ASHPs & VRF: How About These HFC Refrigerants?
Thursday, May 21, 2020

The webinar will begin at 11:00am.

Brought to you by: NESEA
Sponsored by: DAIKIN
ASHPs & VRF
A discussion on refrigerants

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Economics

Environment

Health & Safety
Pre-reqs

- OK with doing a bit of follow-up research
- Desire to create your own *educated* opinion
- Don’t let a little high school chemistry scare you
Agenda

- Why do we care
- Carbon, CFCs, HCFCs, ODP & the Montreal Protocol
- HFCs and refrigerant classification
- Global, Federal and State level HFC phasedowns
- The ‘Low GWP A1’ challenge & LCCP impacts
- Getting A2L into buildings codes
- R-32: the original and the future A2L low GWP refrigerant
Refrigerants are already used in most buildings. If a building has AC, it has refrigerants somewhere.
As energy efficiency, sustainability and climate activists, why do we care about refrigerants?

Refrigerants can have environmental, health & safety and economical impacts.

We care about rules and regulations around them, including timely phase downs when required.
Buildings Tomorrow

- **Cooling**
  - Space Cooling
  - Ventilation Cooling

- **Heating**
  - Space Heating
  - Ventilation Heating

- **Domestic hot water**
  - Domestic hot water heating

- Refrigeration Cycle
- Energy Recovery + Refrigeration Cycle
- HE Energy Recovery + Refrigeration Cycle
- Refrigeration Cycle
As energy efficiency, sustainability and climate activists, why do we care about refrigerants?

1. Refrigerants can have environmental, health & safety and economical impacts.

We care about rules and regulations around them, including timely phase downs when required.

2. Leading technologies to electrify buildings (ASHPs, VRV) now introduce refrigerant throughout the building.

We care about ensuring phase down plans leave sustainable options for refrigerants that can be run through buildings.
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Carbon

Atomic no. 6
4 valence electrons
Looking for 4 bons

O \equiv C \equiv O

Carbon Dioxide
R-744

GWP: 1

CO₂

The Global Warming Potential metric (GWP)

▪ How much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to 1 Ton of CO2.

▪ The time period used is usually 100 years.

▪ GWP is NOT a measure of efficiency
Carbon-based chemicals

- **CO₂**
  - Carbon Dioxide
  - R-744
  - GWP: 1
  - Combustion of methane:
    \[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]
  - 117 lbs of CO₂ per mmBTU

- **CH₄**
  - Methane
  - Natural Gas
  - R-50
  - GWP: 28 [AR5¹]
  - Estimates up to 105²

- **CCl₂F₂**
  - Di Chloro Fluoro Methane
  - Freon
  - R-12
  - GWP: 10,200 [AR5¹]

1. GPW values from the IPCC 5th assessment report, 2014 (AR5 values). [https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20Feb%202016%20%282%29.pdf](https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20Feb%202016%20%282%29.pdf)
Refrigerant Naming Convention

### Rule of 90 (add 90)

- **R-12**
  - $12 + 90 = 102$

#### Series

<table>
<thead>
<tr>
<th>Series</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>Methane Based</td>
</tr>
<tr>
<td>100</td>
<td>Ethane Based</td>
</tr>
<tr>
<td>200</td>
<td>Propane Based</td>
</tr>
<tr>
<td>300</td>
<td>Cyclic Organic Compounds</td>
</tr>
<tr>
<td>400</td>
<td>Azeotropes</td>
</tr>
<tr>
<td>500</td>
<td>Azeotropes</td>
</tr>
<tr>
<td>600</td>
<td>Organic Compounds</td>
</tr>
<tr>
<td>700</td>
<td>Inorganic Compounds</td>
</tr>
<tr>
<td>1000</td>
<td>Unsaturated Organic Compounds</td>
</tr>
</tbody>
</table>

#### Example:

- **CCl₂F₂**
  - 1 x Carbon atom
  - 0 x Hydrogen atoms
  - 2 x Florine atoms
CFCs

Evil Chlorine

HCFCs

Stable molecules with long life cycles.
Carbon-Chlorine bond is broken up by sunlight radiation.
Chlorine molecule reacts with ozone ($O_3$)

1. GWP values from the IPCC 5th assessment report, 2014 [AR5 values].
https://www.ghgprotocol.org/sites/default/files/ghgp/Global_Warming_Potential_Values%20%28Feb%202016%29.pdf
Ozone Depletion Potential (ODP) – Effectiveness of a given compound in removing ozone, relative to R-11, at steady state.

