Making the Transition to All-Electric Buildings: A Design Guide

Introduction

This guide intends to assist designers of multifamily buildings make the transition to all-electric space heating and water heating systems. It should be used as a starting point when considering all-electric design. It provides background on available electric technologies and allows designers to understand the benefits of and potential costs associated with transitioning to all-electric building systems. It focuses on the major building systems that have historically relied on on-site combustion in multifamily construction but does not cover all potential sources of on-site combustion; it is not intended to be a comprehensive solution for every building scenario, as no "one-size-fits-all" approach exists due to differences in multifamily building typologies, location, climate, regulations, and utility costs.

Why Electrify

There are many reasons to consider making the transition to all-electric buildings, including futureproofing building design for a decarbonized future, prioritizing human health, and simplifying the construction process.

The use of natural gas and other fossil fuels in buildings contributes significantly to global warming, indoor and outdoor air pollution, as well as health problems for occupants. Building electrification can help reduce these problematic greenhouse gas emissions by using renewable energy sources such as wind and solar power. In addition, electric heating and cooling systems can improve indoor air quality by reducing the number of pollutants generated by combustion.

Futureproofing

New systems installed today will be in service for decades. When designing and constructing new buildings, design teams need to ensure that the building and its systems won't become obsolete due to updated codes or regulations. Additionally, it is critical for designers to ensure buildings are designed to allow for flexibility in mechanical systems. For example, if a building is designed with a gas boiler today, it may be more difficult and expensive to install a new electric-based system when the boiler eventually dies.

The past 5 years has seen multiple jurisdictions implement gas moratoria, forcing designers to move to all-electric buildings, while others have established carbon emission regulations such as **New York City's Local Law 97**, all-electric building codes, or **building performance standards** (BPS) that either require or strongly encourage all-electric construction. This trend is likely to intensify as more jurisdictions recognize the importance of decarbonizing buildings as part of a climate action plan.

Decarbonization

Transitioning away from fossil fuel systems in homes and buildings is a critical step to reduce the carbon impact of our built environment that also provides positive health impacts for occupants. While not all electricity is sourced from renewable or clean energy at this time, as the electric grid continues to add more renewable sources of energy, the emissions associated with all-electric buildings will naturally fall while emissions at a building utilizing on-site combustion will remain unchanged. Further, there is no avoiding the fact that on-site combustion of fossil fuels emits carbon dioxide and other harmful byproducts. As more building owners and portfolios seek to reduce their carbon footprint and improve indoor air quality, eliminating a significant source of **Scope 1 carbon emissions, or those emissions controlled by owners from onsite fuel combustion**, is very appealing.

Human Health

An often-overlooked benefit of switching to all-electric building design is the positive impact on occupant and community health. Combusting fuel at a building site creates pollution indoors and outside at varying levels, depending on the type of fuel (natural gas, fuel oil, etc.). This pollution is unavoidable, and studies have linked childhood asthma and respiratory illness cases to gas cooking.[1] Improperly vented and poorly maintained gas-fired equipment can emit more harmful carbon monoxide and particulates while increasing the risk of catastrophic events such as fires and explosions.

Reduced Construction Cost

By eliminating gas from new multifamily buildings, projects can reduce first costs—sometimes substantially—associated with establishing gas connections to a building. Natural gas requires extensive plumbing and metering infrastructure, and eliminating gas simplifies design by removing gas meter rooms and piping. Finally, eliminating the gas utility connection can simplify construction scheduling and reduce total construction time.

More Efficient Equipment

Electricity is more efficient at converting energy to heat than the combustion of fossil fuels. The most efficient gas equipment available today converts around 99% of the potential energy of the fuel into heat for space and water heating. That is the same efficiency as the least efficient electric heating equipment, while heat pump efficiency can reach 350% or even higher. This means that site energy use in all-electric buildings can be significantly lower than in buildings with on-site combustion.

1 https://heetma.org/wp-content/uploads/2019/04/Gas-cooking-can-harm-children-4-15-19-clean-1-1.pdf

Items to Consider When Going All-Electric

Now that you have made the decision to pursue all-electric design in your building, there are several factors to consider when selecting appropriate systems and designing mechanical spaces. These include, but are not limited to:

Building Size and Shape

Is your building going to be tall and skinny or low and long, with lots of roof space? This will make a big impact on whether the building should consider central space and water heating systems or in-unit systems.

