Introduction to Decarbonization in HVAC

Decarbonization is gaining traction in a variety of industries as well as consumer and investor decision-making. This movement stems from the global push for a more sustainable world, and it has important implications for the future of HVAC design.

This Engineers Newsletter complements two Engineers Newsletter Live programs: *Decarbonize HVAC Systems* (APP-CMC074-EN) and *Decarbonization of HVAC Systems: Part 2* (APP-CMC081-EN).

***Key Terms**

Greenhouse gas: A gas that contributes to climate change by trapping heat in the atmosphere such as carbon dioxide, nitrous dioxide, sulfur dioxide, etc.

Carbon dioxide equivalent (CO_2e): the amount of CO_2 emissions with the same global warming potential as a given mass of another greenhouse gas.

Fugitive emissions: Greenhouse gases released directly into the atmosphere, such as leaked refrigerant or fire suppressant.

Global Warming Potential (GWP): The degree to which a gas traps heat in the atmosphere, indexed relative to CO_2 which has a GWP of 1.

Defining Decarbonization

As sustainability has grown in business and public purview, use of the term “decarbonization” (or “decarb”) has been rapidly expanded. The most general definition of decarbonization is the removal of carbon dioxide and other greenhouse gases* from a product or process. In today’s world, it typically refers to reduction of the carbon dioxide equivalent (CO_2e)* footprint of buildings and operations. In the context of HVAC, that means reducing the carbon dioxide equivalent emissions intensity of HVAC equipment and operation. There are three main strategies to employ for CO_2e reduction in heating, cooling, refrigeration, and ventilation.

The first strategy is **energy efficiency**. This has been a consideration in HVAC for almost as long as HVAC equipment has existed, but traditionally the motivation for higher efficiency has been energy cost savings. Now, there is additional motivation: carbon footprint reduction. Holding all other variables constant, reduced energy consumption translates to reduced emissions from fuel combustion.

Refrigerant management is an often overlooked but key component of decarbonization. Leaked refrigerant is typically a significant component of a building’s fugitive emissions*,[1]. The high global warming potential (GWP)* of many refrigerants commonly used today, such as R-134a and R-410A, makes leaks especially impactful even at low volumes[2]. Using low-GWP refrigerants and minimizing leakage through proper maintenance and replacement are both important aspects of refrigerant management.

Electrification, particularly electrification of heating, is an emerging strategy for decarbonization. Electrical grids are undergoing their own decarbonization process as electricity generators are replacing high-emissions fuels such as coal and oil with carbon-free energy sources such as solar, wind, and other renewables. This means electricity is becoming less and less emissions-intensive – its CO_2e emissions per unit of energy are decreasing. Although coal, oil, and natural gas are still used to generate electricity, particularly during times of peak demand, in much of the U.S. electricity is trending towards becoming less emissions-intensive than natural gas. This makes electricity the preferred energy source for emissions-conscious HVAC owners, creating a demand that is met with an increasing array of electrified heating solutions such as heat pumps (discussed later in this article). Additionally, heat pumps typically offer an efficiency gain over traditional natural gas or electric resistance heating equipment due to their use of the vapor-compression refrigeration cycle, further lowering emissions. Using electrified HVAC equipment also provides the opportunity for passive emissions reduction in future years, as electrical grids continue their own decarbonization transition to carbon-free generation.

***Key Terms**

Natural gas ban: Policy banning natural gas combustion or hookups in buildings. In the U.S., this policy has been implemented only at the municipal level for new construction.

Stretch code: Optional statewide standards for greater levels of energy efficiency than those required by the mandatory code, which can be adopted by municipalities.

Reach code: Optional statewide standards for greater levels of energy efficiency than those required by the mandatory code, which can be adopted by builders.

Carbon cap: Policy limiting the CO_2e emissions of an entity. New York City's Local Law 97 is a notable example.

Carbon tax: A tax levied on the basis of CO_2e emissions, such as Canada's National Carbon Tax.

Renewable Portfolio Standard (RPS): A policy requiring electricity suppliers to deliver a minimum percentage of electricity derived from renewable or carbon-free generation sources. Most or all RPSs in the U.S. are at the state level.