The Montreal Protocol (ODS)

“The Montreal Protocol to protect the Earth’s ozone layer is to date the only United Nations environmental agreement to be ratified by every country in the world. It is also one of the most successful”.¹

1985
- Atmospheric ozone over Antarctica’s Halley Bay dropping precipitously
- NASA analyzing an ‘ozone hole’ the size of the US over Antarctica

1987
- Montreal Protocol on Substances that Deplete the Ozone Layer was adopted
- Large US involvement (Reagan) in encouraging other countries to adopt
- Goal: Phase out CFC and HCFC refrigerants (containing Chlorine)

1996
- 100% Phase out of CFCs (and other chemicals) [R-11] [R-12]

2010
- No production or import of R-22 (except for equipment built before Jan 1, 2010)

2020
- No production or import of R-22
  - Recycled only
  - Drop-ins available such as Bluon R-458a

iPIC system helps prevent an illegal shipment of 72 tonnes of HCFC-22

An information sharing platform known as the informal Prior Informed Consent (iPIC) system is helping countries enforce the work of the Montreal Protocol. Recent collaboration between China and Thailand using the iPIC system, for example, has resulted in the prevention of a huge consignment of ozone-depleting and climate damaging hydrochlorofluorocarbons (HCFCs). iPIC is a voluntary and informal mechanism of information exchange on intended trade between countries in controlled substances. This case shows that iPIC can be an important tool to weed out any unauthorised trade (intentional or unintentional) to support the licensing system for import and export of ozone depleting substances and hydrofluorocarbons (HFCs) and mixtures containing these substances. To find out more click here.

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### ASHRAE Standard 34 – Designation and Safety Classification of Refrigerants

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<th>Refrigerant Classification</th>
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#### Toxicity
- Toxicity “A” & “B”
- “B” not generally accepted
- Occupational Exposure Limit (OEL) > 400 ppm by volume is classified as “A”

#### Flammability
- All refrigerants can be combusted when put into a high-energy situation such as a fire
- Class 1: no flame propagation (at testing standard of 140F)
  - Class 2 & 3 have flame propagation
- Class 2: lower flammability
- Class 3: higher flammability (LFL < 0.10 kg/m3 or Heat of Combustion HOC > 19 kJ/g)

*New flammability subclass for A2 refrigerants that burn very slow
A2L have slow velocities; <10 cm/sec ~ 20ft/minute

<table>
<thead>
<tr>
<th>Higher Flammability</th>
<th>A3</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Flammability</td>
<td>A2</td>
<td>B2</td>
</tr>
<tr>
<td></td>
<td>A2L*</td>
<td>B2L*</td>
</tr>
<tr>
<td>No Flame Propagation</td>
<td>A1</td>
<td>B1</td>
</tr>
</tbody>
</table>

<table>
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<th>Lower Toxicity</th>
<th>Higher Toxicity</th>
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</thead>
<tbody>
<tr>
<td>A1</td>
<td>B1</td>
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- All refrigerants can be combusted when put into a high-energy situation such as a fire
ASHRAE Standard 15 – Safety Standard for Refrigeration Systems

- Application standard with a focus on health & safety
- Version currently followed by U.S. building codes includes:

7.5.2 Applications for Human Comfort. Group A2, A3, B1, B2, and B3 refrigerants shall not be used in high-probability systems for human comfort.

refrigerant coils in air stream = ‘high probability systems’

What can we use for VRV / ASHP systems?

