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HVAC Refrigerants: A Balanced Approach

One of the constant themes throughout the history of the HVAC industry is the search for a better refrigerant. When considering alternative refrigerants, manufacturers need to balance efficiency with environmental impact to determine the optimal replacement.

This EN will provide a brief history of refrigerants used in the HVAC industry and the developing regulations. From there, we'll discuss considerations for new and existing equipment, along with refrigerant replacement options and risks.

Refrigerant History

In the early years, the primary focus of the HVAC industry was simply on finding a refrigerant that would provide effective cooling. Many of the early refrigerants such as sulfur dioxide, methyl chloride and ammonia met that objective but posed safety hazards due to their toxicity or high flammability potential.

In the 1930s, chlorofluorocarbon (CFC) refrigerants were introduced as safe alternatives to the chemicals used before them. CFCs came to dominate first refrigeration and later HVAC because of their safety and efficiency. Hydrochlorofluorocarbons (HCFCs) were added to the portfolio of refrigerant alternatives in the 1950s.

In the 1970s, environmental concerns came into play. Scientists discovered that CFCs—and to a lesser extent HCFCs—were contributing to the depletion of the ozone layer.

Montreal Protocol. Global concern about depletion of the ozone layer resulted in the Montreal Protocol, an international treaty that established phase-out dates for the use and production of ozone-depleting substances. It went into effect in

1987, first targeting CFCs, then HCFCs. CFCs were replaced with HCFCs, which have lower ozone-depletion potential (ODP), or with hydrofluorocarbons (HFCs), which have zero ODP. The CFC phaseout was completed in 1996.

Due to their low ODP, the phase-out dates for HCFCs were set out later—from 2004 to 2030 (2040 in developing countries).

Kyoto Protocol. In the 1990s, concerns grew that the refrigerants being phased in because of their favorable ODP were contributing to global warming. The global-warming potential (GWP) of refrigerants now became a factor.

These concerns with global climate change led to the Kyoto Protocol, created in 1997. Kyoto set reduction targets for greenhouse gases, including HFCs, in developed countries. Because CFCs and HCFCs were already covered under the Montreal Protocol, they were not included in the Kyoto Protocol.

Where we are today. Both protocols allow each participating country to control its own reductions of the refrigerants to meet their compliance obligations. In the United States, the U.S. Environmental Protection Agency (EPA) issued regulations under the Clean Air Act to phase out the

production and import of CFCs and HCFCs.

Figure 1 provides a summary of the major actions involving refrigerants in developed and developing countries. The dates on the chart are for the United States and Canada (dates in other countries vary).

The Montreal and Kyoto protocols have set dates to ensure long-term availability. When production of a refrigerant stops, the time lines allow for the recycled, recovered and stockpiled supplies to continue to be used without restriction. For example, production of CFCs ended in 1996, but inventory of these refrigerants is still readily available.

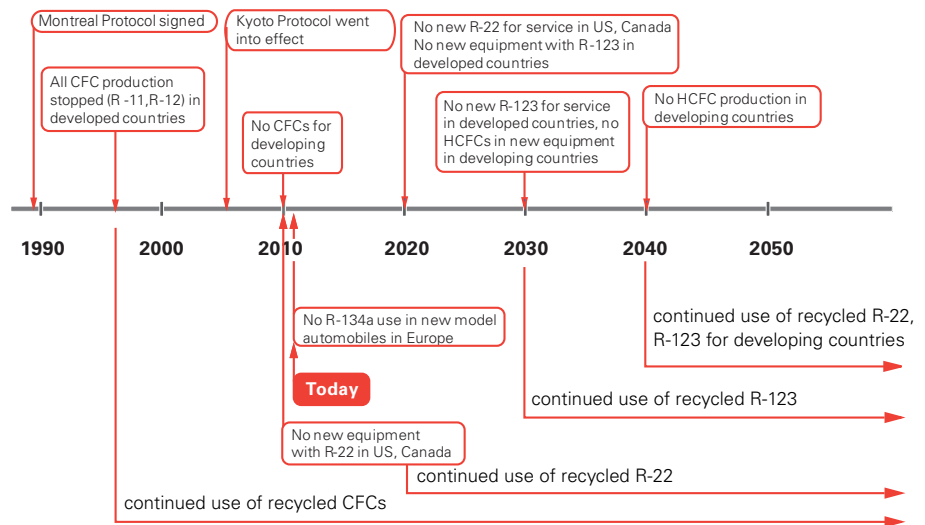
What's ahead. Policy pressure impacting nearly all commercially viable refrigerants available today has accelerated the development of alternatives. The next family of refrigerants, known as hydrofluoroolefins (HFOs), have properties similar to HCFCs and HFCs but with minimal direct environmental impact. The first HFO on the market has been developed to replace R-134a for automotive applications and will begin implementation this year in Europe. Implementation of HFOs will lag in the HVAC industry as manufacturers develop and test new alternatives, and global regulators decide on a future path.

