Decarbonizing HVAC and Water Heating in Commercial Buildings

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Introduction

Electrification of building loads present a significant opportunity to reduce site-level greenhouse gas (GHG) emissions, especially when combined with renewable and zero-carbon electricity resources. Electrification involves the conversion of a building system that would traditionally use fossil fuels (such as, natural gas, fuel oil, or propane) to the use of electrical power, which could be a key strategy in decarbonization. This guidance document is intended to provide building owners and facilities engineers with heating options and design considerations, as well as additional resources on key topics. The document focuses on electrification and decarbonization of space heating and water heating loads using electric heat pump systems.[1]

This resource can be used as a starting point when conducting the technical, economic, and feasibility assessment for converting to all-electric heating solutions. The attractiveness of facility electrification will vary substantially by region, climate, utility rates, existing systems, and other factors. While any of these strategies can be considered for new construction, this publication focuses on applying heat pumps to existing facilities. Key considerations for existing buildings include: Technology availability and performance.

- Technology availability and performance.
- Upfront, annual, and lifecycle costs
- GHG emissions today, and in future years (e.g., anticipated renewable energy procurement, utility supplier and state renewable commitments)
- Infrastructure impacts (e.g., avoided installation, replacement, or repair of gas piping; building envelope/heating distribution system capabilities; electrical panel and wiring upgrades; fuel storage inspection, maintenance, and decommissioning)
- Reliability and resiliency (e.g., backup heating systems and storage needs)

This resource is organized into four sections:

1. Electrification Options for HVAC and Water Heating
2. Evaluation Checklist for Electrification Assessment
3. Industry Transition to Low-GWP Refrigerants
4. Selected Resources for Facility Owners

Better Buildings has additional resources and support for owners working toward low-carbon buildings at the Decarbonization Resource Hub.

[1] This video from the Solar Decathlon Building Science Education Series provides an overview of heat pump operations and electrifying commercial heating systems.

1. Electrification Options for HVAC and Water Heating

Residential, commercial, and industrial facilities use a wide variety of HVAC and water heating technologies. While heat pump solutions are readily available for some equipment types and system designs (e.g., commercial rooftop units below 25 tons), facilities relying on boilers and distributed heating systems as well as those in colder climates have more limited options.

Heat pumps are often classified by their heat source (e.g., air-, water-, and ground-source) and thermal distribution method in the building (e.g., air for packaged rooftop units, water for hydronic heat pumps, and refrigerant for variable refrigerant flow solutions). As U.S. market interest in heat pumps has increased in recent years, manufacturers and system designers continue to develop new strategies to electrify new and existing facilities.

This section describes heat pump retrofit options and key considerations for the following HVAC and water heating system designs common to commercial buildings.

HVAC Systems	Water Heating Systems
▶ Gas-fired packaged rooftop units ▶ Split system air conditioners and gas furnaces ▶ Boiler systems ▶ Air handlers with reheat and/or perimeter space heating ▶ Campus/district chilled water and steam systems ▶ Packaged Terminal Air Conditioners (PTAC) ▶ Gas-fired unit heaters, radiant wall heaters, and other heating systems ▶ Ventilation make-up air units	▶ Gas hot water boiler for central domestic hot water ▶ Gas or electric resistance water heaters ▶ Small electric storage or point-of-use systems

