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Challenges from flammability concerns and related safety standards, possibilities for compact systems limiting charge sizes

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Brief introduction

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Other roles:

- Member of RTOC (Refrigerant Technical Options Committee), the advisory group on refrigerants for the Montreal Protocol. Lead author on the chapter for refrigerant properties.
- Member of ISO/TC86/SC1/WG1 , the group that works on ISO5149.
- Member of CEN/WG182/TC6, the group that works on the next version on EN378.
- Chair of the Danish mirror committee for standards within refrigeration systems.

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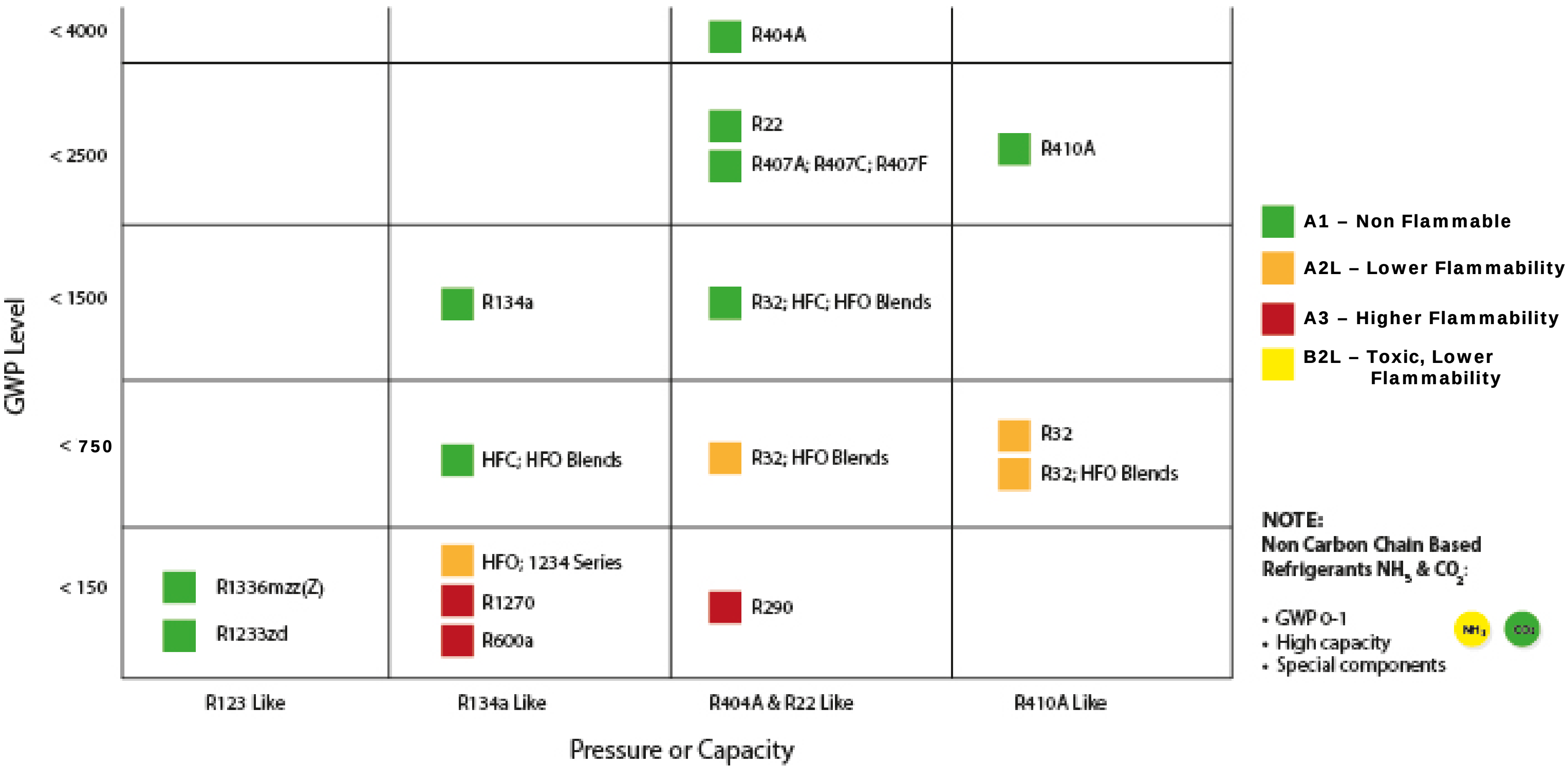
Refrigerant alternatives and safety class

