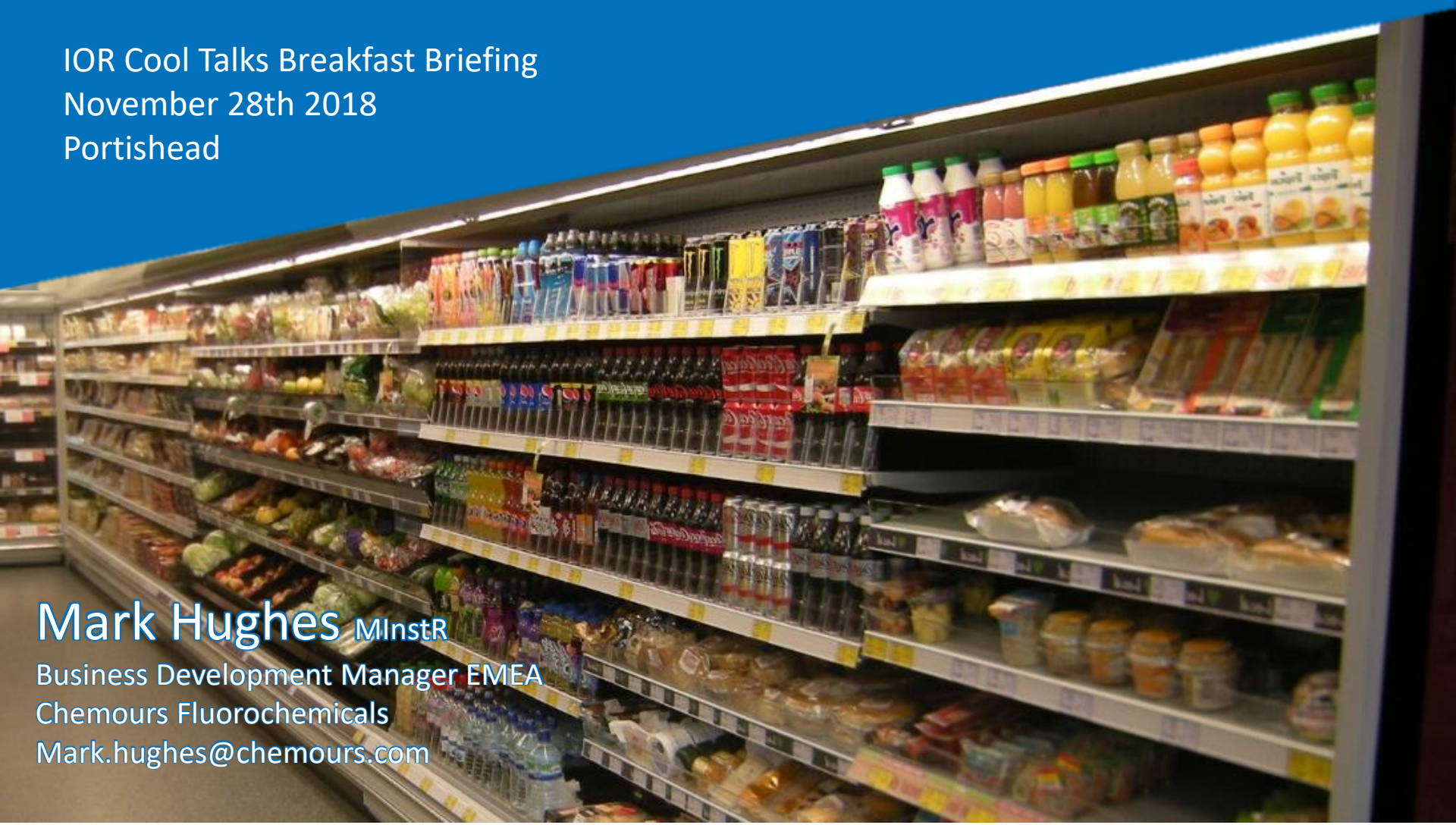
Options for Replacing R-404A

IOR Cool Talks Breakfast Briefing
November 28th 2018
Portishead



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Agenda

- Legislation
  - Where are we today?
  - F-Gas
    - What does it say? How should the market react?
    - How has the market reacted? What needs to change?
- Which Refrigerants Can I use?
  - A1 - Non-flammable Options for R-404A
  - A2L – Mildly Flammable Options for R-404A
  - How Flammable is 2L Mildly Flammable?
- Standards
  - Current Status
  - EN378 – 2L Refrigerant Charge Calculator
- Conclusions

Fluorochemicals – 3 Decades of Regulatory Changes

EU introduces first regulation to control CFCs (EEC) No 594/91 after 1988 agreement (88/540/EEC)

1995 CFCs Banned in developed countries under the MP

1974 | 1987 | 1990 | 1991 | 1997 | 2000 | 2006 | 2014 | 2016

Rowland & Molina Publish paper citing CFCs as major source of ozone depletion

The Montreal Protocol on Substances that Deplete the Ozone Layer

U.S. Environmental Protection Agency introduces the Significant New Alternatives Program under the Clean Air Act (1990)

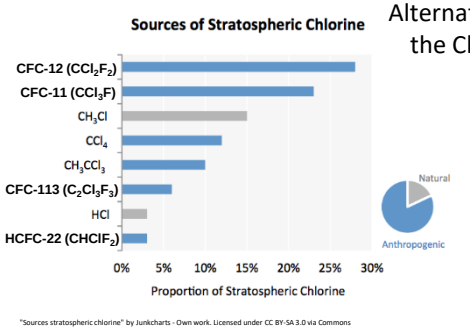
Kyoto Protocol Focus on Climate Change and not just Ozone Depletion. Sets targets for reductions of emissions of a "basket" of greenhouse gases

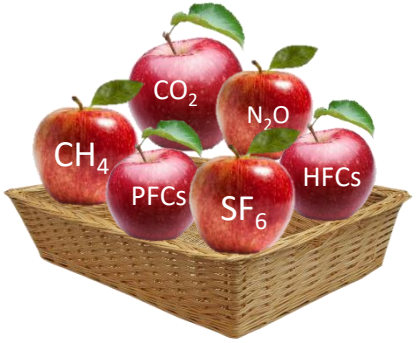
(EC)2037/2000 Defines phase-out of HCFCs in EU

(EC) 842/2006 Introduces emissions controls for HFCs & Directive 2006/40/EC bans the use of products with GWP>150 in Car AC.

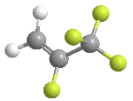
(EC)517/2014 Introduces Phase-Down in terms of CO_2 equivalents of F-Gases in EU encouraging use of Low GWP HFO Products such as R1234yf (CH_2=$CFCF_3$)

An amendment to the Montreal protocol was agreed by 197countries to Phase Down the use of HFCs starting in 2019 and reducing to 15-20% by 2040





HFCs such as R-134a ($C_2H_2F_4$)
PFCs such as R-116 (C_2F_6)



Three Pillars of F-Gas Regulation 517/2014

F-Gas - New Equipment Restrictions

❖ **Domestic Refrigerators and Freezers**

- Only use refrigerants with GWP>150 from **1.1.2015**

❖ **Refrigerators and Freezers for commercial use** (hermetically sealed)

- ❖ **1.1.2020** STOP of R404A/ 507 (GWP>2500)
- ❖ **1.1.2022** STOP of All HFC and HFC-containing blends with GWP>=150

❖ **Stationary Refrigeration**

- ❖ **1.1.2020** STOP of All HFC and HFC-containing with GWP>2500, except applications below -50ºC product temperature

❖ **Multipack centralised refrig systems for commercial use with capacity > 40kW**

- ❖ **1.1.2022** STOP of all HFC and HFC-containing blends with GWP>150
- ❖ Except in the primary refrigeration circuit of a CCD-system with GWP<1500 may be used

❖ **Stat. A/C** (single split a/c with <3kg of HFCs)

- ❖ **1.1.2025** STOP of all HFC and HFC-containing blends with GWP>750, mainly R410A, R407C

F-Gas - Existing Equipment Service Restrictions

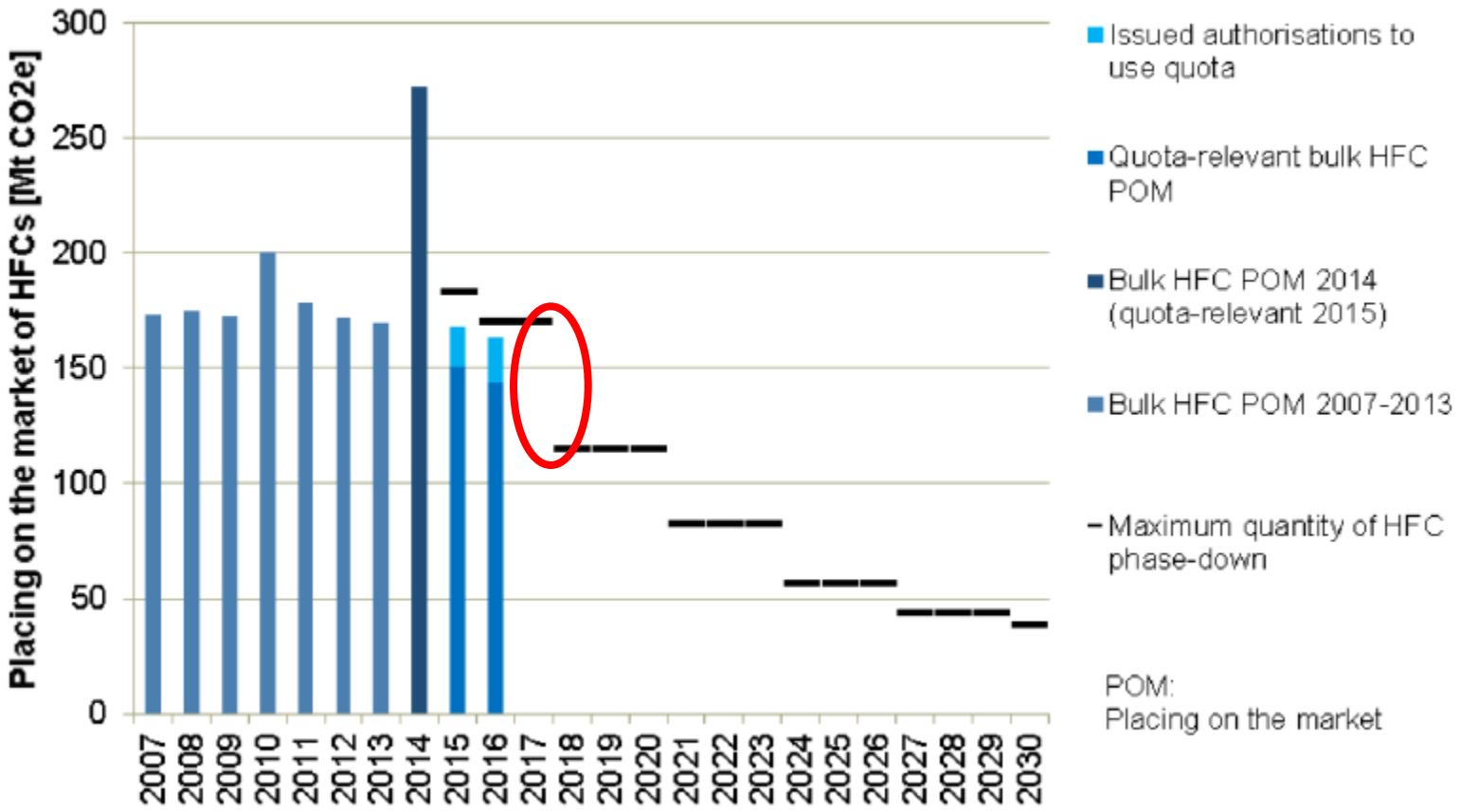
❖Service Ban

- ❖ **Jan 2020** STOP of HFC and HFC-containing (GWP>2500) above 40t of CO2-e (e.g. >10.2kg R404A); means Supermarkets, industrial Refrigeration, larger food stores, etc.

