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Refrigerant Management

slipstream

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Acknowledgements

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Executive Summary

Heating, cooling, and refrigeration systems in buildings use refrigerants to condition the space. Refrigerants leak from equipment during installation, over the life of equipment and from improper equipment disposal. Many commonly used refrigerants in residential and commercial HVAC systems have a potent greenhouse gas effect. This includes chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and natural refrigerants such as CO_2 and NH_3. The impact of refrigerant leakage on global warming has not been fully evaluated, but studies estimate that about 50% of refrigerants leak into atmosphere (PAE, 2020).

Different calculation methods are available to designers and building managers to estimate the potential for refrigerant leak, including LEED calculation method, Lifefront leakage method, and based on field data from F-gas logbooks in the European Union (EU). These methods also help installers and building managers proactively identify leakage risks and complete preventative actions, such as leak testing after installation, deploying monitoring systems, and follow proper decommissioning processes.

Currently used industry standard refrigerants are Hydroflourocarbons (HFCs), which have a very high global warming potential (GWP) and ozone depletion potential (ODP). The typical global warming potential of HFC is between 1000 -12,000 lbs. of Carbon dioxide equivalent (CO_2e). This suggests the urgent need for the industry to transition to low GWP and ODP refrigerants.

For new refrigerated HVAC system installation, and in repair and replacement of existing HVAC systems, it is important to investigate the type of system and refrigerant, and evaluate its emission impact, before installation.

Introduction

Refrigerant use is governed by several regulations due to its impact on ozone depletion and global warming. Prior to key regulations, such as the Montreal Protocol, refrigerants use was based on cost and technical considerations. This led to the development of several chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) since the 1930s. Due to the impact of CFCs and HCFCs on the ozone layer, hydrofluorocarbons (HFCs) have been a replacement refrigerant in recent applications. Older applications with R12, R114, R 500, R502 and R22 have been replaced with newer HFCs (R134a and a blend of R407C and R410A). The global warming potential of HFCs is a major environmental concern since one ton of HFCs has the equivalent impact of 1000 tons of CO_2 (Department of Energy & Climate Change, 2014).

The global warming potential (GWP) of a gas refers to "the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit after reference gas, CO2, which is assigned a value of 1". All ozone depleting substances, including refrigerants, with a

GWP of 150 or higher are considered high GWP substances (California Air Resources Board, 2022). Table 1 provides a list of common refrigerants and the associated GWP and ODP.

The impact of refrigerant management is significant that Project Drawdown project includes refrigerant management as one of the 14 solutions in the building sector. The estimated CO2 equivalent reduction from refrigerant management between 2020 to 2050 is 57.15 Gigatons, which translates to $622.73 billion savings in operating costs (Project Drawdown, n.d.).

ASHRAE standard 15 and 34 provide safety guidelines on the safe handling and use of refrigerants. ASHRAE 15 provides procedure for safe design, construction, installation, and operation of refrigerated systems, and ASHRAE 35 designation and safety classification for refrigerants based on toxicity and flammability data (Bhatia).

Table 1 - Global warming potential and Ozone depletion potential of common refrigerants

Refrigerant type	**Refrigerant**	**GWP**	**ODP**
Chloroflourocarbons	CFC-11	4,750	1
	CFC-12	10,900	1
	CFC-114	9,800	
	CFC-500	7,900	
	CFC-502	4,657	0.25
	CFC-11	725	0.12
Hydrochloroflourocarbons	HCFC-22	1,780	
	HCFC-123	76	
Hydroflourocarbons	HFC-22	1810	0.05
	HFC-23	12,240	
	HFC-134a	1430	0
	HFC-245fa	1020	
	HFC-404a	3922	0
	HFC-407a	2107	0
	HFC-410a	2088	0
	HFC-507A	3,900	
Natural Refrigerants	Cyclopentane	11	0
	Propane	11	0
	Isobutane	3	0
	Ammonia	0	0
	Carbon Dioxide	1	0

This report will provide a comprehensive overview of current market status on HVAC refrigerant use, leak calculation methods, and best practices during equipment installation and maintenance, to minimize high GWP refrigerant leakage.

Refrigerant Leakage

Refrigerant leaks are inevitable and emissions from refrigerant leak are a significant portion of a building's lifecycle GHG emissions. Although the leakage is the highest at the equipment end of life, small to significant leaks can occur during its useful life (California Public Utilities Commission).