A1
ASHRAE Standard 15 – Safety Standard for Refrigeration Systems

- Introduces Refrigerant Concentration Limit (RCL) to ensure safety in case of a complete refrigerant discharge in the smallest occupied space
  - Analyzes toxicity, oxygen deprivation and flammability
  - Worse case maximum concentration determines the RCL

- R-410a
  1. Low toxicity
  2. No flame propagation at 140F
  3. Oxygen deprivation determines the RCL
- RCL of R-410a = 26 lbs / mcf

### Oxygen Percentage Available and Symptoms

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<td>OSHA oxygen-deficient atmosphere.</td>
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<td>Muscular impairment, rapid breaths.</td>
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<td>12</td>
<td>Dizziness, headache, rapid fatigue.</td>
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<tr>
<td>9</td>
<td>Unconsciousness</td>
</tr>
<tr>
<td>7 to 6</td>
<td>Death within a few minutes.</td>
</tr>
</tbody>
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### Altitude equivalent [ft]

- Of effective oxygen %

<table>
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<tr>
<th>Altitude equivalent [ft]</th>
<th>Oxygen Percentage Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>2,000</td>
<td>19.5</td>
</tr>
<tr>
<td>5,500</td>
<td>17</td>
</tr>
<tr>
<td>14,500</td>
<td>12</td>
</tr>
<tr>
<td>22,000</td>
<td>9</td>
</tr>
<tr>
<td>29,000</td>
<td>7 to 6</td>
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Introducing: HFCs

CH$_2$F$_2$

Di Fluoro Methane
R-32

GWP: 677 [AR5']

ODP: 0

Hydro Fluoro Carbons
- No Chlorine
- Relatively low GWP: 677
- Zero ODP

1. GPW values from the IPCC 5th assessment report, 2014 [AR5 values]. [https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%202016%29_1.pdf]
HFCs

CH₂F₂

F
\[ \text{H} - \text{C} - \text{F} \]
\[ \text{H} \]

Di Fluoro Methane
R-32

GWP: 677 [AR5’s]

ODP: 0

- Increasing Hydrogen atoms increases flammability
- R-32 is NOT an A1 refrigerant (A2L)
- Therefore, since 1991, we’ve been mixing R-32 with a fire suppressant called R-125...

Introducing R-410a

- 50% R-32 / 50% R-125
- 400 series Zeotropic mixture
- ODP of 0 (no Chlorine)
- But, GWP of our fire suppressant R-125 is 3,170
- Therefore GWP of R-410a = 1,924¹

Solve our ODP issue with HFCs

Created another problem with GWP

¹ GPW values from the IPCC 5th assessment report, 2014 [AR5 values]. [https://www.ghgprotocol.org/sites/default/files/ghgp/Global_Warming_Potential_Values%20%28Feb%202016%2029%201.pdf](https://www.ghgprotocol.org/sites/default/files/ghgp/Global_Warming_Potential_Values%20%28Feb%202016%2029%201.pdf)
Overview

- CFCs & HCFCs are officially out (Montreal Protocol)
- HFCs solved the Ozone issue (no more Chlorine)
- HFCs tend to be flammable and need to get mixed with some sort of flame retardant to remain A1’s
  - I.e. Mixing R-32 with R-125 to create R-410a
- This results in high GWP refrigerants
- Current U.S. building codes only allow A1 refrigerants to be run through buildings (ASHPs & VRV)
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 Amendment to the Montreal Protocol to globally phase down HFC’s 
(85% reduction in CO₂ tons equivalent)

- **2016**: Signed October 15th 2016 (28th meeting of the Montreal Protocol)
- **2019**: Start of the phase down for developed countries (including USA) by 15%
- **2036**: Phase down of developed countries (including USA) by 85%
- **2047**: Phase down of developing countries by 85%

Estimates that a successful phase down could prevent up to 0.5°C increase in global temperatures by the end of the century
The US has not ratified the Kigali Amendment

- **May 2018**: Letter to President Trump from 32 HVAC&R companies urging he submit the Amendment for ratification

- **June 2018**: Similar demand from 13 Republican Senators

Signed by 13 Republican Senators: Kennedy, Collins, Cassidy, Graham, Mukowski, Isakson, Alexander, Rubio, Moran, Scott, Blunt, Boozman, Young

https://www.documentcloud.org/documents/4501544-Senate-Letter-on-Kigali-6-4-18.html
Significant New Alternative Policy, by the EPA

- Under Clean Air Act (CAA); identify and evaluate substitutes for ozone-depleting substances
- Reviews ODP, GWP, Toxicity, Flammability, H&S, IAQ, Ecosystems
- Rule 20 (2016) and 21 (2017) introduced HFC phase downs

21: Deemed a long list of HFCs unacceptable for chillers (only) starting January 1st 2024 (including R-410a)

(No reference to ASHPs or VRV)
August 2017: Mexichem Fluor Inc. v. EPA regarding SNAP 20

Case won. Not admitted to U.S. Supreme court.