HVAC (Space Heating, Ventilation, and Air Conditioning) System Retrofits

Existing System	Heat Pump Retrofit Options	Key Considerations
Gas-fired packaged rooftop units (RTUs)	▶ **Heat pump RTU**: Most major manufacturers offer air-source heat pump RTUs in capacities of 3-25 tons, with optional auxiliary heating provided by electric resistance coils. ▶ **Dual fuel heat pump RTU**: A few manufacturers offer dual fuel heat pump RTUs which operate the heat pump to around 17°F and then switch over to an integrated gas furnace for colder temperatures. ▶ **Variable Refrigerant Flow (VRF) system**: VRF systems use heat pumps in each zone to provide heating and cooling and modulate the amount of refrigerant sent to each zone. For existing buildings with RTUs, a VRF system is a significant HVAC redesign and retrofit. ▶ **Water-to-air heat pumps:** Water can be conditioned with a ground loop or a separate air-to-water heat pump.	▶ Some heat pump models report heating capacity 0°F to 10°F, although there is no standardized cold-climate specification for RTUs or VRF systems. ▶ When available, dual fuel heat pump RTUs are a relatively straightforward retrofit for gas-fired RTUs.
Split-system ACs and gas furnaces	▶ **Ducted split system heat pump:** Split system AC and gas furnace heating can be replaced with a ducted split system heat pump. The furnace may continue to be utilized for the supply fan and for back-up heating. ▶ **Ductless mini-split heat pump:** Split system AC and gas furnace heating can be replaced with a non-ducted split-system heat pump (ductless mini-split). The gas furnace and ductwork can be removed if it is not used for back-up heating.	▶ Split-system heat pumps are available for both residential (1-5 ton) and light commercial (6-20 ton) capacities, although cold-climate certifications are only available for residential-style models. Cold-climate heat pump solutions are available for residential capacities (up to 5 tons) and can operate down to -15°F. ▶ Larger furnaces/air handling units (AHUs) may not have direct heat pump equivalent. Heat pump replacement of larger capacity furnaces/AHUs may have space constraints (i.e., mechanical closet size).

Existing System	Heat Pump Retrofit Options	Key Considerations
Boilers: **low temperature (110°F to 140°F),** **medium temperature (150°F to 180°F),** **and steam systems**	▶ Air-to-water and water-to-water heat pumps can generate hot water in the range of 110-140°F and come in a variety of configurations and modular capacities to meet the building needs. Some products also provide chilled water as a byproduct and may be called heat pump chillers. ▶ Heat recovery chillers are a good solution where simultaneous chilled water and hot water loads are common throughout the year. The heat generated during the chilled water cycle can be used for space heating or domestic hot water loads rather than being rejected to the outdoor air, which significantly improves overall system efficiency. With heat recovery chillers, the heating is a byproduct of the chilled water production (e.g., "you get what you get" for hot water). ▶ VRF or distributed ductless split-system systems are another electrification option for buildings with legacy boiler systems, especially if the building previously used window AC or no AC system. This system requires full redesign of the building's HVAC system and decommissioning the hydronic piping.	▶ Most systems provide lower hot water supply temperatures (110°F -140°F) than traditional boilers. Buildings may require weatherization to reduce heating loads and radiator redesign to meet building heating needs without replacing hot water piping. ▶ Hydronic heat pump products are available in a range of capacities and configurations and are often designed to connect as modular units to achieve higher capacities. ▶ Systems may include thermal storage tanks to provide buffer capacity during periods of high demand or during defrost cycles. ▶ Comparisons of size, weight, and installation complexity to conventional boiler and chiller systems will vary. ▶ Limited design experience and demonstrations in U.S., particularly for retrofit applications when completely replacing gas-fired boiler systems. Auxiliary electric resistance or gas-fired boilers may be needed for colder climates. ▶ Review utility rate structures (especially if electric resistance is used) due to demand charge impacts.

Existing System	Heat Pump Retrofit Options	Key Considerations
AHUs with reheat and/or perimeter space heating	▶ If the AHUs or Variable Air Volume (VAV) boxes are supplied by a hydronic loop with a gas-fired boiler, consider hydronic heat pump solutions described above. ▶ If the system would operate exclusively in either space cooling or space heating mode, manufacturers offer AHUs that contain water-to-air heat pumps. ▶ If the AHUs or VAV boxes currently use electric resistance heating elements, this strategy would already support heating electrification goals, but additional energy efficiency measures (e.g., envelope improvements) would be advisable to minimize the amount of electric resistance heating used.	▶ Major renovation projects could consider conversion to VRF, or ground-source heat pumps (GSHP) options. ▶ Electric resistance baseboards and VAV electric resistance reheat should not be the primary building heat source for high-efficiency buildings. ▶ Consider strategies to minimize the amount of reheat needed to serve individual building zones. Strategies could include improved controls to balance supply air conditions, incorporating auxiliary cooling solutions to address problem zones, or using higher supply air temperatures coupled with a central dehumidifier.
Campus/district chilled water and steam systems	▶ Campus/ district chilled water/ steam systems for heating, cooling, and often electric generation. ▶ Transition buildings from steam or medium temperature hot water (over 160°F) to low temperature hot water (less than 140°F). ▶ Use large heat recovery chillers to generate hot and cold water. ▶ Use a centralized well field with large centralized hydronic heat pumps that distribute hot or cold water to each building or an ambient hydronic loop between the well field and buildings with water-source heat pumps at each building. ▶ Another opportunity is to transition individual buildings from the campus or district energy system to a decentralized system with heat pumps located at each building.	▶ Few case studies and analyses have been done to evaluate the energy, cost, and emissions impacts with campus-wide heat recovery chillers and/or a decentralized heat pump strategy. ▶ Conversion to a low temperature piping network requires updates to building distribution systems as well as larger central system piping. ▶ Moving to a decentralized system may present space constraints at each building.