Carbon Chain Base Refrigerants



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The Role of Safety Standards

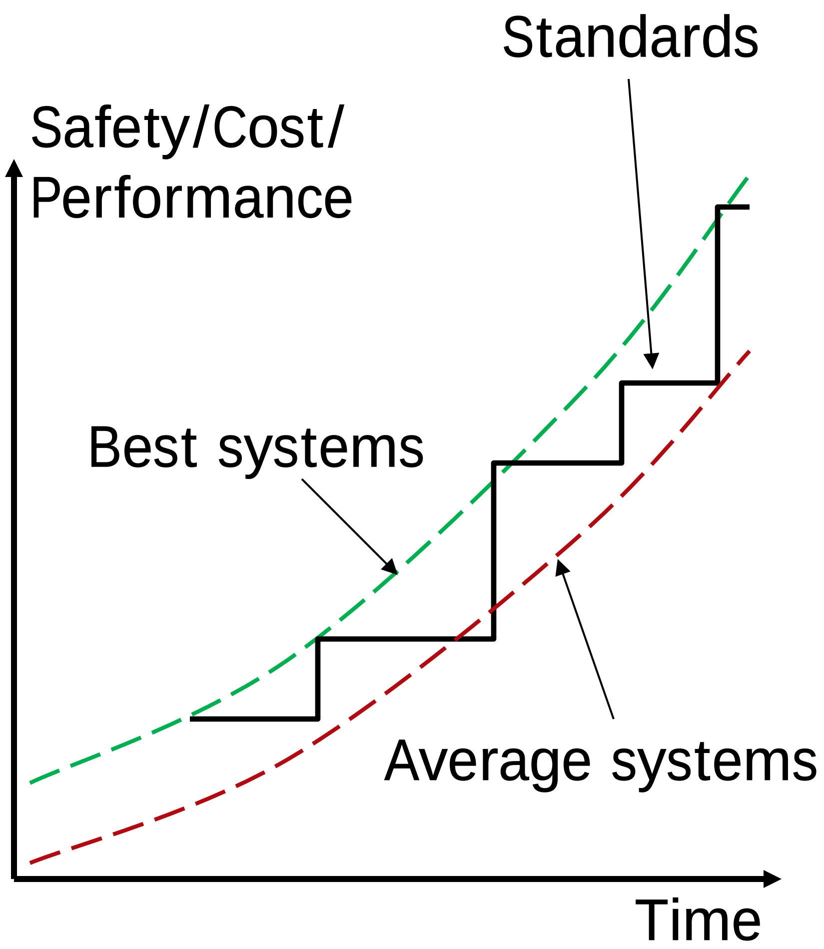
Commonly agreed best practice:

- Base of the best systems
- Improves the average systems
- Good base for insurance companies
- Lightens burden of proof in case of accidents
- Marker of good quality for marketing purposes

Legal basis

- In some countries they are mandatory.
- In other countries they can be deviated from with a thorough risk assessment.

Notice: Standards by nature lags behind the best practices, as they are written based on the best systems.



