BUILDINGENERGY BOSTON

Mitigating Refrigerant Leakage in Residential Electrification

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What got me concerned about refrigerant leakage

- Electrify everything!
- Heat pump use increasing rapidly
- All used the refrigerant R-410a
  - GWP100 = 2285 times CO2
  - **GWP20 = 4705 times CO2**

- **Leaks = Big climate change impact**

A sad story

- High performance new construction home completed in 2015.   HERS 42
- Single 4 ton outdoor unit with 5 indoor units
- High electric bills, humidity, and shut downs
- Inspected in 2022 to find widespread corrosion

Signs of corrosion and service attempts

- 2 branch box systems on this heat pump
- Two zones disconnected due to leakage concerns
- Green indication of copper corrosion observed often

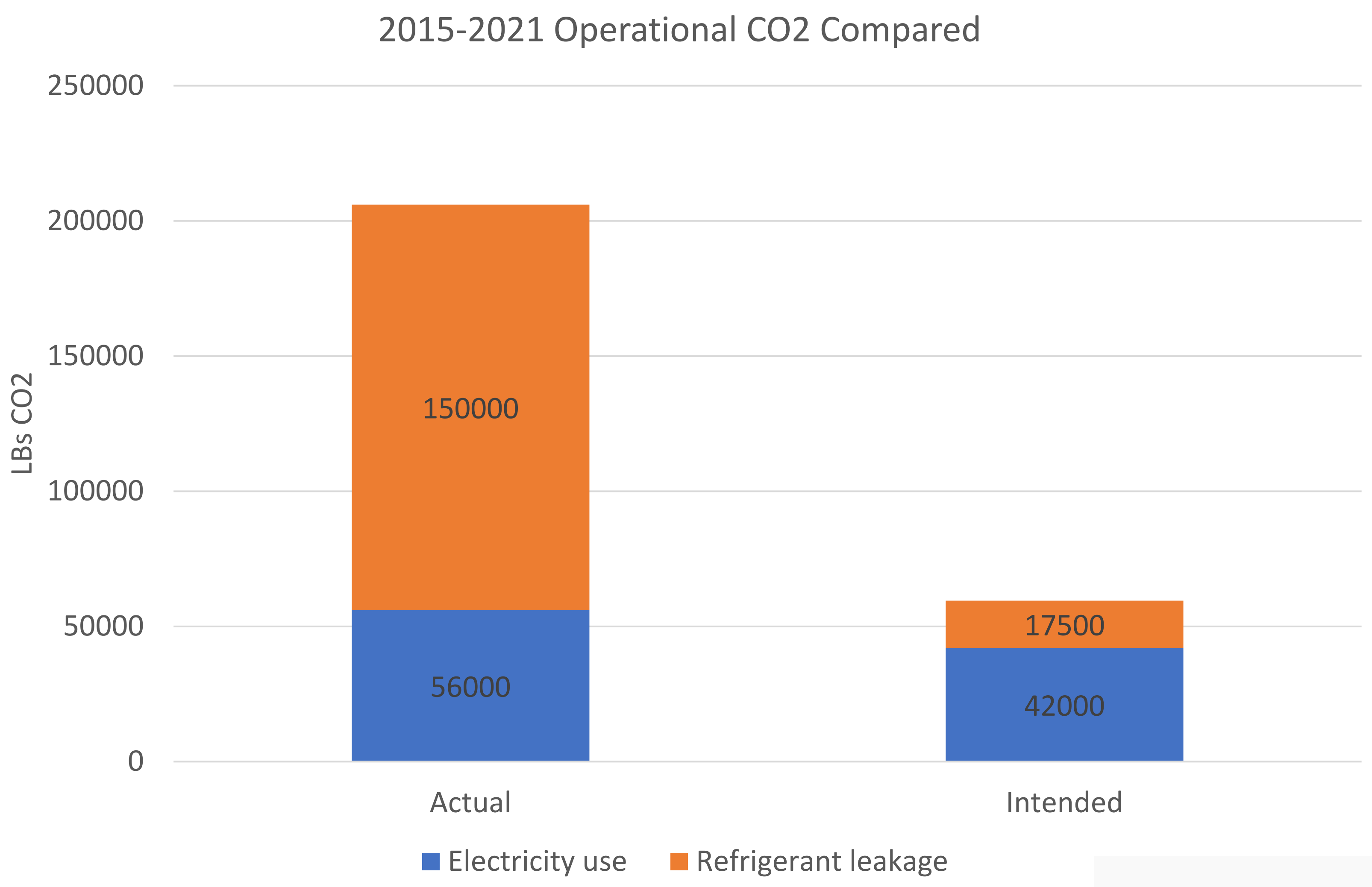
Carbon impact of refrigerant leakage

CO2 from electric use

- 2021: about 15,000 kWh
  - 8,000 lbs CO2
- 2015-2022: 7 years
  - 56,000 lbs CO2

CO2e from refrigerant leakage

- Roughly 11lbs R-410A
- GWP20
  - 50,000 lbs CO2e
- Estimated 3 total losses
  - 150,000 lbs CO2e



Full system replacement

A happy(ish) ending

- 3 new separate 1:1 systems
- No branch boxes, 50% less piping connections
- 20% less total refrigerant
- Electric bills down roughly 50%
- Better dehumidification in summer

White insulation issue

Photo Credit: Brian Chadwick

Preventative solutions

Photo Credit: Neil Comparetto

Black elastomeric insulation

Do all heat pumps leak?

- No.
- But when they do it can be really bad.
- To reduce the impacts we need to:
    - Understand why it's important
    - Educate ourselves on the issue
    - Take steps to reduce the amount of refrigerants leaking into the atmosphere
    - Continue this conversation

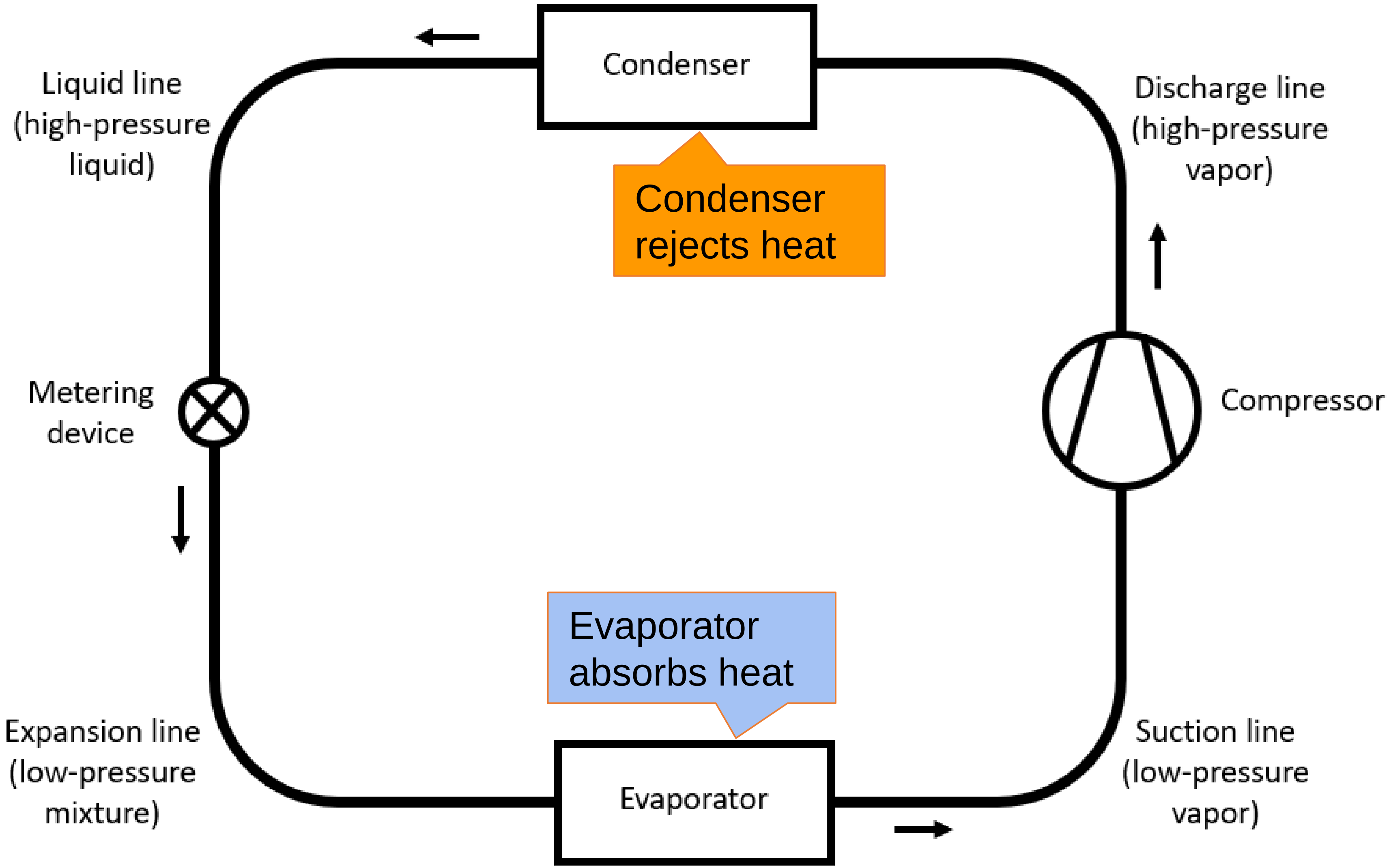
What is a refrigerant?