April 2018: EPA vacated SNAP 20 in its entirety

June 2018: New York Attorney General (and 11 others) suit against the EPA challenging its method for fully vacating SNAP 20

April 2020: Case won. EPA needs to follow proper procedures for vacating SNAP 20.

April 2019: Mexichem Fluor Inc. v. EPA regarding SNAP rule 21

Case won based on precedence.
Update on Federal Policies

- No SNAP 20 or SNAP 21 implementation

- S.2754 – American Innovation and Manufacturing Act of 2019
  - Introduced to Senate October 30th 2019

- H.R.5544 – American Innovation and Manufacturing Leadership Act of 2020
  - Introduced in House January 7th 2020

- Both align with Kigali to phase down HFCs over 15 years

“The world is moving away from HFCs, and the U.S. is in danger of getting stuck at the starting gate. We want these new refrigerants to be produced in the U.S., not in China. We want to export these new refrigerants, not import them. That won’t happen unless we give companies in Louisiana and across the U.S. much-needed certainty to create thousands of new jobs.”

— Sen. John Kennedy (R-Louisiana)
Co-sponsor of S. 2754

*** Not much movement on these… opposition looking for preemption language ***

State Policies

- U.S. Climate Alliance states are taking the lead
- Some states are working on proposals for HFC phase downs
- Many follow the SNAP 20/21 guidelines
- In place or have announced timeline for proposal:
  - CA, WA, VT, NJ
- Intention, no timeline yet:
  - NY, MD, DE, MA, OR, CO, CT, ME, RI, HI
California is going beyond SNAP 21
- Added a GWP limit of 750 for AC & ASHP
- How will they do this with an A1 refrigerant?

California Air Resources Board (CARB) Activity
In September 2018, the California Cooling Act (SB 1013) adopted SNAP Rules 20 and 21. Additional regulations related to the Short-Lived Climate Pollutant (SLCP) plan are proposed, as shown below. CARB is currently seeking stakeholder input.

<table>
<thead>
<tr>
<th>Proposed Stationary Refrigerant Limits</th>
<th>Year</th>
<th>GWP Limit¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Commercial Refrigeration Systems &gt;50 lb</td>
<td>2022</td>
<td>150</td>
</tr>
<tr>
<td>New Air Conditioning and Heat Pump Equipment</td>
<td>2023</td>
<td>750</td>
</tr>
<tr>
<td>Refrigerants Sales and Service (Existing Systems)²</td>
<td>2022</td>
<td>1500</td>
</tr>
</tbody>
</table>

¹GWP – IPCC 4th Assessment Report, AR4
²Exemptions for R-410A and reclaimed refrigerant under consideration

First reference to ASHPs
Overview

- No current Federal plan for HFC phase downs
  - Kigali not ratified
  - SNAP 20/21 ruled out

- A couple new bills with HFC phase down plans similar to Kigali are currently stuck in Congress / House

- Climate alliance states are taking the lead and implementing some phase downs
  - Generally following SNAP 20/21 rules

- Phase downs in HVAC apply to chillers only
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How do we electrify our building HVAC using VRV & ASHP

- While abiding to current building codes pertaining to running only A1 refrigerants through buildings
- While looking to lower GWP
The search for a low GWP R-410a alternative in class A1

Everyone started mixing things…

Low GWP
Class A1

- High efficiency
- Low GWP
R-32

R-1234yf
R-1234ze
R-125
CF₃I
R-134a

- Fluorine based
- High GWP
- Flame retardant
The search for a low GWP R-410a alternative in class A1

What’s so difficult?

- Flammability and GWP are essentially inversely proportional
- As you add Fluorine based chemicals, you decrease flammability, but increase GWP

California CARB 750 GWP maximum

https://www.achrnews.com/articles/141733-understanding-a2l-refrigerants-for-air-conditioners
The search for a low GWP R-410a alternative in class A1

Long story short… nobody can really get there

Some look like they might have…

- Example: R-466A [49% R-32 / 39.5% CF₃I / 11.5% R-125]
- GWP 697
- A1

There are other key characteristics for refrigerants that could make these types of complex blends unviable.
Life Cycle Climate Performance

The total CO$_2$ equivalency from cradle to grave of an HVAC unit

- How much refrigerant do you need?
- How much electricity does the equipment consume?
- Is it stable, is it corrosive?
- Does it use readily available chemicals?
- Is it owned / patented by a single manufacturer?