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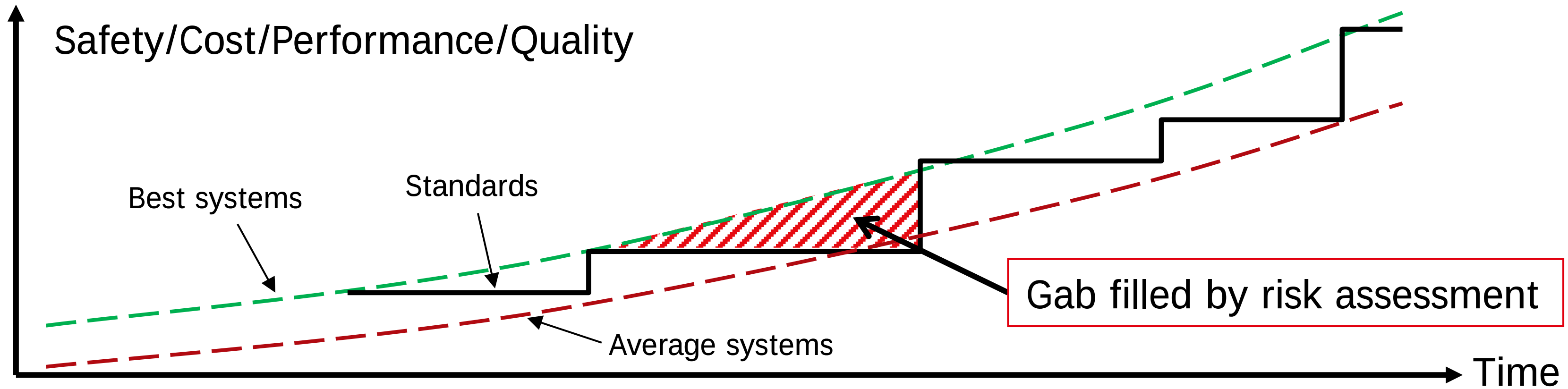
The Policymakers Choice

Policy makers can chose between (for instance using building codes):

1. Ignore safety standards. Enable the best as well as the worst system builders to experiment, but the inevitable accidents will slow down market acceptance of new technologies. **Not a good idea!**

2. Make safety standards mandatory. Forcing the worst system builders to build safe systems, but limit the best by the standards of the day. **May be acceptable** in countries with limited resources.

3. Make safety standards mandatory with the alternative option of risk assessment. Allow developing the next generation systems, but make enforcement of standards more difficult. **Most desirable option!**



2L – Almost new safety class

Current EN378 and previous ASHRAE34:

Higher flammability	**A3:** Hydrocarbons	**B3:** No refrigerants
Lower flammability	**A2:** R32, R152, Most HFO's	**B2:** Ammonia
No flame propagation	**A1:** CFC, HCFC, most HFC's	**B1:** R123
	Lower toxicity	**Higher toxicity**

Increasing flammability

Increasing toxicity

ISO5149:

Higher flammability	**A3:** Hydrocarbons	**B3:** No refrigerants
Flammable	**A2:** R152	**B2:** Seldomly used
Lower flammability	**A2L:** Most HFO's, R32	**B2L:** Ammonia
No flame propagation	**A1:** CFC, HCFC, most HFC's	**B1:** R123
	Lower toxicity	**Higher toxicity**

Requirements to 2L refrigerants are almost the same as to the old class 2 in EN378.

It is actually the new class 2 that is new!

BTW: The largest differences in requirements to system design for flammables are charge limits.

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Charge limits sanity check

Approximation for sanity check - Refrigeration and Chillers

<table>
<tr><th>Allowed Charge</th><th>EN378 current version</th><th>ISO5149 and proposed prEN378</th><th>IEC 60335 -2-40</th><th>IEC 60335 -2-89</th></tr>
<tr><td>Everywhere</td><td>A3: 150g
A2L: 1,2 kg</td><td>A3: 150g
A2L: 1,8 kg</td><td>150g</td><td rowspan="5">150g</td></tr>
<tr><td>Indoors occupied space</td><td colspan="2">A3: $8 g/m^3 \times V$
A2L: $60 g/m^3 \times V$</td><td>See separate slide</td></tr>
<tr><td>Ventilated enclosures</td><td colspan="2">A3: 5kg
A2L: 39kg</td><td rowspan="3">A3: 5kg
A2L: 39kg</td></tr>
<tr><td>Out doors public access (like outdoor residential HP)</td><td colspan="2">A3: 5kg
A2L: No limits</td></tr>
<tr><td>Machine room, or out doors protected from public interference (like typical chiller)</td><td colspan="2">No limits</td></tr>
</table>

V: Volume of room in m3.
Charges in large rooms are typically limited by room volume.