Refrigerant leakage is hard to detect because refrigerants are typically colorless, odorless substances. Typically, leakage is higher in larger, site assembled systems with higher charge per gross square feet (GSF) compared to smaller factory assembled units (PAE, 2020)

Yale’s refrigerant initiative on their campus found that the amount of total refrigerant GHG emissions reported in accordance with the Word Research Institute (WRI) standards was half the actual GHG emissions including smaller units that are often unaccounted. The large central chiller plants and other large HVAC equipment accounted for 2% of the campus refrigerant GHG emissions, but the emissions increased to 4.3% when smaller units were included in the inventory. Yale’s strategy to reduce refrigerant GHG leakage is to replace older systems with higher GWP refrigerant with the newer low-impact refrigerant systems, and to proactively monitor and repair leaks to minimize lifetime leakage (Yale Sustainability, 2021).

Table 2 - Refrigerant type in common heat pump manufacturers

Manufacturer	**Model**	**Refrigerant type**
Daikin	SmartSource Water source heat pumps	R-410A
	Enfinity	R-410A
	Altherma	R-32 or R-410A
Mitsubishi	Ecodan	R744, R32, R410A
Panasonic	Aquarea	R407C, R32, R410A
Valillant	Arotherm	R290, R410A
Kensa	Shoebox	R134A
	Evo	R407C

Currently, HFCs are the most used refrigerant types. It is estimated that the use of HFCs will grow substantially before newer refrigerants with a low GWP are introduced in the market. The most immediate short-term goal is reducing losses from these HFC based systems. In addition to environmental concerns, refrigerant losses also lead the systems to run less efficiently, and consequently unable to meet the thermal comfort. Loss of refrigerant charge may also lead to compressor and other system failures (Harrod, 2021).

Refrigerant Leakage- Calculation Methods

The rates of refrigerant leakage into the atmosphere are not well documented. Studies show that it typically occurs at installation, routine operation, and at end-of-life. Larger systems with high refrigerant charge and systems built at site with multiple joineries are likely to have higher rates of leakage than factory built smaller systems with lower refrigerant charge.

Refrigerant leakage can be measured using four different methods (PAE, 2020):

- LEED leakage method
- Life Front leakage method
- Component leakage method
- Field data from EU F-gas logs

LEED Leakage Methodology

USGBC's LEED rating system requires one prerequisite and provides an optional credit for refrigerant management:

Prerequisite: Fundamentals of refrigerant management

With the intent to reduce stratospheric ozone depletion, this prerequisite requires that the design does not use any CFC based refrigerants for HVAC&R applications. For existing building retrofits that reuse existing systems, a comprehensive CFC phaseout conversion is required. Existing small HVAC&R equipment and small appliances with less than 0.5 lb of refrigerant (such as refrigerators, small water coolers etc.,) are exempt from this prerequisite (U.S. Green Building Council, 2022).

To comply with this credit, commercial refrigeration systems should only use non ozone depleting refrigerants, specify equipment where average refrigerant charge is no more than 1.75 pounds of refrigerant per 1000 Btu/h of total cooling load, and demonstrate annual refrigerant emissions rate of maximum 15%. The leakage testing at installation should be done in accordance with GreenChills best practices guidelines for leak tightness (USGBC, 2022).

Credit: Enhanced refrigerant management

With the intent to reduce ozone depletion and support compliance with the Montreal protocol, this credit has two requirements:

Option 1: No refrigerants or low impact refrigerants

This credit requires that the project does not use refrigerants, or only uses refrigerants that have an Ozone Depletion Potential (ODP) of zero, and a GWP of less than 50.

Option 2: Calculation of refrigerant impact

This credit requires that the design team select refrigerant in HVAC&R equipment “to minimize or eliminate the emission of compounds that contribute to ozone depletion and climate change” following either of the two options outlined in this credit (USGBC, 2022). All new and existing base building refrigerant must comply with the formula calculation method provided in this credit.

