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# Arlington County Building Electrification Report

## Arlington County Green Building Incentive Policy

**DRAFT**

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# 1. EXECUTIVE SUMMARY

Reduction of Greenhouse Gas (GHG) emissions is necessary to reduce the worst impacts of global warming. This reduction cannot take place in urban areas without addressing energy usage and fossil fuel consumption in buildings. Buildings are the largest emitter in the United States, and account for 58% of Arlington County's emissions. Electrification of building systems must occur so that the use of fossil fuels is greatly reduced in order to achieve any meaningful reduction in GHG emissions.

Combustion of natural gas and oil for heating, domestic hot water (DHW), and other end uses results in site GHG emissions. Switching these systems to electric heat pump technology eliminates these emissions and can improve efficiencies by 200-400%. Additionally, these systems rely on an electricity grid that can get cleaner over time (through reduced reliance on fossil fuels for electricity generation), even further reducing emissions resulting from building energy use.

Arlington County is already engaged in energy use and GHG reduction commitments via the Community Energy Plan (CEP) which targets carbon-neutrality by 2050, and building specific efforts including the Arlington County Green Building Density Program and the associated Zero Carbon certification. Other cities and states throughout the country have also developed programs and requirements to electrify and reduce carbon emissions from buildings.

Rollout of an electrification program prioritizing heat pump technology in Arlington should focus on both GHG impact and technology availability. Systems should be prioritized in the following order:

1. Heating and Cooling Systems – these constitute the largest building end uses in Arlington County and the technology is mature and available.
2. Central Ventilation Systems - where present, central supply ventilation systems should be designed in conjunction with heating and cooling systems to ensure that this interacting equipment is sized appropriately to maximize efficiency.
3. DHW Systems – these constitutes a smaller load than heating and cooling, and equipment can be incorporated in more of a plug and play manner.
4. Cooking - cooking loads are a small percentage of overall building energy usage. The health benefits of eliminating natural gas from cooking, however, is well documented.

Other considerations for an effective electrification program should include:

- Encourage future proofing of buildings by reserving equipment space and appropriately sizing electrical service for future upgrades.
- Identify opportunities for refrigerant leak detection.
- Track data for better understanding of Arlington's building performance.
- Design for equity to ensure benefits are shared equally.

This report identifies the key heat pump and electrification technology options for the above end uses for offices, multifamily, and hotels, describing the benefits and challenges for each. It also provides estimated energy savings as compared to a baseline natural-gas consumption scenario as well as cost considerations. Some key benefits include:

- Proven heat pump technology is available on the market for heating and cooling for all building types, particularly through ductless heat pumps and variable refrigerant flow (VRF) systems. Other centralized system approaches are still in development or carry a significant cost.
- DHW is often generated through electric resistance already. Individual heat pump equipment is available, central heat pump equipment is viable but not yet widely implemented.
- Central ventilation systems can be highly efficient and eliminate natural gas usage and electric resistance components. Dedicated Outdoor Air Supply (DOAS) systems with heat recovery and heat pump components can provide fresh air to a building while transferring temperatures from otherwise wasted exhaust air, and reduce ventilation conditioning loads by up to 75%.
- Electrification of cooking, while having a small impact on GHG emissions, has health benefits for residents by avoiding the combustion products associated with burning natural gas indoors.

Key challenges and barriers are also present:

- Some heat pump equipment faces challenges with building size. Split systems and VRF systems have maximum permissible lengths for refrigerant piping which can limit their applicability in tall buildings. These constraints require individual approaches to laying out systems in certain buildings by staggering equipment in different locations.
- Heat pumps use refrigerants which have high global warming potential (GWP) when released to the atmosphere, aka “fugitive emissions.” Future technology may replace these refrigerants with lower GWP refrigerants and methods which do not carry the same negative potential. Given today’s technology, however, monitoring and minimization of leakage is crucial to ensure the benefits of efficient technology is not outweighed by unintended refrigerant release.

# 2. ELECTRIFICATION AND HEAT PUMP TECHNOLOGY

The following section discusses electrification strategies in new construction for heating, cooling, and DHW systems, as well as other building uses, for Arlington's three main building types: Office, Hotel, and Multifamily (any of which may include first floor commercial spaces).

Simple electric resistance technology is not uncommon the United States or in Arlington County. For heating and DHW this means an element is heated with electricity and releases energy directly into the air or water. This technology is 100% efficient as one unit of energy is released for every unit of energy input. This is measured as a Coefficient of Performance (COP) of 1. (For comparison, fossil-fuel fired equipment efficiency is even lower, ranging from 60-85% efficiency in most cases). This is also a very expensive way to heat, as electricity is more expensive on a per-unit (standardized as a British Thermal Unit (BTU)) basis than natural gas or oil.

Electric resistance technology is not recommended for short- and long-term strategies to reduce GHG emissions due to its operational cost and that it is not the most efficient option.

Electrification primarily refers to heat pump technology with regard to heating and DHW purposes. Heat pumps are highly efficient, with COP measurements of 2 and above (twice as efficient or more as electric resistance heat). Heat pumps and their technology are defined as:

*"An electric heat pump is an energy efficient heating and cooling system that can heat buildings by moving heat from outdoors to indoors (during winter) and cool buildings by moving heat from indoors to outdoors (during summer). Because a heat pump moves heat rather than generating it, heat pumps have typical efficiencies between 200 and 400 percent.*

*A heat pump heats or cools buildings through a vapor-compression refrigerant cycle connecting an outdoor compressor with an indoor heat exchanger. For cooling, a heat pump is the same as an air conditioner (moving heat from inside to outside). For space heating, a heat pump reverses the flow of refrigerants and extracts heat from the outside environment - even in cold winter weather - and feeds it into the building. In addition to efficiency, a key health and safety benefit of heat pumps compared to fossil fuel-based heating is the lack of any indoor combustion emissions, such as carbon monoxide (CO), nitrogen dioxide (NO2), fine and ultrafine particles, polycyclic aromatic hydrocarbons (PAHs), and formaldehyde."*[i]

Heat pumps can use different mediums to extract and reject heat[ii]:

- Outdoor air: Air-source heat pumps use outdoor air, directly pulling it from and exhausting it to the exterior of a building. Air-source heat pumps are widespread in warmer climates for cooling, and specific types designed for cold climates can operate effectively during winters in Arlington's climate zone. Individual units can service dedicated spaces directly connected to the outdoors in a through-wall penetration, indoor units can connect to outdoor units via refrigerant piping, or a larger central unit can be tied to a water loop to serve the building.
- Water: Water-source heat pumps extract and release heat through a water loop which circulates throughout a building. The basic configuration is similar to buildings conditioned with heated and chilled water. Water loops can also be run underground where fluctuations in temperature are limited as compared to outdoor air temperatures This specific approach can be efficient but can carry large expense and may be difficult in dense urban areas.

