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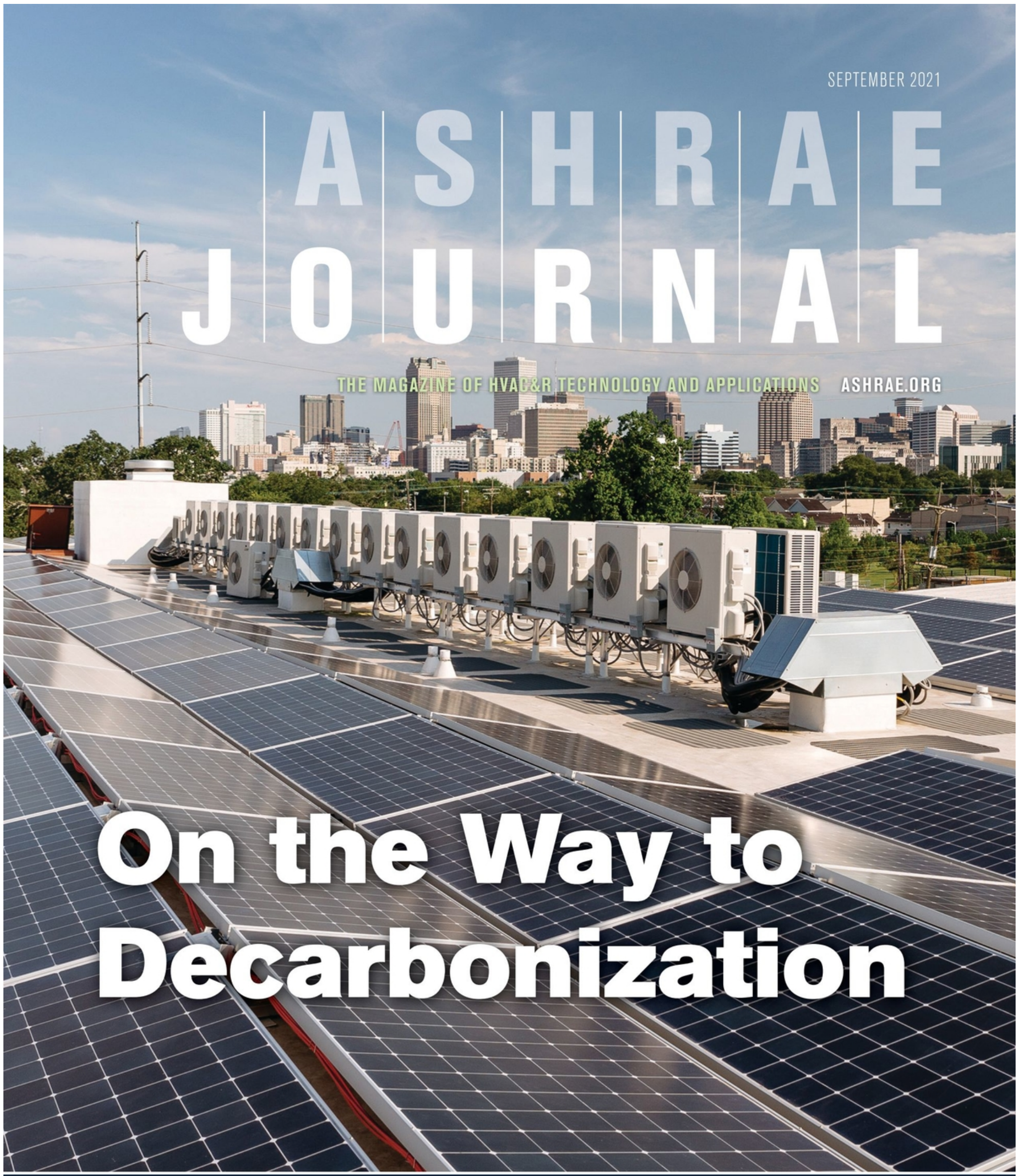

On the Way to Decarbonization

Covering COVID-19 Virus Transmission Modes and Mitigation Strategies: The Final Installment

How Building Decarbonization Can Transform HVAC

BY PETER RUMSEY, P.E., FELLOW ASHRAE; JORLYN LE GARREC, ASSOCIATE MEMBER ASHRAE; AVRIL LEVASSEUR, P.E., ASSOCIATE MEMBER ASHRAE

By the end of 2050, 12 states and 160 cities have official goals to get 100% of their electricity from clean sources.[1] California cities are leading the nation in building electrification legislation, with 28 cities having adopted all-electric requirements for new construction; 50 additional cities and counties have pending electrification legislation as of this writing.[2] Much of the southeast U.S., where heating loads are light, already uses electric sources of heating. And, in moderate and cold climates a surge of interest exists in heat pump systems, which provide an efficient alternative to electric resistance for heating. This article explores heat pump systems as one way building decarbonization can transform HVAC.

Buildings in the U.S. account for 40% of carbon emissions. Eighty percent of that is from electricity use and the remainder is from the combustion of fossil fuels for heating and other uses at the building. Many states, utilities, and large corporations are moving to get electricity from clean, carbon neutral sources. Duke Energy, one of the largest investor owned utilities in the U.S., has committed to having 100% of its energy from carbon-neutral sources by 2050. In addition, many of the U.S.'s largest corporations including Apple, Microsoft, Kohl's, Walmart and Bank of America have made commitments to achieve carbon neutrality or to get their electricity from carbon free sources, namely solar and wind energy.

It is clear that electricity is becoming the carbon free choice of energy for many in the U.S. Buildings that use natural gas and other fossil fuels for heating will be stuck producing carbon emissions, as electricity becomes increasingly carbon free. For that reason, many are starting to look at all-electric options for providing heat to buildings. An all electric building coupled with a renewable or carbon-free source of electricity is considered to be decarbonized in its operation.

