Reduced GWP Refrigerant Evaluations for AC and Heat Pump Applications

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Climate Change Concern Impacts on AC/Heating

- **The HVAC Industry is developing & evaluating options to reduce net CO_2 emissions resulting from climate control.**
- **Regions are considering various regulations to reduce net CO_2.**
- **Proposals to limit direct GWP value of refrigerant gas.**
- **High GWP HFC refrigerants like 410A could be regulated.**
- **Energy Efficiency is being proposed as best alternative to reduce CO_2.**
- **This study evaluates impact of some candidate refrigerants direct GWP value on net CO_2 generation in AC and Heating**
- **Also evaluated is the possibility of using a direct “drop-in" replacement for R-410A.**
- **More equipment types are now being used in the evaluations.**

Refrigerant Evolution

Increasing Environmental Sustainability

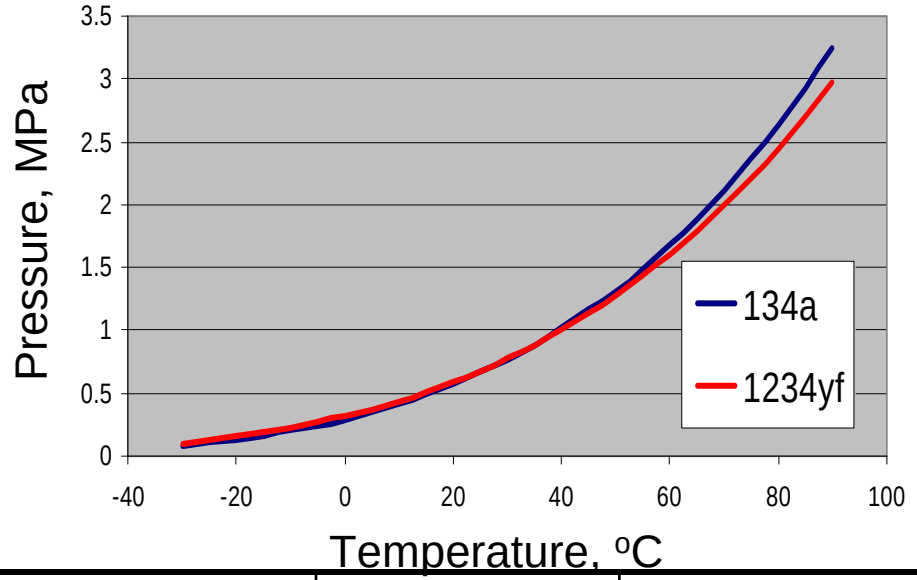
	CFCs	HCFCs	HFCs	HFOs
	CFC-12	HCFC-22	HFC-134a	HFO-1234yf
	CCl_2F_2	$CHClF_2$	CF_3CH_2F	$CF_3CF=CH_2$
Chlorine	High	Less	No	No
ODP	High	Lower	No	No
GWP	High	High	High	Low GWP

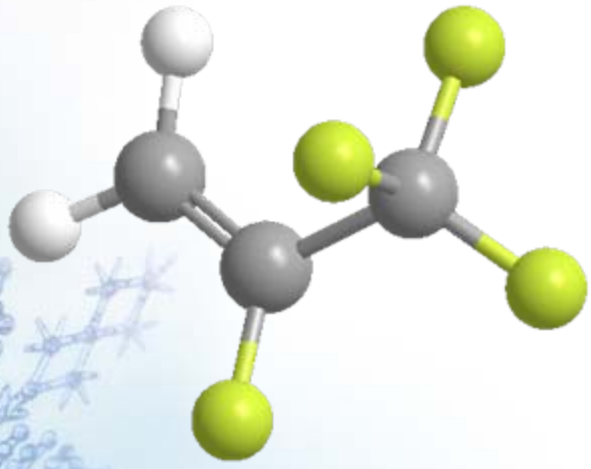
Montreal Protocol Phase-out

F-Gas and other Regulations Pending

HFO-1234yf Performance Very Similar to HFC-134a

- Same operating conditions as 134a (similar P/T curve)
- Thermally stable under extreme use conditions
- Cooling capacity equivalent to 134a
- Energy efficiency equivalent or better than 134a





	R-134a	HFO-1234yf
Formula	CH_2FCF_3	$CF_3CF=CH_2$
Molecular Weight	102	114
ODP	0	0
GWP_{100}	1430(*)	4
T Critical Point	102 ºC	95ºC
Boiling Point	-26ºC	-29ºC

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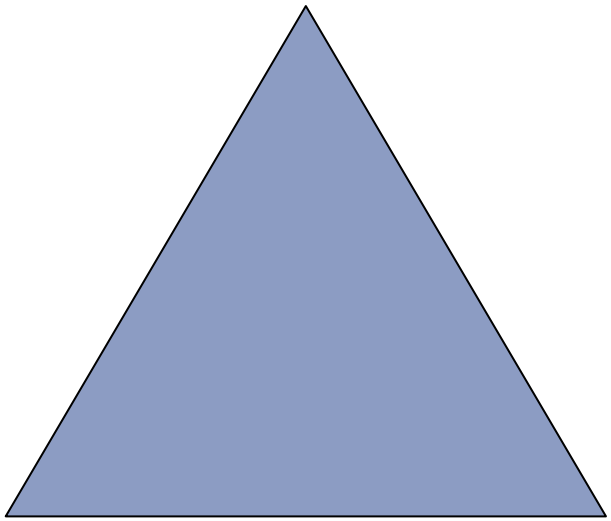
Beyond HFCs – Low GWP Refrigerants