- A substance or mixture of substances used to transfer heat
  - Absorb heat in one location, release it in another

- Most refrigerants undergo a phase change (liquid ↔ vapor)
  - We can manipulate temperature and boiling/condensing point by manipulating the pressure

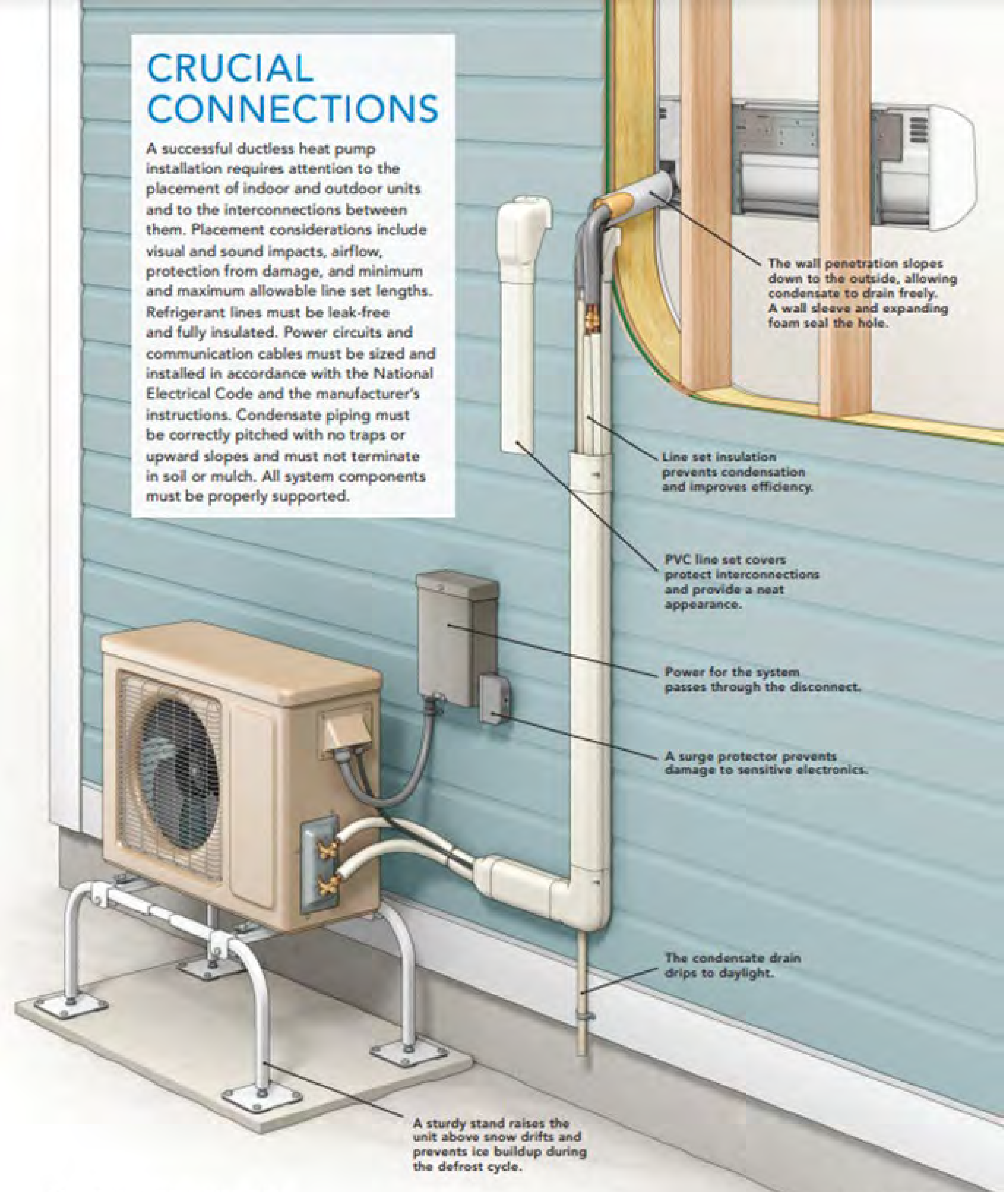
- Typically in a closed-loop system

Basic refrigeration cycle



CRUCIAL CONNECTIONS

A successful ductless heat pump installation requires attention to the placement of indoor and outdoor units and to the interconnections between them. Placement considerations include visual and sound impacts, airflow, protection from damage, and minimum and maximum allowable line set lengths. Refrigerant lines must be leak-free and fully insulated. Power circuits and communication cables must be sized and installed in accordance with the National Electrical Code and the manufacturer's instructions. Condensate piping must be correctly pitched with no traps or upward slopes and must not terminate in soil or mulch. All system components must be properly supported.



Drawing: Christopher Mills

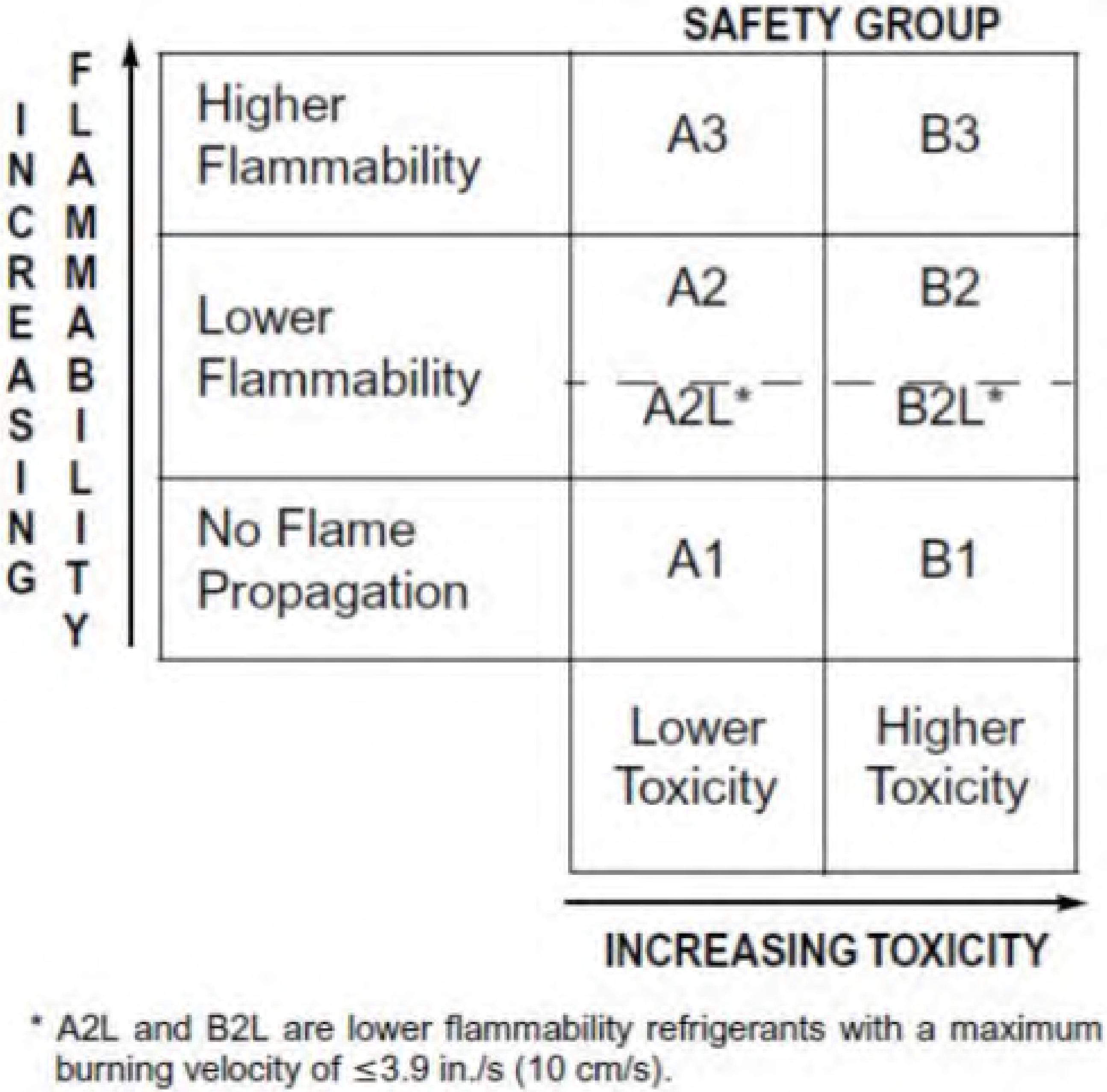
Characteristics of a good refrigerant

- Operating pressures
- Heat transfer characteristics
- Safety
  - Flammability
  - Toxicity
- Environmental impact
  - ODP: Ozone depletion potential
  - GWP: Global warming potential