Note:
A2L: LFL for R32 and HFOs are used.
A3: LFL for hydrocarbons are used.

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Competence standard (EN13313)

- Although competences are strictly not part of safety standards. Competences are important for safety

- EN13313 is a standard for competences for working on refrigerating systems and heat pumps.

- EN13313 is based on the EU f-gas regulation, which requires persons installation, servicing, maintenance, repair or decommissioning to be certified.

- Certification requires training in the competences listed in the legislation (and duplicated in EN13313).

Options for limiting charge

There are several options for limiting the refrigerant charge, for instance:

- Micro channel heat exchangers. Lowers the charge in the heat exchangers, but lower charge creates other challenges.
- Plate heat exchangers + brine. Using a brine to carry the heat to/from the system lowers charge dramatically, but lowers energy efficiency.
- Separating the system in case of leaks lowers the charge in the part of the system where a leak can be a safety problem, but increases cost and option is not yet covered by safety standards

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Conclusion

- Safety standards are important for the low GWP options
- How to integrate safety standards in the legislation is an important policy decision
- The refrigerant options for a given application is limited depending on the charge needed, the location, and the occupancy classification
- Several options are available to reduce the charge of a system, and like all technology changes each option offers both advantages and disadvantages.
- Competences are another important aspect of safety, and there are also standards for competences.

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Danfoss Policy

Danfoss encourages the further development and use of low-GWP refrigerants to help slow – and ultimately reverse – the process of global warming while helping to ensure continued global wellbeing and economic development along with the future viability of our industry

- We will enable our customers to achieve these refrigerant goals while **continuing to enhance the energy efficiency** of refrigeration and air-conditioning equipment.
- Danfoss will **proactively develop products for low-GWP refrigerants, both natural and synthetic**, to fulfil customers' needs for practical and safe solutions without compromising energy efficiency
- Danfoss will lead and be recognized in the development of **natural refrigerant solutions**.
- Danfoss supports the establishment of a global regimen through the Montreal Protocol to **phase down** emissions of high-GWP refrigerants ... to provide for long-term production of very small quantities of HFCs for critical needs.

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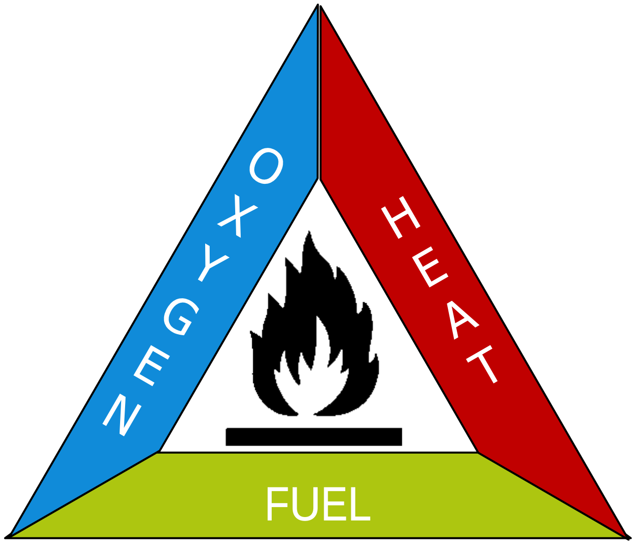
Charge Limits

There are several charge limiting approaches in prEN378 and ISO5149 for flammable refrigerants:

- m_1/150g limit
- 20% LFL for non-human comfort
- Special formula for systems for human comfort
- Special formula for systems for human comfort with small charges (not yet in ISO5949, but in IEC60335-2-40 and prEN378)
- Special option for multi-split A/C systems with A2L refrigerants

Machine rooms have no charge limits (except when used as workshop and regularly occupied)



Limiting the available fuel for a potential fire is a common method of reducing risk

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m_1/150g Limit – Safe and simple

Independent on system location prEN378 and ISO5149 allows:

- $1{,}5 \times m_1 = 6 \times LFL$ for 2L refrigerant charge:
  - R32, R1234yf and R1234ze $1{,}5 \times m_1 = 1{,}8$kg.

