Challenges for Refrigerants at High Ambient Temperatures

Sustainable Technologies for Stationary Air Conditioning Workshop

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Agenda

- **Definition and challenges at HAT**
- **Highlights from research projects**

Information and material for this presentation is derived from TEAP Task Force reports, HAT research projects and related symposia & conferences

Definition and Challenges

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HAT countries' governments and industry concerns

Definition of HAT

- **Percentile method:** incidence of dry bulb corresponding to 0.4%, 1%, 2%, and 5% per year for the last 10 consecutive years exceeding 35, 40, or 45 ºC;
- **Climate Zone method:** AS defined in ASHRAE 169-2013 with zones from A0 extremely hot and humid to zone 2B hot and dry;
- **Bin Weather Method:** offers microanalysis useful for system design requirements;
- **Average Monthly method:** incidence of hours or days at a certain temperature – adopted by Parties of MP for temperatures above 35 ºC for at least two months per year over 10 consecutive years.

HAT Critical Pressure & Safety

- At higher ambient temperatures, refrigerants will be operating closer to their critical pressure and the prescribed high pressure for safe operation approaches the critical pressure for some refrigerants.

Example: at 67 ºC corresponding to the high pressure safe limit prescribed by EN378:

  - HCFC-22 corresponding pressure is 2,760 kPa equivalent to 55% of critical pressure;
  - R-410A corresponding pressure is 4,347 kPa equivalent to 91% of critical pressure.

Ref EN378-2:2008:

Ambient Conditions	**< 32°C**	**< 38°C**	**< 43°C**	**< 55°C**
High pressure side with air cooled condenser	55°C	59°C	63°C	67°C
Low pressure side with heat exchanger exposed to ambient temperature	32°C	38°C	43°C	55°C

HAT Efficiency, Safety & Design

- As ambient temperature increases, condensing temperature increases and efficiency decreases.

$$COP_{Carnot} = T_{ev}/(T_{cd}-T_{ev})$$

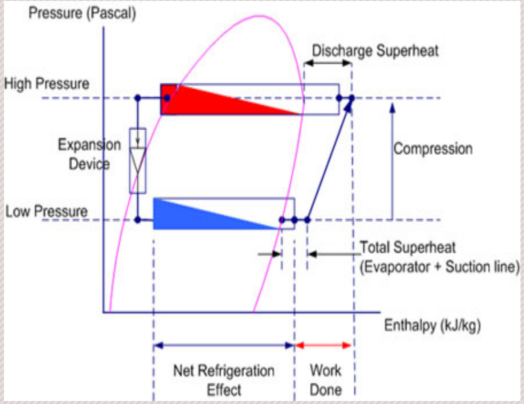
- Two key thermodynamic parameters that affect performance at high ambient temperatures are the critical temperature and molar heat capacity (*McLinden, Domanski, 1999*)

- The system design (size of the condenser, refrigerant charge, expansion device) influences the level of performance degradation;
- At HAT conditions, the cooling load of a conditioned space can be up to three times that for moderate climates;
- larger capacity refrigeration systems may be needed which implies a larger refrigerant charge.

(ISO 5149:2014) Part 1 “describes limits to charge amount depending on system type, system location, and accessibility by people unaccustomed with the safety procedures relating to the system”

