Low GWP/Flammable Refrigerants Enabling Leapfrogging Towards Fossil Free Process Heat for Industry

Safe implementation and requirements for refrigeration systems with flammable refrigerants and their surroundings

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Daniel Colbourne

RE – PHRIDGE LTD

d.colbourne@re-phridge.co.uk

Introduction

General safety requirements for flammable refrigerants, well known

- Specifics detailed in various safety standards
- General concepts in regulations (e.g., ATEX, etc.)

Most prominent aspects are avoiding ignition sources and charge limits

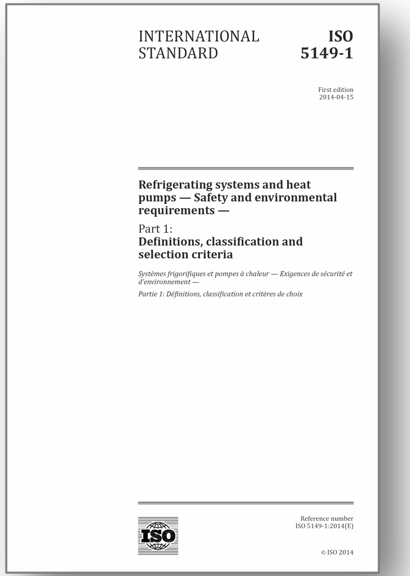
- Charge limits principally intended to avoid flammable mixtures surrounding equipment

* Discussion mostly based on HCs (class A3); flammable HFCs exist (A2, A2L), but all have deleterious environmental impact


IEC 60335-2-89
Edition 2.0 2010-02
INTERNATIONAL STANDARD
NORME INTERNATIONALE
Household and similar electrical appliances – Safety –
Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant unit or compressor
Appareils électrodomestiques et analogues – Sécurité –
Partie 2-89: Règles particulières pour les appareils de réfrigération à usage commercial avec une unité de fluide frigorigène ou un compresseur incorporés ou à distance

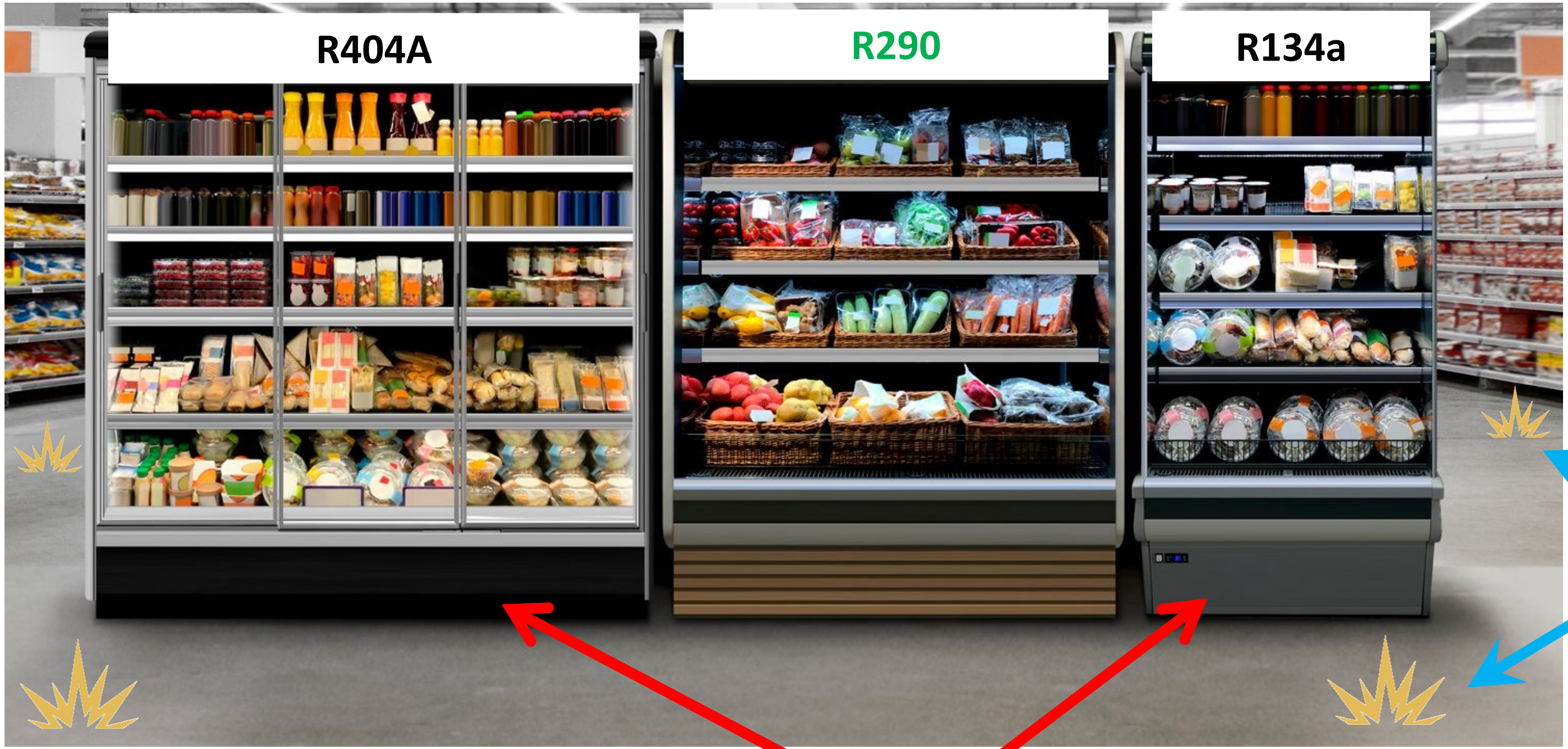

IEC 60335-2-40
Edition 5.0 2013-12
INTERNATIONAL STANDARD
Household and similar electrical appliances – Safety –
Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers


BS EN 378-1:2016
EUROPEAN STANDARD EN 378-1
NORME EUROPÉENNE
EUROPÄISCHE NORM November 2016
ICS 01.040.27; 27.080; 27.200 Supersedes EN 378-1:2008+A2:2012
English Version
Refrigerating systems and heat pumps - Safety and environmental requirements - Part 1: Basic requirements, definitions, classification and selection criteria
Systèmes frigorifiques et pompes à chaleur - Exigences de sécurité et d'environnement - Partie 1: Exigences de base, définitions, classification et critères de choix
Kälteanlagen und Wärmepumpen- Sicherheitstechnische und umweltrelevante Anforderungen - Teil 1: Grundlegende Anforderungen, Begriffe, Klassifikationen und Auswahlkriterien
This European Standard was approved by CEN on 3 September 2016.
CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.
This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.
CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.