In addition to operational carbon, buildings have embodied carbon. Embodied carbon is the total greenhouse gas emissions from the materials and the construction process throughout the life cycle of the

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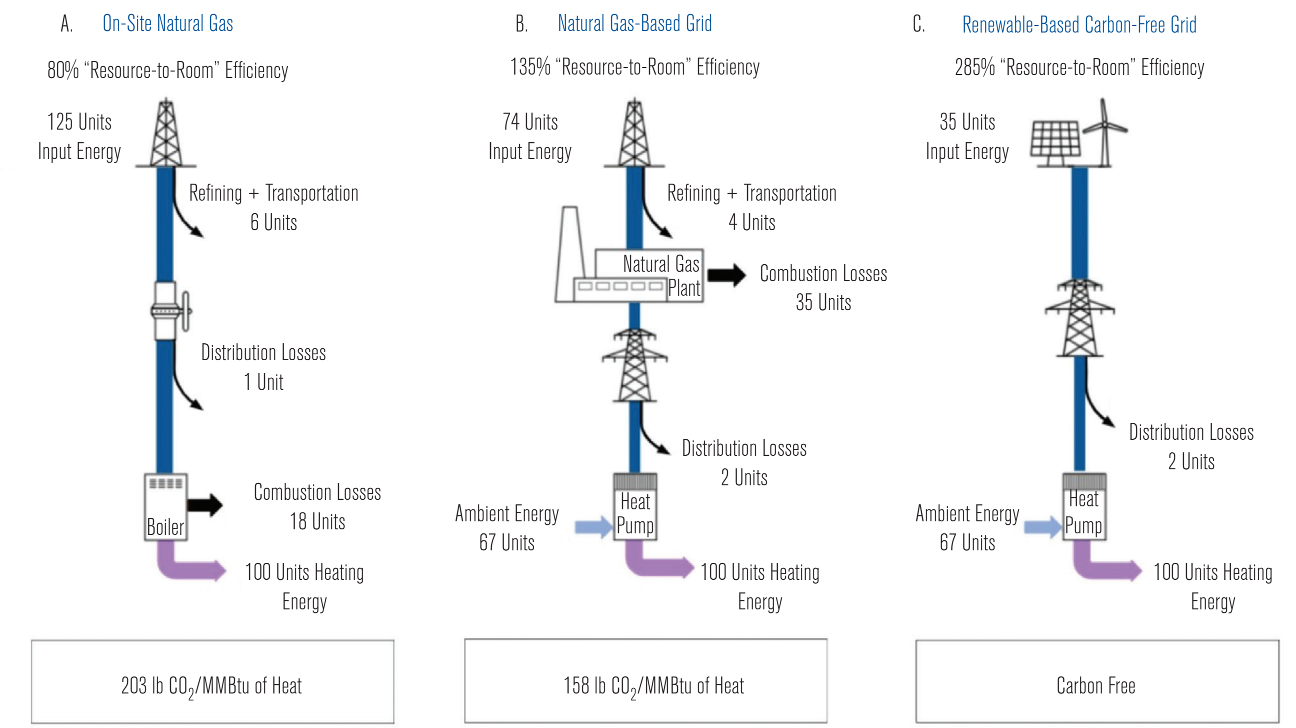


Figure 1 Calculations for grid carbon intensity include the following assumptions: natural gas emission value of 117 lb CO_2/MMBtu,[6] methane leakage rate of 2.3%,[7] air-source heat pump COP of 3, natural gas boiler efficiency of 90% and a methane global warming potential of 84.[8] Since methane has a large global warming potential relative to CO_2, we included the assumption that methane would be 84 times more potent than CO_2 for global warming impacts. Due to the immediate concern for climate change, we used the 20-year methane global warming potential value.

building. While both embodied and operational carbon emissions must be reduced in a decarbonization effort, embodied carbon is a one-time carbon emission during the construction process. Operational carbon, on the other hand, is continuously emitted and significantly outweighs the embodied carbon over a 50-year lifetime of a building. This article will only be addressing operational carbon, which is where the responsibility of those in ASHRAE lies.

Building HVAC systems, water heating and even cooking will be transformed by the move to decarbonized buildings.

Grid Carbon Intensity

The ease of implementing building decarbonization is greatly dependent on the local electricity grid. A building owner is able to make the decision to eliminate on-site fossil fuel use and add photovoltaic (PV) panels to their building, but has no control over the source of energy at the utility level. Three potential scenarios exist for decarbonizing depending on the grid.

Scenario 1: Carbon-Intense Grid

Many electric grids are still heavily reliant on fossil fuels with over 62% of utility-scale electricity generation originating from fossil fuels in the U.S.[3] Over the last decade improvements in power plant efficiency and the switch to more affordable natural gas instead of coal have reduced carbon emissions of electricity. Switching from a gas boiler to a heat pump, even somewhere like Mississippi, which uses mostly natural gas electricity, will still reduce emissions. For a grid that is 100% natural gas generation with an efficiency similar to the assumption in *Figure 1*, heat pump heating systems (*Figure 1b*) would result in a 22% reduction in carbon emissions over on-site natural gas boilers (*Figure 1a*).

In areas that rely heavily on fossil fuel-based electricity, building owners have the option of installing on-site solar systems. Some states make it possible to directly purchase renewable energy either from wholesale providers or "community choice aggregation" (CCA)[4] providers. Other options for eliminating carbon emissions are purchasing renewable energy credits or carbon credits to offset emissions. Renewable energy certificates (RECs)[5] are issued for renewable energy generated but not tied to any specific location. By purchasing carbon credits, an individual or company is essentially financing carbon reduction projects to offset their own emissions.

