In cooperation with

International Webinar

Alternative Refrigerants for High Ambient Temperature (HAT) Countries

10th June 2020

@ 2 pm (CET, Paris Time)

James S. Curlin
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Chief of Montreal Protocol Division
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Session 1

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In cooperation with

HAT definition and Relevant TEAP Assessment and MOP Decisions

Ayman Eltalouny, Int. Partnerships Coordinator– OzonAction, UNEP

10th June 2020

@ 2 pm (CET, Paris Time)

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

Appendix III (Kigali Amendment)

High-ambient temperature exemption

1. That the Implementation Committee and Meeting of the Parties should, for 2025 and 2026, defer the consideration of the HCFC compliance status of any party operating under a high ambient temperature exemption in cases where it has exceeded its allowable consumption or production levels due to its HCFC-22 consumption or production for the sub-sectors listed in Annex [X], on the condition that the Parties concerned follow the phase-out schedule for consumption and production of HCFCs for other sectors, and the Party has formally requested a deferral through the Secretariat.

2. Amounts of Annex F substances that are subject to the HAT exemption are not eligible for funding under the Multilateral Fund while they are exempted for that Party.

3. The Parties shall review, no later than the year following receipt of the TEAP report on suitability of alternatives, the need for an extension of this exemption for specific sub-sectors for a further period(s) of up to 4 years, and periodically thereafter. The Parties shall develop an expedited process to ensure the renewal of the exemption in a timely manner where there are no feasible alternatives, taking into account the recommendation of the TEAP and its subsidiary body.

4. The assessment shall take place periodically starting 4 years from the date of the commencement of any HFC freeze or other initial control obligation and every 4 years thereafter.

Continue…

Appendix III (Kigali Amendment)

High-ambient temperature exemption

5. The Technology and Economic Assessment Panel (TEAP) and a TEAP subsidiary body that includes outside expertise on high ambient temperatures shall assess the suitability of HFC alternatives for use where suitable alternatives do not exist based on criteria agreed by the Parties and can recommend to add or remove sub-sectors to Annex [X], that shall include, but not be limited to, the criteria listed in paragraph 1(a) of Decision XXVI/9,[2] and report this information to the Meeting of the Parties.

6. The exemption shall be distinguished and separate from the essential use and the critical use exemptions under the Montreal Protocol.

7. A new exemption as described shall be available to Parties with high ambient temperature conditions where suitable alternatives do not exist for the specific sub-sector of use.

8. The exemption shall take effect and be available at the commencement of the HFC freeze or other initial control obligation and shall have an initial duration of 4 years.

Continue…

Appendix III (Kigali Amendment)

High-ambient temperature exemption

9. The exemption applies for sub-sectors contained in Annex [X] in Parties: (1) with an average of at least two months per year over 10 consecutive years with a peak monthly average temperature above 35 degrees Celsius[1]; and (2) that have formally notified use of this exemption by notifying the Secretariat no later than one year before the HFC freeze or other initial control obligation, and every 4 years thereafter should it wish to extend the exemption.

10. Any party operating under the high ambient temperature exemption shall report separately production and consumption data for the sub-sectors to which a high ambient temperature exemption applies.

11. Any transfer of production and consumption allowances for the high ambient temperature exemption shall be reported to the Secretariat under Article 7.

12. Parties should consider no later than 2026 whether to extend the compliance deferral in paragraph XI for an additional period of two years, and may consider further deferrals thereafter, if appropriate, for countries operating under the high ambient temperature exemption.

Annex [X]

List of Exempted Equipment for High Ambient Temperatures

1. Multi-split air conditioners for commercial and residential
2. Split ducted air conditioners (residential and commercial)
3. Ducted commercial packaged (self-contained) air conditioners

Appendix III

Reporting on consumption and production under the exemption for high-ambient-temperature parties

If your country formally notified the Secretariat, as specified under paragraph 29 of decision XXVIII/2, of its intention to use the exemption for high-ambient-temperature parties and is listed in appendix II of decision XXVIII/2, please use data form 7 to report quantities of new HFCs imported for use in approved subsectors as listed in appendix I to the decision.

Those imports must be for use within your country and not for export. In case other subsectors are approved after the assessments under paragraphs 32 and 33 of decision XXVIII/2, please use the additional columns in the data form to specify the approved subsectors and the amounts imported for use in those subsectors. Only bulk gases for servicing of equipment in the exempted subsectors should be reported here, not gases imported inside pre-charged equipment.

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Alternative Refrigerants for High Ambient Temperature (HAT) Countries

Research at HAT

Bassam Elassaad, Consultant and RTOC member

10th June 2020

@ 2 pm (CET, Paris Time)

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.

Recent Research Efforts

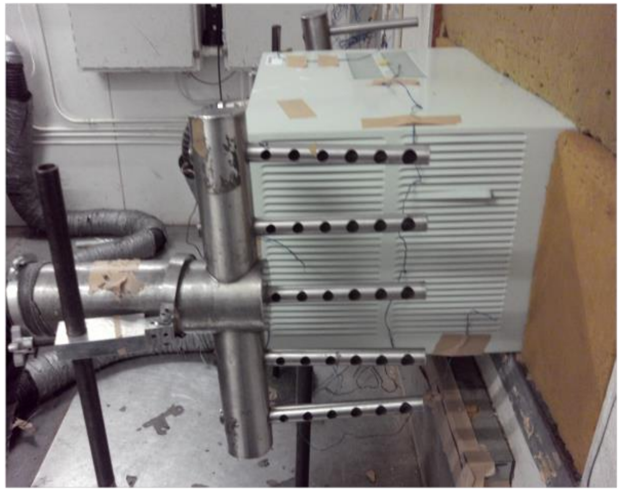
- "Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries" (**PRAHA**)
    - PRAHA-I report published in 2016
    - PRAHA-II report published in 2019
- "Promotion of Low-GWP Refrigerants for the Air Conditioning Industry in Egypt" **(EGYPRA)**
    - Report published 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

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

PRAHA-I

Testing Customs Built Prototypes at HAT Conditions

PRAHA Project

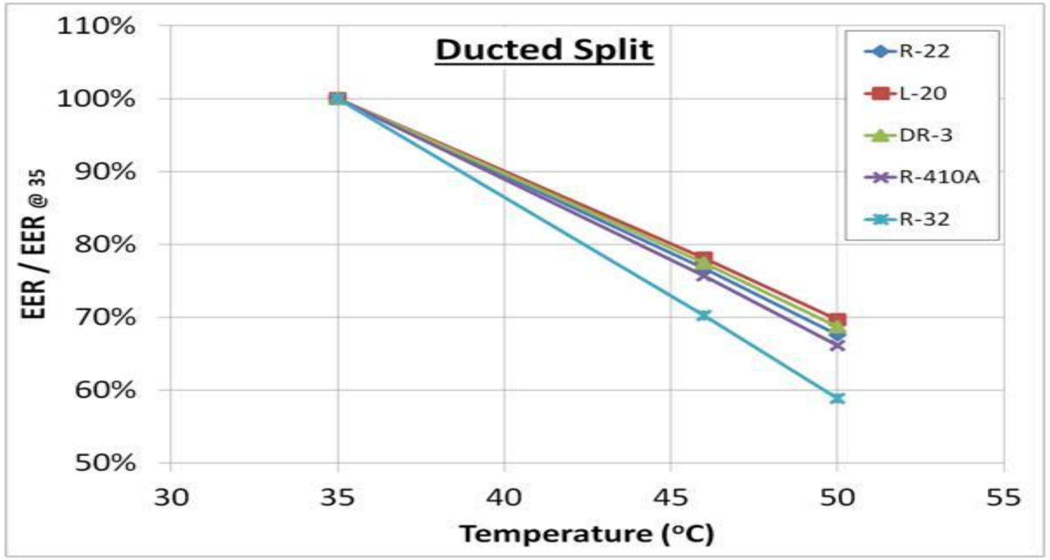


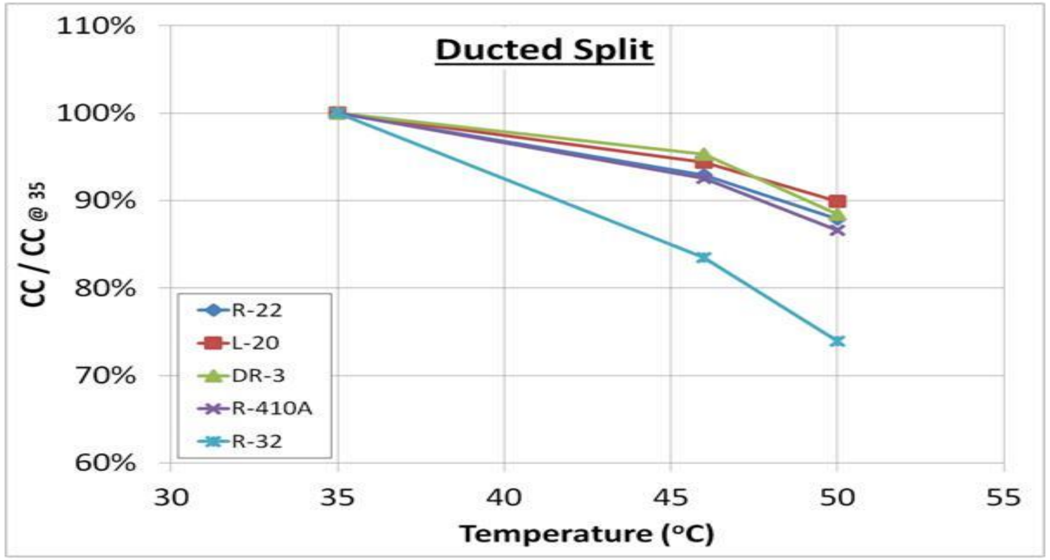
Comparable to HCFC-22	Comparable to R-410A
HC-290	HFC-32
R-444B (L-20)	R-447A (L-41-1)
R-454C (DR-3)	

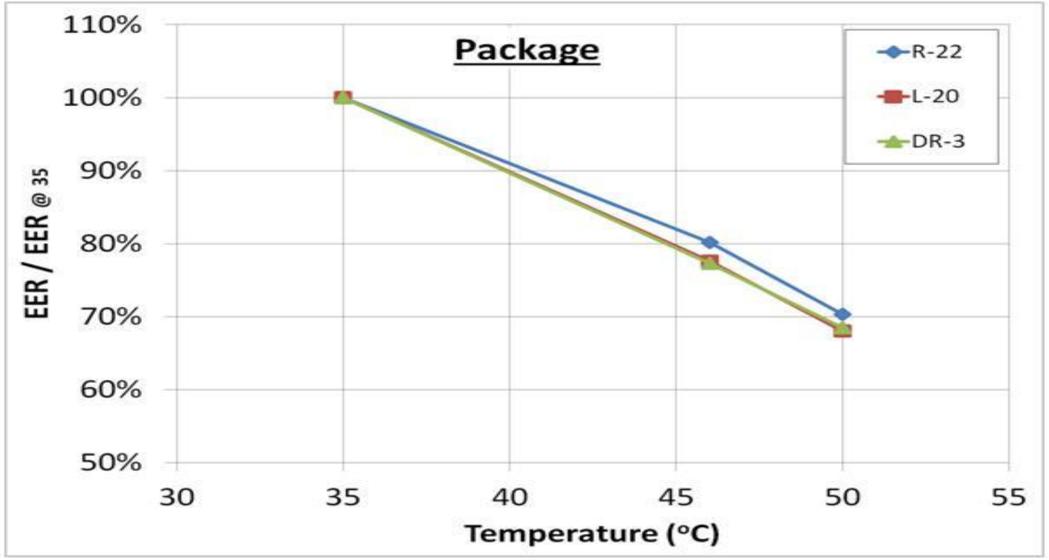
- 13 custom-built prototypes in four categories ranging from 5 to 27 kW, testing five different alternatives against the baseline refrigerants HCFC-22 and R-410A
- 23 units in total, including base units. Each prototype by a manufacturer was tested against a base unit by the same manufacturer;
- An independent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

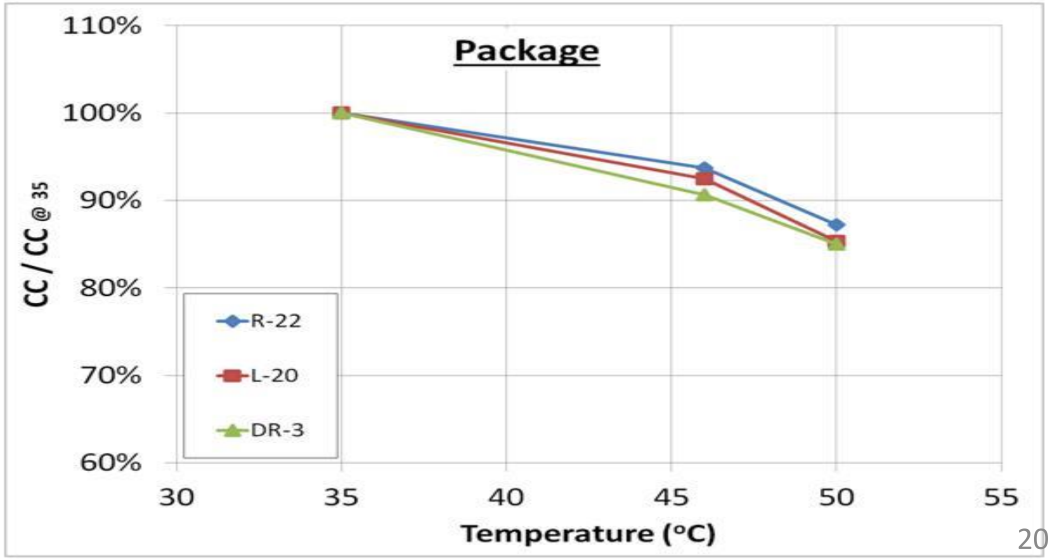
- Prototypes to have the same cooling capacity, fit in the same box dimensions as their respective base units, and meet the minimum energy efficiency, EER of 7 at 46 °C;
- Tests were performed at an independent reputable lab, Intertek;
- Test conditions at 35 °C, 46 °C, and 50 °C ambient;
- An endurance 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

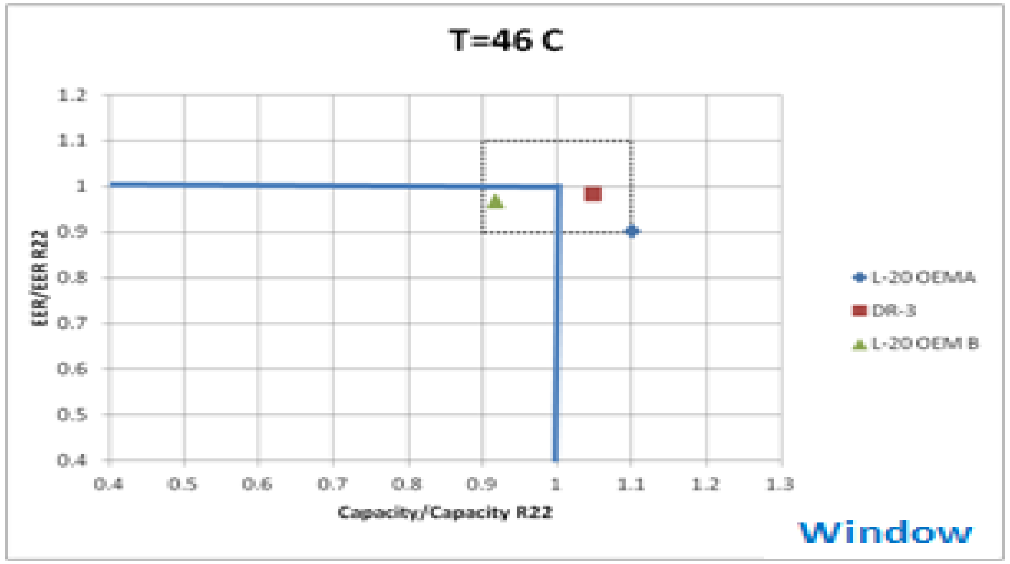


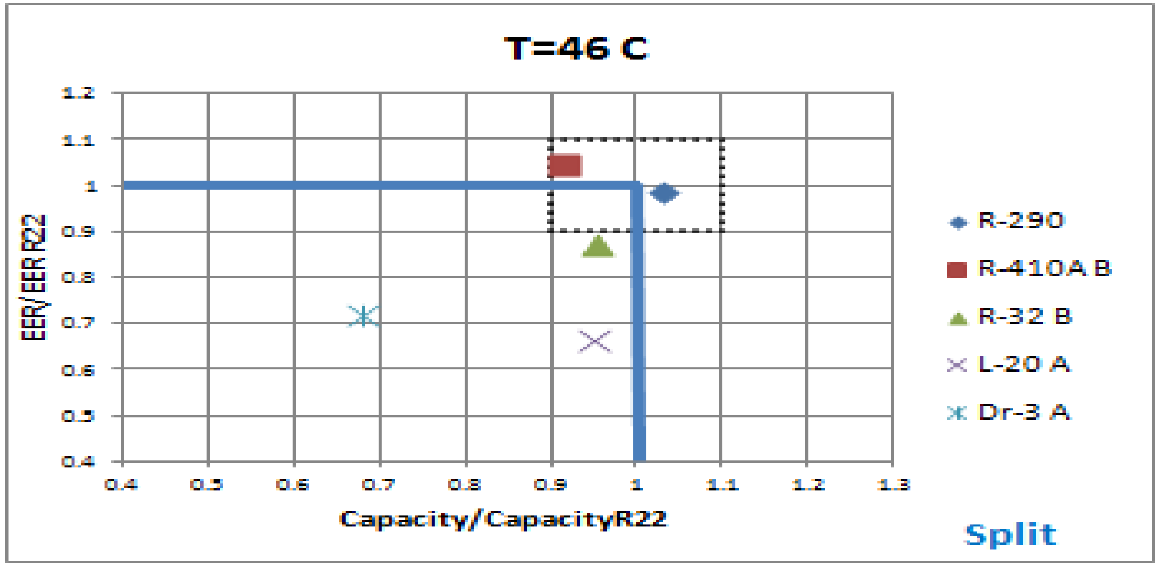


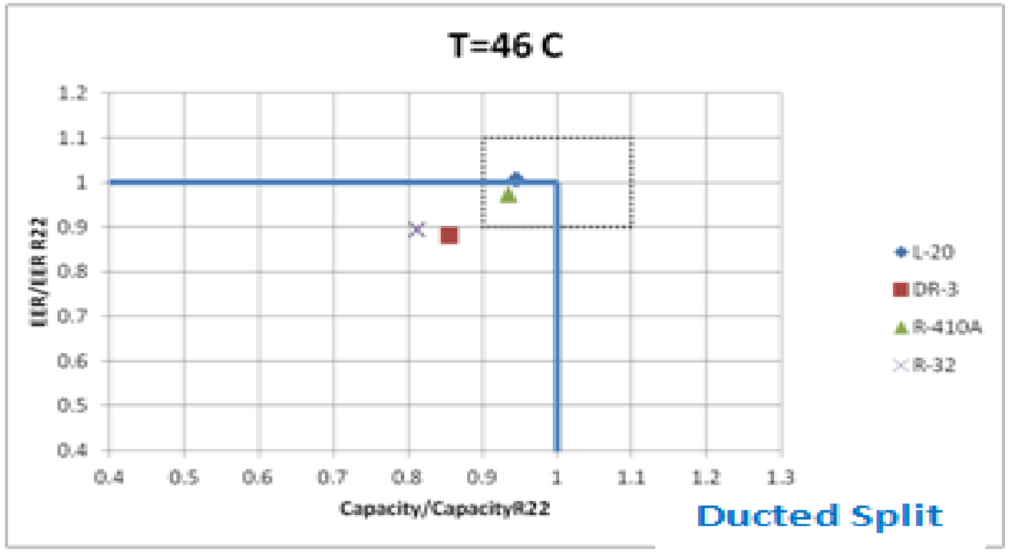


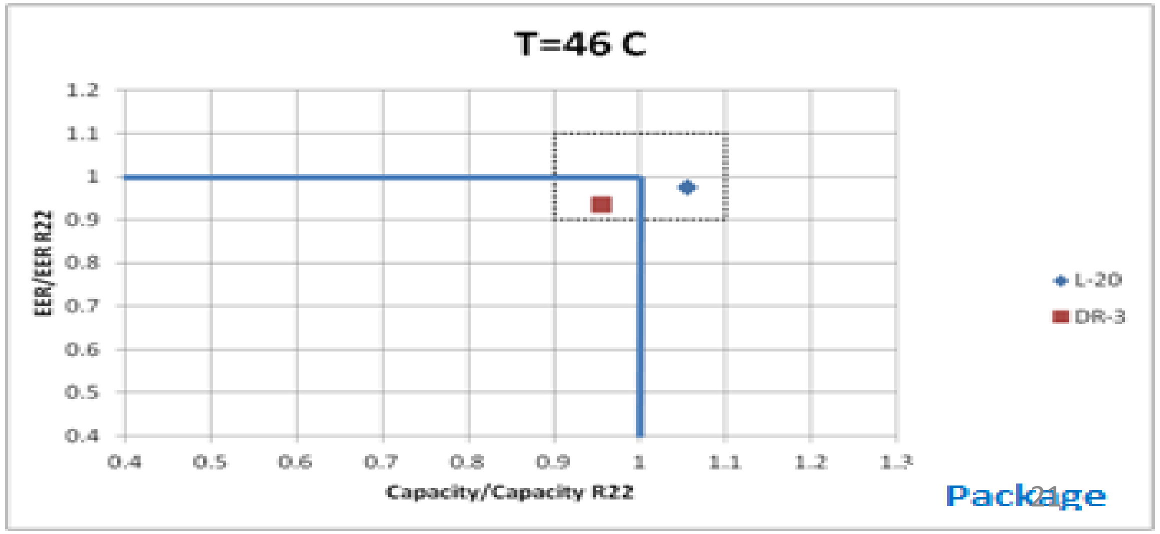


Results graphic summary





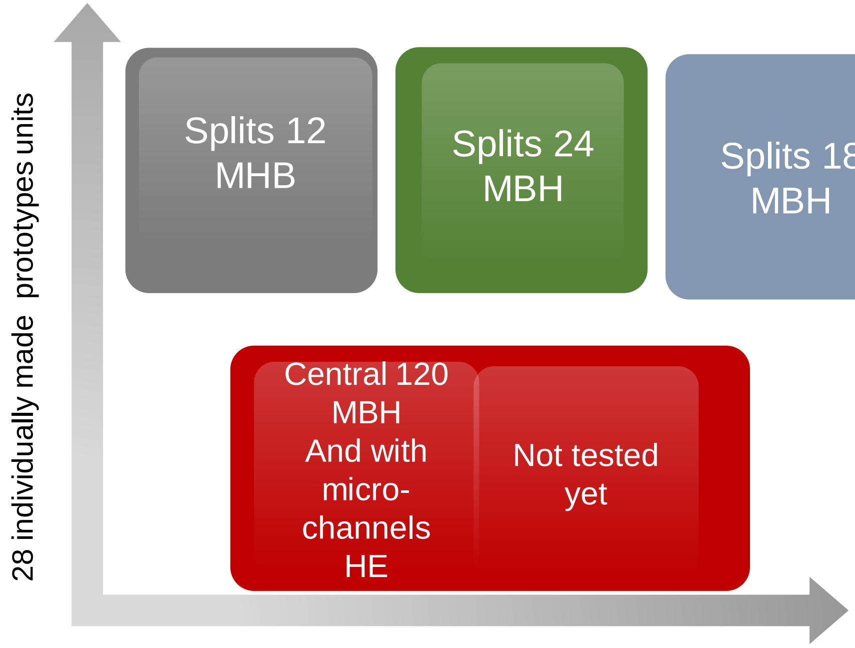




EGYPRA

Testing more refrigerants in more prototypes

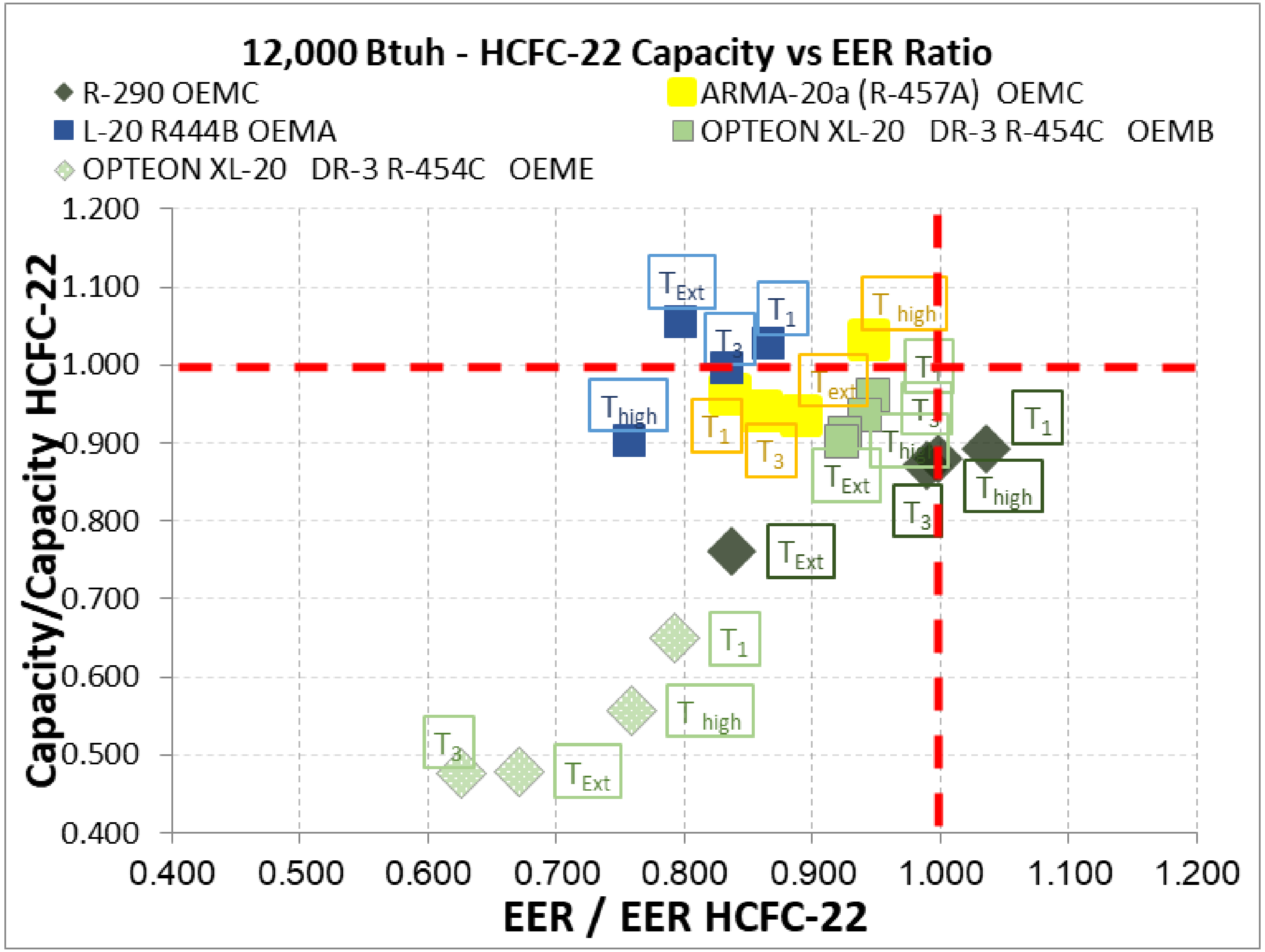
Prototype & Refrigerants



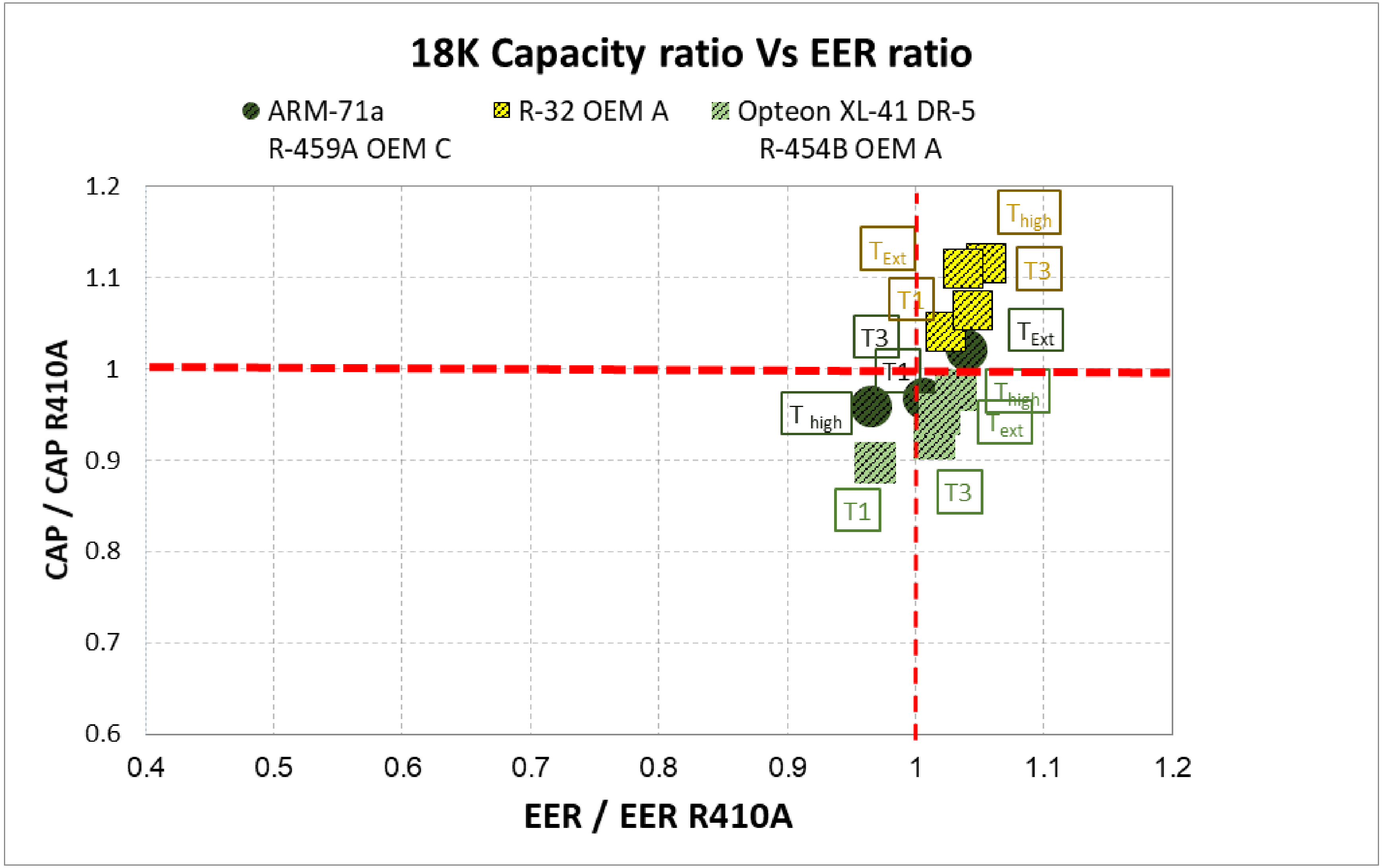
HCFC-22 Alternatives	Technology Provider	ASHRAE classification	GWP (100 years, RTOC)
R-290	-	A3	5
R-444 B (L-20 A)	Honeywell	A2L	310
R-454 C (DR-3) Opteon XL-20	Chemours (Du Pont)	A2L	295
R-457 A (ARM – 20d(a))	Arkema	A2L	251