LCGWP = [GWPr x (Lr x Life +Mr) x Rc]/Life

Where,

LCGWP: Lifecycle Direct Global Warming Potential (lb CO2/Ton-Year)

GWPr: Global Warming Potential of Refrigerant (0 to 12,000 lb CO2/lbr)

Lr: Refrigerant Leakage Rate (Assumed to be 2.0%)

Mr: End-of-life Refrigerant Loss (Assumed to be 10%)

Rc: Refrigerant Charge (0.5 to 5.0 lbs of refrigerant per ton of gross AHRI rated cooling capacity)

Life: Equipment Life (Default assumes 10-year life; If demonstrated otherwise, use actual equipment life)

If the building has multiple types of equipment, the weighted average of all base building HVAC&R equipment can be calculated using the following formula:

(∑ (LCGWP + LCODP x 105) x Qunit) / QTotal ≤ 100

Where,

Qunit = Gross AHRI rated cooling capacity of an HVAC or refrigeration unit (Tons)

Qtotal = Total gross AHRI rated cooling capacity of all HVAC or refrigeration

Following this method, a typical residential installation with 7.3 lb. of R-32 (GWP of 675) refrigerant charge and 15-year equipment life will have the following refrigerant leak:

LCGWP = [GWPr x (Lr x Life +Mr) x Rc]/Life

LCGWP = [675 x (2% x 15 + 10%) x 7.3] / 15

LCGWP = 131.4 lb. CO_2/Ton-Year

A typical residential installation with 7.3 lb. of R-410A (GWP of 2,088) refrigerant charge and 15-year equipment life will have the following refrigerant leak:

LCGWP = [2,088 x (2% x 15 + 10%) x 7.3] / 15

LCGWP = 407 lb. CO_2/Ton-Year

Life Front Leakage Methodology

Life Front leakage methodology was developed based on the most extensive refrigerant systems testing study in the European Union. Based on revenue of 250 league samples and a variety of refrigerants, the study concluded that the type of refrigerant does not influence leakage. The average leakage rate from refrigerated systems is about 5% per year. So, the total refrigerant leakage from the system can be calculated as 5% of the total refrigerant volume per year multiplied by the life of the equipment in years. A big drawback of the life front leakage method is that it does not factor in end-of-life leakage (PAE, 2020).

Following this method, a typical residential installation with 7.3 lb. of R-32 (GWP of 675) refrigerant charge and 15-year equipment life will have lose 0.37 lbs. of refrigerant annually or 5.5 lbs. of refrigerant by end of life. The annual GWP of this loss is 246 lbs. of CO_2e per year.

For the same installation with R-410A, annual GWP is 773 lbs. of CO_2e per year.

Component Leakage Methodology

This method accounts for refrigerant leakage based on different types of field made joints for HVAC systems. An ASHRAE funded study that reviewed 100 each of press and crimp, compression, and flare fittings. Durability testing with pressure-temperature thermal cycling, freeze-thaw cycling, and vibration testing was done on all joints. The study also tested for different tubing material (copper- copper, copper- aluminum), sizes of joints (3/8in and 3/4 in), and incorporated technician experience and complexity of assembly in the analysis. The leak rate for the different types of joints were:

- Press fittings – 0.5 – 1.0 grams/year
- Compression fittings – 0.4 grams/year
- Flare fittings - 0.2 grams/year

Press fittings had the fastest assembly and lowest assembly failure rate, and showed zero failures in harshness testing, making it the most efficient of all fitting types tested. While flare fittings had the longest assembly time, it has the lowest leak rate at 0.2 grams per year. Compression fittings generally had lower leak rate and shorter assembly time but had the highest failure from assembly and leaks after assembly. Most of these leaks could be fixed by tightening the joints. The study also found that technician experience impacted assembly time and success rate.

Using this method, the annual leakage rate can be calculated by multiplying the leakage rate by the number of joints of that type (PAE, 2020) (Elbel, Lawrence, & and Raj, 2018)

UK Department of Energy and Climate Change Data

The study was conducted in response to EU F-Gas regulations to provide evidence-based assessment of heat pump installations. Analysis of F- gas logbooks from 528 installations are summarized in Table 3.

Table 3 - Refrigerant leakage data from F-gas logbooks

	Commercial	Residential
Annual leakage rate	3.8%	3.5%
Percentage of installations that leak annually	9%	10%
Median refrigerant loss	42%	35%
Charge loss in catastrophic leaks	75%	92%

Although this study is currently one of the largest databases of field data on refrigerant leakage from heat pump installations, there are some drawbacks in the data collected. The logbooks do not record the type of refrigerant, type of installation, quantity of refrigerant added, quantity of refrigerant recovered, and the date, cause, and the location of leaks.