Size of Units

If your building consists of smaller units that are tight on free space, in-unit mechanical closets with individual water heaters and heat pump air handling units may not be the ideal solution for your design. Consider central systems or compact in-unit systems.

Ceiling Suspended

Climate

Are you in a hot, humid climate with lower space heating demand or in a cold climate that may require specialized equipment to meet your heating demands? Your climate will have a big impact on system sizing and availability so we will get into specifics below.

Design Best Practices

Once you have considered the above factors, it is time to determine which systems are best for your building. Because no two buildings are the same, there is no cookie-cutter solution to electrify your building design. However, there are several important steps you should take to ensure that you select the correct system for your building.

Reduce Loads

The most important step you can take in electrifying your building is ensuring the building uses as little energy as possible. To do this, focus on the following:

INSULATE & IMPROVE AIR TIGHTNESS

Modern building technologies enable us to design structures that are very well insulated and incredibly airtight. Programs such as Passive House and ENERGY STAR Multifamily New Construction have provided frameworks for airtight design that helps to reduce the amount of energy required for space heating and cooling.

PERFORM ACCURATE LOAD CALCULATIONS

A common mistake designers make is oversizing the mechanical systems, especially in new buildings with good air tightness and insulation. Oversized systems may not effectively dehumidify spaces, can lead to comfort and reliability issues, and cost more to install, maintain, and operate.

Fortunately, there are excellent tools available to designers to properly calculate building system loads that will allow you to properly size your system. ACCA Manual J calculations allow designers to determine the anticipated heating and cooling load for dwelling units and should be performed for each dwelling unit type for your building, not just the worst-case scenario.

By completing load calculations accurately, designers can confidently select building mechanical systems that meet the true heating and cooling demands of the building.

Check the Size of the Electrical Panel

Ensure that electrical service and distribution is appropriately sized for the building. Older buildings may need to upgrade electrical capacity to ensure that all-electric space heating and water heating systems can be safely installed at the building. Work with an electrical engineer to determine the electrical capacity required for the building and make any necessary upgrades.

Select Appropriate Systems for Your Building

Determine whether a centralized approach to air and water heating is most appropriate for your building. Simply selecting the electric alternative to your standard gas design is often not the best choice and can result in higher construction costs and less optimized efficiency.

Generally, taller buildings with less roof space are more likely to consider utilizing central space heating systems that do not require too many outdoor compressors, while shorter buildings with a lot of roof space have more flexibility to accommodate compressors for individual dwelling units.

For water heating, longer buildings are not as well equipped for central hot water systems due to the need for multiple risers and additional recirculation loops.

Space Heating

CENTRAL SYSTEMS

Water Source Heat Pump (WSHP)

WSHPs are similar to other heat pumps (VRF, Air Source Heat Pump) in that they transfer heat to the air using refrigerant. Unlike VRFs, which use large exterior compressors and pipe refrigerant throughout the building to the units, WSHPs operate by using smaller in-unit compressors that connect to a water loop that runs throughout the building. The water loop can be heated and cooled using a variety of technologies, including air source heat pumps and ground-source heat pumps. This makes WSHPs a great bridge option for newer buildings considering future electrification and a possibility for existing buildings that are currently operating on existing hydronic systems. Here are some of the advantages and disadvantages of water source heat pumps:

Advantages:

- Energy Efficiency: WSHPs are highly efficient and can save energy and reduce operating costs compared to traditional HVAC systems. They can also provide zone-based temperature control, which can further increase energy efficiency.
- Durability: WSHPs are durable and have a long lifespan, with many systems lasting up to 20 years or more.
- Flexibility and Control: WSHPs allow individual units to control their temperature settings, allowing for more control and comfort for occupants.
- Less Refrigerant: WSHPs require significantly less refrigerant than VRFs, as all refrigerant is contained in the factory-sealed in-unit system that transfers heat to-and-from the water loop in the building.
- A larger portion of the unit's heating/cooling load can be connected to the unit's utility meter.

