BURO HAPPOLD

Autocase®

QUANTIFYING THE SOCIAL IMPACT OF REFRIGERANT CHOICES

The role of refrigerants in climate change… and what you can do about it

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Contents

The Impact of Refrigerants

Refrigerants are significant contributors to climate change. Project Drawdown identifies refrigerants as the #1 most impactful factor in the construction industry (Project Drawdown, n.d.). Flourinated gases comprise 3% of the total greenhouse gas emissions in the United States, 92% of which are due to refrigerants in buildings and vehicles (Environmental Protection Agency, 2020). The impacts of refrigerants are classified using two measurements: ozone depletion potential (ODP) and global warming potential (GWP). Beyond the environmental impact, refrigerants additionally pose a risk to human health via risks of toxicity, flammability, asphyxiation and other hazards (Advent Air, 2015). Many of these risks can be mitigated via prudent refrigerant management, such as prevention of leakage and proper disposal.

The Montreal Protocol

In order to combat the harmful impacts of refrigerants, the 1987 Montreal Protocol was established to protect the ozone layer through phasing out the usage of refrigerants with high ODPs, including Chloroflourocarbons (CFCs) and Hydrochrloroflourocarbons (HCFCs) (U.S. Department of State, 2019). The Montreal Protocol required a complete phase out of these refrigerants by 2020 in developed countries. Since this agreement was enforced, industries have converted to using hydrofluorocarbons (HFCs). HFCs do not deplete the ozone layer but have high GWPs due to the fluorinated gases. The capacity of HFCs to warm the atmosphere ranges from approximately 1,000 to 9,000 times greater than that of carbon dioxide. In 2016, 170 countries committed to phasing out HFCs as an amendment to the Montreal Protocol known as the Kigali Amendment. The goal of the Kigali Amendment is to achieve an 85% reduction in HFC usage by 2036, with further restrictions enforced as early as 2024.

Alternatives

With HCFC use eliminated from use in new chillers and the upcoming phase out of HFCs, mechanical engineers and manufacturers are turning toward refrigerants not prohibited in the Montreal Protocol, primarily Hydroflouroolefins (HFOs). These refrigerants offer similar performance to HFCs, but exhibit less environmental impact with zero ODP and very low GWP.

