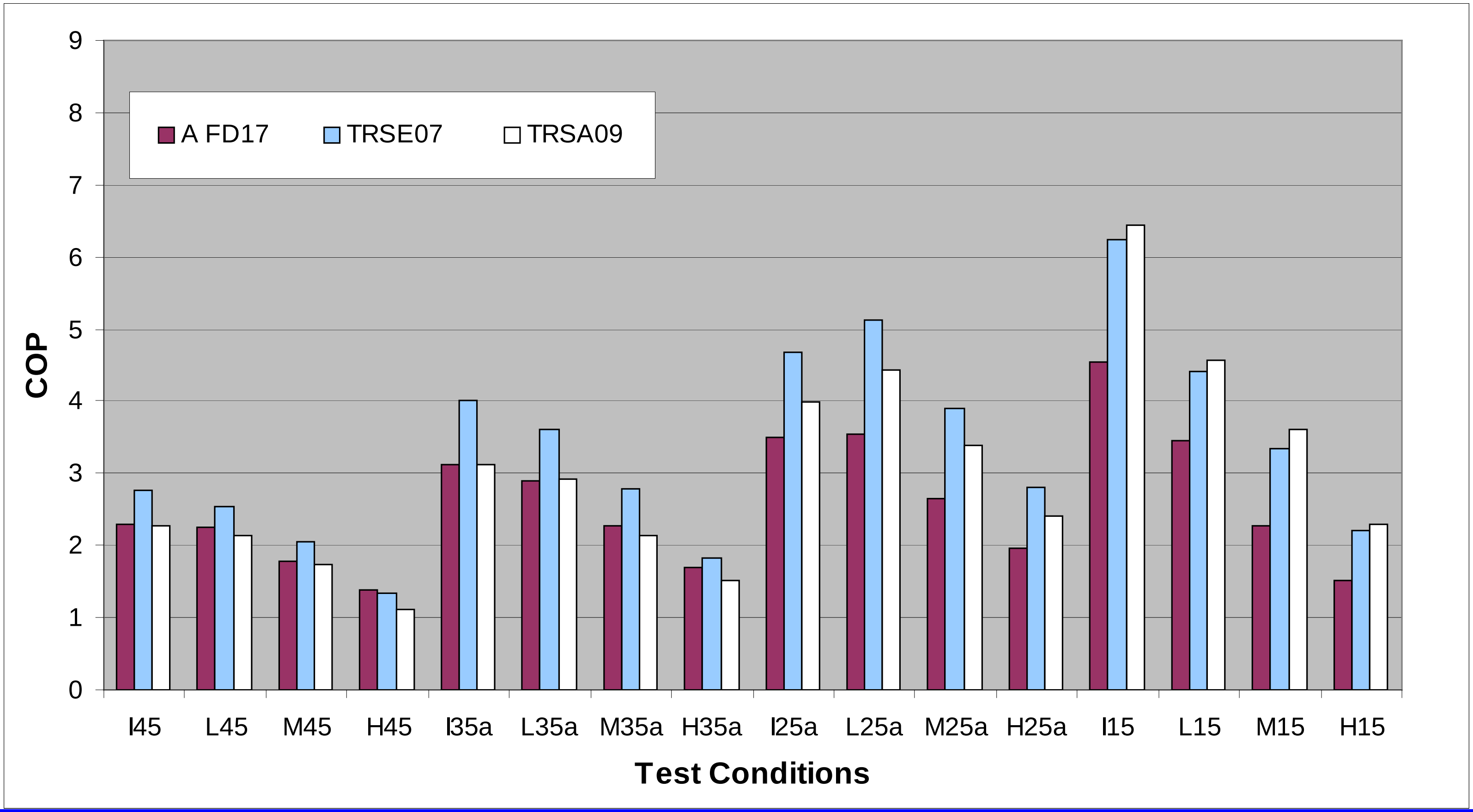
Superheat and Subcooling Comparison



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

Results - TRSE07 & TRSA09 vs. A FD17