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



AREP-II

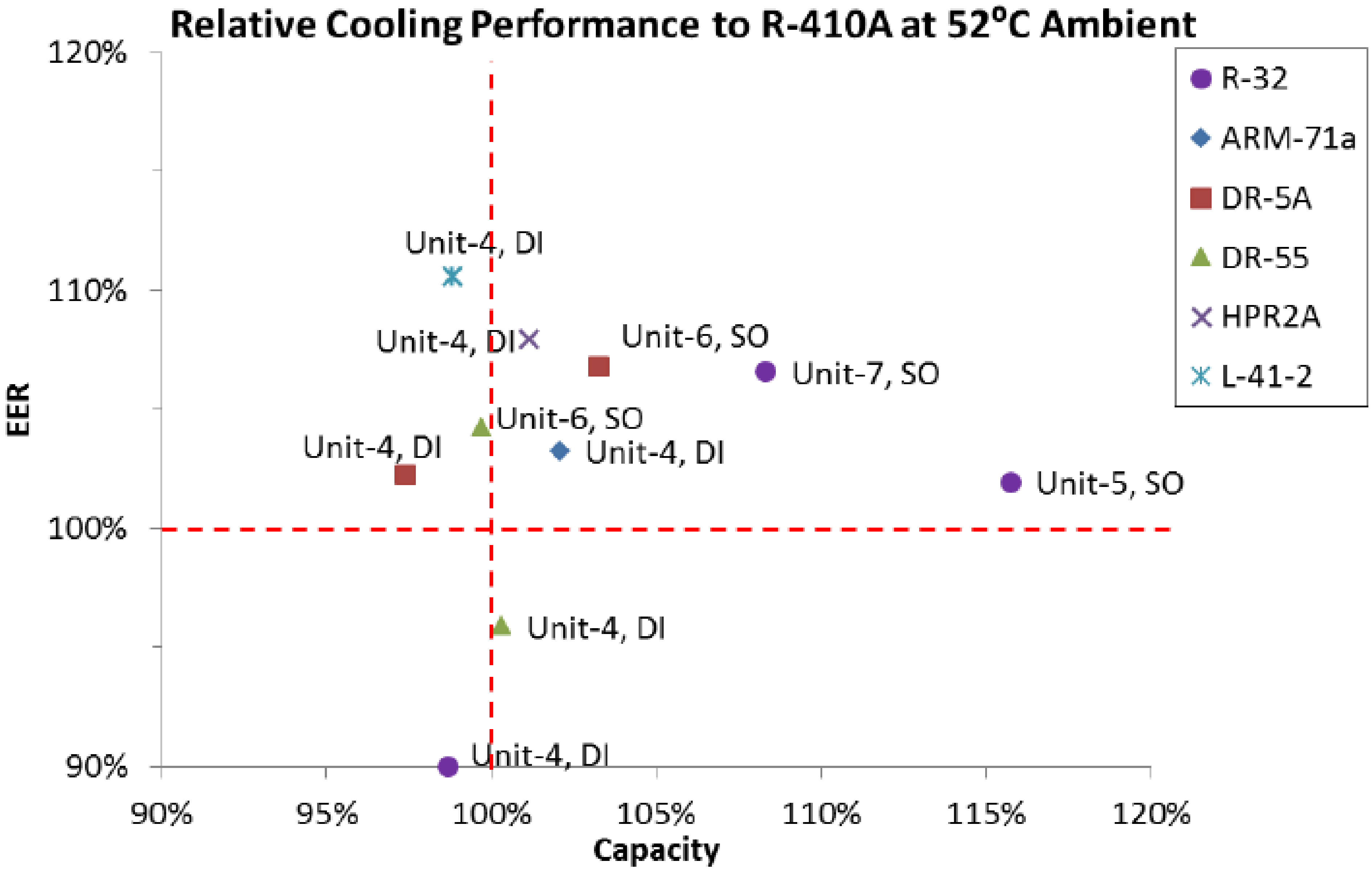
Phase II at HAT

AREP-II testing

- AREP-II testing was conducted by several entities with different test protocols, which led to considerable differences in the results.
- Many refrigerants, 17 total (HFC-32, DR-5A, DR-55, L-20, L-41, N-20, ARM-20, ARM-71A, HPR2A etc.) were tested on a large variety of baseline systems originally charged with HCFC-22, R-404A, R-407C or R-410A either as drop-in or with soft optimization. It also included calorimeter testing and comparisons.
- In total, 33 test reports were published.
- Preliminary observation: "General trends in "HAT performance" are similar for all alternative refrigerants".
- The table in the next slide shows relative results for the baseline R-410A.

Source: AREP-II rreport

AREP-II

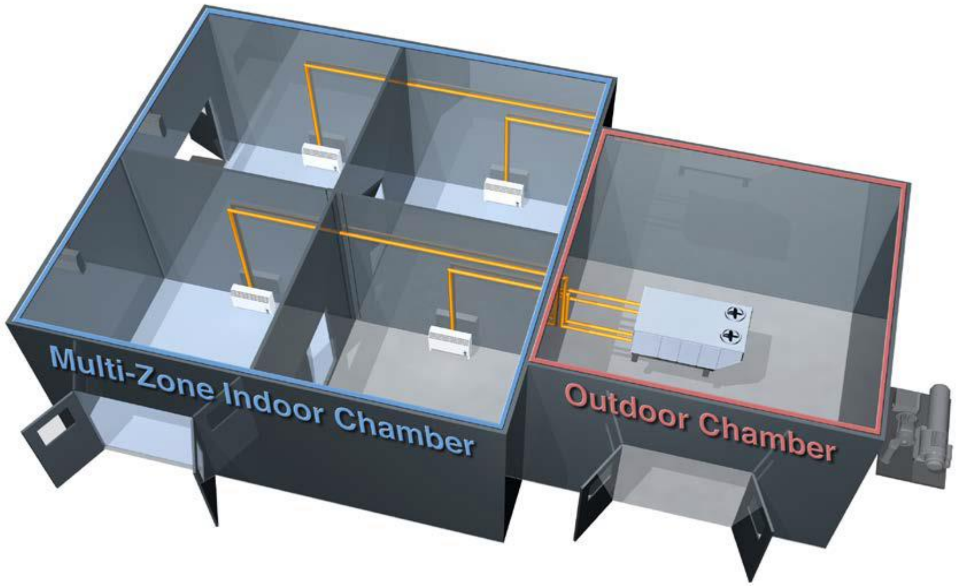


Source: AREP-II Perdue paper 2016

ORNL

Phases I & II

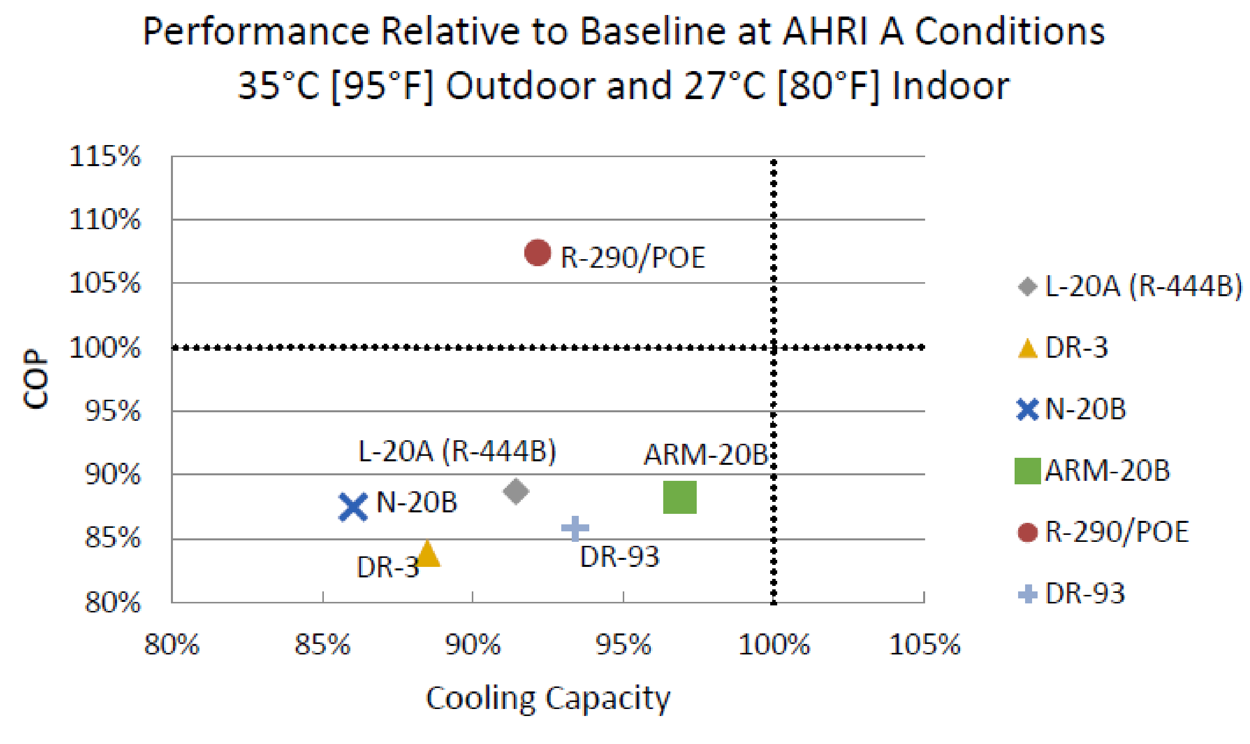
ORNL project testing 2 mini-split systems

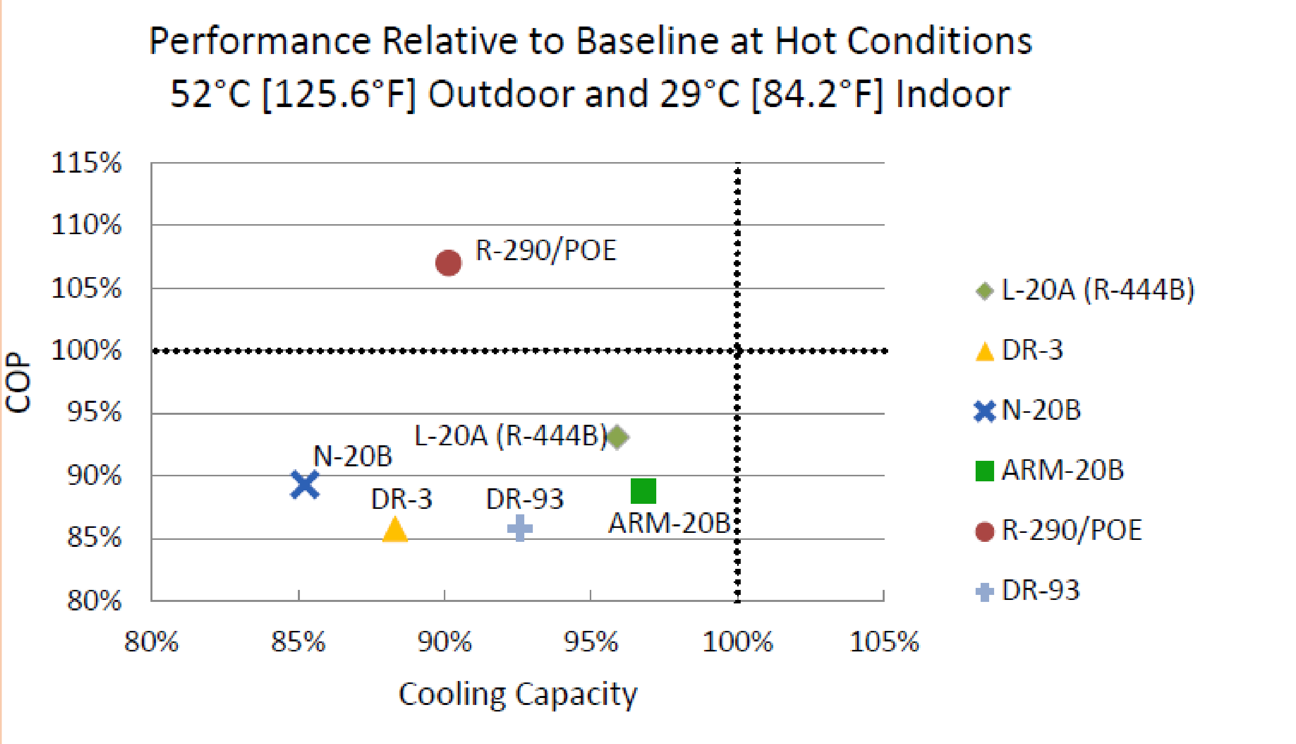


Comparable to HCFC-22	Comparable to R-410A
N-20B	HFC-32
DR-3	R-447A (L-41-1)
ARM-20B	DR-55
R-444B (L-20A)	ARM-71a
HC-290	HPR-2A

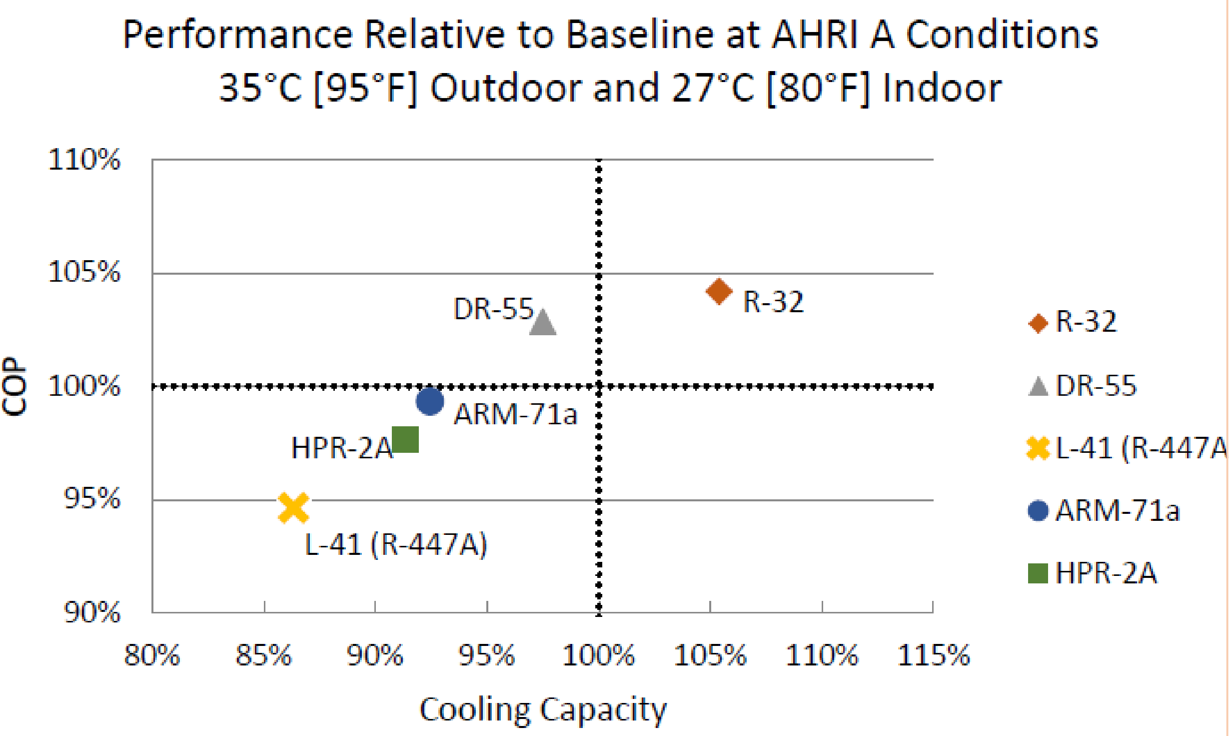
- Testing 10 alternatives in two units of 5 kW cooling capacity against HCFC-22 and R-410A, changing the amount of refrigerant charge and expansion device (soft optimization)
- 84 tests were conducted in total for a total of 10 alternative refrigerants at ambient temperatures varying from 27 to 55 °C. ORNL did measurements at 27.8, 35, 52 and 55°C ambient temperatures;
- Test conditions: For 35°C ambient, indoor 26.7/19.4°C (AHRI-A). For 52°C ambient, indoor = 29/19°C.

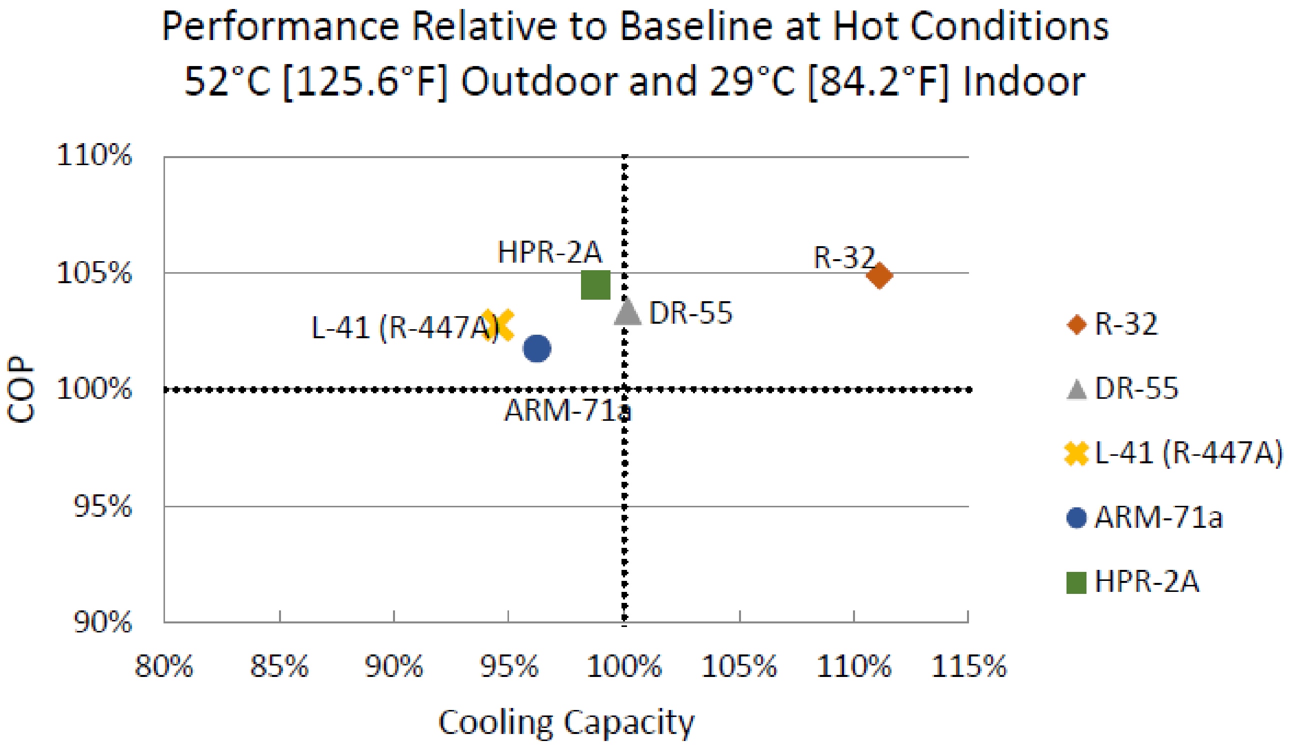
Performance Relative to HCFC-22





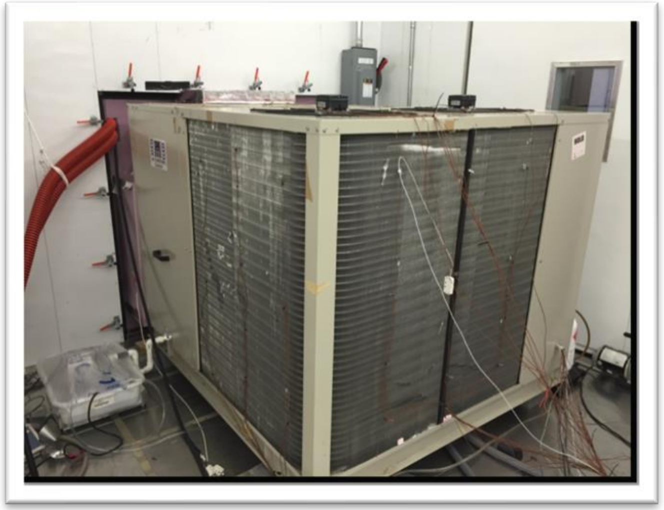
Performance Relative to R-410A



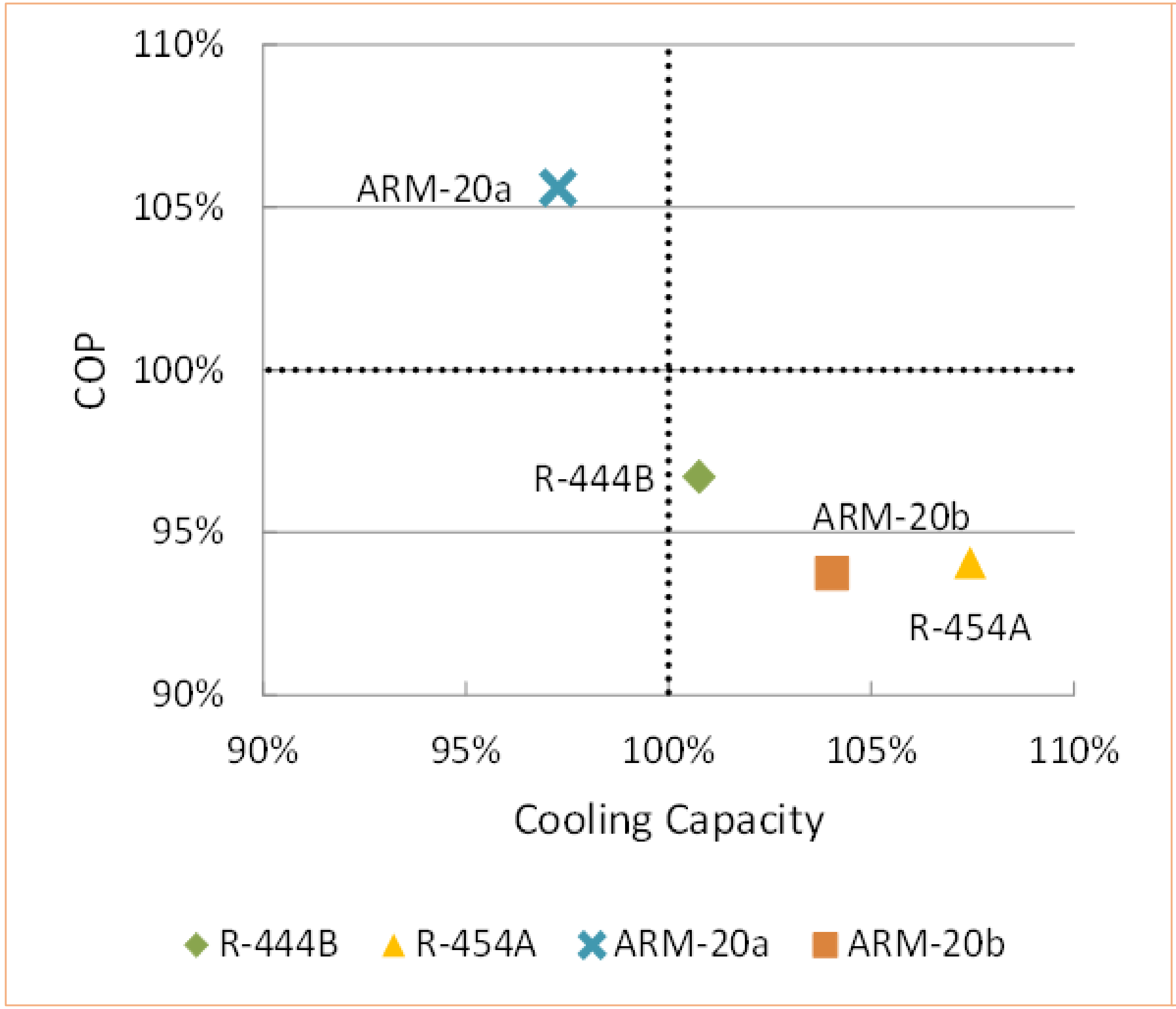


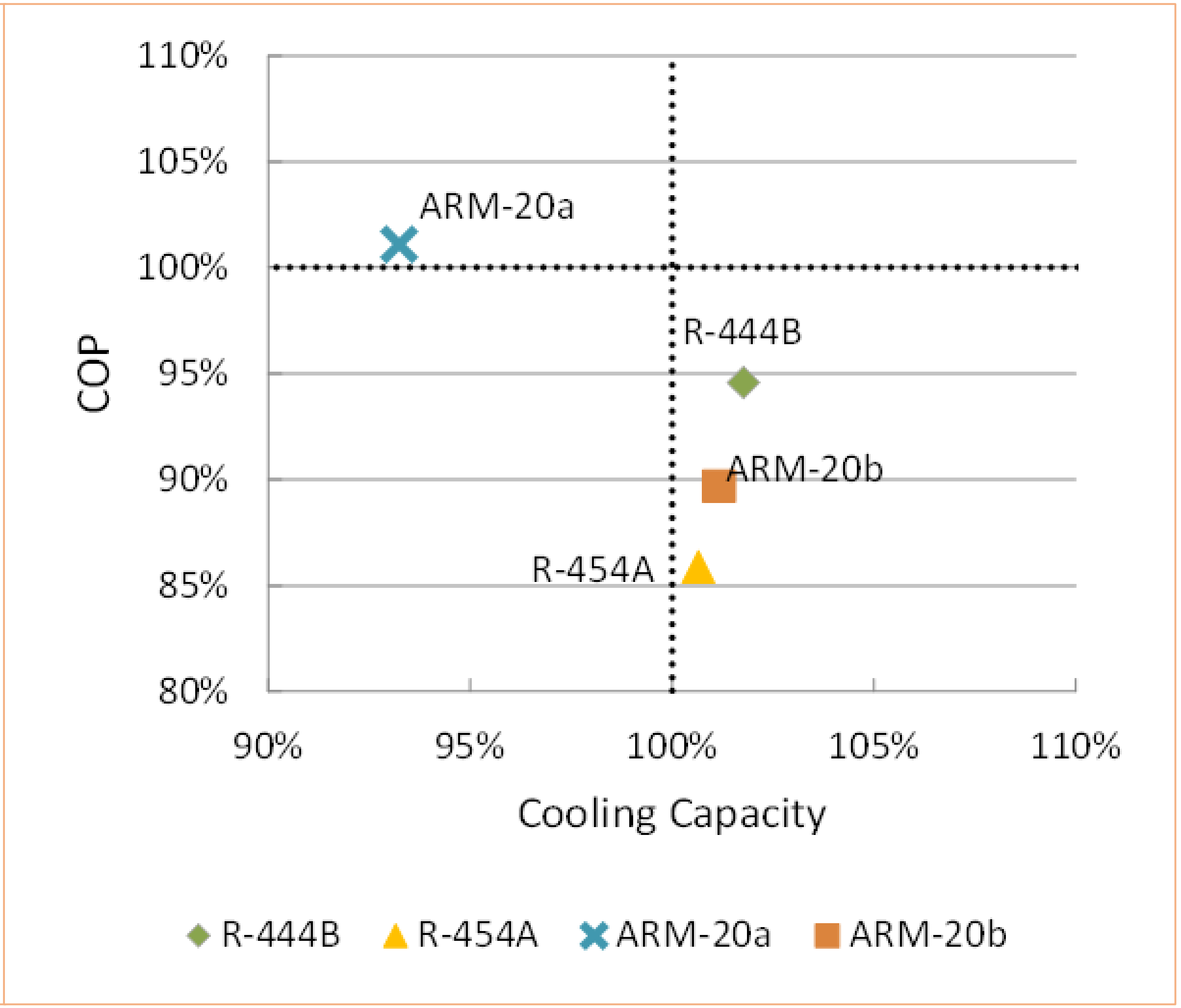
US DOE – II (ORNL): Packaged AC Units

- R-22 Unit (SKM PACL-51095Y)
  - 380/415V, 3 Ph, 50 Hz
  - Capacity*(T1) = 92.8 kBtu/h (27.2 kW)
  - EER = N/A
  - Tested alternative refrigerants: ARM-20a (R-457A), ARM-20b, L-20a (R-444B), DR-7(R-454A)
- R-410A Unit (Petra PPH4 115)
  - 460V, 3 Ph, 60 Hz
  - Capacity*(T1) = 132 kBtu/h (~ 38.68 kW)
  - EER* = 10.66 (COP ~ 3.12)
  - Tested alternative refrigerants: R-32, L41-Z (R-447B), DR-55 (R-452B), ARM-71a