INTERNATIONAL STANDARD ISO 5149-1
First edition 2014-04-15
Refrigerating systems and heat pumps — Safety and environmental requirements —
Part 1: Definitions, classification and selection criteria
Systèmes frigorifiques et pompes à chaleur — Exigences de sécurité et d'environnement —
Partie 1: Définitions, classification et critères de choix

Introduction

Need to ensure a leak cannot be ignited by external ignition source, for example:



Random ignition sources, e.g., floor cleaners, steel-tipped stilettoes

Electrical components on adjacent non-HC cabinets; relays, contactors, thermostats, etc

Charge limits

For RACHP systems indoors, leaked charge means mixture spread across room floor

- Under some conditions, mixture can be flammable
- Local ignition sources (plug switches, candles, cookers, etc.) could ignite the mixture

So charge should be limited

Several approaches:

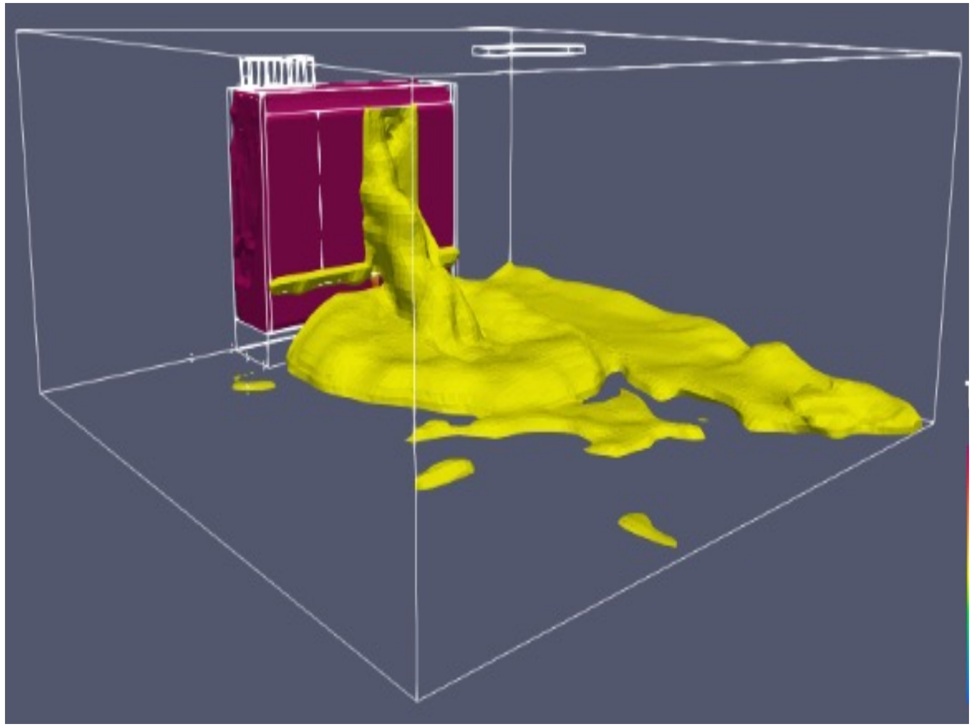
$m_{max} = 0.2 \times LFL \times V_{rm}$ ← EN 378 – to be discarded

$m_{max} = 2.5 \times h \times LFL^{1.25} \times \sqrt{A_{rm}}$ ← EN 378, IEC -40 – flawed

$m_{max} = 0.5 \times LFL \times h_{rm} \times A_{rm}$ ← Draft EN 378, IEC -40 – airflow

$m_{max} = F \times LFL \times h^{*} \times A_{rm}$ ← Draft EN 378, IEC -40, -89 – ETRS

$m_{max} = F \times LFL \times h_{rh} \times A_{rm}$ ← IEC -40 – floor unit airflow



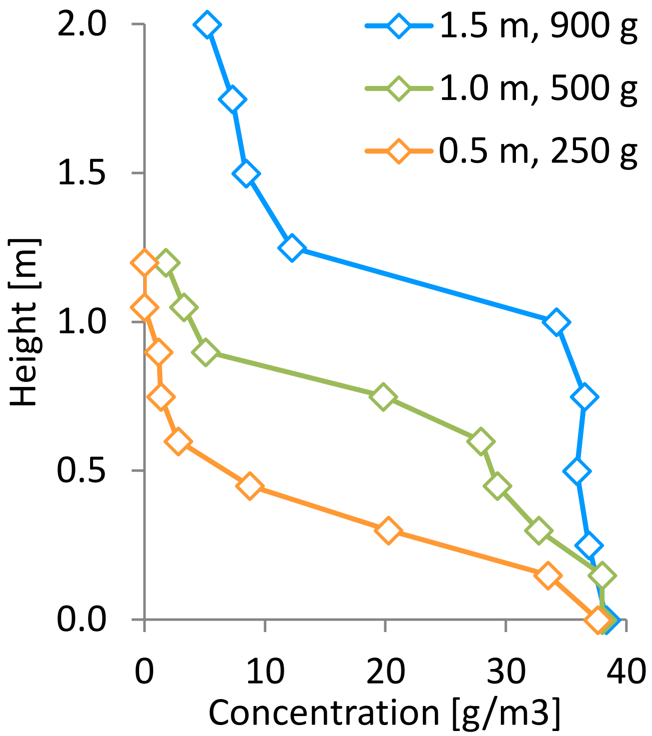
Options for controlling surrounding concentration