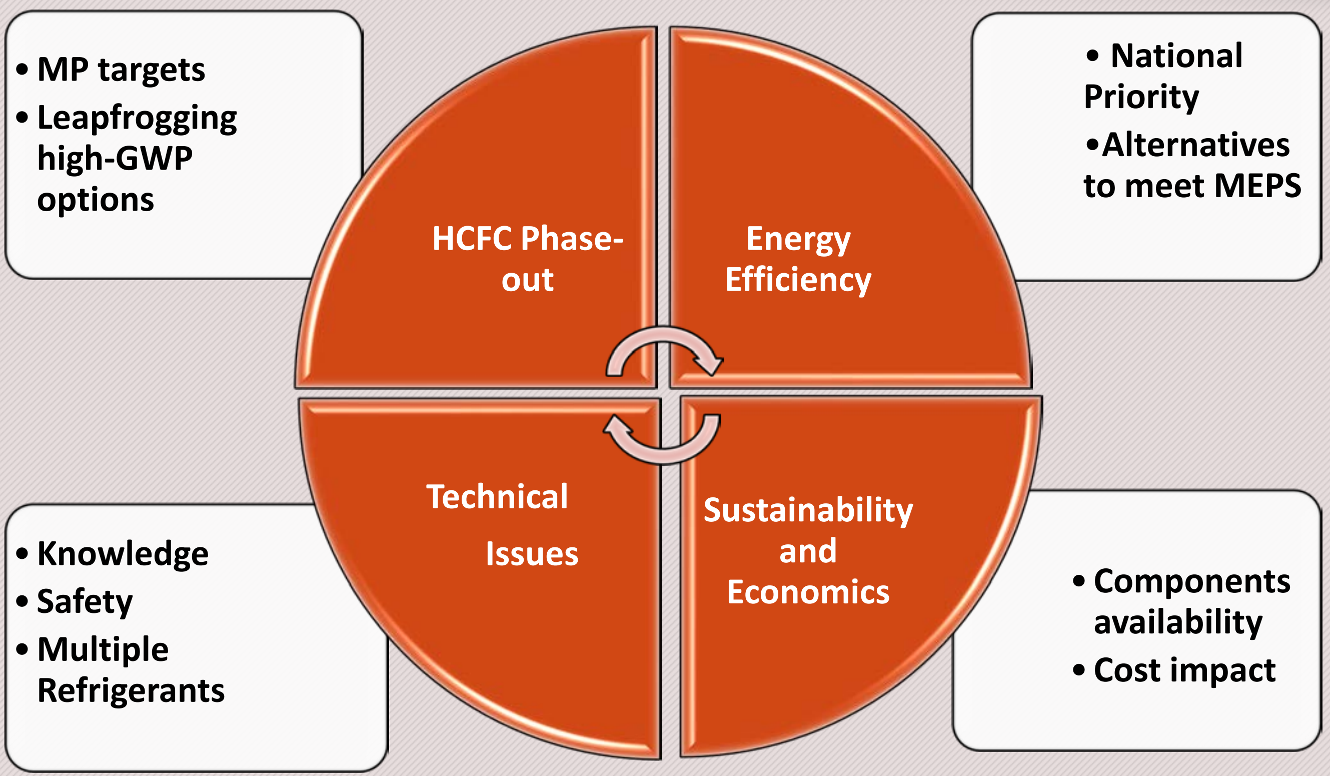
HAT & Reliability

- Cooling capacity decreases due to higher condensing Temperature;
- Vapor-liquid heat transfer becomes shorter due to higher condensing temperature;
- Higher pressure ratio results in higher current & shorter compressor life;
- Refrigerant and oil decompose into water and carbon;
- Viscosity of the oil decreases;
- Insulation of the motor gets worse;
- Reliability decreases



Source: Li Tingxun, HAT seminar 2014

Concerns of HAT Governments and Industry



Source: PRAHA

Research at HAT

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Description and Results

New research efforts

- “Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries” **(PRAHA)**
  - Concluded; report published;
  - Phase II approved and started in 2016
- “Egyptian Project for Refrigerant Alternatives” **(EGYPRA)**
  - Ongoing, results in 2018
- The Oak Ridge National Laboratory **(ORNL)** High-Ambient-Temperature Evaluation Program for low–global warming potential (Low-GWP) Refrigerants Phase I and II
  - Phase I concluded October 2015 with a report published
  - Phase II concluded in September 2016
- The Alternative Refrigerant Evaluation Program **(AREP)** Phase I and II
  - Phase I concluded in 2014 - 40 test reports
  - Phase II concluded in 2016 -33 test reports