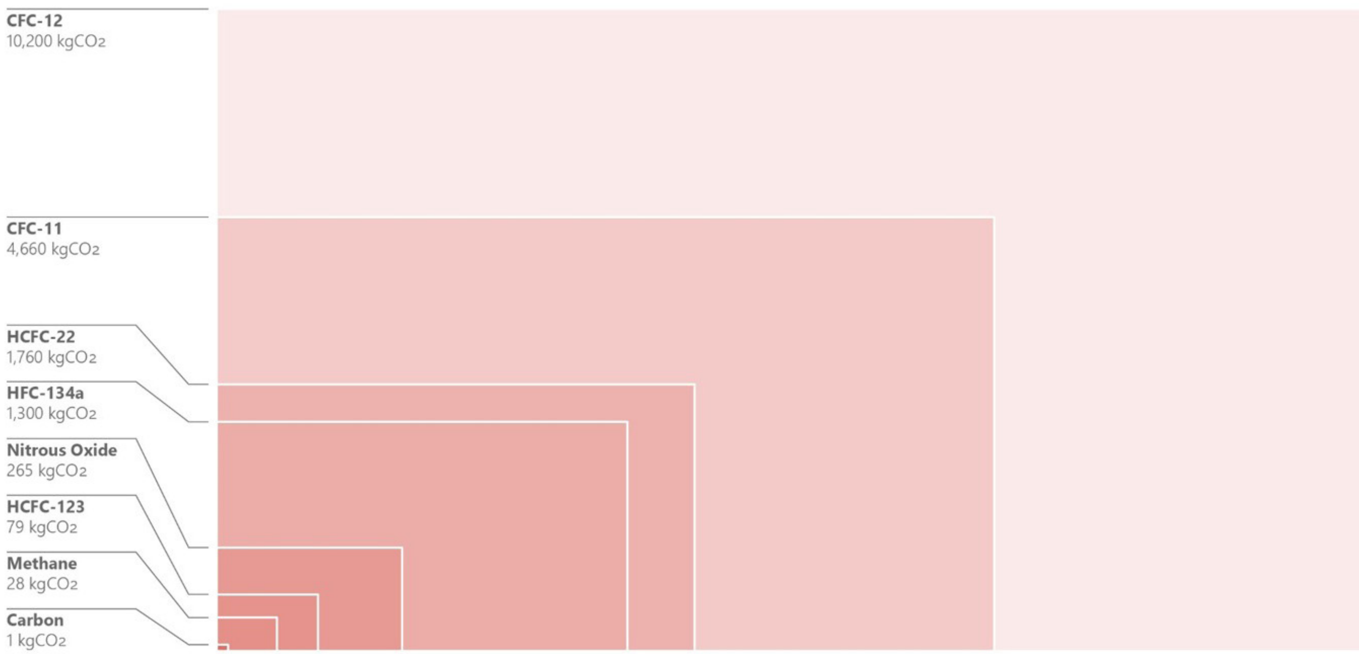

Figure 1 - Global Warming Potential in Kilograms of CO2 for Various Gases and Refrigerants (Buro Happold, 2020)

The Importance of 2024 in California

In addition to the Montreal Protocol, California has adopted a goal to reduce HFC emissions by 40% from 2013 levels by 2030. In order to help ensure California stays on track to meet this goal, the California Cooling Act was passed. The California cooling act adopted two major U.S. Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) rules (California Air Resources Board, n.d.):

- Rule 20: Prohibits the use of high GWP HFC refrigerants such as R-404A and R-507A in new supermarket refrigeration equipment, stand-alone equipment, remote condensing units, and refrigerated vending machines.
- Rule 21: Prohibited certain HFCs in new cold storage facilities beginning in 2023, and in new chillers beginning in 2024.

That phase-out of certain HFC refrigerants in chillers by 2024 will have a massive impact for mechanical (HVAC) engineers and chiller manufacturers. Many chillers commonly used today are only compatible with HFCs and will begin to lose their efficacy as these refrigerants are phased out.

End-Use	Prohibited Substance	Effective Date
Centrifugal chillers (new)	FOR12A, FOR12B, HFC-134a, HFC-227ea, HFC-236fa, HFC245fa, R-125/134a/600a (28.1/70/1.9), R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-423A, R-424A, R-434A, R-438A, R-507A, RS-44 (2003 composition), and THR-03	Unacceptable as of January 1, 2024, except where allowed under a narrowed use limit.
Positive displacement chillers (new)	FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R125/134a/600a (28.1/70/1.9), R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-424A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 composition), SP34E, and THR-03	Unacceptable as of January 1, 2024, except where allowed under a narrowed use limit.

Table 1 - Refrigerants soon to be Prohibited in California

Buro Happold mechanical engineers choose a chiller to fit the design requirements of the system. Chillers are typically compatible with one or two refrigerants, driven by the pressure of the component and decisions by the manufacturer. The majority of chiller manufacturers specify R-134a for medium pressure systems and R-410A for high pressure systems. As displayed in Table 1, R-134A and R-410A will be banned or limited by 2024 in California for use in new chillers. The legislation is for various different applications but at this time the commercial refrigeration industry is most affected by the ban on chillers. It is however expected to eventually encompass other commercial applications, such as variable refrigerant flow (VRF) systems.

New technologies are needed to ensure equipment is compatible with HFO refrigerants and maintain functionality and efficiency. Additionally, some HFOs currently available have drawbacks such as flammability, increased toxicity and lowered efficiency, and thus further improvements are needed in HFO refrigerant development as well.

The Social Cost of Carbon

There is a social cost associated with CO_2 emissions, which represents the monetary value of future climate change-related damages. All greenhouse gases can be expressed as carbon dioxide equivalent (CO_2e), which is the amount of CO_2 that would need to be emitted in order to create the same amount of warming as the gas being compared. The CO_2e value for a gas can then be used to apply a $/metric tonne in order to monetize the impact.