❖Exceptions:

- ❖ Military Equipment
- ❖ Applications with product temp <-50°C, e.g. R23/ R508
- ❖ Recycled/ Reclaimed HFCs with GWP>2500 is allowed until **end of 2029**

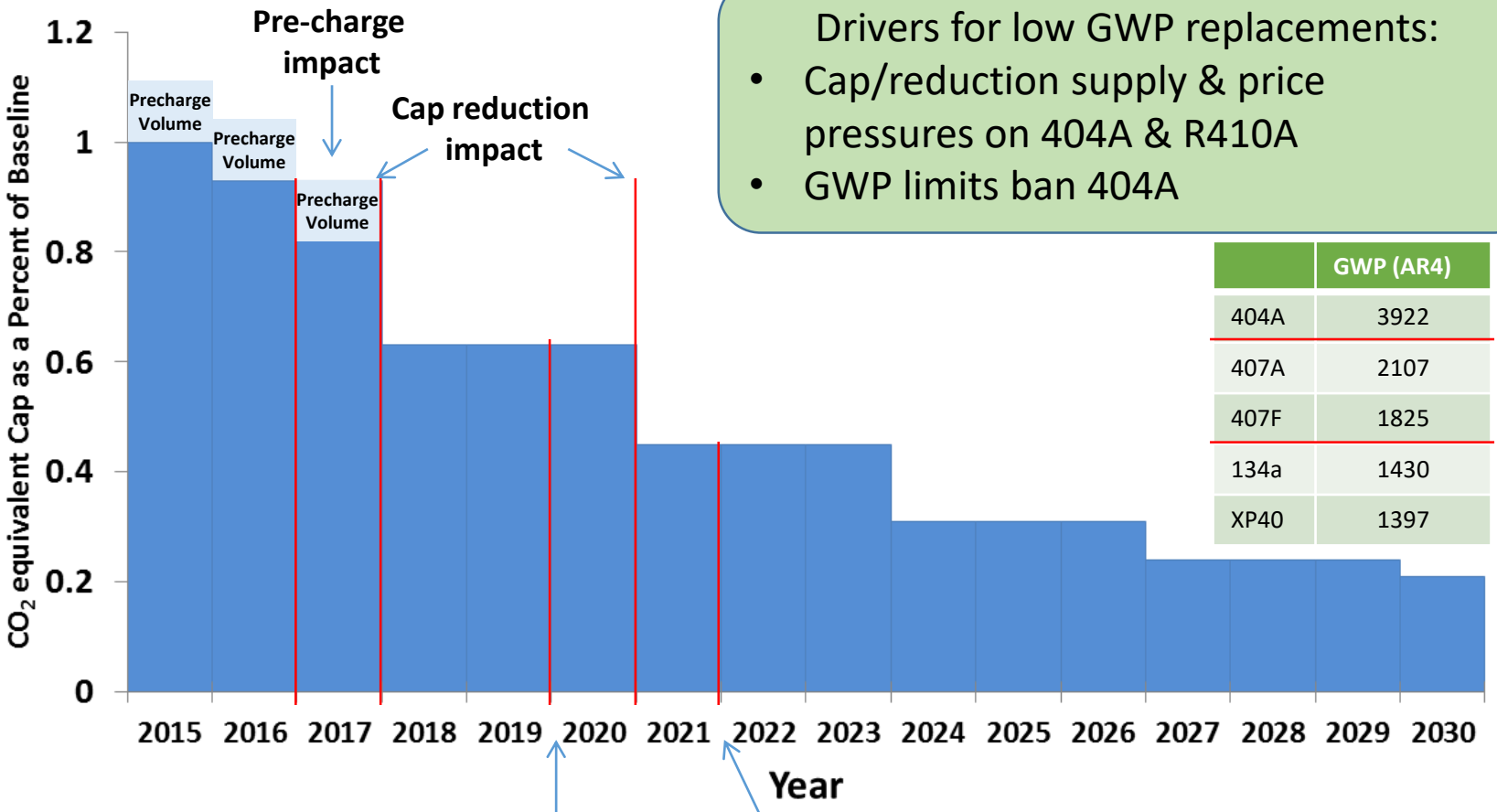
Approaching the Cliff's Edge: F-Gas 2015 to today



Source: EEA Report - Fluorinated GHG 2016

F-Gas - CO_2 Equivalent Phase Down

Precharge Volume = required CO_2-equivalents for precharged equipment (ca. 12 %)



Drivers for low GWP replacements:

- Cap/reduction supply & price pressures on 404A & R410A
- GWP limits ban 404A

	GWP (AR4)
404A	3922
407A	2107
407F	1825
134a	1430
XP40	1397

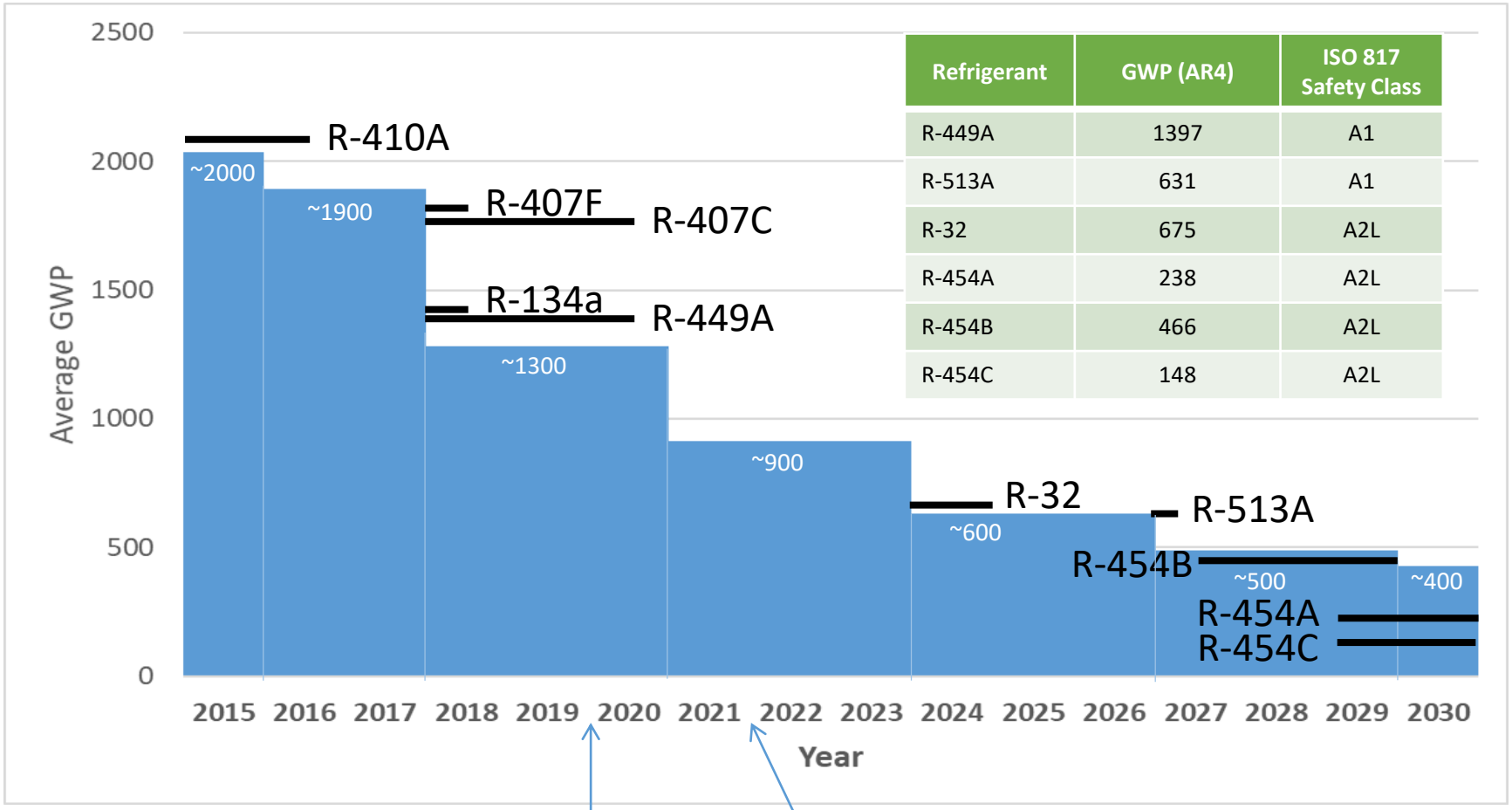
GWP Limits

	GWP Limit
New	2500
Service	2500 > 10kg 404A

	GWP Limit
New multi compressor commercial >40kW	150
Primary of cascade in new multi compressor commercial >40kW	1500

Opteon

F-Gas – Average GWP Phase Down



Refrigerant	GWP (AR4)	ISO 817 Safety Class
R-449A	1397	A1
R-513A	631	A1
R-32	675	A2L
R-454A	238	A2L
R-454B	466	A2L
R-454C	148	A2L