Four Research Projects at HAT

	Low-GWP AREP (AHRI)	ORNL - DOE Evaluation Program	EGYPRA (UNEP, UNIDO, Egypt)	PRAHA (UNEP, UNIDO, HAT countries)
Type of test	Soft-optimization and drop-in tests of several A/C, Heat Pumps, and Ref applications	Soft-optimized tests, of Two (2) base Split A/C units	Build and test 36 prototypes in 3 A/C split and one A/C package categories	Build and test 23 prototypes in Window, split and A/C package categories
Status	**started 2014 and completed**	**Started 2015 and completed**	**Started in 2015 and planned to complete by 2018**	**Started 2013 and completed**
Testing	Units were manufactured or obtained by each party and tested at each party's facilities	The 2 units were optimized and tested at ORNL	Prototypes built at eight OEMs, witness tested at own labs	Prototypes built at 6 OEMs, test at Independent Lab
Refrigerants tested	R-1234yf, R-32, D2Y60, L-41a, D-52Y, ARM-71a, DR-5A, HPR-2A, L-41-1 and L-41-2	HFC-32, R-290, HFC/HFO blends 4 types vs. HCFC-22 HFC/HFO blends (4 types) vs. R-410A	HFC-32, R-290, HFC/HFO blends 3 types vs. HCFC-22 HFC/HFO blends (3 types) vs. R-410A	HFC-32, R-290, HFC/HFO blends 2 types) vs. HCFC-22 HFC/HFO blends (1 type) vs. R-410A
Other components	**N/A**	**N/A**	**N/A**	**Several other assessment elements**

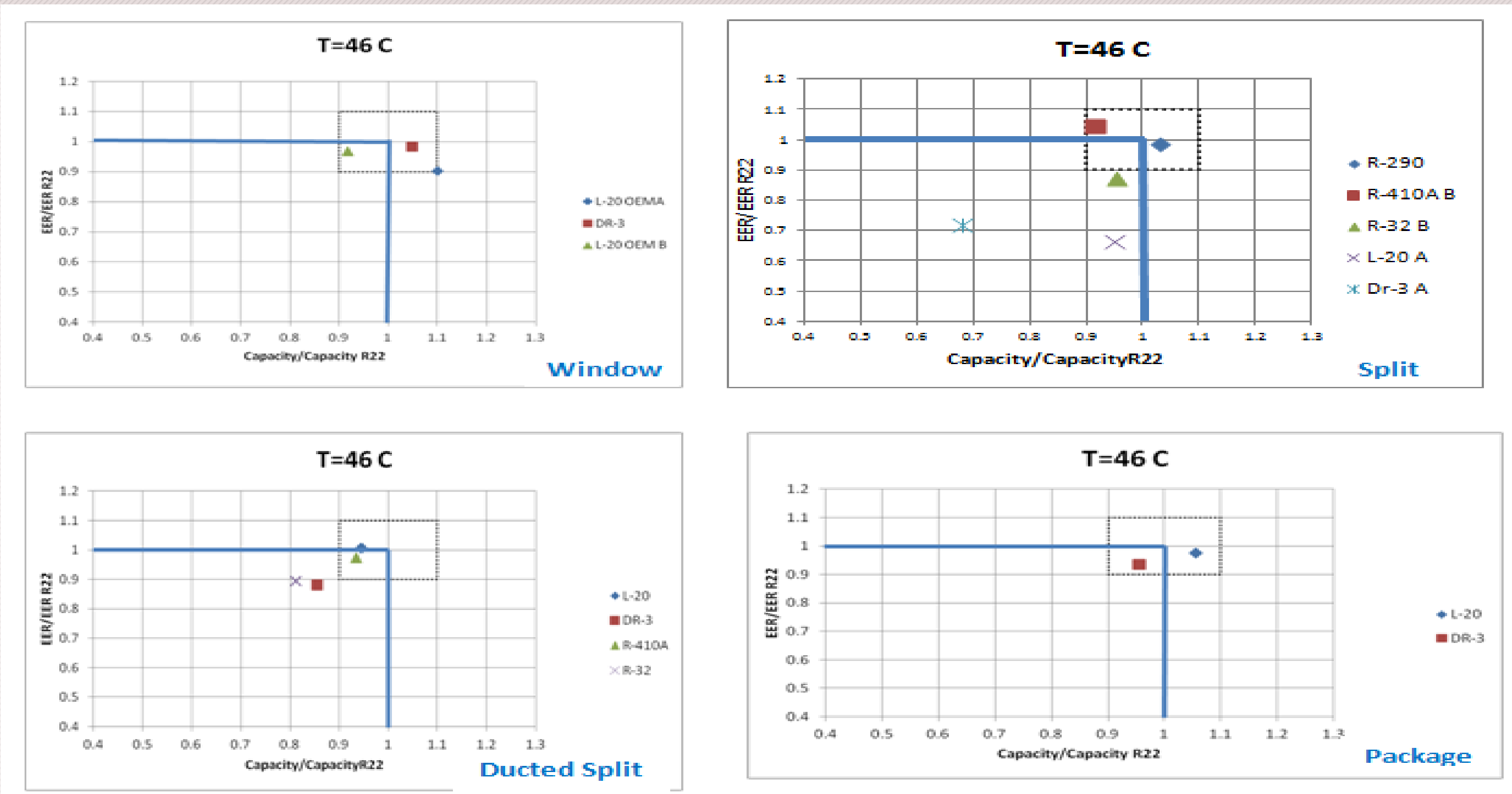
There are several other individual research projects on alternatives for HAT conditions, but above are the independent collective efforts supported by governments or the industry

