Eurovent Partners Meeting

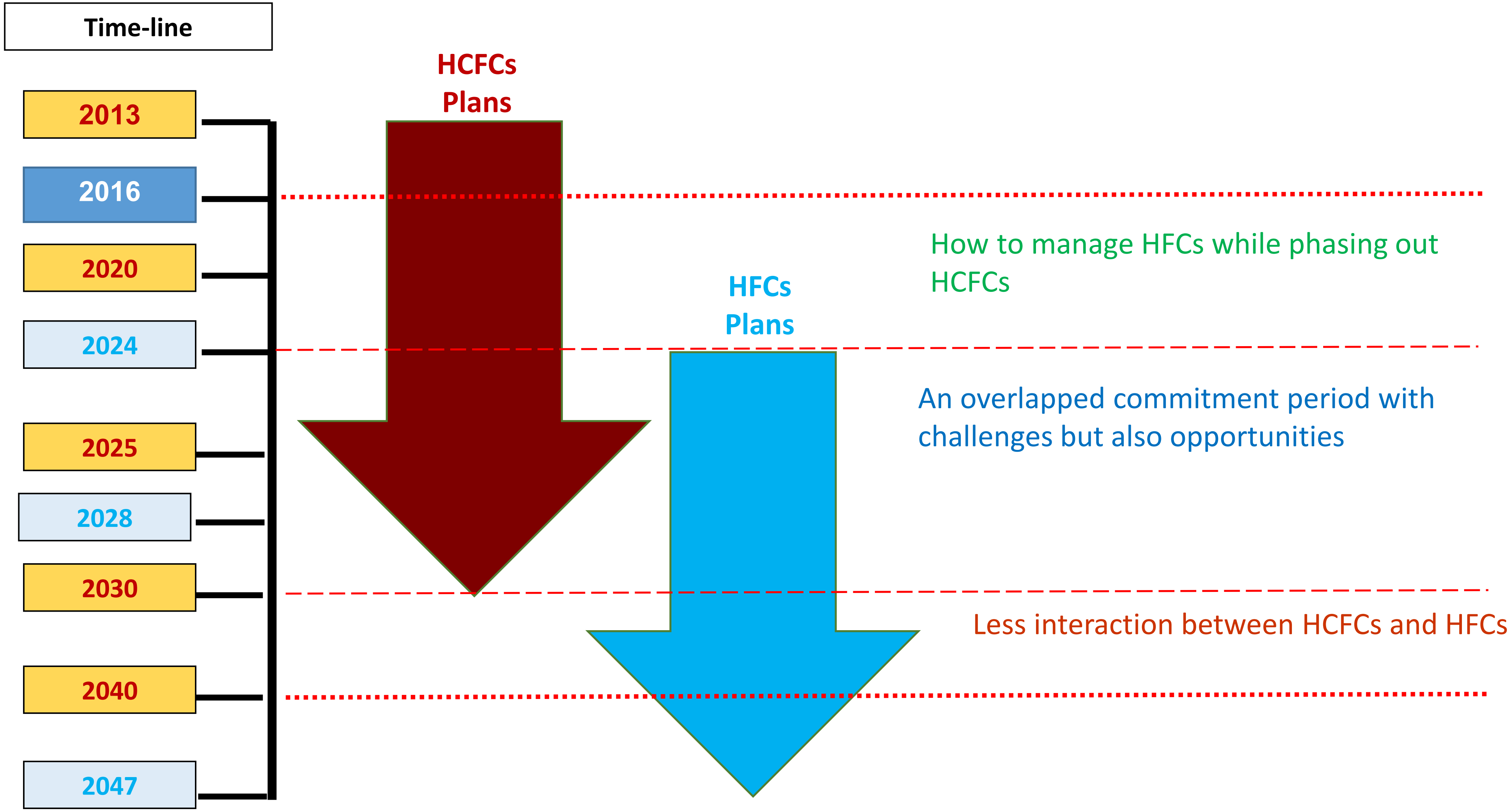
A/C Technology transformation in high-ambient temperature (HAT) countries through MLF

Ayman Eltalouny
International Partnership Coordinator

OzonAction, Law Division
UN Environment Programme (UNEP)

HPMPs Vs. HFCs Phase-down

The Overlapped Commitments for developing countries



Priority Sectors over lifetime of Montreal Protocol

CFCs (1987 – 2010)

- Foam
- Aerosol
- Dom Ref
- MAC
- Solvents + Halon
- Servicing

HCFCs (2007-2030/2040)

- Foam
- Res. A/C
- Comm. A/C
- Servicing

HFCs (2020-2048)

- MAC
- Dom Ref
- Comm Ref (Cold Chain)
- A/C
- Servicing

High Ambient Temperature

Montreal Protocol Definition

An average of at least two months per year over 10 consecutive years of a peak monthly average temperature above 35°C

High Ambient Temperature (HAT) Countries

Algeria, Bahrain, Benin, Burkina Faso, Central African Republic, Chad, Cote d'Ivoire, Djibouti, Egypt, Eritrea, Gambia, Ghana, Guinea, Guinea-Bissau, Iran, Iraq, Jordan, Kuwait, Libya, Mali, Mauritania, Niger, Nigeria, Oman, Pakistan, Qatar, Saudi Arabia, Senegal, Sudan, Syria, Togo, Tunisia, Turkmenistan, United Arab Emirates

- **Africa-Francophone**: Algeria, Benin, Burkina Faso, Central African Republic, Chad, Cote d'Ivoire, Djibouti, Guinea, Guinea Bissau, Mali, Mauritania, Niger, Senegal, Togo and Tunisia
- **Africa- Anglophone**: Egypt, Eritrea, Gambia, Ghana, Libya, Nigeria and Sudan
- **West Asia**: Bahrain, Iraq, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Syria and United Arab Emirates
- **South Asia**: Iran and Pakistan
- **ECA:** Turkmenistan

Background & Early Research

- Most of the research has been at the “standard ambient” of 35°C dry bulb temperature with extrapolation to higher temperatures. Simulation and testing was also done for some of the available refrigerants:
  - Earlier modelling by Chin and Spatz (1999) conducting simulations comparing R-410A to HCFC-22 at 52°C ambient;
  - Domanski and Payne (2002) carried out measurements of a unitary air conditioner to compare HCFC-22 and R-410A;
  - Biswas and Cremaschi (2012) measured the performance of some mixtures like “DR-4” and “DR-5 at 46°C.

Dedicated Research Efforts

- "Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries" (**PRAHA**)
  - PRAHA-I report published in 2016
  - PRAHA-II report published in 2019
- "Promotion of Low-GWP Refrigerants for the Air Conditioning Industry in Egypt" **(EGYPRA)**
  - Report published in 2019
- The Oak Ridge National Laboratory (**ORNL**) High-Ambient-Temperature Evaluation Program for low–global warming potential (Low-GWP) Refrigerants Phases I and II
  - Phase I report published in 2015
  - Phase II Report published in 2016
- The Alternative Refrigerant Evaluation Program (**AREP**) Phases I and II
  - Phase I Reports published in 2014 (40 test reports)
  - Phase II Reports published in in 2016