Scientists expect climate change to have increasingly negative consequences for society due to rising temperatures. For example, increasing temperatures have been linked to raised probabilities and intensities of extreme weather events, such as coastline flooding, droughts, heat waves and wildfires.

There is not a universally agreed-upon social cost of carbon, which can range anywhere from $0/tonne to over $1,500/tonne. The consensus seems to be approximately $30-$100 USD per tonne CO_2e. The social cost of carbon used for this analysis starts off at $53 per tonne in 2021 and increases to $74 per tonne in 2040 (Interagency Working Group on the Social Cost of Carbon, 2016; Turner et al., 2019)

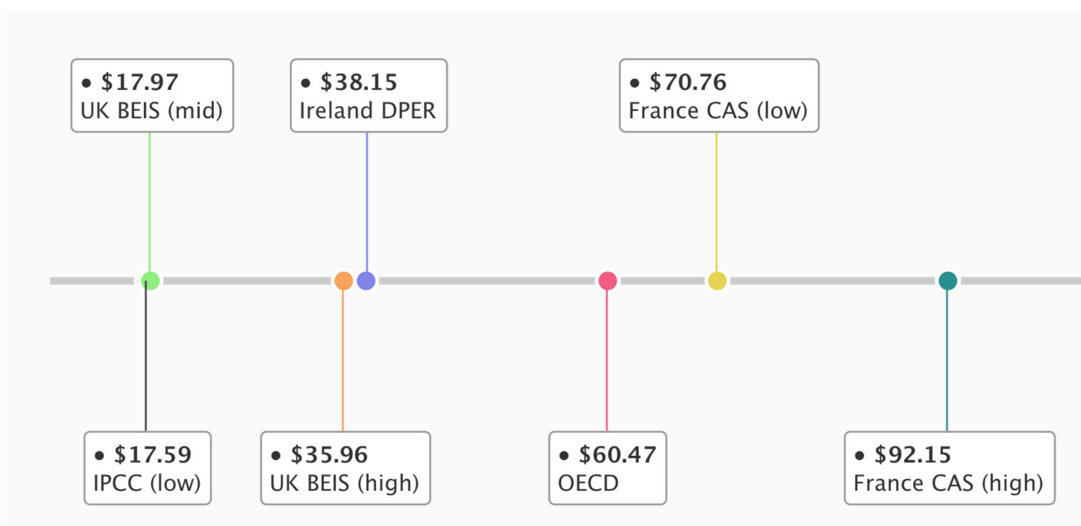

Figure 2 - The Social Cost of Carbon Variations by Sources (Autocase, 2020)

What can HVAC Engineers & Chiller Manufacturers Do?

It is the responsibility of HVAC engineers to strongly weigh the environmental and social impact of refrigerants in their design decisions, and it is the responsibility of manufacturers to continuously improve their products.

Project Drawdown lists the following five as measures to reduce the impact of refrigerants on the environment (Project Drawdown, n.d.):

1. Lowering the demand/use of appliances and thereby production of refrigerants.
2. Replacing refrigerants with low-warming HFCs/new cooling agents/non-HFC substances.
3. Increasing the refrigeration efficiency in appliances, thereby lowering the use of refrigerants.
4. Controlling leakages of refrigerants from existing appliances by good management practices.
5. Ensuring recovery, reclaiming/recycling, and destruction of refrigerants at end of life.

To focus efforts on direct HVAC engineer and manufacturer impact, this document discusses the following strategies:

- Downsizing & refrigerant management, and
- Choosing alternative refrigerants.

Downsizing, Refrigerant Management and Natural Ventilation:

Reducing refrigerant demand is an effective method of refrigerant management. By reducing the installed capacity of systems, the refrigerant installed will also be reduced. Methods of reducing system capacity include utilizing thermal storage for peak shaving, high efficiency central plants, airside energy recovery systems and natural ventilation. Additionally, implementing energy efficiency measures such as high performance glazing or optimized envelopes can lower the cooling demand for a building, thus reducing the overall amount of refrigerant.

Choosing Alternative Refrigerants:

Another method to reduce global warming potential when downsizing is not a viable solution, is to substitute refrigerants with low warming HFOs and other non-HFC substances. Natural refrigerants and alternative refrigerant options are currently available in the industry.