Scenario 2: Low-Carbon Grid

In many states, the grid is currently a mix of carbon-based electricity and renewables. In this scenario, even if there is no gas consumption in the building, a building will never be truly carbon neutral without further interventions. Several other options can achieve carbon neutrality in this case. A building owner can choose to either install on-site renewables to offset energy use, join a CCA or similar consumer choice programs that source carbon-free electricity, directly purchase renewable energy (available to large customers in deregulated markets) or purchase RECs.

Scenario 3: Carbon-Free Grid

Net zero energy buildings that use photovoltaics to offset all electrical energy consumption can easily decarbonize if all of the building systems are electric. Unfortunately, not all buildings can generate enough on-site electricity due to building height, roof capacity, roof orientation or other constraints. Luckily many electric grids are moving in the direction of providing 100% carbon-free electricity.

Coupled with this and all-electric building systems, buildings are considered to be carbon-free. The grids of the nine states, several large utilities and scores of municipalities that have pledged to eliminate their carbon emissions from electricity generation by 2050 in the last five years will use a combination of solar, hydro, wind, geothermal and, when necessary, nuclear energy coupled with batteries and thermal storage to meet electricity demand during the day and night. As mentioned, several utilities now offer options for 100% renewable or carbon-free electricity at slightly higher rates.

Electric Heating Systems

Heat Pumps for Space Heating

Current typical HVAC systems can be replaced with alternative systems that use heat pumps for heating instead of gas. Heat pumps use the refrigeration cycle to transfer heat energy from one space to another. Similar to a refrigerator, home air-conditioning unit and car air-conditioning unit, a heat pump uses a compressor and refrigerant to absorb heat from a cold space and release it to a warmer one. In some cases boilers are replaced with heat pumps. But the most cost-effective option is where a compressor system is designed to provide both heating and cooling, as is the case with variable refrigerant flow (VRF) systems. In these systems a reversing valve changes the direction of refrigerant flow to enable heating and cooling in the building.

The market for heat pumps is growing in the U.S., and new options are coming on the market. Many of the new heat pump systems are coming from Asia and Europe. The quality and number of options available has grown, and the price is coming down. In most cases the conversion to heat pump systems will occur when the building is built or when the building goes through a major renovation in which much of the HVAC equipment is replaced. With most mechanical equipment lasting 20 to 30 years,[9] major HVAC system renovations are more like new construction. The suggestions below apply to new construction, major renovations and retrofits.

Commercial Buildings

VAV Reheat | In a typical variable air volume (VAV) reheat system in a large building, hot water is provided by a central gas boiler. Air-source heat pumps are the most common alternative to boilers. Ground-source heat pumps are sometimes used. In some cases electric resistance reheat is used but can result in higher overall energy costs.

Variable Refrigerant Flow | Variable Refrigerant Flow (VRF) systems have gained traction in recent years given the capital cost savings of using the same compressor for both heating and cooling instead of a separate boiler and cooling compressor. The design is also compact and allows for simplicity of operation. They also offer heat recovery options and can provide simultaneous heating and cooling. The more efficient VRF systems also include variable speed fans and compressors for additional energy savings. VRF systems do require a separate system for ventilation. Dedicated outdoor air systems (DOAS)[10] and their associated benefits couple well with VRF systems.

Single Zone Packaged Unit | Many commercial buildings, particularly retail, use single zone packaged units with natural gas heating and compressor-based cooling. These same packaged units are available in a heat pump configuration in which the cooling compressor coupled with reversing valves is able to produce the required heating. This system is another opportunity for a simple switch from gas heating to heat pump heating. Due to the relatively short life of single zone packaged units, usually only 10 to 15 years, a large, simple opportunity exists to convert to electric heating as the equipment is replaced. Packaged units can operate with compressor-based cooling, and heat pump heating typically does not require additional electrical capacity.

Other Systems | A variety of other heat pump systems are available for commercial buildings. These include ground-source heat pumps, heat recovery chillers, water-source VRF systems to mention but a few.

Multifamily Buildings and Hotels

Multifamily buildings and hotels often use four-pipe fan coil systems, with natural gas heating the hot water side.

Packaged Terminal Air Conditioner | A packaged terminal air conditioner (PTAC) comes in two possible configurations. One has a compressor for cooling, and all of the heating is done with an electric resistance heating element. The second configuration uses the compressor for both heating and cooling through the use of the reversing valve. These are often called packaged terminal heat pumps (PTHP). They come with an electric resistance heating element to supplement the compressor when outdoor temperatures drop below the capability of the heat pump. There are PTAC systems that use only electric resistance for the heating function. They use more electricity but rarely require larger wires and circuits. PTHP units are good for multifamily buildings in which each tenant's energy use is individually metered.

Other Systems | VRF systems can be used in hotels and multifamily buildings. Fan coils come in a variety of configurations that are applicable to these building types. Additional details on VRF systems can be found earlier in the Commercial Buildings section. For multifamily projects, VRF systems are available with metering that allows for per-unit allocation of heating and cooling costs.

Residential Buildings

Central Heat Pump Air Conditioners | Gas furnaces are by far the most common residential heating system in the U.S., particularly in colder climates. Most homes also have air conditioners installed for cooling. The cooling

FIGURE 2 VRF heating and cooling system.

system usually uses the same duct system as the furnace. For many years heat pump systems that use the same compressor to provide heating or cooling have been available and widely used. These systems have an outdoor unit that works as a condenser in the cooling mode. This is connected to a refrigerant coil in an air handler inside the house.

This system can be installed in new homes or retrofitted into existing homes that already have shared heating and cooling ductwork. By purchasing a heat pump that can provide both heating and cooling, homeowners can avoid the cost of two systems (an air conditioner and a gas furnace).