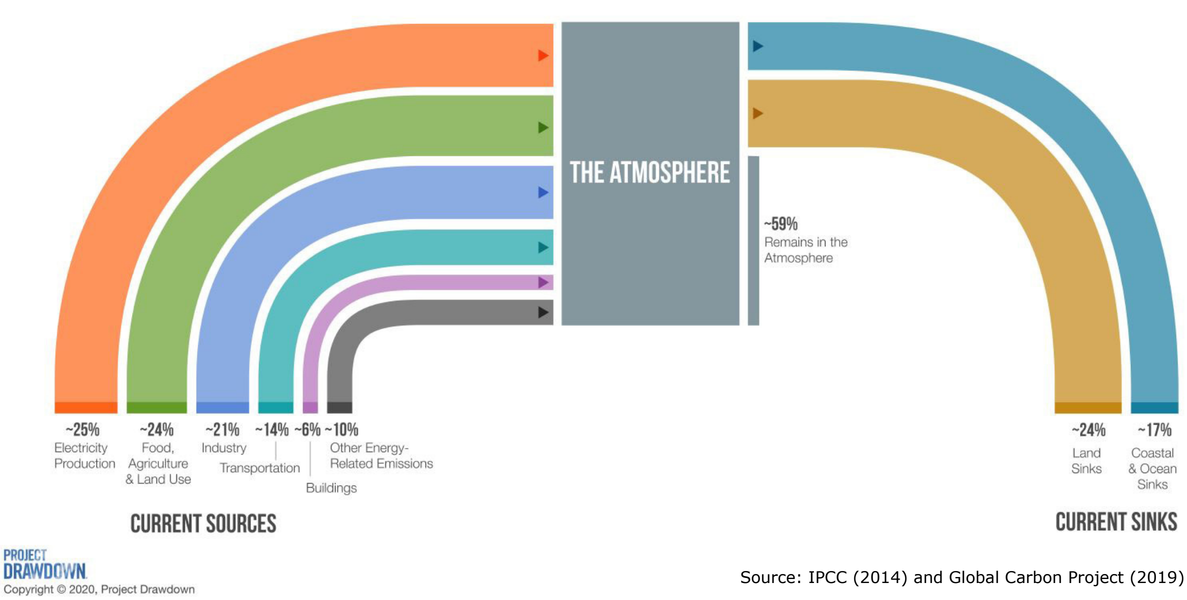
Why is Decarbonization Becoming a Focus?

The fundamental driver for decarbonization in all forms is environmental sustainability. As the Intergovernmental Panel on Climate Change (IPCC) emphasized in its AR6 report[3], "Human-induced climate change is already affecting many weather and climate extremes in every region across the globe," and is projected to exceed catastrophic levels "unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades." Figure 1 illustrates how greenhouse gases are introduced and removed from the atmosphere by outlining CO_2e emissions sources (on the left side of the graph) and sinks (on the right side of the graph). Most importantly, the graphic highlights the approximately 59 percent gap between sources and sinks that leaves greenhouse gases stranded in the atmosphere. HVAC plays a large role in this, currently contributing about 15 percent of global greenhouse gas emissions[4].

In response to this environmental imperative, policymakers are encouraging decarbonization with new requirements and laws. The introduction of decarbonization policy, including refrigerant phase down rules[6], natural gas bans*, all-electric or electric-preferred stretch* and reach codes*, carbon caps* and taxes*, and renewable portfolio standards (RPSs)*, is accelerating as the need for climate action becomes more critical. Recent EPA rulemaking has expanded phase down of high-GWP refrigerants to the national level, while state and local policy is pushing electrification and efficiency improvements. Figures 2 and 3 show the geographic distribution of some of these policy trends: states with counties that have proposed or enacted natural gas bans, and states with renewable energy standards or targets.

Many HVAC equipment owners are also facing environmental, social, and governance (ESG) expectations from customers, shareholders, employees, and building occupants. As sustainability continues to gain public concern and visibility, companies and property managers are receiving pressure from all fronts to report emissions, set sustainability goals, and take transparent and measurable action to reduce emissions.