<table>
<tr><th colspan="2">Program</th><th colspan="4">PRAHA</th><th colspan="4">EGYPRA</th><th colspan="2">ORNL – Phase I (Mini-split AC)</th><th>AREP-II</th></tr>
<tr><td>1</td><td>Type of test</td><td colspan="4">Custom built test prototypes, comparing with base units: HCFC-22 and R-410A</td><td colspan="4">Custom built test prototypes, comparing with base units: HCFC-22 and R-410A</td><td colspan="2">Soft optimization tests, comparing with base units: HCFC-22 and R-410A</td><td>Soft optimization or drop in of individual units tested against a base R-410A unit</td></tr>
<tr><td>2</td><td>No. of prototypes</td><td colspan="4">13 prototypes, each specific capacity and refrigerant built by one or two OEMs, compared with base refrigerants: HCFC-22 and R-410A. Total prototype and base units = 22</td><td colspan="4">28 prototypes, each specific one capacity and one refrigerant built by one OEM, compared with base refrigerants: HCFC-22 and R-410A. Total prototype and base units = 37</td><td colspan="2">2 commercially available units, soft modified to compare with base refrigerants: HCFC-22 and R-410a</td><td>22 units from different OEMs ranging from splits to water chillers</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">No. of categories</td><td colspan="2">60 Hz</td><td colspan="2">50 Hz</td><td colspan="4">50 Hz</td><td colspan="2">60 Hz</td><td>60Hz</td></tr>
<tr><td>Window</td><td>Mini Split</td><td>Ducted</td><td>Packaged</td><td>Mini Split</td><td>Mini Split</td><td>Mini Split</td><td>Central</td><td>Split unit</td><td>Split unit</td><td rowspan="2">34 MBH chiller, 2x 36 MBH split, 48 MBH packaged, 60 MBH packaged, 72 MBH packaged</td></tr>
<tr><td>18 MBH</td><td>24 MBH</td><td>36 MBH</td><td>90 MBH</td><td>12 MBH</td><td>18 MBH</td><td>24 MBH</td><td>120 MBH</td><td>18 MBH R22 eq.</td><td>18 MBH R-410a eq.</td></tr>
<tr><td>4</td><td>Testing conditions</td><td colspan="4">ANSI/AHRI Standard 210/240 and ISO 5151 at T1, T3 and T3+ (50°C) and a continuity test for 2 hours at 52°C</td><td colspan="4">EOS 4814 and 3795 (ISO 5151) T1, T2, and T3 conditions</td><td colspan="2">ANSI/AHRI Standard 210/240 and ISO 5153 T3 (2010) condition</td><td>ANSI/AHRI 210/240, at T1, T3, and 125 °F</td></tr>
<tr><td>5</td><td>Prototypes supplied and tests performed</td><td colspan="4">Prototypes built at six OEMs, test at Intertek</td><td colspan="4">Prototypes built at eight OEMs, witness testing at OEM labs</td><td colspan="2">ORNL, one supplier – soft optimization in situ</td><td>Individual suppliers, testing at own premises</td></tr>
<tr><td rowspan="3">6</td><td rowspan="3">Refrigerants tested</td><td colspan="4">Eq. to HCFC-22: HC-290, R-444B (L-20), DR-3</td><td colspan="4">Eq. to HCFC-22: HC-290, R-444B (L-20), DR-3, R-457A (ARM-32d)</td><td colspan="2">Eq. to HCFC-22:N-20B, DR-3, ARM-20B, R-444B (L-20A), HC-290</td><td rowspan="2">Eq. to R-410A: HFC-32, DR-5A, DR-55, L-41-1, L-41-2, ARM-71a, HPR2A</td></tr>
<tr><td colspan="4">Eq. to R-410A: HFC-32, R-447A (L-41-1), R-454B (DR-5A)</td><td colspan="4">Eq. to R-410A: HFC-32, R-447A (L-41-1), R-454B (DR-5A), ARM-71d</td><td colspan="2">Eq. to R-410A: HFC-32, R-447A (L-41-1), DR-55, ARM-71d, HPR-2A</td></tr>
<tr><td colspan="4">Final report end March 2016</td><td colspan="4"></td><td colspan="2"></td><td></td></tr>
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PRAHA-I

Testing Customs Built Prototypes at HAT Conditions

Source: PRAHA report

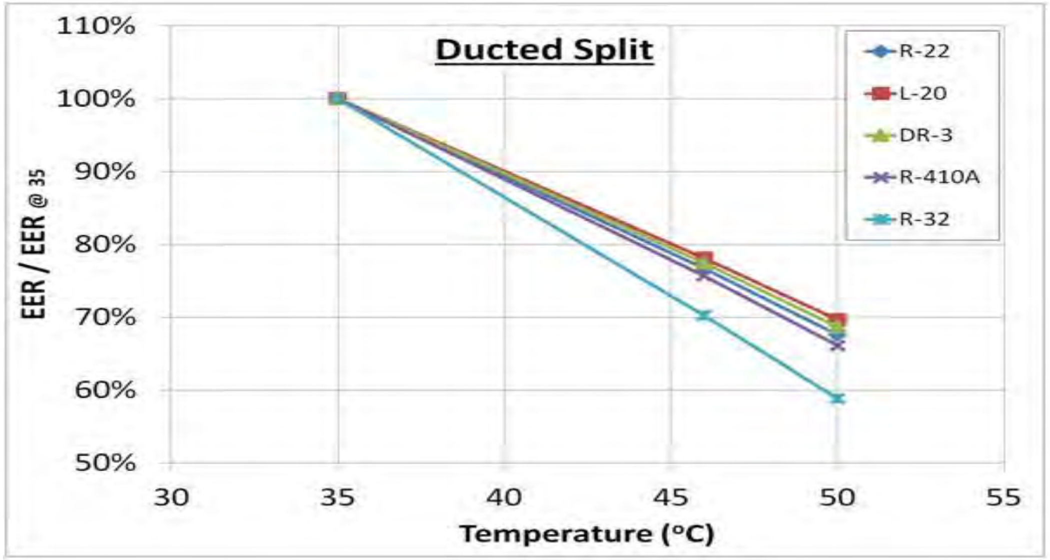
PRAHA Project

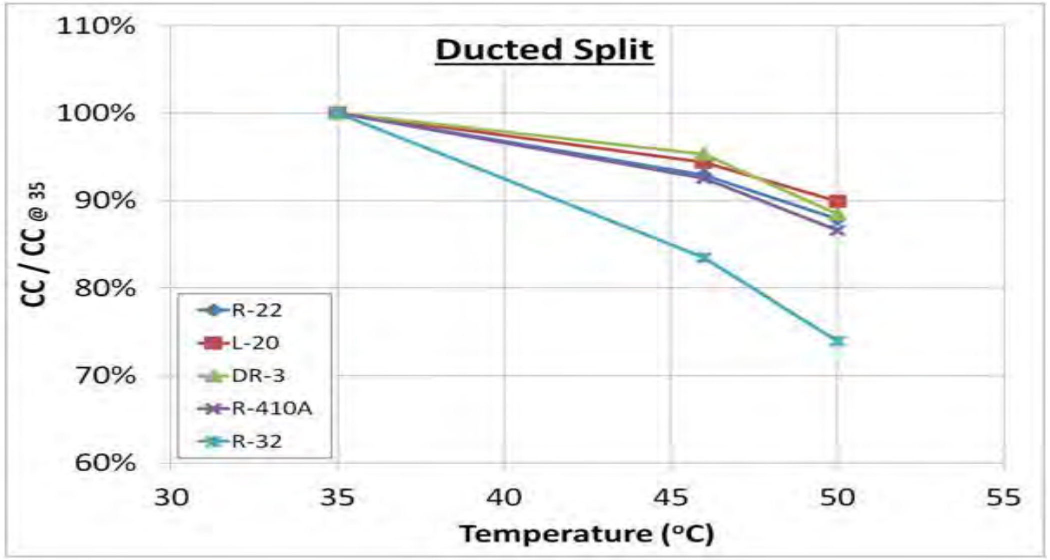
Comparable to HCFC-22	Comparable to R-410A
HC-290	HFC-32
R-444B (L-20)	R-447A (L-41-1)
R-454C (DR-3)	