Disadvantages:

- Upfront Cost: WSHPs can be more expensive than traditional HVAC systems, which can be a barrier to adoption for some building owners.
- Noise: If not designed and installed properly, some WSHP systems can be louder than other HVAC systems.

Variable Refrigerant Flow (VRF)

VRF systems are heat pump systems that use variable speed compressors to vary refrigerant flow to satisfy part-load conditions. They have an outdoor unit, refrigerant piping, and indoor units in each space that transfer heat from the refrigerant to the room air (or from the space to the refrigerant in cooling mode). These are typically larger central systems with outdoor units (most of the electrical draw) on the house meter, and indoor units (low electrical draw) on the apartment panel.

Advantages:

- Energy Efficiency: VRF systems are highly efficient and can save energy and reduce operating costs compared to traditional HVAC systems. They can also provide zone-based temperature control, which can further increase energy efficiency.
- Flexibility: VRF systems are flexible and can be customized to meet the heating and cooling needs of different areas of a building. This can be particularly beneficial in large or multi-story buildings with varying heating and cooling needs.

Credit: Finch Cambridge Housing Complex

- Space-Saving: VRF systems require less space than traditional HVAC systems, which can be beneficial in buildings with limited space for equipment.
- Quiet Operation: VRF systems operate quietly and can reduce noise pollution compared to traditional HVAC systems.

Disadvantages:

- Upfront Cost: VRF systems can be more expensive than traditional HVAC systems, which can be a barrier to adoption for some building owners.
- Maintenance: VRF systems require regular maintenance to ensure proper operation and prevent breakdowns. This can increase operating costs and may require skilled technicians to perform maintenance.
- Compatibility: VRF systems may not be compatible with existing building infrastructure, which can increase installation costs and require additional construction work.
- Complexity: VRF systems can be complex and require skilled technicians to install and maintain. This can make it challenging for building owners and designers to find qualified professionals to work on VRF systems.
- Refrigerant: VRFs pipe a lot of refrigerants through a building. Many refrigerants have global warming potential (GWP) much higher than carbon dioxide and systems with longer refrigerant piping have a higher likelihood of leaking and emitting the refrigerant to the atmosphere. Hydro (or hybrid) VRF systems use water as a heat exchange fluid throughout much of the building, which substantially reduces the amount of refrigerant needed, but the system is slightly less efficient and somewhat more complex.

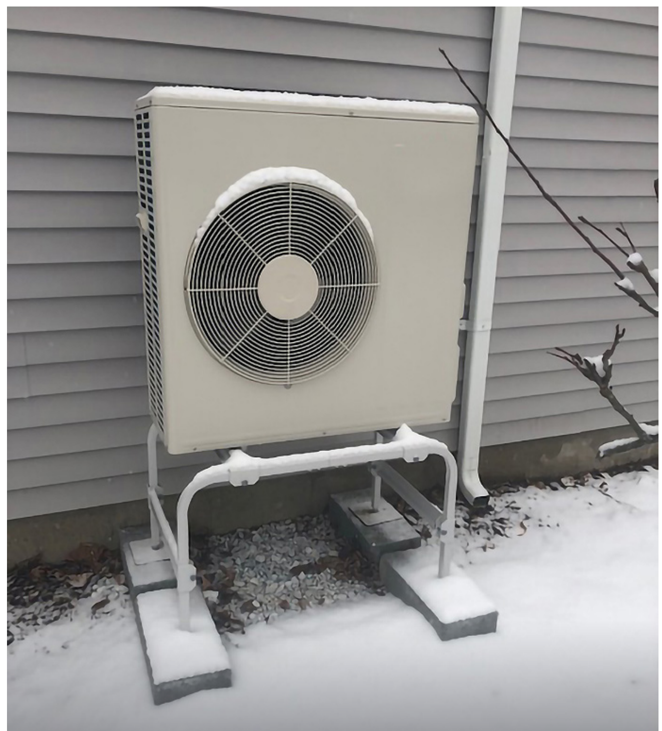
UNITARY SYSTEMS

Air Source Heat Pump (ASHP)

Air source heat pumps are devices that can efficiently heat or cool a home by transferring heat from the outside air to the inside of a building using a compressor and air handler connected by a refrigerant line. Many newer single family and multifamily buildings are designed using ASHPs as they can efficiently provide both heating and cooling to individual units.