Natural & Alternative Refrigerants

Natural refrigerants include ammonia, carbon dioxide, hydrocarbons, water, and air. The appeal of such natural refrigerants is low GWP and low ODP, which has led to widespread adoption into the food refrigeration industry. However, each natural refrigerant poses unique challenges when utilized in HVAC applications, which has resulted in a slower adoption of these refrigerants into the HVAC industry. For example, Ammonia has high energy performance, is easily detected by smell, and has a low cost, but is toxic in higher concentrations above a certain threshold (Occupational Safety and Health Administration, n.d.)

Carbon dioxide also has been used as a natural refrigerant, (GWP of one and zero ODP) but, carbon dioxide chillers tend to be very expensive. Alternative refrigerants are currently used in chillers in the EU and some have been approved for use in the United States. Many of these alternatives are classified as HFOs (Hydrofluoroolefins). While HFOs still contain fluorine gas, the GWP is significantly lower than that of HFCs. For instance, the GWP for R-410A is 2,090, whereas the GWP for R-454B, (an R-410A alternative), is 466, which is a 75% reduction in GWP. The adjacent table lists the global warming potential of various refrigerants for comparison.

Refrigerant alternatives oftentimes have comparable efficiencies to the original refrigerant and require minimal modifications in equipment design. While any modifications may increase the price of manufacturing, the cost uplift is typically negligible compared to the relative electricity cost to operate the chiller. There are instances in which an alternative refrigerant will result in an efficiency loss or is incompatible with the desired equipment. The designer should discuss these details with various manufacturers to determine the optimal solution for the project.

Manufacturers are increasing the amount of products compatible with HFO alternatives. For example, Trane, one of the largest chiller manufacturers in the U.S. has made many of their traditional R-134A chillers compatible with R-513A, an HFO with a GWP of 630. Currently, many large commercial chillers are compatible with HFOs, but physically smaller chillers, high pressure chillers and VRF systems are further behind in the transition to using only HFOs.

Refrigerant	GWP
HFC R-134A	1430
HFC R-404A	3920
HFC R-407C	1770
HFC R-410A	2090
HFO R-1233zd	4.7-7
HFO R-1234ze	6
HFO R-513A	630
HFO R-514A	7

Table 2 - GWP for Common HFC and HFO Refrigerants (Environmental Protection Agency, (2020)

Putting Alternatives into Practice

To illustrate the impact of sustainable refrigerant management, the following section summarizes two project case studies.

1. A naturally ventilated building with no refrigeration compared to a baseline system utilizing R-410A refrigerant.
2. A project in which the specified chiller uses an HFO refrigerant (R-514A) to a traditional HFC (R-134A).

For each case study, the following assumptions were made:

TIME HORIZON
2021 - 2040

LEAKAGE RATE LEED (2020)
2%/YR

END OF LIFE
LEAKAGE RATE LEED (2020)
10%

SOCIAL COST
OF CARBON
$53 / TONNE OF CO_2e

Case Study 1: Natural Ventilation

Overview:

Building size: 150,000 sqft
Building type: Mixed use office
Location: Santa Barbara, CA
Baseline refrigerant: R-410-A (GWP = 2,090)
Alt refrigerant: Natural ventilation
Refrigerant charge = 550 lbs
System capacity = 420 tonnes

Case Study 2: Alternative Refrigerants

Overview:

Building size: 360,000 sqft
Building type: Mixed use office
Location: Minneapolis, MN
Baseline refrigerant: R-134A (GWP = 1,430)
Alt refrigerant: R-514A (GWP = 7)
Refrigerant charge = 3,000 lbs
System capacity = 1,500 tonnes

Case Study 1: Natural Ventilation

Project Description:

Southern California's climate makes natural ventilation and mixed-mode operation viable solutions. This case study quantifies the impact of natural ventilation, where refrigerants were designed out. The baseline for comparison is R-410A, which is a common HFC refrigerant utilized in chillers since the ban of HCFCs. R-410A has a global warming potential of 2,090 – i.e. it is 2,090 times more potent than CO_2e in terms of its impact on climate change.