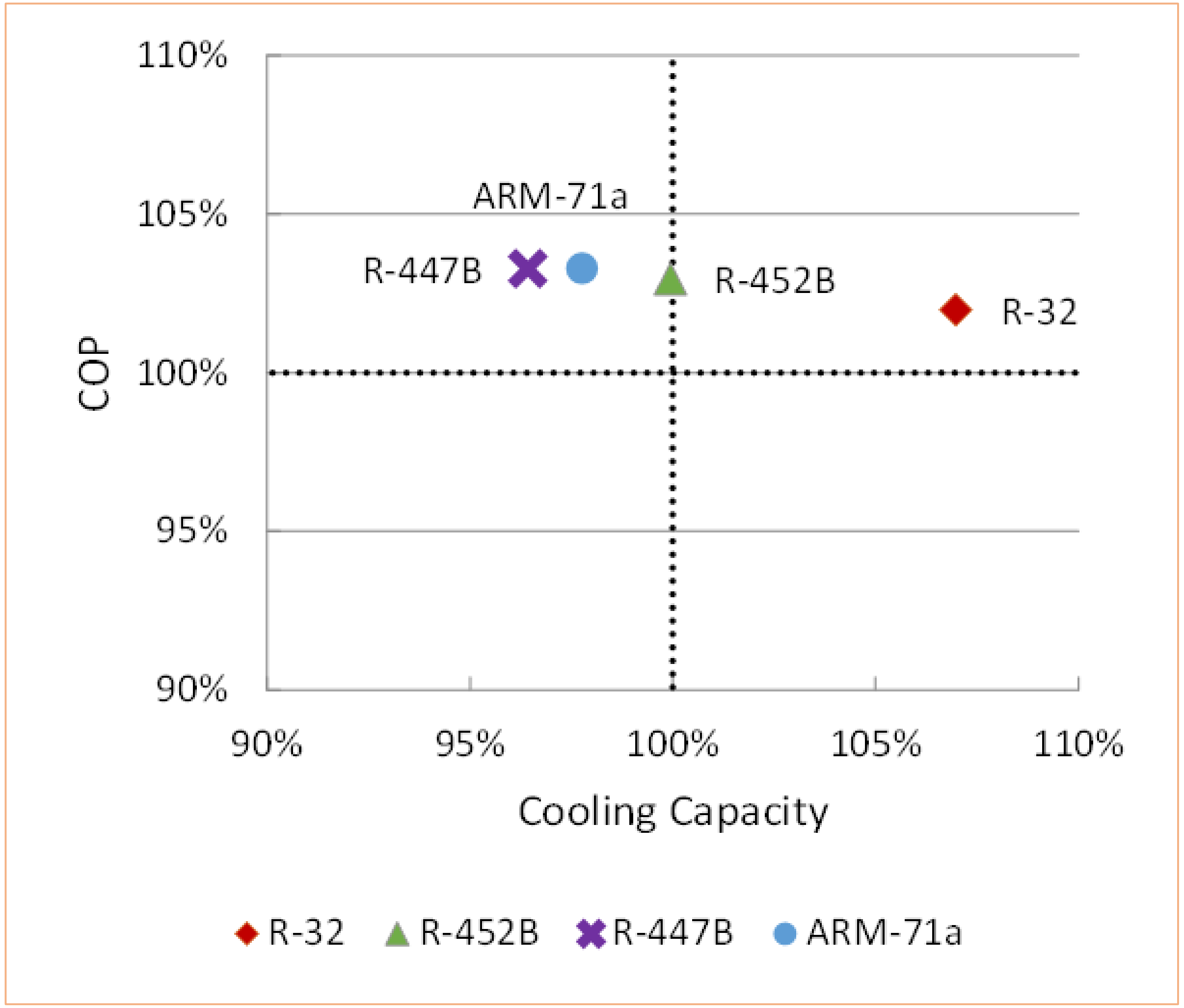


Performance Relative to HCFC-22
at 35°C Ambient 52°C Ambient

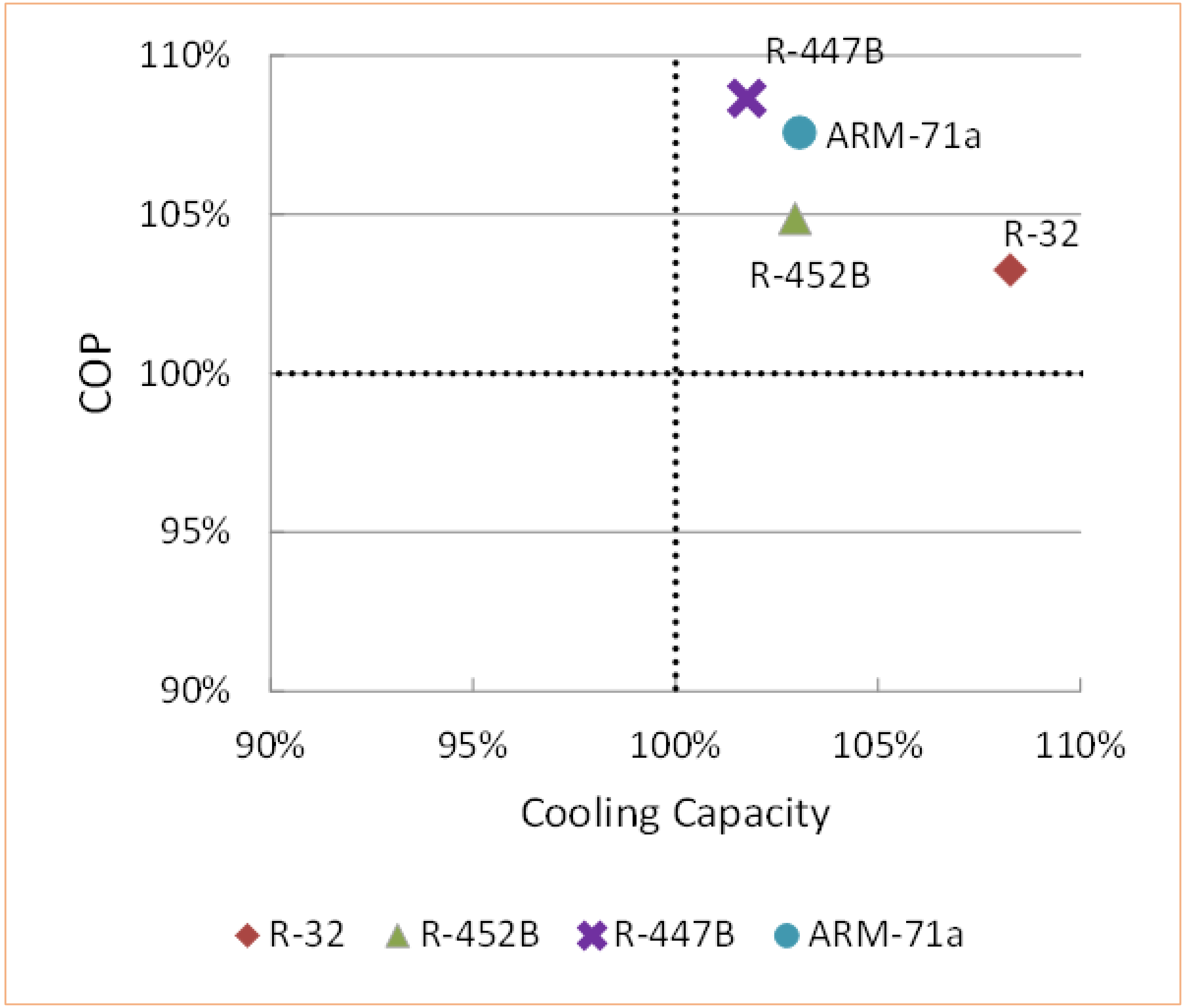




Performance Relative to R-410A at 35°C Ambient



52°C Ambient



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			

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Session 2

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Design Optimization of Prototypes

Bassam Elassaad, Consultant and RTOC member

10th June 2020

@ 2 pm (CET, Paris Time)

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”

Findings: Prototype Analysis

- **Compressors:**
  - The existing units mostly use compressors sized specifically for R-410A or HCFC-22 and in some cases custom made for the particular application.
  - This presents an opportunity for a better compressor selection when migrating to other refrigerants such as R-454B or R-447B;
- **Expansion Devices:**
  - Expansion devices such as TXV's and EXV's may allow for better control and reduced losses in connecting pipes if located near the evaporator.
- **Heat Exchangers (HX):**
  - The objective is to improve performance while minimizing charge which could be achieved by reducing the tube/channel diameter since heat transfer coefficients are inversely proportional to tube diameters.
  - Pressure drop is also inversely proportional to tube diameter so smaller tubes result in reduced size and reduced internal volume but higher pressure drop.
- **Fans and Blowers:**
  - Replacing the fan and blower may be necessary if newly designed heat exchangers offer considerable change in pressure drop over the baseline when the flow rates are kept constant.

Simulated Optimization

Acquiring performance maps for components (compressors, fans) more suitable for the application

Evaluating alternate heat exchanger design configurations

Performing detailed engineering optimization to match or exceed the baseline unit performance

Activity included:

- **Simulation**:
  - Developing a cycle simulation model for each of the baseline systems.
- **Calibration**:
  - Calibrating the models using the data provided in Activity 1.
- **Evaluation**:
  - Whether existing compressor and fans are the best fit, or if alternate designs would be preferred;
  - Heat exchanger design options and suppliers for alternative off-the-shelf solutions;
  - Performance of optimum component selection and quantifying any anticipated performance gains;
- **Analysis**:
  - Parametric analysis study for the air-to-refrigerant heat exchangers for use with the alternative refrigerants

System Design Optimization: Modification Framework

- Properly designing and selecting components that can be replaced with no modification of the cabinets focusing on:
  - Compressor
  - Condenser
  - Expansion valve
- The evaporators, fans, and blowers were not considered for change.
- Conventional 9.5mm diameter tube condensers are good candidates for condenser replacement with either a smaller tube diameter or a microchannel heat exchanger (MCHX).

Result of Design Simulation

	General Information			Hardware					Performance	
System	Rated Capacity (@35°C)	System Configuration	Refrigerant	Compressor		Condenser		Exp Device	CC @ 46°C	EER @ 46°C
-	BTU/hr	-	-	Effective Disp. Vol. (cm^3)*	Efficiency (-)	Type	Effectiveness (-)	Type	%	%
Unit 1 Window	18000	Baseline	R-444B	19.8	0.66	Tube-Fin (5mm Tube)	0.20	Passive	0.00%	**0.00%**
		Alternate 1	HC-290	25.9	0.70	Same as Baseline	0.35	Active (EXV)	1.40%	**8.20%**
		Alternate 2	R-454C	24.8	0.69		0.26		4.00%	**-1.30%**
		Alternate 3	R-444B	19.6	0.70		0.23		4.20%	**9.90%**
		Alternate 4	R-457A	25.3	0.68	MCHX	0.24		2.00%	**3.10%**
Unit 6 Split	24000	Baseline	HFC-32	16.0	0.60	Tube-Fin (7mm Tube)	0.12	Passive	0.00%	**0.00%**
		Alternate 1	HFC-32	16.9	0.65	Tube-Fin (5mm Tube)	0.15	Active (EXV)	3.00%	**11.20%**
		Alternate 2	R-454B	18.4	0.67		0.19		-1.00%	**14.80%**
		Alternate 3	R-452B	19.0	0.70		0.17		2.50%	**13.50%**

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)

Unit 6 – Split: Modifications & Results

System	Unit 6		
	Baseline	Alternate 1	Alternate 2
Refrigerant	R32	R32	R454B
Compressor	GMCC KSG226N1UMT	Copeland ZP20K5E	Copeland ZP21K5E
Expansion Device	Capillary Tube (outdoor unit)	Manual valve (indoor unit)	Manual valve (indoor unit)

		Baseline (35°C)	Alternate 1 (35°C)	Alternate 2 (35°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	-	HFC-32	HFC-32	R-454B	-	-
Charge	lbs.	3.83	4.27	5.02	11.5%	31.1%
Cooling Capacity	BTU/hr	25,192	23,585	21,966	-6.4%	-12.8%
Energy Balance	%	-2.28%	-4.66%	-3.06%	-	-
Compressor Power	kW	2.11	1.79	1.77	-15.1%	-16.2%
Fan Power	kW	0.32	0.33	0.33	2.2%	2.2%
Total Power	kW	2.43	2.12	2.10	-12.8%	-13.5%
EER	BTU/hr. W	10.37	11.12	10.44	7.2%	0.68%

		Baseline (46°C)	Alternate 1 (46°C)	Alternate 2 (46°C)	Alt. 1 vs. Baseline	Alt. 2 vs. Baseline
Refrigerant	-	HFC-32	HFC-32	R-454B	-	-
Charge	lbs.	3.83	4.27	5.02	11.5%	31.1%
Cooling Capacity	BTU/hr	23,390	21,450	21,821	-8.3%	-6.7%
Energy Balance	%	-1.78%	-4.42%	-7.61%	-	-
Compressor Power	kW	2.71	2.32	2.25	-14.2%	-16.6%
Fan Power	kW	0.40	0.42	0.42	5.3%	5.3%
Total Power	kW	3.10	2.74	2.67	-11.7%	-13.8%
EER	BTU/hr. W	7.55	7.84	8.17	3.8%	8.2%

Sample Output

- Unit 6 re-tested baseline exhibited similar performance to that found in PRAHA I testing.
- Baseline unit: capillary tube located in the outdoor unit.
  - This would cause liquid refrigerant leaving the outdoor unit to flash;
  - Manual expansion valves in indoor unit was used for modified system.
- Unit 6 modified systems had lower performance than expected from the design optimization model.
  - The HFC-32 system configuration exhibited more than 10% less flow rate than anticipated which corresponded to 10% lower capacity.
    - This is due to performance maps over prediction in simulation phase.
  - The R-454B configuration exhibited a deviation of 5% between model and test
    - Due also in part to a 3% flow rate over prediction in the model.

Recommendations

- **Alternative to presently used refrigerants are viable**
  - but doing so requires proper component design and selection; particularly the compressor, heat exchangers, and expansion device.
- **Drop-in replacement without hardware change is never recommended.**
- **It is recommended to always perform numerical simulations, and to conduct at least some level of "soft" optimization analyses**
  - This will provide information for an educated system re-design / retrofit at much lower costs than gradual trial-and-error changes.
- **Always test the modified systems in the same test setup as the baseline, with the same instrumentation**

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.

Results

- The comparison refers to a leakage of approximately 30% of charge, while reducing capacity by approximately 50% based on airside only.
- The leak tests showed less than 2% deviation in cooling capacity after re-charge from both vapor and liquid lines

System			Liquid Line Leak		Vapor Line Leak	
		Full Charge	Low Charge	Re-Charged	Low Charge	Re-Charged
Refrigerant	-	R-447B	R-447B	R-447B	R-447B	R-447B
Charge	lbs.	6.625	4.27	6.625	4.23	6.77
Cooling Capacity	BTU/hr	31,073	14,216	30,865 (<1%)	15,171	30,587 (1.6%)
Energy Balance	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Compressor Power	kW	3.18	2.93	3.18	2.94	*
Fan Power	kW	0.95	0.98	0.98	0.98	0.98
Total Power	kW	4.13	3.90	4.16	3.92	*
EER	BTU/hr. W	7.52	3.64	7.42 (1.3%)	3.87	*

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Alternative Refrigerants for High Ambient Temperature (HAT) Countries

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10th June 2020

@ 2 pm (CET, Paris Time)

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Alternative Refrigerants and their Applicability to HAT and Relevant Design Considerations

Omar Abdelaziz, Consultant and RTOC Co-Chair

10th June 2020

@ 2 pm (CET, Paris Time)

Agenda

- Refrigerant Classification
- Thermodynamic Considerations for HAT
- Theoretical Performance of Alternative Refrigerants
- Alternative Refrigerants
- Design Considerations for HAT

Thermodynamic Considerations for HAT

Desired Thermodynamic Properties for HAT

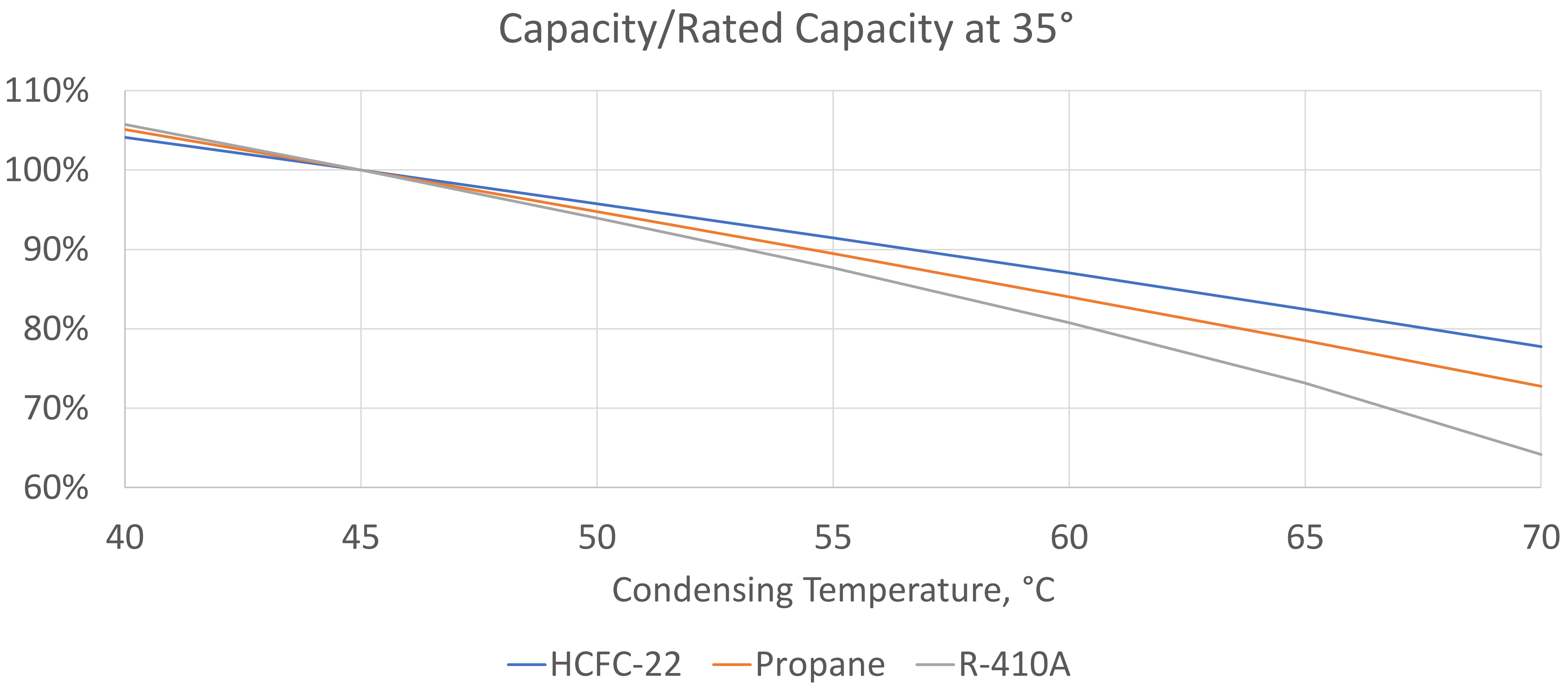
- Critical Temperature should be at least 10°C higher than the maximum expected temperature (~70°C)
- Have sufficient volumetric capacity at the required evaporating temperature
  - Reduce volumetric flow rate/compressor size
  - Reduce refrigerant charge (important for flammable refrigerants)
- Has acceptable isentropic compression performance
  - Acceptable compression power
  - Manageable discharge temperature
- Similar operating pressure to baseline equipment for drop-in application

Thermodynamic Comparison

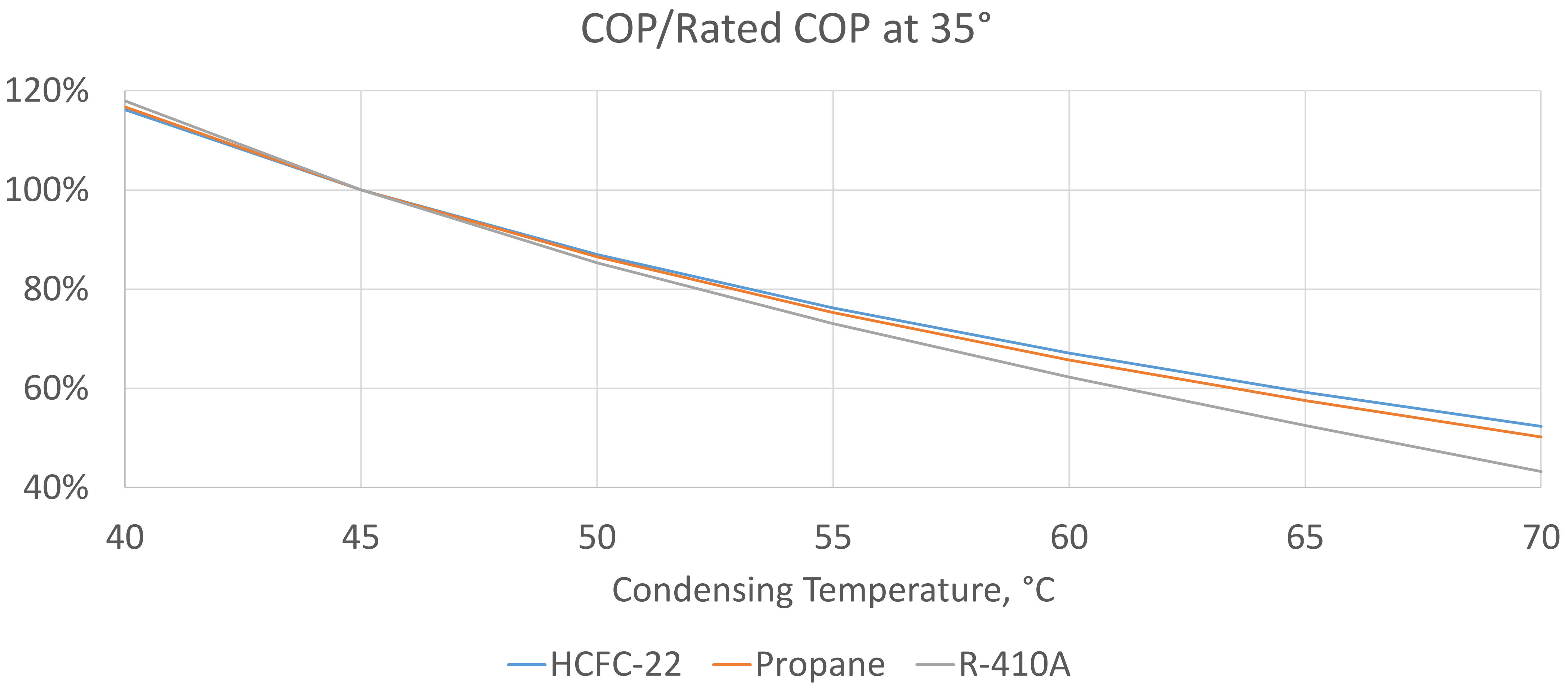
Refrigerant	Condensing Pressure	Discharge Temperature	Volumetric Capacity	COP	Tcritical
HCFC-22	2.427	112.0	3067	2.29	96.1
HC-290	2.117	85.3	2501	2.21	96.7
R-410A	3.842	106.2	4167	2.00	71.3
HFC-32	3.933	134.6	4863	2.14	78.1

Assumptions:
Condensing Temperature = 60°C
Evaporating Temperature = 2°C
Superheat = subcooling = 5°C
Isentropic efficiency = 65%

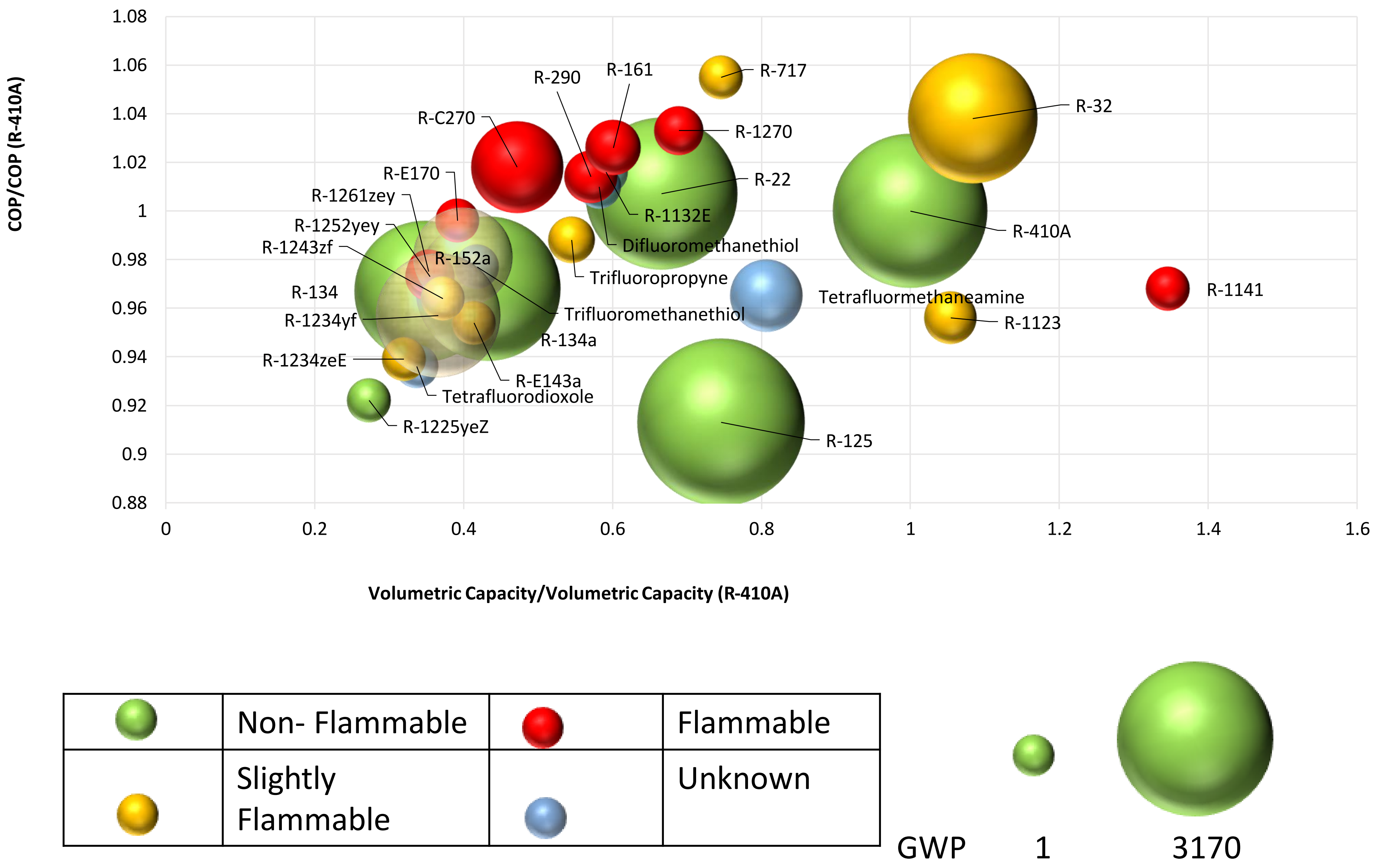
Performance Loss with Increasing Condensing Temperature