Advantages:

- Energy efficient: ASHPs are highly energy efficient, especially when compared to traditional heating systems like electric resistance heaters or gas burning furnaces.
- Versatile: ASHPs can be used for both heating and cooling, making them a versatile option for homeowners.
- Low maintenance: ASHPs require little maintenance, making them a hassle-free option for building operators.
- Flexibility and Control: ASHPs allow individual units to control their temperature settings, allowing for more control and comfort for occupants.



Outdoor unit (horizontal discharge).
Credit: Concord Municipal Light Plant (CMLP)

Disadvantages:

- Weather-dependent: ASHPs are dependent on the outside temperature, which means they may be less effective during extremely cold weather conditions. Cold climate models are available that deliver full capacity down to 5°F, or often even colder. It is very important to consider the climate when selecting a new system, and to specify cold-climate ASHPs where needed.
- Space requirements: Air source heat pumps require outdoor space for installation, which may not be available in all situations. Taller buildings with little roof space, or buildings in urban settings may not have the outdoor space required for ASHPs.

Mini-Splits

Mini-splits, also known as ductless mini-split air conditioning systems, are ASHPs that do not require duct work. They consist of an outdoor compressor unit and one or more indoor air-handling units that are mounted on walls or ceilings.

Advantages:

- Energy Efficiency: Mini-splits are highly efficient, using less energy to heat and cool a space compared to traditional central air conditioning systems. They have a SEER2 (Seasonal Energy Efficiency Ratio) rating of up to 38, which means they can provide efficient heating and cooling while reducing energy costs.
- Zoned Heating and Cooling: Mini-splits can be installed in different zones of a unit, allowing for precise temperature control in each area. This can result in increased comfort and energy savings, as the system can be turned off in areas that are not being used.
- Easy Installation: Mini-splits do not require ductwork, which can make installation faster and less expensive compared to traditional HVAC systems. They can also be installed in homes and buildings where ductwork is not feasible.
- Quiet Operation: Mini-splits operate quietly, making them ideal for use in bedrooms, living rooms, and other areas where noise levels can be a concern.

Disadvantages:

- Aesthetics: The indoor units of mini-splits can be less aesthetically pleasing compared to central air conditioning systems, as they are mounted on walls or ceilings and can be more noticeable.
- Load Capacity: Mini-splits may not be suitable for larger homes or buildings, as they may not have the heating and cooling capacity required to adequately condition larger areas. In such cases, multiple units may be needed to provide adequate conditioning.

Packaged Terminal Heat Pumps (PTHPs)

PTHPs are heating and cooling systems that are commonly used in hotels, motels, apartment buildings, and other commercial or residential settings. They are a type of self-contained unit that typically fits into a wall sleeve and provides both heating and cooling to individual rooms or spaces. PTHPs are likely best suited to smaller units due to capacity restrictions.

Advantages:

- Individual Temperature Control: PTHPs allow for individual temperature control in each room or space, which can increase comfort and reduce energy waste.
- Low Initial Cost: PTHPs can be less expensive to install compared to other heating and cooling systems, particularly if the building already has a compatible wall sleeve in place.
- Space Saving: PTHPs are typically compact and do not require ductwork, which can save space in the building.
- Easy Maintenance: PTHPs are relatively easy to maintain, with most units featuring washable air filters and simple controls.

Disadvantages:

- Noise: PTHPs can be noisy, particularly if they are located close to sleeping areas or if they are older models.
- Limited Capacity: PTHPs may not be suitable for larger spaces or buildings, as they may not have the capacity to heat or cool the space adequately.
- Installation Challenges: Installing PTHPs can be challenging, particularly if the building does not already have a compatible wall sleeve in place. The installation may require cutting through walls or installing new electrical wiring, which can be time-consuming and costly.
- Maintenance Issues: If PTHPs are not properly maintained, they can become less efficient and more prone to breakdowns. Maintenance issues can include dirty filters, refrigerant leaks, and faulty electrical components.
- Lower efficiency: PTHPs tend to be less energy efficient than other heat pump equipment types.