Avoided Carbon Emissions:

In the baseline scenario, with a refrigerant charge of 550 pounds and a conservative 2% annual leakage rate, approximately 10 tonnes of CO_2e would be emitted in the first year of operation. At the system's end-of-life at year 20 (assuming a 10% end-of-life leakage), roughly 36 tonnes of CO_2 would be emitted. In total across the 20 years, 200 tonnes of CO_2e emissions is avoided for this project via natural ventilation. This is equivalent to a lifetime social value worth $9,200.

This is equivalent to:

476
MWh of electricity in Southern California

262
Acres of forest in one year

498,759
Miles driven by an average car

34
Homes of electricity use for one year

AVOIDED YEAR 1 LEAKAGE

10 tonnes CO_{2e}

AVOIDED END-OF YEAR LEAKAGE

36 tonnes CO_{2e}

AVOIDED LIFETIME LEAKAGE

200 tonnes CO_{2e}

LIFETIME VALUE OF AVOIDED CO_2

$9,200

Case Study 2: Alternative Refrigerants

Project Description:

This case study assesses the impact of Buro Happold's decision to specify an HFO (R-514A) refrigerant with a GWP of 7, compared to the baseline HFC R-134a with a GWP of 1,430. A few chiller manufacturers, including Trane, are leading the transition away from HFCs. Because Trane has developed chillers compatible with HFO refrigerants, engineers are able to specify refrigerants with a much lower GWP without compromising the design.

Avoided Carbon Emissions:

For a 3,000 lb. refrigerant charge and a conservative 2% annual estimated leakage rate in the first year, about 39 tonnes of CO_2e would be released in the baseline scenario, whereas only 0.2 tonnes would be released with R-514A. At year 20 (assuming a 10% end-of-life leakage), R-134A releases roughly 133 tonnes CO_2e compared to 0.7 tonnes for R-514A. In the total lifetime of the system, R-134A emits approximately 753 tonnes of CO_2e, compared to 3.7 tonnes emitted with R-514A. Avoiding 749 tonnes of CO_2e over 20 years has a lifetime social value worth $34,210.

This is equivalent to:

929
MWh of electricity in Minneapolis

983
Acres of forest in one year

1,868,486
Miles driven by an average car

127
Homes of electricity use for one year

AVOIDED YEAR 1 LEAKAGE

39 tonnes CO_2e

AVOIDED END-OF YEAR LEAKAGE

132 tonnes CO_2e

AVOIDED LIFETIME LEAKAGE

749 tonnes CO_2e

LIFETIME VALUE OF AVOIDED CO_2

$34,210

Global Leaders

While all countries that ratified the Montreal Protocol are subject to its guidelines, several countries have enforced additional regulations on refrigerant use. For example, Canada implemented the Regulations Amending the Ozone-depleting Substances and Halocarbon Alternatives Regulations to phase-down HFC consumption (manufacture plus import minus export) beginning with a 10% reduction in 2019 and additional steps to achieve an 85 percent reduction in HFC consumption by 2036 (Government of Canada, 2017). Another example is the Australian government, which has committed to reducing greenhouse gas emissions by 26-28 percent by 2030. To accomplish this, the government issued a statutory phase-down of HFC imports, aiming to decrease HFC usage by 85 percent a year ahead of the Montreal Protocol schedule (Australian Government Department of Agriculture, Water and the Environment, 2017).

The issue with enforcing stricter regulations in a shorter time-frame is that the industry needs time to adapt to the measures and develop technologies that will comply with the regulations without compromising design. In Australia, the Department of the Environment and Energy worked together with regulatory agencies and businesses in the industry to understand achievability of the regulations. This is crucial for protocols and regulations to ensure compliance and identify and resolve industry issues preventing the changes. Because of this communication and thorough analysis, manufacturers were able to meet the progressive policy demands, creating chillers compatible with non-HFC refrigerants in many varieties.

The primary issue with using alternative refrigerants in the United States is that engineers may attempt to specify HFO chillers, but oftentimes manufacturers do not have chillers available in the U.S. market that meet the necessary requirements. The industry must increase the demand for HFO chillers and decrease the demand for HFC chillers as a means to accelerate the transition to HFOs. If the demand for HFO chillers exists within the industry, manufacturers will supply it.