# TECHNOLOGY FINDINGS SUMMARY

The electrification and technology applicability, GHG impact, and cost considerations for Arlington County are summarized in the table below. EUI and GHG emissions reductions are dependent on typology and presented as a range in the summary table. Individual reductions figures are shown in the individual measure descriptions. The terms used in this Summary are described on the following page, and more detailed descriptions follow in profiles of the individual technology types. Further information on assumptions and calculations are included in the Appendix at the end of this report.

| Electrification Technology Type | VRF | Mini-Split/ Duct-Less Split Systems | Electric PTHP | Central Heat Pump w/ Hydronic Distribution | Ground Source Loop w/ Hydronic Distribution | Energy Recovery Ventilation w/ Heat Pump |
|---|---|---|---|---|---|---|
| **Configuration** | Centralized | Decentralized | Decentralized | Centralized | Centralized | Centralized |
| **End Use** | Heating, Cooling | Heating, Cooling | Heating, Cooling | Heating, Cooling | Heating, Cooling, DHW | Ventilation, Heating, Cooling |
| **Typology** | Office, Hotel, Multifamily | Office, Hotel, Multifamily | Office, Hotel, Multifamily | Office, Hotel, Multifamily | Office, Hotel, Multifamily | Office, Hotel, Multifamily |
| **Technology Availability** | Mature | Mature | Mature | Mature | Mature | Mature |
| **EUI Reduction Range** | 7.2%-15.7% | 7.2%-15.7% | 7.1%-14.5% | 7.7%-15.7% | 7.4%-16.2% | 4.6%-7.5% |
| **GHG Emissions Reduction Range** | 2.3%-6.6% | 2.3%-6.6% | 2.1%-4.8% | 2.3%-6.6% | 2.5%-7.3% | 5.1%-7.6% |
| **Cost** | **$$$** | **$$** | **$** | **$$$** | **$$$** | **$$** |

| Electrification Technology Type | DHW – Central Heat Pump Plant | DHW – Decentralized Heat Pumps | Induction Cooking - Residential | Induction Cooking – Commercial |
|---|---|---|---|---|
| **Configuration** | Centralized | Decentralized | Decentralized | Decentralized |
| **End Use** | DHW | DHW | Cooking | Cooking |
| **Typology** | Hotel, Multifamily | Multifamily | Multifamily | Commercial |
| **Technology Availability** | Developing | Mature | Mature | Developing |
| **EUI Reduction Range** | 14.4%-20.2% | 20.2% | 2.0% | 2.0% |
| **GHG Emissions Reduction Range** | 3.1%-5.0% | 5.0% | -0.9% | -0.9% |
| **Cost** | **$$** | **$** | **$** | **$** |

## DESCRIPTIONS OF TECHNOLOGIES

Applicable electrification technologies for Arlington's buildings are described below. Information is provided in the following categories:

- **Configuration:** Identifies if the system is centralized or decentralized.
    - Centralized systems contain a single plant of equipment that feeds terminal units within individual spaces. Central systems can be monitored and controlled more simply. When central plants fail or require service, all heating or DHW to the building is put on hold. Central plants contain extensive distribution piping to connect the central plant to terminal units.
    - Decentralized systems have stand-alone equipment in each space. These systems provide more user control and can more easily be placed on resident or tenant electricity meters. Decentralized systems require more upkeep as each unit has equipment, however when one unit fails it does not impact the rest of the building. Decentralized equipment can better match loads and be optimized for each space.

- **End Use:** Identifies the end use the equipment can serve: Space heating, space cooling, DHW, and cooking.

- **Technology Availability**: Comments on whether the technology has widespread market acceptance in terms of performance and installation, or if it is relatively new to the marketplace without experienced installers.
    - Mature: Multiple manufacturers are available with proven equipment; technicians and designers understand and implement the technology
    - Developing: The technology is not in widespread use in the United States, multiple options are not available manufacturers, and a limited number of contractors have completed installations.

- **Benefits:** Describes advantages of the approach as compared to other system types

- **Practical Challenges:** Describes challenges potential roadblocks to the technology, including constraints due to building size or height.

- **EUI & GHG Emissions Reduction:** Whole building GHG emission reductions are estimated for each system type, compared to a baseline natural gas-fired scenario. Energy Use Intensity (EUI) reductions, energy usage on a per square foot basis, is also included. Savings figures differ between building types as each has differing assumed starting end uses for heating, DHW, and cooking, which account for different percentages of their respective building type's total. Additional information is included in Appendix A.

- **Relative Cost**: Cost comparisons between discussed technologies are based on the capital cost of equipment. All HVAC and DHW systems will include soft costs for appropriate design, sizing, and layout that is not necessarily provided by installers. Cost estimates are provided in a scale of low (**$**), medium (**$$**), and high (**$$$**). Estimates were based on available market research and supporting information from known designers and installers in the Arlington market. Additional information is included in Appendix B.

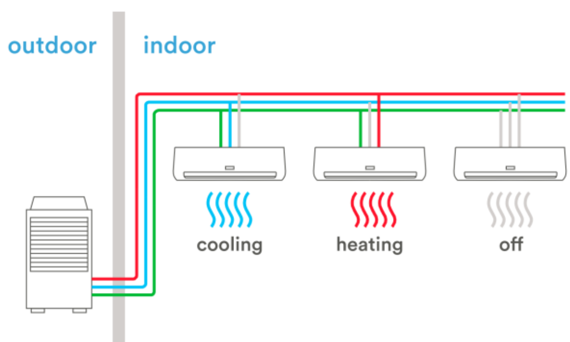
## VRF Systems/ Central Heat Pumps with Refrigerant Distribution

Variable Refrigerant Flow (VRF) systems consist of a central heat pump with refrigerant distribution to individual units. A central heat pump plant (or plants) is connected to individual fan coil heating and cooling in each apartment or room. Variable speed compressors adjust refrigerant flow to satisfy part-load conditions for increased efficiency.

There are two main types of VRF systems. Heat recovery VRF systems are more flexible and more energy efficient - they allow different indoor units to be in heating or cooling mode. Refrigerant is routed between indoor units which allows for heat transfer from units in cooling mode to those in heating mode. They are also more expensive as they require additional refrigerant piping and equipment. This configuration is generally recommended for and seen in multifamily applications as different spaces may require different temperature needs simultaneously.

Heat pump VRF systems require all indoor units are in either heating or cooling mode. As a result of this decreased flexibility they carry lower costs and are less efficient comparatively as they cannot utilize heat transfer between units. Heat pump systems should only be used where zones have the same heating and cooling loads. Some manufacturers of this type of configuration note that their product should not be used in multifamily buildings.