Existing System	Heat Pump Retrofit Options	Key Considerations
PTAC (Packaged Terminal Air Conditioner)	▶ Most PTAC manufacturers offer heat pump models known as Packaged Terminal Heat Pumps (PTHP), and these products typically include electric resistance backup heating. ▶ At least one manufacturer offers a PTHP product that can operate to below zero conditions. ▶ Major renovation projects could consider switching from PTAC/PTHP system designs to VRF or other options.	▶ Very limited availability of cold-climate PTHPs and there is currently no standardized cold-climate specification for PTHPs. ▶ New ventilation requirements (ASHRAE 62.1) prohibit under door ventilation and require PTHPs to provide dehumidified 'makeup' air. In cold climates this can be highly energy intensive. Ventilation requirement can be fulfilled by a secondary system such as a Dedicated Outdoor Air System (DOAS).
Gas-fired unit heaters, radiant heaters, and other miscellaneous heating systems	▶ Electric resistance and electric radiant options are available for most miscellaneous gas-fired heating categories, and conversions may require some electrical upgrades and/or system redesign. ▶ Consider installing ductless split-system heat pumps, VRF, and PTHPs in place of or in combination with electric resistance and radiant options.	▶ Electrifying building heating systems with non-centralized heating systems is an emerging area of HVAC design.
Ventilation make-up air units	▶ Heat pump options are available for some make-up air units and dedicated outdoor air systems; electric resistance heating elements may be used.	▶ Rate of makeup air (cfm) and anticipated outdoor conditions will dictate retrofit selection.

Domestic/Service Water Heating System Retrofits

Existing System	Heat Pump Retrofit Options	Key Considerations
Gas hot water boiler for central domestic hot water (DHW)	▶ Manufacturers have started offering both integrated and split-system heat pump water heaters (HPWH) with higher capacity and supply temperatures for high demand commercial applications, although these have high installed costs. ▶ Like space heating boilers, some air-to-water or water-to-water heat pumps and heat recovery chillers can provide domestic hot water. ▶ If necessary, electric resistance booster heaters can supplement the HPWH to achieve higher temperatures. ▶ Building-level sewer heat recovery systems can be used for domestic hot water. Campus- or city-level systems can be used for space conditioning.	▶ Cost of HPWH solutions may be considerably more expensive than gas-fired solutions. ▶ Availability/sizes of HPWH: limited availability of comparative HPWH systems that can meet the capacity and recovery needs. ▶ Recovery rate of HPWH: Commercial buildings with high hot water loads (e.g., food service, lodging, gyms, dormitories, healthcare) typically have large storage water heaters with high recovery rates, which favors gas due to faster recovery. Size of heat pump and storage need to be matched to anticipated loads to ensure sufficient hot water and good recovery.
Gas or Electric resistance water heater for smaller DHW applications	▶ Similar to the above, more manufacturers are offering both unitary and split-system HPWHs for the light commercial market. ▶ Some applications could use residential-style HPWHs. ▶ Instantaneous electric water heater for small hot water loads (point-of-use) and eliminate recirculation pumping.	▶ Residential and light commercial HPWHs are available today from major manufacturers with storage capacities of 40-120 gallons. ▶ Most HPWHs require a 220V electrical line, but it is anticipated that 110V models will be available soon.
Small Electric Storage/ Point-of-Use systems	▶ Small electric storage or instantaneous electric water heaters are common for building types and applications with relatively low hot water loads (e.g., office sinks).	▶ These systems are unlikely to convert to heat pump systems due to technical, economic, or physical feasibility constraints.