The search for a zero ODP low GWP R-410a alternative in class A1

Long story short… nobody can really get there
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“The trend is clear: to shift the balance towards being more environmentally friendly, we must accept some degree of flammability”¹

- “R-410a behaves very similarly to R-32 [A2L] especially when exposed to higher temperatures (ie. a fire)”¹

- A2L refrigerants will NOT ignite from static sparks or toasters.

- A2L refrigerants cannot sustain a flame with concentrations below the LFL

- A2L and A1 refrigerants have similar Hot Surface Ignition Temperatures (HSIT)

- A2L and A1 refrigerants will produce similar byproducts when combusted
  - Hydrofluoric Acid (HF) is product with both, not Hydrochloric Acid (as with R-22)

². https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2554&context=iracc
ASHRAE 15 2019
- 7.5.2 now includes refers to a new section (7.6) for A2L refrigerants
- Addition of warning labels
- Introduces refrigerant detection (automatic shut down of equipment except fans and dampers)
- Limits on ‘ignition sources’ such as open flames or surfaces > 700C

ASHRAE 34 2016
- Includes A2L classification
UL 1995
- Current standard for safety of VRV and ASHP equipment
- Currently under the 4th edition, valid until 2024

UL 60335-2-40
- New standard for safety for VRV and ASHP equipment, becoming effecting in 2024
- Binational standard (US & Canada)
- Based on IEC 60335-2-40 currently being used in Europe
- UL 60335-2-40 is more conservative
- Introduces factory installed refrigerant leak detection as part of the equipment, and its testing

Codes & Standards on A2L

- ASHRAE standards seem to have A2L covered
- Equipment standards seem to have A2L covered
- Are we good to go???

NO

- Model building codes first need to adopt these new standards
  - Universal Mechanical Code (UMC)
  - International Mechanical Code (IMC)

- So far, the 2021 round of these model codes have essentially rejected A2L

- Next round is 2024 (work starts in 2021)

- State / County / Local codes need updates (1-8 years)
  - Based on one of the model codes

- Some states (CA, WA) considering no longer using the model codes in order to incorporate A2L
WA Code Council Paves the Way for Use of A2L Refrigerants

BY ALEX AYERS
11/13/2019 - HVAC Government Affairs

The Washington State Building Code Council has voted to fully adopt ASHRAE 15-2019 and the 3rd edition of UL 60335-2-40. Adoption of these codes will allow the use of mildly flammable A2L refrigerants in refrigeration and air-conditioning including the use in occupied dwellings. Washington is the first state to bypass the model code organizations to directly adopt the updated ASHRAE and UL standards to allow the use of A2L refrigerants.

With this code adoption, the use of A2L refrigerants can begin on July 1, 2020, however market availability of equipment designed to use A2L refrigerants is not expected for several years. This code adoption will allow manufacturers to begin testing equipment in various conditions for use in a few years.

https://blog.hardinet.org/wa-code-council-refrigerants
AHRI Task Force

AHRI Safe Refrigerant Transition Task Force

AHRI's Safe Refrigerant Transition Task Force has been formed to address every step of the supply chain in the safe refrigerant transition to low global warming potential refrigerants. The task force comprises AHRI members and stakeholders employed with contractors, government agencies, the fire service, unions, training organizations and other businesses.

http://www.ahrinet.org/SafeRefrigerant
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As we (im)patiently wait for A2L to be allowed in buildings… it’s time for manufacturers to start ‘picking their A2L horse’ and start developing high efficiency equipment with it.
The search for a low GWP R-410a alternative in class A2L

Optimizing for best LCCP impacts

Low GWP
Class A2L

- R-32
- R-1234yf
- R-1234ze
- R-125
- CF3I
- R-134a

- Fluorine based
- High GWP
- Flame retardant
- More efficient (10% > R-410a)
  - Major LCCP impacts
  - Operational Cost impact

- Higher capacity (28% less charge)

- GWP of 677
  - Theoretical GWP 472

- Readily available (every lb of R-410a has ½ lb of R-32)
  - 100M+ R-32 AC units around the world