The central heat pump units account for the majority of the electrical usage and are generally on the house meter, while the indoor units with low electrical usage are often on the apartment or individual unit meter.



[iii]


[iv]

*Configuration*

- Centralized

*End Use*

- Heating, Cooling

*Typology*

- Office, Hotel, Multifamily

*Technology Availability*

- Mature: Technology is available on the marketplace and used in new construction for larger multifamily and commercial buildings. Other global regions with high cooling loads use this technology more frequently.[v]

*Benefits*

- User Control: Indoor temperatures can be determined by the occupant
- Envelope Integrity: Minimal envelope penetrations for refrigerant piping as compared to through wall equipment
- Metering: Distributed systems can be made the residents' responsibility in owner-occupied housing, which reduces common-area maintenance charges.

*Practical Challenges*

- Sizing: Sizing is crucial in VRF systems. While these systems vary output to meet demand, the outdoor and indoor equipment have minimum operating capacities. Oversized equipment can waste energy and first costs. Detailed design is needed to ensure sizing and capacities are appropriate, not just based on rule of thumb sizing, and to maximize efficiencies through appropriate refrigerant piping lengths and maximum number of indoor units matched to outdoor units.
- Code Compliance: Mechanical code rules will impact these systems if equipment is ever placed in contained spaces due to leakage concerns.
- Refrigerant Leakage Risk: Refrigerant leakage is most pronounced in VRF systems as compared to other technology described here due to the volume of connections and length of runs. Installation requires trained professionals certified by the manufacturer of the equipment to avoid refrigerant leakage.
- Flexibility During Tenant Space Turnover (Office): Some owners have reported that moving interior VRF equipment can be difficult during fit-outs where interior walls are removed and other major renovations take place.
- Building Size Constraints: VRF systems are generally used in larger multifamily and commercial buildings and in high-rise buildings since floor area is at more of a premium than in low rise buildings. VRF systems, however, do have maximum limits for vertical and horizontal refrigerant piping lengths. Maximum allowable vertical lengths are roughly 150 feet, but this varies by manufacturer and should be verified with the design team. Engineers and manufacturers can design layouts with plants on intermediate floors, rooftops, and exterior grounds to address these constraints.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | **Multifamily** | **Lodging/ Hotel** | **Office** |
|---|---|---|---|
| **EUI Reduction** | 15.7% | 7.7% | 7.2% |
| **GHG Reduction** | 6.6% | 2.8% | 2.3% |

*Relative Cost*

- **High ($$$)**

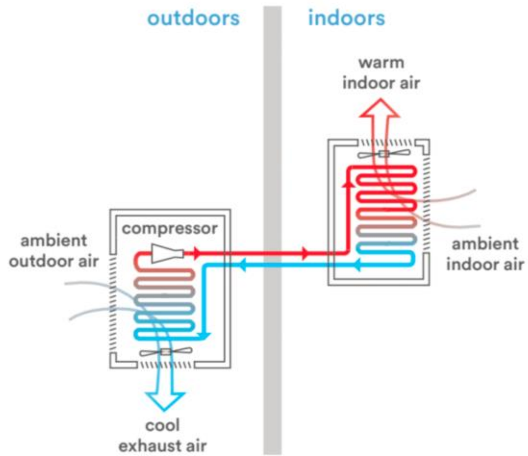
## Mini-Split Heat Pumps/ Ductless Split Systems

Mini-split heat pumps are often referred to as "mini-splits" or "ductless split systems." One outdoor heat pump unit is placed outside, either mounted on an exterior wall or on a roof and is connected to indoor heads (generally one to five) to provide heating and cooling. Mini-split heat pump refrigerant piping length maximum is about 160 feet; performance is increased with shorter line lengths. Outdoor units are often affixed to exterior walls for this reason.

The indoor unit is usually on the apartment or individual unit meter; the outdoor unit can be on the individual or the central common meter.

Mini-split configurations are not commonly installed for apartment level usage in multifamily buildings in Arlington County. This potential design solution, however, may be a viable design option for electrification of multifamily heating systems.


[vi]



[vii]

*Configuration*

- Decentralized

*End Use*

- Heating, Cooling

*Typology*

- Office, Hotel, Multifamily

*Technology Availability*

- Mature: Split heat pumps are nearly the same hardware and layout as ductless split air conditioners seen across the world in hot climates. Manufacturers have developed cold-climate air source heat pumps to provide heating in colder climates, such as the northeast U.S. There are dozens of split heat pump manufacturers. There is an experienced installer industry, and hardware costs are lower as compared to more complicated systems.

*Benefits*

- User Control: Indoor temperatures can be determined by the occupant
- System Simplicity: Field studies indicate that simpler heat pump setups, where the outdoor units are best matched to the load and are not oversized, have the highest efficiency.
- Metering: Distributed systems can be made the residents' responsibility in owner-occupied housing, which reduces common-area maintenance charges.
- Envelope Integrity: Minimal envelope penetrations for refrigerant piping as compared to through wall equipment

*Practical Challenges*

- Design Complexities: Installation costs are often cut that result in reduced efficiencies – connecting multiple indoor units to outdoor units, reducing leakage testing, using less accurate controls, and others. Design and installation should be monitored throughout any construction project.
- Refrigerant Leakage Risk: Installation requires trained professions certified by the manufacturer of the equipment to avoid refrigerant leakage. Split heat pumps require refrigerant piping to be field-connected at multiple junctions between the outdoor and indoor units.
- Refrigerant Piping Constraints: Poor installation can result in decreased efficiency through excessive line lengths, equipment oversizing, poor pipe insulation, and poor siting of outdoor and/or indoor units. Split heat pumps have shorter maximums for refrigerant piping – indoor and outdoor units must be placed relatively close to each other, making central grouping of outdoor units in high-rise buildings difficult or impossible.
- Additional Equipment: Decentralized equipment increases the amount of equipment needing ongoing maintenance.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | **Multifamily** | **Lodging/ Hotel** | **Office** |
|---|---|---|---|
| **EUI Reduction** | 15.7% | 7.7% | 7.2% |
| **GHG Reduction** | 6.6% | 2.8% | 2.3% |

*Relative Cost*

- **Medium ($$)**

## Electric Packaged Terminal Heat Pumps (PTHP)

Package Terminal Heat Pumps (PTHP) are self-contained, individual pieces of equipment that provide heating and cooling and are installed in a wall penetration in each room. PTHPs use the same refrigerant circuit and hardware to control and manage room conditioning. The air directly outside the room is the heat source when in heating mode, and heat is rejected into the outside air in cooling mode. During low temperatures, the units operate in basic electric resistance mode, which is a standard efficiency.