Figure 1. Greenhouse gas emissions sources and sinks[5]



Source: IPCC (2014) and Global Carbon Project (2019)

Figure 2. U.S. States containing counties with proposed or enacted natural gas bans[6]

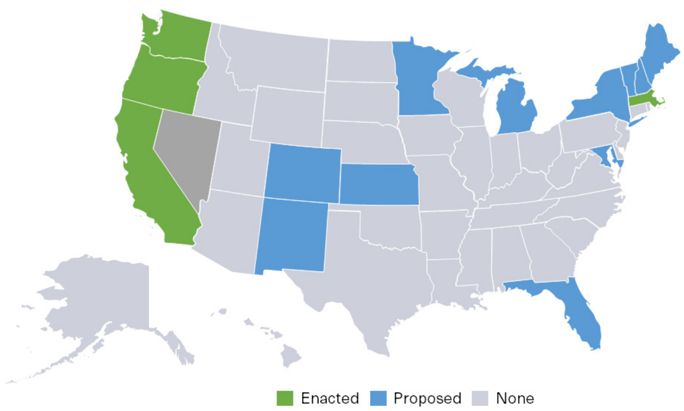
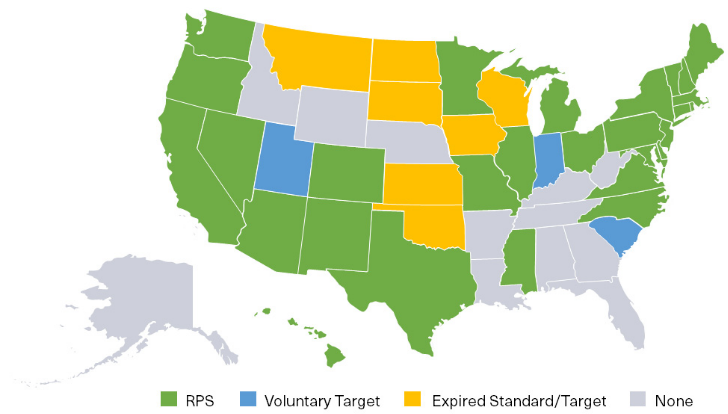


Figure 3. U.S. State Renewable Energy Policy[7]



***Key Terms**

Renewable Energy Credit (REC): A certificate representing the environmental attributes of 1 MWh of renewable power generation.

eGrid: The U.S. Energy Information Administration's Emissions & Generation Resource Integrated Database. Among other data, it includes annual electricity emissions factors (CO_2e emissions per electricity generated) at the state and regional levels.

Emissions Categories

Emissions reporting standards and regulating agencies such as the Environmental Protection Agency (EPA) classify CO_2e emissions into three scopes based on the level of control the reporting entity has over the emissions[8]: Scope 1 includes direct emissions from sources that the entity owns or controls (this includes fugitive emissions), Scope 2 includes emissions from the generation of purchased energy, and Scope 3 includes indirect emissions from the entity's value chain. Emissions from onsite natural gas or oil combustion for heating typically fall into Scope 1, while the electricity used by chillers and heat pumps is usually in Scope 2.

Electrification of heating moves heating emissions from Scope 1 to Scope 2, which is favorable due to the continuous decarbonization of the electrical grid as well as opportunity to reduce market-based emissions through the purchase of Renewable Energy Certificates (RECs)*. RECs can be traded, and allow the owner to claim consumption of low- or zero-emissions electricity, reducing or eliminating associated Scope 2 accountable emissions[9].

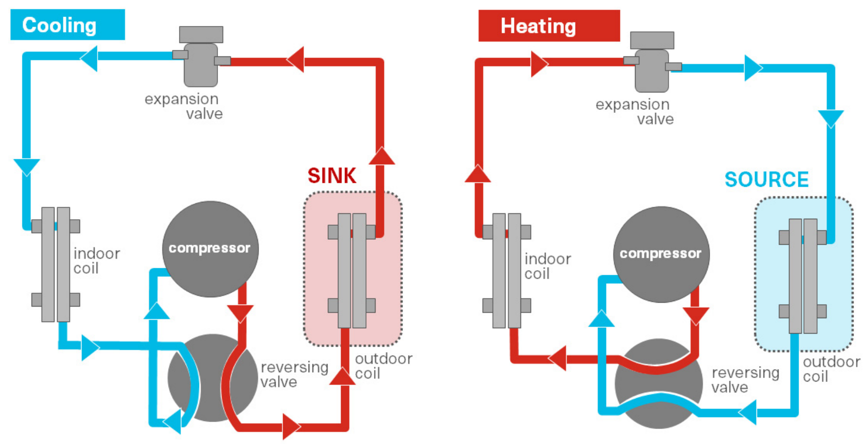
ASHRAE Standard 105-2014, *Standard Methods of Determining, Expressing and Comparing Building Energy Performance and Greenhouse Gas Emissions* provides a method for calculating building emissions[10] (and an ASHRAE 189.1 Working Group is in the process of developing another method based on energy usage and eGrid*,[11] emissions factors), but this level of detail is not required for a simple estimate of emissions saved by an HVAC decarbonization project. The example on page 6 demonstrates a method for quickly estimating CO_2e emissions reduction for a rooftop unit retrofit electrification project in Boston, Massachusetts.