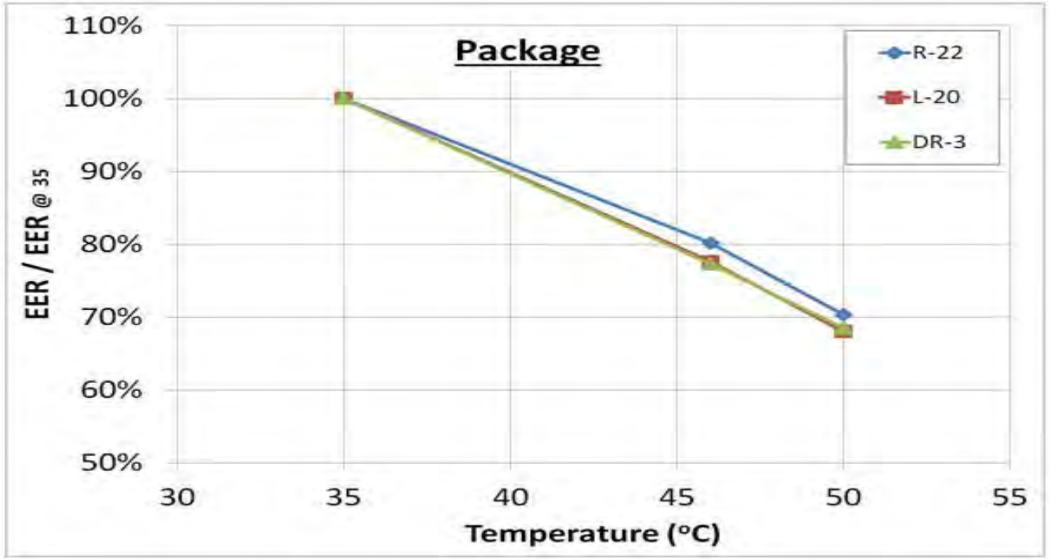
- 13 custom-built prototypes in four categories ranging from 5 to 27 kW, testing five different alternatives against the baseline refrigerants HCFC-22 and R-410A
- 23 units in total, including base units. Each prototype by a manufacturer was tested against a base unit by the same manufacturer;
- An independent International Technical Review Team to assist project team in reviewing the process, results, and final report.

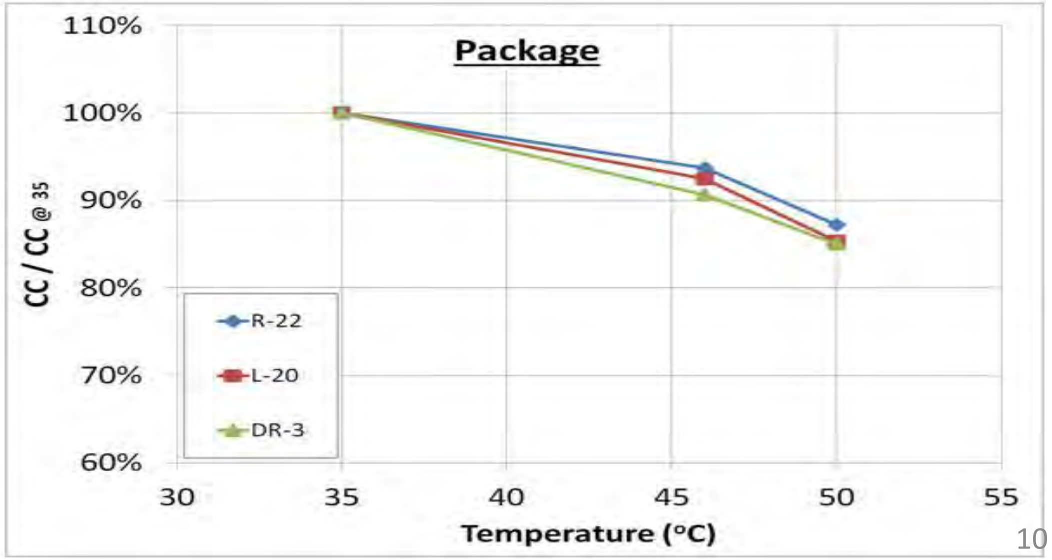
- Prototypes to have the same cooling capacity, fit in the same box dimensions as their respective base units, and meet the minimum energy efficiency, EER of 7 at 46 °C;
- Tests were performed at an independent reputable lab, Intertek;
- Test conditions at 35 °C, 46 °C, and 50 °C ambient;
- An endurance test at 52 ^{o}C: compressor will not trip when run continuously for two hours;
- Tests performed at maximum speed setting (full load);