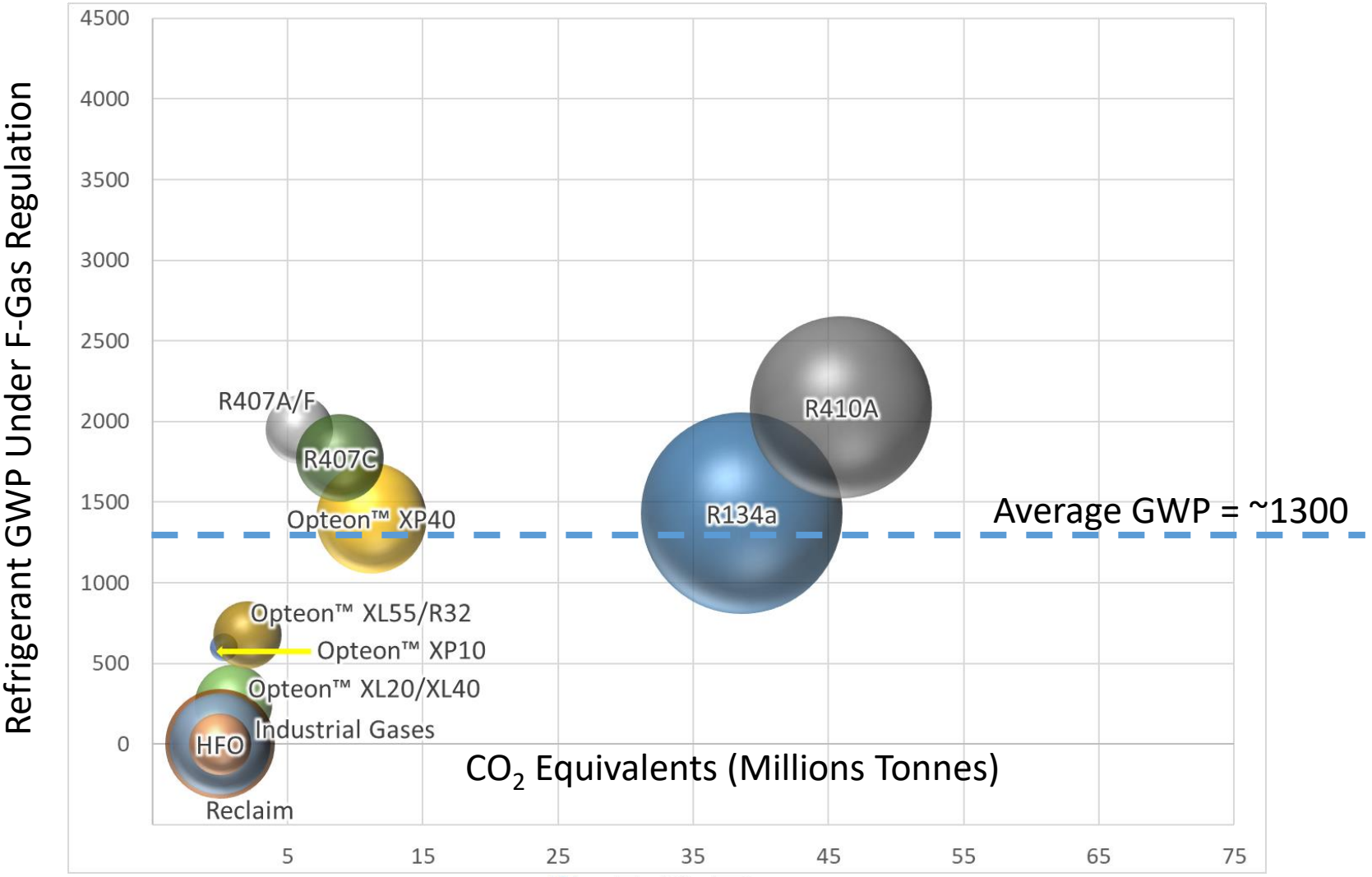
GWP Limits

	GWP Limit
New	2500
Service	2500 > 10kg 404A

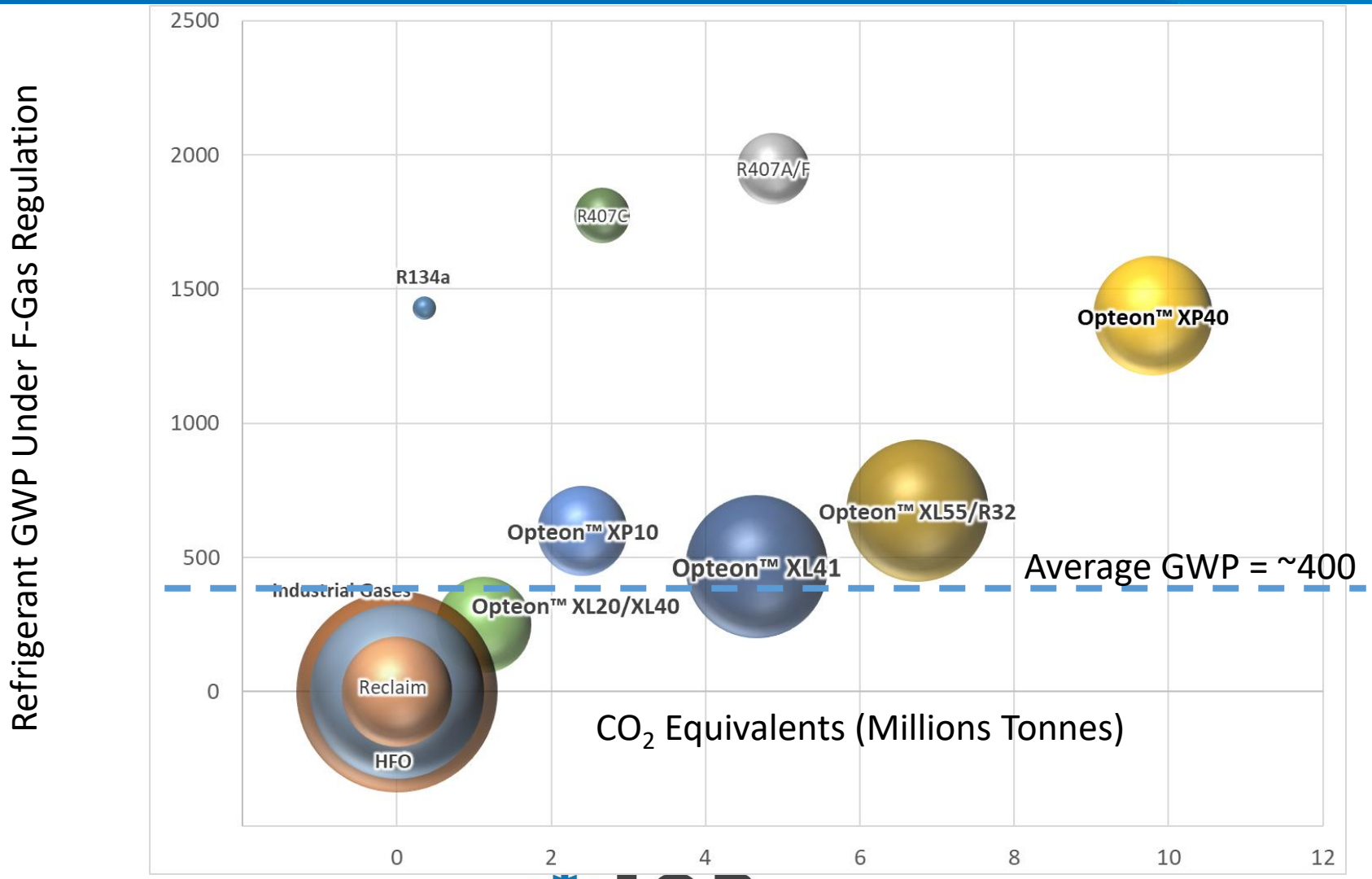
	GWP Limit
New multi compressor commercial >40kW	150
Primary of cascade in new multi compressor commercial >40kW	1500