In most climates, the combination heat pump air conditioner has the same electrical draw as the air conditioner alone. In colder climates, these systems can be supplemented with electric resistance heaters in the air handler for when temperatures go below the capacity of the heat pump (typically below 10°F to 20°F [–12°C to –6.7°C]).

Other Systems | In residential applications in which no central air system exists or needs to be installed, a ductless mini-split system can be an excellent alternative. A mini-split system will provide both heating and cooling, without the complication or space requirements of ductwork. The only equipment required are the interior (usually wall-mounted) units, the exterior condensing unit and refrigerant piping connecting the two. Since this system avoids the need for ducts, it is a relatively simple retrofit into existing buildings.

Heat Pumps for Domestic Hot Water

An opportunity also exists to replace more conventional domestic hot water (DHW) heaters with heat pumps. In fact, the residential heat pump water heater (HPWH) market is already far more developed than the heat pump market for space heating.

Residential Buildings

Residential domestic hot water heaters are the best opportunity for installing a heat pump. The market for residential HPWH has been active for years and many options are available. Switching from an electric resistance water heater to a heat pump water heater with an integrated tank is straightforward and results in significant energy cost savings. Heat pump water heaters are more expensive than electric resistance water heaters. Some utilities offer rebates or incentives for the use of heat pump water heaters. A new category of heat pump water heaters where the tank is separate from the heat pump has emerged. One "split system water heater" available in the U.S. uses CO_2 (R-744) as the refrigerant. CO_2 as a refrigerant has a global warming potential (GWP) of 1, as compared to the GWP of more typically used refrigerants, which can be as high as 1,300 for R-134A or more for older refrigerants. Several CO_2 refrigerant systems are available in Europe and Asia.

Multifamily Buildings and Hotels

Large Centralized Domestic Hot Water Systems | In larger domestic hot water systems, for example a large hotel or apartment building, a central hot water heater can be replaced with larger air-source heat pumps. In larger building complexes where hydronic space heating or hot water reheat is needed, heat pumps can serve both space heating and domestic hot water (DHW) uses. Some jurisdictions require that DHW systems are separated from space heating water with a double-wall heat exchanger. In some cases, heat recovery chillers can be used where the waste heat of the chiller is used to heat water. This only works in situations in which a consistent demand for chilled water exists.

Small- to Medium- Centralized Domestic Hot Water Systems | Smaller multifamily buildings can use residential heat pump water heaters piped together or separately for each unit. In a recent project in New Orleans, residential heat pump water heaters were placed in closets in the apartments. The waste cooling from the water heater was ducted into the living area, reducing the cooling load. For medium DHW systems, larger air-source heat pumps can be used with storage tanks.

FIGURE 3 Roof-mounted air-source heat pumps.

Commercial Buildings

In commercial buildings, a heat pump water heater may not necessarily be the best choice. Given the limited amount of hot water required, using instantaneous, electric resistance hot water heaters can be a better option. Although a central heat pump water heater would have a much better COP, the additional energy required to make up for losses from the circulation loop and tank, as well as the pumping energy, can outweigh this efficiency gain. Instantaneous water heaters can provide the small amount of hot water required, on demand, without the inefficiency associated with a centralized system, usually resulting in overall lower energy consumption and less up-front cost.

If a commercial building includes a kitchen, however, a heat pump water heater is usually the best choice.

Electrical Resistance-Only Heating Systems

Some may consider switching from a gas boiler to electric resistance heating as an electrification measure, particularly given the lower up-front cost. However, although this is technically electrification, it is a problematic solution. Energy efficiency is a key component of decarbonization. Even though electric resistance heating eliminates fossil fuels burned on-site, it uses approximately three times more electricity than heat pump systems. Furthermore, an increased electric demand in winter could strain the grid if it becomes widespread. It also encourages increased electricity production in the winter, when renewable solar energy production is at its lowest. Ultimately, in all but the warmest climates, electric resistance heating will result in higher energy costs.

In some instances, when a building is super insulated electric resistance heating can make sense. Since very little heating is required in this situation, the additional expense of a heat pump may not be worthwhile. However, this is only the case when heating loads are extraordinarily low.

Conversion of Existing Buildings

Using heat pumps in new construction is more straightforward compared to retrofitting heat pumps into existing buildings. The best time to retrofit an existing building is when the building is going through a gut rehab and much of the HVAC system is going to be replaced. A valid concern when converting existing buildings to all-electric heating systems is the increase in electric requirements.

Heating loads, which were previously met through natural gas piping and infrastructure, are converted to share the electrical service, which already serves lighting, plug loads and other building systems. When designing electrical systems, the code requires conservative assumptions and that spare capacity be built into the system. Most buildings operate well below their electrical capacity. In many cases this buffer is more than enough to cover the additional electrical load required by the heat pump. Several recent projects by the authors of this article have not required electrical service upgrades when converting the building to all-electric heating and cooking systems.

Where little additional electrical system capacity is available, system design options exist such as system efficiency, energy storage and sharing load with cooling systems. For commercial buildings converting to a VRF system or for residential buildings that already have cooling, converting to a heat pump air conditioner or multizone split system usually results in little or no increased electrical loads. In larger buildings, thermal storage coupled with heat pumps allows for smaller and/or fewer heat pumps, resulting in smaller peak electrical loads.

In some cases, increases to electrical service will be required. This can be time-consuming and expensive. Longer-term planning, coupled with other improvements to the building such as higher density or higher-paying tenants, can offset these costs.

TABLE 1 Low temperature limits by equipment type.

EQUIPMENT TYPE	LOWER TEMPERATURE LIMIT
R-32 Heat Pump	5°F
R-134a Heat Pump	–4°F
CO_2 Heat Pump	–20°F
High Efficiency VRF	–22°F

TABLE 2 Hours per year at each temperature by city.