Performance Loss with Increasing Condensing Temperature



NIST Study—Basic Cycle



Mark O. McLinden, J. Steven Brown, Riccardo Brignoli, Andrei F. Kazakov & Piotr A. Domanski, “Limited options for low-global-warming-potential refrigerants”, Nature Communications 8, Article number: 14476 (2017),doi:10.1038/ncomms14476

HFO Developments (ASHRAE Standard 34)

First HFO Molecule in Standard 34	2008 – HFO-1234yf
First HFO Blend in Standard 34	2012 – Class 2L
First Non-Flammable HFO Blend	2013
HFO/HCFO Status as end of 2019 (Includes refrigerants proposed, but not necessarily listed)	• 9 distinct molecules • 43 refrigerant blends (23 flammable, 20 non-flammable)

Safe (A1) Lower-GWP Proposed between 2010 and 2018

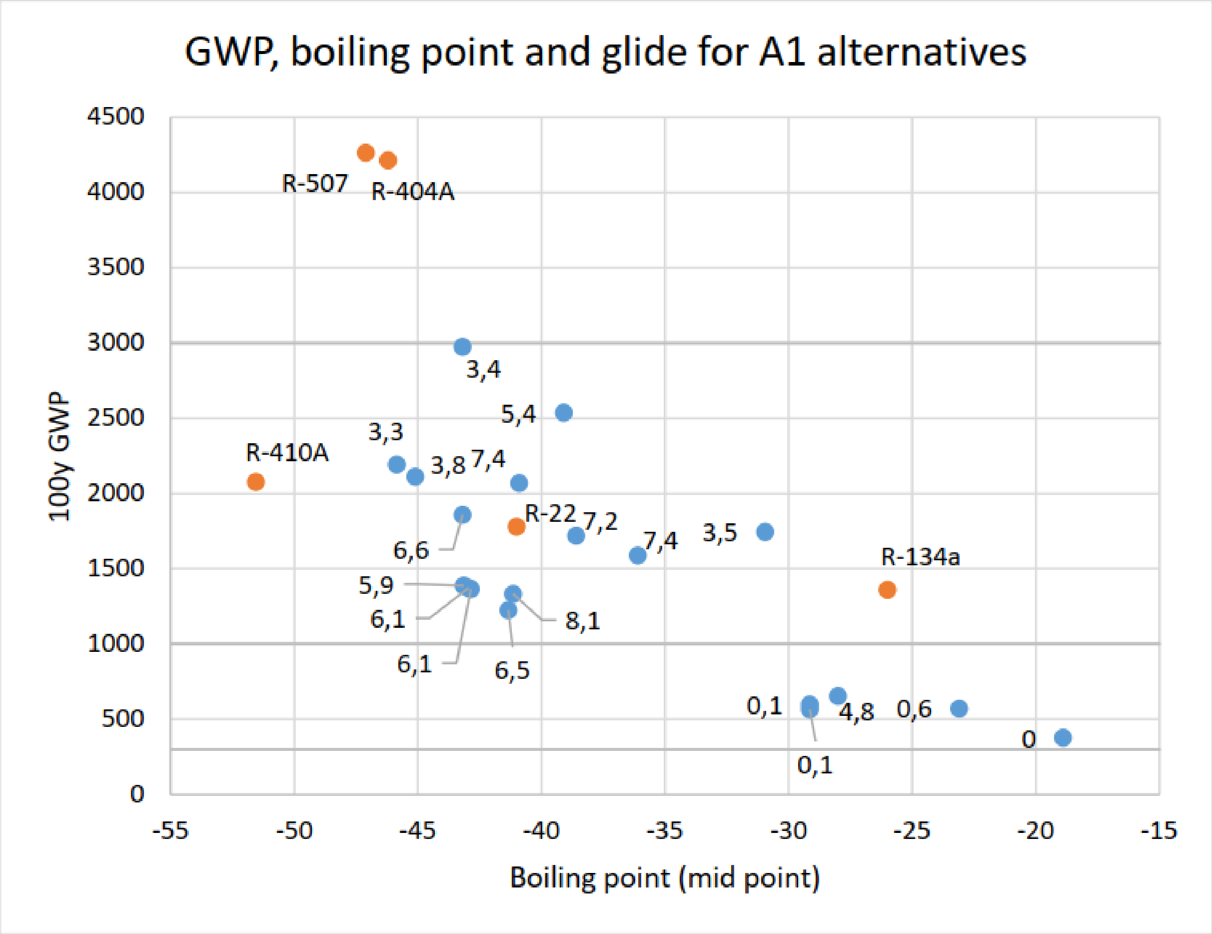


Figure 2-1 from the 2018 RTOC report.

A2L Lower-GWP Proposed between 2010 and 2018

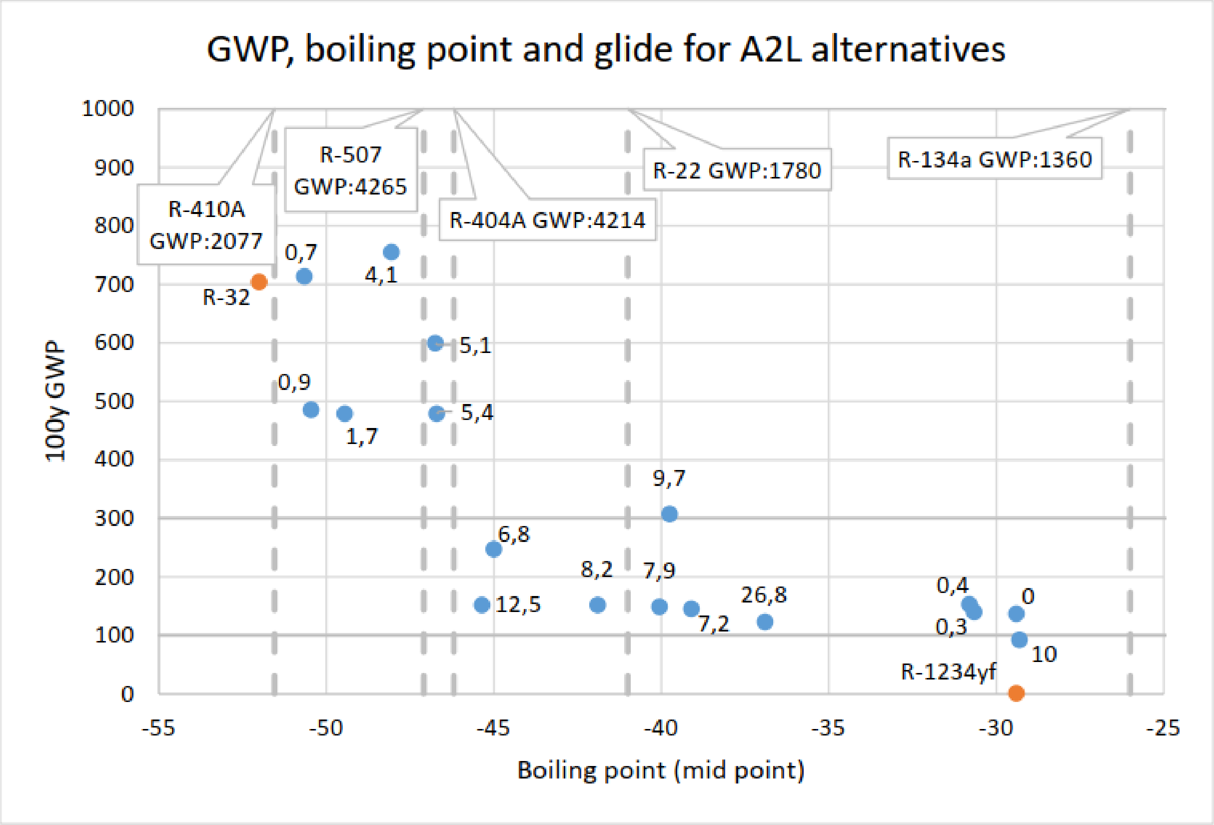
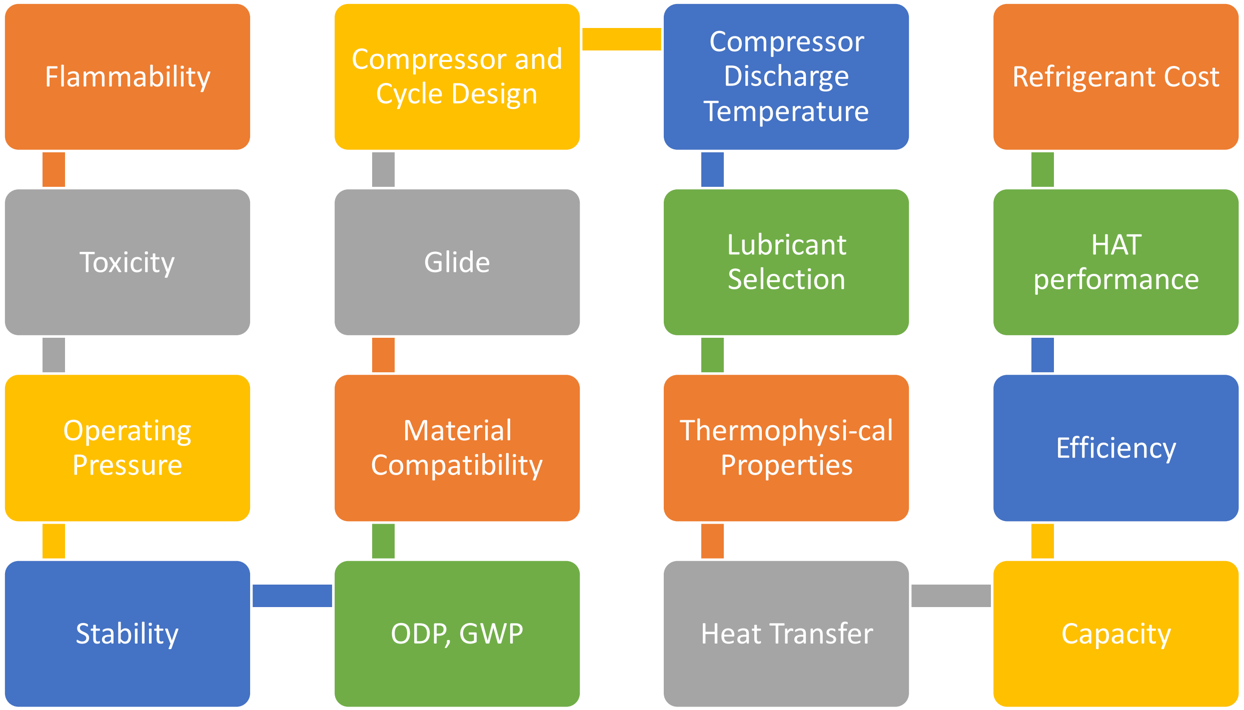


Figure 2-2 from the 2018 RTOC report.

Design Considerations for HAT

Refrigerant Selection: A Trade-off

- Environmental performance (~0 ODP and reduced GWP)
- Safety for consumers (flammability and toxicity)
- Energy efficiency (reduced indirect CO_2 emissions, especially at high ambient operations)
- Intellectual property considerations
- Transition costs (industry and consumers)
- Product sustainability



Allowable Flammable Refrigerant Charge

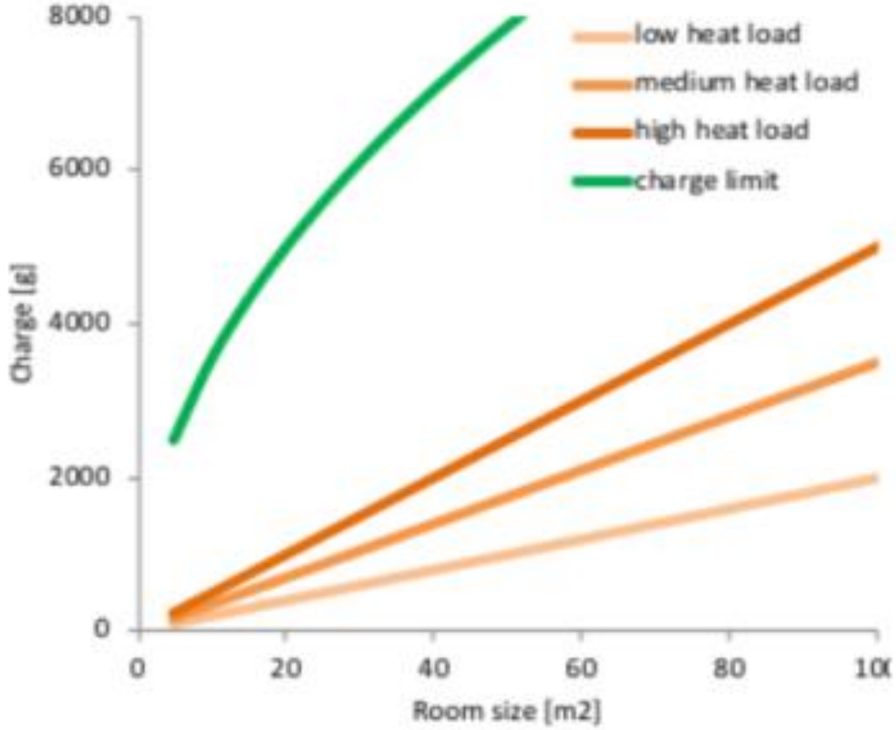


Figure 13-4: Comparison of charge limits for 2 m²[21] units and likely charge needs for A2L refrigerants

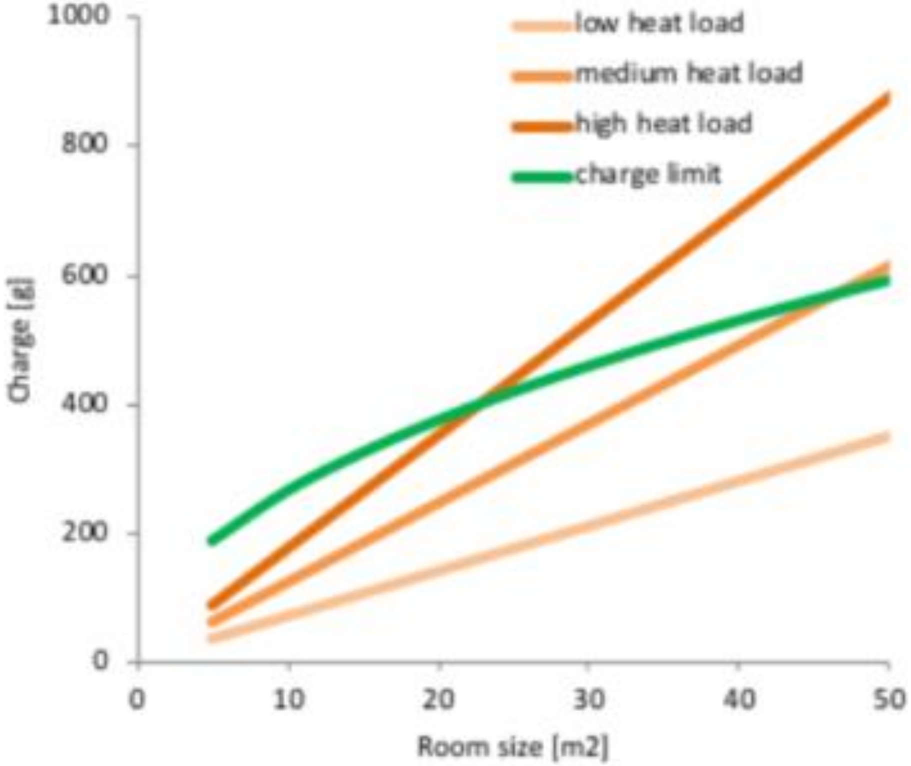


Figure 13-5: Comparison of charge limits for 2 m²[22] units and likely charge needs for A3 refrigerants

The 2018 RTOC report, based on current IEC 60335-2-40 which is **currently under revision**

Test Pressures

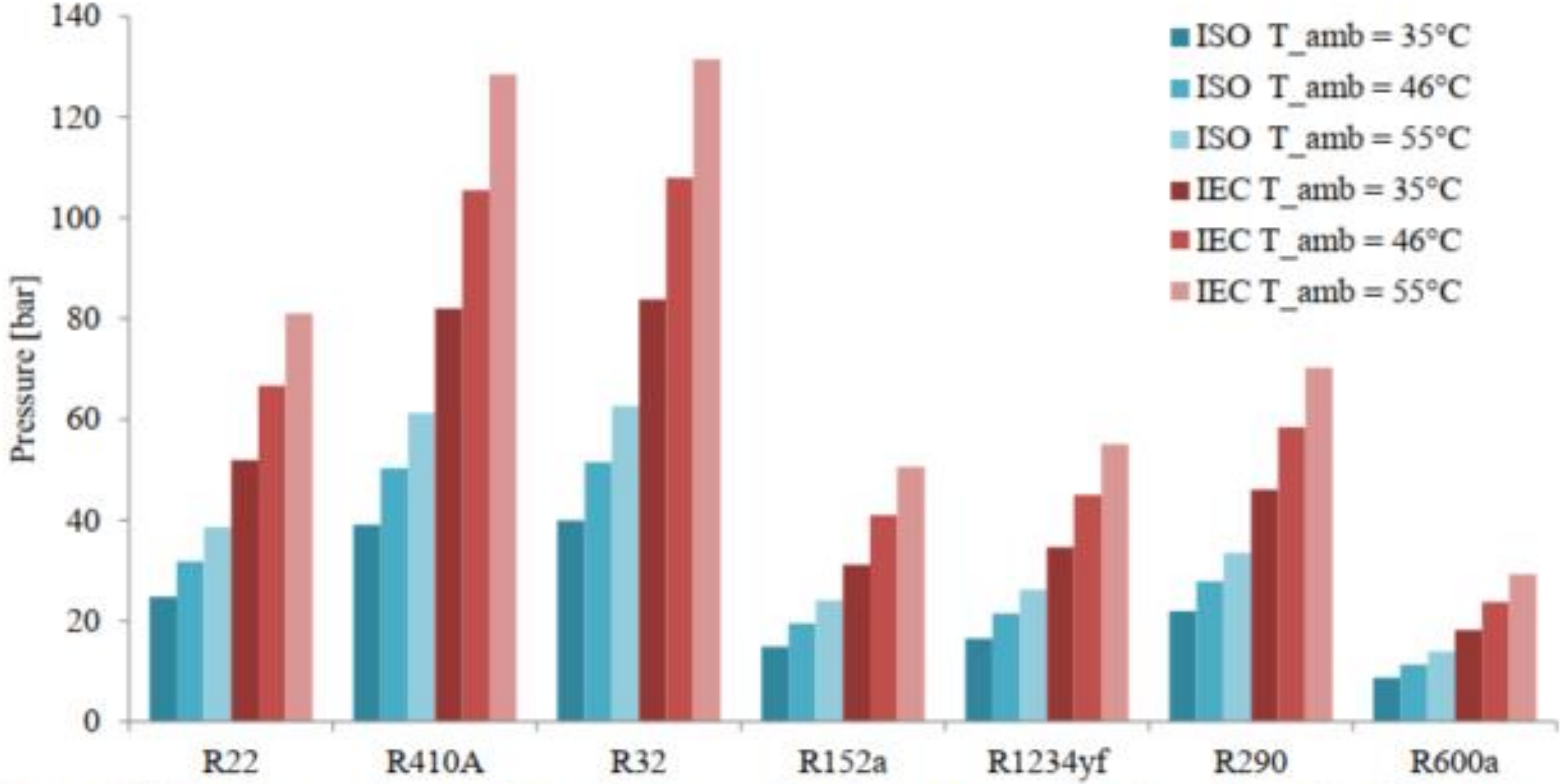
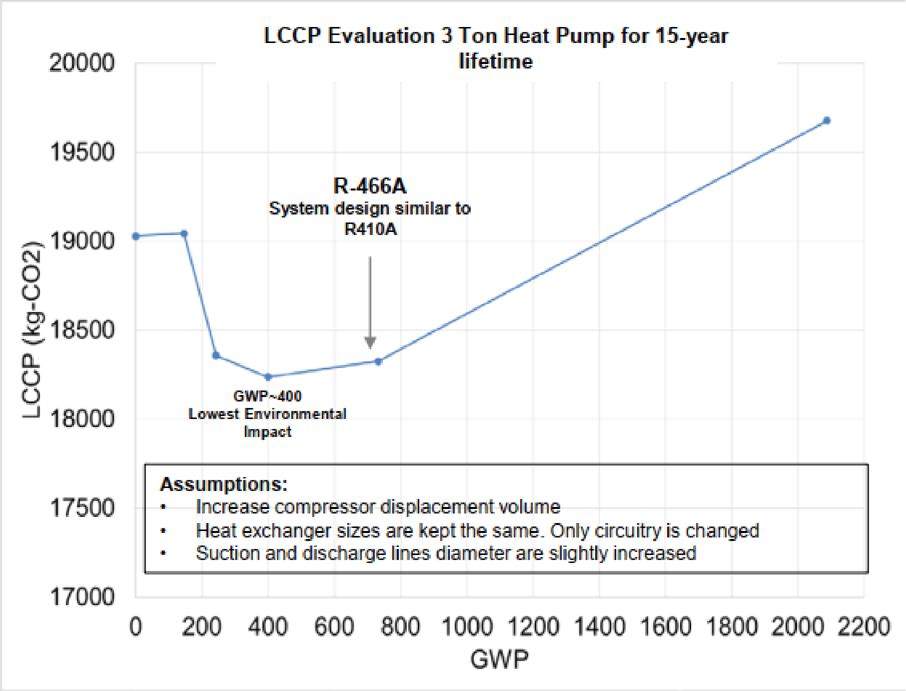


Figure 13-3: Comparison of maximum strength test pressure for selected refrigerants according to ISO 5149 and IEC 60335-series[20]

The 2018 RTOC report.

LCCP Considerations for R-410A Alternatives

- Non-flammable option with GWP<750:
  - Similar system design, ➔ swift transition for the industry due to reduced development time
  - A2L readily available and A1 option under investigations (material compatibility)
- Non-flammable option with GWP<400 or GWP<300:
  - Potential for lowest LCCP
  - Some trade-off in system design is needed.
- Non-flammable option with GWP<150:
  - Higher indirect emissions due to worse system performance.
  - Significant system design changes are needed to improve efficiency.

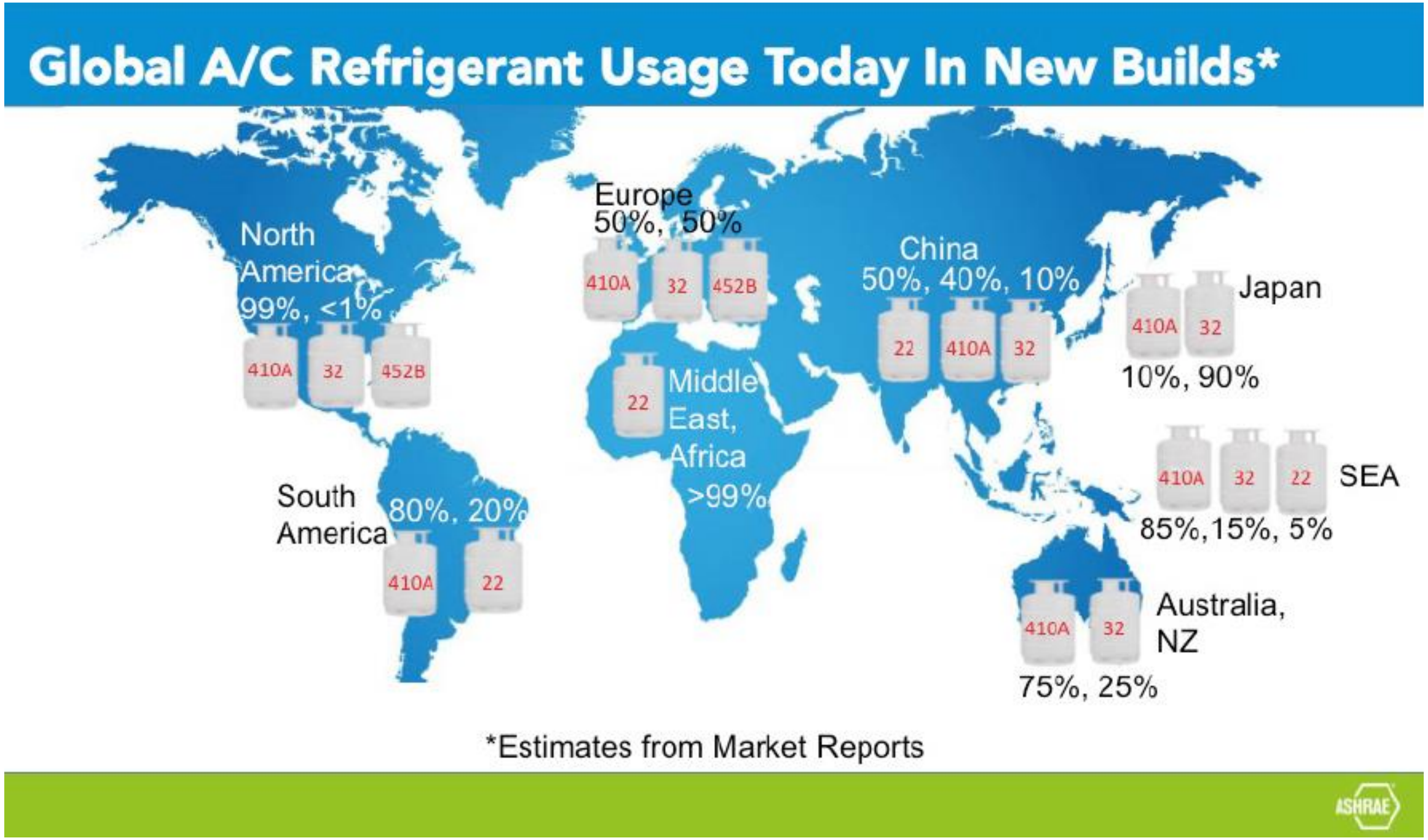


Adapted from: "Low GWP Refrigerants for Heat Pump Systems" by S. F. Yana Motta and A. Sethi, ICR 2019

Cost Implications of New Refrigerants

- Global cost-effectiveness is key to the transition to sustainable A/C
- Since the 1970s, U.S. manufacturers have steadily reduced the inflation-adjusted cost of residential central-ducted A/C systems while maintaining or improving performance, even while transitioning away from ODS to today's HFC refrigerants
- Performance improvements and charge minimization efforts supporting transition towards low-GWP can offset upfront cost increased through life-cycle energy savings