Opteon

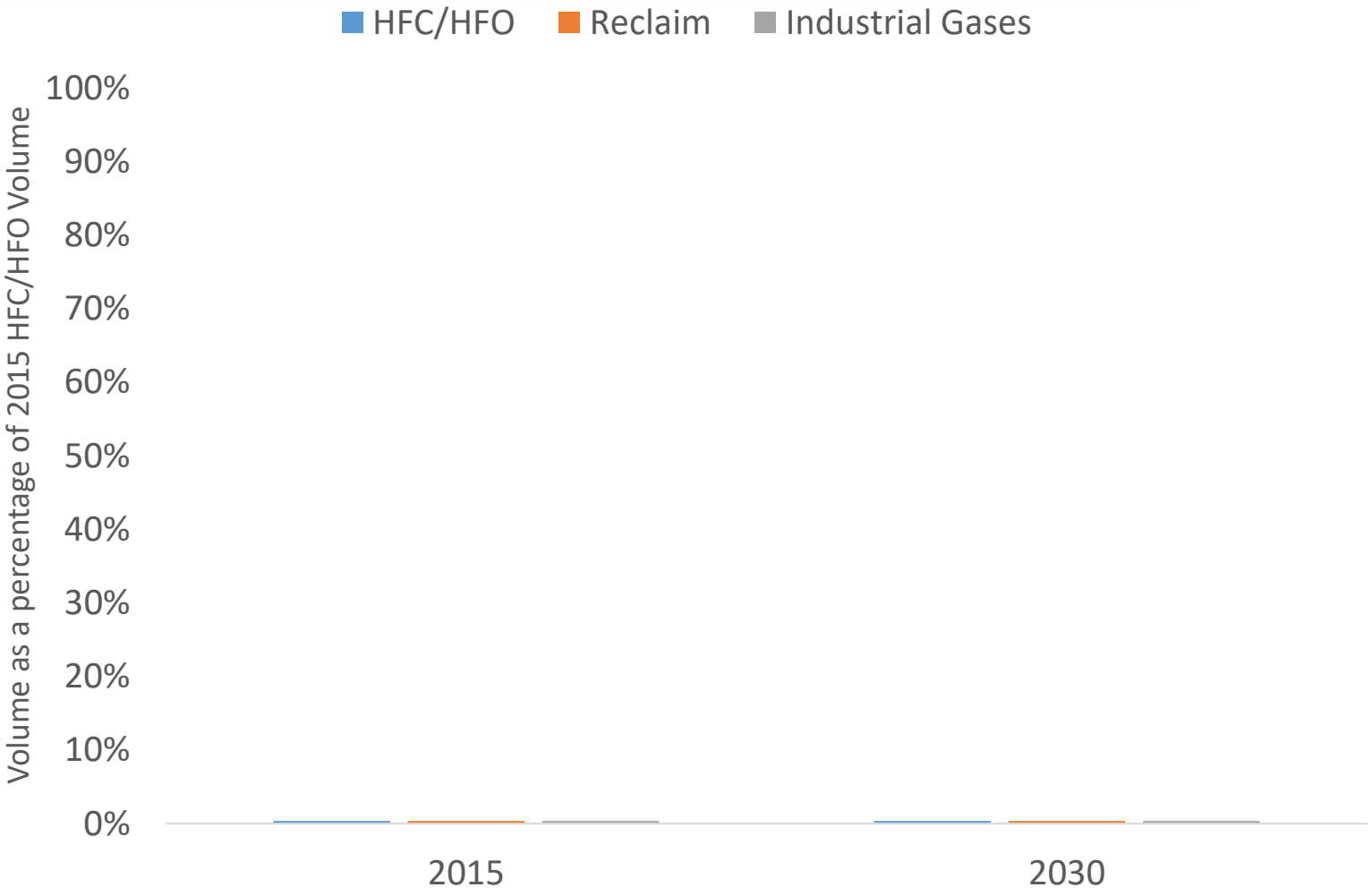
F-Gas Phase Down Scenarios - 2018



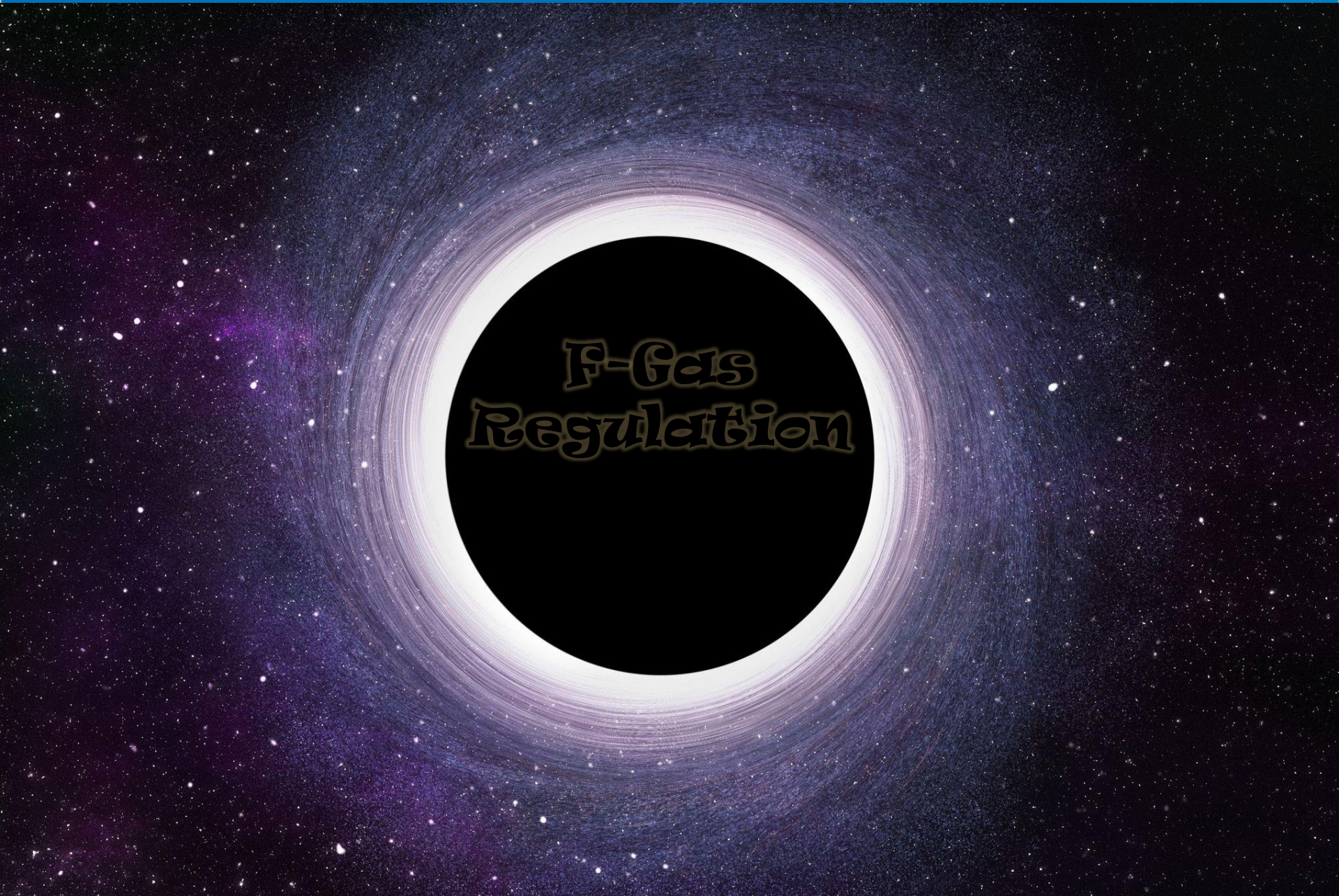
F-Gas Phase Down Scenarios - 2030



Relative Volumes (Tonnes Product) represented as a Percentage of the 2015 HFC/HFO Volume



Where are we today?



Low GWP R-404A Alternatives

Putting into Use Replacement Refrigerants (PURR)

2nd Edition – January 2018

	R404A	R448A	R449A	R407H	R407F	R407A	R452A
Commercial Name		N40	XP40		Performax LT		XP44
GWP (AR4)	3922	1387	1397	1495	1825	2107	2140
Toxicity Class	A						
Flammability Class	1						
Application	Frozen and Chill						
General Comments		Most manufacturers of components and equipment have approved these refrigerants		No manufacturer approvals at publication Date.	Most manufacturers of components and equipment have approved these refrigerants		Use in some LT Hermetic Compressors and Transport refrigeration
		Additional cooling may be required at low temperatures					

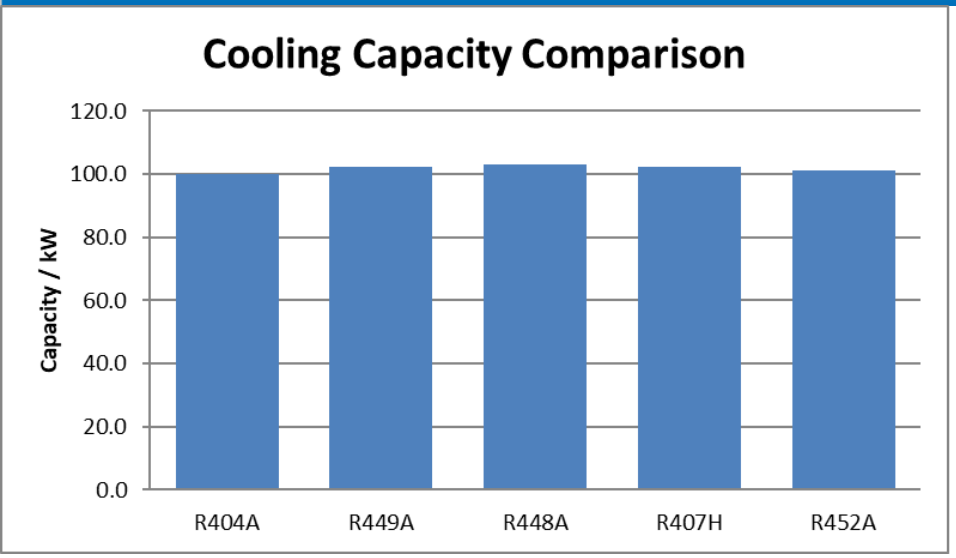
Very Low GWP R-404A Alternatives

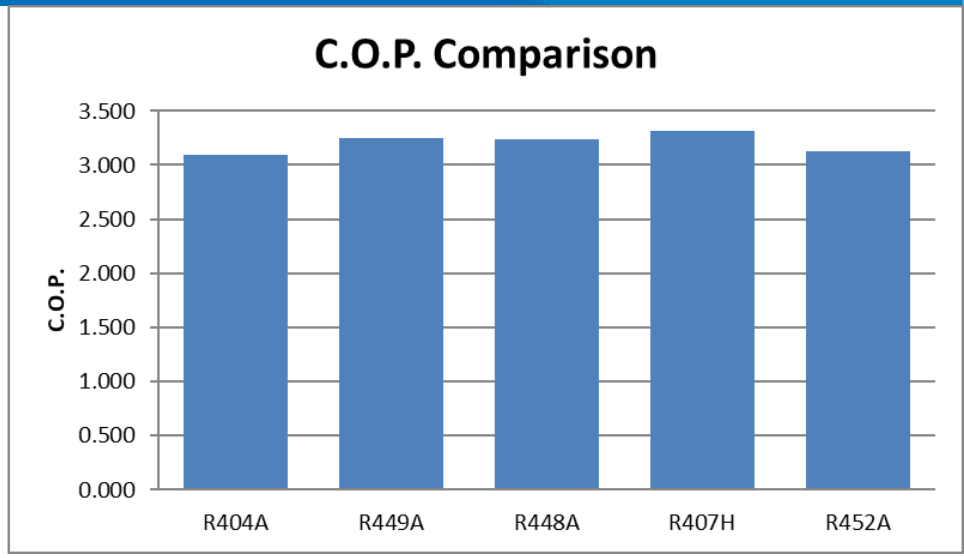
Putting into Use Replacement Refrigerants (PURR)

2nd Edition – January 2018

	R404A	R455A	R454C	R454A
Commercial Name		L40X	XL20	XL40
GWP (AR4)	3922	148	148	238
Toxicity Class	A			
Flammability Class	1	2L	2L	2L
Application	Frozen and Chill			
General Comments	Require special handling and storage			

Non-Flammable R404A Alternatives Theoretical Calculation @ MT Conditions

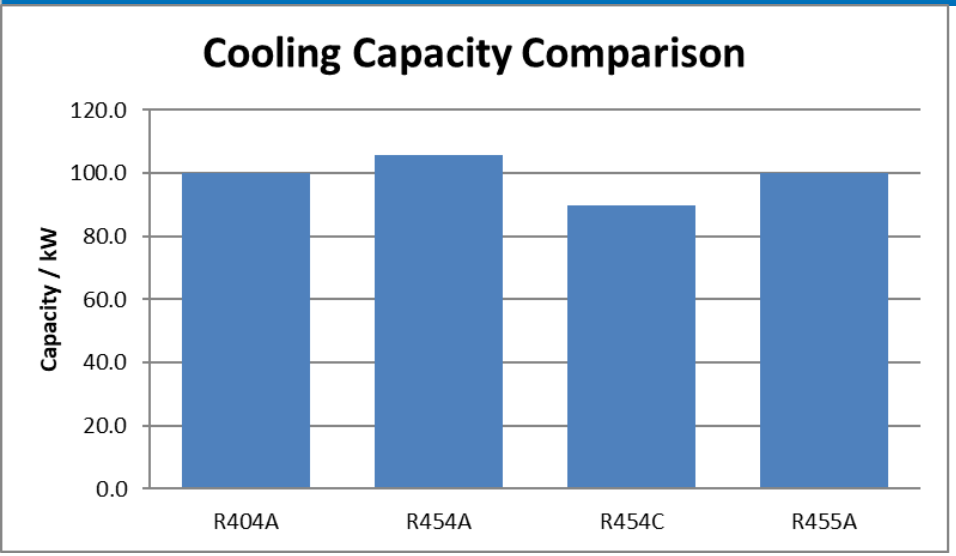


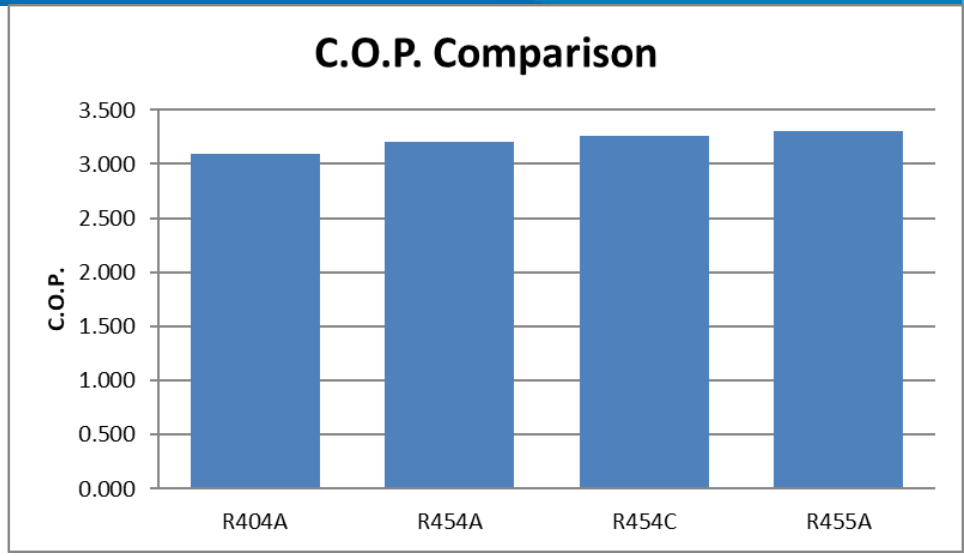


Refrigerant	Capacity Δ%	C.O.P. Δ%	Mass Flow Δ%	Discharge Temperature / ºC	Discharge Temperature Δ K	Condenser Pressure Δ bar	Evaporator Glide / K	Condenser Glide / K
R404A	0%	0.0%	0%	63.9	0.0	0.00	0.4	0.4
R449A	2%	4.9%	-22%	76.1	12.2	-0.60	4.3	4.8
R448A	3%	4.7%	-22%	77.3	13.4	-0.45	4.7	5.1
R407H	2%	7.0%	-34%	84.5	20.6	-1.09	5.0	5.2
R452A	1%	0.9%	1%	66.2	2.3	0.11	3.0	3.7

T_{evap}=-8°C, T_{cond}=35°C, $Superheat_{Total}$=15K, Liquid Subcool=3K, Compressor Isentropic Efficiency = 0.7