CITY	HOURS PER YEAR BELOW 5°F	HOURS PER YEAR BELOW –20°F
Fairbanks, Alaska	2,177	130
Duluth, Minn.	676	12
Helena, Mont.	188	0
Minneapolis	387	5
Boulder, Colo.	120	0
Chicago	163	0
Denver	25	0
Nashville, Tenn.	0	0
New York	0	0
Seattle	0	0

Heat Pumps in Low Ambient Conditions

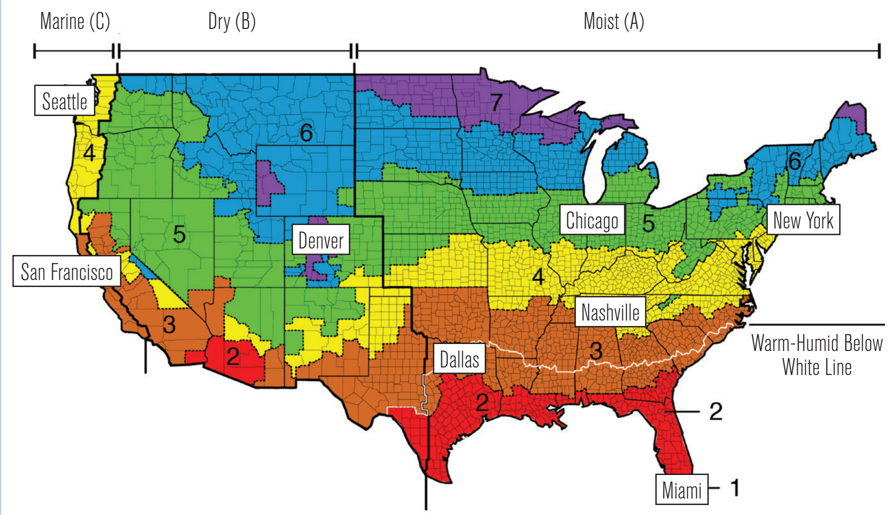
A limiting factor of air-source heat pumps is their operation at low ambient temperatures. In colder climates such as the Midwest or Canada, heat pump applications have historically been limited to more expensive ground-source heat pumps to ensure they would be able to operate during the extreme winter cold. However, heat pump technology has now advanced to the point where they are able to operate at all but the lowest temperatures.

Table 1 shows the lower operation limits of heat pump products currently available on the market. Several companies are also currently researching and testing new products with improved low ambient performance. We expect significant progress in this area in the coming years.

Currently available products are already more than sufficient in all but the coldest climates. As per *Table 2*, outside of Minnesota and Alaska, a properly sized high-efficiency VRF system should be able to satisfy all heating requirements. These systems are generally also available with a backup electric resistance coil for extreme days. It is, however, important to ensure the controls are properly calibrated so the electric resistance coil is not operating when it is not required.

The limitation of low ambient heat pumps is they are currently limited to fairly small capacities. This is less of an issue for VRF systems given their modular nature, but for a larger centralized system this may incur additional costs and require more space.

FIGURE 4 Cities used in energy models.



Modeled Energy and Carbon Impacts of Studied Systems

Methodology

Analysis for the studied system types was performed by the authors' firm using industry standard energy modeling software EnergyPlus version 9.1. All models factored in the TMY3 weather data from the EnergyPlus Weather Data site. The building geometry for all systems was created using the U.S. Department of Energy (DOE) commercial reference Medium Office prototype building. All building inputs (other than HVAC and domestic hot water [DHW]) remained the same between system types, and all modifications from the original DOE prototype building are outlined below. The HVAC and DHW were modified from the original prototype building to compare four distinct system types.

Weather Locations

Each system was modeled in the eight cities shown in *Figure 4*. Cities were selected to represent a wide range of climates and demonstrate system performance in different conditions. Utility rates for the given city were used in determining the annual energy costs.

Baseline Model

The baseline model was created using the DOE commercial reference Medium Office prototype. Most fundamental building properties were not changed from the original prototype. However, a few inputs were modified to better represent typical building design and operating conditions.

The following changes were made to the original DOE reference building and modeling parameters:

- The window-to-wall ratio of the baseline building was increased from 33% to 60%, which we deemed to be more typical of office buildings being built today.
- Daylighting controls were modified from stepped controls to continuous/off controls.
- The elevator load was very high for the original prototype building. The elevator loads were modified to be the equivalent of two traction elevators.
- The HVAC system, instead of turning off at night, was modified to be "available" so occupied and unoccupied setpoints could be used. The occupied setpoints are 70°F (21°C) heating and 74°F (23°C) cooling. The unoccupied setpoints are 65°F (18°C) heating and 78°F (26°C) cooling. Occupied hours were from 8 a.m. to 6 p.m. Monday through Friday and 8 a.m. through 6 p.m. on Saturdays with lower occupancy values.

System Types

We selected four common system types to compare (*Table 3* and *Figure 5*). The first is a typical VAV reheat system with hot water provided by a central gas boiler. This system is very common, particularly in cold weather climates. The second is the same typical VAV reheat system. However, the hot water is provided from a central air-source heat pump. The third is a VRF system with dedicated outdoor air ventilation. The final system is the same typical VAV reheat system but with electric resistance reheat instead of hot water.