2. Evaluation Checklist for Electrification Assessment

As described in the previous tables, there are a wide variety of heating electrification options available and challenges to consider when evaluating opportunities for specific facilities. This section outlines some additional topics to evaluate when performing a site electrification assessment.

- **Placement of All-Electric Systems**: Heat pump systems may have a larger footprint than the existing fuel-fired systems and may require larger hot water storage tanks. During the site assessment, the team should evaluate the available floor or roof space that would be available for the heat pump systems and necessary heat exchangers. In addition, many newer rooftop units have larger footprints than older models and may require roof curb redesign or structural supports to accommodate the larger size and weight. Air-based systems need large quantities of outside air to exchange heat, which often requires outdoor placement of units (rooftop or ground mount).
- **Electrical Service, Panels, and Wiring**: Conversion to all-electric systems may require some redesign or upgrade of the facility's electrical panels and wiring, especially for older buildings where electrical upgrades have not been performed recently. On the smaller end, this may include running a dedicated electrical line for a HPWH. On the larger end, this may involve an upgrade of the electrical service line from the utility as well as panel and wiring upgrades within the building. Most commercial buildings should have excess electrical capacity available, especially if they have existing space cooling systems, but an evaluation of the new power requirements and available electrical capacity will confirm whether upgrades are needed. In addition, the new electrical loads may change the electrical rate class or the monthly demand charges for the building and should be evaluated. If it appears that extensive upgrades or utility rate changes would be necessary, the team could consider incorporating on-site renewable generation, battery storage, building envelope and window improvements, lighting retrofits, and other energy efficiency measures to mitigate the increase in electrical demand.
- **Thermal Distribution Systems**: Facilities using high temperature steam or hot water distribution (180°F and above) should evaluate whether there is sufficient radiator and heat exchanger capacity to accommodate the lower supply temperatures of hydronic heat pumps (often 110-140°F). In some cases, the existing distribution system is oversized and would have sufficient capacity for the lower temperatures, especially if the building envelope is upgraded to lower the heating load. In other cases, decommissioning the steam/hydronic system and transitioning to a VRF system may be preferable if there were leakage and other problems with the existing distribution system.
- **GSHP Solutions**: GSHPs are an attractive electrification strategy due to their strong performance and efficiency throughout the year, even in extreme cold weather. GSHPs can make sense for both new and existing applications if the heating and cooling loads are balanced through most of the year to make the most benefit of the ground wells. For retrofit, land is required for the well field; a combination well and air-based system can also be considered.

- **Central vs. Distributed Solutions:** Many buildings today use large, centralized space and water heating systems, which may pose technical or feasibility challenges for electrification projects. If the project is part of a larger renovation, the team may consider moving towards a decentralized strategy where smaller heat pump and electric resistance systems are placed throughout the building. For example, if a large gas-fired boiler previously provided both space and water heating to the building, the team could consider separate systems for space heating and water heating or placing individual heat pump or point-of-use water heaters throughout the building. Ductless mini-split heat pumps are also effective distributed solutions where only a small area of the building requires thermal conditioning (for example, an office in a warehouse) or if an area is significantly warmer or cooler than other parts of the building.
- **Auxiliary and Back-up Systems:** The heating capacity and efficiency for air-source heat pumps decreases at colder temperatures, which requires careful consideration for peak day capacity needs including during defrost cycles. Ideally, choose heat pumps that will operate at the coldest possible temperatures for the location to satisfy the building's heating loads. For small amounts of backup capacity, thermal storage can be used to cover a few hours when the heat pump is in defrost mode or during extreme cold if feasible at the site. If the electric system is replacing a fossil fuel system, the fossil fuel may be used as a backup for extreme cold days. Electric resistance is common for all-electric heating solutions but has much lower efficiency and higher operating costs than heat pump operation. Electric resistance back-up systems should be designed to operate sparingly (for example, during defrost cycles) and carefully sized to minimize potential electrical capacity upgrades.
- **Review Available Utility and State Incentives**: Many electric utilities and state energy efficiency programs offer financial incentives and rebates to support the installation of high-efficiency electric technologies. In some cases, utilities offer additional incentives for early replacement and fuel-switching projects. For complex projects or technologies that are not listed in the incentive programs, the team should communicate with the energy efficiency program to understand the custom application process. Furthermore, electric technologies can participate in demand response and load flexibility programs, particularly those technologies that utilize hot water storage systems.