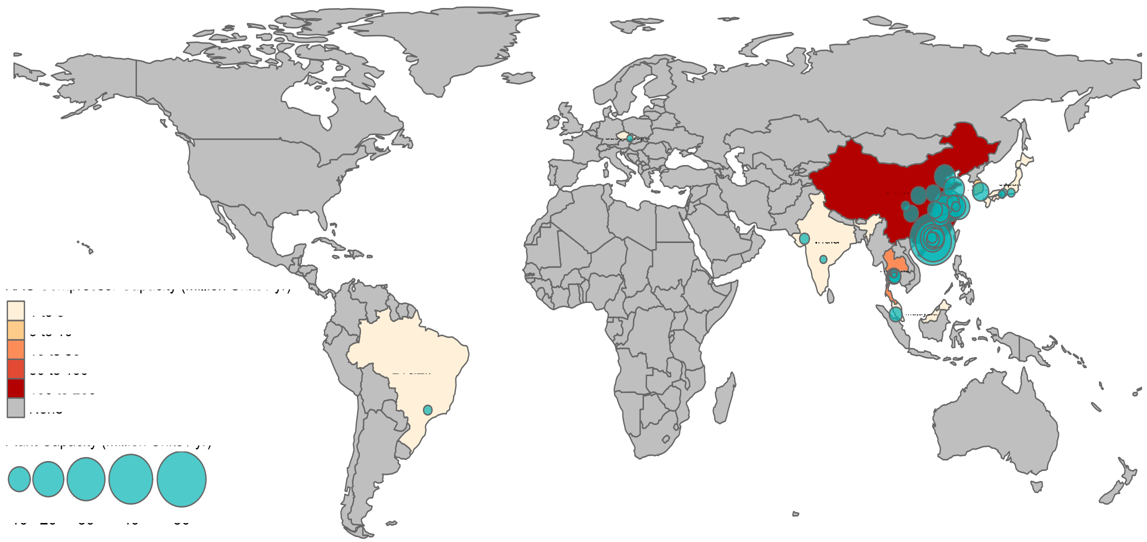
Availability of Refrigerants



Source: ASHRAE 2019

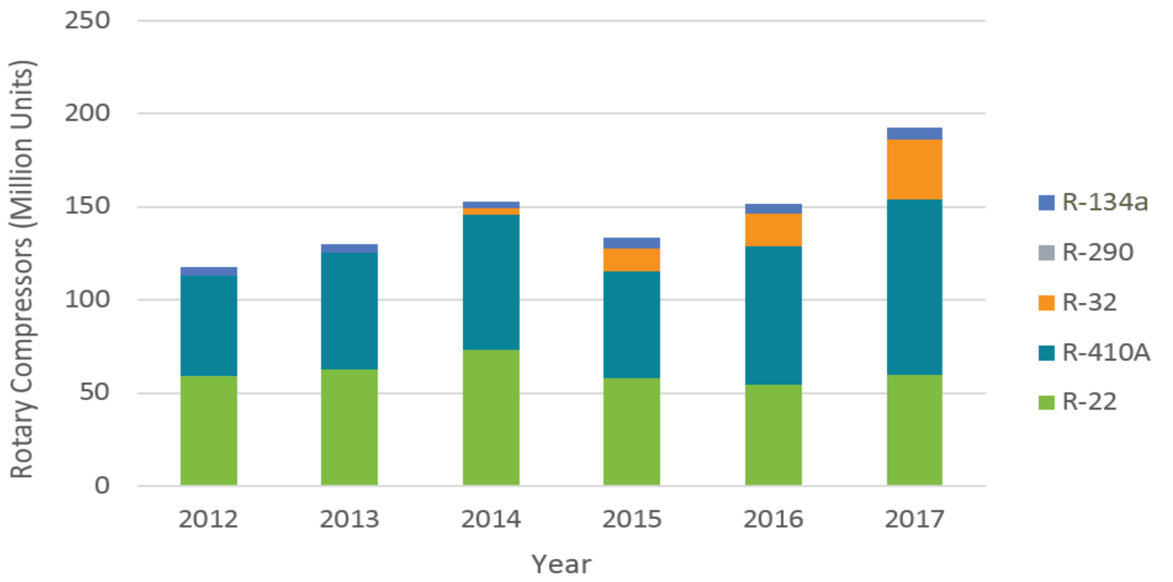
Availability of Compressors

Component	Presently in use?	Remarks	Necessary components	Max potential improvement	Incremental cost for RAC unit
Compressors					
Higher efficiency	Y	Mostly rotary compressor			
Inverter driven	Y	Mostly used for rotary	Inverter, dedicated compressor	20% to 30%	20%
two stage compression	L	Very limited availability		10%	10% – 20%
motor efficiency controllers	L	Standard		same	Same

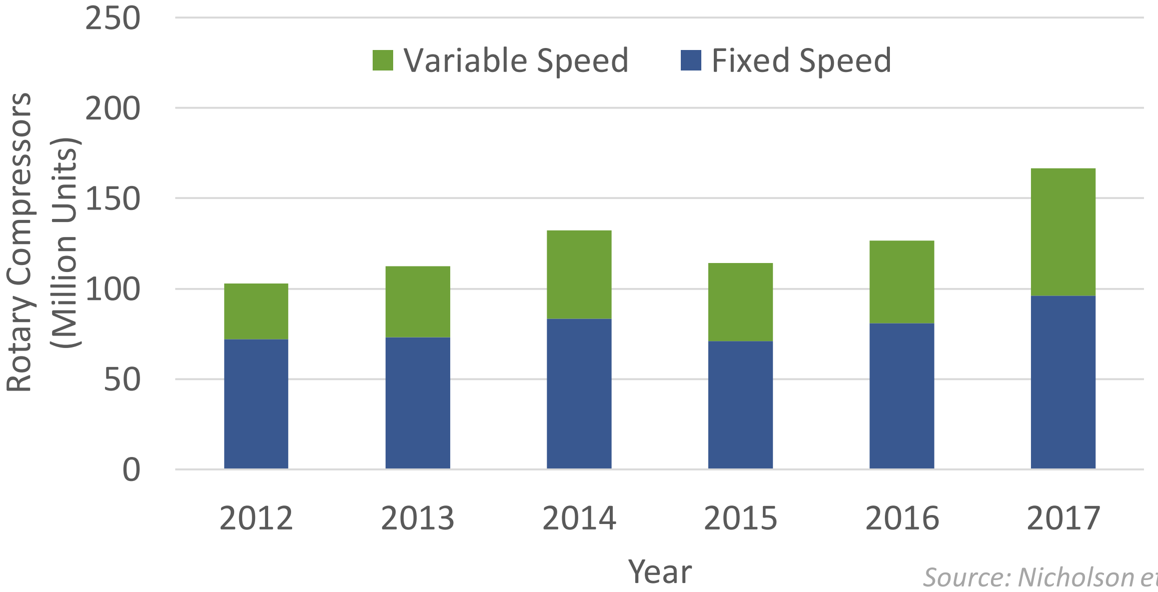


Source: Nicholson et al 2019

Compressors by Refrigerant and Type



Source: ChinaIOL



Source: Nicholson et al 2019

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Best practices for conversion projects

Presented by:

Ole Nielsen, Chief of Montreal Protocol Division, UNIDO

10th June 2020

@ 2 pm (CET, Paris Time)

Intervention - manufacturing

MLF supports A5 countries to convert to lower GWP technologies;

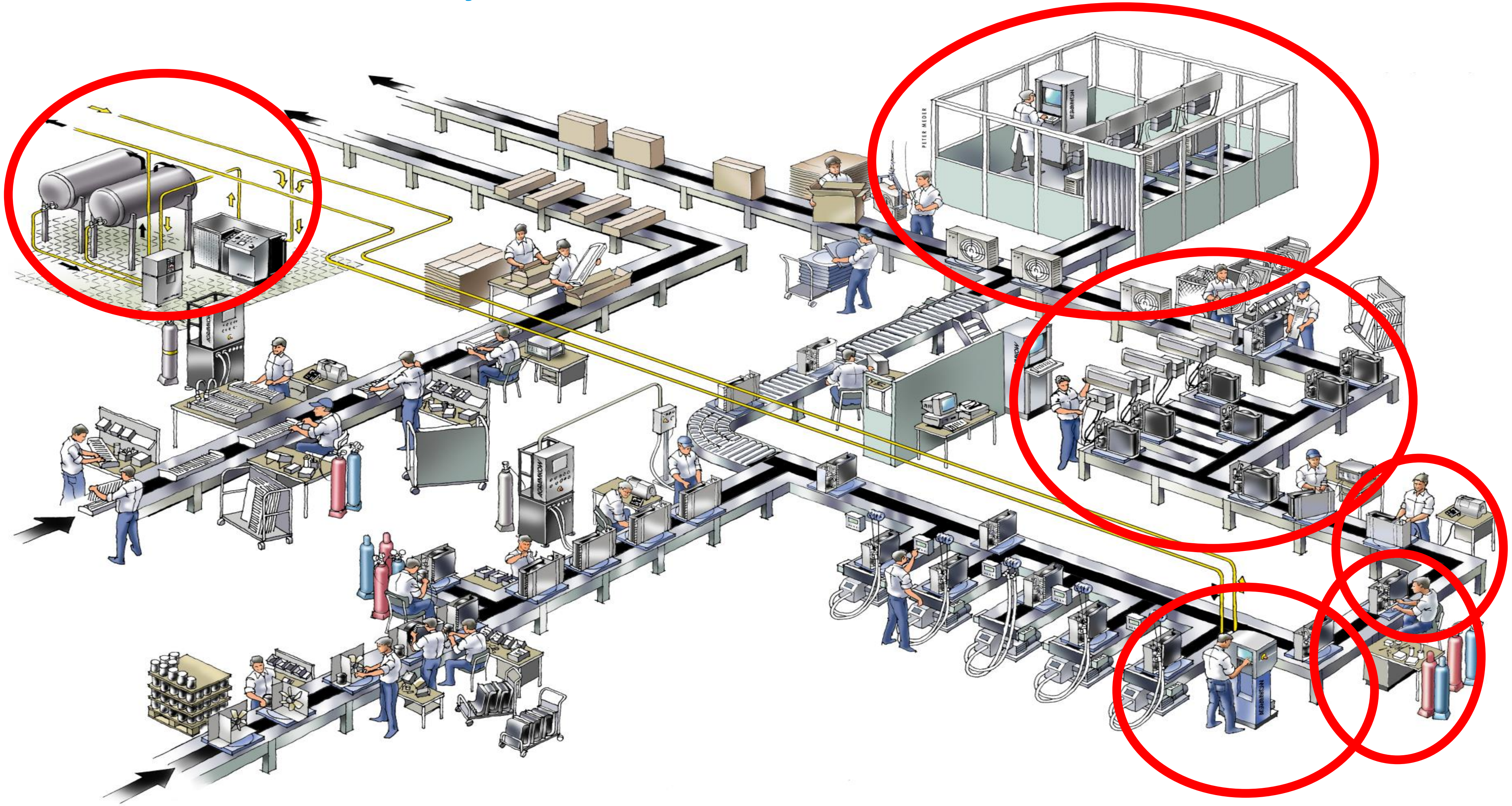
Eligible actions:

- No capacity upgrade
  - One-to-one replacement;
- Only processes affected by change of refrigerant;
- Cost effectiveness (US$/kg)
  - In relation to ODS phase-out

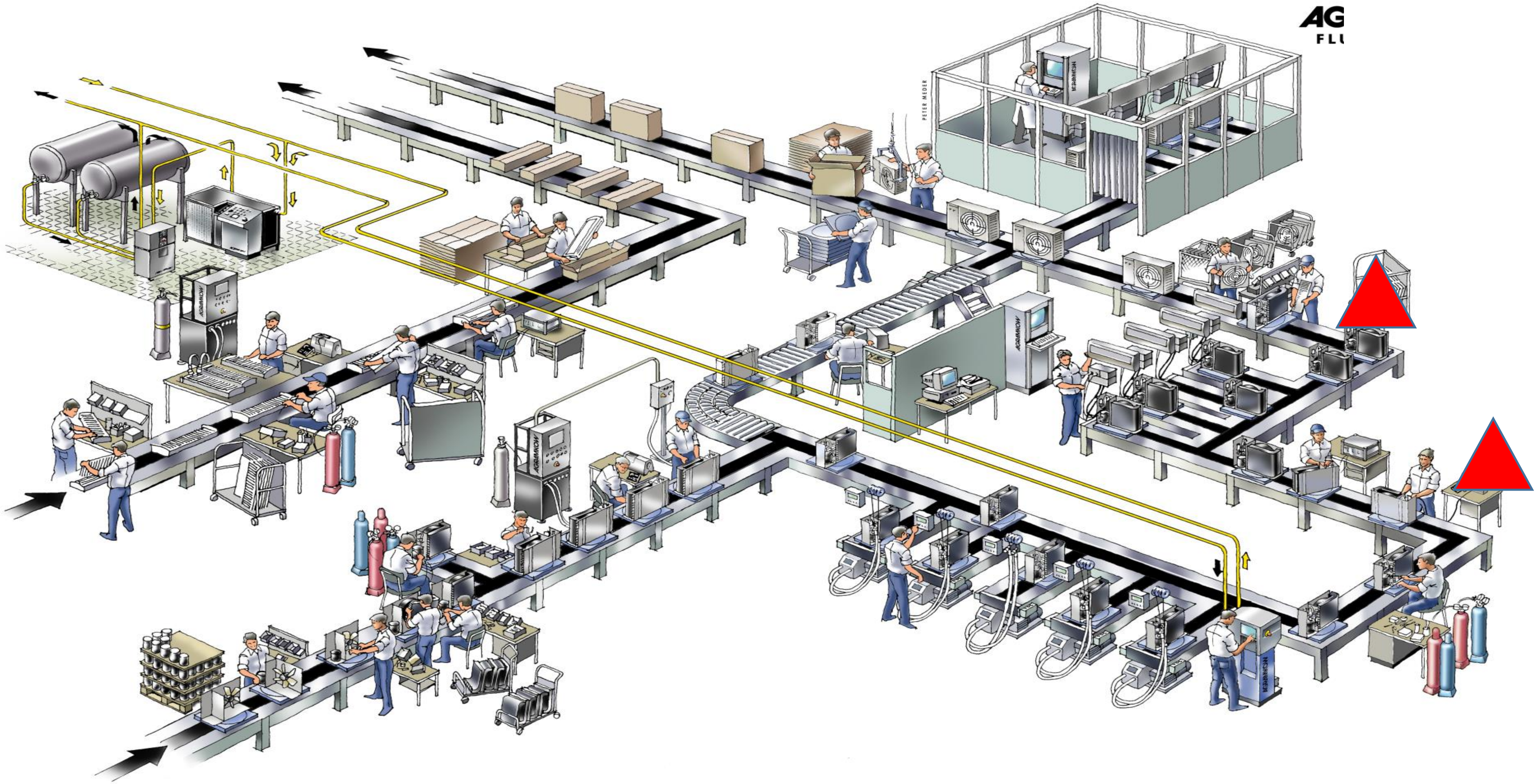
Conversion safety

- ATEX directive – safety zones;
- Mitigation of risks:
    - Equipment designed for flammable refrigerants;
    - Prevent flammable atmosphere;
    - Eliminate ignition sources;
    - Few modifications to production layout; and
    - Independent safety review.
- Production safety
    - Resolved!

A/C assembly line – intervention - flammable



A/C assembly line – intervention - flammable



Concluding remarks

- Safety aspects in regards to conversion of manufacturing facilities to flammable refrigerants well defined and solutions available;
- Main barrier is related to installation, maintenance and EOL.

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Q&A

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Break (10 mins)

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Session 3

10th June 2020

@ 2 pm (CET, Paris Time)

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Alternative Refrigerants for High Ambient Temperature (HAT) Countries

Codes & Standards

Omar Abdelaziz, Consultant and RTOC Co-Chair

10th June 2020

@ 2 pm (CET, Paris Time)

Agenda

- Regulatory and Legislative Landscape
- Standards on Flammability
- Standards on Energy Efficiency
- Standards on Competence

Regulatory & Legislative Landscape

Regions face different challenges with different priorities

	Europe	North America	China	Middle East	Developing Countries
Technical issues	F-Gas regulation phase down of HFCs over time based on production allocations. Safety code changes for 2L refrigerants required.	2L Flammability for direct systems will be paced by code changes. Indirect 2L systems will appear in the market	Safety is a concern … service tech skills gap in market and code enforcement not consistent. Pace to develop safety code slower than expected.	High ambient operation a concern for high pressure alternatives in air-cooled equipment	Safety is a concern for 2L refrigerants. Service tech skills gap in market and code enforcement not consistent
Commercial	Sectorial bans do not affect Stationary AC but niche preference for low GWP.	Safety and liability concerns with direct systems will limit market acceptability ahead of regulatory mandates. Adoption of safety standards and building codes an issue.	Proprietary fluids disrupt local refrigerant supply base. Preference for R-32 and in high pressure equipment and propane in small charge systems.	R-410A increasing presence in the market due to absence of consensus on alternatives	Low cost and availability the main driver.

Adapted from: JCI – Sustainable Building Symposium, Beirut 2016

Standards on Flammability

Global update

International and Relevant Standards

International General Standards

- ISO 817—Safety classification
- ISO 5149—Application rules
- EN378—Design guide for AC, heat pump, and refrigeration equipment, with required safety

ASHRAE Standards

- ASHRAE Standard 34—Safety classification
- ASHRAE Standard 15—Application rules, large equipment
- ASHRAE Standard 15.2—Residential and light commercial AC and HP

International and Relevant Standards

International Product Standards

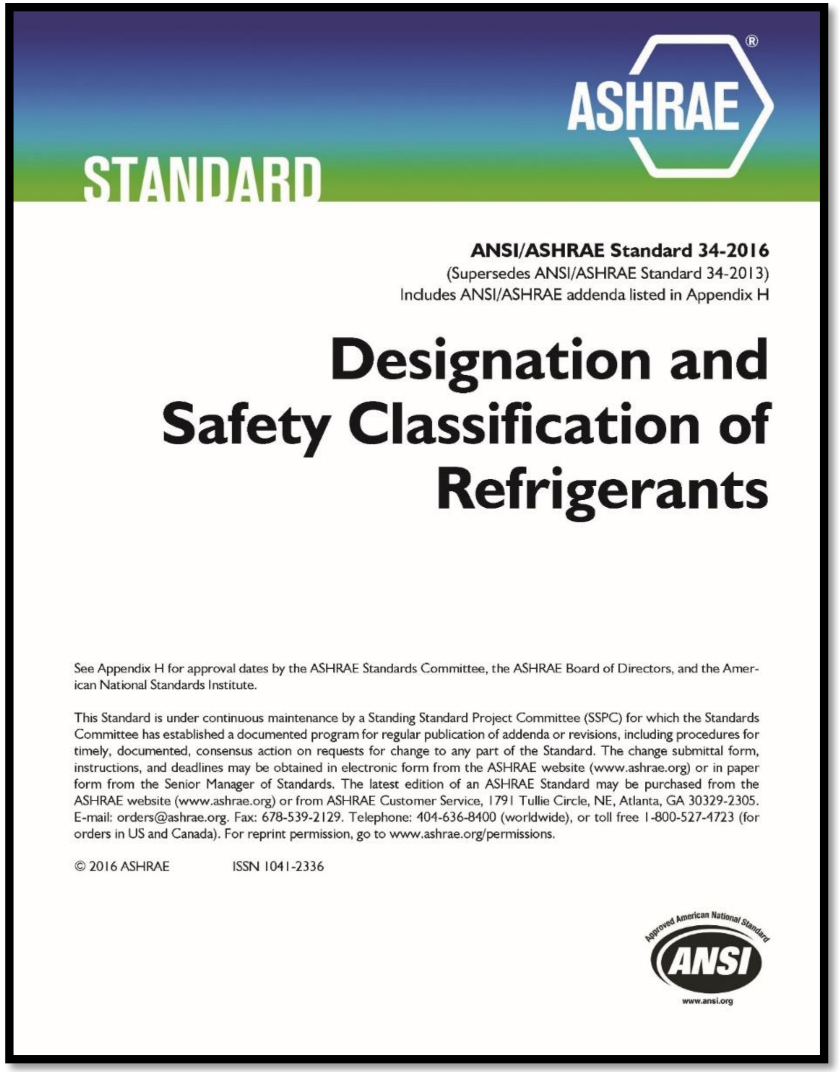
- European Norms (EN) and International Electrotechnical Commission product and equipment standards, which have precedence in many venues:
  - EN/IEC 60335-2-89—Commercial refrigeration and freezing,
  - EN/IEC 60335-2-40—Electrical AC and heat pumps,
  - EN/IEC-60335-2-24—Domestic refrigerators, and
  - more for other equipment types

U.S. Product Standards

- Underwriter's Laboratories standards for certification of specific equipment uses:
  - UL 471—Commercial refrigeration and freezers,
  - UL 484—Room air conditioners,
  - UL 250—Domestic refrigerators, and
  - More for other equipment types

ASHRAE Standard 34

- A listing of refrigerants that have been reviewed and evaluated for safety.
- An evergreen document subject to continuous maintenance.
- New refrigerants can be added to this standard after a new refrigerant application is submitted to and reviewed by the Standing Standards Process Committee that oversees this standard—SSPC34.
- As necessary, new refrigerant safety classification rules can be added.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STANDARD

ANSI/ASHRAE Standard 34-2016
(Supersedes ANSI/ASHRAE Standard 34-2013)
Includes ANSI/ASHRAE addenda listed in Appendix H

Designation and Safety Classification of Refrigerants

See Appendix H for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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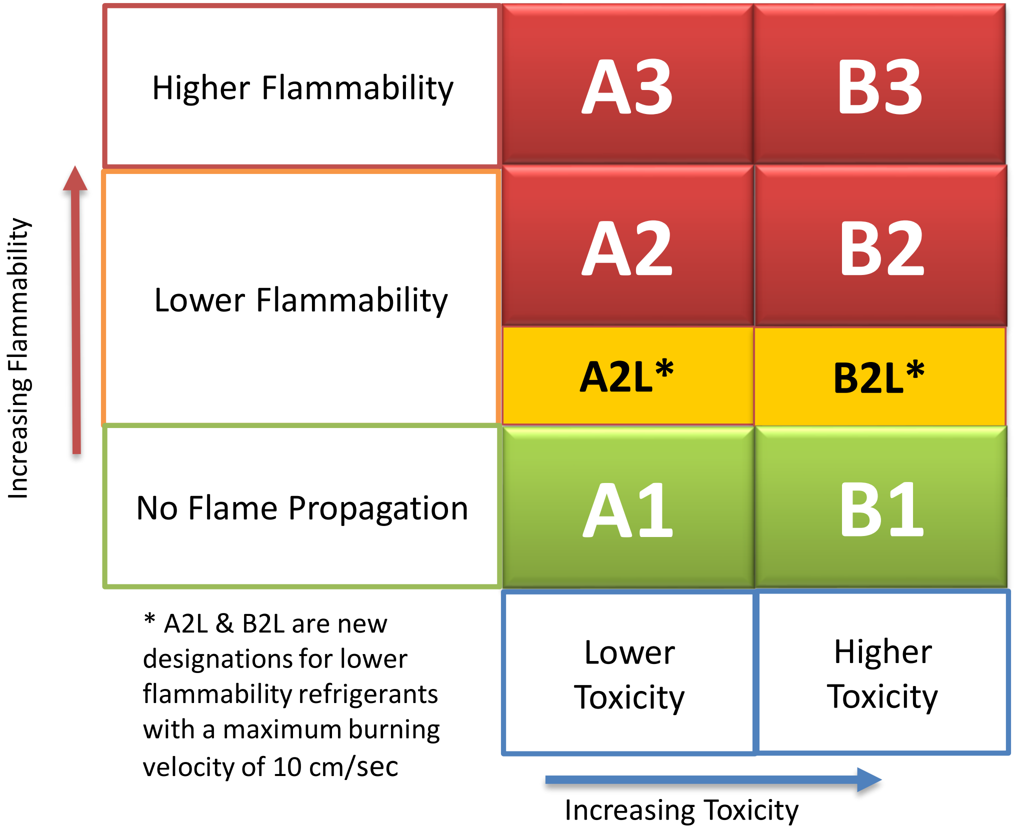


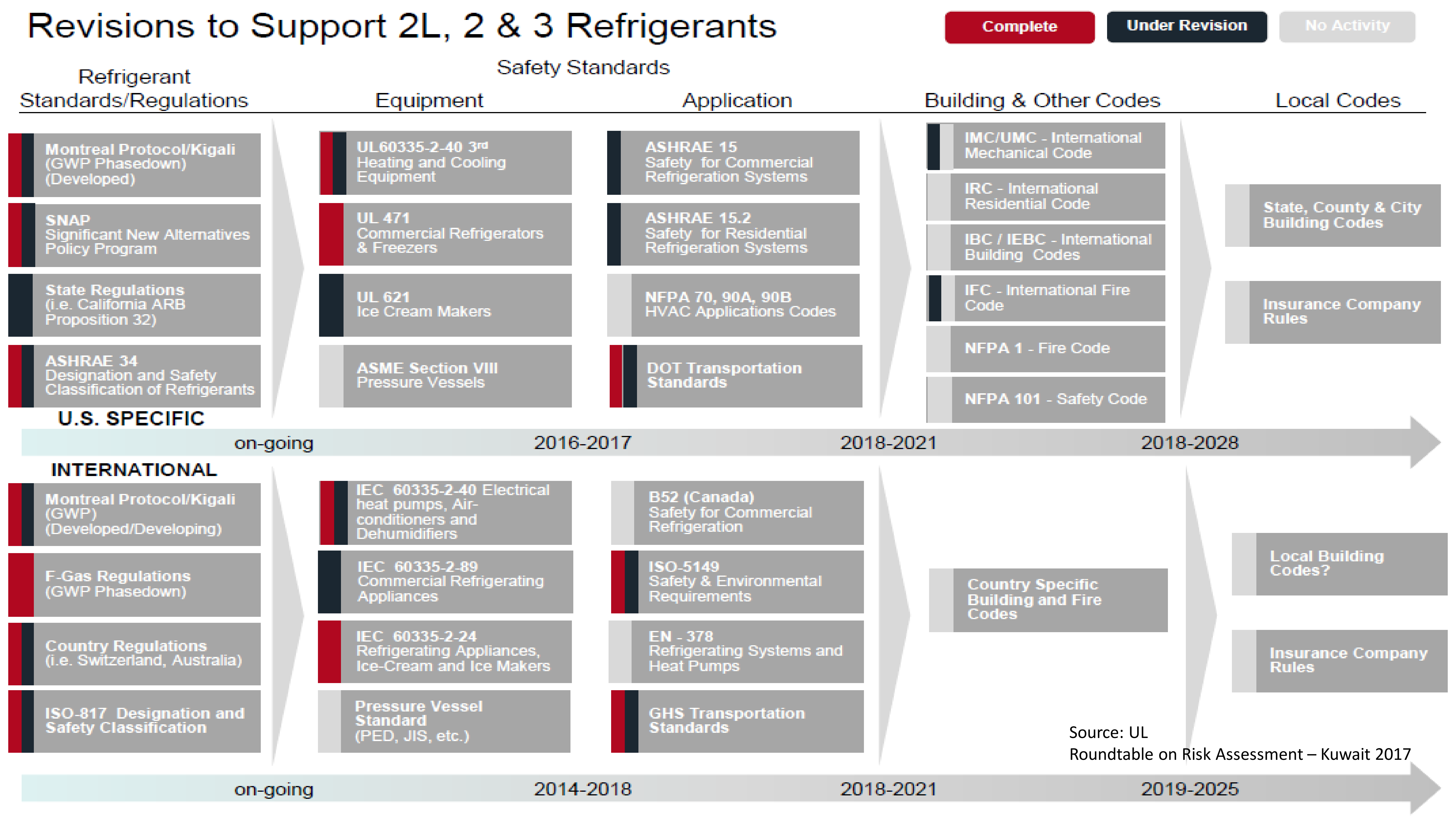
- Safety Classification depends on flammability and toxicity (ISO-817 and ASHRAE-34
- Flammability is determined based on lower flammability limit (LFL), flame velocity, and heat of combustion
  - Class 1: Non-flammable
  - Class 2L: Feeble, slow flame, slow low-pressure rise
  - Class 2: Burns faster, low heat of combustion
  - Class 3: Burns at explosive speed, high heat of combustion
- Toxicity depends on the Occupational Exposure Limit (OEL)
  - Class A: > 400 ppm
  - Class B: < 400 ppm