HVAC equipment was auto-sized to meet the building required loads. Unmet load hours of all buildings did not exceed 300 hours in accordance with ASHRAE Standard 90.1-2016 Appendix G

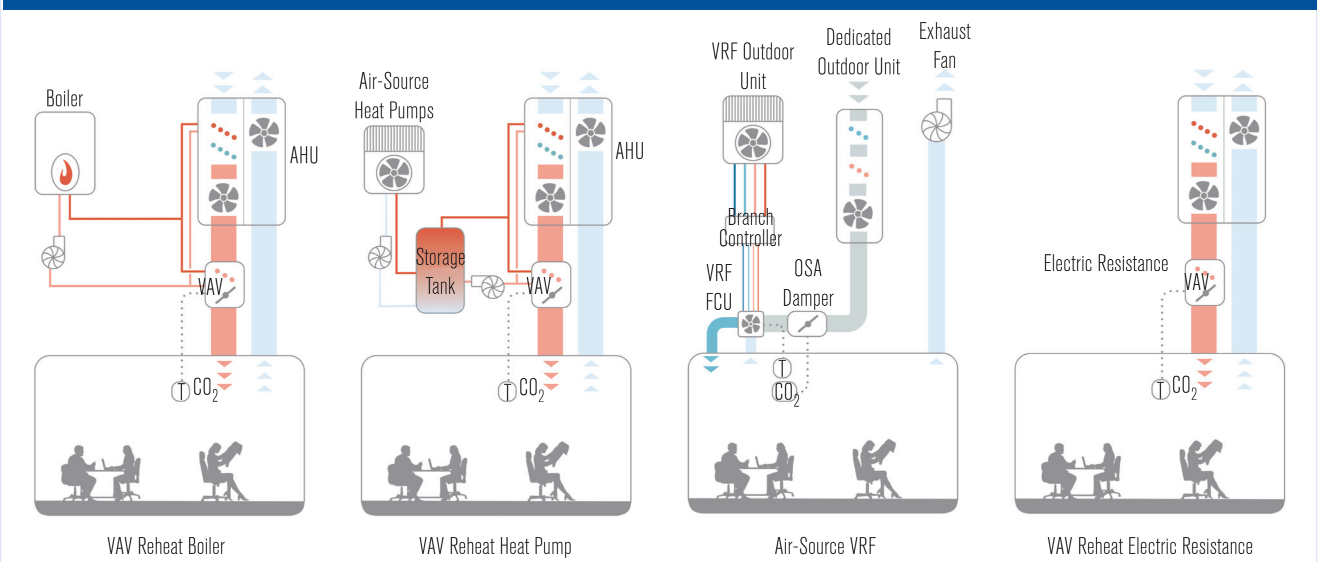
Insights and Results

The four systems types are modeled in eight cities to determine energy use, energy cost and carbon emission

TABLE 3 Energy model inputs.

PARAMETER	PROTOTYPE MODEL	GAS BOILER	HEAT PUMP	VRF	ELECTRIC RESISTANCE REHEAT
DESCRIPTION	Standard VAV Packaged Unit With Gas Heating and Electric Resistance Reheat	Standard VAV Packaged Unit With Gas Boiler Hot Water Heating	VAV Reheat With Heat Pump Hot Water	Dedicated Outdoor Air Unit AHU with VRF Integrated	Electric Resistance VAV Reheat
HVAC EQUIPMENT DETAILS					
OUTDOOR AIR	AHU With VAV Reheat	AHU With VAV Reheat	AHU With VAV Reheat	Dedicated Outdoor Air Unit	AHU With VAV Reheat
ECONOMIZER	Yes (High Limit Shutoff 75°F)	Yes (High Limit Shutoff 75°F)	Yes (High Limit Shutoff 75°F)	None	Yes (High Limit Shutoff 75°F)
HEATING SOURCE	Gas Heating Coil	Gas Boiler Hot Water	Heat Pump Hot Water	Air-Cooled VRF Outdoor Condensing Unit	Electric Resistance
HEATING SOURCE COP	0.8	0.8	2.82	3.40	1.00
HEATING CURVE SOURCE	N/A	N/A	Heat Pump Curves	VRF Component Library Curves	N/A
COOLING SOURCE	DX Coil	DX Coil	DX Coil	Air-Cooled VRF Outdoor Condensing Unit	DX Coil
COOLING SOURCE COP	3.64	3.64	3.64	3.15	3.64
PLUMBING EQUIPMENT DETAILS					
DHW SYSTEM TYPE	Natural Gas Boiler	Natural Gas Boiler	Hot Water Heat Pump	Hot Water Heat Pump	Hot Water Heat Pump
DHW EFFICIENCY	0.8	0.8	2.82	2.82	2.82
DHW LOOP TEMPERATURE	140°F	140°F	140°F	140°F	140°F
DHW FIXTURE FLOW RATE–PEAK (GPM)	0.87	0.87	0.87	0.87	0.87

FIGURE 5 HVAC systems used in energy models.



for each case. The results are presented and compared in the following sections.

Energy Results

The energy results (*Figure 6*) predictably show that the gas boiler hot water heating uses the most energy in all cases because a gas boiler is less efficient than its all-electric counterparts. Electric resistance reheat was a close second in energy use in all cases. While electric resistance is more energy efficient than a gas boiler, it only has a COP of 1, making it less efficient than a heat pump system. Heat pump and VRF systems have similar results, with the VRF pulling ahead for least energy use in most cases except San Francisco. This is likely due to the benefit of airside economizer operation that an air-handling unit has over a dedicated outdoor air unit

FIGURE 6 Total building site energy results for all climates.