3. Industry Transition to Low-GWP Refrigerants

Electric heat pump technologies contribute to a facility's GHG emissions through both their energy consumption and their refrigerant usage. Refrigerants are the primary working fluid for most current building air conditioning, heat pump, and refrigeration systems, with most systems using a class of refrigerants known as hydrofluorocarbons (HFCs). HFCs have zero ozone-depletion potential (ODP), but high global warming potential (GWP), which is why global policymakers and HVAC&R industry stakeholders are transitioning to refrigerants with lower GWP values. For many equipment categories, refrigerant leakage occurs slowly over the system lifetime and service technicians must periodically replace it. In addition, refrigerant leakage can occur during system decommissioning if the refrigerant is not recovered properly. These issues are more prevalent in split-systems with field installed piping and less prevalent for factory sealed systems and those returned to a facility that can decommission the equipment. Minimizing field installation of refrigerant lines and refrigerant tends to result in less leakage and fewer long-term maintenance issues.

The table below summarizes low-GWP alternatives under consideration for major space heating and water heating sectors. All major HVAC and water heating equipment categories have promising low-GWP alternatives, although refrigerant approval and product availability may still be under development. Low-GWP options under consideration will typically share similar characteristics to the high-GWP refrigerant targeted for replacement, except for potentially flammability and toxicity properties. Some low-GWP refrigerants offer energy efficiency and performance benefits over HFC technologies (e.g., HPWHs using CO_2 [R-744]).

Many low-GWP options are readily available in global markets, but are waiting for U.S. Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) program approval and state building code updates before adoption in new systems in the U.S. Other low-GWP refrigerants are subject to EPA SNAP charge limits due to flammability risks (i.e., labelled as A3 or A2L under ASHRAE Standard 34), which prevents their use in higher capacity applications.

Very few alternative refrigerants are direct drop-in replacements for HVAC&R and other end-use sectors, which can pose challenges to adoption because the only alternative is a full system replacement. Even in instances where an alternate refrigerants' properties are similar, systems may require some redesign and component upgrades to manage flammability risks.

Current and Alternative Refrigerants for HVAC and Water Heating Applications

Category	Current HFC (100-year GWP)	Promising Low-GWP Alternative (GWP, Class)*	U.S. Approval Status
Residential HVAC	R-410A (2,088)	R-32 (675, A2L) R-466A (733, A1) R-454B (466, A2L) R-290 (3, A3)	▶ Alternative refrigerants are generally not available in the U.S. today for central split-system, ductless split-system, geothermal AC/HP, rooftop unit, and VRF systems, but will be available in the next several years. ▶ R-32 and R-290 are approved for use in room/window AC/HP and PTAC/PTHP systems in the U.S. HVAC manufacturers have announced plans for offering products using A2L refrigerants (e.g., R-454B, R-32) in the coming years. ▶ EPA SNAP Rule 23 (May 2021) approved several new A2L alternatives subject to use restrictions. ▶ State and local building code updates would be necessary for flammable A2L and A3 refrigerants in most states. ▶ California and Oregon have passed regulations requiring low-GWP refrigerants (<750 GWP) starting in 2025. ▶ The industry expects a similar national transition to occur nationally around 2025
Commercial HVAC	R-410A (2,088) R-134a (1,430)	R-32 (675, A2L), R-466A (733, A1) R-454B (466, A2L) R-450A (604, A2L) R-513A (631, A2L) R-290 (3, A3) R-600a (3, A3)	
Chillers (small to medium)	R-410A (2,088)	R-32 (675, A2L), R-466A (733, A2L) R-454B (466, A1) R-450A (604, A1) R-513A (631, A1) R-717 (0, B2L)	▶ Alternative refrigerants that are approved for use in the U.S. are R-744 (A1), R-717, R-450A (A1), R-513A (A1), and R-1234ze (A2L) ▶ HVAC manufacturers offer products today using low-GWP refrigerants and several states have already restricted the use of chillers using high-GWP refrigerants.
Chillers (large)	R-134a (1,430)	R-1234yf (4, A2L), R-1234ze (7, A2L)	
Water Heating	R-134a (1,430)	R-1234yf (4, A2L) R-1234ze (7, A2L) R-744 (1, A1)	▶ High-efficiency systems using R-744 are commercially available in heat pump water heating applications.