Package Terminal Air Conditioners (PTACs) are a common existing HVAC option in buildings, PTHPs are similar in size and operation. The improved efficiency of PTHPs comes from when the heating process can operate in heat pump mode. PTHPs generally only require an electrical outlet rated for 230V for a power source.

Note that this technology is primarily recommended as a retrofit option for existing buildings already using electric PTACs. While the scope of this study focuses on new construction, the widespread availability of this electric heat pump product is mentioned here as a low-cost option for some retrofit situations.


Photo: Steven Winter Associates


Photo: Steven Winter Associates [viii]

*Configuration*
- Decentralized

*End Use*
- Heating, Cooling

*Typology*
- Hotel, Multifamily

*Technology Availability*
- Mature: PTHP technology is widely available by many manufacturers. They are particularly in use in hotels where heating and cooling needs vary greatly. The hospitality sector accounts for between one-half to two-thirds of all PTAC shipments in the United States, it's possible it constitutes a similar portion of PTHP shipments.[ix] Manufacturers are developing new high-performance cold climate units for use in new construction projects.

*Benefits*

- User Control: Indoor temperatures can be determined by the occupant
- Metering: PTHPs can be placed on individual unit electrical meters where users are incentivized to reduce use and costs, or house meter.
- Equipment Simplicity: PTHPs can be maintained by building staff; they do require periodic cleaning and maintenance. Installation is simpler since there will be no requirement for field leak testing
- Reduced Refrigerant Leakage Risk: Refrigerant leakage is less of a concern as all components are factory assembled and tested
- No Building Size Constraints: There are no limitations based on building size.

*Practical Challenges*

- Efficiency Considerations: PTHPs may likely not operate as efficiently as advertised when not operating in heat pump mode when intended. The units will switch between heat pump and electric resistance mode based on outdoor and indoor temperature. Some units switch to electric resistance mode when outdoor temperatures drop below 45F, whereas others can defrost down to 25F. This process can be managed for improved efficiencies, including through improved placement of indoor temperature sensors to more accurately read room temperatures.
- Drainage Required: PTHPs with active defrost capabilities result in large flows of water out of the unit. A drain system is needed to prevent this water from freezing and causing damage to building façades. Summertime condensate (drained from the interior) is typically evaporated off the exterior coil without causing issues.
- Equipment Sizing: Equipment must be sized properly to ensure both heating and cooling needs are met based on climate.
- Envelope Integrity: PTHPs require a wall penetration, which unless well sealed can present opportunities for uncontrolled air leakage in the building.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | **Multifamily** | **Lodging/ Hotel** | **Office** |
|---|---|---|---|
| **EUI Reduction** | 14.5% | 7.1% | n/a |
| **GHG Reduction** | 4.8% | 2.1% | n/a |

*Relative Cost*

- **Low ($)**
- PTHPs are generally considered the least-cost option as compared to split system technology.

## Central Air to Water Heat Pump with Hydronic Distribution

A common configuration in buildings is a central gas-fired boiler that serves a water loop supplying water source heat pump terminal units within apartments. Instead, a central air to water heat pump can generate hot water for heating and some models can also produce chilled water for cooling. This conditioned water can be pumped to water source heat pumps within apartments in the same way without the fossil fuel plant.

The central plant must be designed to supply low-temperature heated water, lower temperatures than generated in standard hot water heated systems today. Some plants are able to reverse cycle and generate chilled water for cooling with standard chilled water coils. Alternatively, a cooling tower can be installed in the building to reject heat for air conditioning in water source heat pump systems.

The apartment terminal units must be individual water source heat pumps or a low-temperature variation with hybrid water-cooled air conditioners to work best with the characteristics of a central air to water heat pump plant. Both terminal unit options use compressors to provide cooling in the summer, and that electricity usage will increase resident bills. The water-source heat pumps will also use their compressor to extract heat out of the water loop in the winter, but the hybrid water-cooled units use a lower-energy fan coil for heating.


x

*Configuration*

- Central

*End Use*

- Heating, Cooling

*Typology*

- Office, Hotel, Multifamily

*Technology Availability*

- Uncommon but Available: Central heat pumps that generate hot water and meet process loads are used around the world. Commercial-scale equipment for heating and hot water in colder climates is available in the United States, but the technology is still in development as demand is not high. Designers and installers must be properly educated on system requirements and local regulations since they are not in wide use.

*Benefits*

- User Control: Indoor temperatures can be determined by the occupant
- Reduced Refrigerant Leakage Risk: Refrigerant leakage is less of a concern as all components are factory assembled and tested and no refrigerant distribution piping is needed. A central heat pump means a central piece of equipment with a factory sealed refrigerant circuit, reducing opportunities for leakage. A single central plant also means that equipment can be upgraded as technology advances without changing the distribution system or accessing apartments. This modularity provides insurance against the unknown technology and regulatory future.
- Technology Acceptance: Central hydronic systems are used in multifamily buildings nationwide. This configuration's distribution system can be installed and serviced the same as typical systems.
- Campus Connectivity: Hydronic distribution can connect multi-building complexes in a district heating and cooling system. Efficiency gains can arise when heating and cooling loads occur simultaneously; heat exchangers can transfer heat between loops where needed. Underground piping, however, can be difficult to repair and manage.
- No Building Size Constraints: There are no limitations based on building size. High-rise buildings can use this technology, using heat exchangers to divide the building into zones.

*Practical Challenges*

- Equipment Lifespan: Central heat pumps currently have an expected lifespan of 15-20 years, as compared to an expected 15 year lifespan of modern high efficiency/ condensing boilers.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | **Multifamily** | **Lodging/ Hotel** | **Office** |
|---|---|---|---|
| **EUI Reduction** | 15.7% | 7.7% | 7.2% |
| **GHG Reduction** | 6.6% | 2.8% | 2.3% |

*Relative Cost*

- **High ($$$)**

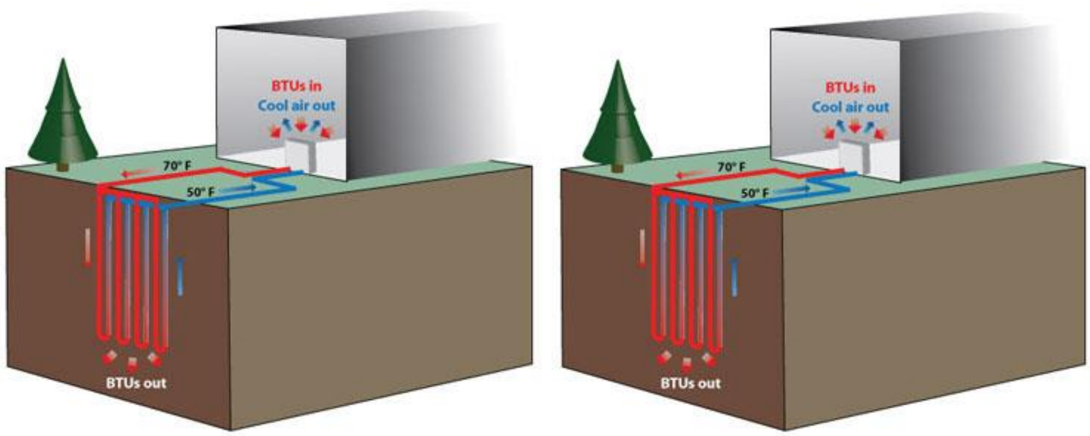
## Ground Source Loop with Hydronic Distribution

This configuration is similar to the *Central Air to Water Heat Pump with Hydronic Distribution* above, but instead of a central heat pump conditioning water, a water loop circulates underground and feeds the hydronic distribution to apartment water source heat pumps via a heat exchanger or central water-to-water heat pump.