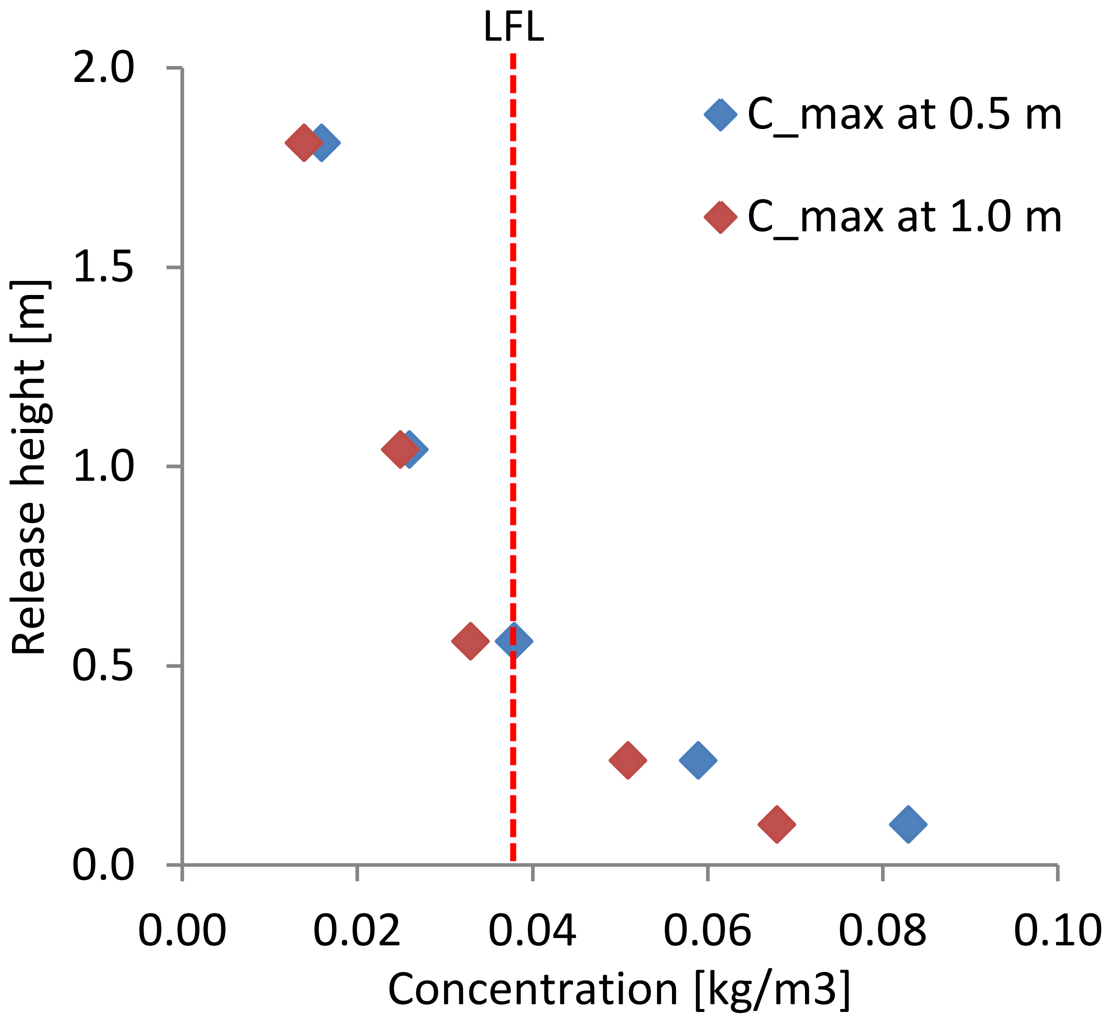
Approach	Details	Safety standards
Limit charge amount	Basic charge size formula	EN 378, IEC 60335-2-40, IEC 60335-2-89, ISO 5149
System height	Higher above floor helps dilute leak	EN 378, IEC 60335-2-40, IEC 60335-2-89, ISO 5149
Limit releasable charge	Use shut-off valves to prevent some refrigerant release	Draft EN 378, draft IEC 60335-2-40
Limit leak mass flow	Improved tightness systems, implying smaller hole sizes	EN 378, IEC 60335-2-40, IEC 60335-2-89
Enclosure/housing design	Construction features help pre-mix release	Draft EN 378
Airflow	Airflow in room helps dilute leak	Draft EN 378, IEC 60335-2-40, IEC 60335-2-89
Surrounding conc test	Measure surroundings to prove no LFL	Draft EN 378, IEC 60335-2-89

System height

300 g release from unit at incremental heights in 13.5 m² room (right)

- Lower heights give higher floor concentrations
- Greater mass can be released at hight before LFL