A Balanced Approach

When considering refrigerant alternatives for the future, policy makers, the public, and manufacturers must balance direct environmental concerns (ODP, GWP, leak rates), indirect environmental concerns (energy efficiency), safety and performance.

Direct versus indirect impact. The *direct* environmental impact of an HVAC system is dependent on the ODP and GWP of the refrigerant and the rate of refrigerant leakage into the environment.

Figure 1. Legislative actions involving refrigerant



Note: Included in the use of "recycled" refrigerants is also the use of stockpiled supplies of the refrigerant produced before the phase-out date. In addition, there is no restriction on the importation of recycled and recovered supplies of refrigerant.

While leakage rates can vary widely among different HVAC products, good design and servicing can keep leakage to a minimum. (See the sidebar on p. 4.)

Years ago, when chillers used CFCs and service practices were less concerned with minimizing emissions, leak rates were 2½ to 10 times what they are today. Due to advances in technology and the use of refrigerants with significantly lower GWP, the direct environmental impact from HVAC equipment is now from 20 to 600 times lower than the older CFC chiller designs.

These reduced leak rates, coupled with newer refrigerants, bring the direct global warming impact to under 5 percent of the application's total global warming impact.

For hermetic systems, up to 95 percent of the total environmental impact is the *indirect* impact—the energy used to power HVAC systems. According to the U.S. Department of Energy, 83 percent of the primary power consumed in the U.S. is generated by the burning of fossil fuels, which emits greenhouse gases.

When considering both the direct and indirect environmental impact, HCFCs and HFCs, because of their high energy efficiency, can be the most environmentally responsible and appropriate refrigerants available today for many HVAC applications.

Evaluating alternatives. Let's take a look at the refrigerants that are currently available, taking into consideration their efficiency, direct and indirect environmental impact, and safety.

Figure 2 compares the ODP, GWP and energy efficiency of today's commercial refrigerants and potential future refrigerants. While there is no perfect refrigerant, the chart shows that HCFC-123 (R-123), HFC-152a (R-152a) and HFC-32 (R-32) strike a good balance between ODP, GWP and efficiency. However, the use of R-152a and R-32 is limited because of flammability.

Refrigerants such as CO₂, hydrocarbons and ammonia have zero ODP and a very low GWP. Let's take a closer look.

Carbon dioxide. CO₂ has potential as a low-temperature refrigerant in refrigeration applications. However, it has very low efficiency in HVAC applications, more than 20 percent below the efficiency of R-22 and R-410A, due to operation above the critical point of CO₂ in these applications. Today's equipment would therefore consume at least 20 percent more energy with CO₂ to get the same cooling tonnage, compared to the existing HCFCs and HFCs used today.

Switching from fluorocarbons to CO₂ to reduce direct environmental impact (5 percent), while significantly increasing the indirect impact (95 percent), would not be a good trade-off.

Hydrocarbons. Hydrocarbons may perform well in stationary air conditioning applications, but they

present safety issues in application, service and recovery because they are highly flammable.

Ammonia. Ammonia has been used for years and has potential for low-temperature and process chiller applications in remote locations or where people density is low. Its flammability and high toxicity strictly limit its broader use.

Maintaining a balance between the lowest possible refrigerant emissions and the best possible energy efficiency is the key to being both environmentally and economically responsible. Achieving this balance in a cost effective manner is critical in order to make these new designs affordable for the end user.