Safety

Flammability	**no or low**
Toxicity	**low**
Environmental	**low GWP, no ODP**



Performance

Energy Efficiency
Cooling Capacity

Cost

First & Operating

No Perfect Refrigerant – Best Balance for each Application

Other Types of Considerations and Drivers

Environmental Laws and Regulations

- Montreal Protocol ODP Phase Out
- Direct GWP Limits
- Life Cycle Analysis
- Net Carbon Footprint limitations (LCCP)
- Safety & Building Codes

Equipment Design and Installation Considerations

- Leak Resistant Connections

Human Factors

- Service Practices:
- Recovery, Reclaim, Recycle
- Refrigerant recovery at decommissioning
- Training and Certification Requirements

What Next after R-410A for AC and Heating?

Performance for AC and Heating should be compared to R-410A, using new lower GWP refrigerant candidates For Example:

Refrigerant	Direct GWP	Glide K
• R-410A	GWP 2088	0.14
• R-32	GWP 675	0
• HFO-1234yf	GWP ~ 4	0
• DR-5 (blend)	GWP < 500	1

- **DR – blends with lower GWP and higher glide**

Thermodynamic Model Comparisons for AC

Modeling of Cycle Performance at AC Conditions, vs. R-410A

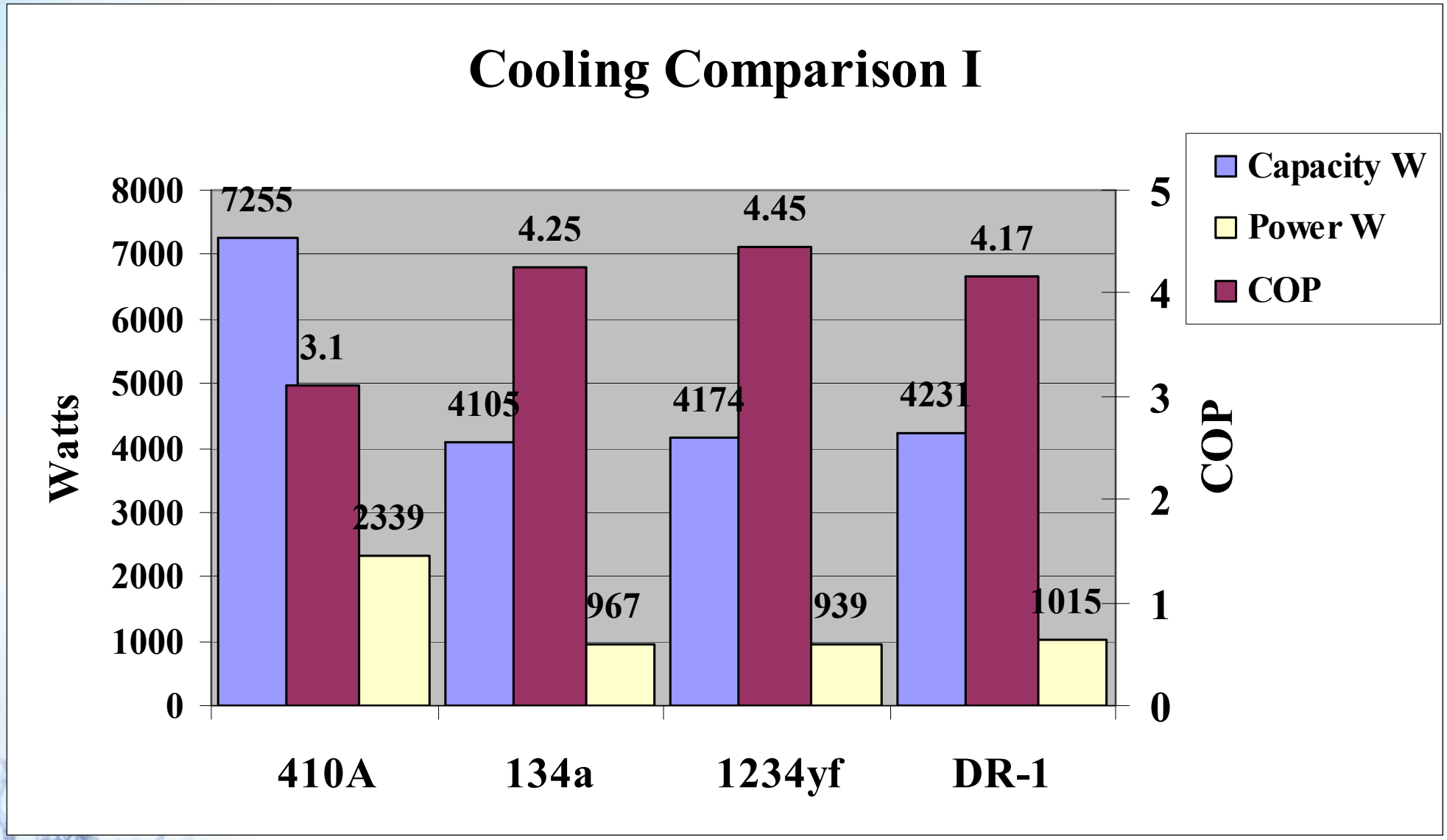
T Evap = 7º C, T Condenser = 47 C Subcool = 12 K