This means there is no central plant in some cases. Pumps circulate water between the ground or body of water and building. Ground temperature varies much less than air temperature, so ground-source methods remain efficient even on the coldest days of the year and result in a more stable, predictable load.

Apartments will contain water source heat pumps which extract or dump heat to the central loop. Temperatures are controlled by residents, and heating and cooling can be provided simultaneously since the central loop uses heat recovery.

DHW can also be generated with this system with the addition of a central water to water heat pump, where heat is extracted from the loop. This approach can also improve cooling efficiency in the summer as it cools the loop water.




xi

*Configuration*

- Central

*End Use*

- Heating, Cooling, DHW

*Typology*

- Office, Hotel, Multifamily

*Technology Availability*

- Mature: The general technology is mature and available in the United States. Some configurations incorporate central equipment to supplement the ground source loop, in that case a central heat pump is required for an electrification approach, rather than a gas-fired plant.

*Benefits*

- User Control: Indoor temperatures can be determined by the occupant
- Reduced Refrigerant Leakage Risk: Refrigerant leakage is less of a concern as all components are factory assembled and tested.

*Practical Challenges*

- Cost and Permitting: Installation of a ground source loop is inherently site-specific and requires drilling and trenching underground.
- Geological Constraints: Natural ground conditions and underground infrastructure may prohibit drilling. A geothermal feasibility study is needed for every installation as a result. The presence of bedrock can rule out the possibility of well drilling, for example this is a known issue in Rosslyn. Adequate space is also needed. The number of wells and required area relates to building size and load; the larger the building and the higher the energy needs, the more underground space is needed. A New York City case study estimates that for a 100,000 square foot office tower, 10 standing column vertical wells would be needed to meet loads, and 8 wells would be needed for a multifamily building of the same size.[xii]
- Contractor Knowledge Base: Availability of installers with knowledge of installation and design of large-scale systems may be limited. Identifying contractors with experience in these systems is particularly crucial due to the high cost.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | Multifamily | Lodging/ Hotel | Office |
|---|---|---|---|
| **EUI Reduction** | 16.2% | 8.0% | 7.4% |
| **GHG Reduction** | 7.3% | 3.1% | 2.5% |

*Relative Cost*

- **High ($$$)**
- Major drivers of cost are the bore field, new hot water distribution piping (depending on if the building's piping can be reused), and the terminal heat pumps in each room.

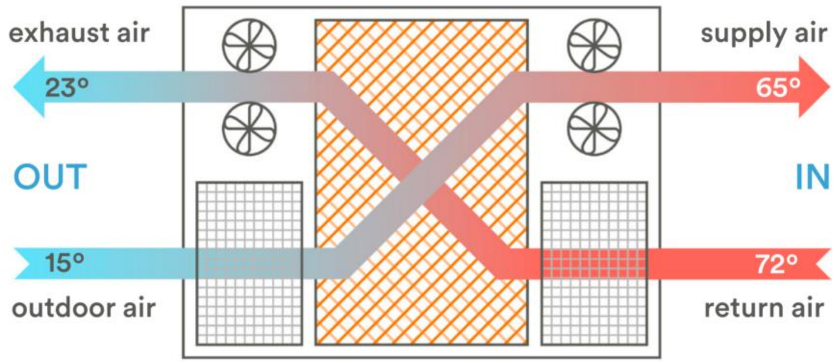
## Energy Recovery Ventilation with Heat Pump

Electrification of the ventilation system first means eliminating natural gas-fired supply air sections. A central ventilation supply system can be optimized to operate efficiently alongside the building's heating and cooling system, and can utilize heat pump technology when needed rather than electric resistance or natural gas.

The most efficient approach is a Dedicated Outdoor Air Supply (DOAS) system, a unit that supplies fresh outdoor air to the building in a controlled manner to meet ventilation needs. It is capable of cooling and dehumidifying the air in the summer and heating it in the winter if needed, but the air flow rate is not sized to provide conditioning to the space above the base ventilation needs.

The addition of an Energy Recovery Ventilator (ERV) can create major efficiencies and cost savings. An ERV transfers heat from one air stream to another; in winter it transfers heat from exhaust air to warm the fresh supply air, in the summer the supply air is cooled. This technology can reduce the fresh air heating and cooling load by 75%. This means 75% of the load is met passively, and when designed properly, no additional heating or cooling element may be needed if the use case can support some additional load in the spaces served. For example, interior heat gains and the existing heating systems may keep temperatures comfortable on their own. This reduces equipment cost significantly up front, as well as reducing energy usage and associated piping and other components needed for conditioning.

Heat pump heating and cooling sections are available to temper the outdoor air in situations where additional heating and cooling is needed to maintain temperatures. The ERV already tempers the air which eliminates the need for a preheater, and the heat pump components are highly efficient. Electric resistance heat may be used instead, however use of heat pump components greatly reduce operating costs and require smaller electrical service comparatively.

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*Configuration*

- Central

*End Use*

- Ventilation, Heating, Cooling

*Typology*

- Office, Hotel, Multifamily

*Technology Availability*

- Mature: DOAS and ERV equipment is available in the United States. ERV is required by code in various jurisdictions. Heat pump heating sections are available through some but not all manufacturers. An ERV with a heating section can be efficiently electrified, but requires some research on manufacturer compatibility.

*Benefits*

- Reduced First Costs: Reduced needed for natural gas piping, potential elimination of heating and cooling elements.
- Reduced Refrigerant Leakage Risk: Refrigerant leakage is less of a concern as many systems will not require use of additional heating or cooling sections, and if needed, sections are reduced in size due to the decreased load from use of an ERV.