2L Flammable R404A Alternatives
Theoretical Calculation @ MT Conditions

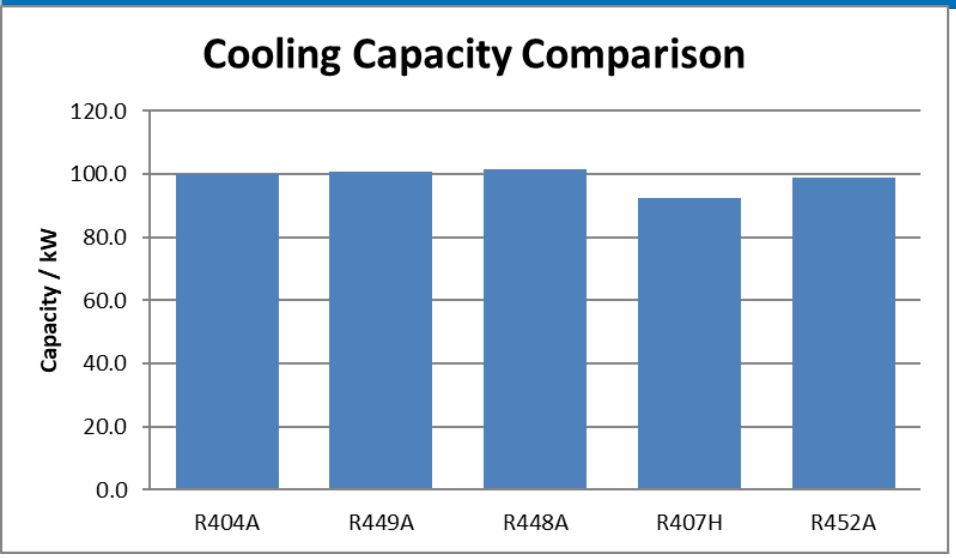


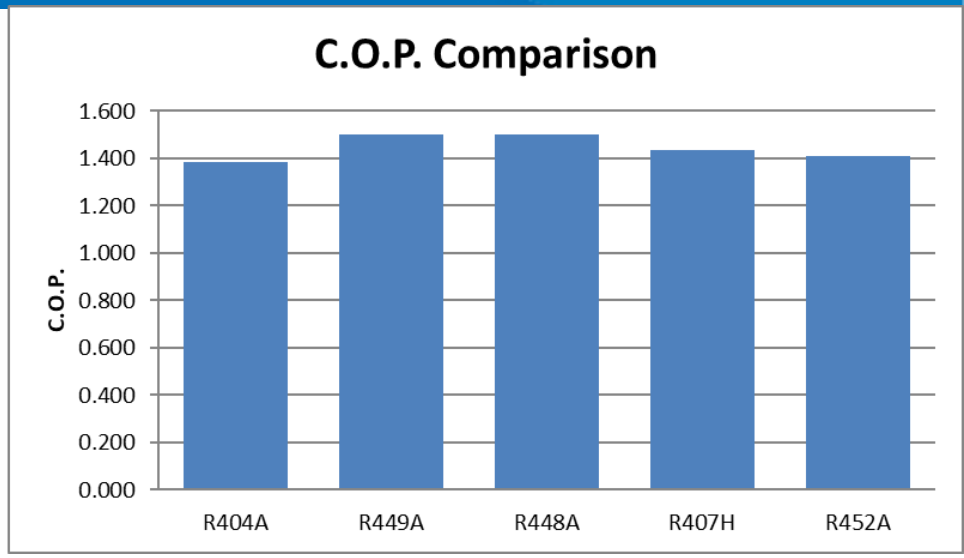


Refrigerant	Capacity Δ%	C.O.P. Δ%	Mass Flow Δ%	Discharge Temperature / ºC	Discharge Temperature Δ K	Condenser Pressure Δ bar	Evaporator Glide / K	Condenser Glide / K
R404A	0%	0.0%	0%	63.9	0.0	0.00	0.4	0.4
R454A	6%	3.7%	-22%	77.7	13.8	0.00	5.0	5.7
R454C	-10%	5.3%	-27%	71.0	7.1	-2.45	5.7	6.9
R455A	0%	6.8%	-22%	73.8	9.8	-1.20	7.7	10.2

T_{evap}=-8°C, T_{cond}=35°C, $Superheat_{Total}$=15K, Liquid Subcool=3K, Compressor Isentropic Efficiency = 0.7

Non-Flammable R404A Alternatives Theoretical Calculation @ LT Conditions

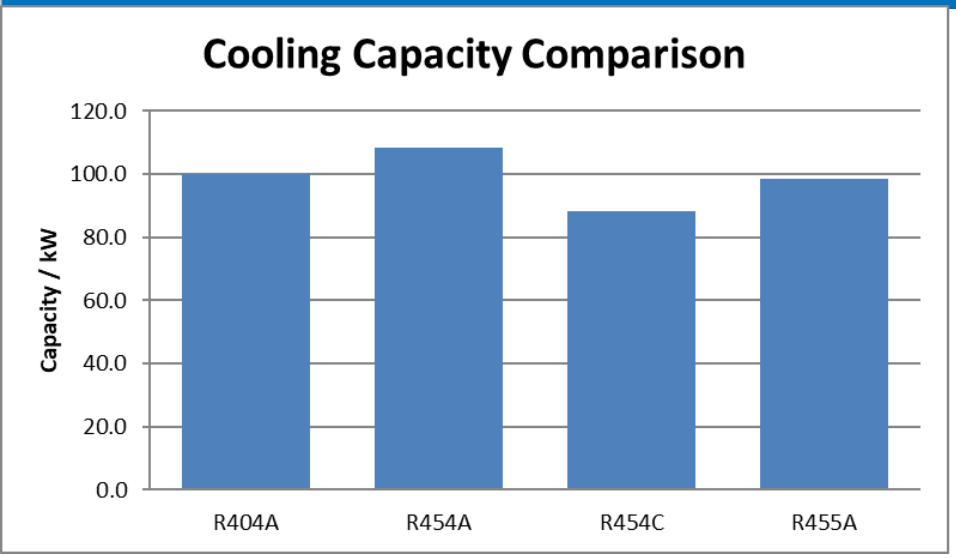


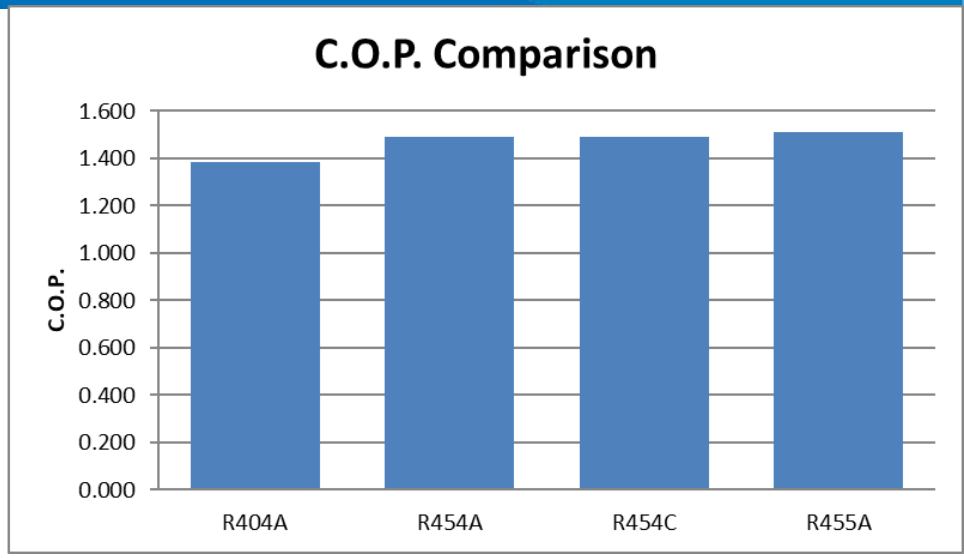


Refrigerant	Capacity Δ%	C.O.P. Δ%	Mass Flow Δ%	Discharge Temperature / ºC	Discharge Temperature Δ K	Condenser Pressure Δ bar	Evaporator Glide / K	Condenser Glide / K
R404A	0%	0.0%	0%	88.7	0.0	0.00	0.5	0.4
R449A	1%	8.4%	-26%	110.7	21.9	-0.60	3.9	4.8
R448A	2%	8.4%	-26%	112.6	23.9	-0.45	4.3	5.1
R407H	-8%	3.3%	-39%	127.1	38.3	-1.09	4.6	5.2
R452A	-1%	1.6%	-1%	91.4	2.7	0.11	2.4	3.7

T_{evap}=-35°C, T_{cond}=35°C, $Superheat_{Total}$=25K, Liquid Subcool=3K, Compressor Isentropic Efficiency = 0.7, Liquid Injection >115°C

2L Flammable R404A Alternatives
Theoretical Calculation @ LT Conditions





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R404A	0%	0.0%	0%	88.7	0.0	0.00	0.5	0.4
R454A	8%	7.6%	-23%	112.6	23.8	0.00	4.5	5.7
R454C	-12%	7.4%	-29%	100.1	11.3	-2.45	4.8	6.9
R455A	-1%	9.0%	-25%	104.6	15.8	-1.20	6.2	10.2

T_{evap}=-35°C, T_{cond}=35°C, $Superheat_{Total}$=25K, Liquid Subcool=3K, Compressor Isentropic Efficiency = 0.7, Liquid Injection >115°C

R-404A / R507A Alternatives

Non-Flammable Low GWP

~4000 GWP

2140 GWP

<400 GWP

Ahold, Marum, Netherlands Retrofit from R507 & R407F to R-449A

R-407F Base Data gathered from July to November 2013

R-449A Data Measured from November 2013 until June 2014

Medium (100 kW) and Low temperature (14 kW) Racks Monitored

Copeland Compressors (MT = 1x D4DH-250 50-100% & 2x D4DA-200x, LT = 1x D3DC-100 & 2x D3DA-75X

Danfoss ADAP-Kool Controller and electronic expansion valves

Italian Supermarket – Medium Temp Cascaded with LT CO_2 - 2014

Cabinet & Expansion Valve Models

VETRINE TN (R404A)					71
N°	Descrizione	L (m)	Pot. (W)	Evap (°C)	Valvola
9	Berlino h 220 F.V.	3,75	6141 W	-15	AKV 10-6
3	Berlino h 220 F.V.	2,5	4094 W	-15	AKV 10-5
4	Berlino h 220 C.V.	3,75	6141 W	-15	AKV 10-6
	Berlino h 220 C.V.	2,5	4094 W	-15	AKV 10-5
1	Berlino h 220 pesce	3,75	6141 W	-15	AKV 10-6
1	Berlino h 220 pesce	2,5	4094 W	-15	AKV 10-5
	Mitili	1,25	2700 W	-15	AKV 10-4
10	Berlino h 220 latticini	3,75	6141 W	-15	AKV 10-6
4	Berlino h 220 latticini	2,5	4094 W	-15	AKV 10-5
1	Banco latte h 220	?	4637 W	-15	AKV 10-6
1	Testata latticini h 220	?	3100 W	-15	AKV 10-5
2	Sidney h 125 F.V.	3,75	4850 W	-15	AKV 10-6
	Sidney h 125 F.V.	2,5	2700 W	-15	AKV 10-4
4	Sidney h 125 C.O.	3,75	4850 W	-15	AKV 10-6
1	Sidney h 125 C.O.	2,5	2700 W	-15	AKV 10-4
3	Sidney VCA gastronomia	3,75	2000 W	-15	AKV 10-4
	Sidney VCA gastronomia	2,5	1400 W	-15	AKV 10-3
	Sidney VCA pane	3,75	2000 W	-15	AKV 10-4
1	Sidney VCA pane	2,5	1400 W	-15	AKV 10-3
	Isola lucerna	3,75	4850 W	-15	AKV 10-6
6	Isola lucerna	2,5	2000 W	-15	AKV 10-4
	Isola Algor	?	1600W	-15	AKV 10-3
6	Testata lucerna	?	2000.W	-15	AKV 10-4
6	Cassetti gastronomia	?	700W	-15	AKV 10-2
1	Cassetti pane	?	700W	-15	AKV 10-2
3	CDZ carne	?	10000W	0	AKV 10-7
3	CDZ pesce	?	10000W	0	AKV 10-7
1	Scalino	?	1500 W	-15	AKV 10-3