- Simple pure refrigerant
  - Not a Zeotropic mixture

https://www.daikin.com/csr/information/influence/hfc32.html
Daikin is highly involved with R-32

- 2011: Offered free access to 93 patents to emerging countries
- 2012: Launched first global R-32 residential equipment in Japan
- 2015: Expanded free patent access globally

But – this is not just Daikin

https://www.daikin.com/patent/r32/
R-32 VRV

Since the launch of Bluevolution in 2016, the world's first air conditioning using R-32 refrigerant, we have worked to convert our portfolio to lower-GWP refrigerants. The latest evolution is the completely newly developed VRV 5 S-series. Incorporating all latest technological developments, such as the new GWP refrigerant R-32.
Remember this slide?

ASHRAE Standard 15 - Safety Standard for Refrigeration Systems

- Introduces Refrigerant Concentration Limit (RCL) to ensure safety in case of a complete refrigerant discharge in the smallest occupied space
  - Analyzes toxicity, oxygen deprivation and flammability
  - Worst case maximum concentration determines the RCL.

- R-410a
  1. Low toxicity
  2. No flame propagation at 60C
  3. Oxygen deprivation determines the RCL
  - \( \text{RCL of R-410a} = 25 \text{ lbs / mcl} \)

### Oxygen Percentage and Symptoms

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Altitude equivalent (M) of effective oxygen %:

- 0: 0
- 2,000: 14.5%
- 5,000: 11.5%
- 14,500: 9.9%
- 22,000: 7.5%
- 20,000: 3.2%
Refrigerant Concentration Limit (RCL) is the worse case between:
1. Toxicity concentration limit
2. Oxygen deprivation concentration limit
3. Flammability concentration limit

- **R-32**
  1. Low toxicity
  2. Oxygen deprivation limit is not the limiting factor
  3. Flammability concentration limit = 25% of LFL
     - RCL of R-32 = 4.8 lbs / mcf

- **ASHRAE 15 2019**
  1. A2L systems > 4 lbs require refrigerant detection (new 7.6 section on A2L)
  2. No wording yet on whether refrigerant detection mitigates the 4.8 RCL limit
Variable Refrigerant Flow (VRF)
ASHRAE Technical Committee 8.7

Agenda
TC0807 Orlando Agenda 20200203

Committee Chair
Arturo Thur de Koos
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Committee Scope
TC 8.7 is concerned with the design, performance, and application of variable refrigerant flow systems into commercial HVAC systems.

Upcoming TC Meetings
Location: Orlando, FL

http://tc0807.ashraetcs.org/index.php
• CFCs & HCFCs are fully phased out, we are now using HFCs

• HFCs have high GWP due to flame retardant additives to maintain A1 class

• Building codes (model or local) do not currently allow anything but A1 refrigerants through buildings (VRV & ASHPs). Still years away.

• There are no Federal phase down plans for HFCs (some bills in the works)

• Climate Alliance states starting to implement SNAP-like phase downs
  ▪ Applies to chillers only in HVAC

• VRV & ASHPs cannot transition to lower GWP HFCs until A2L is allowed in buildings
  ▪ Standards are already addressing A2L and incorporating leak detection

• R-32 is the go-to A2L refrigerant with lowest LCCP impact
Extra Resources

- Understanding A2L Refrigerants for Air Conditioners (ACHR News)
  - https://www.achrnews.com/articles/141733-understanding-a2l-refrigerants-for-air-conditioners

- About Montreal Protocol (UN Environment)
  - https://www.unenvironment.org/ozonaction/who-we-are/about-montreal-protocol

- U.S. STATES TAKE THE LEAD IN HFC PHASEDOWN (NRDC)

- Refrigerants and their environmental impact Substitution of HCFC and HFC. Search for an adequate refrigerant (Benhadid-Dib / Benzaoui)

- US Refrigerant Regulations Update and Emerging Trends (Emerson)

- Your Guide to Federal and State HFC Regulations in North America for HVACR Refrigerants (Opteon)

- R-32: The Most Balanced Refrigerant for Stationary Air Conditioners and Heat Pumps (Daikin)

- Lower Global Warming Potential Refrigerants: Frequently Asked Questions (AHRI SRTTF)

- New Refrigerants, Higher-Flammability Refrigerants Addressed in Updated ASHRAE Standards 15, 34 (ASHRAE)
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