Degradation vs. temperature

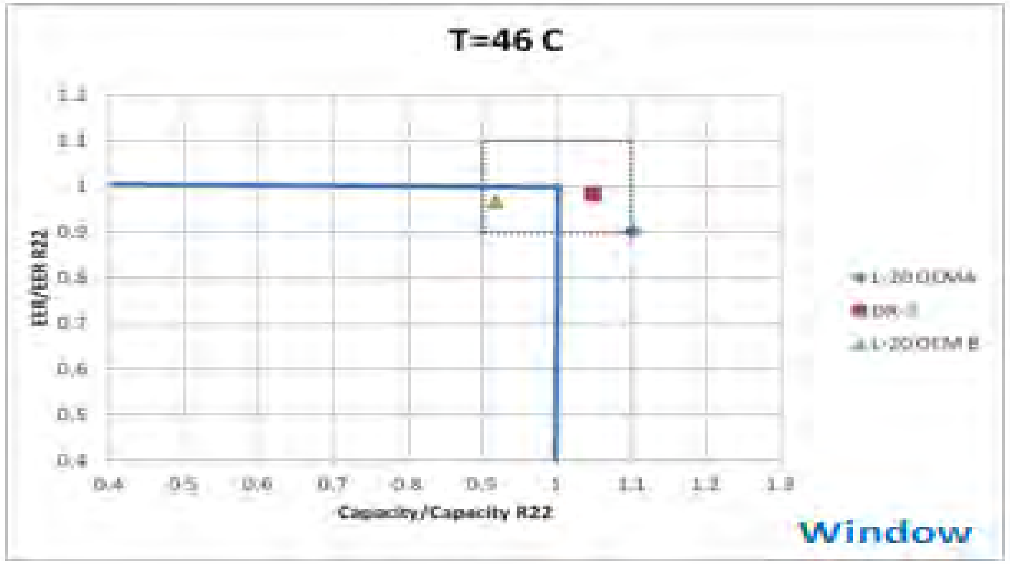


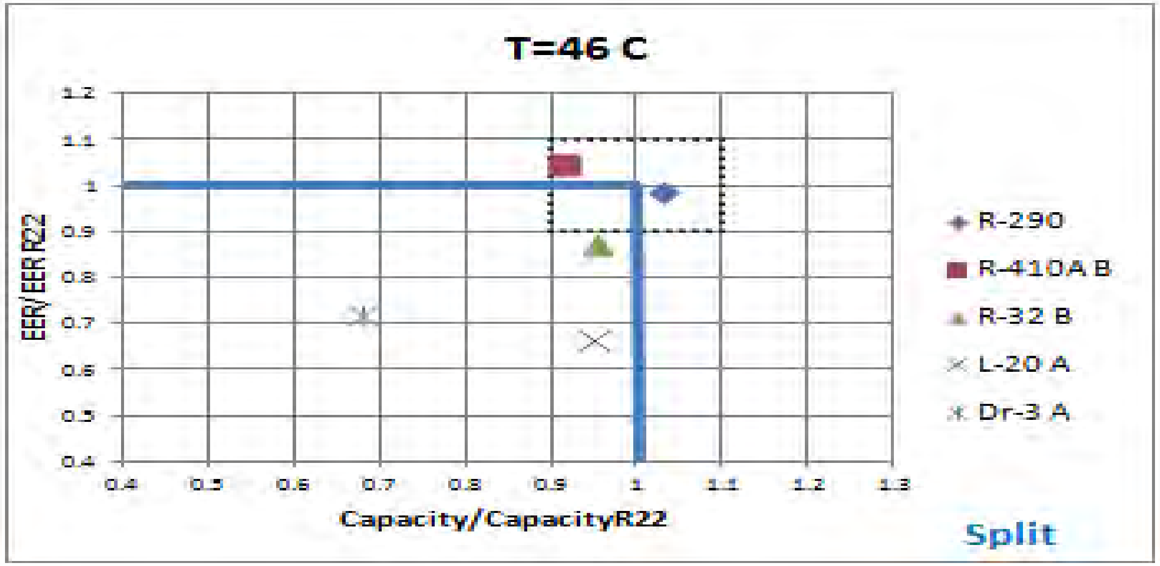


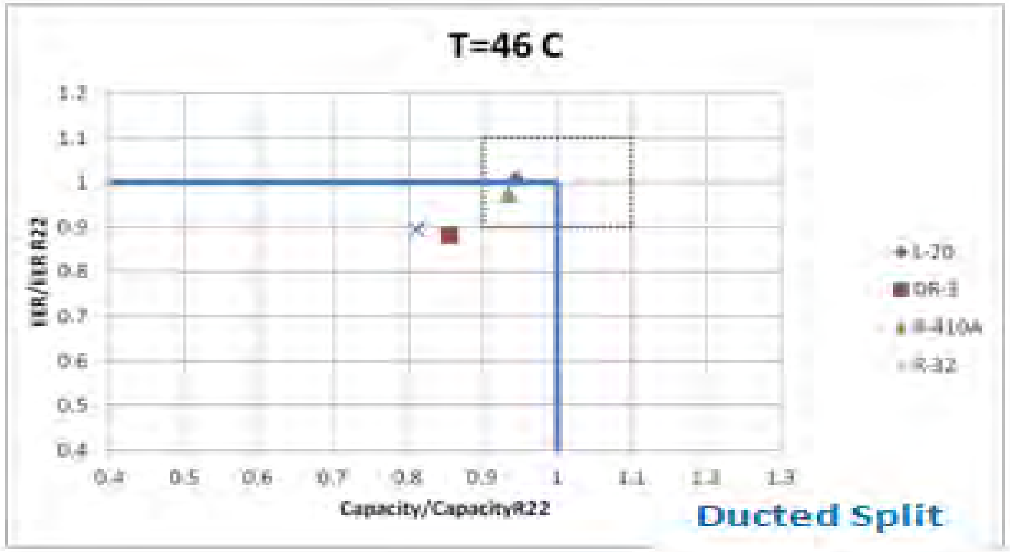


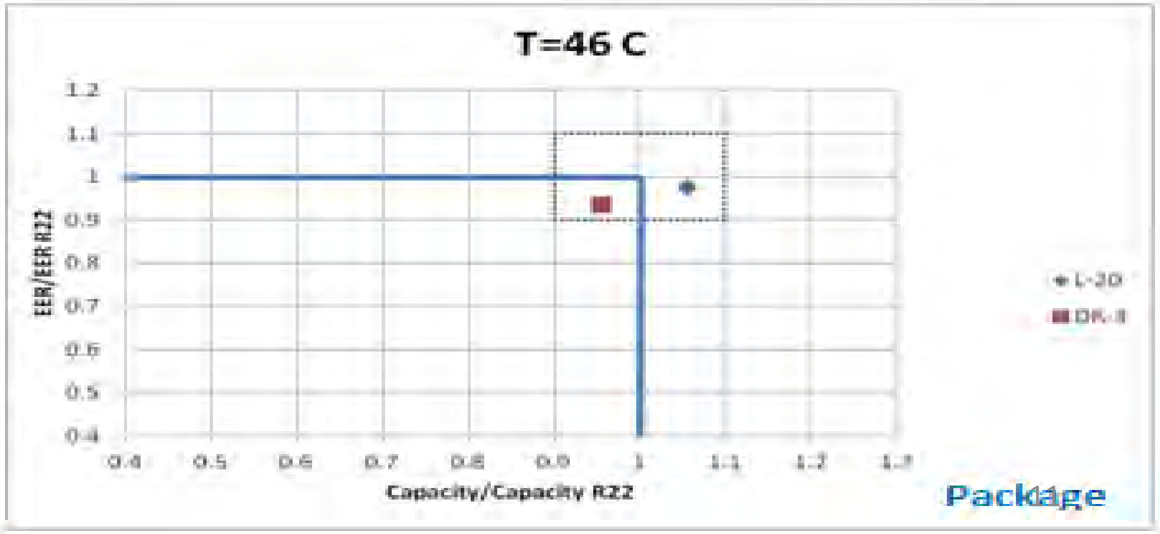


Results graphic summary





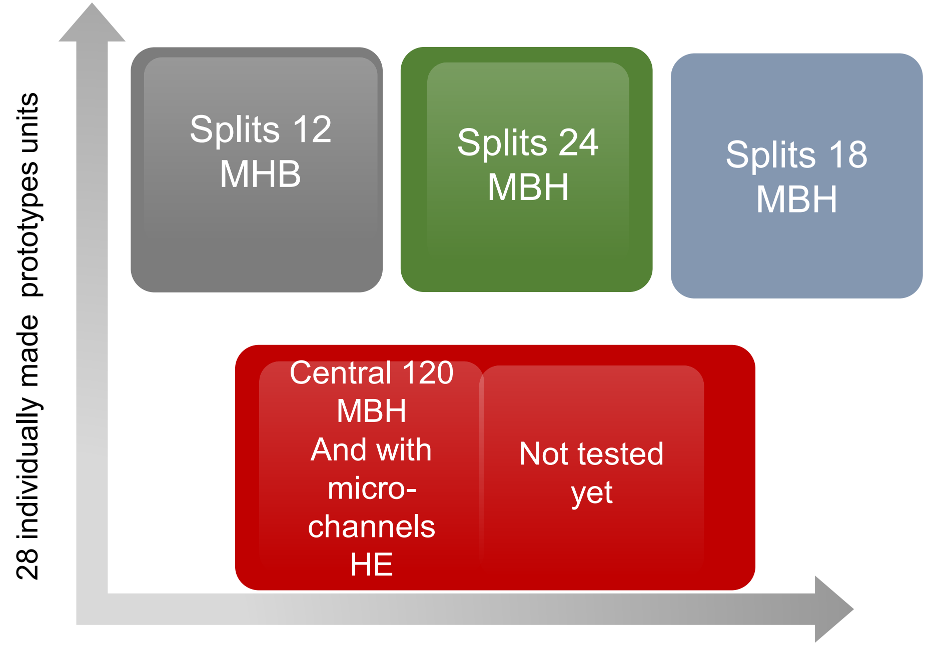




EGYPRA

Testing more refrigerants in more prototypes

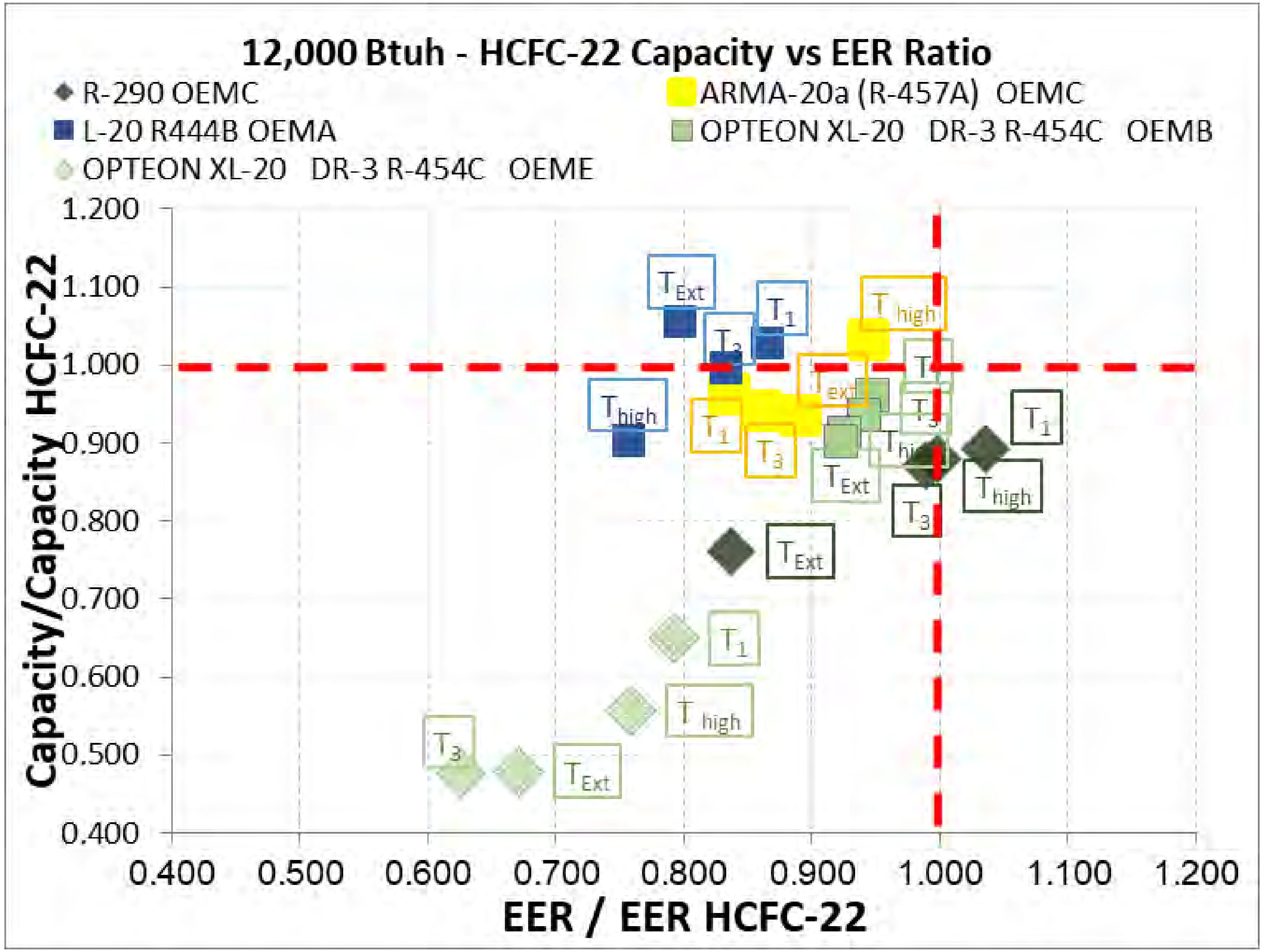
Prototype & Refrigerants



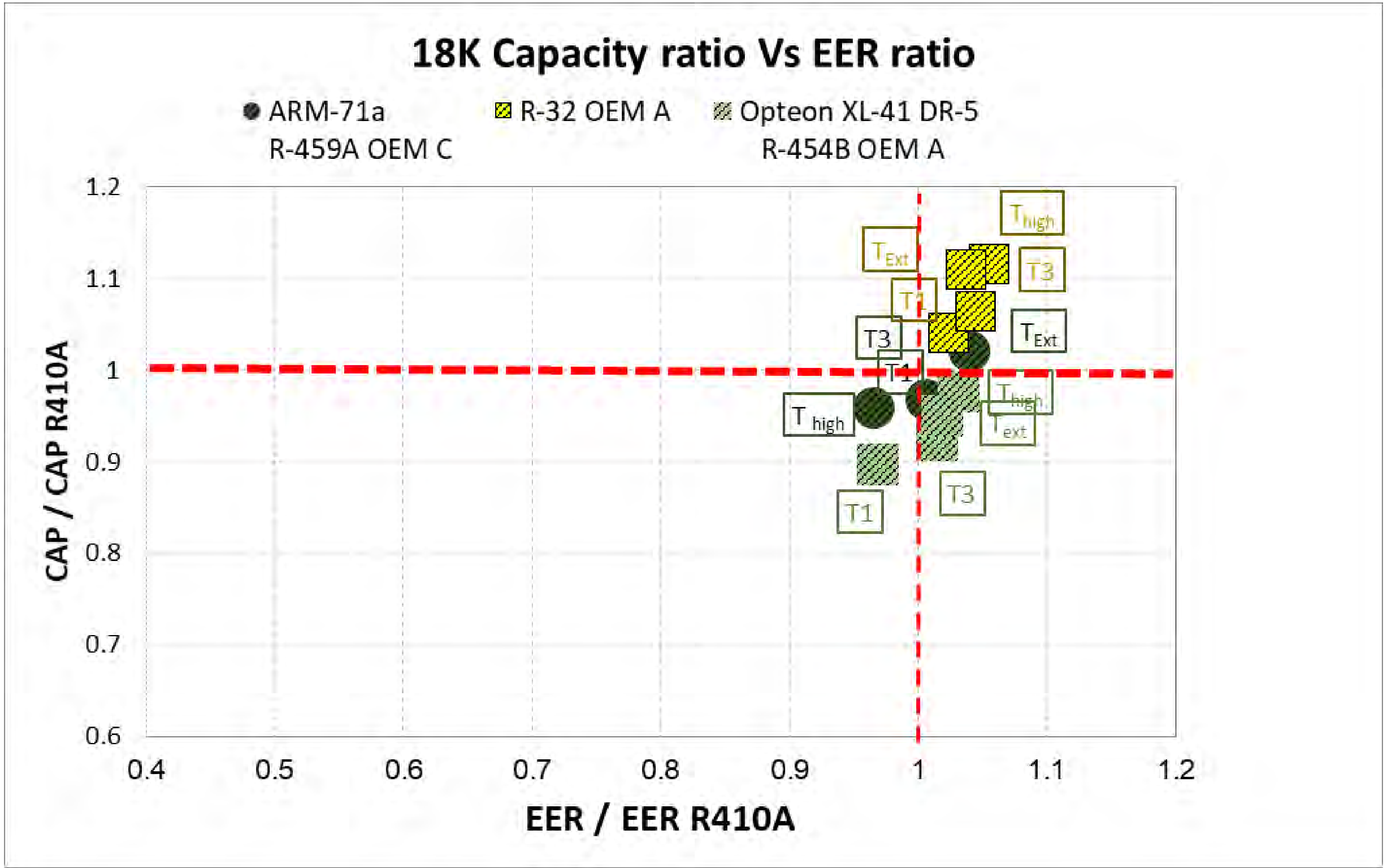
HCFC-22 Alternatives	Technology Provider	ASHRAE classification	GWP (100 years, RTOC)
R-290	-	A3	5
R-444 B (L-20 A)	Honeywell	A2L	310
R-454 C (DR-3) Opteon XL-20	Chemours (Du Pont)	A2L	295
R-457 A (ARM – 20d(a))	Arkema	A2L	251

R-410 A Alternatives	Technology Provider	ASHRAE classification	GWP (100 years, RTOC)
R-32	Daikin	A2L	704
R-447A (L-41-2)	Honeywell	A2L	600
R-454 B (DR-5) Opteon XL-41	Chemours (Du Pont)	A2L	510
R-459 A (ARM – 71a)	Arkema	A2L	466