36.0 °F
46.5
35.3
LG
FLIR


71.6 °F
94.9
65.9
FLIR

Safety characteristics



Refrigerants and ozone

Stratospheric ozone

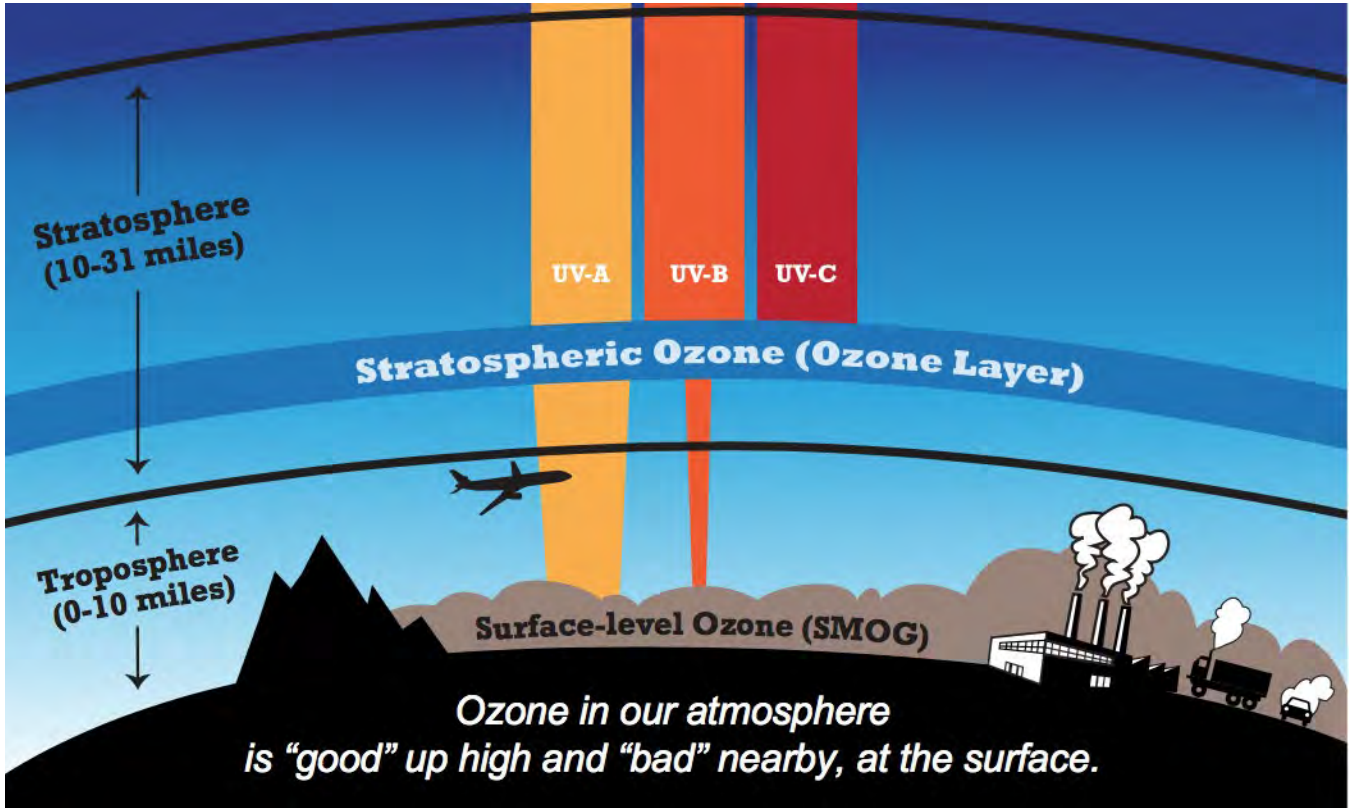
-Protects Earth from UV radiation

Chlorine-containing refrigerants

-Damage ozone Layer

Ozone depletion potential (ODP)

-Measure of relative damage



NASA.gov

Global warming potential (GWP)

- Measures the global warming impact of gases relative to CO_2
  - GWP of CO_2 = 1

- Measured over 20-year and 100-year time frame

Refrigerant types

- CFC: Chlorofluorocarbon
- HCFC: Hydrochlorofluorocarbon
- HFC: Hydrofluorocarbon
- HFO: Hydrofluoroolefin
- HC: Hydrocarbon
- Natural refrigerants: CO_2, NH_3

Refrigerants: A Brief History

- 1902: First refrigerant based air conditioner (ammonia)
- 1928: First CFC refrigerants
- 1970s: Discovery of the ozone hole
- 1987: The Montreal Protocol
- 1990-1995: Rapid phasedown of CFCs
    - Initial replacement with HCFCs
    - Prohibition on venting
    - Requires technician certification
- 2010-2020: Transition to HFCs
- 2016 Kigali Amendment
- 2020 AIM act
    - Sets timeline for HFC phasedown
    - 85% reduction by 2036
    - Transition to A2L and other low-GWP refrigerants

Refrigerant	Type	Safety classification	ODP	GWP (20 year)	GWP (100 year)
R-12	CFC	A1	0.820	12,700	12,500
R-22	HCFC	A1	0.034	5610	1910
R-410A	HFC blend	A1	0	4705	2285
R-32	HFC	A2L	0	2620	749
R-454B	HFC/HFO blend	A2L	0	1806	516
R-290 (propane)	HC	A3	0	<1	<1
R-744 (CO2)	Natural	A1	0	1	1

https://iifiir.org/en/fridoc/montreal-protocol-on-substances-that-deplete-the-ozone-layer-2022-146932

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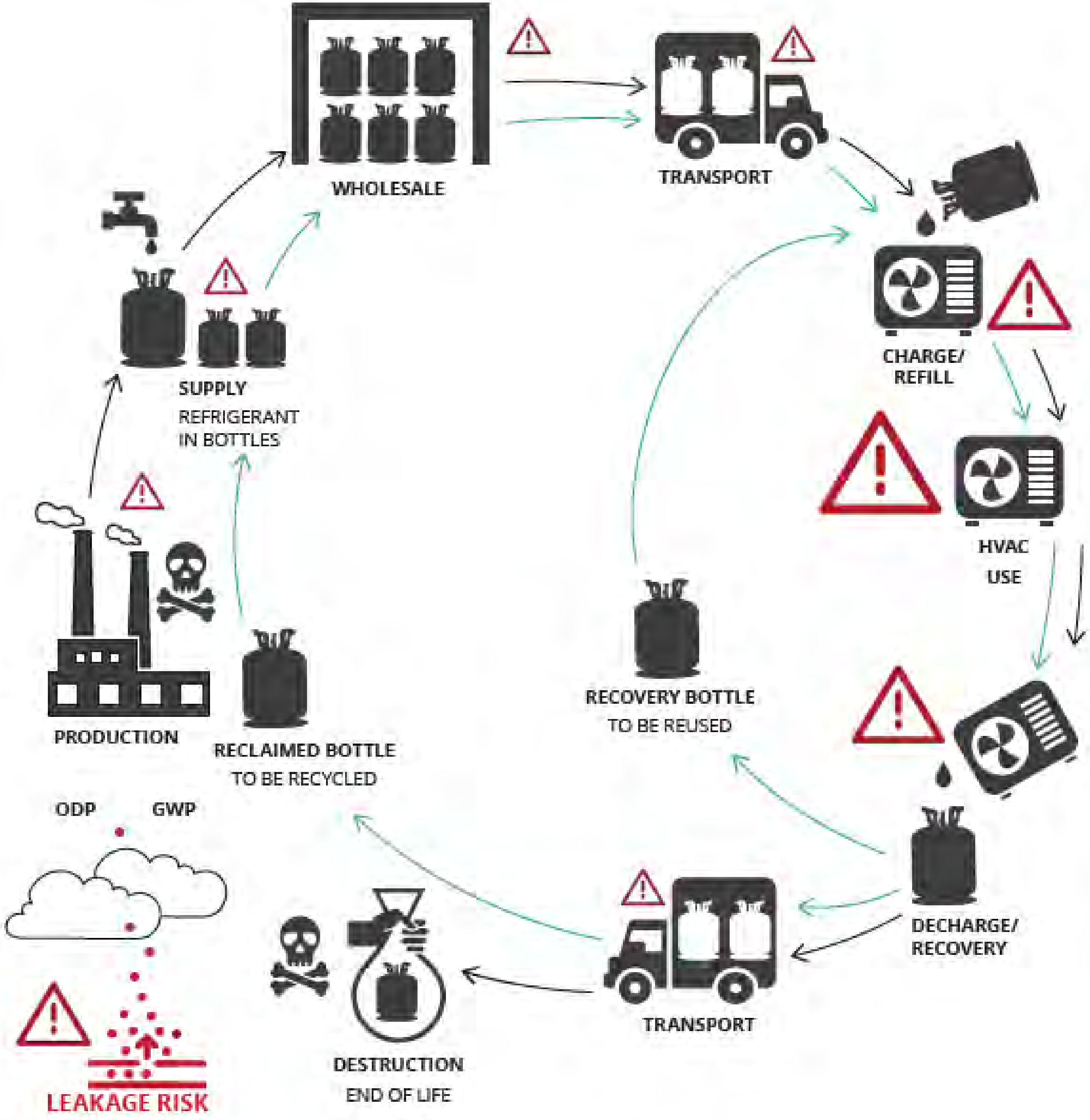


When can leakage occur?