Using data from this study, the refrigerant loss for a typical residential installation with 7.3 lbs. of R-32 (GWP of 675) refrigerant charge and 15-year equipment life can be estimated as:

- Typical leak in residential heat pumps equal = 10%
- Median charge loss = 35%
- Equivalent annual leakage rate = 3.5%
- Average annual leakage = 3.5% x 7.3 = 0.256 lbs.
- Charge at filling = 0.13 lbs.
- Re-charging = 0.13 lbs.
- Leakage = 10% x 35% x 7.3 lb. x 15 yrs. = 3.81 lbs.
- Decommissioning loss = 15% x 7.3 lb. = 1.1 lbs.

The total refrigerant loss using this method is 4.91 lbs. over the equipment lifetime or 0.33 lbs. annually. For a system using R-32 and R-410A, the annual GWP is 223 lbs. and 689 lbs. of CO_2e per year, respectively.

Using this method, Table 4 shows the estimated annual and lifetime leakage in a typical, DOE prototype mid- and high-rise multifamily building (DOE, 2019). The average lifetime refrigerant leak in a typical multifamily building is 0.006 lbs. per sf of building area.

Table 4 - Annual and lifetime refrigerant leak in a typical mid- and high-rise multifamily building

	Mid-rise multifamily	**High-rise multifamily**
No. of units	32	80
Annual leakage (lbs.)	10.3	26
Lifetime leakage (lbs.)	206	516
GWP (CO_2e)	176,904	442,260

The research also showed that refrigerant leakage had an impact on heat pump performance. A 3% reduction in heating and 15% reduction in cooling coefficient of performance (COP) resulted from a 10% refrigerant charge loss. A 40% loss in charge resulted in a 45% and 24% COP reduction in heating and cooling mode respectively.

Table 5 - Loss in equipment efficiency from refrigerant leaks

Refrigerant loss	**Heating COP loss**	**Cooling COP loss**
10% Loss	3%	15%
40% Loss	45%	24%

The study (conducted in 2014) predicted that the number of heat pumps would increase tenfold between 2014 to 2020. But the refrigerant across these installations increased by only half this amount, since 93% of heat pump installations were smaller residential units with much lower installation charge (Department of Energy & Climate Change, 2014) (PAE, 2020).

System Installation

Proper installation technique has a significant improvement on air source heat pump performance by preventing refrigerant loss. It is important to follow proper installation techniques to minimize refrigerant leakage, especially with flare joints as outlined below (Harrod, 2021), (NEEP, 2020)

- Flare fittings should be installed, connected, and tightened to manufacturers specifications.
- Flares and fittings should not be re-used. If any defective flares found, it is recommended to start the joinery again rather than attempting to tighten it further.
- Flare joints damaged in transit should be replaced
- Ensure that the flare assembly is not too loose to form a good seal or two tight resulting in cracks or splits.
- Flare fittings should be minimized except when necessary, in favor of gasketed press and crimp joints. Field fabricated flare joints should be entirely avoided.
- For difficult to access connections, brazing is recommended due to its durability and results in a reliable, leak free joint.

- Protect refrigerant lines from corrosive chemicals and avoid installing lines in wall cavities, where they could be damaged inadvertently
- Oxidation should be prevented in brazed joints with dry nitrogen
- In cold climates built up ice could crush outdoor coils. It is recommended to provide drainage to the unit, base pan heaters, and snow shields for outdoor units

Proper design and installation are especially critical in Variable Refrigerant Flow (VRF) systems since leak from these systems would infiltrate the occupied space, leading to hazardous conditions. For safety purposes, the total refrigerant in the VRF systems should not exceed the Refrigerant Concentration Limit (RCL). This design limitation is a challenge, particularly in small spaces such as hotel rooms and dormitories etc., since a leak would lead to the loss of the entire refrigerant volume into that room, resulting in hazardous refrigerant concentration levels. If a room is too small for the RCL, it can be remedied in one of three ways: increase in the room volume, remove or relocate refrigerant piping or the indoor unit, or by reduce the refrigerant charge into smaller systems (Bhatia).