- $m_1 = 4 \times LFL$ for class 2 and class 3 refrigerant charge:
  - R290 $m_1 = 152$g,
  - R1270 $m_1 = 184$g,
  - R152a $m_1 = 520$g.

But only from a flammability point of view.
Toxicity needs to be evaluated seperately.

150g hydrocarbon
< 300 ml = 1 bottle

20% LFL Limit for A2L and A3:

For non-"human comfort" 20% of LFL × room volume is allowed, but with an upper limit depending on location and occupation of the room:

A2L		Location			
Occupancy		I (occupied)	II (Compressor & Vessels outside)	III (not occupied or outside)	IV (Ventilated Enclosure)
a		$1{,}5 \times m_2$	$1{,}5 \times m_2$	non*	$1{,}5 \times m_3$
b			25kg		
c	> 1 person per 10 m^2				
	< 1 person per 10 m^2	50kg	non*		

Example R32 (≈R1234):
20% LFL ≈ 61g/m^3, $1{,}5 \times m_2 = 11{,}97$kg, and $1{,}5 \times m_3 = 59{,}87$kg.

A3		Location			
Occupancy		I (occupied)	II (Compressor & Vessels outside)	III (not occupied or outside)	IV (Ventilated Enclosure)
Above ground	a	1,5kg		5kg*	m_3
	b	2,5kg		10kg*	
	c	10kg	25kg	non*	
Below ground		1kg		1kg*	

Example R290 (propane):
20% LFL = 8g/m^3, m_3 = 4,94kg.

a = general occupancy
b = supervised occupancy
c = authorized occupancy
* = independent of room size

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Charge Limits for Human Comfort, small systems (IEC 60335-2-40)

For non-fixed factory sealed single package systems with charge between m_1 and 2 x m_1:

- Charge as function of area: $m_{max} = 0,25 \times A \times \mathrm{LFL} \times 2,2$
- Expressed in a different way: $A_{min} = m \times (0,25 \times \mathrm{LFL} \times 2,2)^{-1}$
  - The minimum area will be in the range from $7,3 m^2$ to $14,5 m^2$.

Typical values of m_1:

- R290 m_1=152g,
- R1270 m_1=184g,
- R152a m_1=520g,
- R32, R1234yf, R1234ze(E): m_1=1,2kg.

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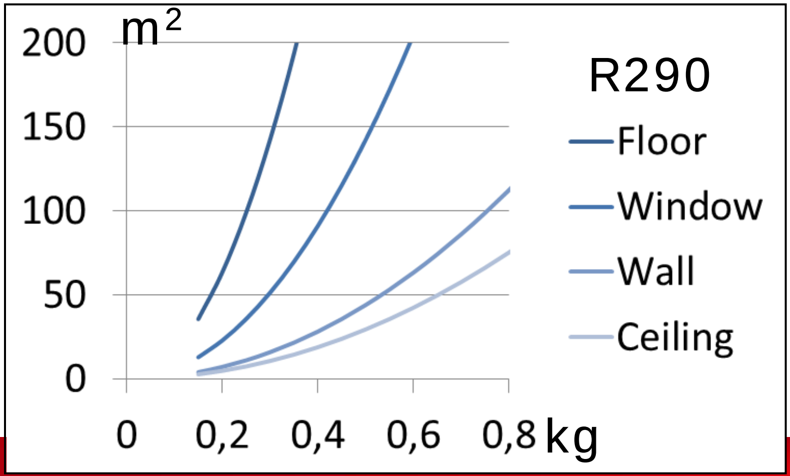
Charge Limits for Human Comfort