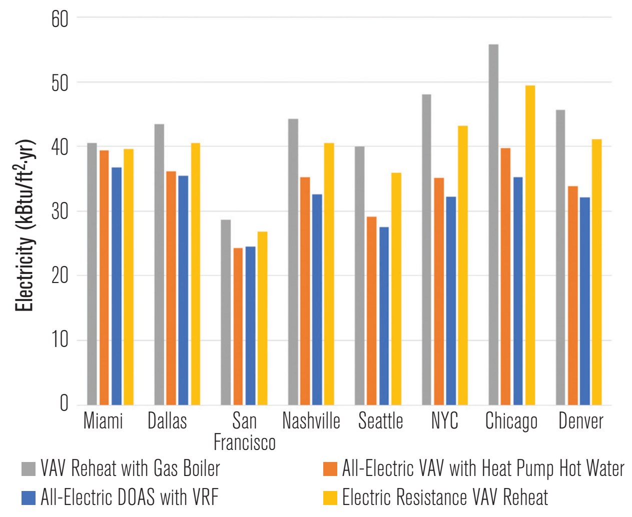
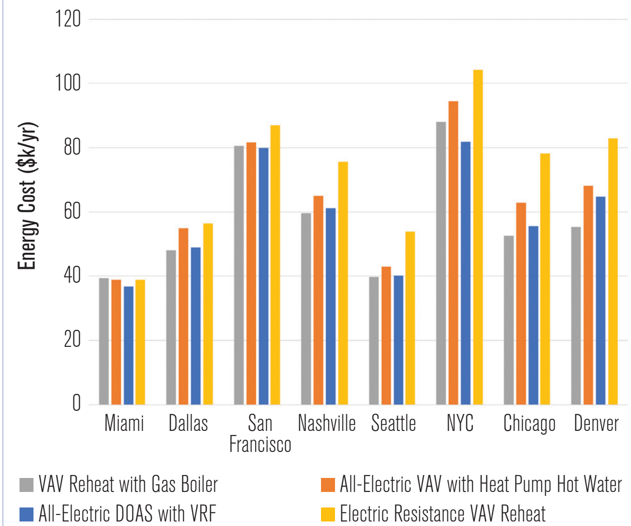


FIGURE 7 Total building energy cost results for all climates.



in mild climates. Overall, all-electric options provide energy savings in all climates.

Energy Cost Results

Figure 7 shows energy cost results. Electric heat pump systems are competitive with natural gas boilers in most U.S. cities. Natural gas costs vary widely from state to state and are the key determinant on relative cost competitiveness. In cities where gas costs are high such as Miami and San Francisco, heat pump systems, especially VRF systems, can cost less to operate than boilers. In only one of the eight cities, Miami, were electric resistance boilers competitive, in part due to the very low heating loads in that climate zone. We did see lower energy costs with VRF systems compared to VAV systems with heat pump hot water because of VRF systems' ability to eliminate reheat and provide heat recovery for part of the year.

Carbon Emissions Results

Many believe that burning fossil fuels on-site will emit less carbon than equivalent electricity use due to inefficient central power plants and transmission losses. These results (*Figure 8*) show the opposite, that all-electric heat pump systems actually produce less carbon than on-site gas alternatives. This reduction is true in all heat pump cases except Denver, which has a coal-intensive grid. The carbon reduction is particularly pronounced for heat pump and VRF cases, which use less energy than electric resistance.

Barriers

Refrigerants

Global warming potential (GWP) is a measure to compare the relative climate impacts of different climate pollutants. Refrigerants, if leaked to the atmosphere, have hundreds or thousands of times more potency as a greenhouse gas (GHG) than carbon dioxide. As new refrigerant options become available, the climate impact of refrigerants decreases. One of the next generation of refrigerants, difluoromethane or R-32, is now commonly available in heat pump products and has a 100-year GWP of 675 compared to the widely used refrigerant R-410A with a 100-year GWP of 2,088. Some manufacturers are beginning to sell systems that use R-744 (CO_2) with a GWP of 1 as a refrigerant.

A recent comparison of a heat pump water heater to a gas water heater (*Figure 9*) compared the greenhouse emissions from burning gas to the emissions of the refrigerant leakage from a heat pump water heater.[11] This comparison assumes that over the lifetime of the equipment, all of the refrigerant escapes. Even so the global warming impact of the heat pump is half that of the gas water heater. As heat pumps with lower GWP refrigerants become available, the gap of the greenhouse gas will widen.

Costs

Costs are always a factor in building systems decisions. Heat pump systems that provide only heating generally are more expensive than their natural gas counterparts. Nonetheless, in the residential market, heat pump sales have increased by 78% since 2010.[12] The rapid growth in heat pumps means that the costs will most likely drop as further economies of scale are reached. In the commercial buildings market, stand-alone air-source heat pumps are far from reaching full market penetration.

Heat pump systems that can provide heating and cooling can be cost-competitive today. When comparing costs, the cost of gas piping needs to be considered. With that in mind, in the residential sector central or split type heat pump systems have been used for many years and can be cheaper to install than a separate furnace and air conditioner. In the commercial sector VRF systems that provide heating and cooling from the same compressor system are competitive with compressor cooling with gas heat such as a VAV hot water reheat system.

Stand-alone air-source heat pumps that provide only heating or hot water are currently more expensive than their gas equivalents. In most cases the cost difference is due to the higher costs of heat pump equipment. Installation labor costs tend to be the same for both. As the market grows for heat pumps and an economy of scale is reached, we do anticipate heat pump equipment costs to drop. Globally, VRF system sales are expected to double between 2020 and 2025 to a total market of over $30 billion USD.[13] With this rapid growth comes competition and lower prices.