Testing and Refrigerant Charge

The refrigerant loss in the supply chain between the supplier to the installation site is not been well understood and is mostly unknown (Department of Energy & Climate Change, 2014). Typically, refrigerant charge does not need to be adjusted in most installations and should be adjusted only if necessary following manufacturer's instructions (NEEP, 2020). In a field test conducted by the London South Bank university, the median loss in refrigerant charge was determined to be 0.062 kg (0.14 lb.) of refrigerant from field recharging tests. From refrigerant recharging data recorded in F- gas logbooks, the study also found that 8.97% of commercial installations and 10% of domestic installations had significant leaks that required a recharge (Department of Energy & Climate Change, 2014).

It is recommended that refrigerant pipes be tested for leaks before charging the system. Gradual pressurization helps detect catastrophic leaks with minimal waste, and this testing process ensures that there is no significant refrigerant loss over the life of the system. 3447 kPa to 3792 kPa is the typical target pressure recommended by manufacturers (Harrod, 2021). When adjusting refrigerant charge for nonstandard lengths of line, it is important to follow installation manuals and employ software tools to determine proper protocol for weighing, adding or removing and recovering refrigerants (NEEP, 2020).

LSBU Conducted a field test to assess the impact of heat pump performance from reduced charge during operation. Testing was done for four different levels of refrigerant charge - 100%, 60%, 70% and 90% of total charge in a 125 kW system. The results showed a significant reduction in COP associated with refrigerant loss, as shown in Table 5.

Table 6 – Actual COP from varying refrigerant charge in a heat pump system

Mode	100% charge	60% charge	75% charge	90% charge
Heating	9.1	5.0	-	8.8
Cooling	14.9	11.3	-	14.1

The study showed that a 10% loss in refrigerant (operating at 90% charge), resulted in a 3% reduction in heating COP and 5% reduction in cooling COP. When the refrigerant charge was lowered by 40% (operating at 60% charge), the COP reduction was 45% and 24% in heating and cooling modes, respectively. The study did not provide conclusive results on heat pump performance at 75% charge due to a weekend schedule during the testing period, when the heat pump was not operated.

The results show that cooling performance of a system is more impacted by minor refrigerant loss than heating performance. When a catastrophic leak occurs with a higher percentage of refrigerant loss, it results in a significant reduction in heating and cooling COP. This increases the electricity used to meet the heating and cooling demands of the space (Department of Energy & Climate Change, 2014).

Refrigerant Monitoring

Field data indicates that leakage from ongoing equipment operation is the most significant contributor to refrigerant loss compared to supply chain losses. Therefore, monitoring systems with refrigerants on a continuous basis to reduce operational leakage has the most significant impact for refrigerant management.

Refrigerant monitoring systems should be placed in the refrigeration equipment rooms to monitor refrigerant buildup and trigger alarms, if needed. The sensors should be regularly tested and calibrated and can be set to sensitivity between 1-1000 ppm.

The Threshold Limit Value (TLV) is “the concentration of refrigerant vapor in air for a normal 8-hour workday and 40-hour work week to which occupants may be repeatedly exposed without adverse effects” (Bhatia). The recommended setpoint for sensors to trigger emergency ventilation is 1/2 of the TLV of the refrigerant with the lowest TLV, when multiple refrigerant types are used.

Sensors should be placed within 20 feet of a chiller, and in locations where leakage is likely to concentrate. Although a single sensor is sufficient, it is recommended that large multi-level rooms have multiple sensors. A recommended best practice in refrigerant monitoring is to set up dual alarms - the first alarm level is set for low ppm and helps detect and minimize refrigerant loss; the second alarm level is set to a high concentration when a catastrophic leak occurs, and triggers emergency mechanical ventilation and central plant shut down.

A building management system (BMS) can also help with refrigerant leakage monitoring and be programmed to trigger mechanical ventilation when high refrigerant level is detected (Bhatia).

Decommissioning

Refrigerant leaks into the atmosphere occurs due to system leakages and during end-of-life appliance and HVAC systems disposal. 90% of refrigerant leakage occurs at end of life and effective disposal is therefore critical (Project Drawdown, n.d.).
The EPA vintage model assumes 15% - 95% of refrigerant charge gets recovered based on the refrigerant charge at end of life and recovery efficiency for different equipment types. Refrigerant recovery reduces the need for virgin refrigerant (Ferenchiak, 2020).