Return Gas superheat = 3 K Compressor Efficiency = 70 %

Refrigerant Candidate	GWP	Glide K	Dischg Press kPa	Dischg Temp ºC	Critical Temp ºC	Cap % Δ Vs R-410A	COP % Δ Vs R-410A	Flammable Rating
R-410A	2088	0.1	2823	81	71	0	0	1
R-32	675	0	2939	102	78	9.7	0.3	2L
DR-5	< 500	1	2748	89	81	0	0.8	2L*
R-134a	1430	0	1222	64	102	-55	8.4	1
HFO-1234yf	4	0	1209	55	95	-57	5.6	2L
DR-1	<700	0	1280	59	98	-54	7.1	1*

Test Description

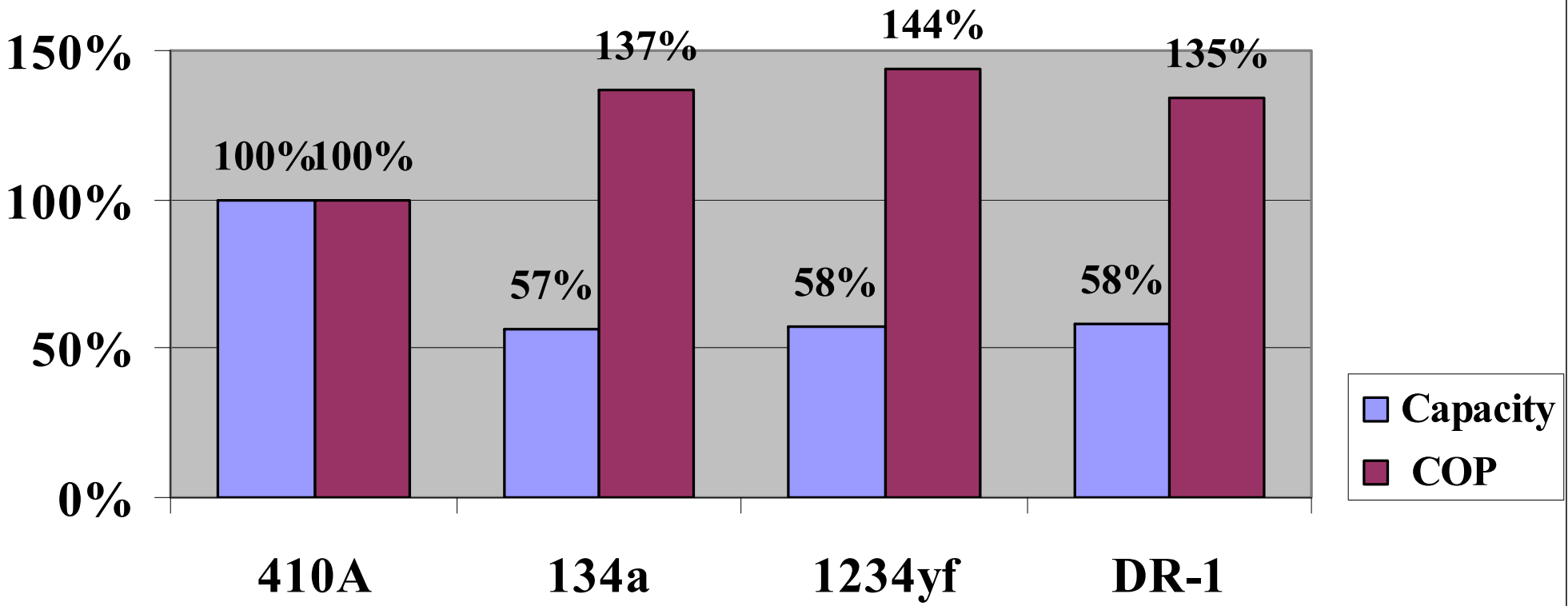
- **7.2 kW, Split type Inverter Heat Pump system.**
- **Tests run in Psychrometric Environmental Chamber.**
- **First, baseline performance was established with R-410A.**
- **Then test refrigerant was added, and run at the same condition.**
- **When appropriate, capacity was adjusted to match R-410A by changing compressor speed.**
- **Cooling or Heating capacity were measured, along with power consumption.**
- **COP was calculated from the above measured values.**