Source: PRAHA report

Differences between projects

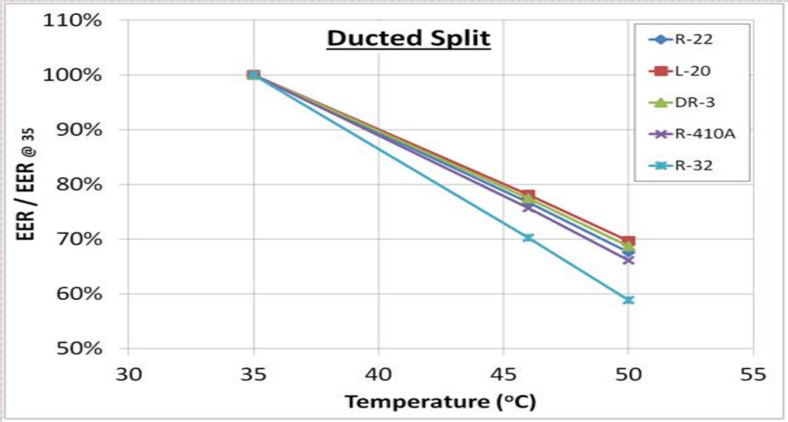
- PRAHA & EGYPRA use custom built prototypes with special compressors and optimized charge and expansion device;
- ORNL optimized the charge and the expansion device to achieve same superheat and sub-cooling as the base units;
- AREP was either a drop-in or soft optimized. Some experiments matched the capacity, others used variable drives, while measured the same refrigerant with two types of oil.