*Practical Challenges*

- Appropriate Design Needed: Code prescribes ventilation rates based on occupancy, space type, and space size. Exhaust and supply loads must be balanced to maximize ERV efficiency and heating and cooling capacity. As an example, spaces such as laundry rooms are complex as dryer exhaust may not be run through an ERV and instead directly exhausted. This space as a result needs 100% outdoor air which adds conditioning load.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | **Multifamily** | **Lodging/ Hotel** | **Office** |
|---|---|---|---|
| **EUI Reduction** | 5.5% | 4.6% | 7.5% |
| **GHG Reduction** | 6.4% | 5.1% | 7.6% |

*Relative Cost*

- **Medium ($$)**
- A DOAS system using an ERV may reduce first costs by reducing the required size of the rest of the heating and cooling equipment.

## DHW - Central Air to Water Heat Pump (AWHP) Plant

An air to water heat pump (AWHP) DHW central plant uses the same distribution as a standard central DHW system. A large AWHP or grouping of smaller units are joined together with adequate thermal storage to generate DHW. Thermal storage is necessary as these plants operate most efficiency with long runtimes with minimal compressor cycling. Storage also allows for reduction in plant capacity as the tanks can act as a buffer during demand spikes. Appropriate sizing of a plant and storage is crucial for this reason.

The AWHPs cool air to heat water. These systems are either located within a building's mechanical room or outside which use outdoor air. Note that it is very uncommon for typical multifamily buildings to have enough ambient waste heat in mechanical rooms to support AWHPs producing the whole site's DHW load. The AWHPs typically are located outdoors and only indoors if there is a unique condition leading to a high and continuous need for cooling.

This is a stand-alone equipment option that solely generates DHW and can be paired with other heating and cooling systems.

One residential sized model using $CO_2$ as opposed to refrigerants are available within the United States, more models are currently available internationally.[xiv] More models are expected to enter the United States market within the next few years.


[xv]

*Configuration*

- Central

*End Use*

- DHW

*Typology*

- Hotel, Multifamily

*Technology Availability*

- Developing: This technology is not currently widely available in the United States, but it is being piloted in larger buildings now.

*Benefits*

- Refrigerant Options: Commercial-scale $CO_2$ based models will be available in the future, allowing the technology to stay ahead of regulations and reduce unintended emissions.

*Practical Challenges*

- Refrigerant Constraints: Units that use R410a refrigerant cannot produce hot enough water on particularly cold days to charge a storage tank to Legionella-safe temperatures. Design solutions for this problem require close attention when applying these products. Units that use $CO_2$ as a refrigerant can create hotter water on cold days to avoid this concern more easily.
- Temperature Balancing: Domestic hot water recirculation is difficult to manage with these systems; minimizing and balancing recirculated water is important and must be part of the design process.
- Building Size Constraints for Units Using $CO_2$: Units that use R410a refrigerant are sized for larger buildings, but face temperature issues during cold outdoor temperatures. The limited number of units utilizing $CO_2$ as a refrigerant are currently available only for smaller-scale applications. Units of this type can be combined for smaller buildings, roughly for a multifamily building with 60 apartments or less. It is possible to compile multiple small zones to serve larger buildings, but this increases the complexity of the system. Larger buildings can be served more easily as more commercial grade $CO_2$ units come to the market,

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | **Multifamily** | **Lodging/ Hotel** | **Office** |
|---|---|---|---|
| **EUI Reduction** | 20.2% | 14.4% | n/a |
| **GHG Reduction** | 5.0% | 3.1% | n/a |

*Relative Cost*

- **Medium ($$)**

## DHW - Decentralized Heat Pump Water Heaters

Decentralized heat pumps water heaters operate in the same manner as the centralized system described above, but are individually placed in each unit or space.

[xvi]

*Configuration*

- Decentralized

*End Use*

- DHW

*Typology*

- Multifamily

*Technology Availability*

- Mature

*Benefits*

- Refrigerant Options: Models that use $CO_2$ do not need to pull as much heat from surrounding spaces or create excessive noise.
- Metering: Distributed systems can be made the residents' responsibility in owner-occupied housing, which reduces common-area maintenance charges.
- No Building Size Constraints: There are no limitations based on building size.

*Practical Challenges*

- Space Constraints: Distributed water heaters take up space in residences which could be used for other purposes. Greater infrastructure may also be needed for additional electrical service. Standard model heat pump water heaters can only be installed where there is air flow and heat to harvest to operate. Locating a heat pump water heater in an inhabited space means that the unit will pull heat from its surroundings, creating cooler areas. These units' compressors can also create noise issues in occupied areas if located centrally.[xvii]
- Design Constraints: Space heating and cooling loads could be impacted if the unit uses indoor air as a heat source, potentially in an uncontrolled way. Interactions and equipment sizing must be taken into account.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | Multifamily | Lodging/ Hotel | Office |
|---|---|---|---|
| **EUI Reduction** | 20.2% | n/a | n/a |
| **GHG Reduction** | 5.0% | n/a | n/a |

*Relative Cost*

- **Low ($)**
- Heat pump water heaters can cost 2.5 times less to operate than standard electric resistance water heating systems.[xviii]

## Induction Cooking – Residential

Electric induction cooking technology is highly efficient; up to 90% of the energy consumed is transferred to the cooking process, as compared to 74% for standard electric ranges and 40% for natural gas equipment. Through magnetic induction, heat is generated directly into cookware and far less heat is loss as compared to thermal induction between a heating element and a vessel.[xix]


[xx]

*Configuration*

- Decentralized

*End Use*

- Cooking

*Typology*

- Multifamily

*Technology Availability*

- Mature

*Benefits*

- Compatibility with Existing Construction: Equipment can be installed in place of standard electric units.
- Improved Performance: Induction cooking heats faster, wastes less heat into the indoor space, and safer as there is no radiant heat source or hot coil.[xxi]
- Indoor Air Quality: Gas cooking burners and stoves product significant quantities of nitrogen dioxide, carbon monoxide, and other ultrafine particles, all of which are dangerous to human health.[xxii] Proper ventilation can minimize the risk, but studies have shown electric induction equipment can emit less pollutants.[xxiii] Electrification of gas ovens also greatly reduces sources of carbon monoxide.
- Reduced Infrastructure: Eliminates need for gas piping for cooking
- No Building Size Constraints: There are no limitations based on building size.

*Practical Challenges*

- User Preference: It is possible that residents will prefer natural gas equipment, however many opinions on electric cooking is based on electric resistance equipment rather than induction technology.
- Cost: Induction equipment is higher cost than standard electric resistance equipment.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | Multifamily | Lodging/ Hotel | Office |
|---|---|---|---|
| **EUI Reduction** | 2.0% | n/a | n/a |
| **GHG Reduction** | -0.9% | n/a | n/a |

- GHG savings are estimated as nearly 0 since energy savings are so low. The resulting figure is a factor of this limited efficiency gain and the GHG coefficients for Arlington County. GHG reductions will improve as the electric grid becomes cleaner.