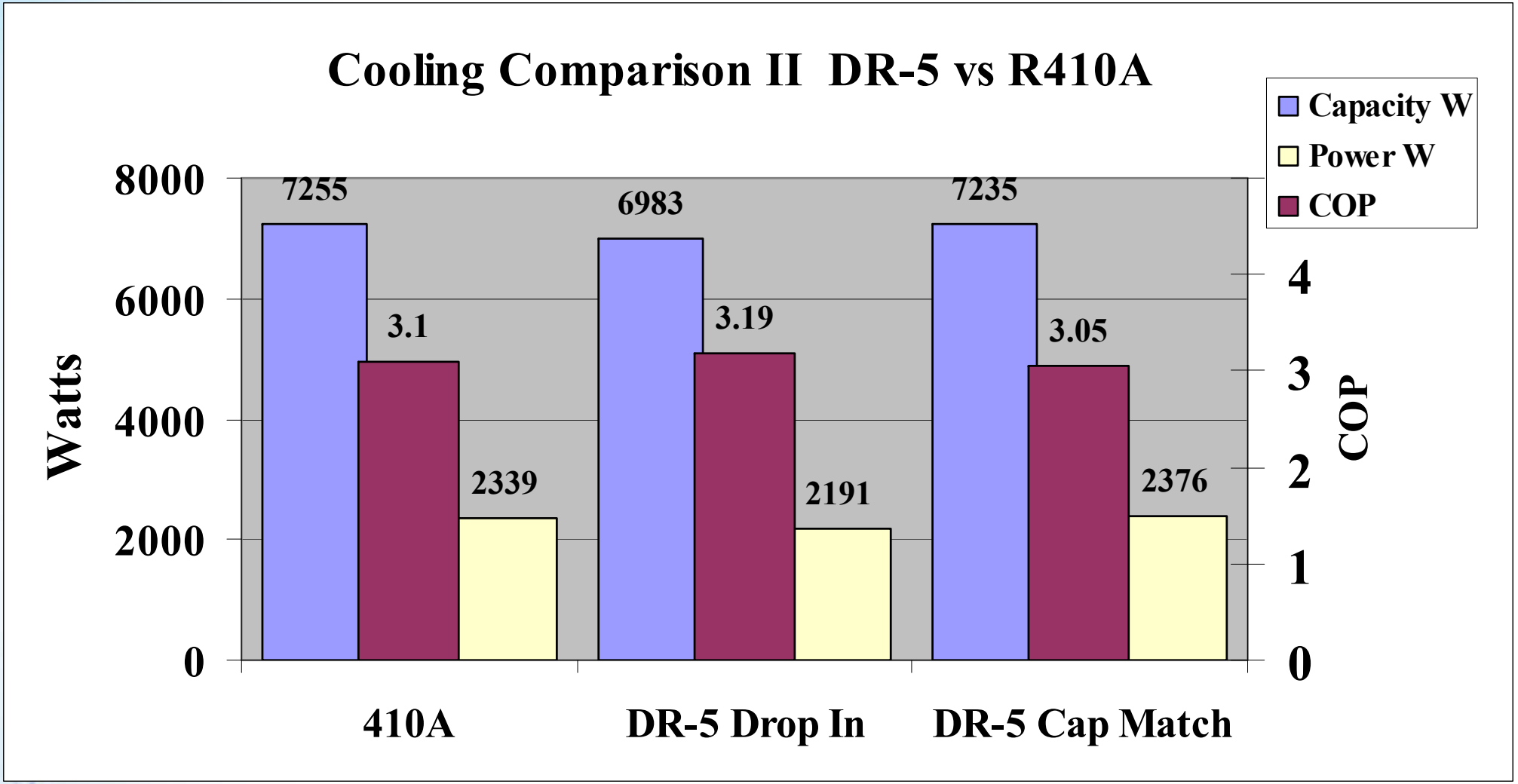
The lower pressure refrigerants have less capacity, but higher COP.

Capacity for cooling or heating a room or house is very important.