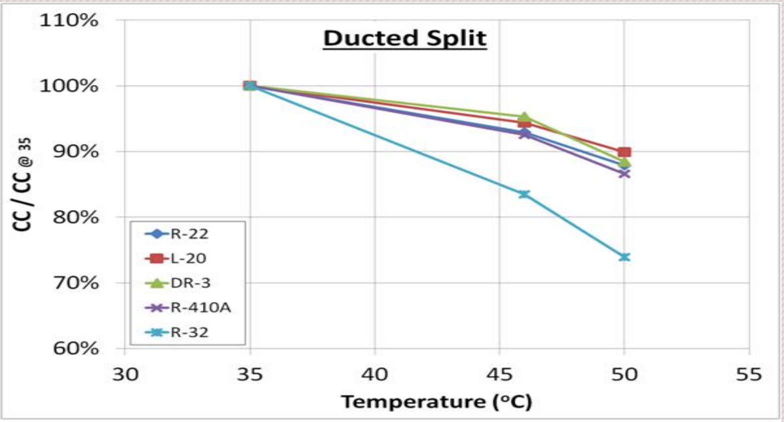
PRAHA Results - graphic summary

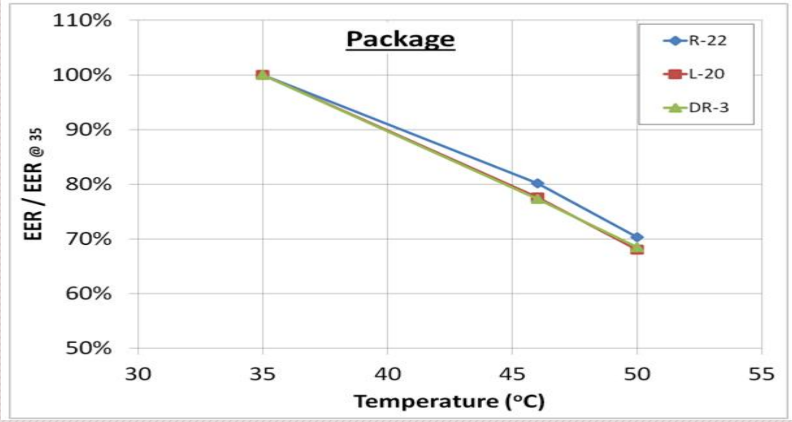


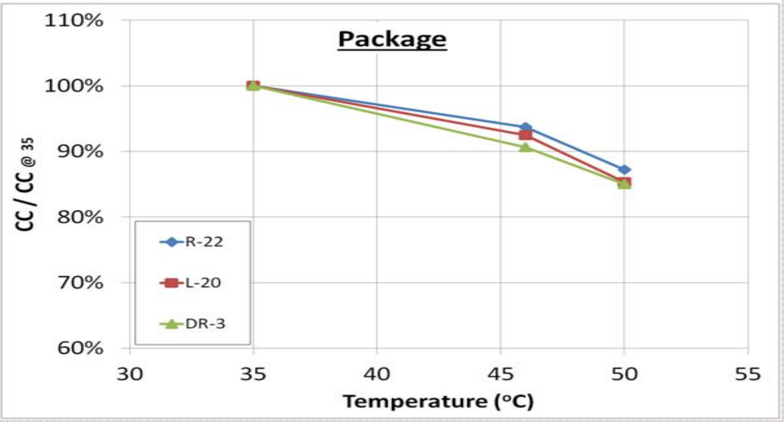
Source: PRAHA report

PRAHA: Degradation vs. temperature



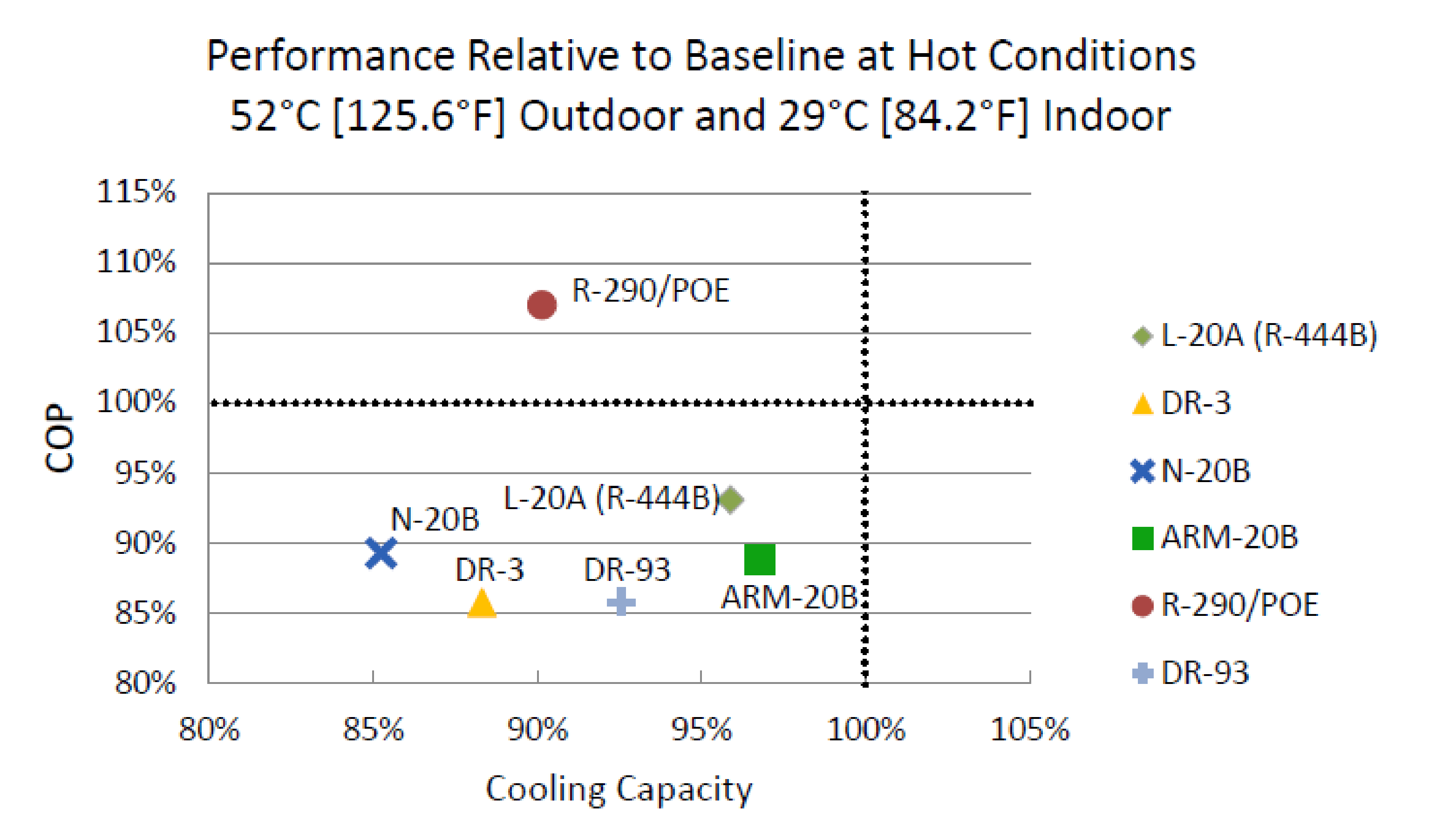






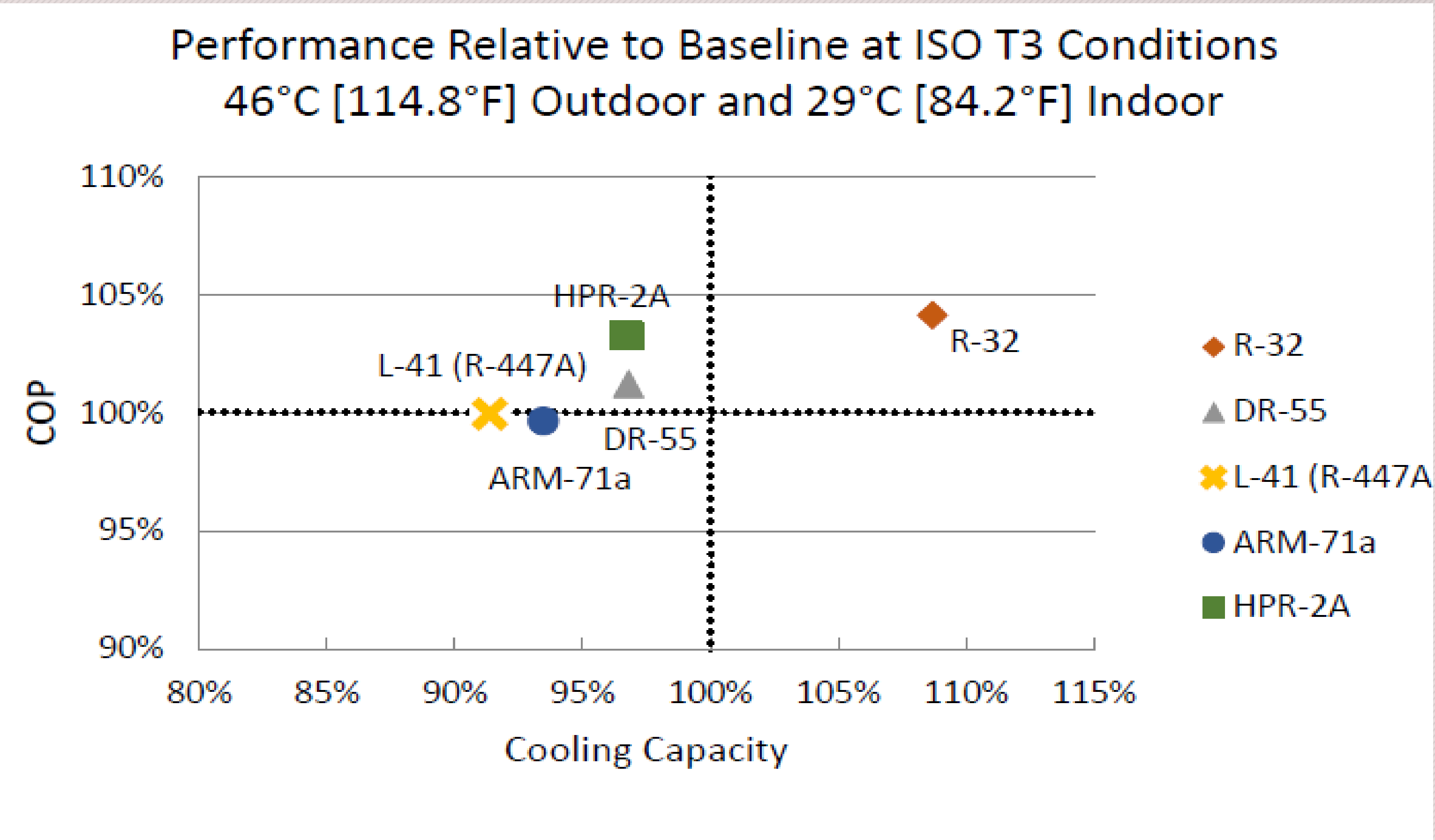
Source: PRAHA report

ORNL HCFC-22 alternatives