VETRINE BT (CO2)					28
N°	Descrizione	L (m)	Pot. (W)	Evap (°C)	Valvola
12	Perth superiore	3,75	2300 W	-35	AKV 10-2
2	Perth superiore	2,5	1500 W	-35	AKV 10-1
12	Perth inferiore	3,75	1800 W	-35	AKV 10-2
2	Perth inferiore	2,5	1200 W	-35	AKV 10-1
	Produttore ghiaccio	?	4500W	-26	AKV 10-4
	Celle fermolievita	?	2000W	-26	AKV 10-2

EVAPORATORI CELLE TN (R404A)					9
N°	Descrizione		Pot. (W)	Evap (°C)	Valvola
	SHDN	37-50	2000 W	-15	AKV 10-4
	SHDN	56-50	2600 W	-15	AKV 10-4
1	SHDN	82-50	3500 W	-15	AKV 10-5
2	SHDN	111-50	5100 W	-15	AKV 10-6
5	SHDN	166-50	7900 W	-15	AKV 10-7
1	SHDN	222-50	10500 W	-15	AKV 10-7
	SHDN	278-50	12900 W	-15	AKV 10-7

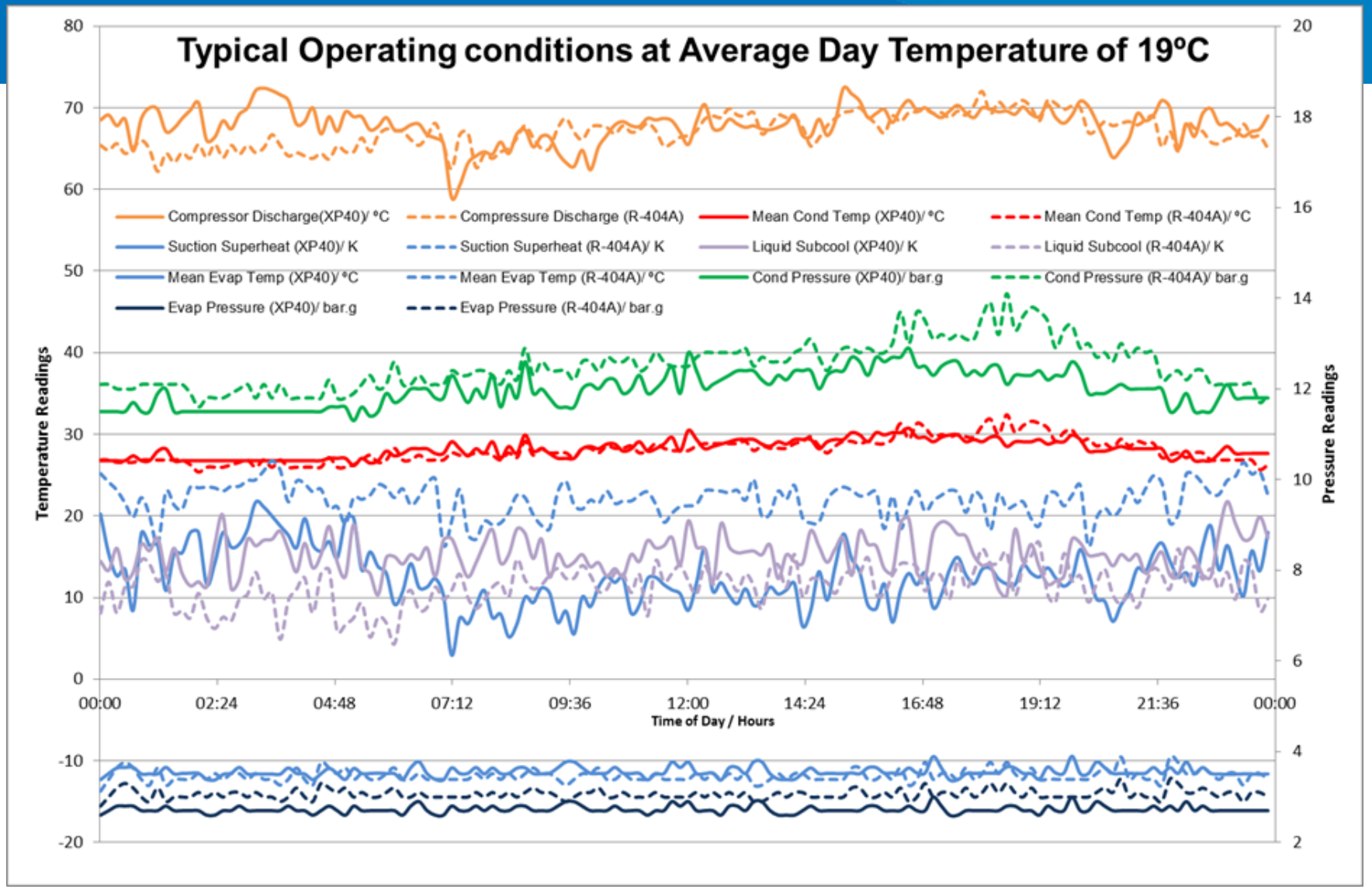
EVAPORATORI CELLE BT (CO2)					4
N°	Descrizione		Pot. (W)	Evap (°C)	Valvola
2	SHA	52-80	2300 W	-35	AKV 10-2
2	SHA	70-80	3200 W	-35	AKV 10-3

	Tot.
AKV 10-1	4
AKV 10-2	33
AKV 10-3	4
AKV 10-4	16
AKV 10-5	10
AKV 10-6	33
AKV 10-7	12
TOTALE	112

Compressor Models (Bitzer Screw)

	Compressor Model	Quantity	Range	Capacity / W
1	HSK 6451-50	1	–15/°+45°C	83200
2	HSK 6451-50	1	–15°/+45°C	83200
3	HSK 6451-50	1	–15°/+45°C	83200
4	HSK 6451-50	1	–15°/+45°C	83200
5	HSK 6451-50	1	–15°/+45°C	83200
6	HSK 7471-90	1	–15°/+45°C	105500
Total Capacity / W				521500
Margin relative to requirement / W			57412	(11,01%)

System Measurements – Daily Average Temperature of 19ºC



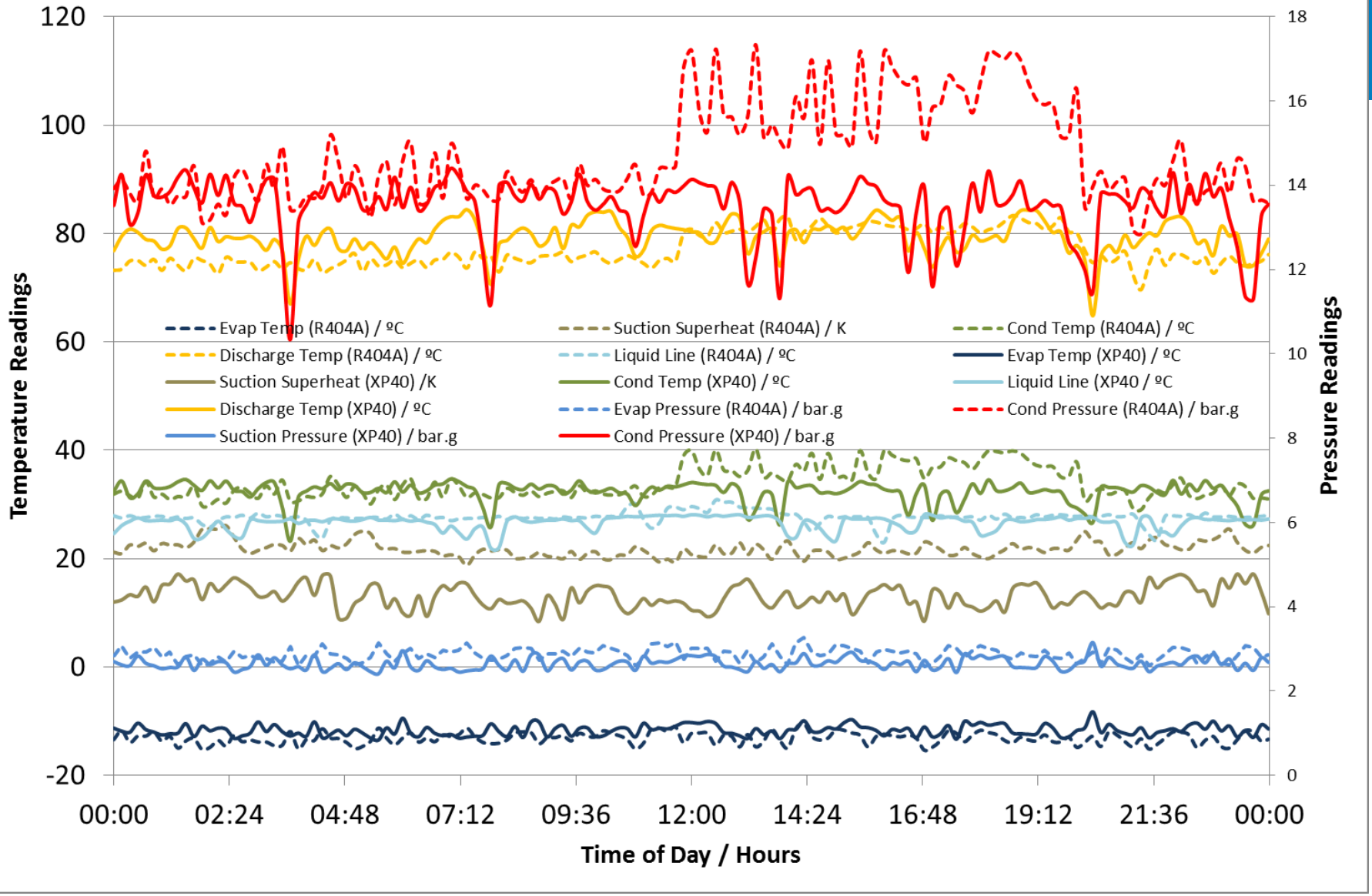
Delhaize, Belgium - Supermarket Retrofit - 2014

2 Medium Temperature (MT) Racks each with 2 Bitzer 4J-22.2Y (35kW) compressors.
Rack A has an expected maximum load of 46kW and Rack B an expected maximum load of 73kW.