Cooling Performance I
Relative to R-410A

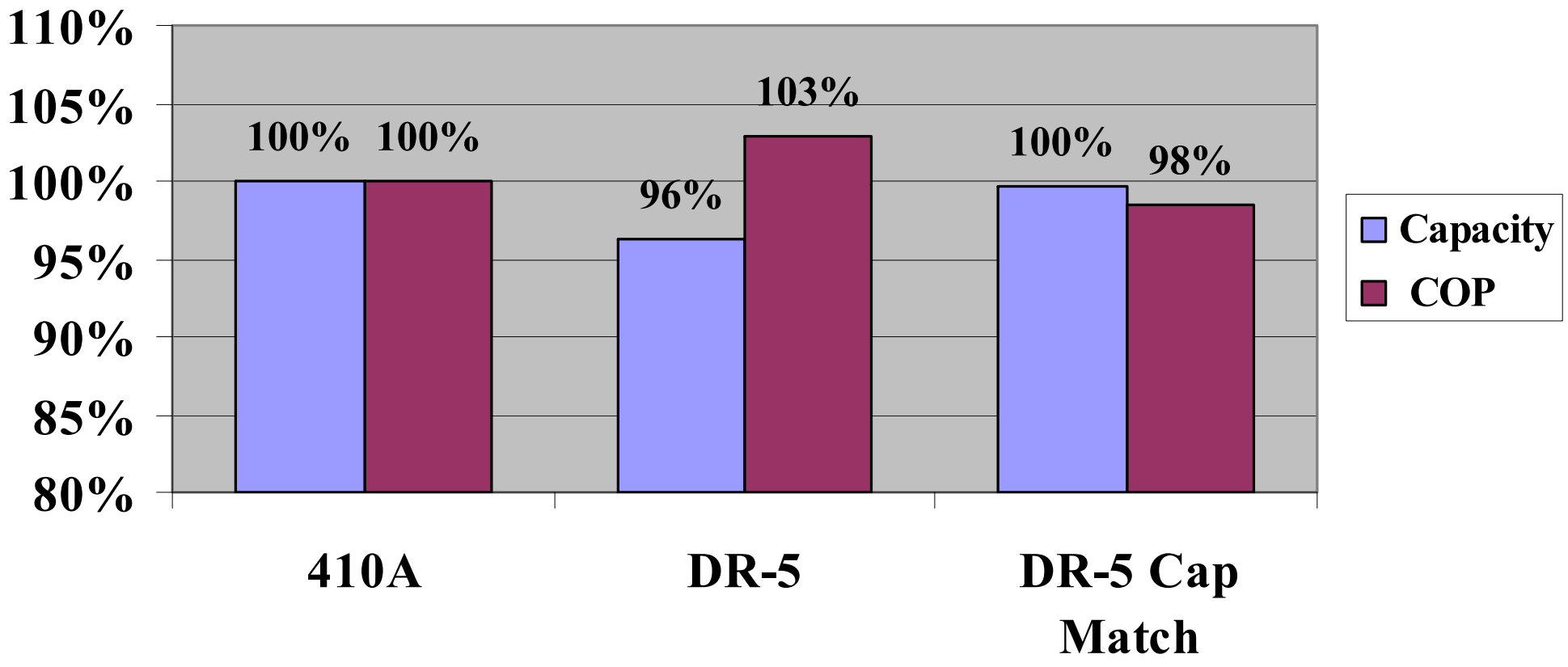


Notice the trade-off between Capacity and COP in every example, including upcoming charts and examples!



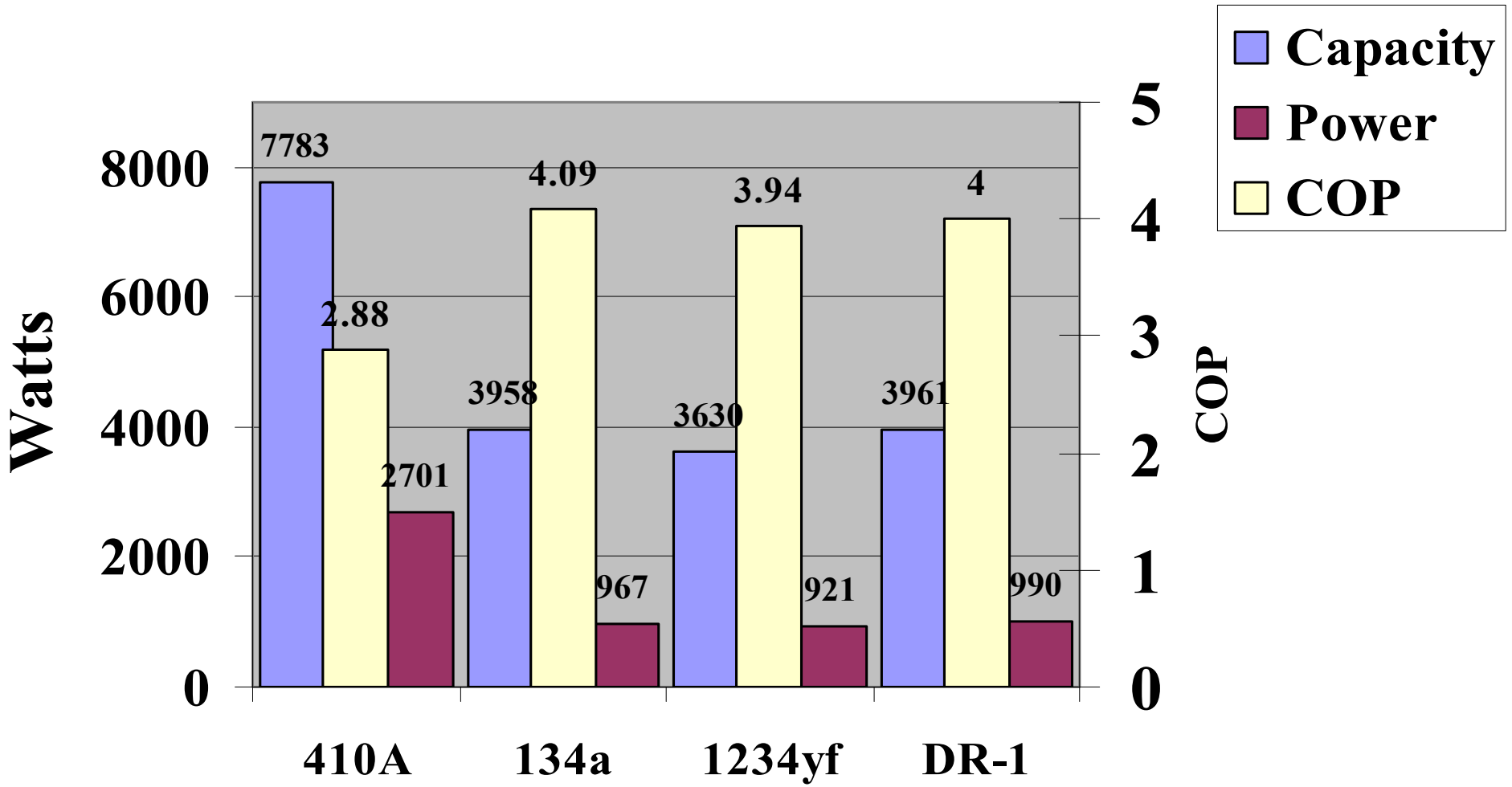
Capacity Match was obtained by increasing the compressor speed.