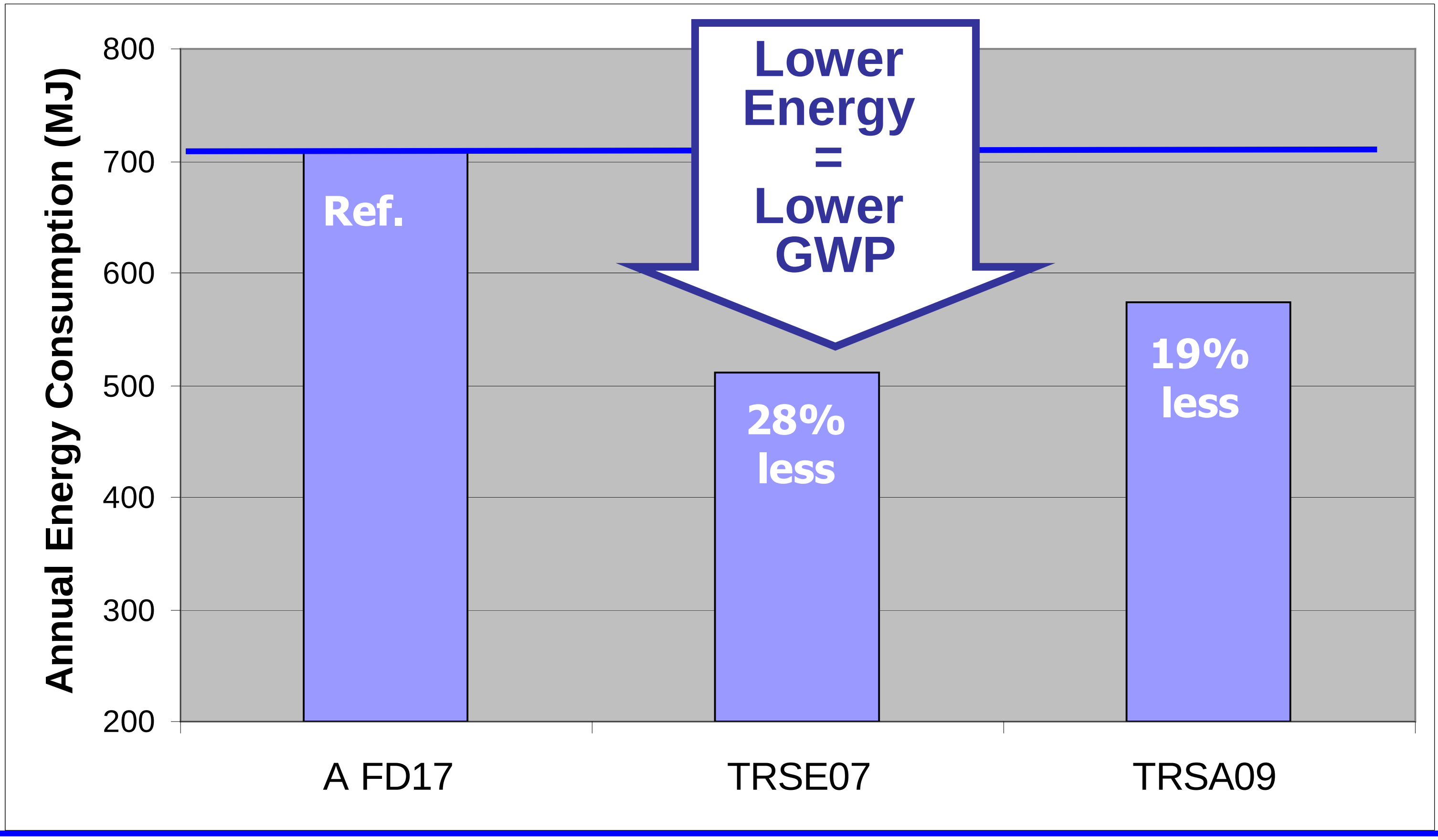
COP Comparison



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

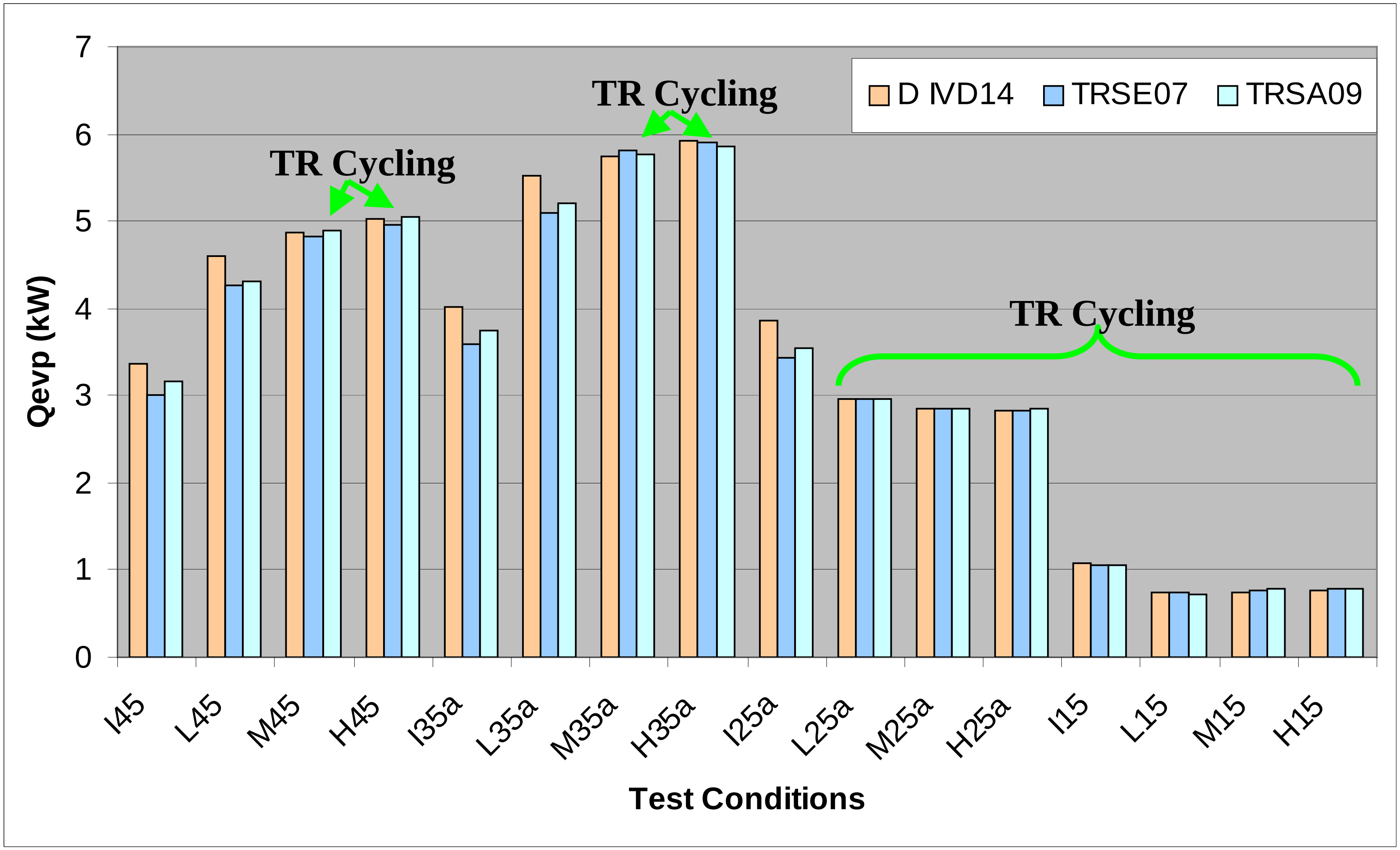
Results - TRSE07 & TRSA09 vs. A FD17