Electrified Product Solutions

Fortunately, there is a wide and increasing variety of electrified heating solutions on the market today to meet different application needs, including both heat pumps and heat recovery systems. While the term "heat pump" is often used to refer broadly to any piece of heating equipment, a more exact definition indicates that heat pumps contain a reversing valve that essentially switches the roles of the condenser and evaporator (in this context referred to as the source or sink depending on which mode the heat pump is operating in). Figure 4 shows diagrams illustrating this reversal. Heat recovery systems are another category of electrified heating equipment. Heat recovery describes scavenging waste heat from a cooling process. The reverse process – utilizing cooling as a byproduct of heating – can also be categorized under the same umbrella.

There are many factors to consider when selecting the best electrified heating system for an application. Climate is a good starting point, as heat pump performance is highly dependent on ambient conditions. As ambient temperature drops, heat pump COP decreases – especially for air-source heat pumps. Ambient temperature and humidity also affect the need for defrost. The defrost cycle reverses the refrigeration cycle, applying heat to the outdoor coil to melt frost when condensate freezing is detected. For single circuit heat pumps, defrost mode consumes all the unit's heat, leaving none for space heating and resulting in cold air being sent into the occupied space. Dual fuel (natural gas) and auxiliary (electric resistance) backup can be used in some heat pumps to compensate for this limitation.