Cooling Comparison II: DR-5 vs R410A



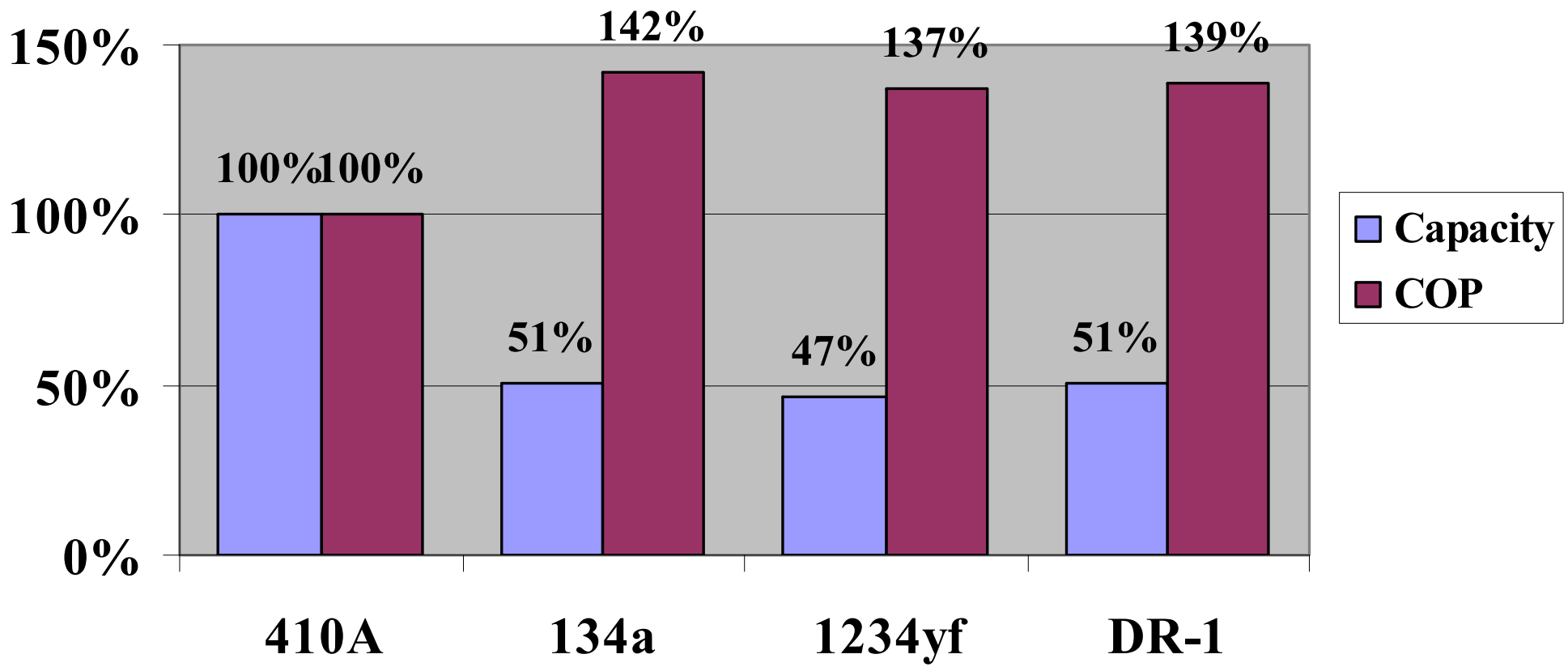
Capacity Match was obtained by increasing the compressor speed.