Refrigerant Management- Current Status

In the United States, residential unitary air conditioners are predicted to be the highest contributors to HFC consumption and leakage from 2012 to 2050. Commercial refrigeration in large retail facilities, like supermarkets, have been the second largest HFC users between 2011 to 2013 (Figure 1). A significant fraction of commercial refrigeration has transition to R-404A between 2001-2017. Other HFC applications in the building sector includes standalone commercial and industrial refrigeration. A drawback of this model is that it does not factor in refrigerant recovery and reuse, and consequently, represents a hypothetical worst-case scenario where 100% of refrigerant is released into the atmosphere (Ferenchiak, 2020).

Figure 1 - HFC consumption in the U.S. in Million Metric Tons of CO2e

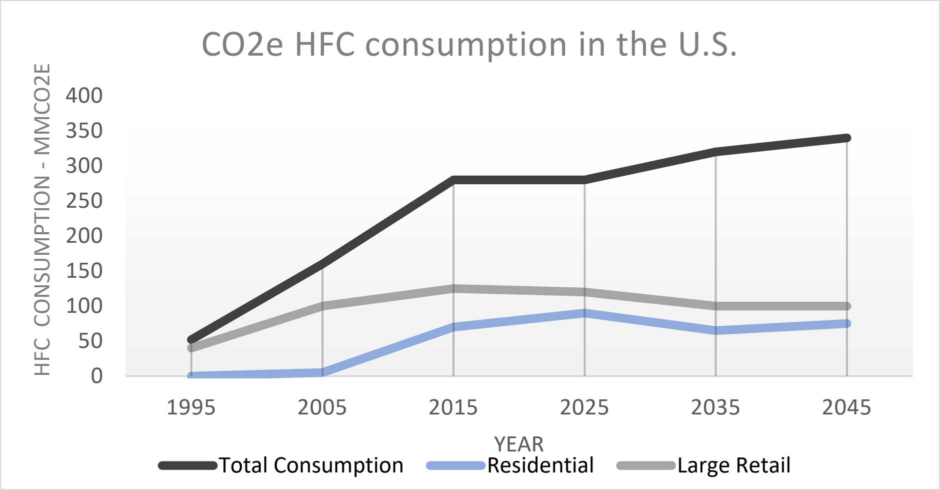
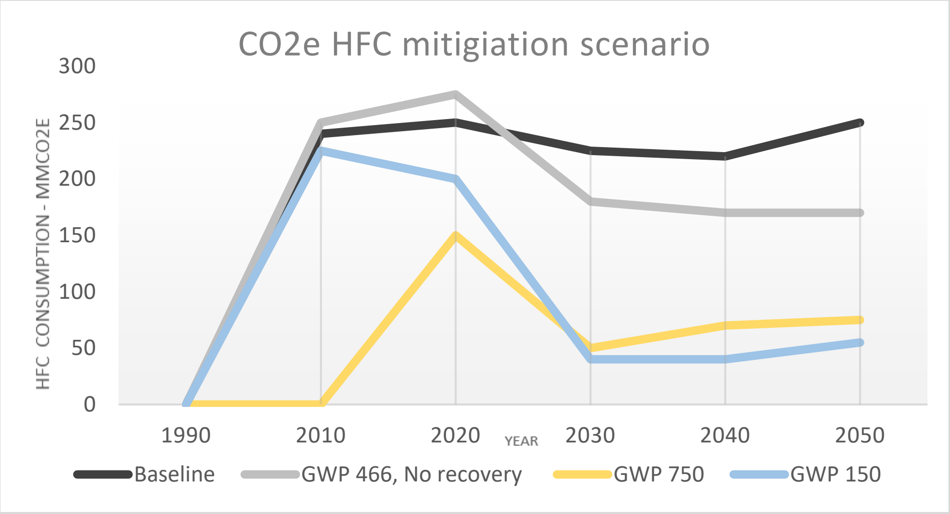


Figure 2 - HFC consumption in the U.S. in mitigation scenario 3 in Million Metric Tons of CO2e



A study evaluated three different mitigation scenarios to identify the impact of refrigerant on future HFC consumption (Ferenchiak, 2020):

- Scenario 1: The first scenario evaluated change in refrigerant type and reduction in baseline condition, without any mitigation measures for a refrigerant use.
- Scenario 2: The second scenario evaluated change and refrigerant type and a set of mitigation options, such as CO_2 refrigerant in medium and large retail food applications, HC-290 in ice makers, 513A in fleet etc.
- Scenario 3: in addition to the mitigation measures evaluated in scenario 2, scenario 3 also includes measures to reduce HFC consumption, such as increase the market adoption of R-744 in medium and large refrigerated food systems, R-290 in residential window AC's and dehumidifiers etc.,

Among the three scenarios evaluated, scenario three shows the highest potential for HFC reduction as shown in Figure 2.