Annualized Energy Consumption



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

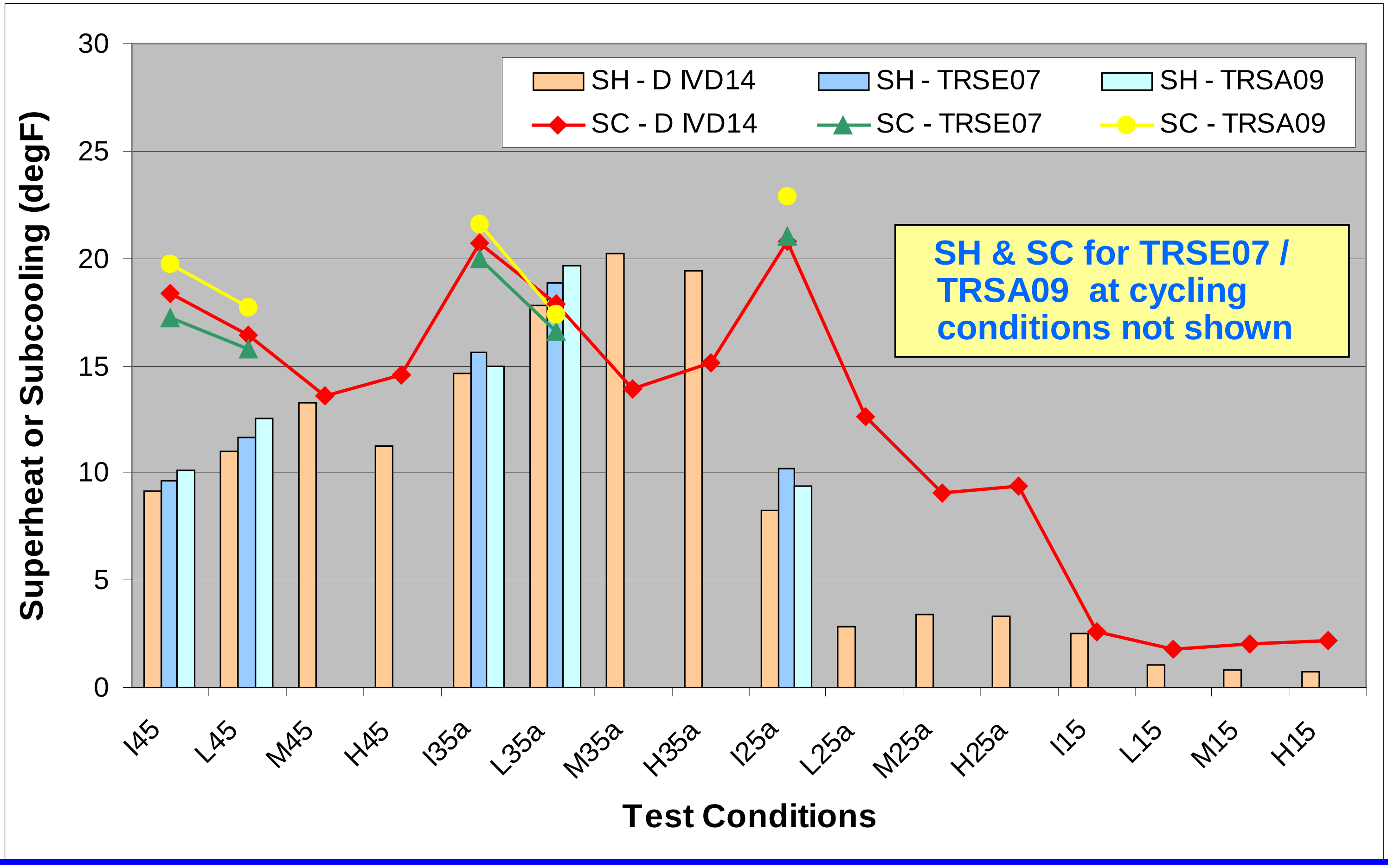
Results - TRSE07 & TRSA09 vs. D IVD 14