UNEP-ASHRAE Classification flyer available for further information

Standards and their Impact on Flammable Refrigerant Charge Limit

Standard	Title	Application	Factors that dictate allowable charge limit	Charge with limited measures	Charge with additional measures
IEC 60335-2-24 ANSI/UL 60335-2-24 (6th)	Particular requirements for refrigerating appliances, ice-cream appliances and ice-makers	Domestic refrigeration		A3 ~ 150 g per circuit	
IEC 60335-2-89 ANSI/UL 60335-2-89	Particular requirements for commercial refrigerating appliances with an incorporated or remote condensing unit or compressor	Any refrigeration appliances used in commercial situations	Minimum room size, leak detection sensors, fan circulation	A2L ~1.2 kg A3 ~ 0.5 kg	
IEC 60335-2-40 (6th)	Particular requirements for electrical heat pumps, air conditioners and dehumidifiers	Any air conditioning and heat pump applications	Minimum room size, LFL, lowest release height, max. releasable charge, leak detection sensors, ventilation	A2L ~ 1.8 kg A2 ~ 0.5 kg A3 ~ 0.15 kg/2.5kg	A2L ~ 8kg/70 kg A2 ~ 3.4 kg A3 ~ 0.3 kg/1.0kg
ISO 5149	Mechanical refrigeration systems used for cooling and heating - safety requirement	Any refrigeration, air conditioning and heat pumps: domestic, commercial and industrial	Varies by access category and location classification	A2L ~ 1.8 kg A2 ~ 0.5 kg A3 ~ 0.15 kg	A2L ~ 60 kg/unlimited A2 ~ 3.4 kg/unlimited A3 ~ 1.5 kg/2.5kg/unlimited

TEAP EETF 2019 TEAP TASK FORCE Decision XXVIII/4 Report: on safety standards relevant for low-GWP alternatives

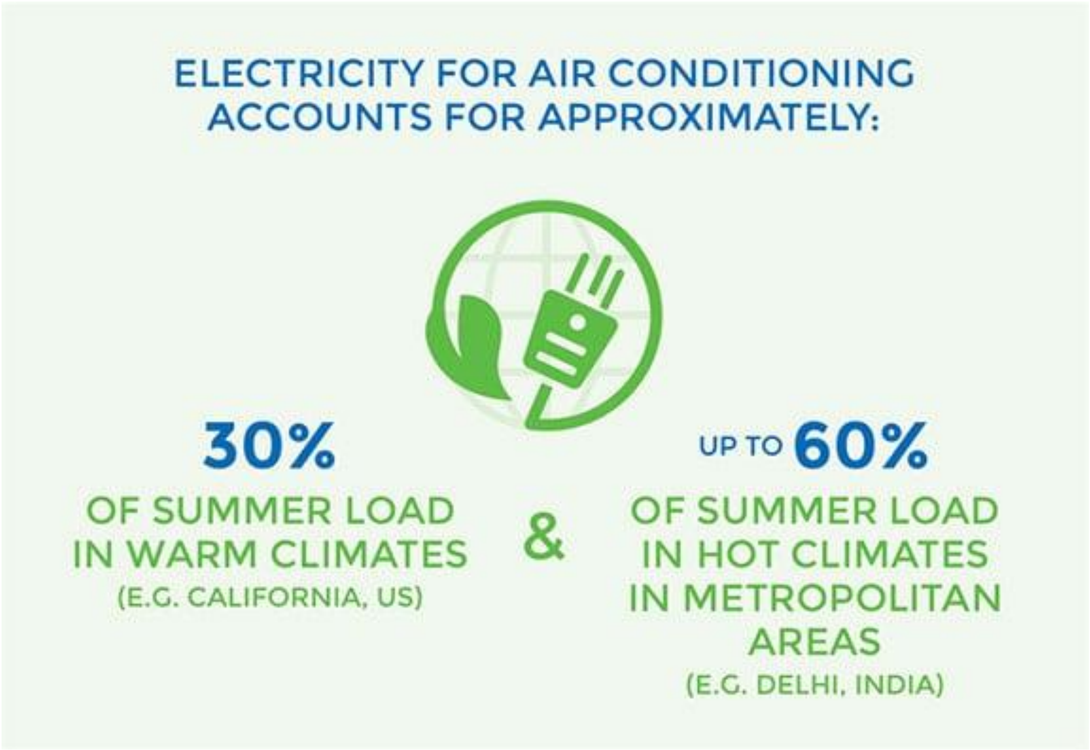


Source: UL
Roundtable on Risk Assessment – Kuwait 2017

Standards on Energy Efficiency

Global update

Room AC Efficiency Landscape



By 2030, an estimated annual savings of 620 TWh from 150 developing countries and emerging economies this is equivalent to:

- The consumption of Germany
- Connecting 310 Million household to the electric grid
- 480 $MMTCO_{2eq}$
- $56 Billion in consumer savings in electricity consumption

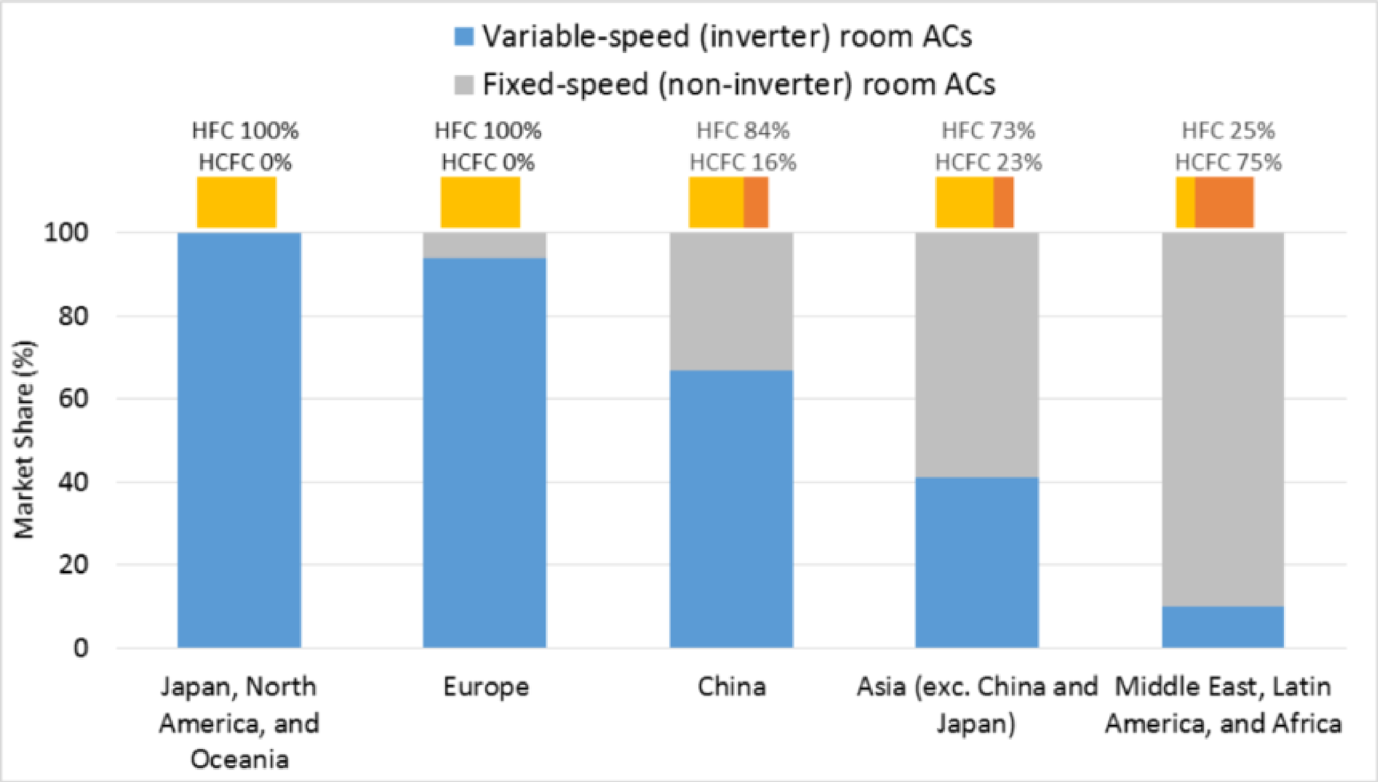
https://united4efficiency.org/products/room-air-conditioners/

UN Environment United for Efficiency Model Regulation Guidelines

- The Model Regulations Guidelines support the global market transformation to energy-efficient technologies
- Develop globally applicable model regulations to help Governments
  - Establish cost-effective policy measures to remove the least efficient products from the market
  - Accelerate the adoption of the highest efficiency models
- Model regulation guidelines
  - Simplify the deployment, adoption and enforcement of regulations in developing and emerging countries
  - Contain all essential pieces, including products scope, definitions, test methods, minimum efficiency levels, and a set of minimum performance requirements along with market surveillance to ensure consumers satisfaction
- Model Regulation Guidelines are a supplement to the Policy Guides which is one of a series

https://united4efficiency.org/resources/model-regulation-guidelines-fact-sheet/

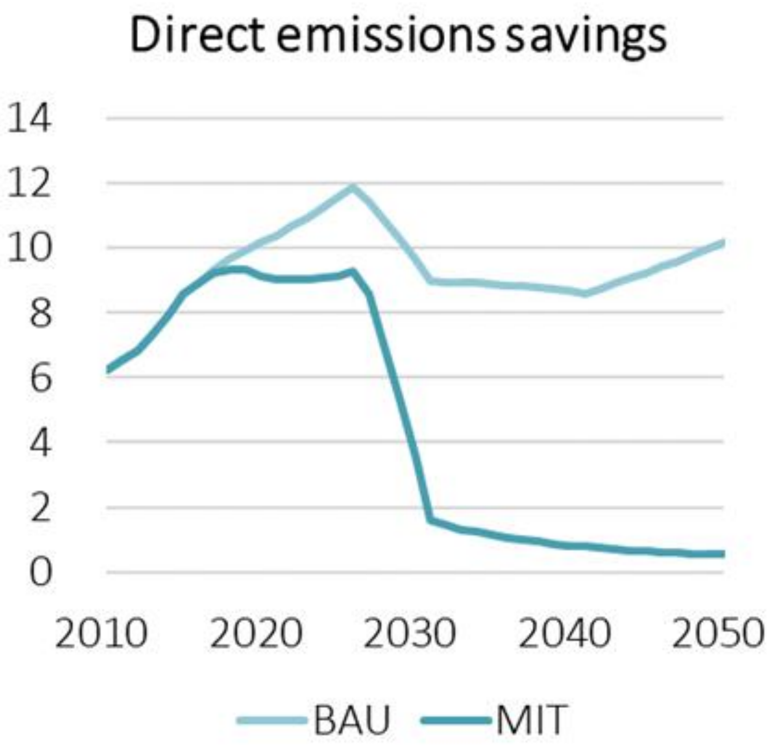
Market share of ACs by technology and refrigerant in 2017

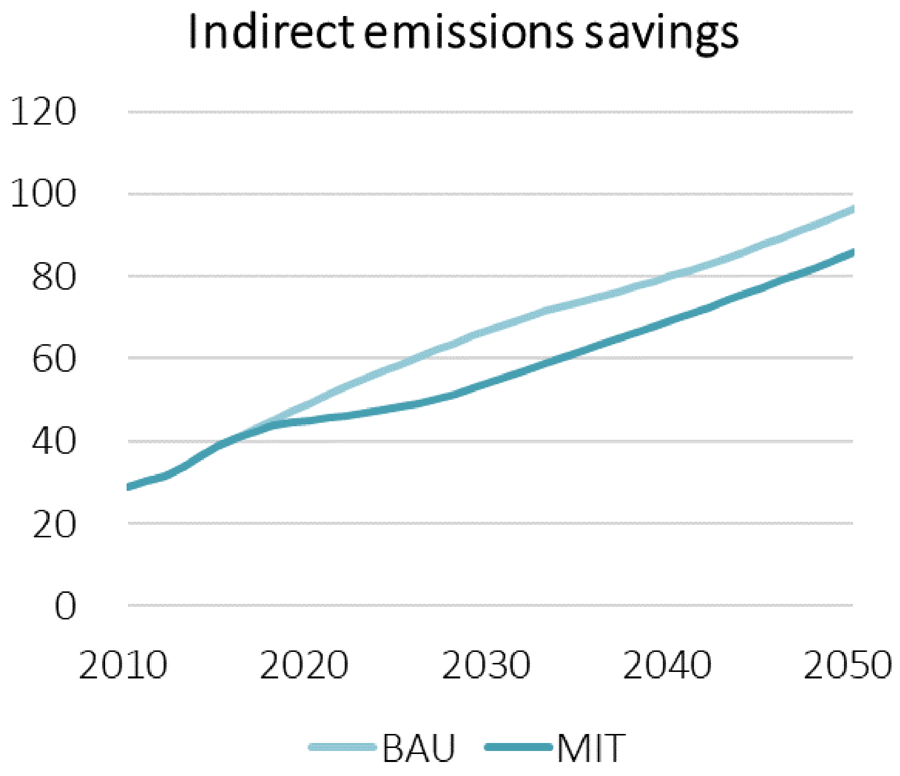


https://united4efficiency.org/wp-content/uploads/2019/11/U4E_AC_Model-Reg-Supporting-Info_20191029.pdf

HAT considerations

- HAT conditions demand more cooling compared to normal design conditions
- Energy consumption for cooling purposes is higher compared to normal conditions
- Energy efficiency has greater economic, social and environmental impact





Source: TEAP EETF, 2019

Standards on Competencies and Skilled Personnel

Global update

Standards Hiraracchy

- Types of standards:
  - Standards that define requirements how to properly install, maintain, dispose of refrigeration systems (safety & environment) ➔ rely on competent persons
    - ISO 5149-4
    - IEC 60335-2-40 [Annex DD]
  - Standards that define the aspects that need to be considered to determine competence to handle installation, maintenance and disposal of refrigeration systems
    - prEN ISO 22712 (EN 13313)
    - Takes into account technology development, regulations, etc.
    - Can be used to develop national and international qualification/certification programmes
    - Will allow further harmonization between those schemes

Source: Els Baert, "International Standards related to the servicing sectors". Convenor and expert for international standardisation

EN 13313 & prEN ISO 22712 Defined Activities and Competence Levels

- Designing
- Pre-assembling
- Installation
- Putting into operation
- Commissioning
- Operating
- In-service inspection
- Leak checking
- General maintenance
- Circuit maintenance
- Decommissioning
- Removing of refrigerant
- Dismantling

LE : leading edge
(level of expertise required for significant development of the skill area)

FO : fully operational
(level of expertise required to perform personally the majority of the activities)

WK : working knowledge
(level of expertise required for direct involvement in decisions and actions)

BA : basic appreciation
(level of expertise required to discuss main elements of the skill with others)

Theoretical and practical assessment required!

System and Safety Standards Summary

Standard	Scope of the standard/title	Technical aspects	Further information	Life cycle stage
ISO 13043	Road vehicles – Refrigerant systems used in mobile air-conditioning systems (MAC)	Safety requirements	Addresses the use of only R-134a, R-1234yf and R-744	Equipment/system design, Installation of new equipment/system, Operation, Maintenance and repair, Decommissioning.
IEC 60335-2-11	Household and similar electrical appliances – Safety	Particular requirements for tumble dryers	Currently allows 150 g of flammable refrigerant; Refrigeration systems requirements are copied from IEC 60335-2-24; No open proposals on changes to refrigerant charge limits	Equipment/system design, Installation of new equipment/system, Operation,
IEC 60335-2-24	Household and similar electrical appliances – Safety	Particular requirements for refrigerating appliances, ice-cream appliances and ice makers	Currently allows 150 g of flammable refrigerant; No open proposals on changes to refrigerant charge limits	Equipment/system design, Installation of new equipment/system, Operation,
IEC 60335-2-40	Household and similar electrical appliances – Safety	Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers	Work ongoing to address aspects relating to charge limits for all flammable refrigerants; Two rounds of voting needed to reach publication	Equipment/system design, Installation of new equipment/system, Operation, Maintenance and repair, Decommissioning.
IEC 60335-2-89	Household and similar electrical appliances – Safety	Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor	Upper limit on flammable refrigerant charge approx; 500 g of propane and 1.2 kg of A2L refrigerant	Equipment/system design, Installation of new equipment/system, Operation,
ISO 80079-36	Explosive atmospheres – Part 36: Non-electrical equipment for explosive atmospheres – Basic method and requirements	Provides basic requirements for prevention of ignition of flammable gases due to mechanical equipment	New standard not widely applied for common refrigeration systems; References other parts of the ISO 80079 series for particular construction details; Not applicable for domestic applications	ISO 80079-36

https://ozone.unep.org/system-safety-standards

System and Safety Standards Summary

Standard	Scope of the standard/title	Technical aspects	Further information	Life cycle stage
ISO 5149-1	Refrigerating systems and heat pumps – Safety and environmental requirements	Basic requirements, definitions, classification and selection criteria	Major revision of refrigerant charge limits in 2014, with a correction to A2L requirements published in 2015; Several proposals for modifying charge limits are being considered by the working group; Amendment likely in 2020, without changes in charge limits; Next full revisions with changes in charge limits could be in 2024	Equipment/system design,
ISO 5149-2	Refrigerating systems and heat pumps – Safety and environmental requirements	Design, construction, testing, marking and documentation	Focus of the working group is on part 1, where the charge limits are stated; Some work ongoing to align text with EN378 and refine language; Publication of amendment likely in 2020	Equipment/system design, Installation of new equipment/system,
ISO 5149-3	Refrigerating systems and heat pumps — Safety and environmental requirements	Installation site	Focus of the working group is on part 1, where the charge limits are stated; Some work ongoing to align text with EN378 and refine language; Publication of amendment likely in 2020	Installation of new equipment/system,
ISO 5149-4	Refrigerating systems and heat pumps — Safety and environmental requirements	Operation, maintenance, repair and recovery	Focus of the working group is on part 1, where the charge limits are stated; Given the proposal to replace EN378-4 with ISO5149-4, there will likely be a set of proposals to align with EN378-4 before it is replaced	Operation, Maintenance and repair, Decommissioning.

https://ozone.unep.org/system-safety-standards

System and Safety Standards Summary

Standard	Scope of the standard/title	Technical aspects	Further information	Life cycle stage
ANSI/IIAR 2	American national standard for safe design of closed-circuit ammonia refrigeration systems	Closed-circuit ammonia refrigeration systems	Draft amendment adds requirements for absorption systems using ammonia as a refrigerant	Equipment/system design, Installation of new equipment/system, Operation, Maintenance and repair, Decommissioning.
ISO 817	Refrigerants	Designation and safety classification	Refrigerant tables of the standard are being moved to a webpage to allow new refrigerants to be added; Long-term plan to harmonize requirements with ASHRAE 34, with the eventual goal of a single standard	
ANSI/ IIAR 3	Ammonia refrigeration valves	Provides minimum construction standard and performance conditions for ammonia valves	Generally considered a manufacturer's standard; Does not cover atmospheric relief valves	
EN 13313	Refrigerating systems and heat pumps	Competence of personnel	The plan is to replace this standard with ISO standard 22712, which is being developed by the same working group that authored the EN standard and has been sent out for the first of two rounds of voting before publication	
ISO 20854	Thermal containers – Safety standard for refrigerating systems using flammable refrigerants – Requirements for design and operation	Risk assessment of containers for refrigerated cargo using flammable refrigerants.	The standard describes how to do risk assessment of refrigerated cargo containers. It does not prescribe specific limits to refrigerant charge amount, and most requirements are related to what needs to be considered in the risk assessment.	Equipment/system design, Installation of new equipment/system, Operation, Maintenance and repair, Decommissioning.

https://ozone.unep.org/system-safety-standards

System and Safety Standards Summary

Standard	Scope of the standard/title	Technical aspects	Further information
IEC 60079-0	Explosive atmospheres – Part 0: Equipment - General requirements	Provides general requirements for construction, testing and marking of explosive equipment and explosive components intended for use in explosive atmospheres	Currently does not consider any special conditions that may be relevant as further guidance for A2L refrigerants; Intended for work environments only; not applicable for domestic applications; This standard has always included ammonia, which is a 2L refrigerant
IEC 60079-7	Explosive atmospheres – Part 7: Equipment protection by increased safety "e"	Provides requirements for the design, construction, testing and marking of electrical equipment and explosive components with type of protection increased safety "e" intended for use in explosive gas atmospheres	Currently does not consider any special conditions that may be relevant as further guidance for A2L refrigerants; Intended for work environments only; not applicable for domestic applications; This standard has always included ammonia, which is a 2L refrigerant
IEC 60079-10-1	Classification of areas – Explosive gas atmospheres	Provides guidance in assessing and ranking the potential for an explosion due to the possible release of flammable gas	Currently does not consider any special conditions that may be relevant as further guidance for A2L refrigerants; Intended for work environments only; not applicable to household usage; This standard has always included ammonia, which is a 2L refrigerant; Work is under way to look at developing requirements more tuned to 2L refrigerants; Drafting of the next revision is under way; Proposals have been submitted to try to make certain requirements more applicable to refrigeration, air-conditioning and heat-pump systems
IEC 60079-13	Explosive atmospheres - Part 13: Equipment protection by pressurized room "p" and artificially ventilated room "v"	Provides requirements where mechanically induced ventilation is used to reduce the hazard of flammable gas	Not applicable for domestic applications; Drafting of the next revision is under way
IEC 60079-14	Explosive atmospheres - Part 14: Electrical installations design, selection and erection	Provide requirements for the types of electrical equipment and electrical installations in areas classified under IEC 60079-10-1	Currently does not consider any special conditions that may be relevant as further guidance for A2L refrigerants; Refers to other parts of the IEC 60079 series for specific details of equipment construction and other hazards such as ignition due to electrostatic discharges; Not applicable for domestic applications; Drafting of the next revision is under way
IEC 60079-15	Explosive atmospheres – Part 15: Equipment protection by type of protection "n"	Provide requirements for sealed devices, non-incentive components and restricted breathing enclosures	This standard is referenced by most system safety standards for protection against ignition of leaked flammable refrigerant; The planned phase out of this standard is a minor problem for the safety standards that refer to the 2010 version; Not a long-term solution; It has yet to be decided which reference to use instead in the system safety standards
IEC 60079-29-1	Explosive atmospheres – Part 29-1: Gas detectors - Performance requirements of detectors for flammable gases	Performance requirements of detectors for flammable gases	
IEC 60079-29-2	Explosive atmospheres – Part 29-2: Gas detectors – Selection, installation, use and maintenance of detectors for flammable gases and oxygen	Selection, installation, use and maintenance of detectors for flammable gases	Other parts of the IEC 60079 series specify requirements for construction and performance of gas detectors; Not applicable for domestic applications

https://ozone.unep.org/system-safety-standards

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UN environment programme

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International Webinar

Alternative Refrigerants for High Ambient Temperature (HAT) Countries

In cooperation with

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Alternative Refrigerants for High Ambient Temperature (HAT) Countries

In cooperation with

10th June 2020

@ 2 pm (CET, Paris Time)

International Webinar

Alternative Refrigerants for High Ambient Temperature (HAT) Countries

In cooperation with

Risk Assessment

Bassam Elassaad, Consultant and RTOC member

10th June 2020

@ 2 pm (CET, Paris Time)

Agenda

- Definition of flammability

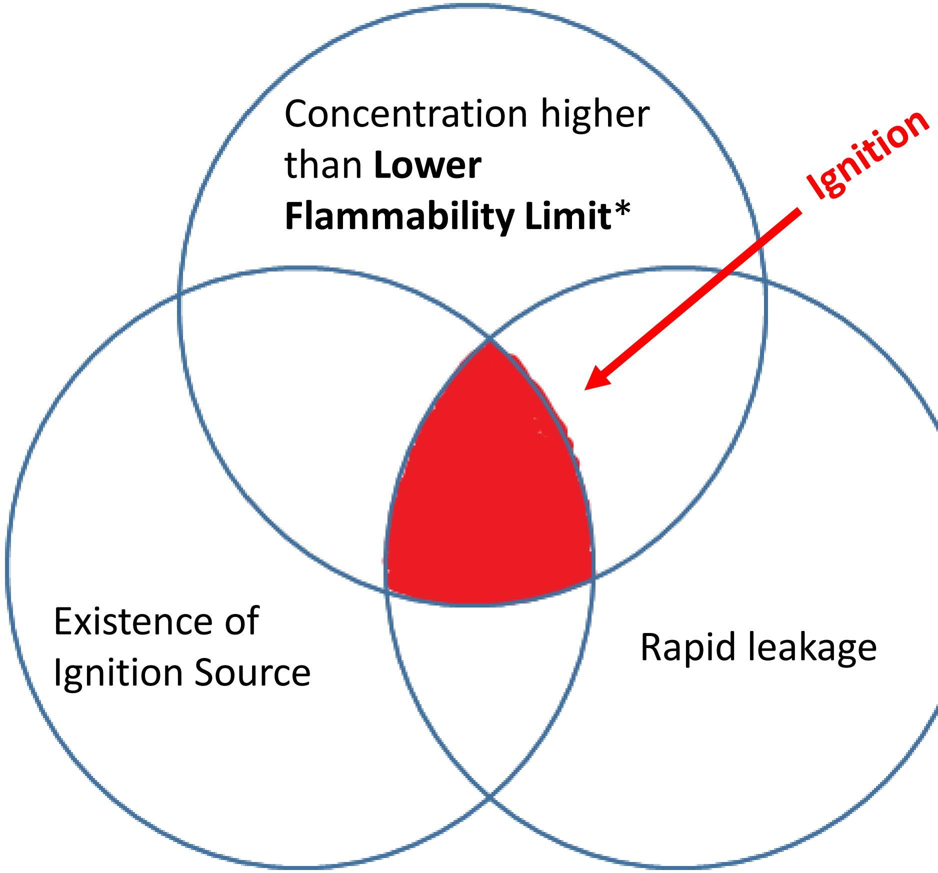
- Definition of

- Approach to a Risk Assessment Model

Flammability

Definition and Classes

Flammability



***Lower Flammability Limit** (LFL), usually expressed in volume per cent, is the lower end of the concentration range over which a flammable gas can be ignited at a given temperature and pressure.

Probability = [rapid Leakage] x [High Concentration] x [Ignition Source]

For more info on the concept of flammability

OzonAction Kigali Fact Sheet 10

OzonAction

UN environment

Technical Issues: Flammability

Background: The phase-down in the production and consumption of HFCs under the Kigali Amendment will ultimately lead to an 85% cut in the amount of HFCs that can be sold globally. To achieve such significant cuts, the users of HFCs will need to start utilising alternative fluids with much lower global warming potentials (GWPs[1]) than the current HFCs. Many of the low GWP alternatives[2] to HFCs are flammable – this creates potential safety issues and may restrict their usage. Safe and successful application of flammable refrigerants can be achieved providing the related safety issues are properly addressed. This Fact Sheet provides guidance on the impact of using flammable HFC alternatives.

Most HFCs are non-flammable and this is a characteristic that makes HFCs a popular choice for many end user applications. Being non-flammable makes it relatively easy to manufacture, install and maintain equipment such as refrigeration and air-conditioning (RACHP) systems. If some non-flammable refrigerant leaks, there will be no risk of fire. Similarly, an aerosol using a non-flammable HFC propellant may be safer to use in circumstances where there may be a source of ignition.

One of the reasons that most HFCs are non-flammable is that their molecular structure is very stable. Unfortunately, this property also gives HFCs a high GWP. Low GWP alternatives usually have less stable molecules – this results in many alternatives being flammable.

The Spectrum of Flammability: Prior to the Kigali Amendment there were plenty of non-flammable fluids available and a simplistic approach to flammability was used. If a flammable fluid is undesirable, many safety codes and standards took a conservative view and stated that flammable fluids cannot be used.

This simplistic approach is not ideal when there are fewer non-flammable fluids to choose from. To make more widespread use of low GWP alternatives, it is important to recognise that there are widely varying "levels of flammability". There is a continuous spectrum of flammability which includes:

- **Higher flammability fluids** – these are very easy to ignite and can burn with explosive impacts.
- **Flammable fluids** – these are more difficult to ignite, but once ignited will continue to burn and could create a significant hazard.
- **Lower flammability fluids** – these are very difficult to ignite, burn "gently" and might be extinguished when the source of ignition is removed. Mildly flammable fluids create a smaller fire risk than an equivalent amount of a more flammable fluid.
- **Non-flammable fluids** – cannot be ignited.

Some important international refrigeration safety codes recognise this spectrum of flammability. For example ISO 817, ISO 5149 and EN 378 include four distinct flammability classes. Unfortunately, not all standards take this approach; some simply refer to substances as being either non-flammable or flammable. This means that lower flammability fluids are treated in the same way as higher flammability ones, severely restricting the safe application of some flammable fluids.

Flammability Parameters:

A problem faced by both the authors of safety codes and users of flammable fluids, is that flammability is a complex issue and it is not easy to find a simple way of defining a safe operating envelope for each fluid. Flammability can be measured in a number of ways. The most important parameters include:

1. **LFL, lower flammability limit.** LFL is the minimum concentration of a gas or vapour that is capable of propagating a flame within a homogeneous mixture of that gas or vapour and air.
2. **UFL, upper flammability limit.** UFL is the maximum concentration of a gas or vapour that is capable of propagating a flame within a homogeneous mixture of that gas or vapour and air.