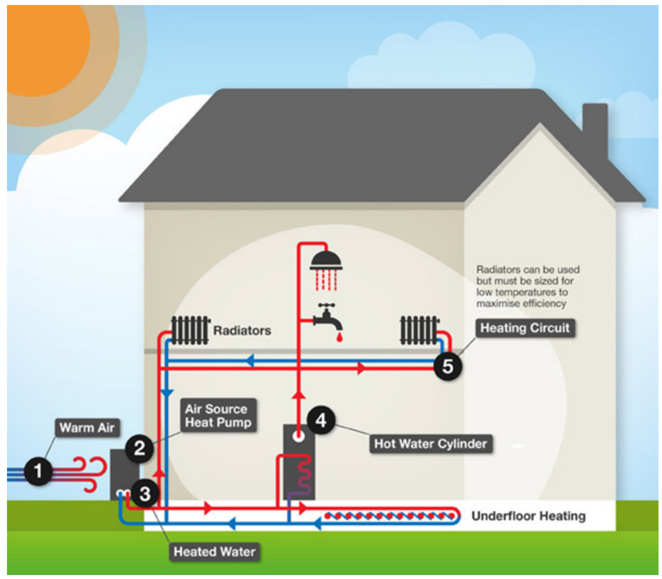
Water Heating

Electrifying Domestic Hot Water (DHW) for multifamily buildings presents additional challenges to design teams due to standard design practices and the availability of proven technologies that can handle the DHW load in a multifamily setting. Multifamily buildings are typically designed with either central hot water systems that supply DHW from a common area such as a boiler room to each individual dwelling unit, or unitized hot water systems that contain a DHW heater in a mechanical closet within each dwelling unit. Both centralized and unitized systems have advantages and disadvantages when it comes to DHW design, and each presents unique challenges when it comes to electrifying DHW design.

CENTRAL SYSTEMS

Air to Water Heat Pump + Storage

Buildings with existing central hot water systems and those being designed with centralized hot water systems should consider utilizing Air to Water Heat Pumps (AWHPs) with DHW storage tank(s). AWHP systems operate similarly to Air Source Heat Pumps in that they extract heat from ambient air using refrigerant. Hot water is then stored in large tanks and distributed throughout the building on demand as it would be in a standard centralized domestic hot water distribution system. Because the AWHP system requires ambient heat from the air to heat the water, these systems are best suited for locations with outdoor space available for the compressor units.



Source: Prince Energy, 2021

Advantages:

- Low greenhouse gas emissions: AWHPs have lower greenhouse gas emissions than gas water heaters since they don't burn any fuel. Some AWHP systems use low-GWP refrigerants such as CO_2, further lowering their emissions.
- More efficient: Sizing is critical when designing centralized AWHP systems, which can be challenging, but when done right leads to more efficient operations (typically two to three times more efficient than a standard gas boiler or electric resistance system).

Disadvantages:

- Sizing is complicated: Traditional fossil fuel boiler systems are often over-sized to allow for spikes in DHW demand throughout the day. AWHPs require constant operation for maximum efficiency and therefore require more accurate sizing to meet demand.
- Space: Compressor units should be placed outdoors to ensure the units do not freeze out mechanical spaces. Buildings with smaller footprints or space constraints around mechanical rooms will be difficult to design.
- Climate-dependent: AWHPs work best in moderate to warm climates where the ambient air temperature is warm enough for the systems to operate efficiently. If considering this technology in a cold climate, be sure to keep all water lines withing the building envelope.

Distributed Central Systems

Some buildings may have the opportunity to utilize a distributed central hot water system. These systems work are similar to central systems in that multiple units are served by one DHW system, however, these systems do not serve all units in a building. Buildings using this approach can optimize the design of the system to reduce recirculation piping and DHW heat loss. Distributed systems work with either a single large AWHP and storage tank or multiple smaller AWHPs ganged together to mimic a larger AWHP.

Advantages:

- Optimize design efficiency: Distributed systems can reduce redundant piping and provide DHW efficiently to multiple units, lowering infrastructure costs and increasing usable space in dwelling units.
- Distributed risk: Lowers the risk of the entire building losing hot water due to a system malfunction.