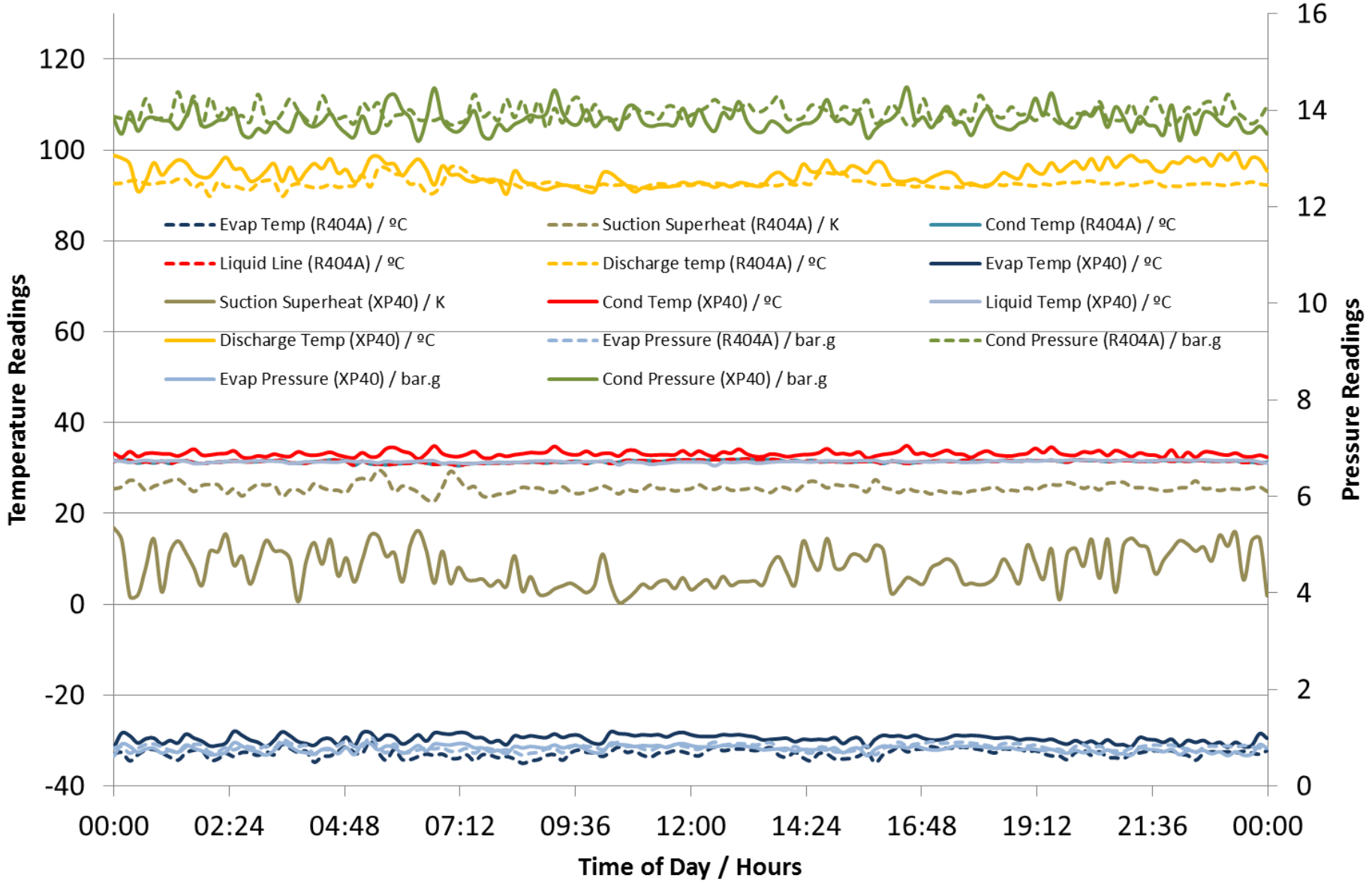
The Low Temperature (LT) rack (Rack D) has 3 Bitzer 4NCS-12.2Y (8.63 kW) compressors with cooling fans fitted and an expected maximum load of 24kW.

47 cabinets (35 MT and 12 LT) with 10 cold rooms (8MT, 2LT) operating on the racks. All the cabinets and cold rooms use Danfoss (TE) thermostatic expansion valves.

Medium Temperature System – 15ºC Average Daily Temperature



Low Temperature System – 15ºC Average Daily Temperature



R404A / R507A Replacement

R-449A & R-448A

Lowest GWP Non-flammable Option= <1400 (AR4).
Thousands of systems successfully retrofitted from R404A.
Major Compressor Manufacturer Approvals.
Most Energy Efficient Non-flammable R404A Replacements.

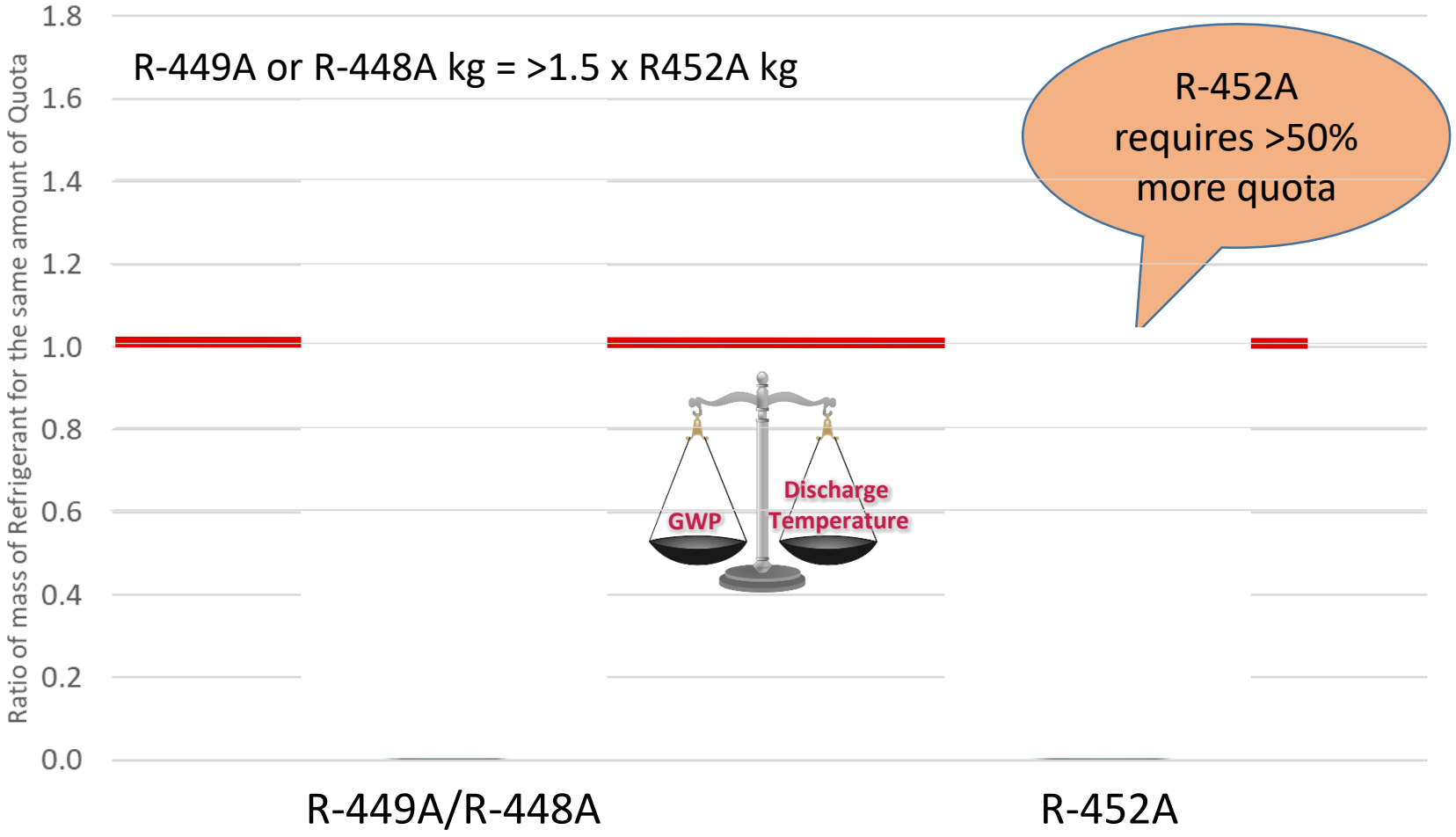
R-452A

Lowest compressor discharge temperature R404A replacement.
Thousands of new systems successfully introduced.
Major Compressor Manufacturer Approvals.
Ideally suited to applications sensitive to high compressor discharge temperatures. e.g. LT hermetic piston compressors, transport refrigeration.

Choose the Lowest GWP Product That Can Do The Job

		R-449A/ R-448A	R-452A
GWP		<1400	2140
Replaces	R-404A/R-507	✓	✓
Applications (New & Retrofit)	**Commercial Refrigeration – Large Systems** LT & MT **commercial and industrial** DX refrigeration • Food service (e.g., condensing units) • Cold storage • Self-contained systems • Supermarkets - Centralized rack systems - Distributed systems - Walk-in coolers/freezers, prep rooms, etc.	✓	✓
	Commercial Refrigeration – Small Piston Hermetics Low-temperature **commercial** DX refrigeration • Food service (e.g., condensing units) • Cold storage • Self-contained systems • Convenience stores - Walk-in coolers/freezers, prep rooms, etc.		✓
	Chillers - Direct expansion	✓	✓
	Transport Refrigeration Low- and medium-temperature **transport** DX refrigeration • Refrigerated trucks • Refrigerated vans • Reefer containers		✓
Benefits	Closest match in compressor discharge temperature to R-404A/R-507; Ideal for applications where low compressor discharge temperatures are essential		✓
	Closest non-flammable match where compressor discharge temperature is less critical and ***Lowest GWP***	✓	