[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used
[2] See Kigali Fact Sheet 3 for further information on low GWP alternatives

Risk Assessment

Definitions

Concept of Risk Assessment

The concept behind risk assessment is to define what is an acceptable risk given the conditions for ignition in a particular location.

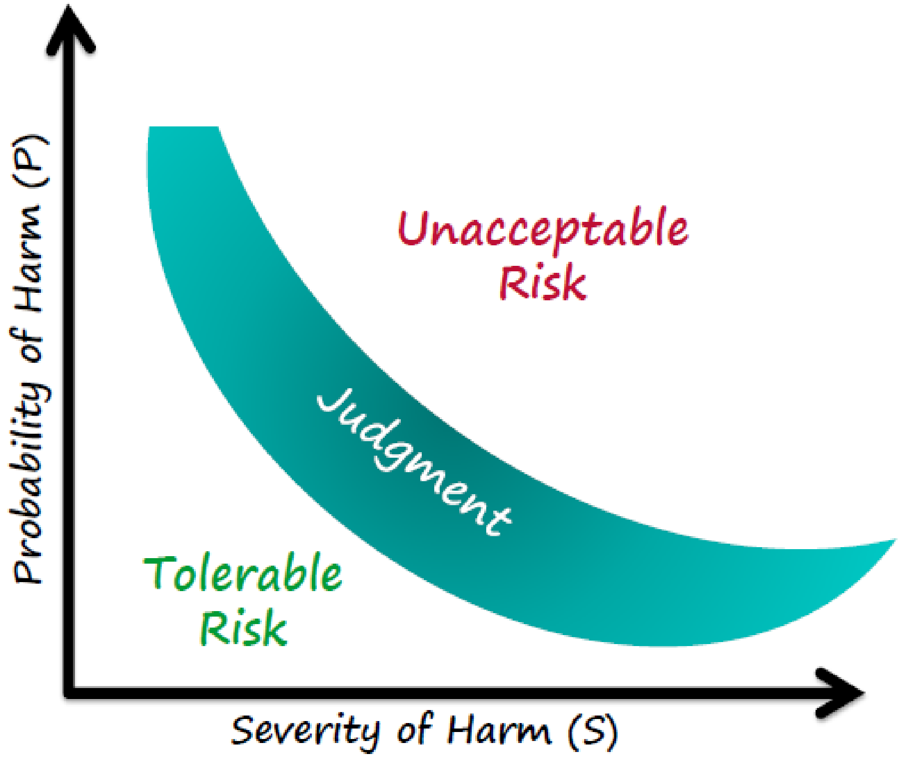
To begin: a definition of risk is agreed upon and a matrix of probability vs. severity is built.

Definitions:

- ❑ ***Risk*** is a combination of the probability of **concurrence of harm** and the **severity of that harm**.
- ❑ ***Tolerable risk*** is the level of risk that is accepted in a given context based on the current acceptable values by a community.
- ❑ ***Residual risk*** is the risk remaining after reduction measures have been implemented. Safety is freedom from risk which is not tolerable.

Tolerable vs. Unacceptable Risk

The risk levels depend on the severity of injury, the amount of damage to the environment, the frequency at which people are exposed to the danger and the duration of exposure.



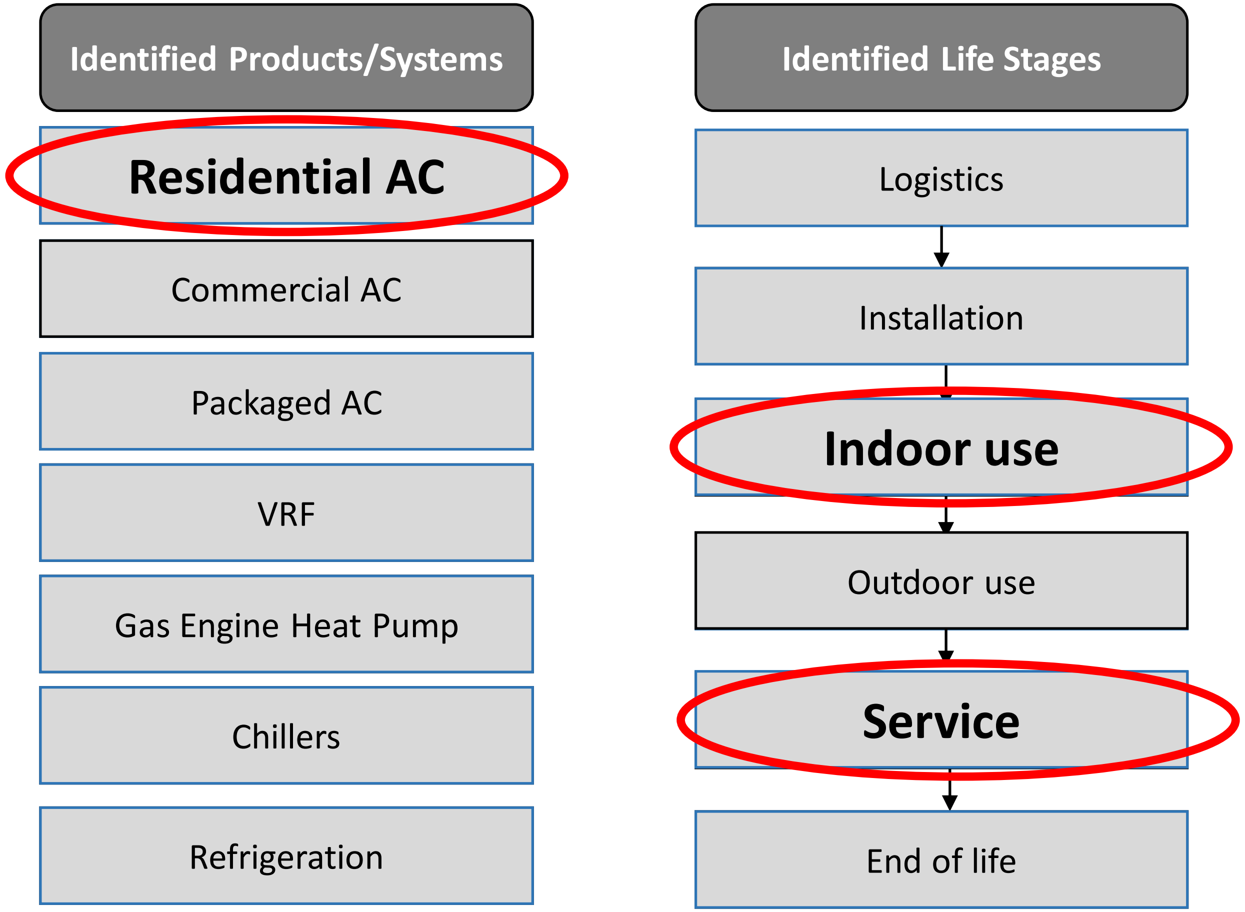
Risk Assessment Model

Approach

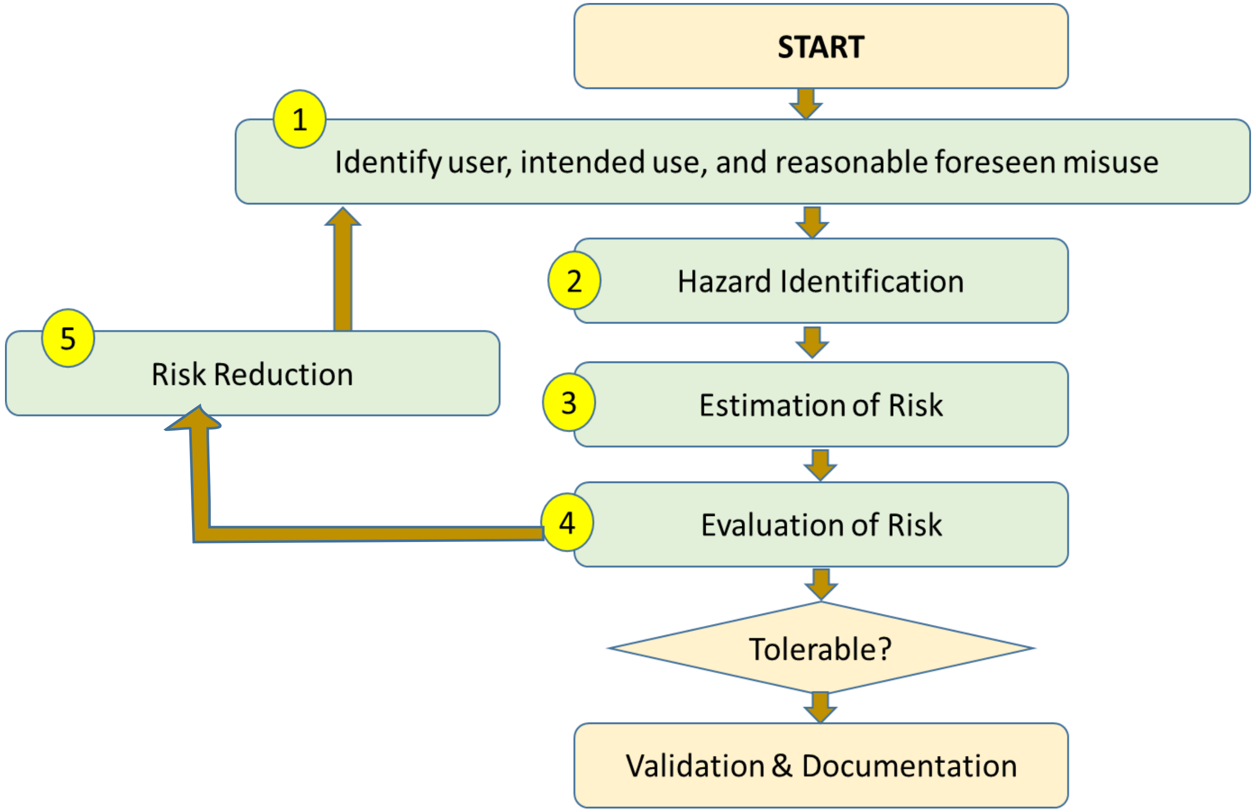
Process to build a model

- An outline of the methodology and the components that are the basis for the risk assessment model;
- A model of what data can be collected;
- Information on the regulatory regime and the enforcement mechanisms;
- International standards play a role in the next step of risk assessment in the form of recommendations for local standards;
- Rigorous regulations as those adopted in other regions must be adapted to HAT countries;
- Stakeholders: governments and local research institutions, industry and private sector, and UN Environment & UNIDO

Selection of equipment type and application



Procedure of Risk Assessment according to ISO/IEC 51



Hazard Identification

	None	**Negligible** (slight injury)	**Marginal** (need for outpatient treatment)	**Critical** (serious injury or need to be hospitalized)	**Catastrophic** (death)
Frequent	C	B3	A1	A2	A3
Probable	C	B2	B3	A1	A2
Occasional	C	B1	B2	B3	A1
Remote	C	C	B1	B2	B3
Improbable	C	C	C	B1	B2
Incredible	C	C	C	C	C
A = Unacceptable risk levels: 1=least, 3= highest		B= Risk levels should be reduced 1= least, 3= highest		C= Socially acceptable risk levels	

Estimation of Risk: Risk Map

Likelihood		
	Frequently	10^{-4}
	Sometime	10^{-5}
	Rare	10^{-6}
	Usually not	10^{-7}
	Very difficult	10^{-8}
	Extremely difficult	10^{-9}
	Near Zero	10^{-10}

Possibility of an incident	0	I	II	III	IV
	No damage	Minor damage	Light damage	Major damage	Lethal damage
	Severity →				

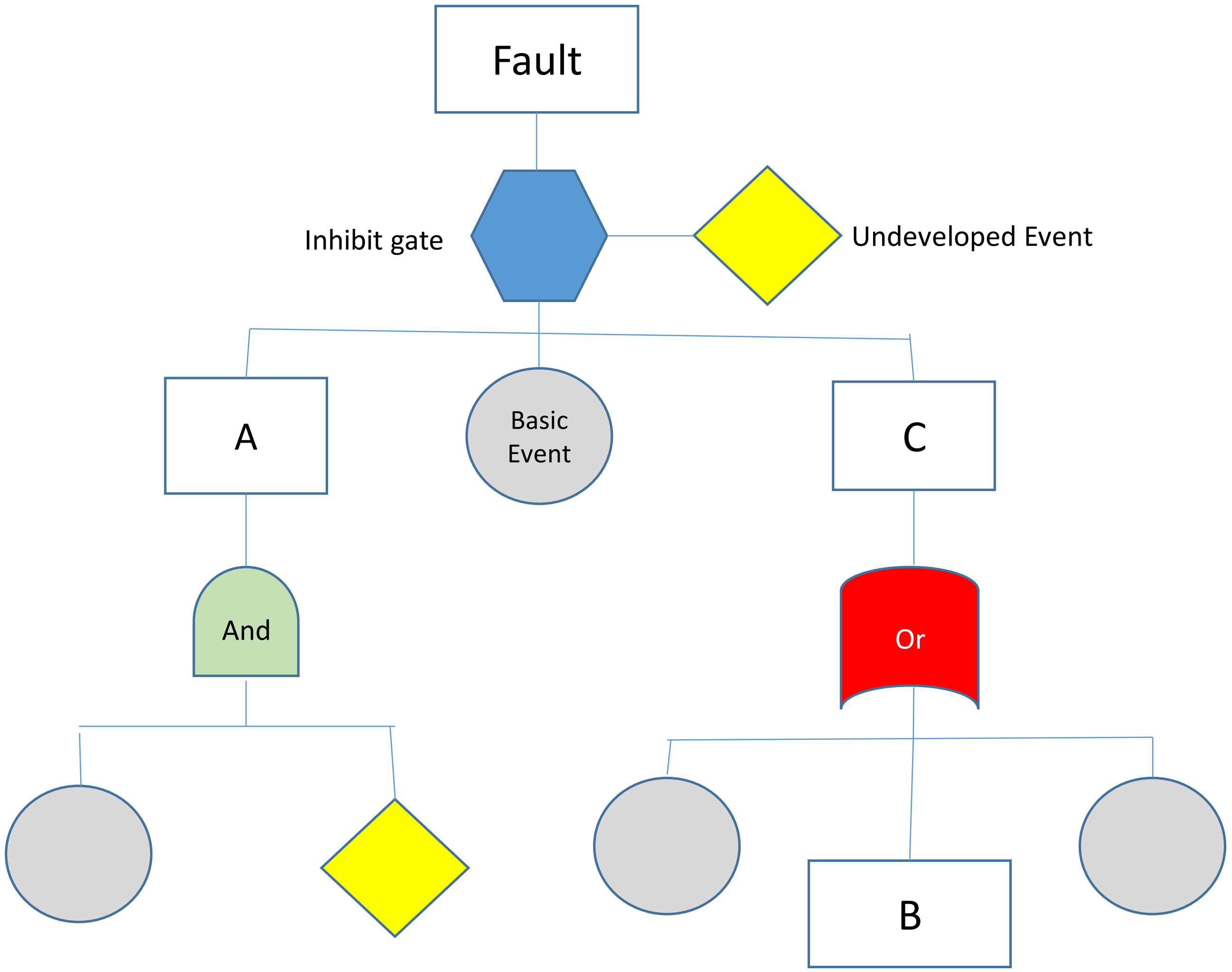
Tolerable Risk

Product/System	Unit Population	Tolerable risk	
		Usage stage	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}

Tolerable risk depends on the number of units in the market of the product identified.
Tolerable risk depends on the frequency and severity of the accident.

Evaluation of Risk: Fault Tree Analysis

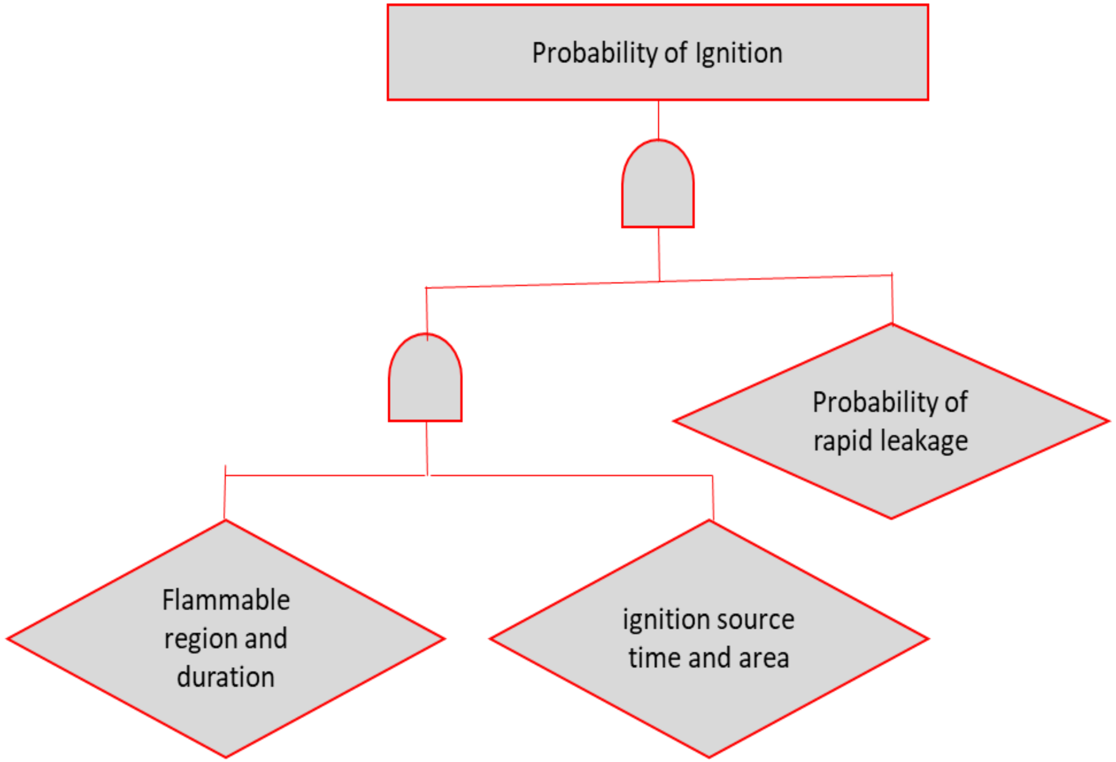
- A "top-down" approach, starting with the undesired effect as the top event of a tree of logic.
- Fault trees (FTs) consist of various event boxes, which reflect the probability or frequency of key events leading up to a system failure.
- The event boxes are linked by connectors (gates), which describe how the contributing events may combine to produce the system failure.
- Events may be combined in different ways: in cases where a series of events must all occur to produce an outcome (e.g., ignition source and sufficient oxygen to support combustion), the probabilities or frequencies of the individual contributing events are multiplied via an "AND" gate;
- in cases where only one of a series of events is needed to produce an outcome (e.g., a strong spark, open flame, or a hot surface all possibly leading to refrigerant ignition), the probabilities are usually added via an "OR" gate.



In the case of flammability

Ignition would happen when

- ✓ the probability of leakage is combined with (“and” gate)
- ✓ the possibility of the length of time that a flammable cloud exits in a covered area
- ✓ in case of the existence of an ignition source (another “and” gate)



Validation and Documentation

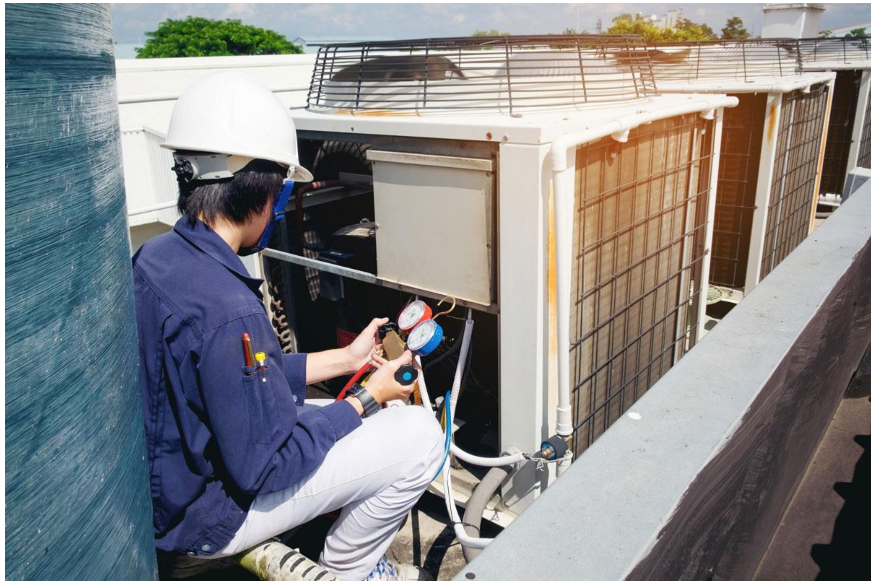
- Once the countermeasures have been introduced, the FTA factors are reviewed and these countermeasures are added in the appropriate position of the tree.
- A new calculation can then be made and repeated until the calculations confirm the accepted tolerance according to the risk map.
- The results can then be released to the public and standards and codes can be drawn.

HAT Example

Of a Risk Assessment Model

Background

- The example was done in collaboration with HAT countries and Japan.
- The purpose is to simulate a risk scenario in HAT region with unique climate, product-usage, lifestyle and culture which differs from Japan's case.



Workshop in Tokyo

Case Study Parameters

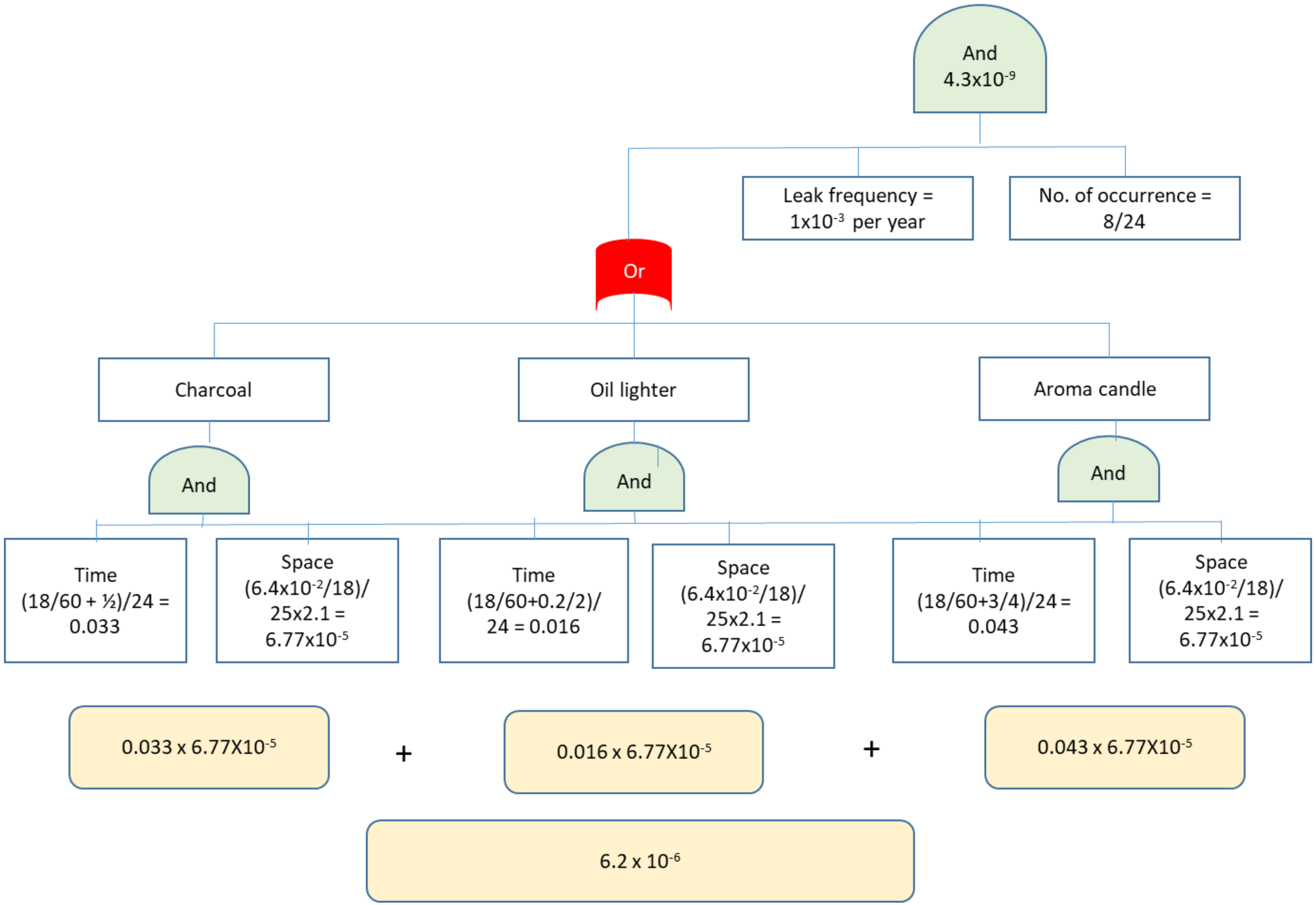
- An office space in a government building with a 5.3 kW split system using an A2L refrigerant.
- Usage stage when the equipment is running and during repair service stage

Indoor Condition during usage of target product		Value
Room size (m^2)	max	25
	min	16
Height of installation(m)		2.1
Ceiling height(m)		2.8
Ventilation	yes/no	YES
	Ventilation amount (m^3/hr.)	80
The area of the gap under the door (m^2)		0.02
other openings, if any (m^2)		0

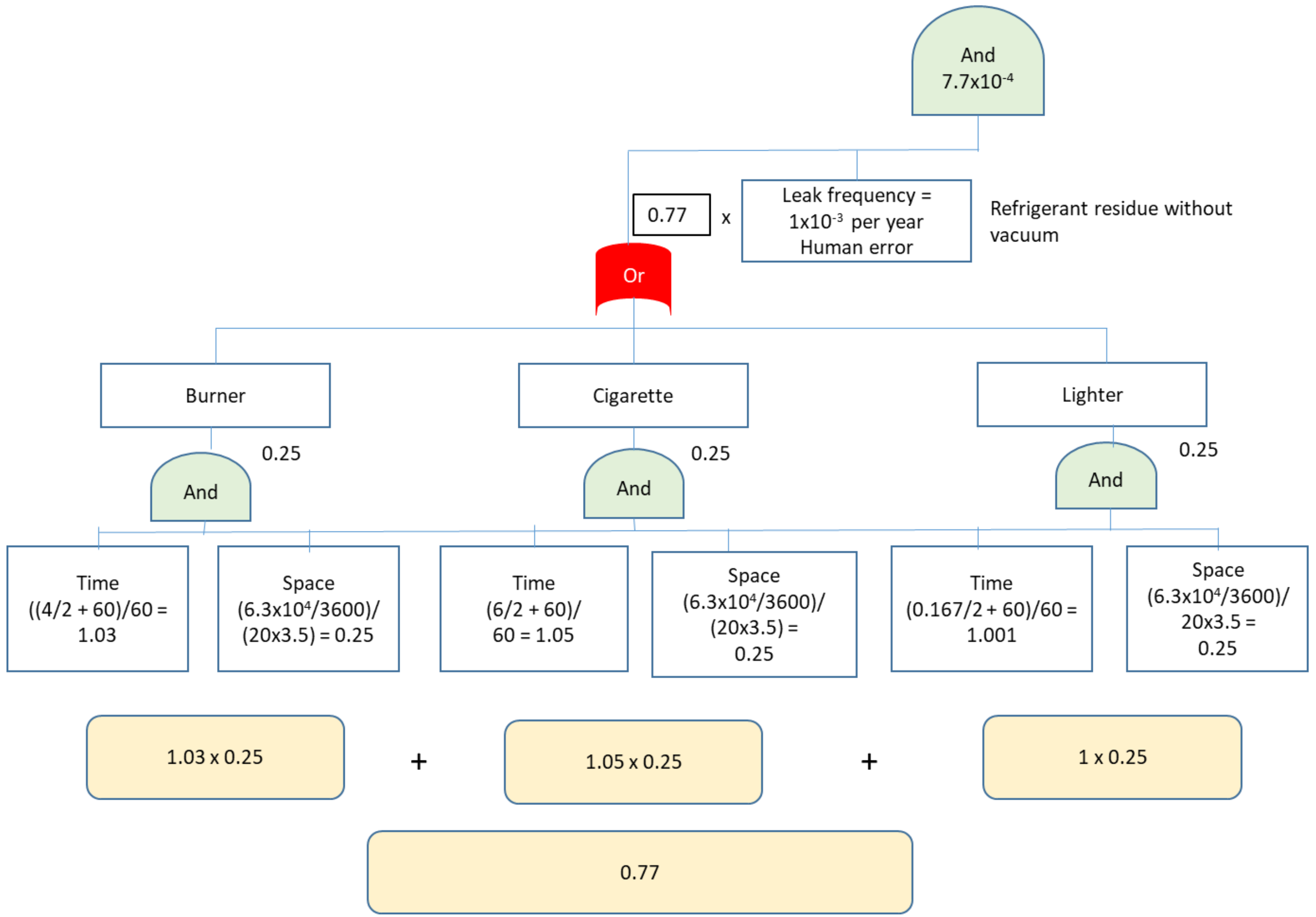
Outdoor Condition during usage of target product		Value
Size of the place enclosed with walls , or fences etc.(m^2)	max	8
	min	4

Condition during repair of target product	value
Average size of outdoor spaces for repairs (m^3)	20
Percentage of single outdoor unit installations(A%）	50
Percentage of the installations of multiple outdoor units (B%）	50
Average working hours per repair (outdoor unit) (hr.)	1
Average working hours per repair (indoor unit)(hr.)	0.5
Wind condition (wind velocity）(m/s)	1 TO 3
Windless condition percentage (%)	10

FTA Usage Stage



FTA Servicing Stage



Mitigation

- The calculations are similar to the usage stage.
- The Total probability is 0.77x $1x10^{-3}$ = $7.7x10^{-4}$ which is shown in the top "And". This puts it in the "Frequent" from the Risk Map
- Mitigation measures should be taken.
- One evident measure is to ban smoking in the service area!