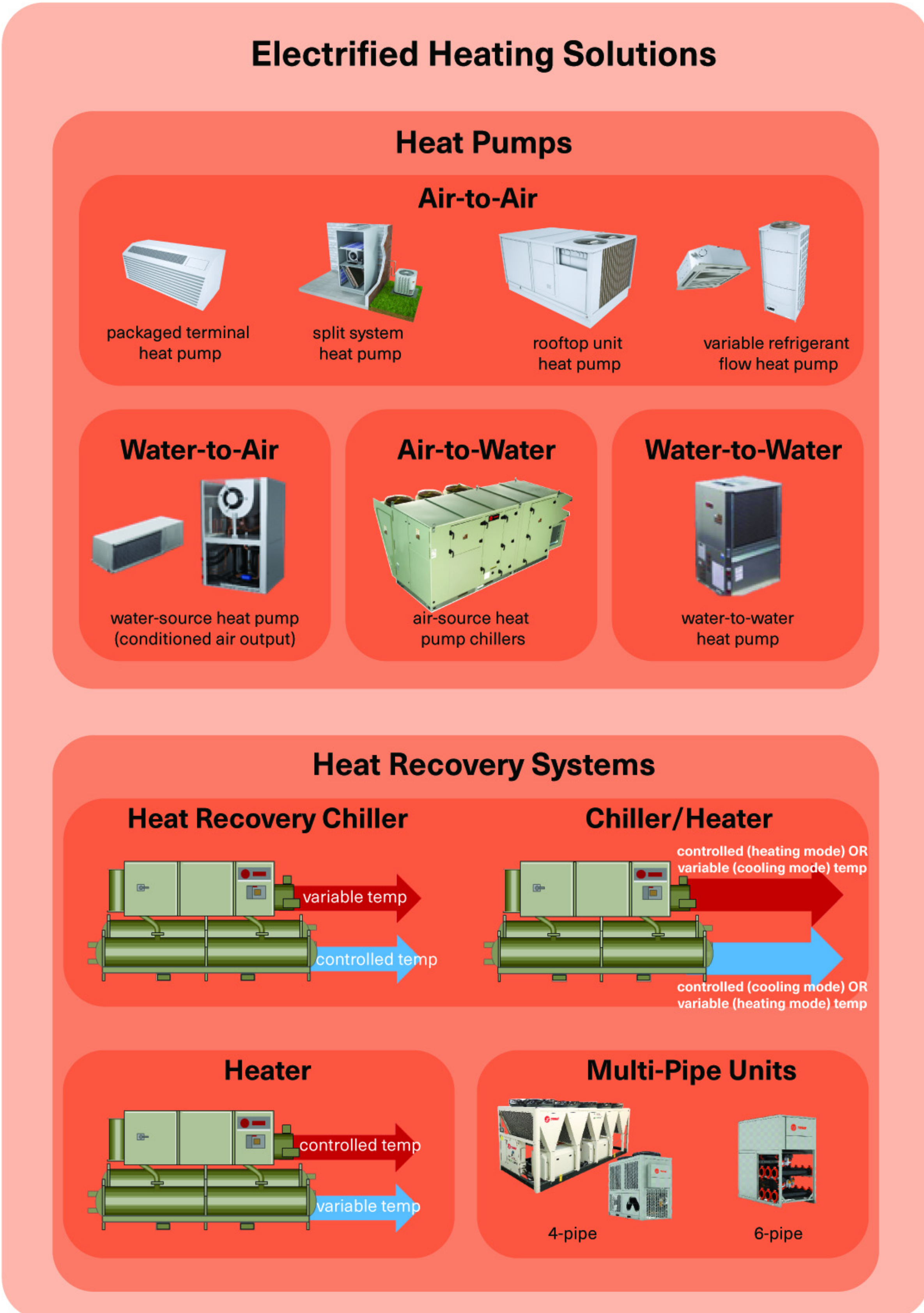
Figure 4. Heat pump diagrams



For smaller applications, there are several types of heat pumps designed specifically for ease of retrofit, including packaged terminal heat pumps, split system heat pumps, and rooftop unit (RTU) heat pumps. All these products share similar footprint and accessibility to their respective gas heat counterparts, essentially allowing for an in-kind replacement. However, all three are limited on cold climate capability to varying extents and may require dual fuel or auxiliary backup for some applications. Water-source heat pumps (WSHP) offer more flexibility in cold climate operation: these systems can be paired with electric resistance backup heaters, or the condenser loop can be tempered with heat from an air-source heat pump, electric boiler, or gas fired boiler. Finally, variable refrigerant flow (VRF) heat pumps are a standout option for smaller applications on the basis of efficiency and cold climate capability, in some cases reaching all the way down to -22°F (-30°C). Electric resistance heating in the terminals can also be used as an auxiliary fuel option for VRF heat pumps in even more extreme climates.

For larger applied systems, hydronic heat recovery can be used to provide heating. Unlike heat pumps, which operate in either heating or cooling mode, heat recovery-based systems can provide simultaneous heating and cooling. Thanks to the reduction of wasted heating or cooling energy, these systems are almost always higher efficiency than traditional chiller and boiler systems. The key consideration in this type of application is the load profile. For applications with cooling-dominated load, a heat recovery chiller may be the best option. In this system, cooling is the primary application and the chiller is controlled to a cooled water setpoint; heat is recovered as a byproduct, and the system must be making chilled water in order to produce any heat. Conversely, a heater can be used to serve a heating-dominated load. It is essentially the same machine but is controlled to a hot water setpoint and recovers cold water. For applications where the load varies widely between heating and cooling throughout the year, a chiller/heater system can provide more flexibility by switching control between heating mode and cooling mode based on which function is more in demand at the time. Finally, multi-pipe units are an excellent option for more balanced loads. These units provide simultaneous heating and cooling by combining heat pump and heat recovery operation. They contain one heat exchanger for cooling, one for heating, and one that balances net energy transfer between a source/sink.

In large applications, air-source heat pumps (ASHPs) can also be used to supplement or replace boilers. For example, an ASHP on the return side of a boiler can preheat its return water. This is a good option to reduce a boiler's natural gas consumption in retrofit applications where a heat pump or heat recovery system cannot completely replace the boiler due to temperature limitations. ASHPs can also be used instead of a boiler to temper a water source heat pump loop, completely electrifying the system.


Electrified Heating Solutions
Heat Pumps
Air-to-Air
packaged terminal heat pump
split system heat pump
rooftop unit heat pump
variable refrigerant flow heat pump
Water-to-Air
water-source heat pump (conditioned air output)
Air-to-Water
air-source heat pump chillers
Water-to-Water
water-to-water heat pump
Heat Recovery Systems
Heat Recovery Chiller
variable temp
controlled temp
Chiller/Heater
controlled (heating mode) OR variable (cooling mode) temp
controlled (cooling mode) OR variable (heating mode) temp
Heater
controlled temp
variable temp
Multi-Pipe Units
4-pipe
6-pipe

Analysis on Electrification of Heating: Example RTU Heat Pump with Dual Fuel Backup in Boston.