Disadvantages:

- Space: Similar to central systems, distributed systems require access to outdoor space. Depending on the design approach, space may be required on each floor or more roof space may be required.
- More equipment: While there are fewer pieces of equipment to maintain than in unitary systems, a distributed system requires operators to maintain more equipment than a centralized system.

UNITARY SYSTEMS

Heat Pump Water Heater (HPWH)

HPWHs in unitary DHW systems operate similarly to AWHP + storage in central DHW systems, but many available units contain a compressor and storage tank in one unit. While these units look much like standard gas or electric resistance water heaters, designers should be careful to ensure that there is sufficient ambient space surrounding the unit because the heat pump both draws from and exhausts to the ambient air to operate. This can present a challenge to multifamily buildings where DHW systems are confined to small mechanical closets.

Advantages:

- Energy-efficient: HPWHs are about **2-3 times** more energy efficient than traditional electric resistance or gas tank water heaters.
- Low greenhouse gas emissions: HPWHs have much lower greenhouse gas emissions than gas water heaters: they do not burn any fuel. HPWHs contain a small amount of refrigerant, but because they are factory-sealed, leakage tends to be minimal.
- Can provide dehumidification: HPWHs exhaust cool air and can dehumidify units.
- Cools ambient air: HPWHs exhaust cold air which cools ambient spaces and can reduce space cooling and dehumidification costs in warmer seasons and climates.

Disadvantages:

- Space requirements: HPWHs require more space than traditional electric water heaters, both to fit the heat pump (usually located on top of the tank: HPWH tend to be taller) and to have enough air around the unit for heat exchange needs. **DOE recommends** at least 1,000 cubic feet of air space around the HPWHs (for example, a 10x12 room with 8-foot ceiling).
- Noise: HPWHs can be louder than traditional water heaters, as the heat pump unit makes some noise while operating. Noise levels vary by model but are often around the volume level of conversation or background music.
- Condensate management: HPWHs produce a small amount of condensate water which must be drained or pumped away.
- Cools ambient air: HPWHs exhaust cold air, which cools the space around the unit slightly (by up to 2°F during operation, according to a **Michigan field study**).

Electric Resistance Water Heater

Most designers will be familiar with electric resistance water heaters, as they are the standard system for generating DHW with electricity. These systems are proven, can be placed in small closets, and can be sized to meet anticipated demand easily. They use an electric heating element to heat water and store the water in a tank for distribution throughout the dwelling unit.

Advantages:

- Proven: Electric resistance systems have been available for decades and are the standard when it comes to in-unit electric-based DHW systems.
- Space-saving: Electric resistance DHW tanks fit easily into mechanical closets and do not require open space to operate.
- Improved Indoor Air Quality: Electric resistance DHW tanks do not emit GHGs or carbon monoxide and do not require ventilation to the exterior of the building.
- Easy Swaps: Electric resistance DHW systems do not require reconfiguring space or significant redesigns of a space and can be installed quickly by experience contractors.

Disadvantages:

- Less efficient: Electric resistance systems are 2-3 times less efficient than HPWH systems and are therefore more costly to operate and in many parts of the country result in higher GHG emissions than gas water heaters.
- May require more electrical service: Because they use more electrical power than HPWHs and gas systems, they may require expensive upgrades to electrical service for retrofit projects depending on the level of current service provided.

Credit: NEEA

Install and Commission Equipment

Proper installation and commissioning of equipment is essential for ensuring that the equipment operates efficiently and safely, while meeting the required specifications and standards.

Ensuring Safe Operation	minimizes the risk of accidents or injuries. Faulty installation or commissioning can lead to equipment malfunction, which can be dangerous for operators and residents.
Maximizing Equipment Efficiency	can result in lower energy consumption, reduced operating costs, and increased equipment lifespan.
Meeting Performance Requirements	important for ensuring that the equipment operates reliably and consistently and meets any regulatory requirements.
Avoiding Equipment Failure	which can be costly in terms of downtime, repair costs, and lost productivity.
Maintaining Manufacturer's Warranty	If the equipment fails due to improper installation or commissioning, the warranty may be voided, and the cost of repairs will fall on the operator.

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