Information is limited, one 2014 study suggests:

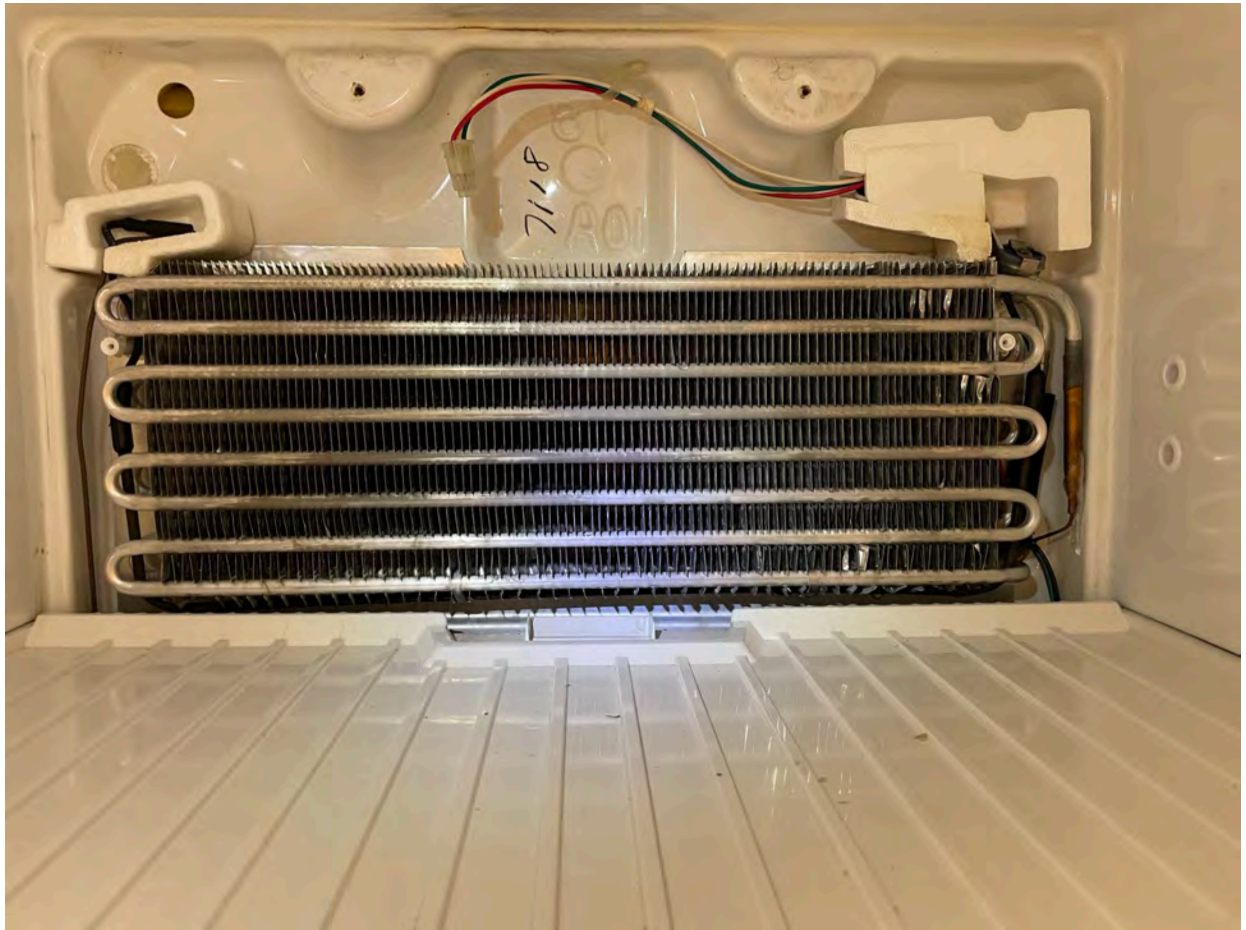
- Production stage: 1-3%
- Transportation: Unclear, likely low
- **Use stage: Widely variable**
- End of life/Recovery: 9 – 55%

Hamot, L., Dugdale, H., & Boennec, O. (2020, September 1). Refrigerants & Environmental Impacts: A Best Practice Guide. Integral Group. https://www.integralgroup.com/news/refrigerants-environmental-impacts/

Leakage rates by system type

Available studies show variety of results, however type of system matters

- **Factory sealed & charged: less leakage potential**
    - Refrigerators, window AC units, heat pump water heaters & driers
- Estimate industry average leakage rate of **1-6% per year**



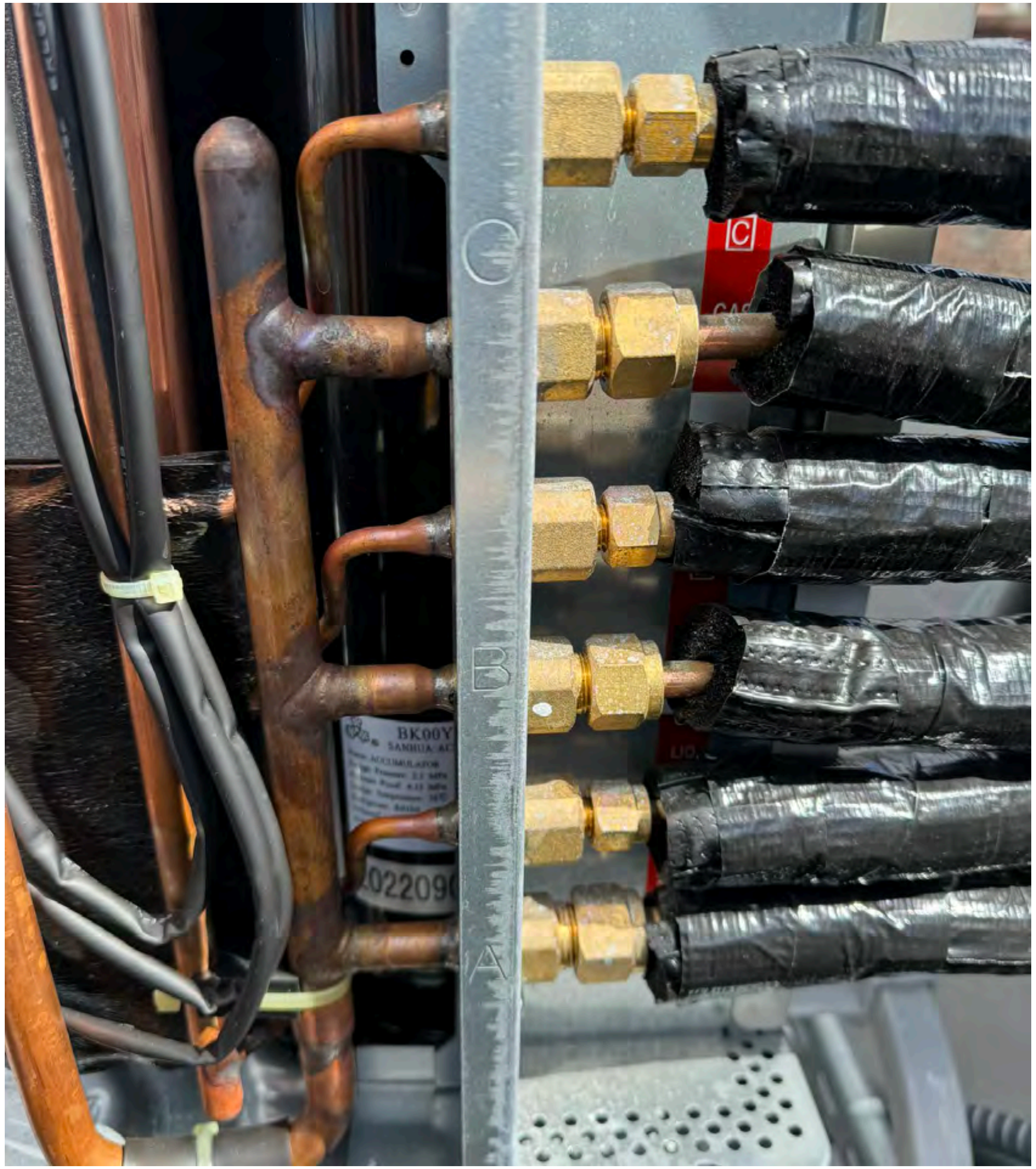
Field assembled & charged

- Central AC & heat pump systems
    - Higher leakage potential
- Estimate industry average leakage rate of **1-10% per year**