Choose the Right Product for the Job



R-404A / R507A Alternatives

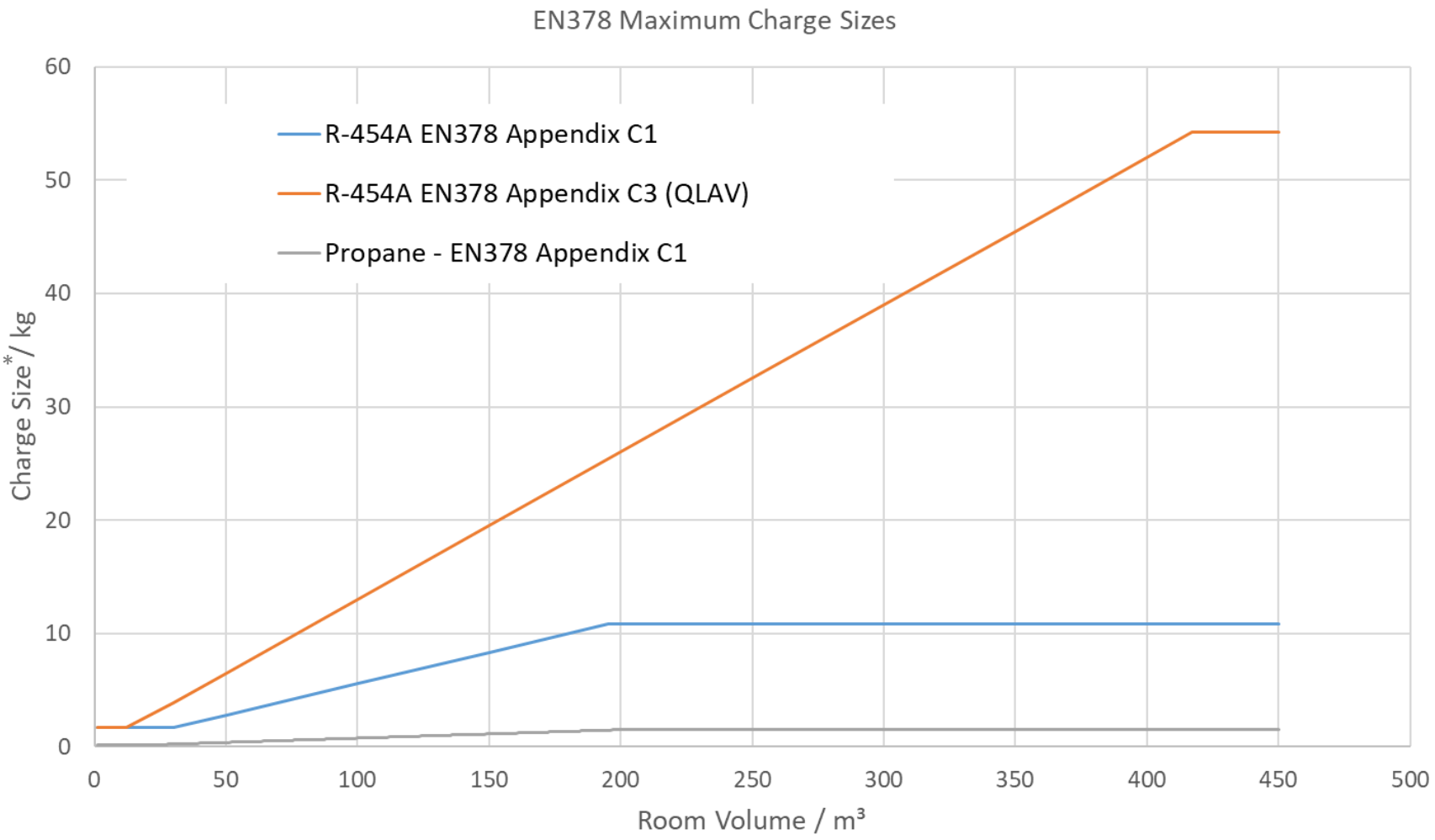
2L Flammable Very Low GWP

~4000 GWP

<250 GWP

<150 GWP

EN378 Maximum Charge Sizes for Access Category a (public buildings), Location Category II (compressors open air or in a machine room)



*Sealed System Assumed until EN 378 Appendix C1 cap factor m_1 charge amount

R454A – Park Cake Bakeries, UK

Freeze Store (-18ºC)

Cold Store Dimensions: 24m x 11.9m x 6.4m

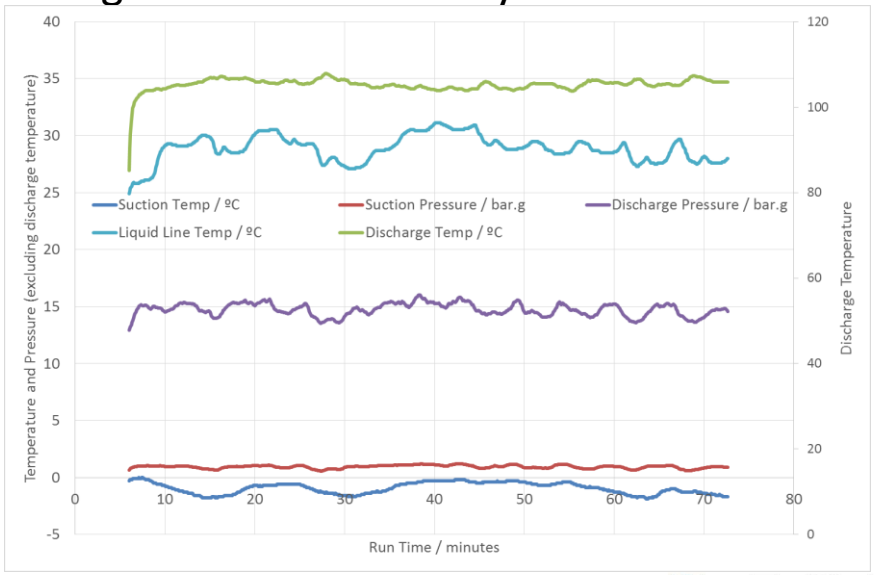
Capacity 360 Pallets

3 x Zanotti HCU5180B941J Condensing Units

Bitzer Compressor 4HE-18Y-40P, BSE 32 Oil

23 kg Refrigerant per Unit

Designed and installed by Dawsonrentals



How Flammable is Mildly Flammable ?

AHRI
AIR-CONDITIONING, HEATING, & REFRIGERATION INSTITUTE
we make life better™

Final Report

AHRI Report No. 8017

Investigation of Energy Produced by Potential Ignition Sources in Residential Application

Table 19.1. Test matrix and result summary.

	R-32	R-452B	R-1234yf	R-1234ze
Hot wire	D	D	D	D
Safety match	D	D	L	D
Lighter flame insertion	D	L	L	L
Leak impinging on candle	L	N	L	L
Cigarette insertion	N	N	N	N
Barbeque lighter	N	N	N	N
Plug and receptacle	N	N	N	N
Light switch	N	N	N	N
Hand mixer	N	N	N	N
Cordless drill	N	N	N	N
Friction sparks	N	N	N	N
Hair dryer	N	N	N	N
Toaster	N	N	N	N
Hot plate insertion	N	N	N	N
Space heater insertion	N	N	N	N

Legend:

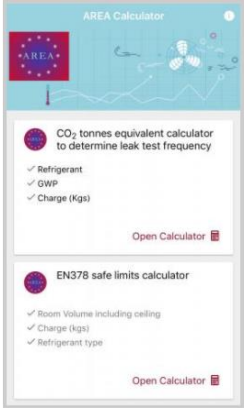
D - Deflagration
L - Localized flame

N - No refrigerant combustion

Standards

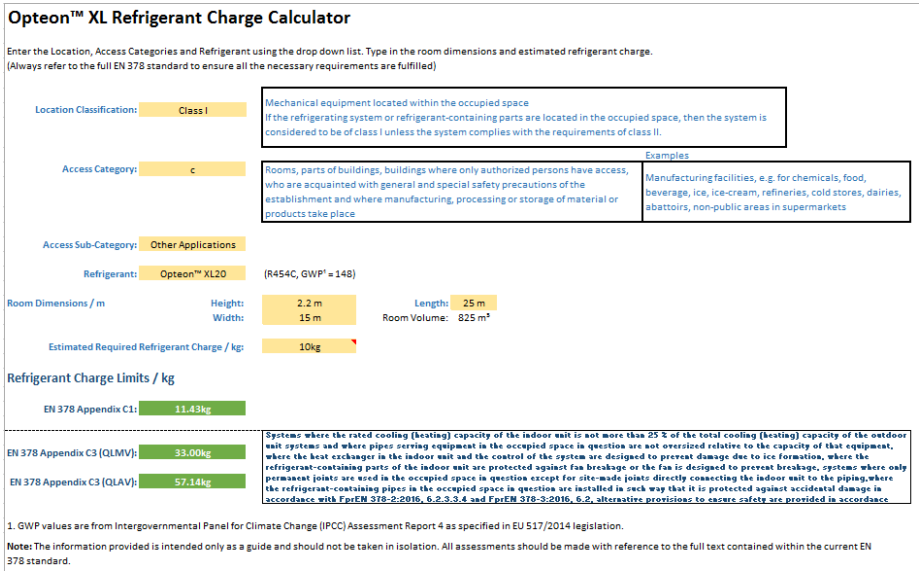
- **EN378 (2016), incl 2Ls, is published**
- **Standard: ISO 817**
  REFRIGERANTS - DESIGNATION AND SAFETY CLASSIFICATION
- **International Working Groups are active on other standards**

EN378 (2016) Refrigerant Charge Calculator



AREA app calculator for F-Gas and EN378

- Calculate concentration and flammability safety limits under EN378.
- Includes R454A, R454B, R454C & R455A which are not yet published in EN378 tables.
- Calculate CO_2 tonnes equivalent values for various refrigerants under F Gas for completion of log books and labels on equipment.
- Available for IOS and Android



Opteon™ XL Refrigerant Charge Calculator

Enter the Location, Access Categories and Refrigerant using the drop down list. Type in the room dimensions and estimated refrigerant charge.
(Always refer to the full EN 378 standard to ensure all the necessary requirements are fulfilled)

Location Classification:	Class I	Mechanical equipment located within the occupied space If the refrigerating system or refrigerant-containing parts are located in the occupied space, then the system is considered to be of class I unless the system complies with the requirements of class II.
Access Category:	c	Rooms, parts of buildings, buildings where only authorized persons have access, who are acquainted with general and special safety precautions of the establishment and where manufacturing, processing or storage of material or products take place Examples: Manufacturing facilities, e.g. for chemicals, food, beverage, ice, ice-cream, refineries, cold stores, dairies, abattoirs, non-public areas in supermarkets
Access Sub-Category:	Other Applications	
Refrigerant:	Opteon™ XL20	(R454C, GWP[1] = 148)

Room Dimensions / m — Height: 2.2 m — Length: 25 m — Width: 15 m — Room Volume: 825 m³

Estimated Required Refrigerant Charge / kg: 10kg

Refrigerant Charge Limits / kg

EN 378 Appendix C1:	11.43kg	
EN 378 Appendix C3 (QLMV):	33.00kg	Systems where the rated cooling (heating) capacity of the indoor unit is not more than 25 % of the total cooling (heating) capacity of the outdoor unit systems and where pipes serving equipment in the occupied space in question are not oversized relative to the capacity of that equipment, where the heat exchanger in the indoor unit and the control of the system are designed to prevent damage due to ice formation, where the refrigerant-containing parts of the indoor unit are protected against fan breakage or the fan is designed to prevent breakage, systems where only permanent joints are used in the occupied space in question except for site-made joints directly connecting the indoor unit to the piping,where the refrigerant-containing pipes in the occupied space in question are installed in such way that it is protected against accidental damage in accordance with FprEN 378-2:2016, 6.2.3.3.4 and FprEN 378-3:2016, 6.2, alternative provisions to ensure safety are provided in accordance
EN 378 Appendix C3 (QLAV):	57.14kg	

1. GWP values are from Intergovernmental Panel for Climate Change (IPCC) Assessment Report 4 as specified in EU 517/2014 legislation.

Note: The information provided is intended only as a guide and should not be taken in isolation. All assessments should be made with reference to the full text contained within the current EN 378 standard.

- Chemours Can also assist
- Spreadsheet based Charge Calculator for All Opteon™ Refrigerants.

Conclusions

- The Phasedown is now affecting refrigerant choice.
- Virgin R404A/R507A availability strongly effected by the phasedown
- To fit ‘Under the Cap’ Stop using R404A and Even R410A needs to reduce.
- Use the lowest GWP product available suitable for the job.
- Only where high discharge temperatures are a problem use R-452A.
- Ask Equipment suppliers for Very Low GWP A2L Options – Create a pull effect.
- If applications can comply with EN 378 consider using A2L refrigerants, R-454C/ R-455A for Hermetic systems, R-454A for <40 kW non-hermetic retail systems and other non-hermetic systems.

Thank you

Mark.hughes@chemours.com

Opteon

IOR.org.uk
REFRIGERATION AIR CONDITIONING HEAT PUMPS