Matched Cooling Capacity

Results - TRSE07 & TRSA09 vs. D IVD 14

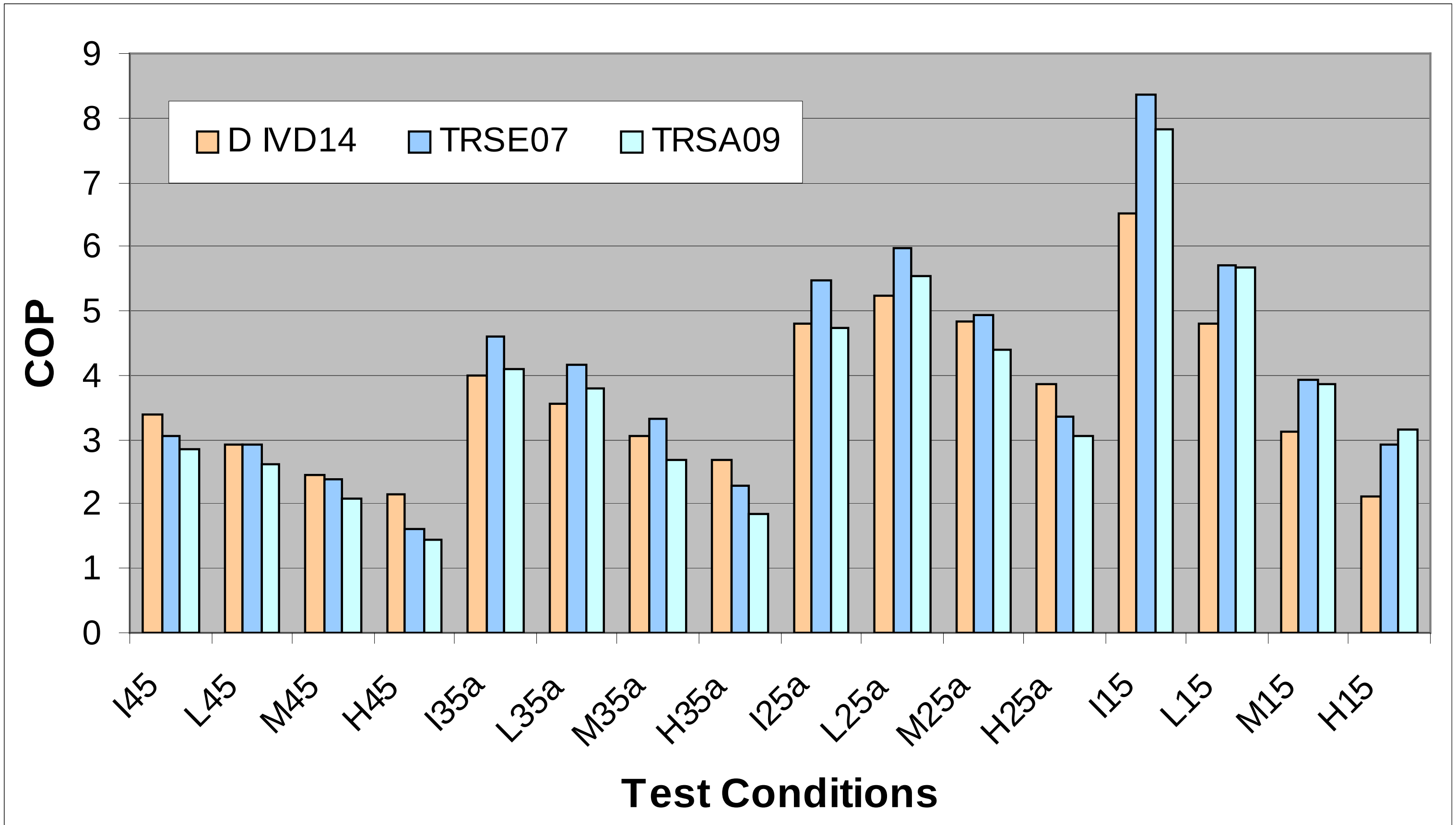
Superheat and Subcooling Comparison