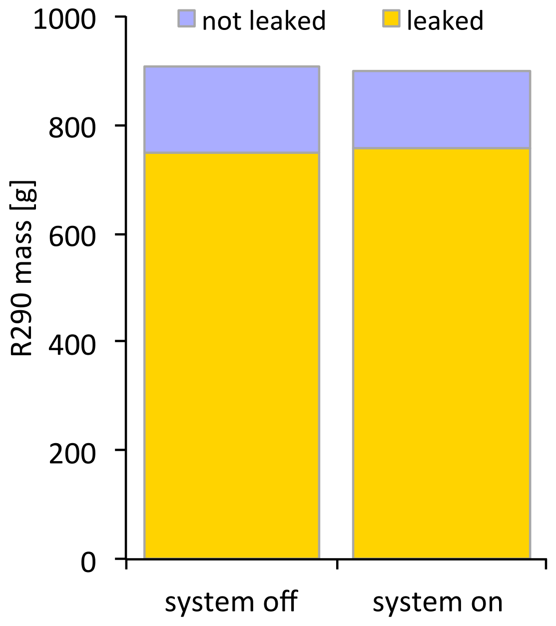




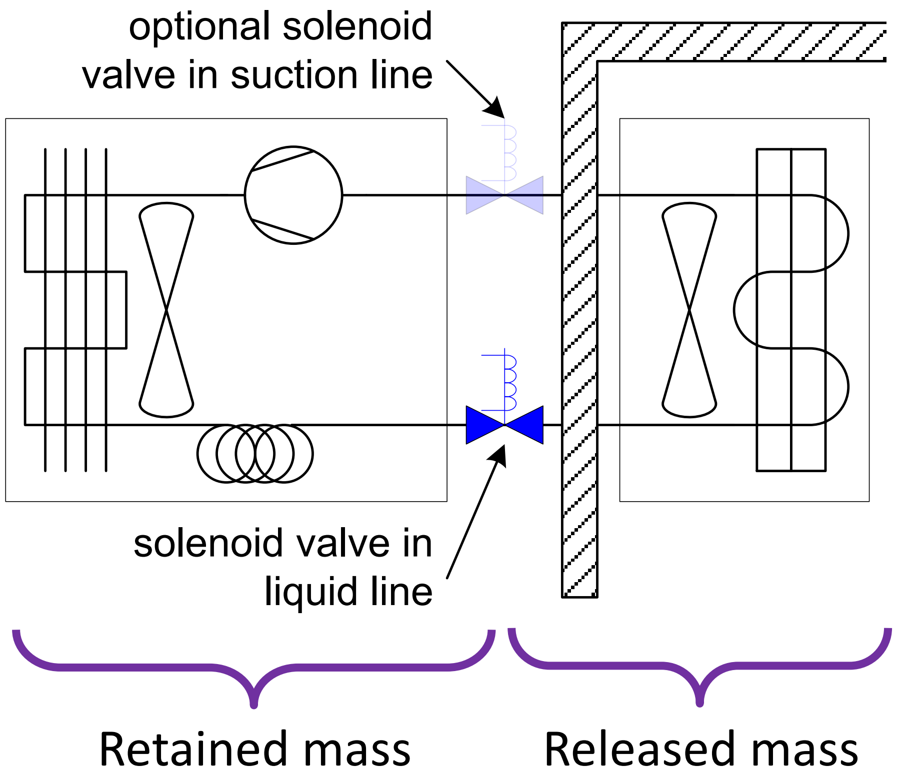
Limit releasable charge

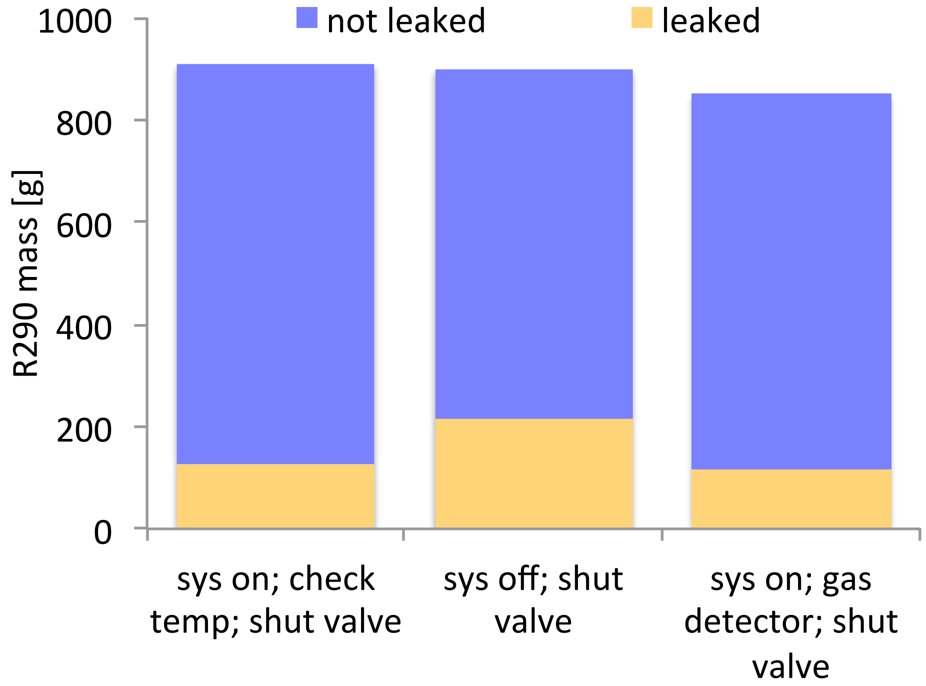
Can consider "static" or "active" cases

- Active case uses sensors to detect leak and close valves to prevent further release
- Example of large split AC



In typical static case, about 10-20% of charge is retained





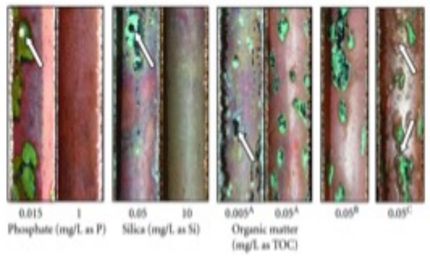
Tests found up to 80% charge retained

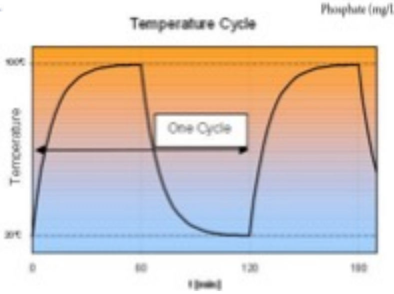
Limit leak mass flow

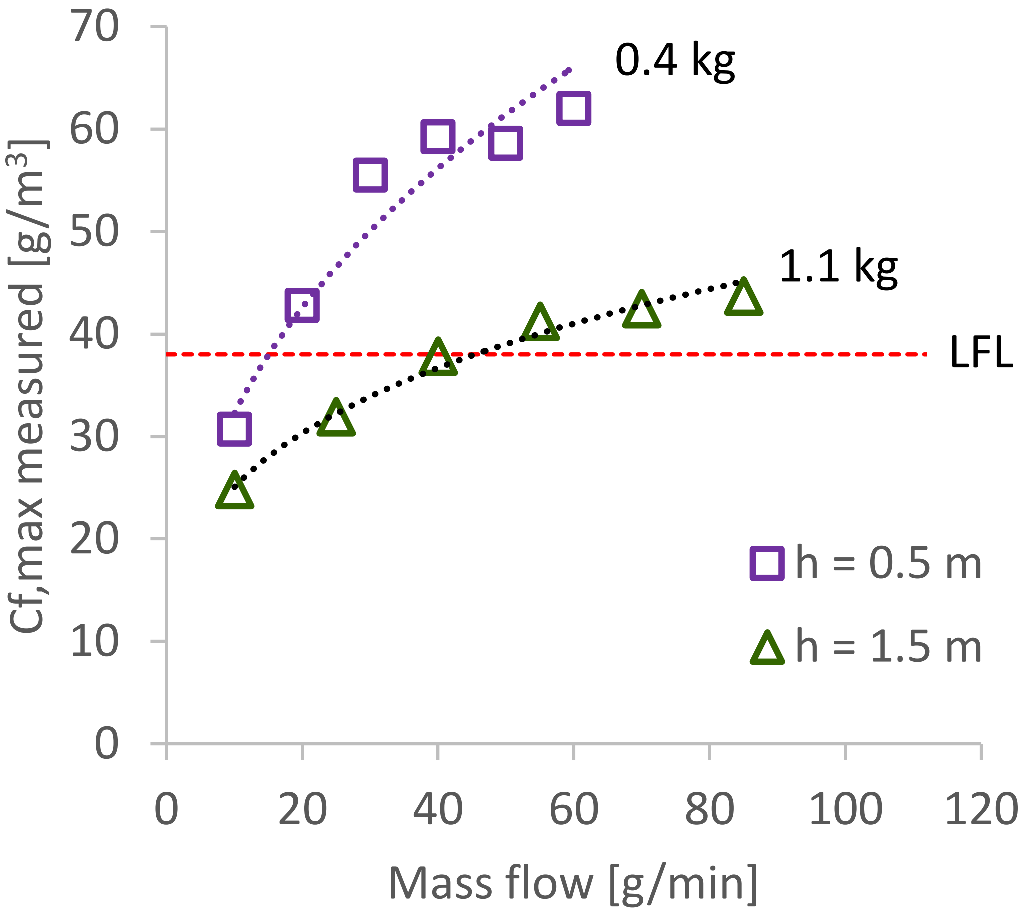
Smaller leak mass flow results in lower floor concentration