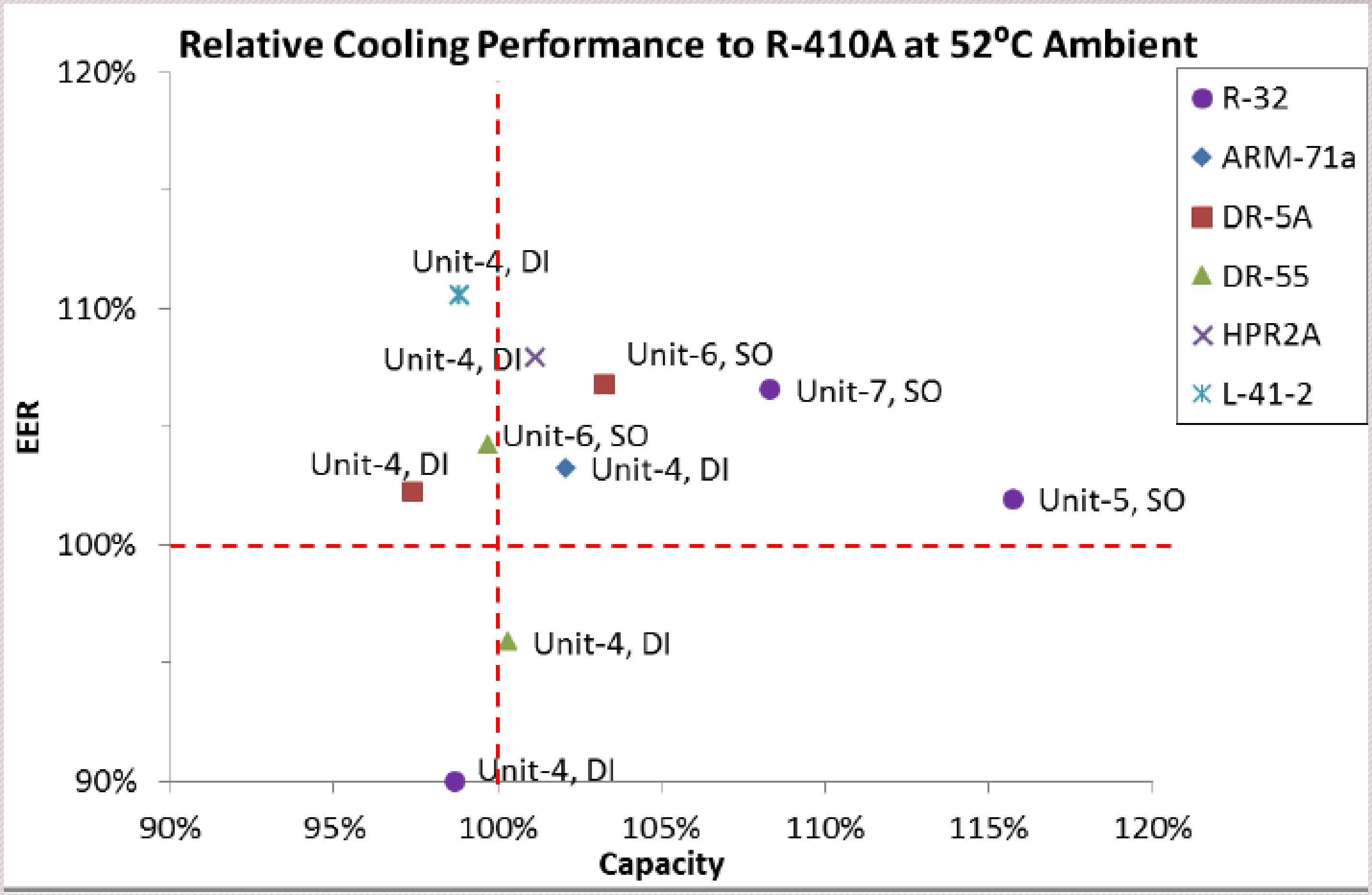
Source: ORNL report

ORNL R-410A alternatives



Source: ORNL report

AREP-II



Source: AREP-II Perdue paper 2016

Conclusions

- *The test results should be carefully interpreted along with system modifications, test procedure variations etc.*
- *Some tested refrigerants show promise in meeting specific, current R/AC equipment requirements for operation under HAT conditions;*
- *There is a potential improvement through further “soft optimization” but full optimization of systems will likely improve the performance of these refrigerants;*
- *Losses in cooling capacity are typically easier to recover through engineering optimization than are losses in COP;*
- *The primary practical limit to improvements in capacity is the physical size of the unit; but that is not expected to be a significant concern;*
- *The COP losses and the increases in compressor discharge temperature are particularly important results, in that these variables will be the primary focus of future optimization efforts.*

Source: AREP-II and ORNL reports

Thank you !

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