*Relative Cost*

- **Low ($)**

## Electric Cooking – Commercial

Many multifamily developments contain retail and commercial spaces on the ground floor. Electric commercial cooking, which includes stove top cooking as well as griddles, fryers, ovens, etc. can be electrified. Additionally, commercial grade electric induction equipment can reduce emissions resulting from natural gas-fired equipment.

*Configuration*

- Decentralized

*End Use*

- Cooking

*Typology*

- Commercial spaces within Multifamily and Hotels

*Technology Availability*

- Developing

*Benefits*

- Improved Performance: Induction cooking heats faster, wastes less heat into the indoor space, and safer as there is no radiant heat source or hot coil.[xxiv]
- Indoor Air Quality: Gas cooking burners and stoves product significant quantities of nitrogen dioxide, carbon monoxide, and other ultrafine particles, all of which are dangerous to human health.[xxv] Proper ventilation can minimize the risk, but studies have shown electric induction equipment can emit less pollutants.[xxvi] Electrification of gas ovens also greatly reduces sources of carbon monoxide.
- Reduced Infrastructure: Eliminates need for gas piping for cooking
- No Building Size Constraints: There are no limitations based on building size.

*Practical Challenges*

- User Preference: Business owners will need to be willing to adopt electric technology. Some types of cooking are more amenable to electrification than others, depending on need.

*EUI & GHG Emissions Reductions from Natural Gas-Fired Baseline Scenario*

| | **Multifamily** | **Lodging/ Hotel** | **Office** |
|---|---|---|---|
| **EUI Reduction** | 2.0% | 2.0% | n/a |
| **GHG Reduction** | -0.9% | -0.9% | n/a |

- GHG savings are estimated as nearly 0 since energy savings are so low. The resulting figure is a factor of this limited efficiency gain and the GHG coefficients for Arlington County. GHG reductions will improve ss the electric grid becomes cleaner.

*Relative Cost*

- **Low ($)**

## REFRIGERANTS

Heat pumps rely on refrigerants, which are fluids used to transfer heat energy from one space to another. Refrigerants have global warming potential (GWP) when released into the atmosphere, the very issue that electrification is meant to combat. As such, the use of harmful refrigerants in heat pump systems and oversight of any potential leakage is critical. Proper installation and testing during the commissioning process must take place to limit unintentional leakage.

Most manufacturers use blends of fluorinated chemicals for refrigerants, such as R410a and R134a. The leakage rates of these refrigerants in HVAC systems are regulated by the United States Environmental Protection Agency (EPA) when containing more than 50 pounds of refrigerant. This level is feasible in some of the central systems described in this report.

Future requirements impact the section of products today: the Montreal Protocol - Kigali Amendment will likely phase out refrigerants in use today over the next 15-20 years. Heat pumps currently have a lifespan of 15-20 years, however equipment installed today may need to be replaced in part or entirely at the end of that period, depending on adaptability to new refrigerant regulations.[xxvii]

Alternative refrigerants such as R-744 (carbon dioxide) are used for a growing number of products domestically and internationally; these mediums may be phased in in light of future regulations. For example, New York and California have passed legislation to phase out R410a and R134a hydrofluorocarbon (HFC) refrigerants

## UTILITY & OPERATING COSTS

Electricity is a more expensive energy source than natural gas or oil. Electric systems, however, are more efficient. In general, operating costs for buildings with heat pump systems have been found to be lower as compared to buildings with electric resistance or fuel oil systems. Costs may even be lower in some situations as compared to buildings using natural gas.

## BACKUP GENERATION

An electrified approach to backup generation is both expensive and complicated as it relies on solar PV and battery storage. This approach may not be able to supply needed power; the cost of such a system is better applied to other areas of the building.

The use of diesel fuel is likely the most appropriate at this time; backup generation usually relies on fossil fuels and by its nature operates infrequently. Generators are also replaceable equipment that can be swapped out when better technology exists. Diesel fuel combustion emits more GHG emissions than natural gas but its use in this context is not necessarily in conflict with a low carbon strategy. Natural gas equipment requires expensive infrastructure (piping, meters), and this sunk cost could encourage the use of other gas equipment at the site.

## METERING

Electrical metering determines who pays for heating, cooling, and potentially DHW – either the resident/ commercial tenant or the building owner. Some or all of the electrical usage can be placed on the occupants' meter based on a system's configuration.

Shifting the cost responsibility to individual users removes a financial burden for building owners, and has been shown to reduce energy usage up to 20% as users have control over their own expenses. This shift, however, may not be feasible for some residents, depending on the existing rent structure. There are generally three types of metering configurations:

- Master metering: One central meter for the entire building where all electrical usage is charged. Occupants pay towards electricity usage through some division of the total bill based on unit size or another consideration, but not based on actual usage since it is not measured.
- Direct metering: Each unit is connected to its own meter and responsible for payment of their bill. It is the simplest approach to placing the responsibility of cost on occupants.
- Submetering: A master meter records building-wide electricity usage and this usage is charged to one bill with the utility. Dedicated submeters read individual usage at the apartment level so tenants can be charged for their consumption. A third-party must administer the calculation and distribution of bills. Each state and some jurisdictions have their own rules regarding submetering practices.
    - Despite the additional administrative costs, submetering carries advantages since there is technically one utility meter. As a result, demand management practices, utilizing on-site solar, and use of advantageous time-of-day rates to reduce costs are options that do not exist with direct metering.
    - Beyond electrical submetering, many VRF manufacturers are capable of submetering refrigerant usage for indoor units in order to proportionally allocate the electricity consumed by the outdoor unit. This requires the purchase and installation additional monitoring/metering equipment and software.
    - Hot water (hydronic) heating systems can be submetered, but it requires a custom solution to measure heat in/out of the water loop. This requires knowing the flow rate through the terminal unit and the change in temperature across it. This practice is common within the European Union and beginning to appear in the United States.

### Virginia Submetering Regulations

Electrical submetering is permitted in Virginia. Virginia Administrative Code Chapter 305 and Code of Virginia section 55-226.2 lay out regulations on the administration and billing of submetering in multifamily and commercial buildings.

Ratio Utility Billing (RUBS) is also permitted in Virginia. RUBS billing is the division of master-meter energy usage across individual units based on a set formula, such as unit size, occupancy, or other factors since actual usage is not known.

### Affordable Housing Metering Regulations

Heating, cooling, and DHW can be on the resident meter in Arlington's affordable housing. Properties constructed using Low Income Housing Tax Credits (LIHTC) must cap rents based on a resident's income. This rent includes utility costs. Decentralized systems' electrical usage can be placed on a resident's meter, however, provided that a utility allowance is granted to the resident. A utility allowance is a calculated reduction in rent for the resident; the owner charges a lower rent as a result, but also does not have the responsibility of individual utility costs.