Improve system tightness

- Construction to minimise leakage and various tests to confirm
- Implemented in new/draft standards (“enhanced tightness refrigeration systems”, ETRS)



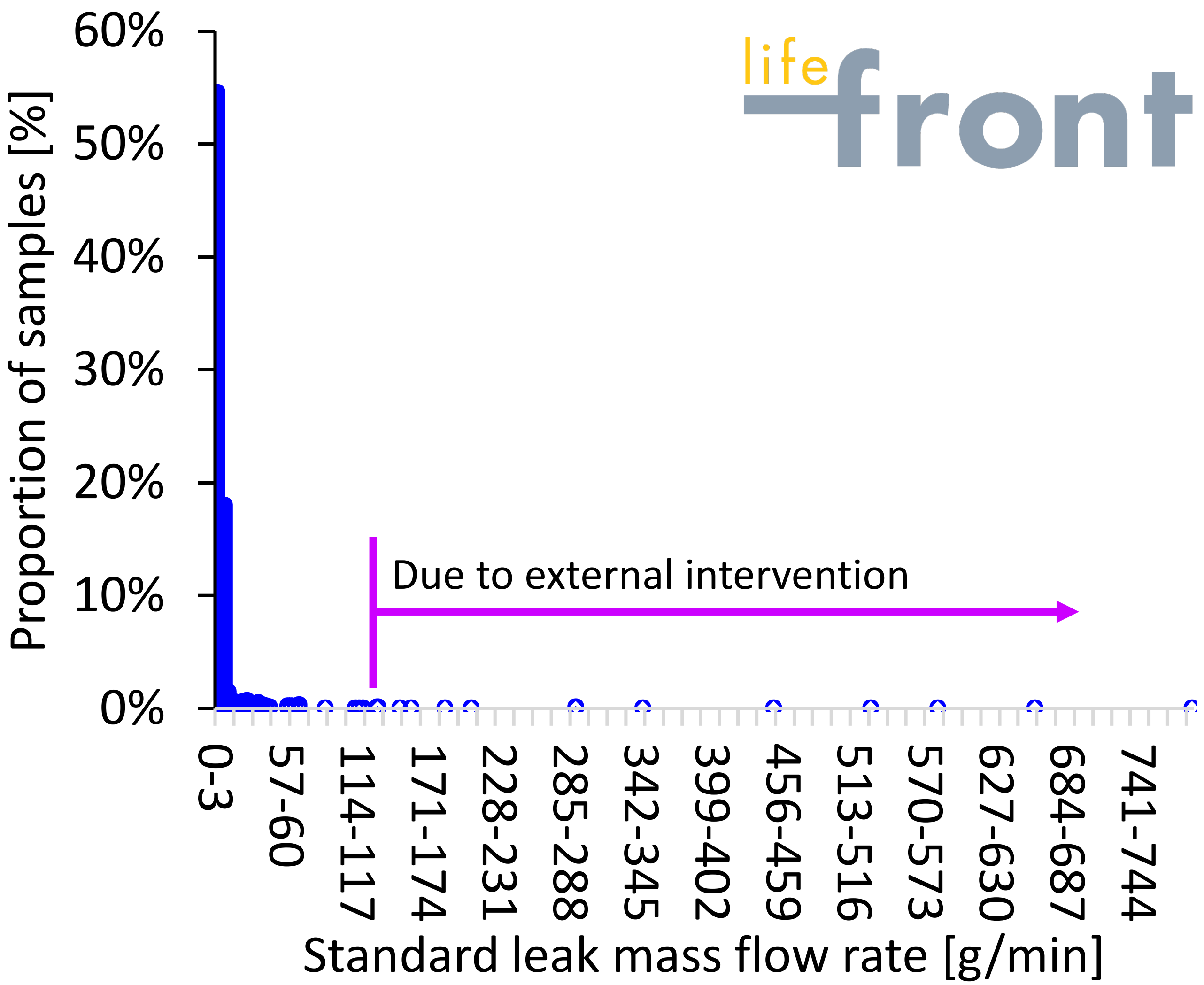




Limit leak mass flow

For EU LIFE FRONT project, analysed 1000+ leak holes from RACHP systems

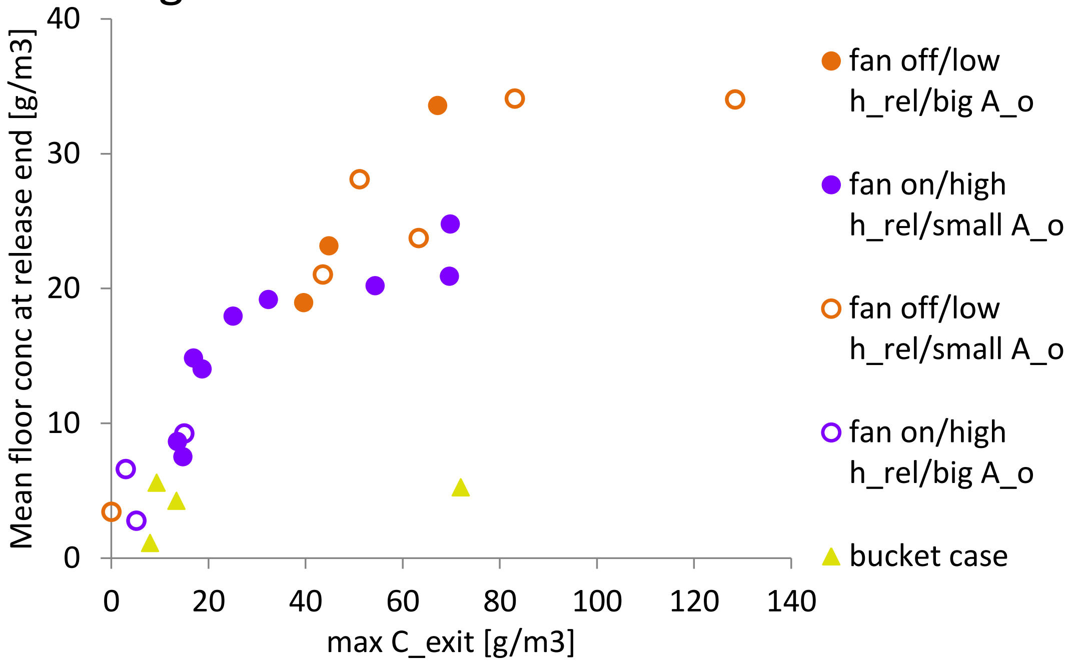
- >98% smaller than 0.5 mm^2 or 70 g/min of R290
- All holes > 1 mm^2 (150 g/min R290) were due to technician/human intervention