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

Results - TRSE07 & TRSA09 vs. D IVD 14

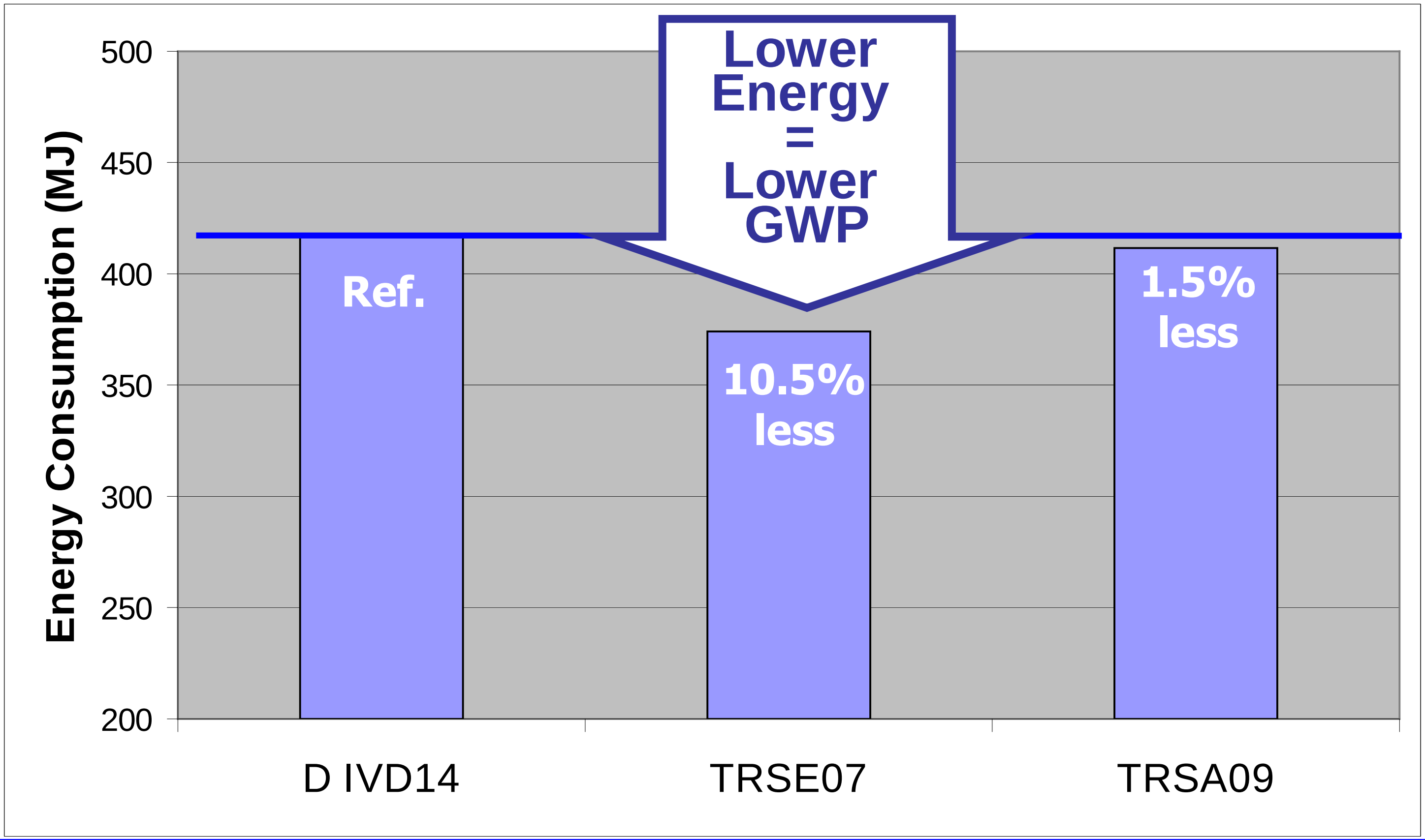
COP Comparison



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