FIGURE 8 Heating and domestic hot water carbon emission results for buildings in all climates.[11]

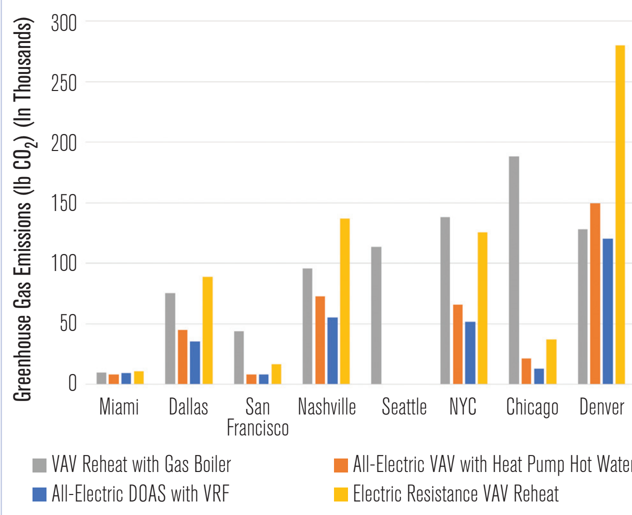
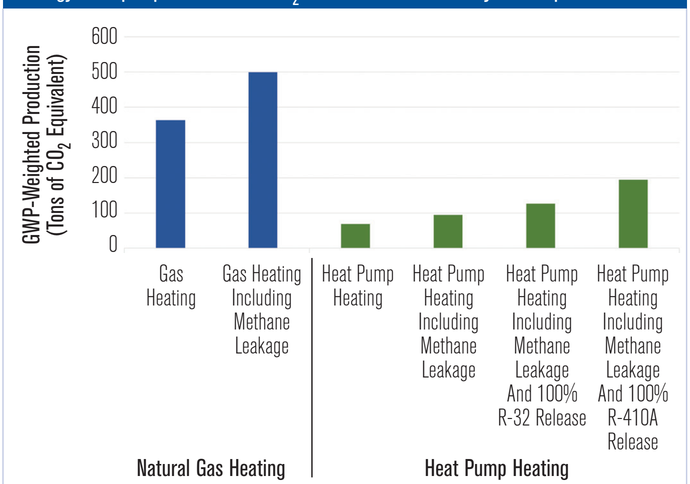


FIGURE 9 San Francisco office building–20-year global warming potential of heating energy. Heat pump cases include CO_2 emissions from electricity consumption.



Other Considerations

All-electric buildings have been around for a long time. The difference today is that buildings can also be efficient and use carbon-free sources of electricity. Affordable renewable energy and heat pumps are two critical components that are making decarbonized buildings possible today.

The use of renewably generated sources of electricity has been steadily increasing. The U.S. Energy Information Administration (EIA) projects that 76% of all new electric generating capacity in 2020 will be renewable.[14] Over 250 companies have signed on to the EPA's RE100 pledge, committing to 100% renewable energy (mostly as it relates to electricity) within various time frames from immediately to 2050. This pledge includes companies such as Bank of America (by 2020), Kellogg (by 2050) and Nike (by 2025).[15]

Energy costs of electrified buildings are roughly equivalent to gas buildings, but their carbon emissions are lower. Like electric cars, electric buildings using heat pumps have lower emissions than their fossil fuel cousins in all but the most carbon-intensive electrical grids.

Similar to renewable energy, the market for heat pumps has taken off over the last few years, encouraging innovation. In the last 10 years air-source heat pumps sales have increased by 75%. The new generation of heat pumps using variable speed compressors and fans are able to more precisely meet HVAC loads. Electric induction cooking is faster and more precise than gas. All-electric buildings take gas out of the building and in the long term out of the neighborhood, resulting in improved safety and better air quality. Utilities that provide both gas and electricity like California's Pacific Gas and Electric are supportive of this transition. They see the lower liability from gas-related fires as a benefit, and the lower costs of maintaining one energy infrastructure instead of two is in their and their customers' best interest.

The biggest challenge to widespread adoption of decarbonized buildings will be in existing buildings. It is hard to imagine how a high-rise in New York will be able to use heat pumps. While electric resistance heating might be needed in those buildings, 90% of commercial buildings, and 65% of housing is in two-story or less structures.[16] For these buildings, largely due to the fact that most light commercial and residential HVAC equipment has an expected life of 20 years, it is entirely possible that we could see rapid adoption of decarbonized all-electric buildings throughout the country in the next two decades.

Conclusions

Manufacturers now supply numerous heat pump options that can replace gas heating systems. These range from stand-alone heat pump water heaters to large centralized air-source heat pumps or heat recovery chillers. These systems use a wide variety of refrigerants including lower GWP refrigerants such as R-32 and R-744 (CO_2). Depending on the refrigerant used, heat pumps can perform in most of the cold climates in the U.S.

Heat pumps lower greenhouse gas emissions in all but the most carbon-intensive electrical grids. Heat pumps generate less carbon emissions even when powered by natural gas-generated electricity. With 12 states and 160 cities with official goals to get to 100% carbon-free electricity by or before 2050, it is clear that heat pumps will be the clean source of heat for the future of U.S. buildings.

A detailed comparison of office buildings in a variety of climates found that heat pump system energy costs go up or down slightly depending on the costs of electricity and gas in a given geographic region. In only one case, Miami, where heating requirements are very low, did electric resistance heat come in at a lower cost than gas systems.

Capital costs for heat pump systems, in which the compressor provides both heating and cooling, are in line with systems that have separate cooling and natural gas heating. Where stand-alone heat pumps replace a gas boiler, capital costs are higher. The market for heat pumps, especially VRF systems, is growing rapidly.

We have seen and expect to see strong momentum in the use of heat pump systems. The costs of heat pumps will most likely drop as sales increase. Units available in Europe and Asia and soon to be available in the U.S. allow for improved efficiency and lower emission refrigerants. When coupled with low carbon or renewably generated electricity, electric buildings with heat pumps provide a clear path to building decarbonization. As ASHRAE members, as we design and guide our clients towards decarbonized buildings, we are unique among professionals in our ability to shape the future of human impact on the climate.

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