Results – Alternatives to HCFC-22



Results – Alternatives to R-410A



Combined Findings

Of the four projects

Combined Findings

Category	PRAHA	AREP	ORNL	EGYPRA
Availability of Alternatives	There are potential alternatives that have comparable cooling capacity and energy efficiency performance to the baseline refrigerants	There are several alternative candidates with comparable performance to the baseline refrigerants they intend to replace	Losses in cooling capacity are typically easier to recover through engineering optimization than are losses in COP	Test results show that all refrigerants used in the project are viable alternatives from a thermodynamic point of view
Potential for Improvement	There is a significant need to improve the R&D capacity at the local air-conditioning industry	The test results should be carefully interpreted and additional study is required to evaluate the potential improvement through further “soft optimization”	The primary practical limit to improvements in capacity is the physical size of the unit; but not expected to be a significant concern	The potential for improvement for prototypes working with alternatives to R-410A is better is better than for those working with alternatives to HCFC-22
Energy Efficiency	The process of improving energy efficiency (EE) standards for air-conditioning application in HAT countries is progressing in much quicker pace compared to assessing alternative refrigerants	Full optimization of systems will likely improve the performance of these refrigerants	The COP losses and the increases in compressor discharge temperature will be the primary focus of future optimization efforts	when compared to MEPS) for Egypt, results show there are challenges for the industry to provide high efficiency AC units
Other	A comprehensive risk assessment tailored to HAT conditions is needed			

PRAHA-II

PRAHA-II Components

Component A

Capacity Building of local design capabilities

- 1) Knowledge sharing and developing a technical platform
- 2) Optimizing the design of local industry-built prototypes

Component B

3) Developing a comprehensive risk assessment model

Optimizing the design of local industry-built prototypes

Elements include:

1. Analyzing the design of PRAHA-I prototypes;
2. Design optimization of a selected number of PRAHA-I prototypes;
3. Building and testing prototypes to optimized design plus testing new refrigerants emerging since PRAHA-I;

Additional component:
Analyzing leak-recharge effect on performance for high glide alternatives

Matrix of Activities

		Activity 1	Activity 2	Activity 3	Activity 4	Additional
Unit	Type	Phase I data Analysis	Simulated Optimization	Optimizing PRAHA-I prototype	Testing Optimized Prototypes	Leak Analysis
1	Window	R444B (L-20)	R444B			
			R454C			
			R290			
			R457A			
6	Split	R32	R32	R32	R32	
			R454B	R454B	R454B	R454B
10	Ducted	R32	R447B	R447B	R447B	R447B
			R452B	R452B	R452B	R452B
4	Split	R290	R290			
2	Window	R444B				
3	Window	R454C (DR3)				
5	Split	R-32				
7	Split	R447A (L41)				
8	Split	R444B				
9	Split	R454C				
11	Ducted	R444B				
12	Ducted	R454C				

Analysis of PRAHA-I Prototypes

Physical inspection

Prior experimental results assessment

First order assessment of component and refrigerant performance

Development of a validated model

Detailed assessment of why the performance is "good, i.e. as designed" or "bad, why it did not perform as designed"

Evaluation of Optimized Prototypes

Optimized prototypes tested in a multi-zone environmental chamber to evaluate their performance according to ASHRAE Standard 37 at relevant indoor and outdoor conditions (AHRI 210/240 “A” condition, ISO 5151 “T3” condition, hot and extreme conditions)

Leak Charge Analysis

Analyzing leak-recharge effect on performance for high glide alternatives

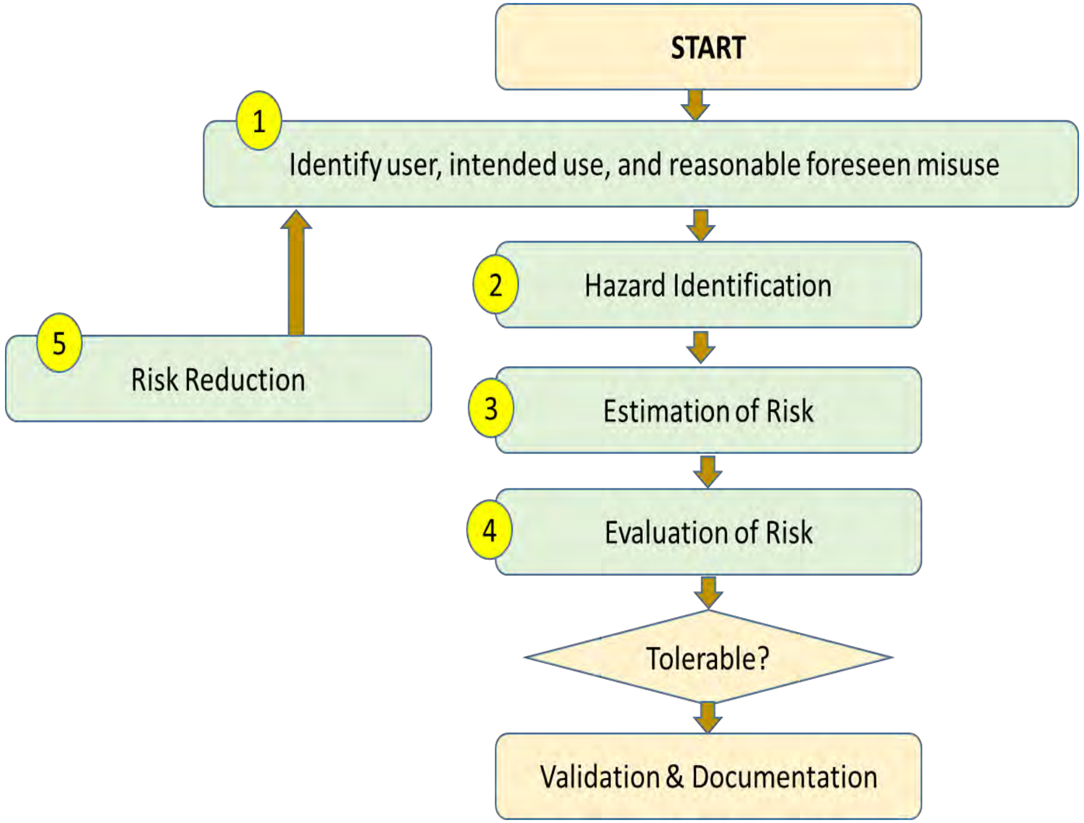
Procedure

1. Run unit until steady-state is achieved (repeat 46°C performance test), monitoring capacity and sub-cooling;
2. Gradually remove refrigerant from vapor line until capacity is reduced to approximately 50%, if possible;
3. Store and weigh removed refrigerant;
4. Re-charge with new refrigerant until same sub-cooling is achieved;
5. Compare cooling capacities; if more than 5% deviation is observed, repeat steps 1-4, however in step 2, reduce capacity to 25% only;
6. Repeat steps 1-5 for the liquid line.