In 2006, the U.S. EPA launched the Responsible Appliance Disposal (RAD) program. The program works with various market actors such as utilities, retailers, manufacturers, state and local government agencies, and other customers on using best practices for proper disposal of old appliances with refrigerants. Since 2006, the program has collected over 9.3 million appliances and HVAC units, minimizing adverse environmental impact (U.S EPA, 2021).

Between 2010 to 2020, between 9-11 million pounds of refrigerant have been reclaimed per year. Majority of this, between 7-10 million pounds of refrigerants is HCFC-22, while a smaller percentage of other HCFCs and CFC's have been reclaimed as well (U.S. EPA, 2021).

Through the significant new alternatives policy (SNAP), EPA has sought to develop close to 500 substitutes in eight industrial sectors based on an analysis of environmental, health and safety risks in different industrial and consumer uses ODS. The list of alternates evolves as EPA update its current knowledge on available substitutes with the lower environmental and human health impact. They key purpose of the SNAP program is to evaluate substances with high ODP, publish and promote acceptable substitutes, and educate the public on environmental and human health impacts. The evaluation framework includes atmospheric effects of ODP and 100-year integrated GWP, and exposure assessment from leaks in built spaces and the environment (U.S. EPA, 2021).

Avoided Cost Component

The California Public Utilities Commission (CPUC) introduced the avoided cost component (ACC) metric to measure the impact of GHG from refrigerants with GWP. ACC factors in the following components (California Public Utilities Commission):

- Several DER programs in California reduce GHG emissions from reducing natural gas use and consequently, methane leakage.
- Simultaneously, DER programs also increase electricity consumption and refrigerant use in electric systems and appliances.
- DER programs are designed to reduce electric use. This results in reduced natural gas use at the power plants and decreases natural gas use in buildings.

CPUC has introduced the “Refrigerant Avoided Cost Calculator” to calculate avoided cost from refrigerant usage (CPUC, 2022). The calculator also includes “incurred costs” to account for instances where a device containing refrigerant is installed. This ensures that both avoided and incurred costs are fully accounted for. The 2022 refrigerant leakage calculator estimates the avoided cost of refrigerant leakage for three types of measures:

- Normal replacement measure
- Add-on equipment measure
- Accelerated replacement measure

The normal replacement measure is applicable when an existing equipment is replaced with new equipment at the end of its useful life. The add-on equipment measure is applicable when an additional piece of equipment is installed along with the existing equipment, and both are replaced at the end of their useful life. To determine measure life, the calculator uses inputs including device type, lifetime, installation year, refrigerant charge, type of refrigerant or a user specified GWP.

Accelerated replacement measure is applicable when an existing equipment is removed before it's end of useful life and replaced with new equipment. This measure has higher leakage potential since it replaces a device before it's end of useful life. This measure requires the user to specify inputs for the existing equipment being replaced and the new equipment to be installed.

The cost of refrigerant leakage is estimated using the following formula:

Value of refrigerant leakage = $M_i * (q_{ann,i}\, t_i + q_{EOL,i}\,(1- {}_{qann,i}\; t_{EOL,i})) * GWP_i * P_{GHGe}$

Where,

M_i is the refrigerant charge in tons

q_{ann} is the annual leakage rate

t is the expected useful life of the equipment in years

q_{EOL} is the end-of-life leakage rate for each device, depending on typical disposal practice

GWP is the global warming potential for the type of refrigerant in tons of CO_2e

P_{GHGe} is the GHG electric adder in $ per ton of CO_2e

CO_2E Net Impact

By 2050, the volume of installed refrigerant is expected to increase three times from increased heat pump deployment compared to 2020 levels. During the same period, the level of R401A is expected to decrease to a fraction of current use, along with an increase in HCs, CO_2 and HFOs as the predominantly used refrigerant types.