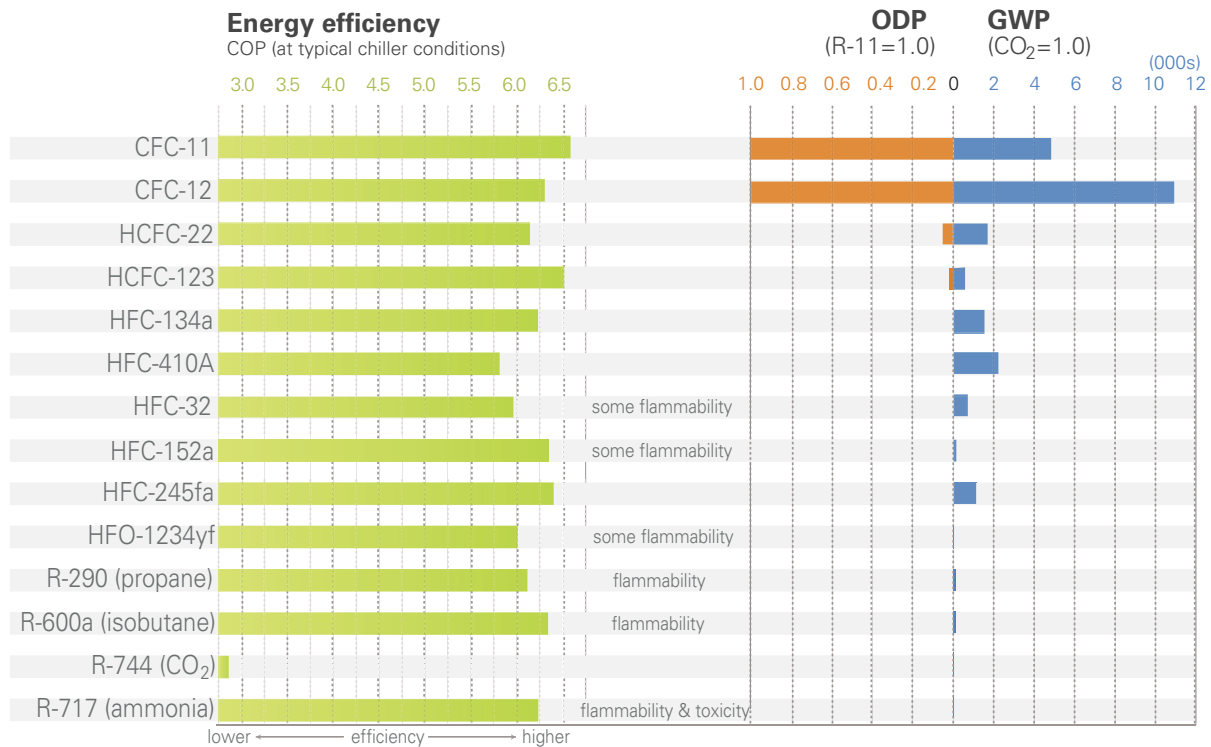
Green building and refrigerant selection

Green building rating systems such as USGBC's LEED (Leadership in Energy and Environmental Design) and GBI's Green Globes take refrigerant usage into consideration. The current LEED rating system uses a formula to calculate the impact of ozone depletion, global warming, equipment life, leakage rate, and refrigerant charge. The Green Globes rating system accounts for ozone depletion, global warming and leak detection.

By following the criteria in the rating systems, the selected refrigerants can help the project achieve points toward green building status. For example, most centrifugal chillers (both R-123 and R-134a) can achieve the refrigerant points for LEED Energy and Atmosphere credit 4. Many split systems, due to the large volume of refrigerant, cannot.

For more information, see www.usgbc.org or www.thegbi.org.

Figure 2. Overview of the environmental impact of current refrigerants



Options for Existing Equipment

So, what do we do with existing equipment containing refrigerants that will be phased out?

There is no definitive answer. However, there are options and a logical progression to determine the best solution for each project.

Options:

- Maintain existing refrigerant
- Replace the refrigerant
- Replace the equipment

Evaluate existing equipment

The first step is to evaluate the current inventory of equipment. When tracking the current inventory, obtain records that document the energy performance and refrigerant leakage rate of existing equipment.

Track leakage rate of equipment. The U.S. Clean Air Act requires that leakage rate data records be kept for all equipment with more than 50 lbs of refrigerant charge. These records should be available either from the owner's maintenance records or from the records of the servicing contractor. If records are unavailable, then record keeping should begin immediately to understand the state of the existing equipment.

As of January 2011, for equipment with more than 50 lbs of refrigerant charge, the U.S. EPA's maximum allowable leakage rates over a 12-month period are:

- Commercial refrigeration: 35 percent
- Industrial process refrigeration: 35 percent
- Comfort cooling: 15 percent

Venting is prohibited for any equipment, regardless of size.

A note regarding equipment using HFCs: There are no specific record-keeping requirements or maximum leakage rates for this equipment, but due to direct global warming, venting of these chemicals is also prohibited. In the future, maximum leakage rates will most likely cover the HFCs as well.

Track the equipment performance.

The performance data of the equipment can be provided either by the building automation system (preferred), or by the original nameplate data of the equipment. Proper service practice should be able to maintain close to original performance on most equipment, but individual equipment monitoring will provide an even better performance baseline.