Present-day emissions baseline:

Start with the HVAC system's current annual heating energy usage. This value should be as close as possible to *actual* heating energy consumption, but typically estimation is required. Common estimation methods include utility bills, a building energy model constructed with building energy modeling software such as TRACE® 3D Plus, or estimates of heating load and existing equipment efficiency. We will use the latter in this example.

Annual Heating Load = 575 MMBTu / year

Gas burner efficiency = 80%

Natural gas consumption = 575 MMBTu/80% = 719 MMBTu

Calculate annual emissions caused by the annual natural gas consumption using average emissions intensity of natural gas[12] (116.65 lb CO_2e/MMBTu, or 0.05 metric tons CO_2e/MMBTu).

719 MMBTu x 116.65 lb CO_2e/MMBTu = 83,871 lb CO_2e (38.04 metric tons CO_2e)

Present-day electrified emissions:

For heat pumps with dual fuel (natural gas) or auxiliary (electric resistance) backup, cold-climate operation must be differentiated from standard heat pump operation. One way to do this is completing a weather analysis to understand how much of the heat pump operation will be cold climate operation (using dual fuel or auxiliary backup). This ratio or percentage can be applied to the heating load along with the backup fuel efficiency to calculate the energy consumption for cold-climate operation, which can then be converted into emissions.

Boston cold climate percentage: 7% (this means the unit will be operating in cold-climate mode – i.e., using the dual fuel natural gas backup burner – 7 percent of its operating time)

Dual fuel gas burner efficiency: 80%

Natural gas consumption from dual fuel operation = 719 MMBTu x 7% / 0.8 = 63 MMBTu

Natural Gas emissions from dual fuel operation = 63 MMBTu x 116.65 lb CO_2e/MMBTu = 7,349 lb CO_2e (3.33 metric tons CO_2e)

Apply a climate-appropriate COP value to the standard heat pump operation heating load to determine the electricity usage.

Standard operation percentage = 93% (this means the unit will be operating in standard heat pump mode – i.e., using the vapor compression refrigeration cycle to transfer heat – 93 percent of its operating time)

Boston COP = 3.00

Standard Operation Electricity consumption = 719 MMBTu x (0.293 MWh/MMBTu) x 93% / 3.00 = 65 MWh

Use the state or regional eGrid emissions factor to estimate the CO_2e emissions associated with the electricity usage.

Massachusetts: 781 lb CO_2e/MWh (0.35 metric tons CO_2e/MWh)

781 lb CO_2e/MWh x 65 MWh = 50,765 lb CO_2e (23.03 metric tons CO_2e)

Add natural gas and electricity emissions to find the total annual emissions caused by heating with the electrified system.

7,349 lb CO_2e + 50,765 lb CO_2e = 58,114 lb CO_2e (26.36 metric tons CO_2e)

The emissions from the RTU heat pump with dual fuel backup are 31 percent lower from the gas/electric RTU.

Electrified emissions in 2030

One of the key advantages of electrification of heating is the continued emissions reduction that follows electricity grid decarbonization. State legislation such as Renewable Portfolio Standards (RPSs), and electric utility reports such as integrated resource plans, can be helpful for estimating grid decarbonization.

Massachusetts' RPS of 35% carbon-free electricity generation by 2030 will reduce its electricity emissions intensity to an estimated 622.47 lb CO_2e/MWh (0.28 metric tons CO_2e/MWh)

Heating electricity emissions in 2030 = 65 MWh x 622.47 lb CO_2e/MWh = 40,461 lb CO_2e (18.35 metric tons CO_2e)

Total heating emissions in 2030 = 7,349 lb CO_2e + 40,461 lb CO_2e = 47,810 lb CO_2e (21.69 metric tons CO_2e)

The expected emissions from the electrified system in 2030 are 43 percent lower than present-day emissions from the gas/electric RTU.

Financial Considerations

Historically, cost has been one of the major hurdles for heat pump implementation. Heat pumps typically have a higher first cost than their traditional gas heat counterparts, and in most parts of the U.S. electricity has been significantly more expensive per unit of energy than natural gas.