The CO_2e is predicted to drop by 85% from 2025 to 2050. The following factors contribute to the variations in CO_2e during this period (Department of Energy & Climate Change, 2014):

- The modeled impact of CO_2e from refrigerant leakage shows an increase in CO_2 emissions till 2025 as heat pump deployment increases and the industry slowly transitions away from high GWP refrigerants.
- CO_2e drops significantly starting 2025 once the major shift in heat pump deployment and refrigerant type transitions are well established
- The transition to low GWP refrigerants and progressive increase in heat pump efficiency in the market reduces the electric demand
- Grid decarbonization also reduces CO_2e impact, increasing net benefit

The modeling study tested for various sensitivities including level of heat pump deployment, leakage rate, variation in refrigerant type, and variation in system performance. Heat pump deployment showed the highest variation in annual net benefit (in tons of CO_2e), with the high deployment scenario resulting in 76% higher benefit compared to the median deployment scenario (Department of Energy & Climate Change, 2014).

Recommendations

Current HFC refrigerants are being replaced by low GWP refrigerants such as CO2, R32, R-466-A, which are in limited HVAC appliance use but rapidly gaining market share (Harrod, 2021). However, existing equipment should only be replaced at end of useful life as several studies have shown that replacing equipment before useful life leads to the highest leakage potential (CPUC, 2022).

CARD recommends exceptionally leakproof and tight systems, high reclamation and introducing low GWP alternatives to reduce risk from high GWP refrigerants (California Air Resources Board, 2022).

Project drawdown recommends 5 methods of refrigerant management (Project Drawdown, n.d.):

- Reducing the use of refrigerant based systems and appliances
- Replacing high GWP refrigerants with new cooling agents and HFC's with low GWP potential
- Install high efficiency equipment
- Manage and reduce refrigerant leakage from existing appliances and adopt best practices at end of life for recovery, reclaiming, and recycling.

Utility incentive programs should also consider the following factors to minimize refrigerant leakage: increase contractor trainings on leak prevention, verify with documentation that best practices have been followed during installation, conduct quality assurance for leak detection and provide corrective trainings, provide incentives for recycling and proper disposal of equipment using refrigerants.

Challenges and Limitations

The US Environmental Protection Agency (U.S. EPA) notes that HVAC units installed before 2010 contain HCFC-22 and these systems currently do not need to be retrofitted. These system components are not compatible with newer refrigerants and continue to be recharged with HCFC-22 during routine repair and maintenance. These systems will continue to operate till end of life, and it is critical to perform routine servicing to reduce environmental impacts. EPA recommends that homeowners work with technicians who are EPA section 608 certified (U.S. EPA, 2021).

Another key limitation is the issue of flammability. Most currently available lower GWP refrigerants are mild to highly flammable. Building and fire codes currently allow for mildly flammable refrigerants when appropriate preventative and risk management measures are in place (California Public Utilities Commission).

Conclusions

With the increase in refrigerated equipment in the multifamily sector, refrigerant management should be an area of increased focus to avoid on-going refrigerant leakage and hazardous end-of-life disposal. The 2019 Chicago Energy Benchmarking report shows that multifamily buildings are the largest building type across the city, accounting for 48% of total built area at 346 million square feet (City of Chicago, 2020). In Chicago, the lifetime refrigerant leakage potential from refrigerant based HVAC equipment could range between 211,000 to 1,058,000 lbs. for 10-50% market penetration, without any preventative measures. This contributes to 1.1 billion CO_2e for R-410A. This scenario shows the need for newer, low GWP refrigerants to be deployed at scale, and for preventative refrigeration management practices.

The negative impact from refrigerant loss is estimated to be 46,000 tons of CO_2e by 2050 compared to 128,000 tons CO_2e in 2021. This 82,000-ton reduction in emissions is due to the progressive switch from HFC's to low GWP refrigerant alternatives. Over the long-term emissions reductions increases markedly- the avoided emissions of 2.2 million tons of CO_2e in 2020 increases to 7.4 million tons of CO_2e by 2050.

The emissions reductions analysis for refrigerated HVAC systems shows that the net benefit is 6 million tons of avoided CO_2e emissions between 2013 and 2020. This benefit can be further maximized through effective refrigerant management where systems are monitored pre- and post-installation, tested for leaks early, and refrigerant loss is minimized by using installation and management best practices.

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