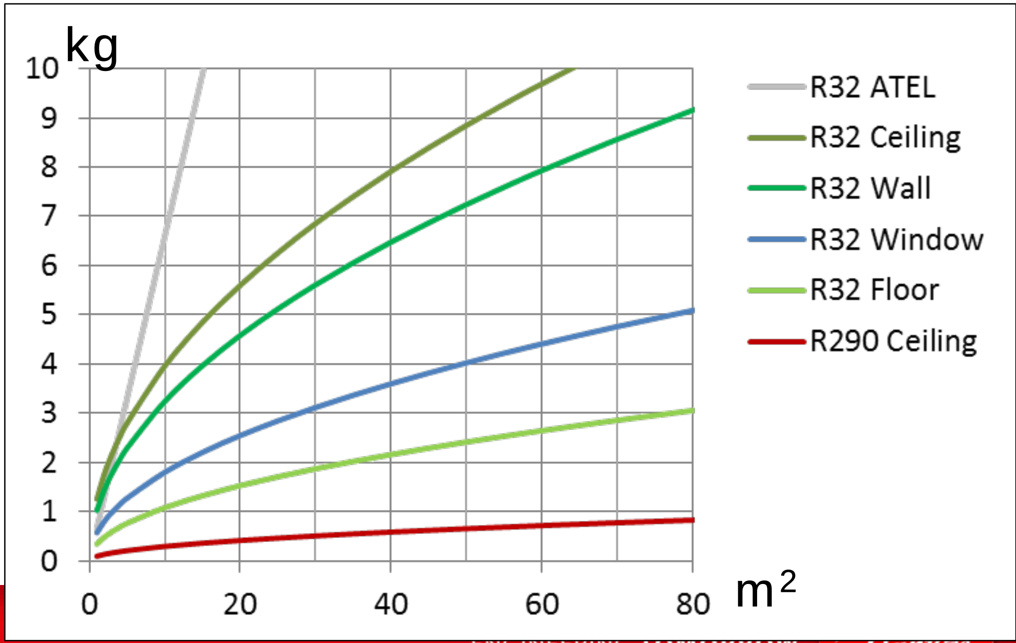
- The maximum charge for a given room size is determined by:

$$m_{\max} = 2{,}5 \times \mathrm{LFL}^{5/4} \times h_0 \times A^{1/2}$$

- prEN378 (proposal) keeps the formula but also requires toxicity to be taken into account separately.

Note: For R-1270 this means max. 8g/m³ room volume





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Option for multi-split systems with A1 and A2L

When a leak appears in a distributed system:

- It takes time for the refrigerant to come out.
- During that time some of the leaked refrigerant will leave the room due to air exchange.
- This is taken into account to allow a larger charge.

Solve the below for $s\big|_{x=\mathrm{RCL}}$

$$\frac{dx}{ds} = \dot{m} - x \times A \times c \times \sqrt{2 \times \left(1 - \frac{\rho_a}{\rho}\right) \times h \times g} \quad \text{where} \quad \rho = x + \rho_a - x\frac{\rho_a}{\rho_r}$$

Allowed charge per m³ is $\mathrm{QLMV} = s\big|_{x=\mathrm{RCL}} \times \dot{\mathrm{m}}$

Formula is complex (a table of common QLMV values is given).