However, a basic price comparison fails to account for the costs that climate change levies on operations through natural disasters and extreme weather conditions. Many companies have started using a customized internal carbon price to bring these considerations to the table when making decisions.

Additionally, incentives from government agencies and utility providers are increasing in number and breadth, reducing the hurdle of capital expense for efficiency and electrification projects.

In Summary—Now is an Opportune Time for Decarbonization of HVAC Systems

The emissions-intensive design choices of the past have caught up with us in the form of a looming climate crisis. Legislation, regulation, and incentive programs reflect this reality in their emphasis on reducing CO_2e emissions, and technological innovation has kept pace in offering new products for a breadth of applications. These environmental pressures and green solutions together encourage timely investments in decarbonized solutions.

By Emma Van Fossen, Trane. To subscribe or view previous issues of the Engineers Newsletter visit trane.com. Send comments to ENL@trane.com.

References

[1] United States Environmental Protection Agency, *Direct Fugitive Emissions from Refrigeration, Air Conditioning, Fire Suppression, and Industrial Gases*. 2015.

[2] Trane®. *Refrigerant Industry Update*. REFR-PRB001-EN. 2021.

[3] Intergovernmental Panel on Climate Change. *Sixth Assessment Report*. 2021.

[4] Project Drawdown. *The Drawdown Review: Climate Solutions for a New Decade*. www.drawdown.org/drawdown-review. 2020.

[5] Project Drawdown, "Emissions Sources & Natural Sinks." www.drawdown.org. 2020.

[6] S&P Global, "Gas Ban Monitor: Building electrification evolves as 19 states prohibit bans." www.spglobal.com. 2021.

[7] National Conference of State Legislatures, "State Renewable Portfolio Standards and Goals." www.ncsl.org. 2021.

[8] Greenhouse Gas Protocol. *Corporate Value Chain (Scope 3) Accounting and Reporting Standard.* 2020.

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[10] ANSI/ASHRAE, Standard 105-2014. *Standard Methods of Determining, Expressing and Comparing Building Energy Performance and Greenhouse Gas Emissions*. Atlanta. ASHRAE. 2014.

[11] United States Environmental Protection Agency. Emissions & Generation Resource Integrated Database (eGRID). www.epa.gov/egrid. 2021

[12] United States Energy Information Administration, "Carbon Dioxide Emissions Coefficients." 2021.

Additional Resources

[1] Trane®. (2020). *Decarbonize HVAC Systems*. Engineers Newsletter Live. APP-CMC074-EN.

[2] Trane®. (2022) *Decarbonization of HVAC Systems: Part II*. Engineers Newsletter Live. APP-CMC081-EN.

2022 Engineers Newsletter *Live!* program schedule

MARCH

Applying VRF for a Complete Building Solution Part II. This program builds on the December 2020 ENL that covered variable refrigerant flow systems. This program will dive deeper into the topic of integrated controls and will review energy modeling software tips and tricks unique to VRF. We will also discuss the concept of applied VRF systems which combine traditional system concepts while using refrigerant in lieu of water as well as a brief review of several applicable requirements from ASHRAE® Standards 62.1-2019 and 90.1-2019.

MAY

Decarbonization of HVAC Systems Part II. In this program we will look at potential electrification solutions for three different applications; small office, K-12 school, and a healthcare facility. We will model these electrification solutions for locations across the country, provide outputs related to energy and emission reductions, and compare different electrified designs against traditional gas heating solutions.

SEPTEMBER

Air-to-Water Heat Pump System Design. Building on the previous two Decarbonization of HVAC Systems ENLs, this program will cover electrified building heating systems utilizing air-to-water heat pumps. Topics covered will include operating characteristics of air-to-water heat pump equipment, system load and unit sizing considerations, system hot water design temperature considerations, system configurations and options including heat recovery, storage and auxiliary heat, as well as system control considerations.

NOVEMBER

Chillers and Heat Pumps with Energy Storage. Adding energy storage to buildings not only saves energy, energy costs and water, but it also saves carbon. In this program we will revisit the benefits and techniques for incorporating thermal energy storage for cooling. In addition, we will explore ways to use storage to minimize the impact that decarbonization of buildings and electrifying heat are expected to have on energy costs.

Contact your local Trane office for more information or visit www.Trane.com/EN.

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