***ASHRAE Standard 34 classifies new refrigerants based on flammability and toxicity. Toxicity Groups: A – Nontoxic, B – Toxic. Flammability Classes: 1 – No flame propagation (i.e., non-flammable), 2L – Lower flammability 2 – Flammable, 3 – Higher flammability**

4. Selected Resources for Facility Owners

The table below provides a list of available research literature and case studies that focus on heating electrification and decarbonization of commercial buildings. Most building decarbonization analyses focus on the single-family residential sector, with fewer studies providing extensive analysis on the decarbonization feasibility for commercial, large multifamily, and industrial facilities. The following resources may be useful to examine specific building subsegments and technologies in greater detail.

Selected Electrification Resources and Case Studies

Title	Topic Areas	Case Studies	Notes
Thermal Electrification of Large Buildings in the Commonwealth (A Better City/ Cadmus, 2020)	▶ Large multifamily and commercial buildings ▶ Space heating and water heating	Yes, several real-world case studies	The report provides an overview of heating electrification options in Massachusetts, with several case studies for new construction and retrofits, including those with boiler systems.
Zero Carbon Commercial and Multifamily Construction (Redwood Energy, 2019)	▶ Two reports, one for large commercial and one for multifamily (mostly new construction) ▶ Space heating, water heating, cooking, and transportation electrification	Yes, several real-world case studies	The guide contains examples of large new commercial and multifamily developments that have avoided fossil fuel use in favor of all-electric designs and provides examples for specific all-electric technologies.
Heat Pump Retrofit Strategies for Multifamily Buildings (NRDC, 2019)	▶ Residential multifamily, both small and large (may have applicability for some commercial as well) ▶ Space heating and water heating, both in-unit and central	Yes, for several prototypical retrofit projects	The report examines heating electrification options for multifamily buildings, with a particular focus on technology options for existing buildings with central steam and hot water systems.

University of California Strategies for Decarbonization: Replacing Natural Gas (IEE, NCEAS, Univ of California, 2018)	▶ Focus on large commercial buildings, particularly those on campus district energy systems ▶ Space heating, water heating, CHP, and process loads	Yes, some real-world examples and some feasibility analysis	The report examines strategies to decarbonize the University of California campuses, many of which use gas-fired central energy plants for electricity generation, and district heating and cooling. It focuses on complimentary solutions including deep energy efficiency, biogas, electrification, and the synergies with energy storage in the campus setting.
Advanced Energy Design Guides: Achieving Zero Energy Series (ASHRAE)	Guides available for: ▶ Small to medium offices (2019) ▶ K-12 schools (2018) ▶ Multifamily (Coming 2021)	Yes	The guides offer contractors and designers the tools, including recommendations for practical products and off-the-shelf technology, needed for achieving a zero-energy building. Mechanical recommendations in chapter 5 provide insights on heat pumps.
AHRI Directory of Certified Product Performance	▶ Performance database for a variety of HVAC and water heating products	No	This is the HVAC/WH industry's central resource for certified performance data for new equipment.
NEEP Residential Cold Climate ASHP Product List	▶ Performance database for residential ducted and non-ducted air-source heat pumps meeting NEEP's cold-climate specification	No	The current NEEP specification focuses on residential cold-climate heat pumps (up to ~6 tons). Other equipment categories may be considered in the future.