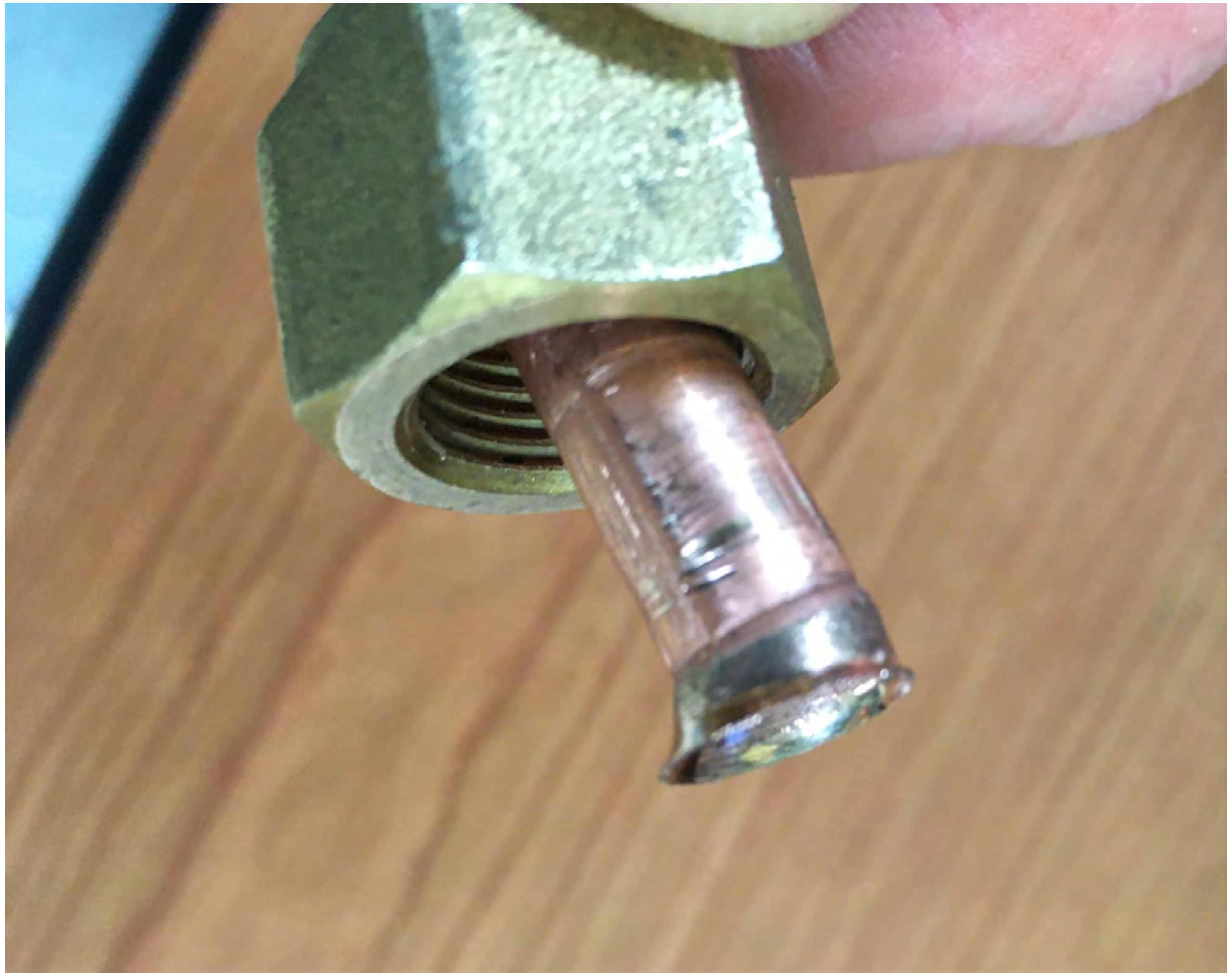
Use stage leakage modes

- During installation
  - Connection errors, damaged equipment
- Shortly after installation
  - Damage by other trades, poor drainage
- During regular operation
  - Formicary corrosion, Schrader valves
- End of life
  - Lack of proper recovery

Piping connection joints



Crushed flare joints (over-torqued)



Interior coils

- Reportedly one of the most common modes of failure in the operational phase

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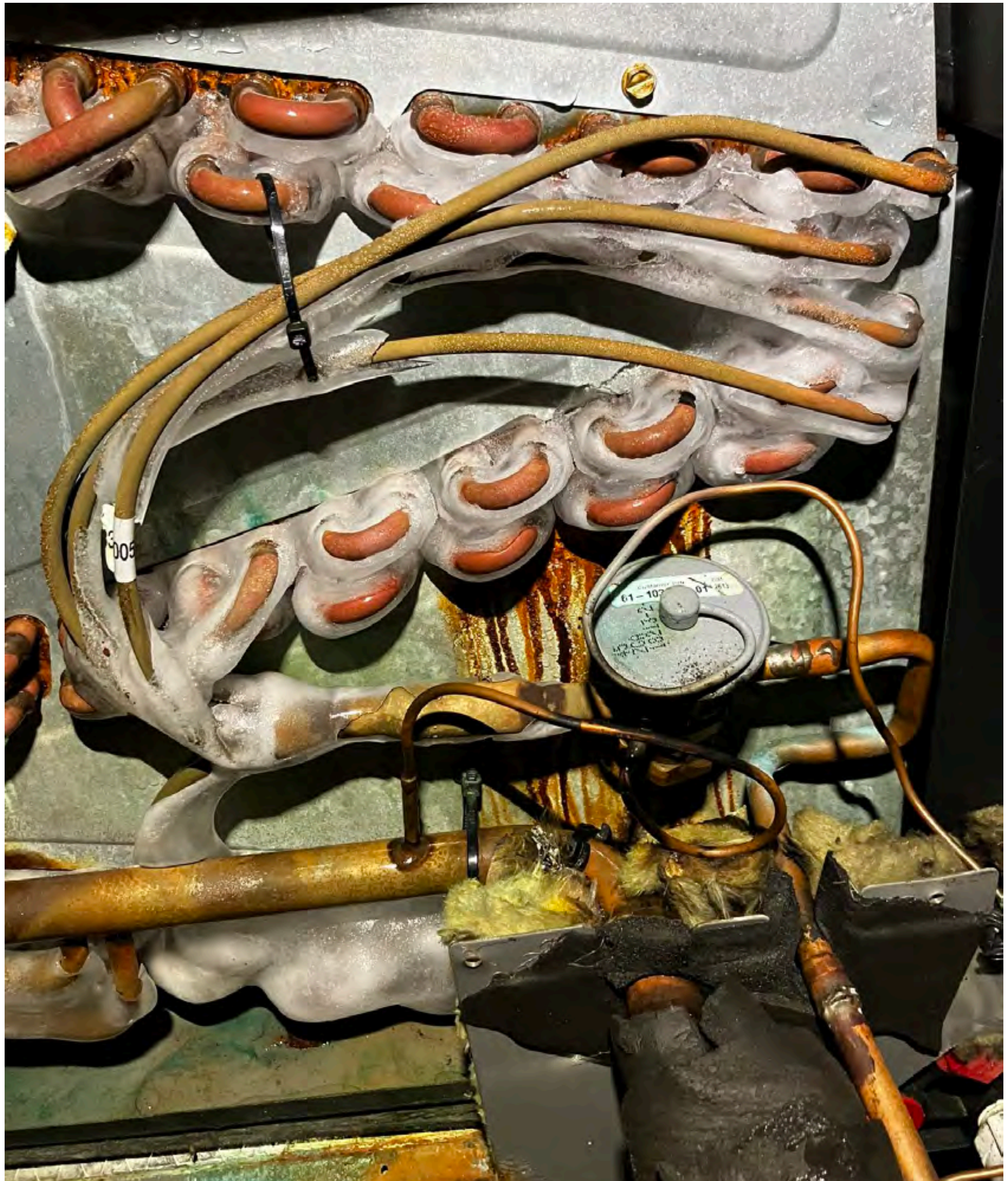
Exterior coils