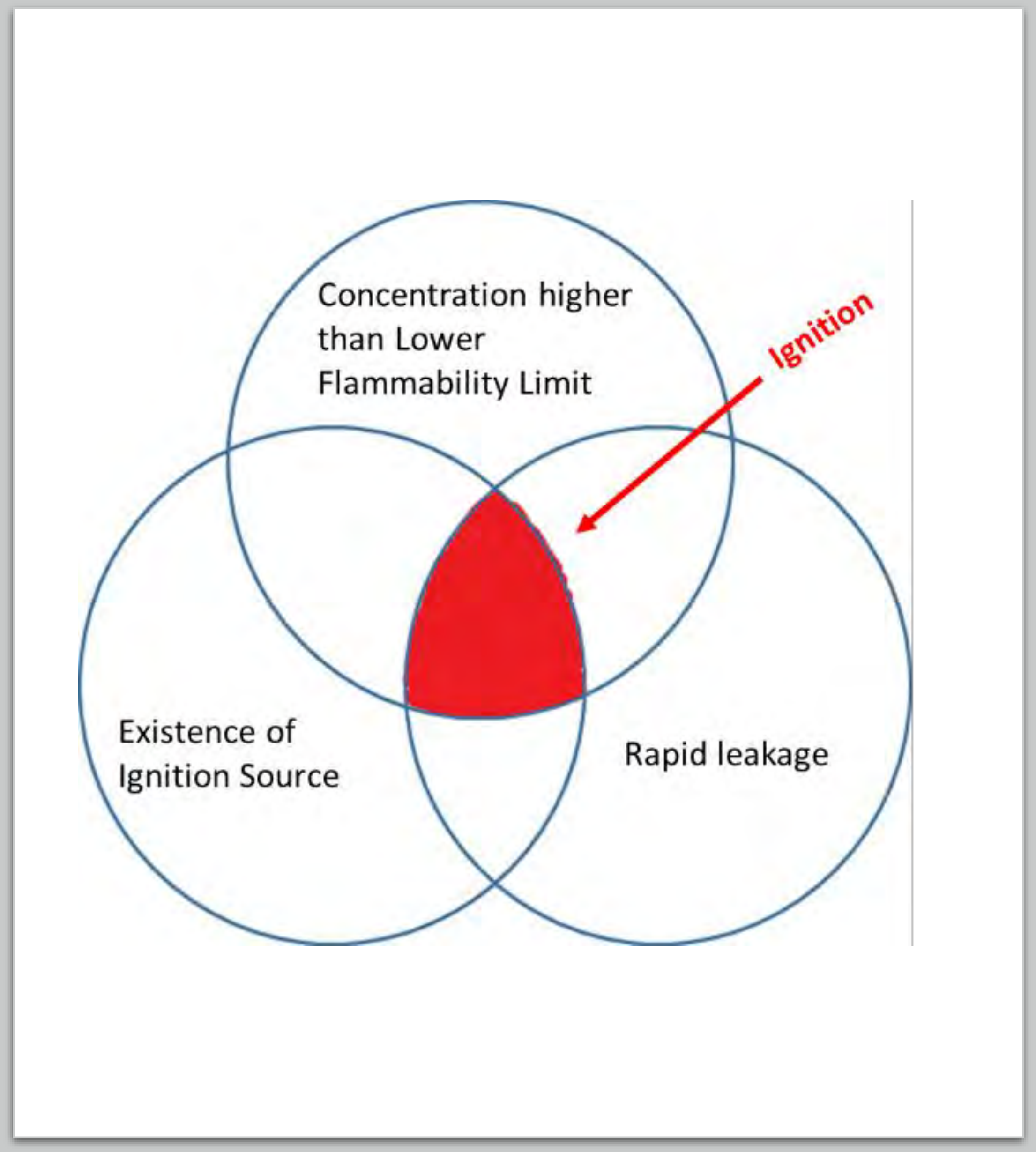
Risk Assessment Study

Flammability

For a fire to happen there needs to be three elements: a rapid leak of the flammable gas, a concentration higher than the lower flammability level, and a source of ignition.



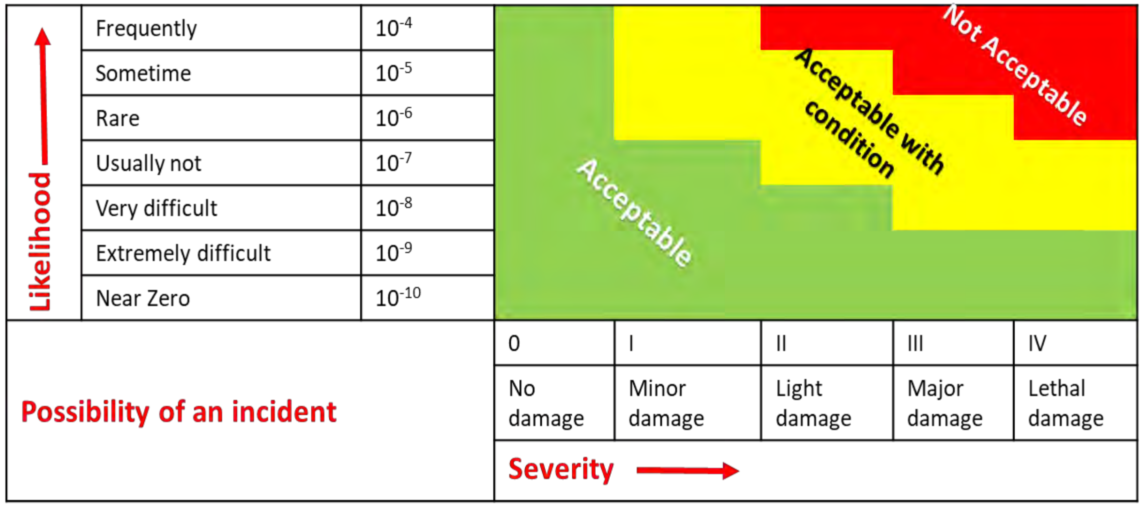
Procedure of Risk Evaluation according to ISO/IEC 51

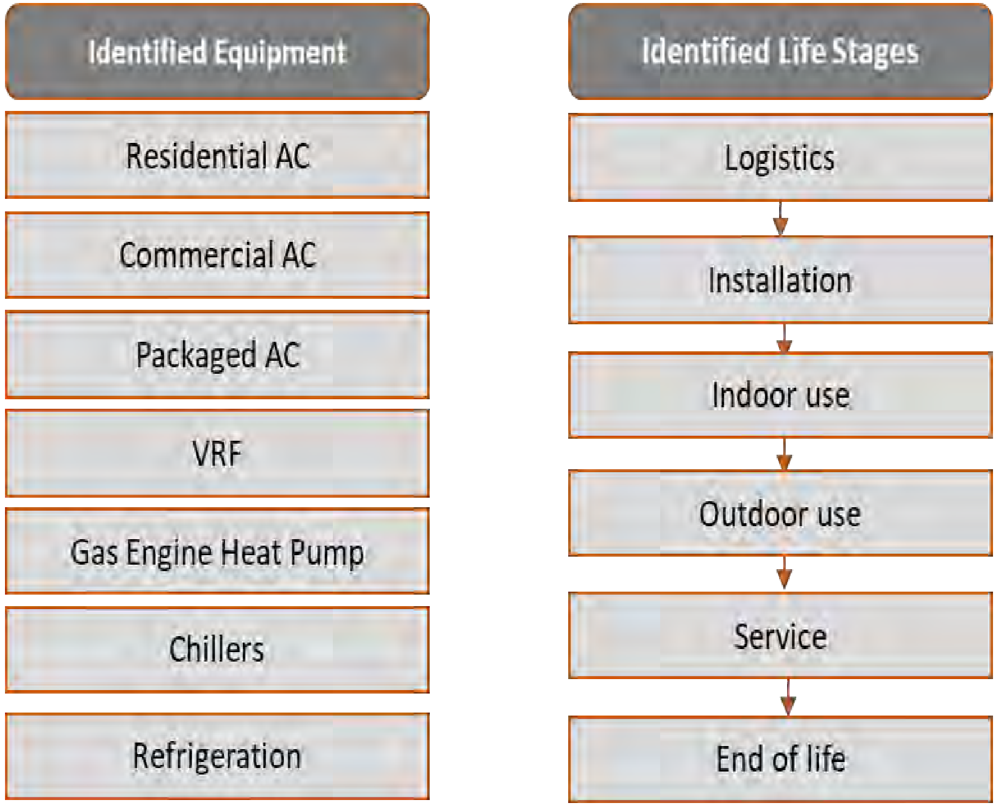


Process of a Risk Assessment Model

I. Selection of equipment type and application
II. Identify Acceptable and tolerable risk
III. Analyze Product Cycle
IV. Risk Scenarios & Risk Analysis Sources
V. Data Collection
VI. Fault Tree Analysis (FTA)
VII. Suggest Measure to Mitigate Intolerable Risk