SAE®

Contents

Further Analysis – Beyond IMAC Study

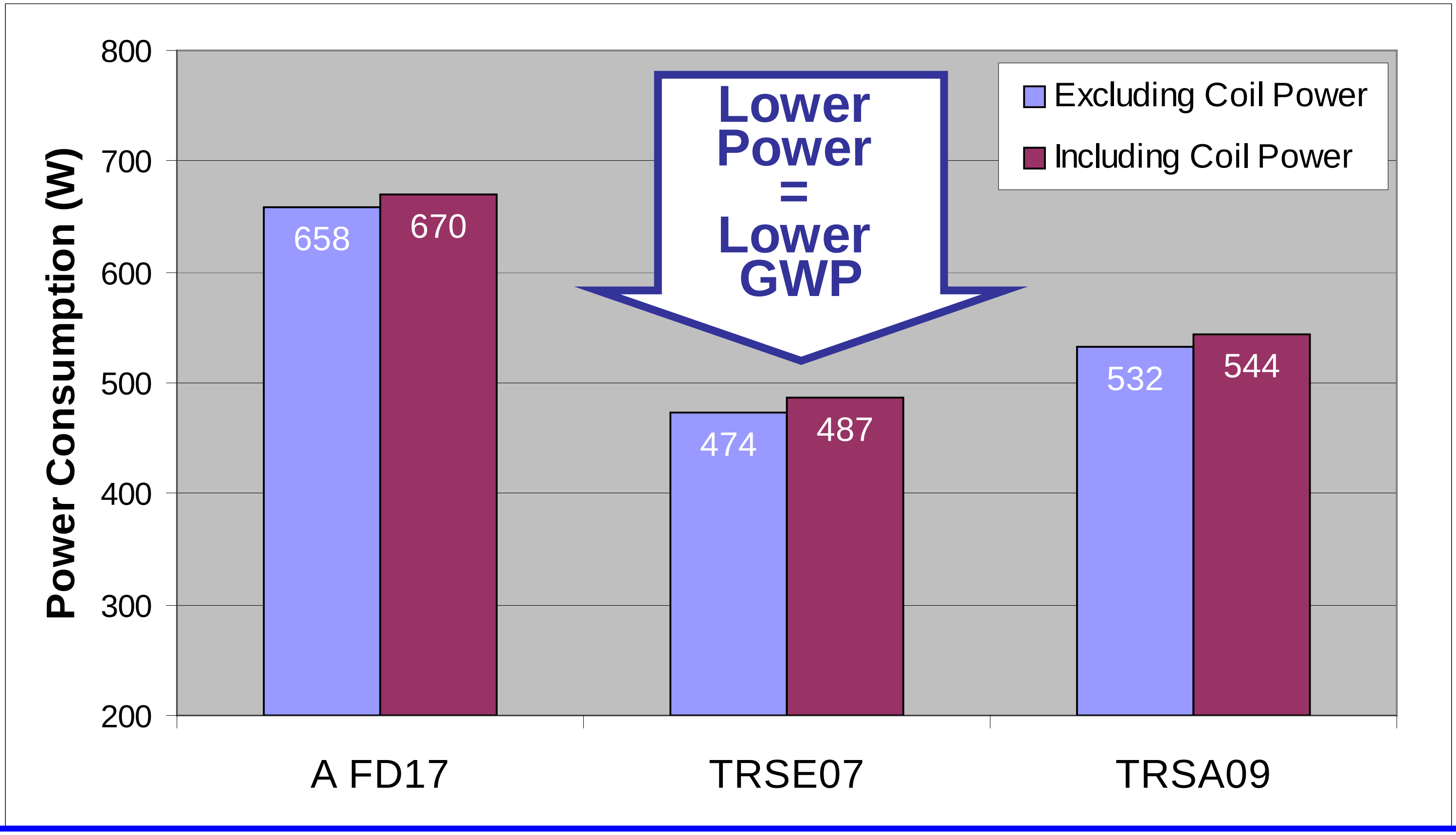
- **Compressor clutch coil power consumption**
- **Annualized power consumption in Watts**

Further Analysis – Beyond IMAC Study

TRSE07 & TRSA09 vs. A FD17

Annualized Power Consumption in Watts

(w/ & w/o clutch coil power consumption)