Evaluate refrigerant changeout

Before replacing a refrigerant, determine the capacity and efficiency impact. This impact is clearly understood in some equipment types, such as centrifugal chillers, where replacements are clearly defined and several years of performance data has been accrued.

For other equipment, there are many replacement options in the marketplace, and even more claims of seemingly miraculous capacity and efficiency improvements by using these replacements. Basic physical properties, as well as industry experience, have clearly shown that any refrigerant replacement in existing equipment will result in some sort of capacity and efficiency reduction. The specific reduction depends on the type of equipment and the specific replacement refrigerant. *Note: When retrofitting existing equipment, do not use a flammable refrigerant in equipment that was not specifically designed for it.*

Replacements for the refrigerants R-11 and R-12 are relatively straightforward (R-123 and R-134a, respectively). The

Use best practices to minimize environmental impact

Best practices in design and servicing can keep refrigerant leaks to minimal levels. In fact, a Trane study conducted as far back as 1997 determined the annualized total loss rate for every single R-123 chiller that Trane had under service contract at the time. The study included all leaks whether from accidental discharge, servicing or normal operation. It showed that of 2768 R-123 chillers studied, only 16,229 pounds per year of charge was lost—less than 0.4575 percent annual leakage rate.

It's important to note that operating pressure can also impact how likely a leak is to occur and how much refrigerant will escape during a leak. In addition, innovative technologies can be employed that minimize the refrigerant charge for a given amount of refrigeration or cooling capacity, with the percent charge reduction directly reducing refrigerant emissions over the life of the equipment by the same amount. So, use of low pressure technology with reduced refrigerant charge levels can result in nearly an order of magnitude reduction in lifetime emissions compared to other higher pressure centrifugal chillers.

decision gets more complex with the replacement of R-22. Many solutions are available, and it is impractical for equipment manufacturers to test and analyze all of them. Generally, these replacements incorporate the use of multi-chemical blends in order to mirror the properties of R-22. *Note: Because of its higher operating pressure, R-410A cannot be used in R-22 products.*

Blends work in many applications, but be sure to weigh the following risks:

- **Different leakage rates**

Concerns exist in the marketplace about what happens when refrigerant leaks occur. The different components in the blend could potentially leak at different rates, and therefore change the composition and performance of the equipment. When these replacement refrigerants incorporate as many as four or more chemicals in the blend, these concerns increase.

- **Change in oil**

In many cases, a refrigerant changeout requires a change in the oil needed in the system. CFCs and HCFCs are able to use mineral oil with the refrigerant. HFCs, however, generally require the use of POE or other synthetic oils.

So that an oil change may not be required, many of the R-22 substitutes incorporate a small amount of hydrocarbons, such as butane, in order to improve their miscibility with mineral oil.

However, the refrigerant and oil chosen must have sufficient solubility and miscibility throughout the refrigeration system—which may not be the case for some R-22 substitutes and mineral oil. If in doubt, consult the unit or compressor manufacturer for the required oil type.

When a refrigerant and/or oil changeout is evaluated, all the components of the refrigeration system must be scrutinized for compatibility with the refrigerant and oil. Gaskets and o-rings are of particular importance because they may shrink or expand and cause a refrigerant release. It is strongly suggested that the gaskets and o-rings be proactively replaced during a refrigerant or oil conversion.

- **Future availability and GWP**

If a proprietary blend is used for an alternative refrigerant, it should be ensured that the blend will still be available in the future. In addition, many of these blends are very high in GWP. The GWP of refrigerants will likely be regulated or taxed in the coming years, making many of the alternatives unattractive.

Review and assess

After you have reviewed the data and evaluated the possibility of refrigerant changeout, determine the best solution for your particular application.

In most cases, retaining the existing refrigerant in the equipment, or replacing the equipment altogether will make the most sense. If leakage rates with the existing refrigerant cannot be contained to a minimal level with the current refrigerant, then it is unlikely that leaks will be contained with the new refrigerant. In addition, significant investments in inefficient equipment that will result in a loss in capacity and efficiency will often not be the most attractive solution. In many cases, investment in minimizing leaks and maintaining the equipment to its peak energy performance will result in a smaller up-front investment and better life cycle cost.

Summary

Since the early 1900s, the HVAC industry has been faced with the challenge of constantly changing refrigerants. While change is constant, it's important to remember that the industry has successfully navigated refrigerant phaseouts in the past and can apply the lessons learned to future transitions. As an industry, the key is to carefully consider alternatives and strike a balance that is financially and environmentally responsible.

Today we have good, solid refrigerant options and availability with HCFCs and HFCs. There's no need to panic. The future will bring different options, challenges, and opportunities.

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