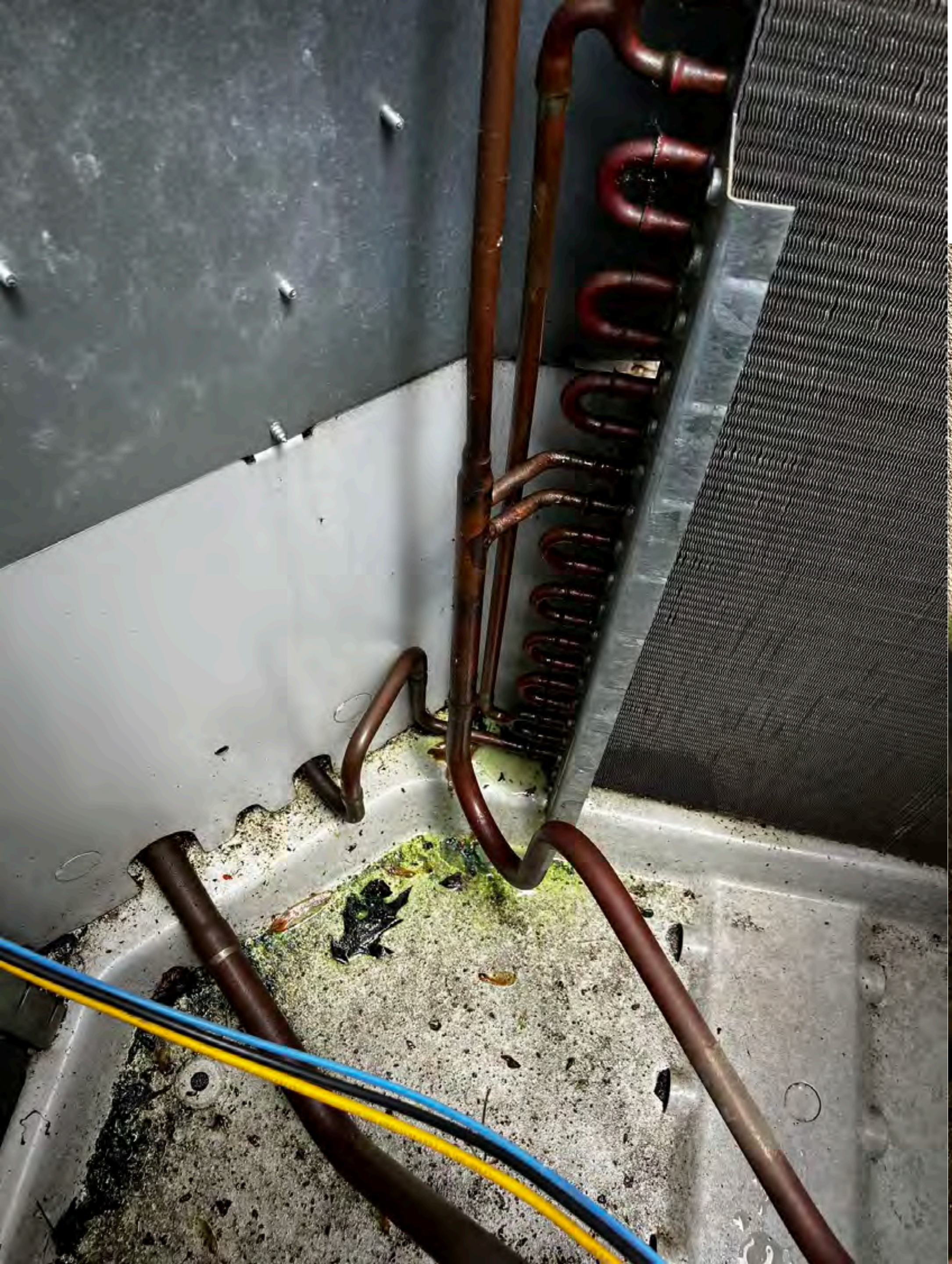
- Less common, but still happens



Indications of low refrigerant

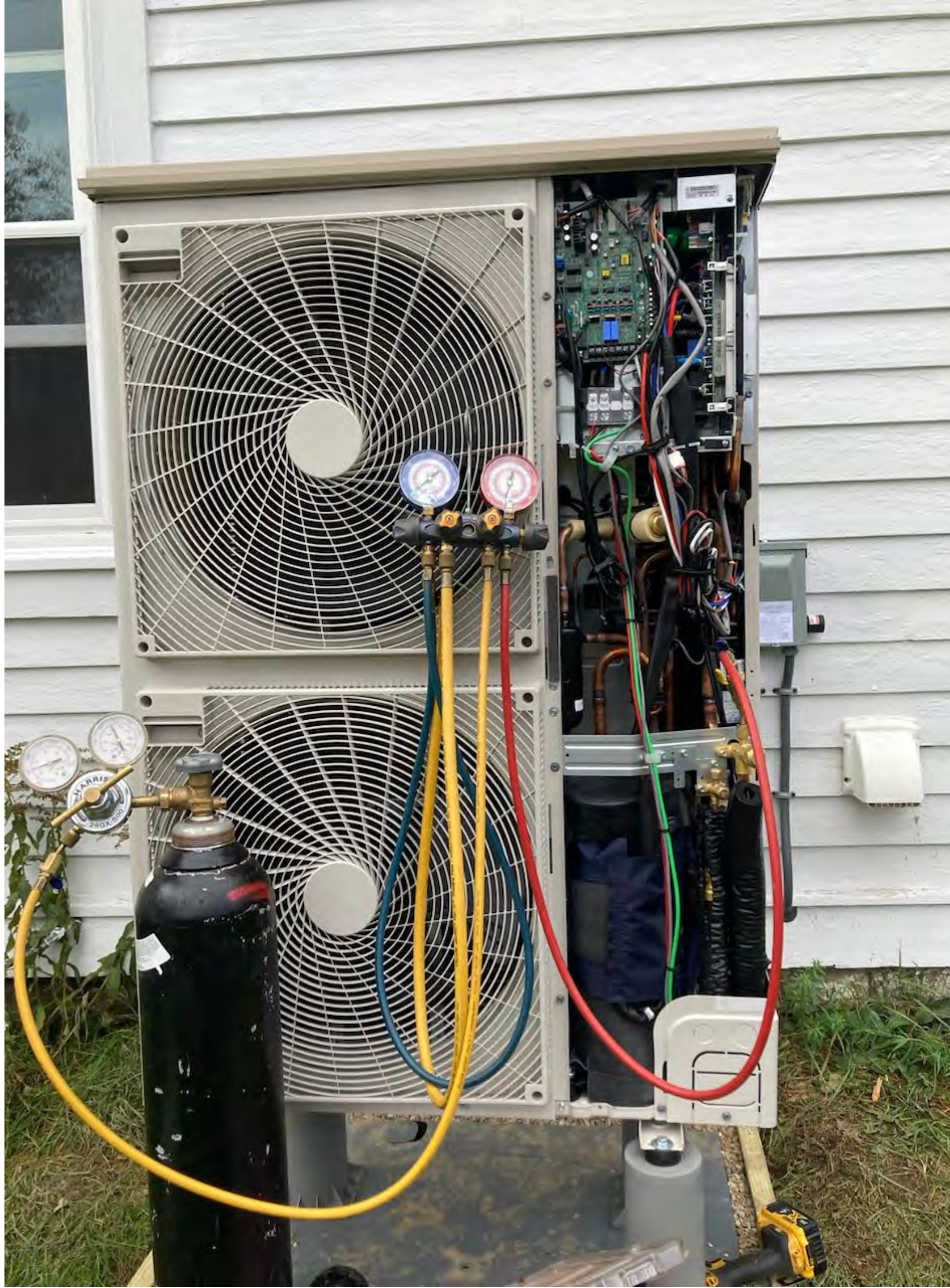


Indications of refrigerant leaks



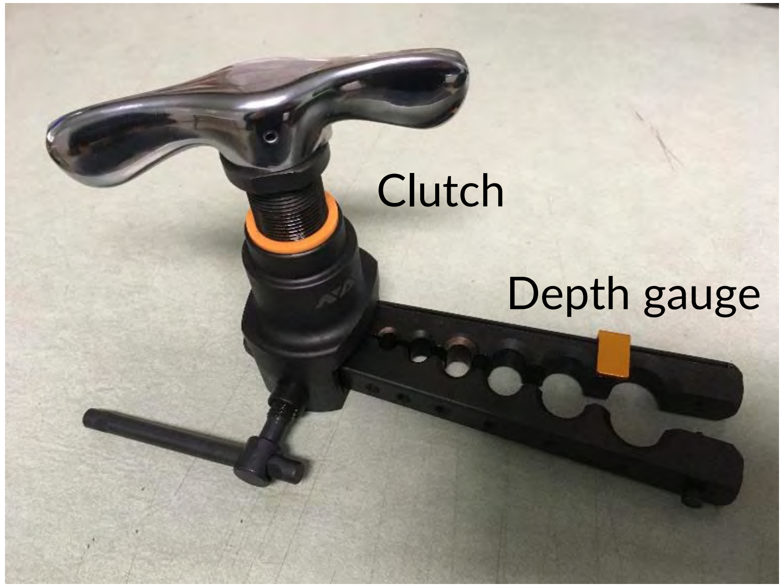
Installation

- Making good flares
- Using brazing and press connectors where appropriate
- Line set protection, support, insulation
- Meticulous leak testing
    - 4-part methodology
- Record keeping



Making a good flare

- Cutting
- Deburring
- Forging the flare
- Assembling
- Tightening
  - Always use torque wrenches!
- Testing



Always use torque wrenches

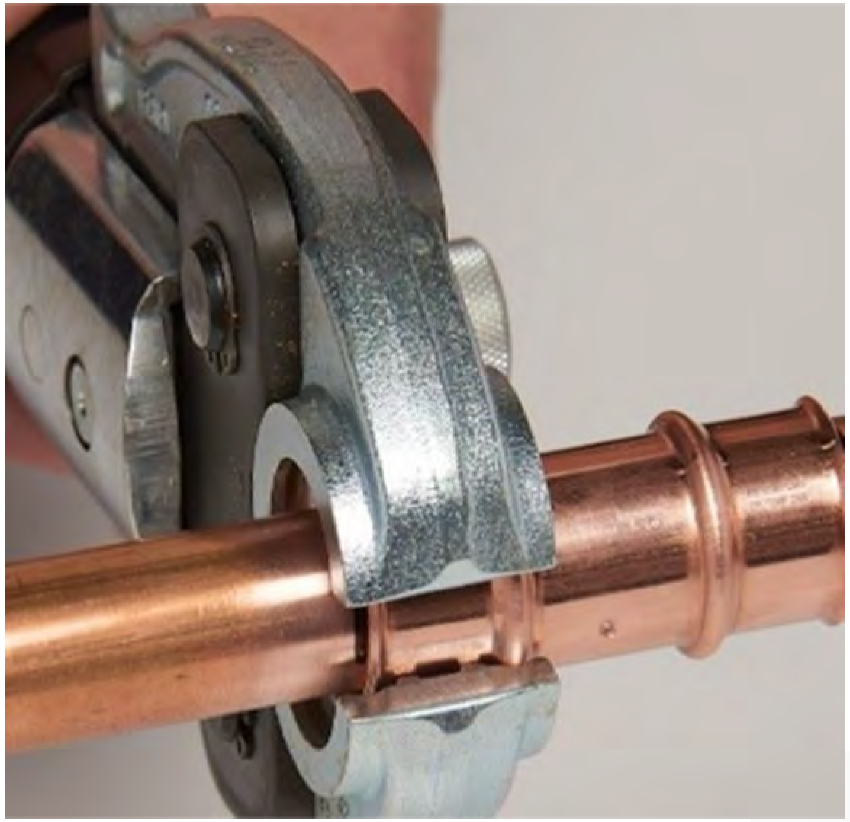
Flare connections:

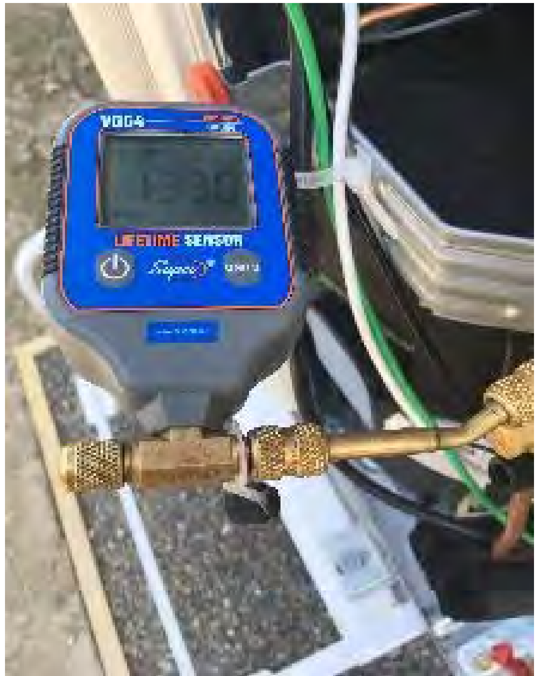
- Too loose→ Leak
- Too tight→ Crushed flare→ Leak
- Torque wrench→ Just right

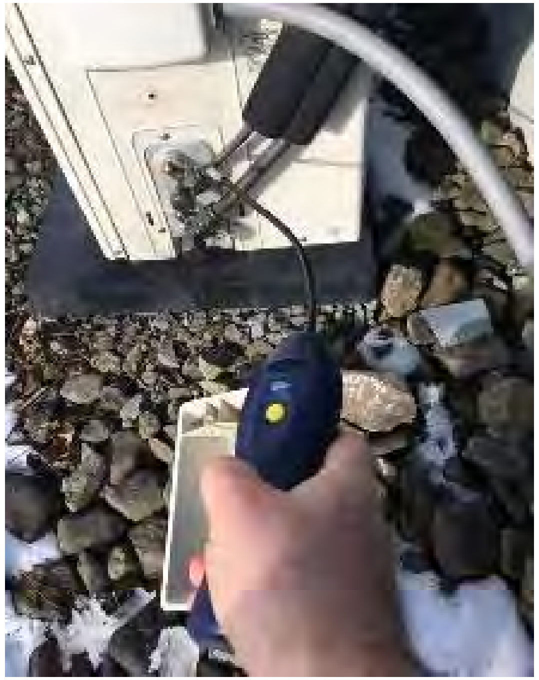
Alternatives to flares

Brazing

Pressfit







Refrigerant leak testing

Majority of leaks can be prevented with thorough testing

Four steps for leak testing:

1. 500-600 PSI standing pressure test
2. Bubble solution
3. Vacuum decay test
4. Electronic leak detector

Service procedures

- Non-invasive performance testing
- Thorough refrigerant recovery prior to opening refrigerant circuit
- Leak check & repair whenever refrigerant is low
    - No "gas and go"

End of life

- All refrigerant must be recovered prior to equipment disposal
- Develop an efficient system for consolidating and reclaiming refrigerant

Design approaches

- Simpler split systems
- Smaller capacity split systems
- Packaged and monobloc systems
- Refrigerants in life cycle analysis

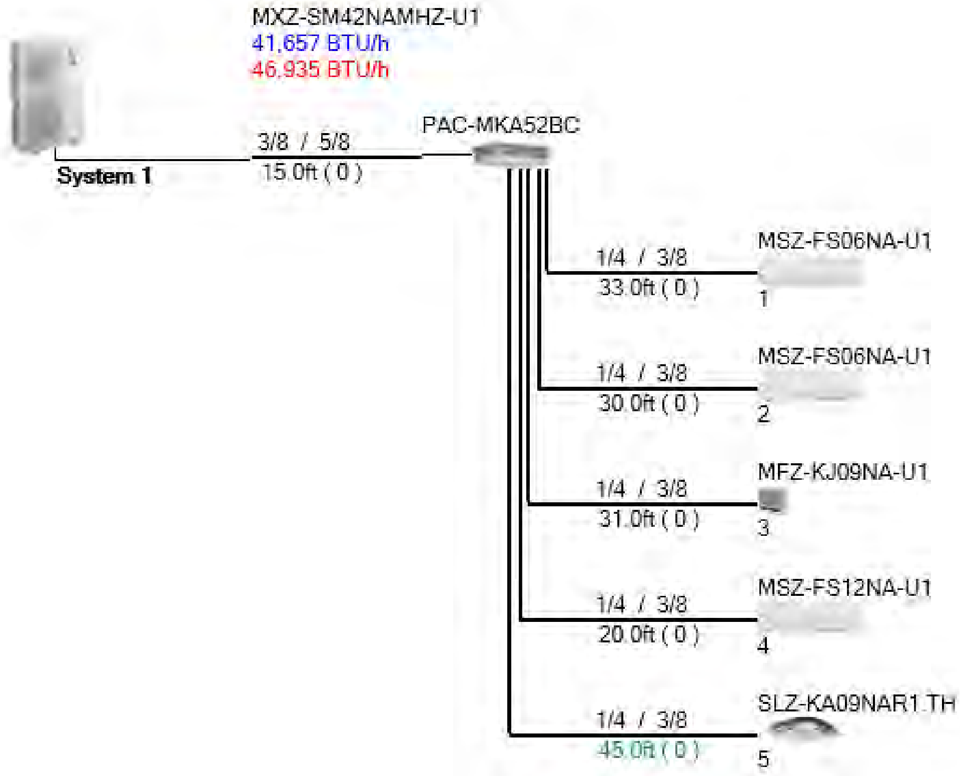
Fittings leak!

Fitting Type	Fitting Size	Experienced Normal	Experienced Difficult	Inexperienced Normal	Inexperienced Difficult
Brazed	1-1/8 in.	0/10	0/5	0/5	3/5
Press	3/8 in.	0/20	0/10	0/10	0/10
Press	1-1/8 in.	0/20	0/10	1/10	0/10
Compression	3/8 in.	1/20	0/10	2/10	0/10
Compression	3/4 in.	1/20	1/10	2/10	1/10
Flare	3/8 in.	0/20	0/10	1/10	0/10
Flare	3/4 in.	1/20	0/10	1/10	2/10

From Elbel et al. 2018 https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2939&context=iracc

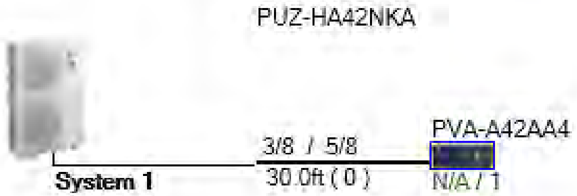
3.5 ton ductless multi split

- 5 ductless zones
- 46,935 Btu/hr @ 5F
- 174' of line set (x 2)
- 24 flares
- 18.68 lbs R-410A