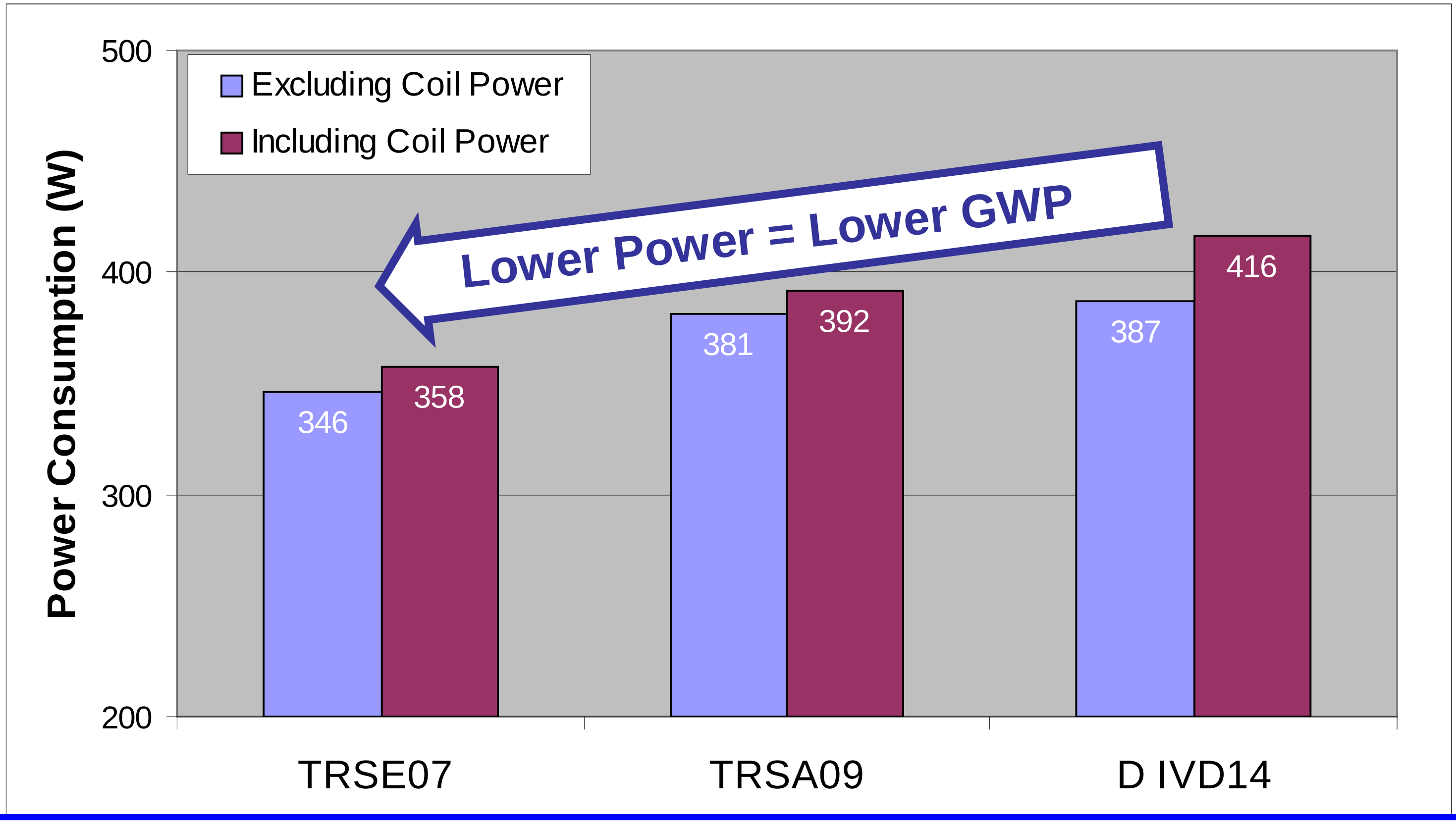
Coil power consumption has little impact on the overall power consumption rate. TR compressors power consumption is significantly lower than A FD17

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.

Contents

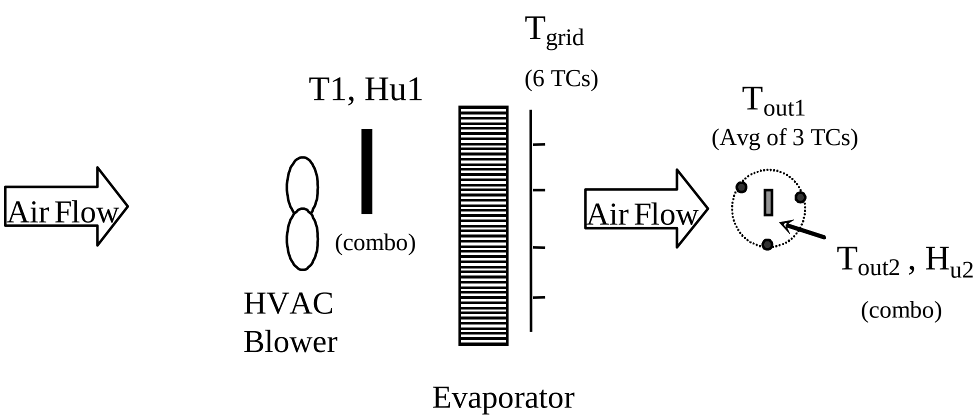
Appendix

I. Evaporator Cooling Capacity Calculations:

Qevp: 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).



I. Evaporator Cooling Capacity Calculations:

Qevp: 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.

II. COP & Energy Consumption Calculation:

• Compressor power consumption

$\dot{W}_c$ = 2p*(shaft torque)*(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 = Qevp / $\dot{W}_c$

Only Qevp 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** =

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

  – *(Average Qevp)*$_i$ = average Qevap of all compressors at *i*th test condition

  – $wt_{climate}$, wt_{RPM} = IMAC climate and speed weighting factors