Product/System	Unit Population	Tolerable risk Usage stage	Tolerable risk Service stage
Residential AC	1×10^{8}	1×10^{-10}	1×10^{-9}
Commercial AC	7.8×10^{6}	1.3×10^{-9}	1.3×10^{-8}
VRF	1×10^{7}	1×10^{-9}	1×10^{-8}
Chillers	1.34×10^{5}	7.5×10^{-7}	7.5×10^{-7}
Condensing units	1.46×10^{5}	6.9×10^{-8}	6.9×10^{-7}





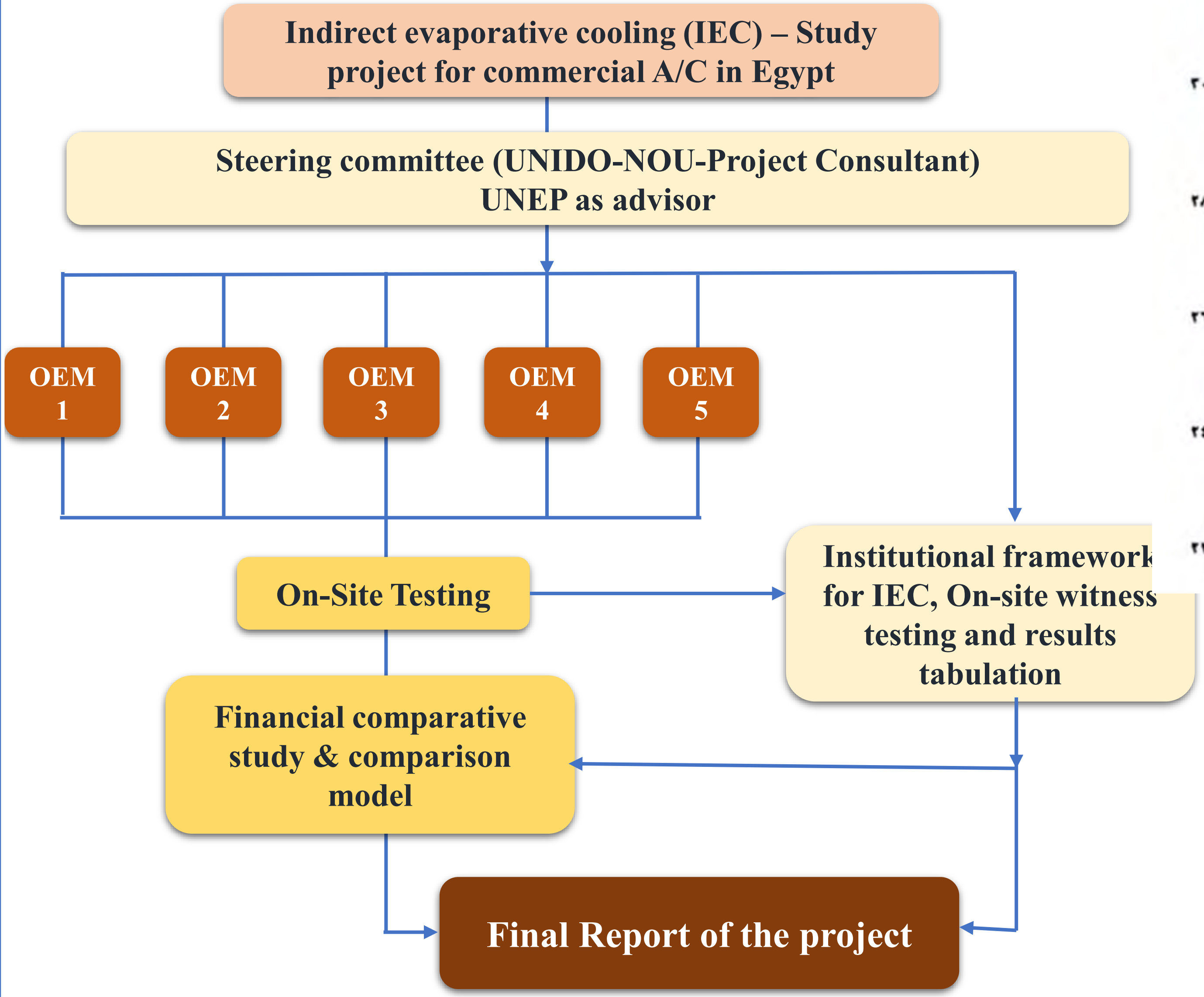
Conclusions

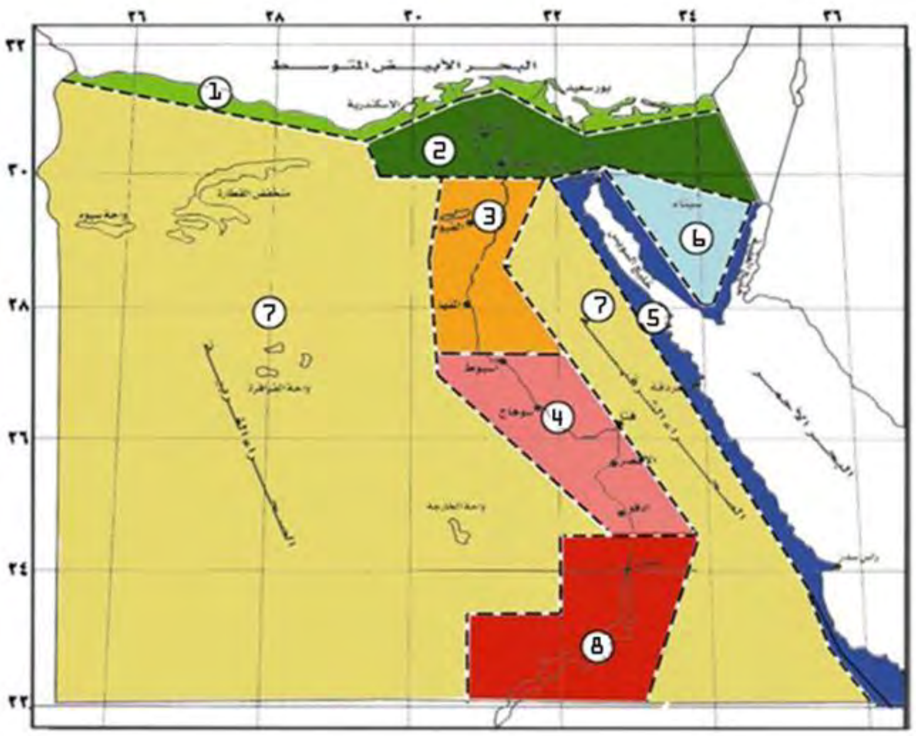
- Building a risk assessment model for the HAT countries that suits the climate and the service practices of the local technicians helps the HAT countries,
  - Also sets the stage for all A5 countries, in understanding the risk associated with flammable refrigerants;
- The model helps in adopting the needed regulations and training programs
  - especially in relation to the logistics of lower-GWP based technologies i.e. installation, transportation, storage, servicing and decommissioning;
- The concept of risk assessment is quite similar worldwide,
  - including methodologies in calculating and analyzing severity and frequency of risks.
  - However, criteria for acceptable tolerance levels may differ depending on local considerations;
- Measures to mitigate risks would depend on type of existing/operational standards and/or codes in each country;
- Learning from the pioneers in risk assessment models through partnership and cooperation will leapfrog the technical difficulties and provide a quick access to building the model.

Indirect Evaporative Cooling Project for Egypt.(IEC)

Project Outline

EUROVENT - Testing Technical Advisor





#	Zone
1	North Coast Region
2	Delta and Cairo region
3	North Upper Egypt Region
4	Southern Upper Egypt Region
5	Eastern Coast Region
6	High Heights Region
7	Desert Region
8	South of Egypt Region

Thank you

Ayman Eltalouny
Coordinator International Partnerships
OzonAction, Law Division
UN Environment Programme (UNEP)
Email: ayman.eltalouny@un.org
https://www.unenvironment.org/ozonaction/

UN environment programme