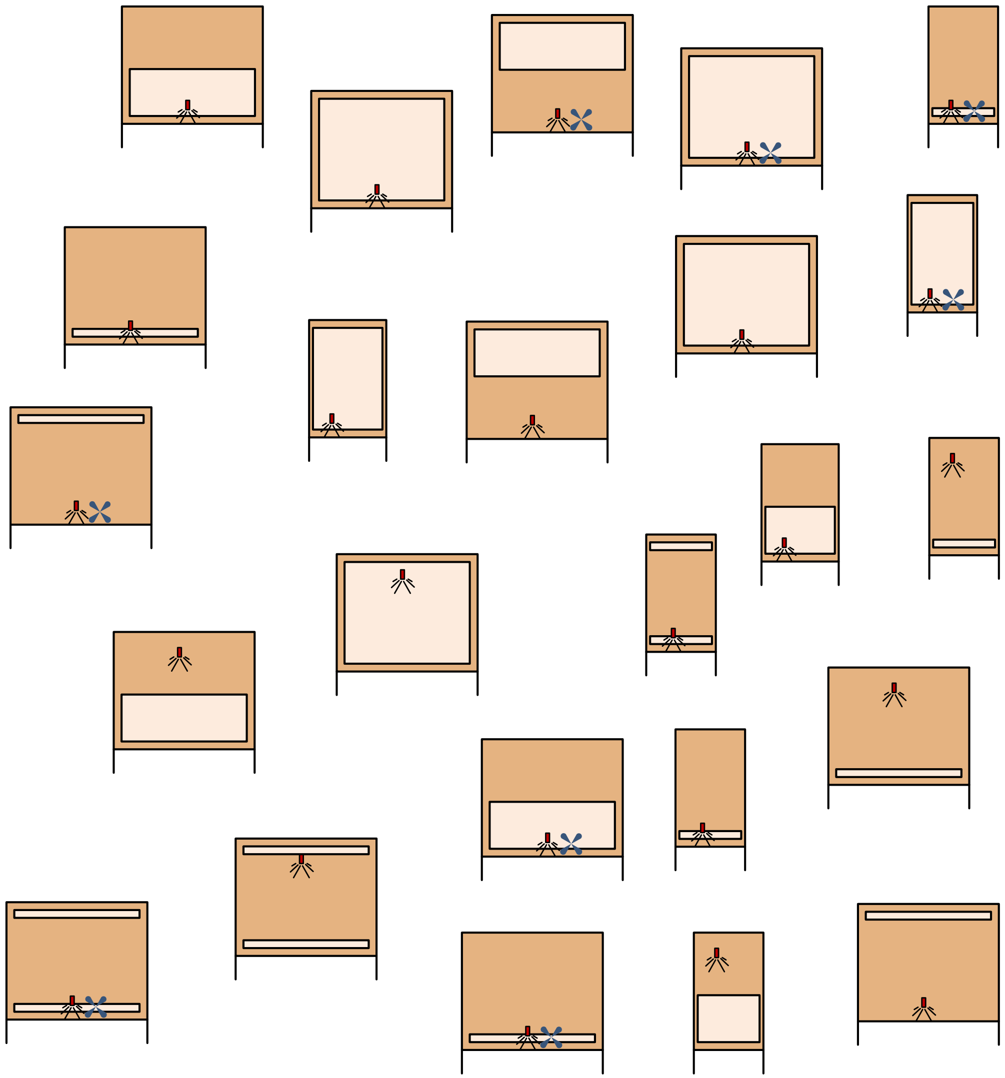


Enclosure/housing design

Investigated effect of different enclosure/housing construction on room floor concentrations

- Found a strong correlation between enclosure exiting conc and max floor conc
- Good enclosure design can be used to pre-mix release before flowing into room





Enclosure/housing design

Factor, F, correlated against exiting concentration

- If the enclosure can be designed to give lower exiting concentration, more charge can be used

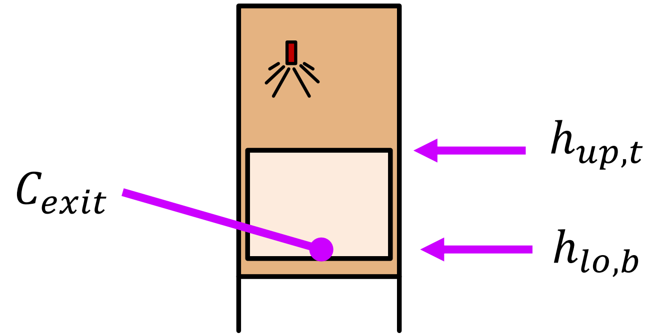
$$m_{max} = F \times LFL \times h^{*} \times A_{rm}$$