Heating Summary I

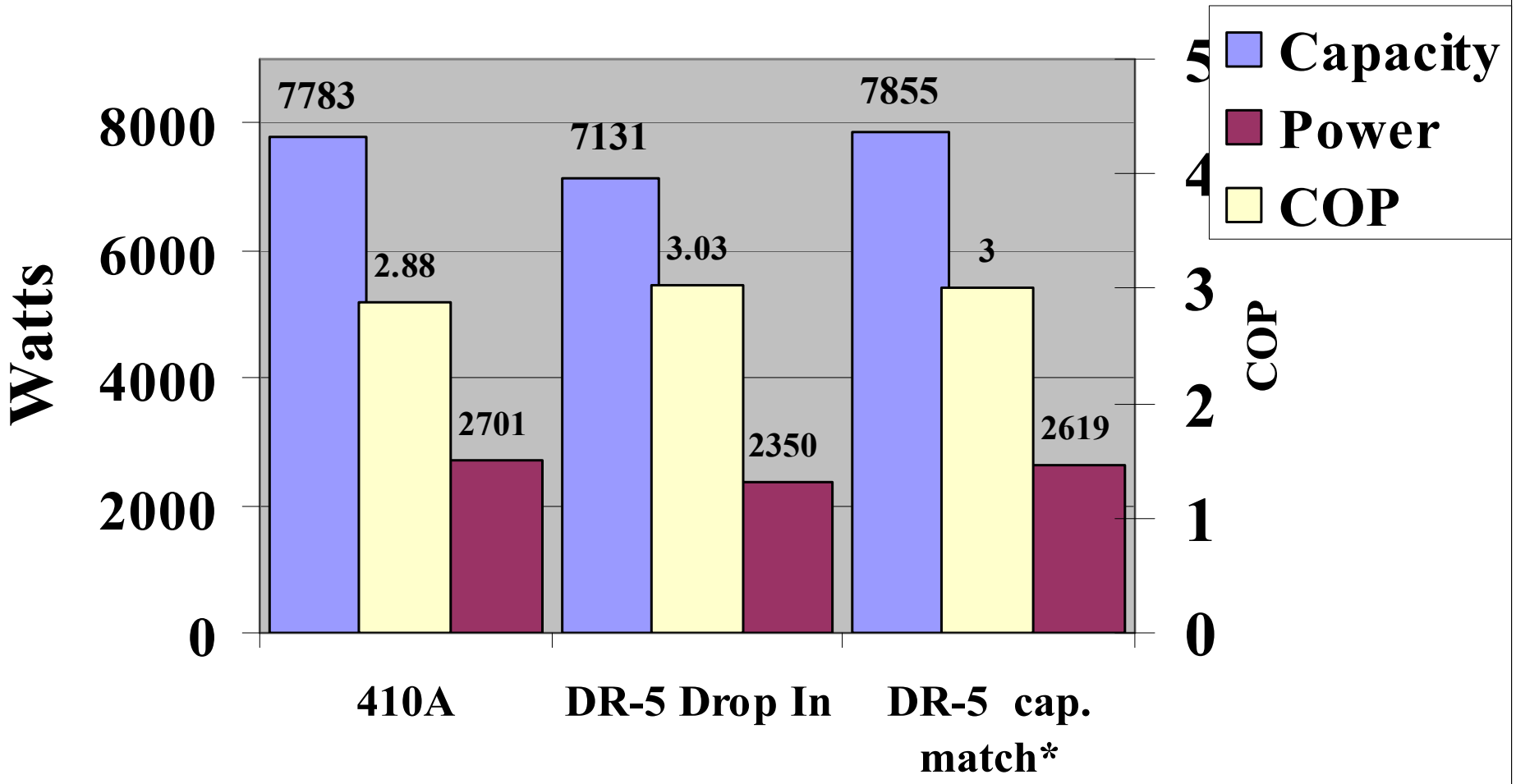


R-134a, HFO-1234yf, and DR-1 do not have the capacity of R-410A.