Conclusion

And Recommendations

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.

Recommendations

- Analyze risks in the logistics side of the supply-chain i.e. Installation, In-door use, outdoor use, servicing and end of life (decommission);
- For HAT countries: continue risk assessment based on actual situations, and reduce the risk by implementing various measures that are verified by FTA;
- Minimize ignition probability by implementing various measures that are verified by FTA;
- Risk assessments of other stages matching cultural and lifestyle aspects should also be studied.

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UN environment programme

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International Webinar

Alternative Refrigerants for High Ambient Temperature (HAT) Countries

In cooperation with

ASHRAE

International Webinar

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10th June 2020

@ 2 pm (CET, Paris Time)

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Other Examples of Relevant Flammability Research

Omar Abdelaziz, Consultant and RTOC Co-Chair
&
Ole Nielsen, Chief of Montreal Protocol Division, UNIDO

10th June 2020

@ 2 pm (CET, Paris Time)

Agenda

45 min, 20 - 25 slides

- Flammability Research From Around the World:
  - Air Conditioning Heating and Refrigeration Institute (AHRI)
  - ASHRAE
  - U.S. Department of Energy

- Other (worldwide activities)

AHRI – Previous Flammability Work

Study	Report Author(s)	Report ID
Risk Assessment of Residential Heat Pump Systems Using 2L Flammable Refrigerants	T. A. Lewandowski, 2012	AHRI–8004
Risk Assessment of Class 2L Refrigerants in Chiller Systems	B. Goetzler, M. Guernsey, and C. Weber, 2013	AHRI–8005
Risk Assessment of Refrigeration Systems Using 2L Flammable Refrigerants, 2015	N/A	AHRI–8009
Risk Assessment of Class 2L Refrigerants in Commercial Rooftop Units,	B. Goetzler, M. Guernsey, S. Faltermeier and M. Droesch, 2016	AHRI–8016

* Furthermore, there were 9 project reports published under the "refrigerant flammability" task for the MCLR Program between 1994 and 1998 (HCFC phaseout period)

AHRI – Recently Concluded Flammability Work

Study	Report Author(s)	Report ID
Investigation of Energy Produced by Potential Ignition Sources in Residential Application	D.K. Kim and P.B. Sunderland, 2017	AHRI–8017
Benchmarking Risk by Whole Room Scale Leaks and Ignitions Testing of A2L Refrigerants	P. Gandhi, G. Hunter, R. Haseman and B. Rodgers, 2017	AHRTI–9007–01
Benchmarking Risk by Whole Room Scale Leaks and Ignitions Testing of A3 Refrigerants	George Hunter, 2019	AHRTI–9007–02

http://www.ahrinet.org/Resources/Research/AHRI-Flammable-Refrigerants-Research-Initiative

AHRI – Recently Concluded Flammability Work

Study	Report Author(s)	Report ID
Hot Surface Ignition of A2L Refrigerants	M. Cundy, 2017	AHRTI–9008
Leak Detection of A2L Refrigerants in HVACR Equipment	M. Wagner and R. Ferenchiak, 2017	AHRTI–9009
Experimental Study on the Consequences of Full-scale Ignition Events Involving the A2L Refrigerant R-454C	Davis and Pagliaro, 2019	AHRTI–9013

http://www.ahrinet.org/Resources/Research/AHRI-Flammable-Refrigerants-Research-Initiative

ASHRAE Flammability Research

- Concluded
  - RP-1580: Study of Input Parameters for Risk Assessment of 2L Flammable Refrigerants in Residential Air Conditioning and Commercial Refrigeration Applications
  - RP-1794: White Paper Investigation Relating to the Use of Odorants in Flammable Refrigerants
  - RP-1807: Guidelines for Flammable Refrigerant Handling, Transporting, Storing and Equipment Servicing, Installation and Dismantling
  - RP-1808: Servicing and Installing Equipment using Flammable Refrigerants: Assessment of Field-Made Mechanical Joints
- Ongoing
  - RP-1806: Flammable Refrigerants Post-Ignition Simulation and Risk Assessment Update
- Co-Funded with AHRI:
  - **ASHRAE-1773:** Ignition Potential from Electrical Devices in Commercial and Residential Applications Using 2L Refrigerants

U.S. DOE funded Research into Flammable Refrigerants

- Determination of setting charge limits for various types of equipment employing flammable refrigerants (Completed)
  - The primary objective of the project is to examine the currently imposed limits for flammable refrigerant alternatives (A2L, A2, and A3) and identify reasonable adjustments to these limits as appropriate.
- Modelling Tools for Flammability Ranking of Low-GWP Refrigerant Blends (Ongoing)
  - The project is to develop modelling tools that can predict the burning velocity of arbitrary mixtures of R32, R125, R134a, R152a, 1234yf, and 1234ze(E), so that flammability of a blend can be minimized, while simultaneously maximizing performance related to other parameters

http://www.ahrinet.org/Resources/Research/AHRI-Flammable-Refrigerants-Research-Initiative

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International Webinar

Alternative Refrigerants for High Ambient Temperature (HAT) Countries

In cooperation with

Other examples of flammability research (for A3)

Webinar, June 10, 2020

Presented by:
Ole Nielsen, Chief of Montreal Protocol Division, UNIDO

Based on material received by:
Mr. Tingxun Li / Sun Yat sen University; and
Mr. Yanwei Dou / CHEAA

Available online at www.sciencedirect.com
SciVerse ScienceDirect
journal homepage: www.elsevier.com/locate/ijrefrig

Research on the flammability hazards of an air conditioner using refrigerant R-290

Wang Zhang[a,b,*], Zhao Yang[a], Jin Li[b], Chang-xing Ren[b], Dong Lv[b], Jie Wang[b], Xin Zhang[b], Wei Wu[b]

[a] School of Mechanical Engineering, Tianjin University, 92 Weijin Road, Tianjin 300072, PR China
[b] Tianjin Fire Research Institute of MPS, No. 110 Weijinnan Road, Tianjin 300381, PR China

INTERNATIONAL JOURNAL OF REFRIGERATION 40 (2014) 380–389
Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/ijrefrig

Indoor leakage test for safety of R-290 split type room air conditioner

Tingxun Li

School of Engineering, Sun Yat-sen University, West XINGANG Road 135, Guangzhou 510275, China

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/ijrefrig

Comparative evaluation of risk of a split air conditioner and refrigerator using hydrocarbon refrigerants ☆

D. Colbourne[a,*], K.O. Suen[b]

[a] Re-phridge, PO Box 4745, Stratford-upon-Avon CV37 1FE, UK
[b] University College London, Gower Street, London WC1E 6BT, UK

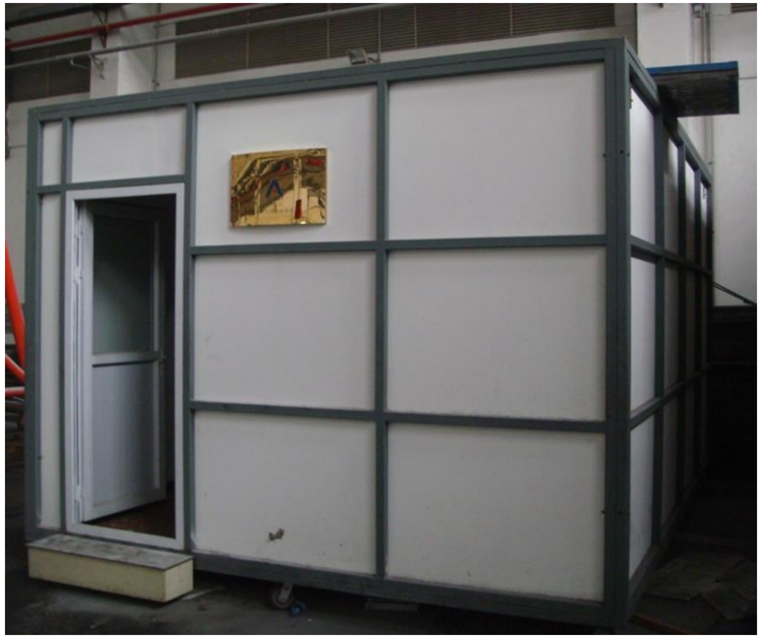
International Journal of Refrigeration 90 (2018) 163–173
Contents lists available at ScienceDirect
International Journal of Refrigeration
journal homepage: www.elsevier.com/locate/ijrefrig

Experimental and numerical simulation analysis of R-290 air conditioner leak

Hu Maojuan[a], Li Jinbo[b], Liu Zhe[a], Li Tingxun[a,*]

[a] School of Engineering, Sun Yat-sen University, Xingang West Road 135, Guangzhou 510275, China
[b] Midea Group, No. 6 Midea Avenue, Shunde 528311, China

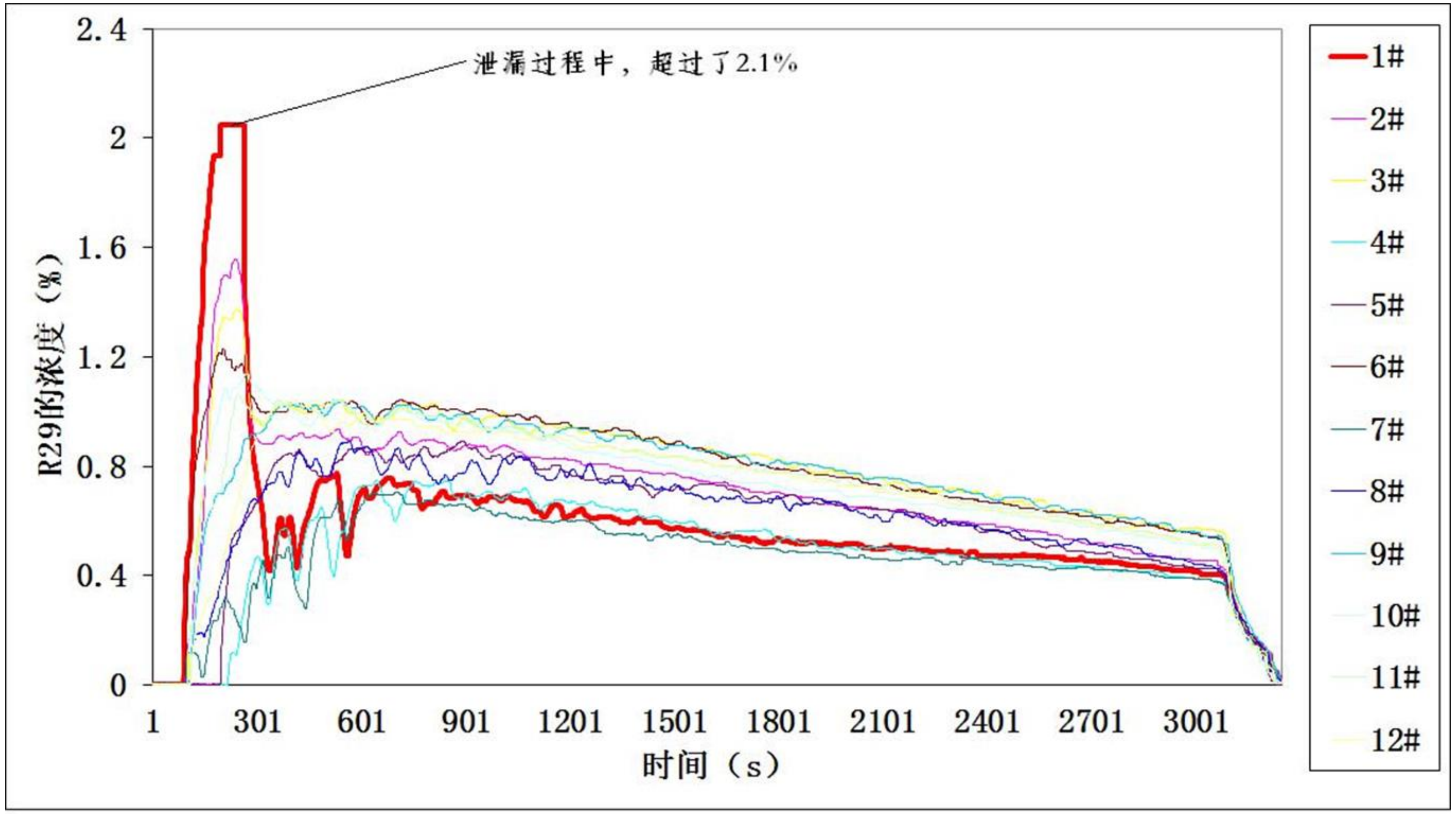
Substantial practical tests in China



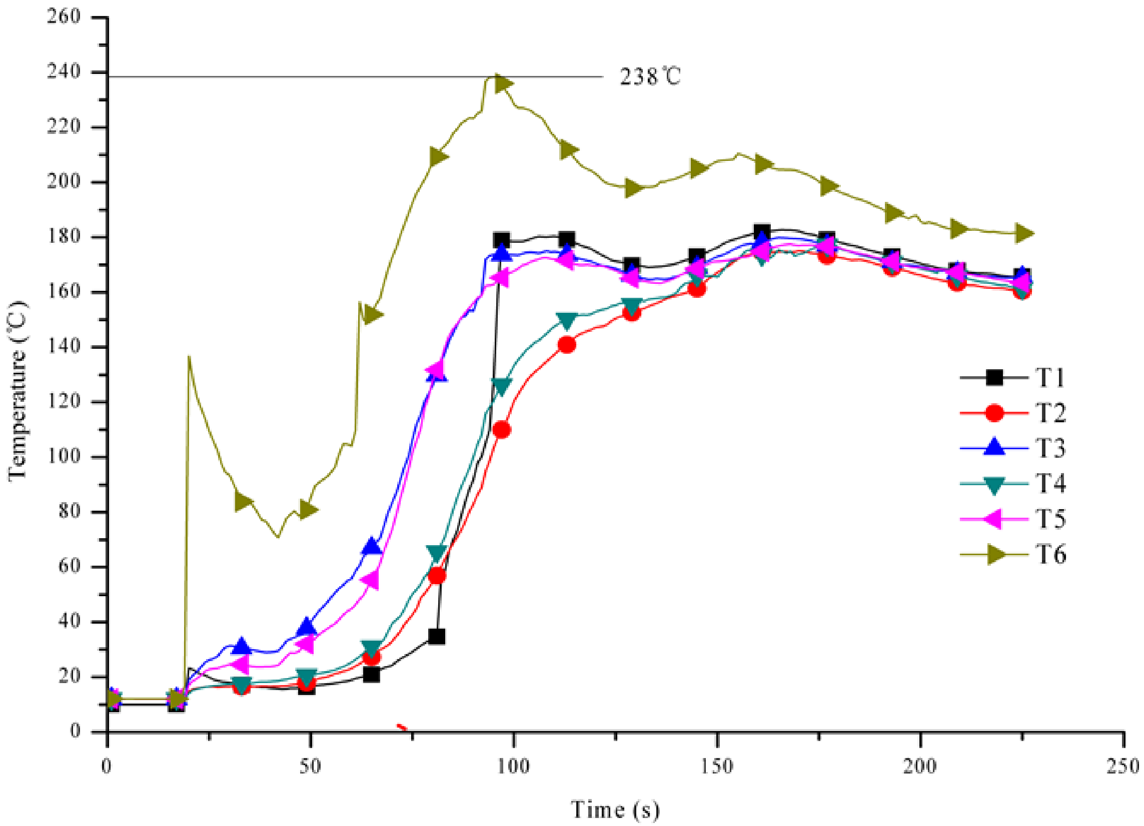
4.8m×3.6m×2.6m (382g)
3.6m×3.6m×2.6m (331g)

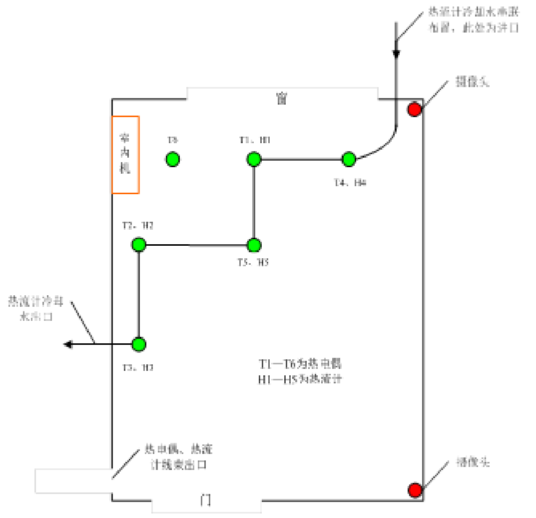
h: 0.2m ; 0.8m; 1.5m

Refrigerant concentration distribution during leak

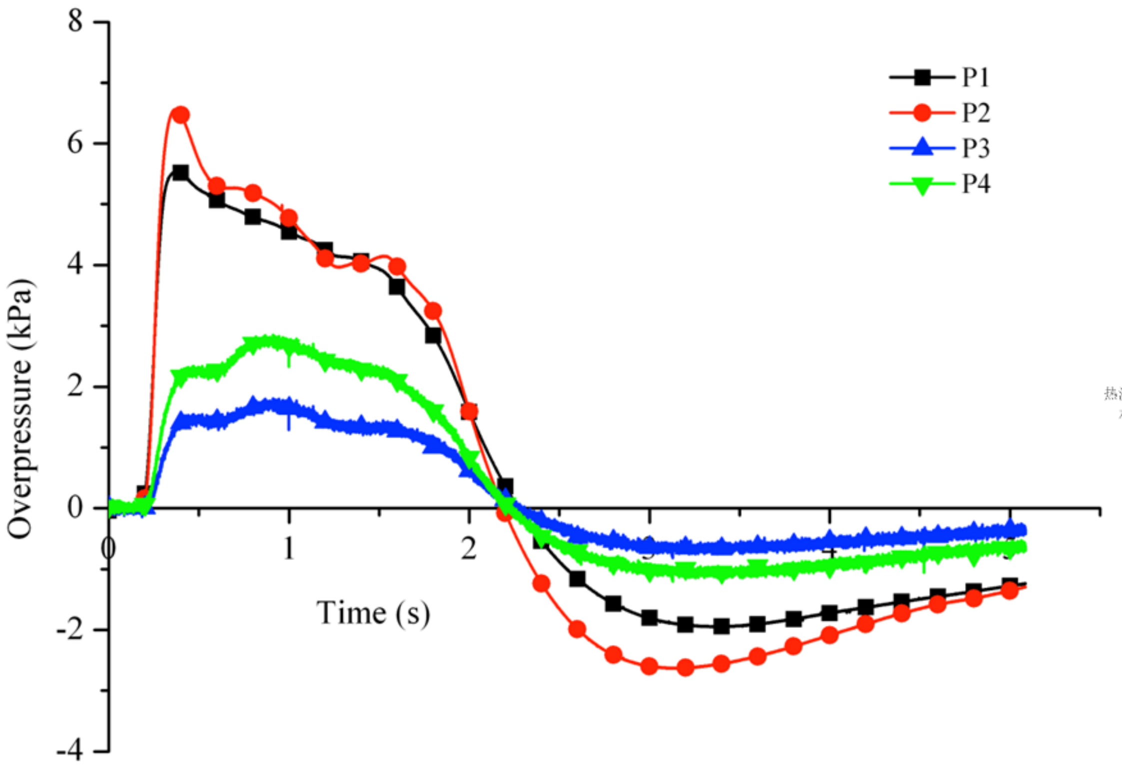


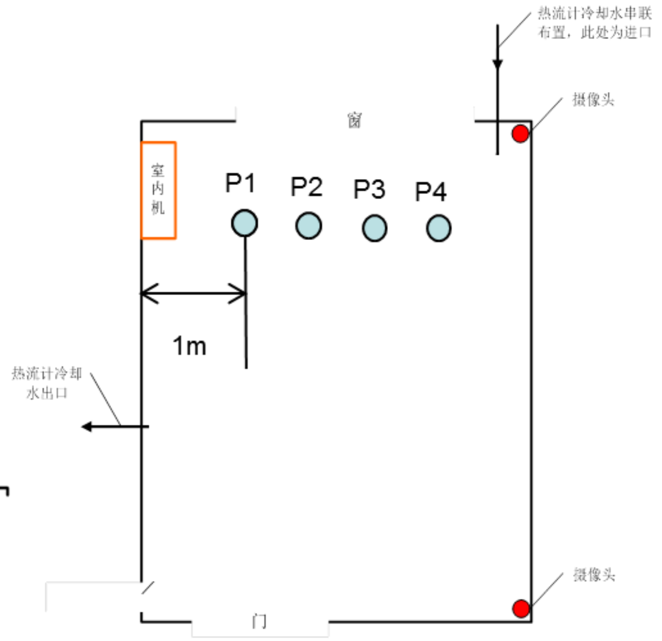
Ignition test of indoor unit



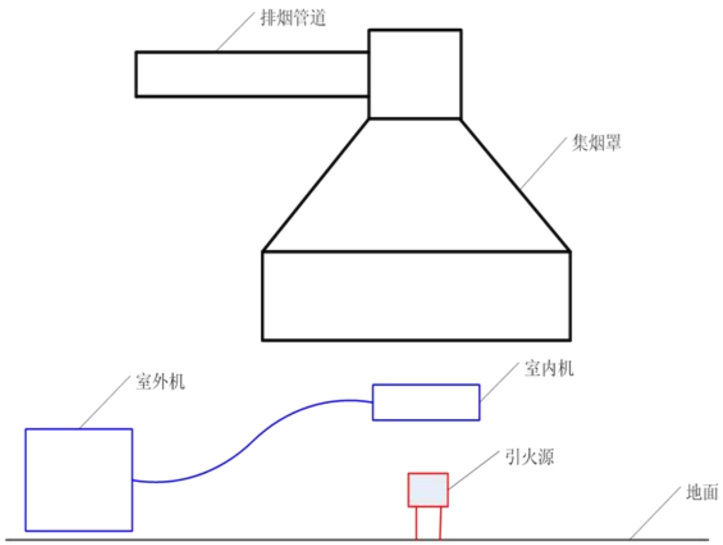


Ignition test of indoor unit

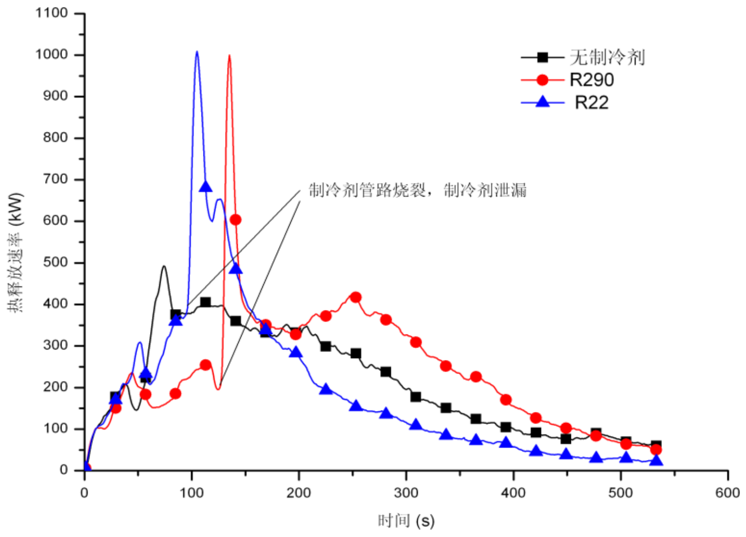




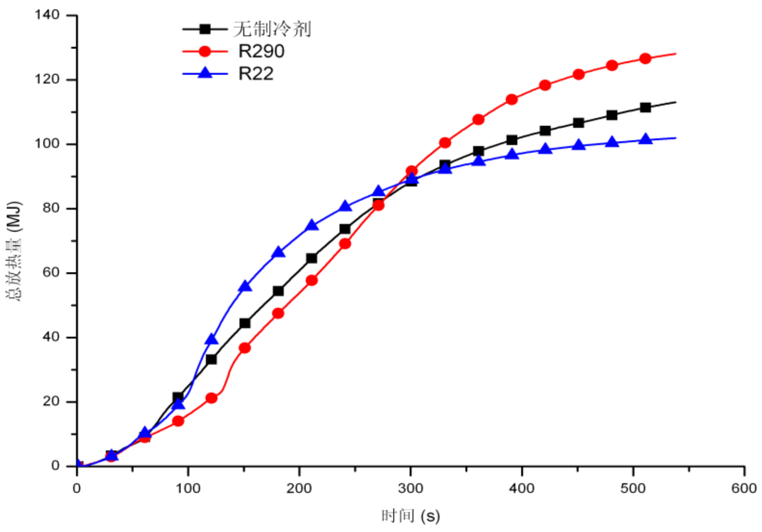
Test of combustion of indoor unit



Test of combustion of indoor unit



Heat flux



Heat

O.Nielsen@unido.org

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Session 3

International Webinar

Alternative Refrigerants for High Ambient Temperature (HAT) Countries

In cooperation with

10th June 2020

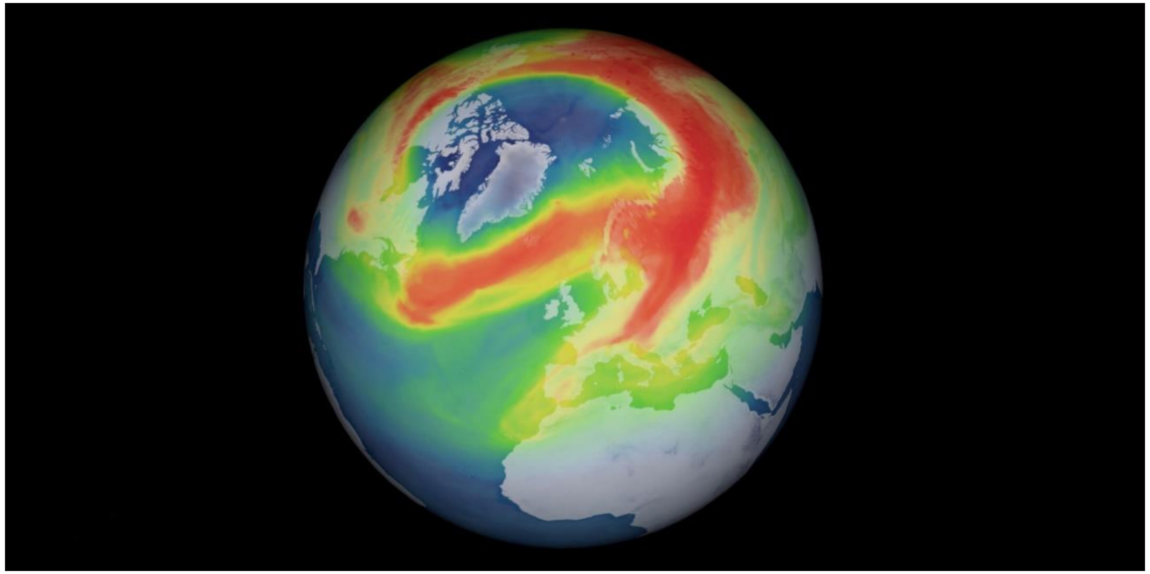
@ 2 pm (CET, Paris Time)

International Webinar

Alternative Refrigerants for High Ambient Temperature (HAT) Countries

In cooperation with

Feedback and Comments by HAT National Ozone Units (NOUs)



UN environment programme

UNIDO

OzonAction

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10th June 2020

@ 2 pm (CET, Paris Time)

vote of thanks