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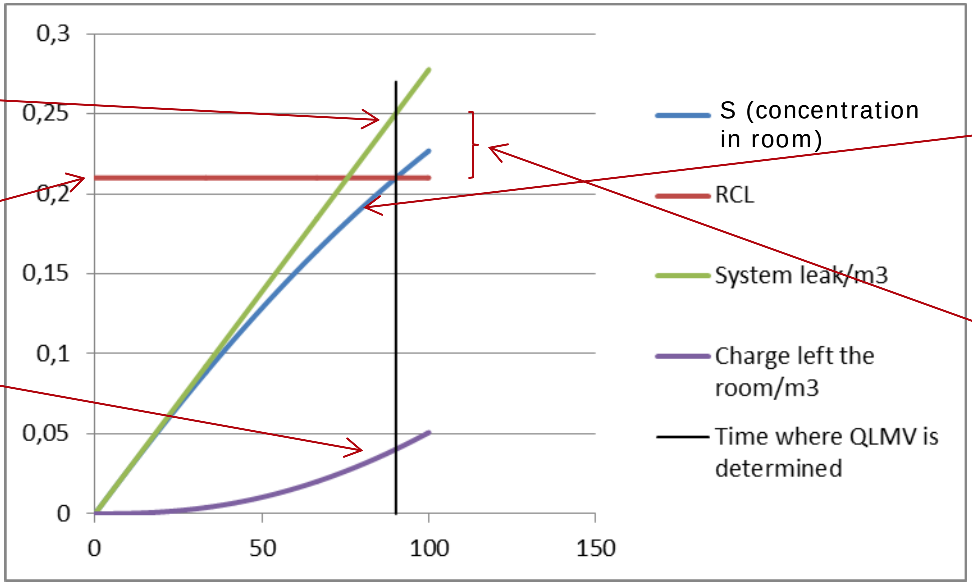
Option for multi-split… explaining the formula

The formula for QLMV is a differential equation describing the dynamics of the refrigerant concentration in a room:

Total amount of refrigerant leaked from the system

RCL is the max concentration allowed in a room

Some refrigerant will be ventilated from the room while the leak is occurring



The resulting concentration in the room will be slightly lower than without natural ventilation.

Slightly more charge is therefor allowed (QLMV).

$$\frac{dx}{ds} = \dot{m} - x \times A \times c \times \sqrt{2 \times \left(1 - \frac{\rho_a}{\rho}\right) \times h \times g}$$

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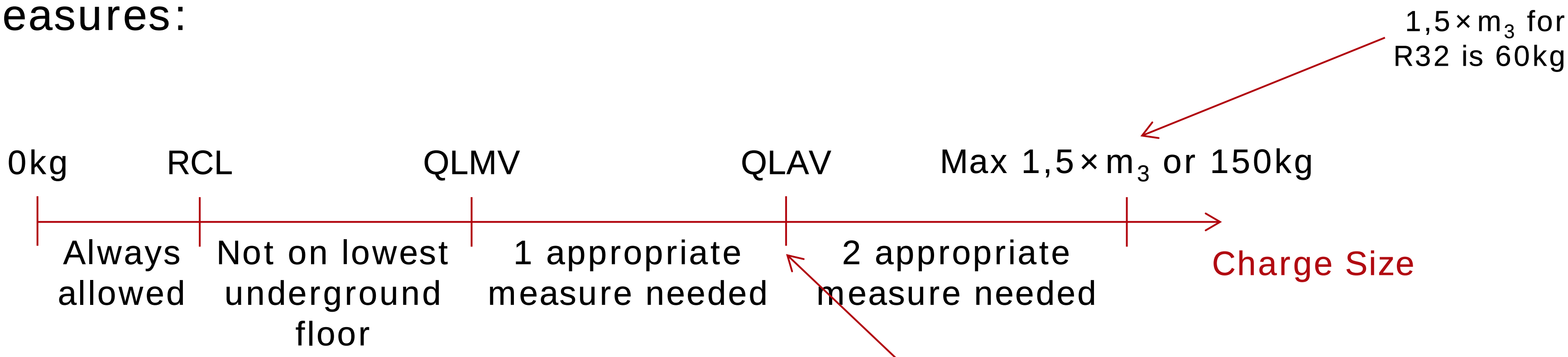
Option for multi-split… even larger charges

- There is also an attempt to take catastrophic leaks into account (QLAV)
- Charges can be above RCL, QLMV or even QLAV with appropriate measures:



Appropriate measures can be (in prEN378-3):

- ventilation (natural or mechanical)
- safety shut-off valves
- safety alarm, in conjunction with a gas detection device

QLAV is 50% of LFL, or oxygen deprivation limit, or 10% for CO_2

Guess: In the future a similar type of mechanism may also apply to HC's?