Call to Action

As designers of the built environment, it is important that we constantly remind ourselves of the significant impact we have, and never let profit outweigh concern for our people and our planet. Sustainable Development is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs. Since refrigerants contribute to approximately 3% of the greenhouse gas emissions in our atmosphere, mitigating this environmental impact should be a top priority in pursuing sustainable development goals. While California legislation states most HFCs, including R-134a and R-410A, must be discontinued for commercial use in new chillers by 2024, there is no reason to wait until then to start finding ways to incorporate more environmentally friendly refrigerant systems into our designs. Taking initiative in making this change is the easiest way that we can make a big impact in the sustainability and environmental footprint of our industry.

HVAC Engineers:

HVAC engineers should no longer be specifying HCFCs, and reasons for specifying HFCs are quickly diminishing as HFO alternatives are becoming more widely available. It is our responsibility as designers to drive this change. If we create a market for HFOs through our design, the industry will follow. To initiate the transition to HFOs, we should not only be specifying HFO-compatible equipment, but we should also be advocating to our manufacturer reps to develop better equipment. While many manufacturers have developed some technologies allowing the use of HFOs in their chillers, we need to continue to encourage alternatives to HFC refrigerants in more complex systems, such as VRF or high pressure chillers.

Chiller Manufacturers:

Manufacturers have significant control over the environmental impact of their products. Rather than waiting for regulations to be enforced, manufacturers should proactively work to incorporate more HFO-friendly designs. While a few chiller manufacturers like Trane and York have shown that they are trying to stay ahead of the regulations by offering select HFO chillers now that can be adapted to larger, more standard systems, there is ample room for improvement by manufacturers. For example, HFO alternatives to R-410A must be developed for VRF systems. Trane has made some progress in this area, testing out R-466 and R-1234yf, but there are additional regulatory issues that need to be addressed, primarily with flammability. Manufacturers could address these issues through advocacy to regulatory agencies and lobbying for code changes to allow use of these HFOs.

Owners:

One of the most crucial roles in the development of new buildings is that of the owner. All decisions made in the design of new buildings are guided by the Owner Project Requirements or similar documents. Steps that building owners can take to eliminate HFCs include updating these requirements to only allow HFOs or require that designers consider natural ventilation if the climate permits. If owners update project requirements to require responsible refrigerant selection and management, engineers and manufacturers will find a way to satisfy these requirements. To ensure a carbon neutral future, proper refrigerant selection cannot be neglected.

Manufacturer Advocacy Letter

We encourage HVAC designers to send the following letter to all relevant manufacturers you work with:

Dear Product Representative,

Refrigerants contribute to approximately 3% of all greenhouse gas emissions, and cause hundreds of times more warming than carbon dioxide. According to Project Drawdown, the most impactful and simple way for the construction industry to decrease its carbon footprint is to eliminate the use of harmful refrigerants with high Global Warming Potential (GWP), such as Hydrofluorocarbons (HFCs). California has begun to address this issue, mandating HFC phase-outs starting in 2024. There is no reason to wait until 2024 to stop using harmful refrigerants though, seeing as improved alternatives already exist. Hydrofluoroolefins (HFOs), for example, have significantly lower GWP values than that of HFCs. As such, Buro Happold Engineering aims to eliminate the use of HFCs in HVAC systems as soon as possible.

While some chillers are compatible with HFOs, there are many improvements to be made with chillers and VRF systems to allow engineers to abandon HFCs entirely and solely specify HFOs. For example, oftentimes design requirements necessitate small chillers, high-pressure chillers, or VRF systems as the cooling equipment of a building, which typically require HFCs. Thus expedited development of such equipment that is compatible with HFOs, minimizes refrigerant leakage, and maintains efficiency is required.

Buro Happold recognizes the significant benefits of HFOs and the responsibility we have as HVAC designers to integrate them into our designs. We cannot drive this change alone, though. Chiller and heat pump manufacturers must take the initiative to develop compatible equipment. We hope that your company will take these necessary strides; we would like to continue specifying your products in our future designs.

Sincerely,

CONTRIBUTORS & REFERENCES

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