Heating Performance I
Relative to R-410A



Heating Summmary II DR-5 vs R410A



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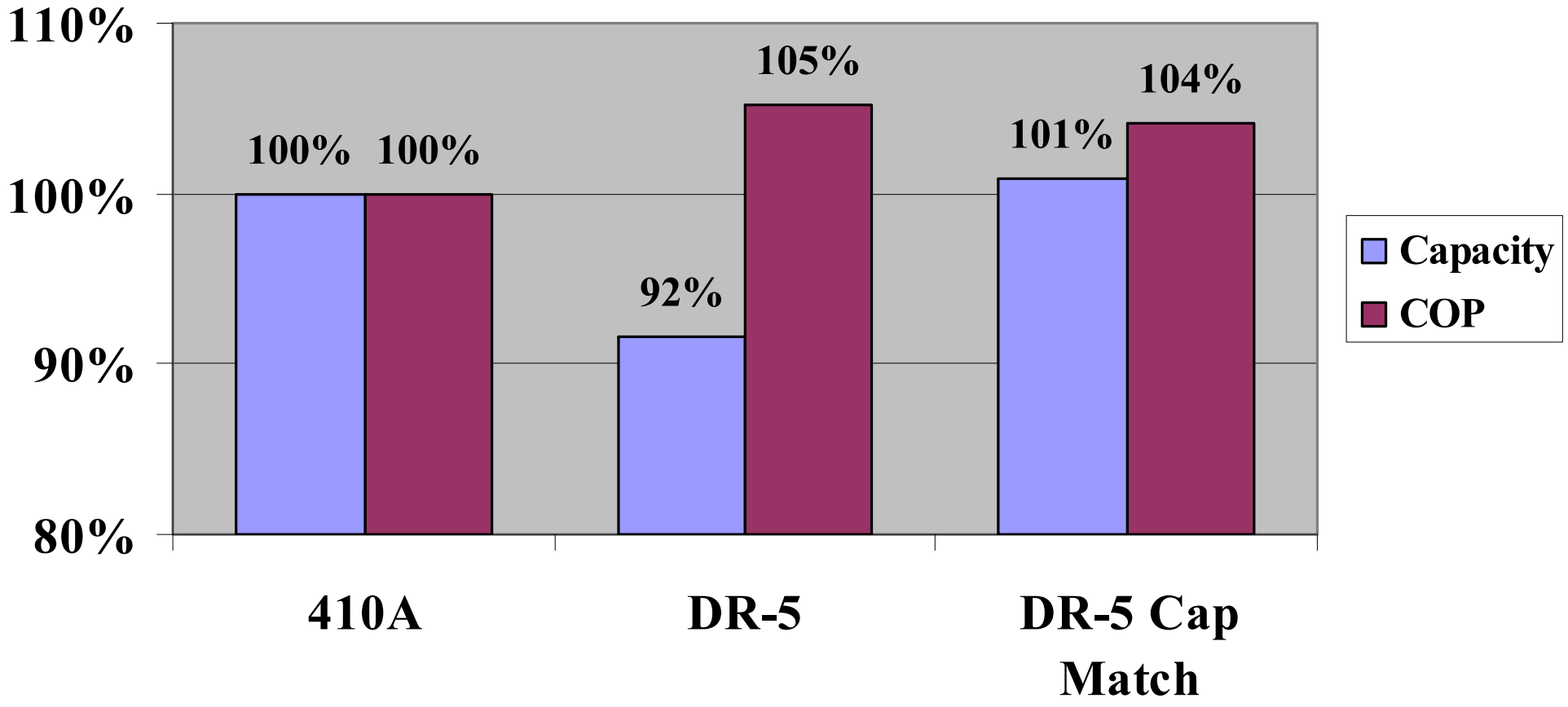
Heating Comparison II: DR-5 vs R410A



When compressor speed is adjusted for capacity, DR-5 outperforms R-410A

Drop In Test Observations I : Medium Pressure

HFO-1234yf , R-134a, and DR-1

COP Cooling and Heating,	**135 % to 144%,of R-410A**
CAPACITY Cooling and Heating	**47 % to 58%, of R-410A**

Although the medium pressure fluids show higher COP in this test, in order to achieve the capacity needed to heat and cool rooms, the required larger compressors, heat exchangers, etc. would require larger charge sizes and substantially larger footprint for the equipment. Substantial re-design and cost and increase of LCCP due to large flow rates and large amounts of metal. This would be resource intensive.

DR-5 Summary – Performance vs. R410A

	"Drop In"	"Match" Capacity with compressor speed
Cooling COP	+3 %	- 2 %
Cooling Capacity	-4 %	even
Heating COP	+ 5 %	+4 %
Heating Capacity	- 8 %	+ 1 %

CONCLUSION: In this equipment, DR-5 good for cooling, Great for Heating!

Conclusions & Observations:

- **HFO-1234yf is a safe, effective refrigerant for environmentally sustainable solutions for MAC and many R-134a applications that can use 2L flammability.**
- **HFO-1234yf and DR-1, like R-134a, are not replacement for R-410A.**
- **We have developed reduced GWP blends with good capacity and COP that may be useful in R-410A applications to substantially improve LCCP.**
- **There are trade-offs of GWP, Flammability, Performance, Discharge Temperature, and Glide that must be considered.**
- **While Low GWP is Important due to direct emissions considerations, the Best Environmental Performance is not from the lowest GWP Candidates**
- **Regulations not finalized. Opportunity exists to select Optimal Fluids and to Create most optimal regulations for minimum environmental impact**
- **It is suggested that regulatory structures not be based only on direct GWP , but also consider energy efficiency, capacity and other performance related issues so that the best environmental solutions can be applied.**
- **A potential "Drop-in" replacement for 410A has been identified. Use of a drop-in can facilitate easy transition to environmentally beneficial refrigerants.**
- **Flammability risk issues must be assessed for safety codes in residential and commercial buildings before this new generation of refrigerants can be fully implemented.**

Possible Future Work

- Evaluations in other equipment types, such as light commercial size equipment.
- Complete evaluation work with other candidate refrigerants
- Drop-in test with alternate blends DR-6 (GWP ~ 400) and DR-4 (GWP ~300) and R-32 (GWP ~675)
- Continue to evaluate life cycle performance for heating as well as cooling performance, especially at a wide range of conditions: high ambients, non standard conditions, etc.

Thank You !!

QUESTIONS ?

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