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Micro Channels Heat Exchangers

Opportunities

- Using MCHE can dramatically reduce charge
  - Micro channel heat exchangers (MCHE) have much less volume than traditional fin and tube
- System costs are typically lower

Challenges

- Controlling where the charge is can be a challenge
- Higher sensitivity to charging precision
- Higher sensitivity to leaks
- Operation below 0°C can be challenging due to frost build-up

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Plate heat exchangers + Brine

These systems includes chillers and cassette systems

Opportunities

- Using a brine can reduce refrigerant charge needed
  - Brine cooled heat exchangers have much lower volume than air cooled heat exchangers
- Using a brine can remove the need for circulating refrigerant in occupied space
- Systems can be factory build lowering costs compared with site build systems

Challenges

- Using a brine gives a temperature loss in the heat exchanger, which would be avoided in a direct system
  → lower energy efficiency

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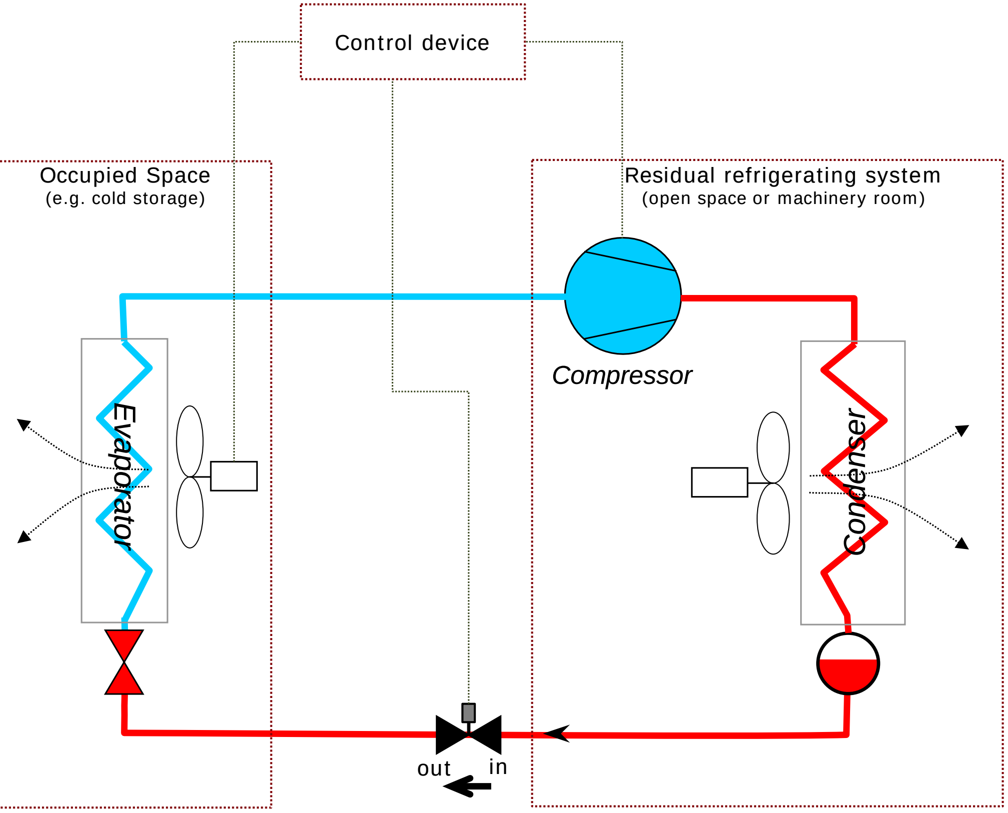
Separation Valves to Limit Charge in Part of System



Opportunities

- Limits the amount that can leak
- Increases the potential capacity of the system

Challenges

- Not covered by safety standards, requires risk assessment
- Extra valves increases cost
- Detecting leaks can potentially increase cost
  - It is also possible to couple fan and valve activation to increase the acceptable charge

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