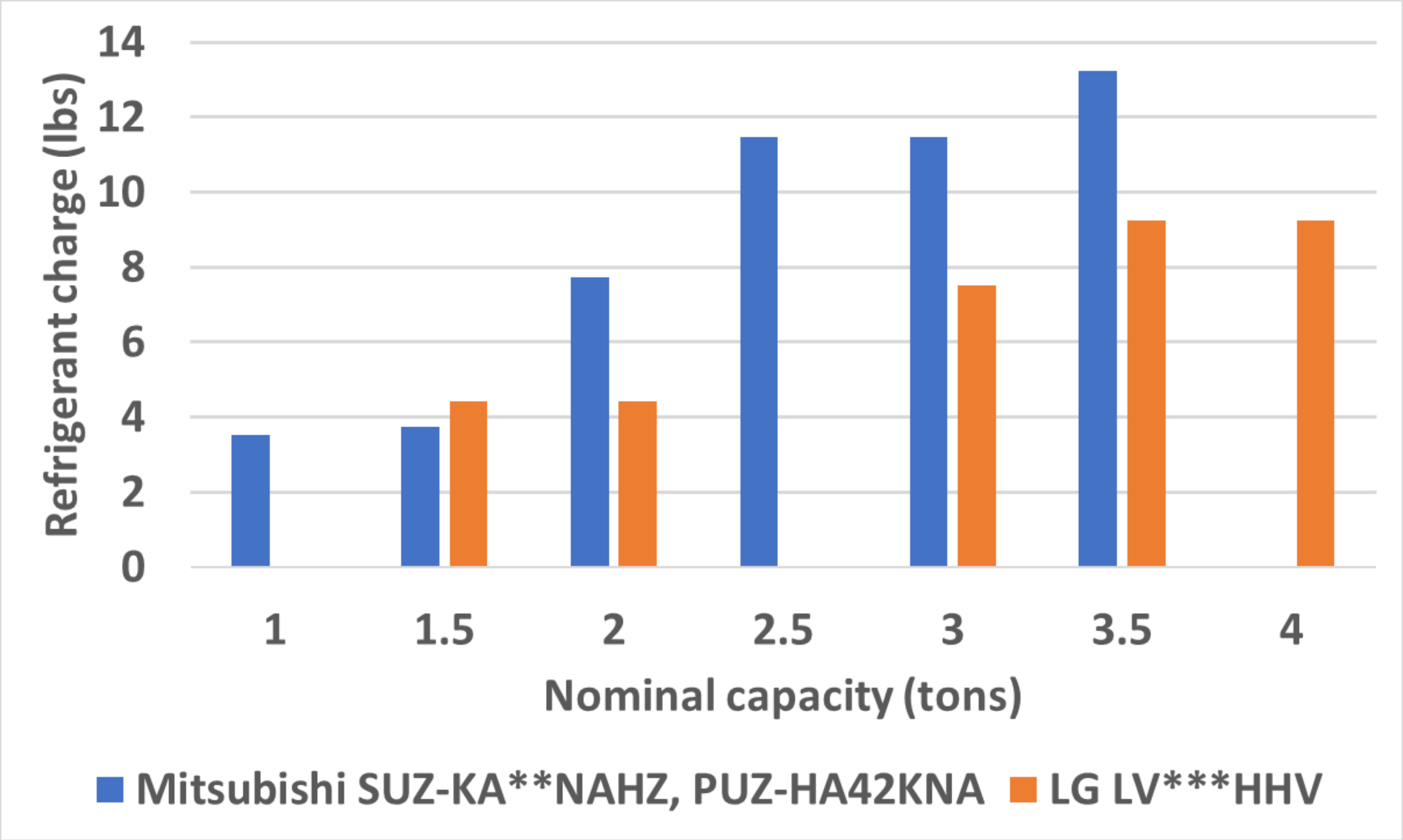
3.5 ton ducted 1:1 air handler

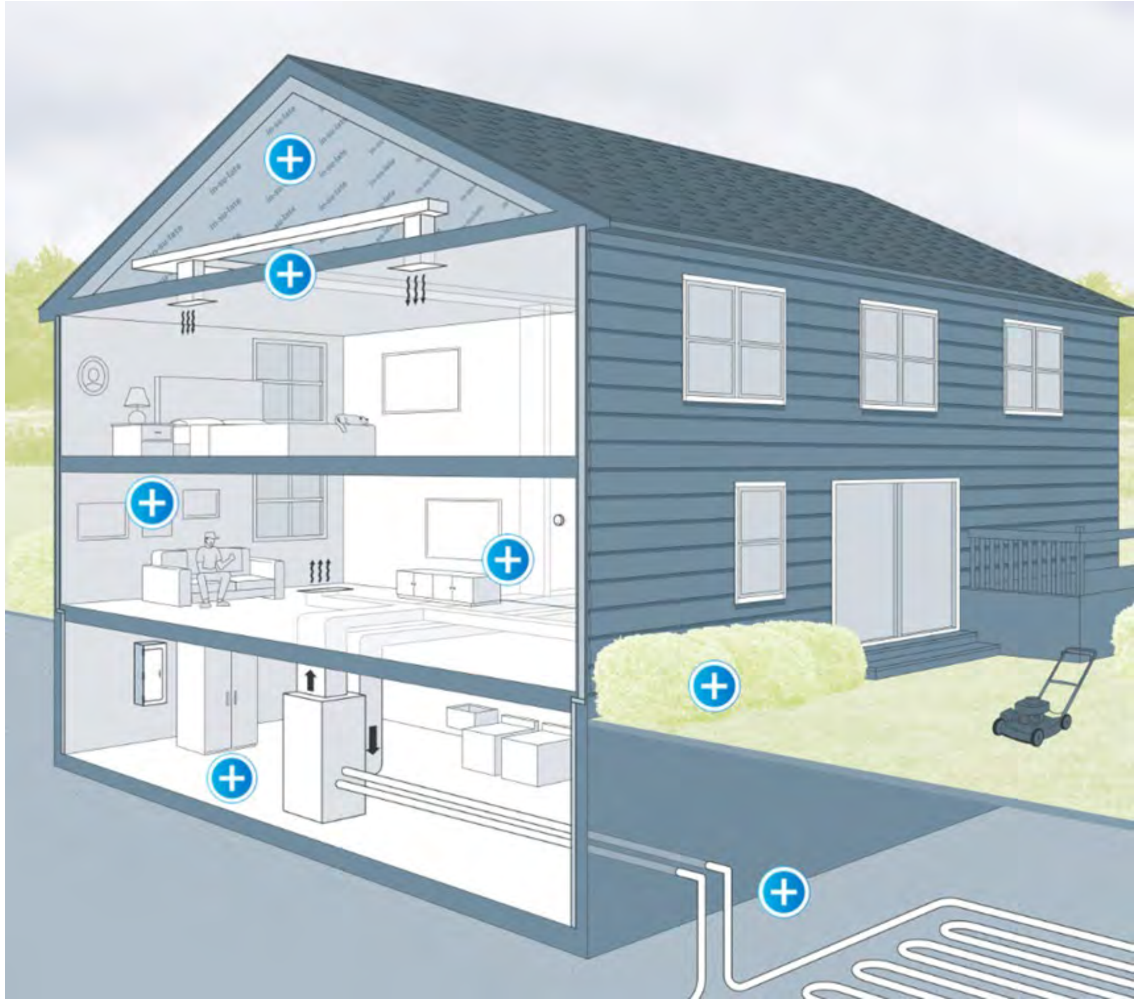
- Single zone
- 47,289 Btu/hr @ 5F
- 30' of line set (x 2)
- 4 flares
- 13.23 lbs R-410A



Refrigerant charge

- Increases with nominal size
- Varies with brand and product line
- Cold-climate ducted air handler example





Source: nyserda.ny.gov

Ground-source heat pump

- ~8 lbs R-410a
- Only factory joints
- No piping exposed to outdoors

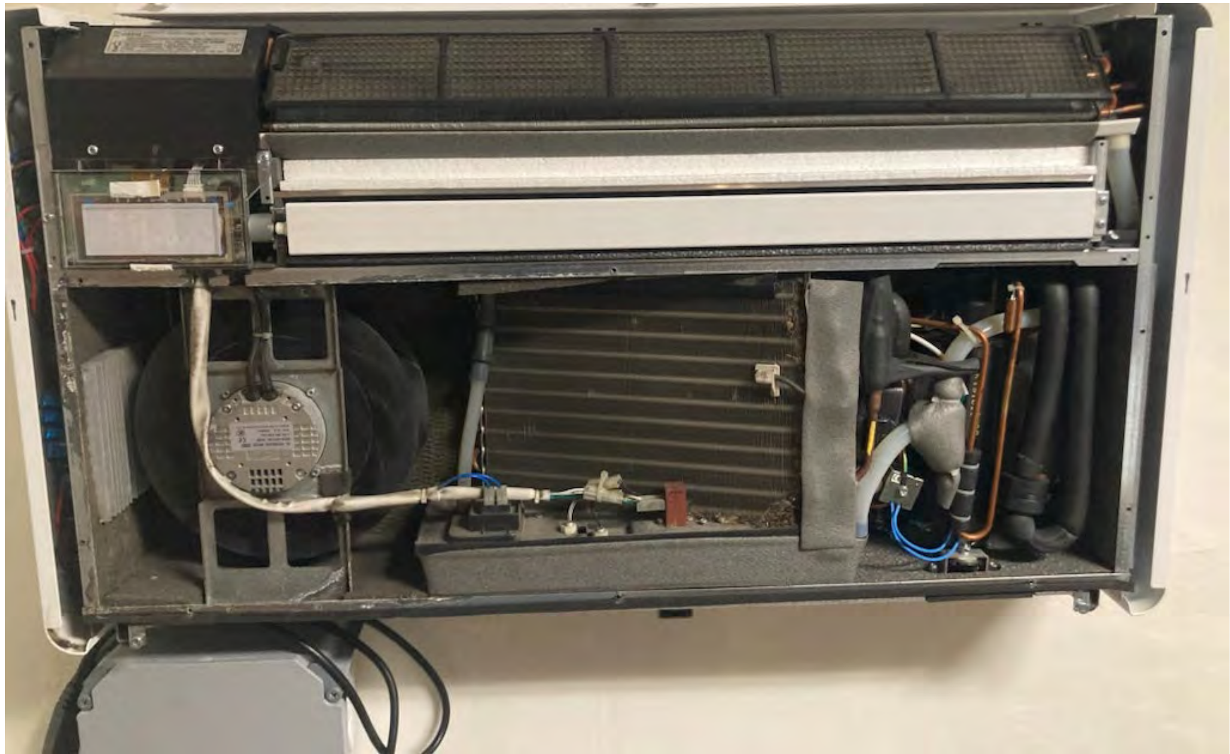
Source: Taitem Engineering

Air-to-water heat pump

- ~6 lbs R-410a
- Monobloc design
- Only factory joints
- All refrigerant outdoors
    - Safer for A2L & A3 refrigerants
- Cost & retrofit challenges

Ephoca packaged vertical heat pump

- 1.4 lbs R-410a
- 6800 Btu/hr @ 5F
- Self-contained, two 8" holes to outdoors
- NEEP listed



CO_2 water heater

Source: energy.gov

What can nondesigners do?

- Be careful with selecting installers
- Keep filters clean & schedule service visits
- Have available back up heaters just in case
- Try not to “gas & go” if there’s an issue
- Prepare for system’s end of life

Closing questions and thoughts

- Should the impact of refrigerant leaks deter folks from installing heat pumps?
  - No, they are still are most affordable high efficiency electric option we just need to be thoughtful and careful.

- How should folks think about the coming shift from R-410A to A2L alternatives?
  - Overall it will be a strong step in the right direction but there will likely be some initial challenges to push through.

Closing questions and thoughts

- What information do we need to know better?
  - We really need better tracking of refrigerant that gets into the atmosphere so we can know what works and doesn't.

- Can anything be done at the policy level?
  - Incorporate refrigerant management training in heat pump program requirements.

Open discussion

Thank you

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