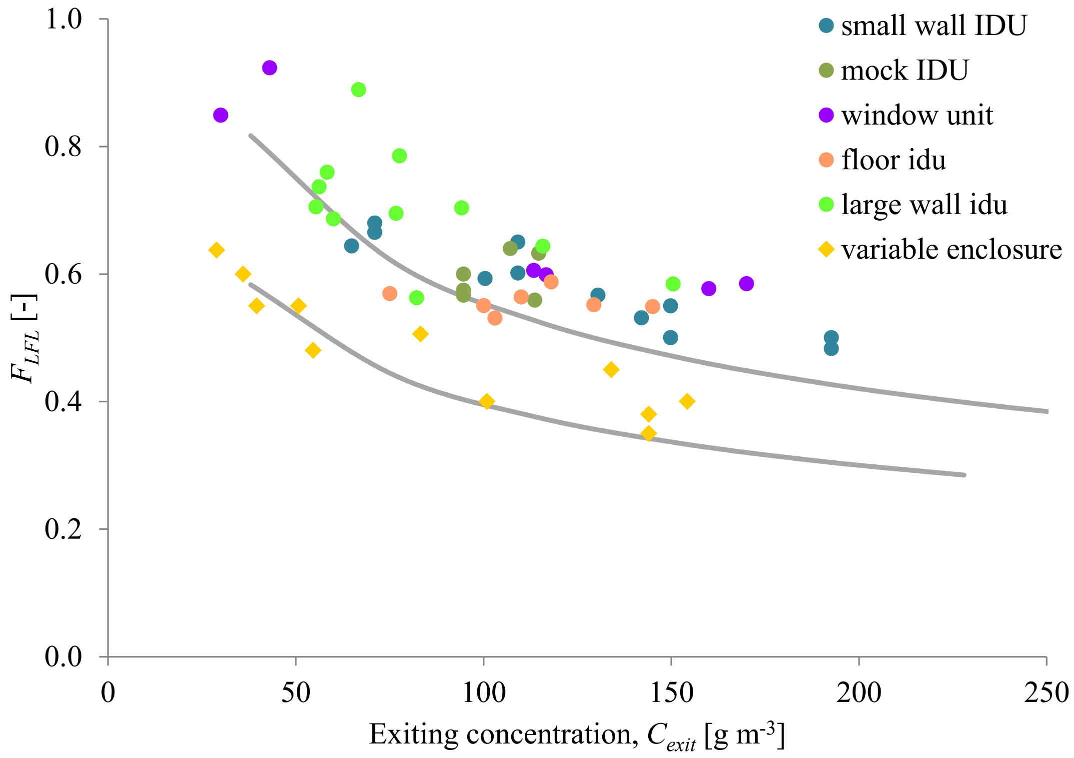
- If release is at or below the opening

$$h^{*} \cong h_{lo,b}$$

- For release higher than openings

$$h^{*} = \frac{1}{2}\left(h_{lo,b} + h_{up,t}\right)$$





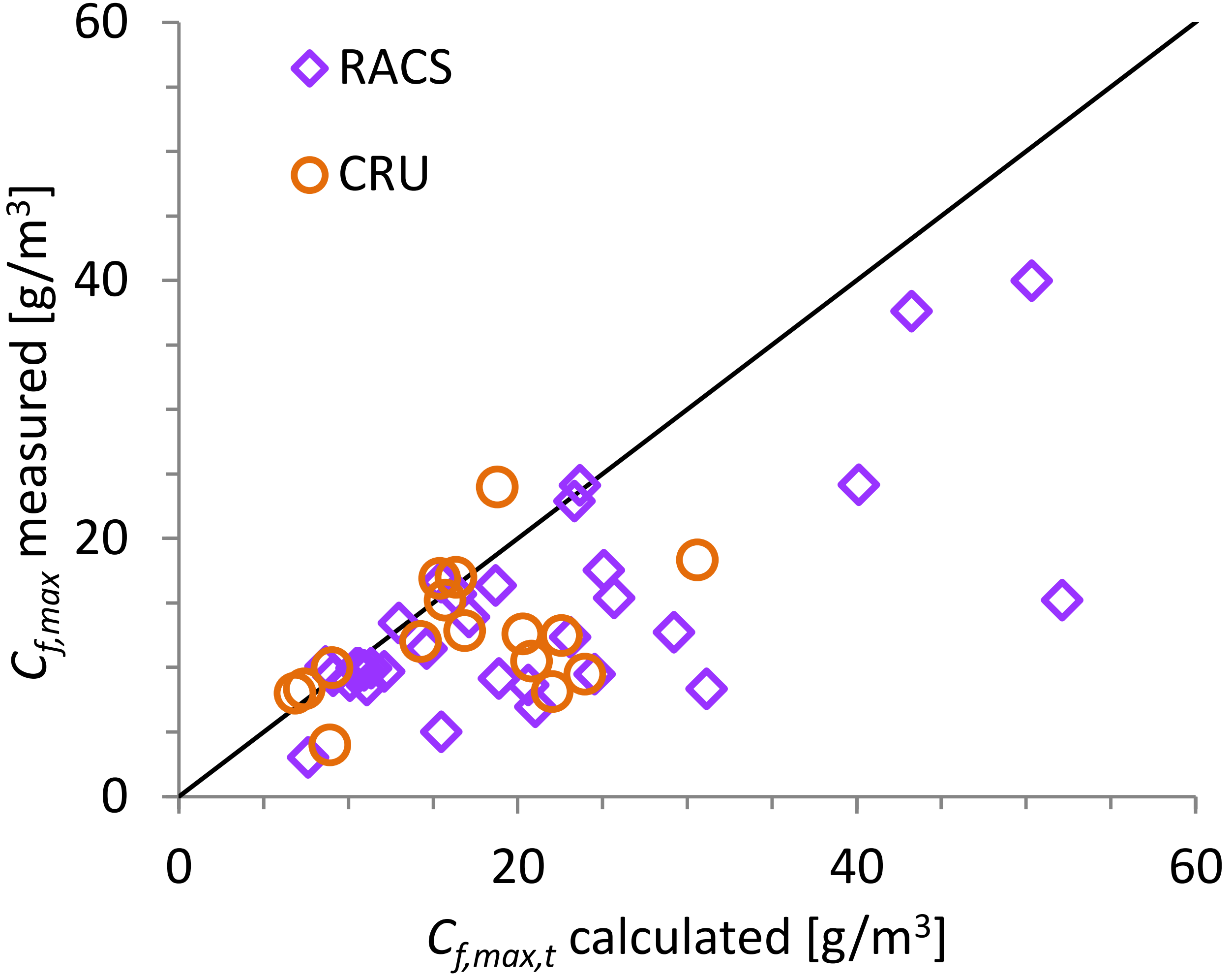
Airflow

New semi-empirical formula to determine minimum airflow, ensuring entire room is well-mixed

- A_o is air discharge outlet area, $\dot{m}_{leak}$ is assumed leak rate, h_o is unit height and F is concentration factor; 0.5 for HCs and 0.75 for A2Ls

$$\dot{V}_{o,min} = \frac{5.0\sqrt{A_o}\dot{m}_{leak}^{3/4}}{h_o^{1/4}[LFL_m(1-F)]^{5/8}}$$

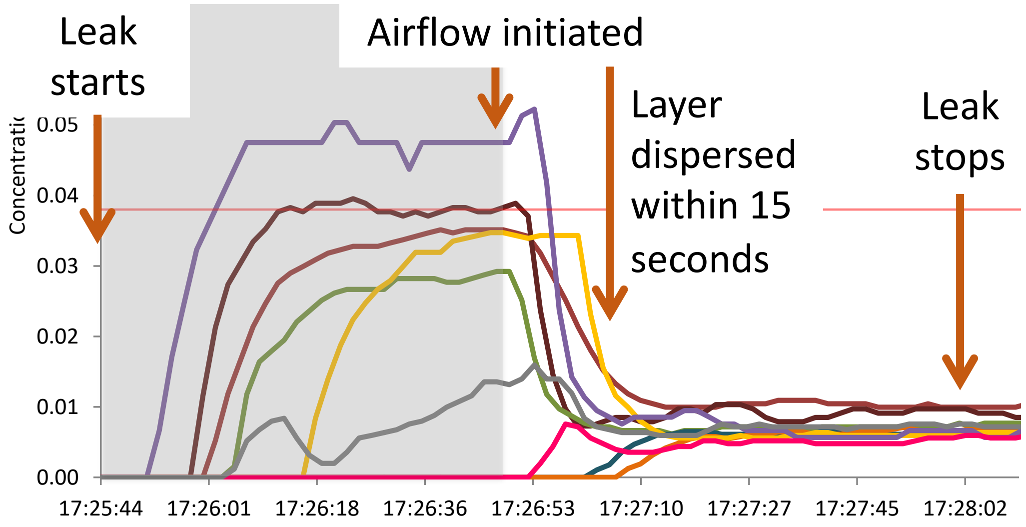
$$m_{max} = F \times LFL \times h_{rm} \times A_{rm}$$



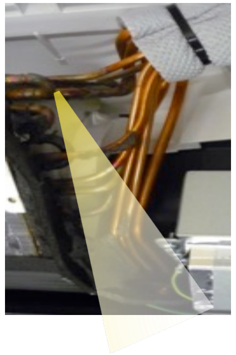
Airflow

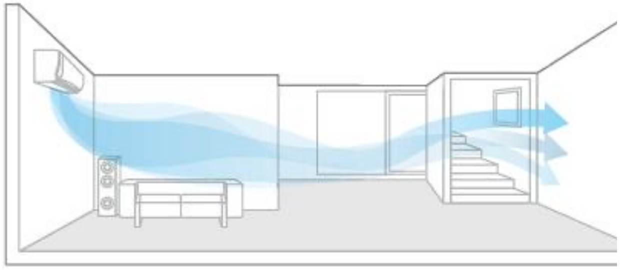
Should avoid fan operating continuously, just in case of a leak

- Sensor detects leak, controller starts fan
- Found $\dot{V}_{o,min}$ effectively disperses stratified layer within 15 s of starting



8 kW wall unit at 1 m, 500g R290, 90 g/min, 1260 m^3/h

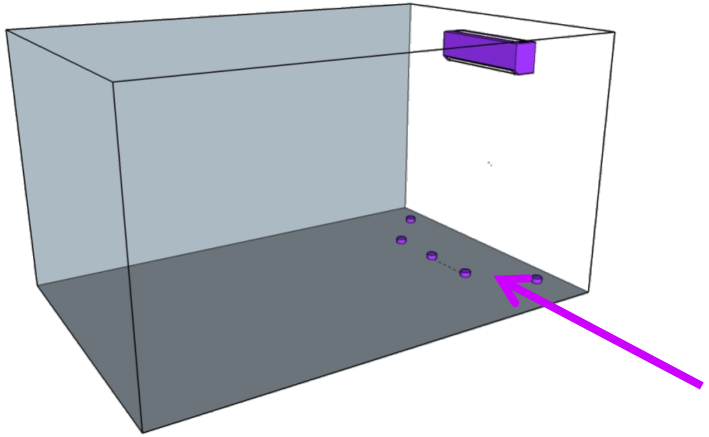


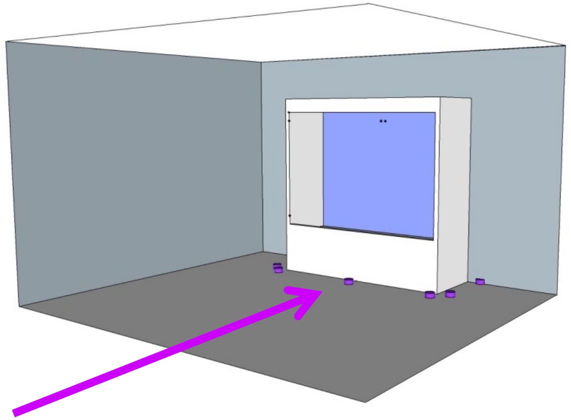


Surrounding concentration test

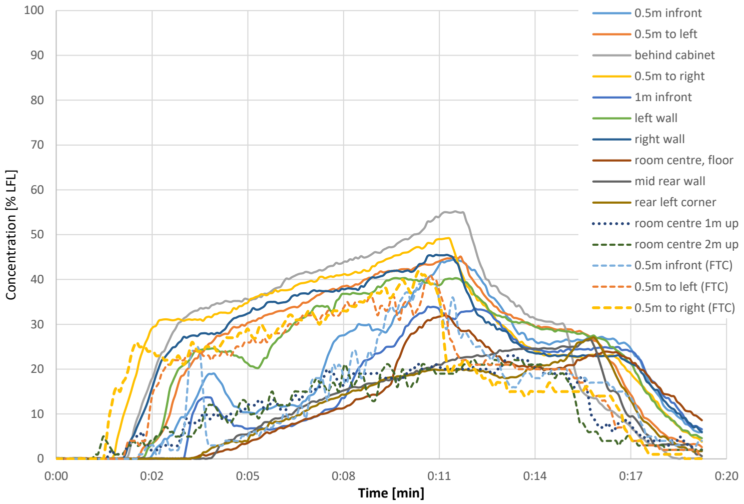
Use test to measure floor concentration surrounding the RACHP equipment – pass if conc < LFL

- Lots of mitigation measures discussed above
- All or any can be integrated into RACHP equipment and treated as “black box”
- Just prove that floor concentration remains below LFL in event of a leak, in any operating mode
- Offers freedom to manufacturers to enhance design of unit





Gas sensors



Final remarks

Avoiding high concentrations of flammable refrigerant beyond RACHP systems is principal safety consideration

- Primarily addressed through limits on charge amount

Can be achieved through one or more approaches

- Limit system charge
- Limit releasable charge
- Height of RACHP system
- Improve system tightness
- Guarantee minimum airflow
- Good enclosure/housing design

Can prove effectiveness through surrounding concentration leak sim test

With more safety concepts, application of HC can expand throughout “sensible” end uses

Seems a little “complicated”, but soon becomes second nature! Everyone will have to know!

Thank you for your attention

Daniel Colbourne

RE – PHRIDGE LTD

d.colbourne@re-phridge.co.uk