# 3. BUILDING ELECTRIFICATION & POLICY FRAMEWORK

Climate goals cannot be met and GHG emissions cannot be meaningfully reduced without addressing energy usage in buildings. Buildings in the United States account for 40% of total GHG emissions, making them the biggest contributing source.[xxviii] In cities with colder climates, fossil fuel use in buildings can account for 40% or more of total citywide emissions. Nationwide, fossil fuels can account for 50-75% of building energy use and emissions in a typical residential building.[xxix] Further, natural gas extraction and distribution can result in methane leaks. Methane has 80 times the warming impact of carbon dioxide over a 20-year timeframe, therefore even small leaks have a significant impact. Methane leaks are estimated to be between 2-12%; a 2.3% leak rate makes the global warming impact from gas equivalent to that of coal.

Jurisdictions and utilities have historically used voluntary programs to target energy savings. Cities, counties, and states, however, are now developing mandatory standards with increased frequency to address the need to reduce emissions.[xxx] Increasingly, cities are adopting “80x50” or carbon goals and implementing efforts to achieve them.[xxxi]

Any plan to reduce building GHG emissions must address the use of fossil fuels (oil and natural gas) for heating, cooling, and hot water, as well as cooking and other process loads. Electrification must take place – the replacement of fossil fuel-using systems with high efficiency electric heat pump systems. This equipment is the most efficient available on the market and electricity emits no emissions at the site level, unlike fossil fuels. Widespread adoption of heat pump technology is estimated to reduce economy-wide energy consumption, even when increasing electricity consumption due to efficiency gains.

Technologies using electricity are also crucial as they can be powered by renewable energy and a cleaner grid in the future that relies more on renewable generation. Efficient cooling systems are important as regions face increased extreme heat resulting from climate change.[xxxii]

## ARLINGTON COUNTY CONTEXT

Building energy usage constitutes the largest share of consumption in Arlington County. Electricity consumed in buildings accounts for roughly 38% of Arlington’s county-wide energy use, while 23% is natural gas consumed in buildings for heat and hot water. The remaining 39% is associated with transportation.[xxxiii] In 2016, building energy usage accounted for 58% of Arlington’s GHG emissions, 23% from the residential sector and 35% from commercial buildings.[xxxiv]

A study of Arlington County’s building stock found that the energy split between commercial and residential overall site energy usage was roughly 50/50 in 2012. Commercial building energy usage was primarily electricity (81%), where residential buildings used electricity and natural gas in a 52% to 48% split. The overall fuel split for both sectors was 66% for electricity and 34% for natural gas.[xxxv]

Multiple initiatives are underway in Arlington County and Virginia to reduce carbon emissions, either through reducing energy consumption by end users or during the production of electricity at the grid level:

### Virginia Carbon Free

In 2020 Governor Northam signed into law the Virginia Clean Economy Act, requiring a transition to 100% carbon-free electricity generation in the state by 2045. The law also sets targets for large expansion of renewable power, including an expansion of offshore wind and improved access to rooftop solar. Virginia joins five other states, California, Hawaii, New Mexico, New York, and Washington, as well as Puerto Rico and Washington, D.C., in signing laws that require a full transition to carbon-free or renewable energy, rather than simply goal-setting. [xxxvi]

## Dominion Energy

Dominion Energy has set its own renewable energy goals to meet standards in Virginia and North Carolina. It targets achieving 12.5% renewable power by 2021 and 15% renewable power by 2025.[xxxvii]

## Arlington Initiative to Rethink Energy – Carbon 2050 Neutral

Arlington County adopted a Community Energy plan in 2013 as part of the County's Comprehensive Plan (2013 CEP) to formulate energy policy and a climate action framework. The plan was updated in 2019 (2019 CEP) to respond to improvements in the marketplace and technology.[xxxviii]

The 2019 CEP has four principal goals:

1) a 2050 emissions goal to achieve Carbon Neutrality, which is a change from the 2013 goal of 3.0 metric tons (mt) of CO2e/capita/year;
2) an accelerated community renewable energy goal of 100% by 2035;
3) an accelerated government operations renewable energy goal of 50% by 2022 and 100% by 2025; and
4) addition of Equity as a focus area to inform design, investment and implementation of the 2019 CEP.[xxxix]

## Arlington County Programs

The Arlington County Green Building Density program encourages building energy efficiency in new construction projects by offering buildings bonus density allowances in exchange for projects achieving the nationally-recognized LEED certification. A Zero Carbon certification allow developers to earn further bonus density.[xl] Arlington County also incorporates green features and energy efficiency in its public facilities through Arlington's Policy for Integrated Facility Sustainability.[xli]

## Arlington County Green Building Density Program Outcomes

SWA reviewed building data for a portion of buildings that are recent participants in Arlington's Green Building Density Incentive program and found the following typologies and participation:

| Status | In Design | Under Construction | Completed | Total |
|---|---|---|---|---|
| **Multifamily High Rise & Mid Rise** | 8 | 12 | 1 | 21 |
| **Affordable Multifamily High Rise & Mid Rise** | 0 | 2 | 0 | 2 |
| **Office** | 0 | 2 | 1 | 3 |
| **Total** | **8** | **16** | **2** | **26** |

Design strategies in the Arlington County Green Building program show movement toward electrification.

Twelve of the 21 multifamily buildings with available information (two did not have system information) were designed with VRF systems in apartments and one with PTHP. Seven designed water source heat pump systems with natural gas-fired condensing boilers, and one building designed a hot water (hydronic) heating system.

Thirteen of those same 21 properties utilized electricity for domestic hot water (DHW) production. Six MF buildings and three offices use electric storage units, one of which designed electric heat pumps utilizing waste heating from condenser water systems. The other MF buildings used electric instantaneous and in-unit electric storage approaches.

Most corridors are heated with gas-fired equipment through rooftop equipment that provides fresh air. One development (Best Western) has designed a VRF system for corridors.

Electric stoves were specified in five projects. Full information on cooking systems for all buildings, or if induction technology was specified, was not available. Information is not sufficient to draw larger conclusions.

## OTHER CITIES AND STATES

Total current-year budgets for building electrification programs across the United States are nearly $110 million, up 70% from the prior year. As these programs develop, they are adjusting their incentives, adding components, and including additional components such as optimized whole-home retrofits and all-electric new construction. Programs are most extensive on the West Coast and Northeast but growing in other regions.[xlii] Examples of such efforts include:

- New York, NY: Committed to an 80% reduction of GHG emissions from a 2005 baseline by 2050 (80x50). As part of this effort, New York City's Local Law 97 requires all buildings over 50,000 SF to meet strict GHG targets or face fines, beginning in 2025.
- Berkeley, CA: Committed to 100% renewable electricity by 2035, and net-zero carbon emissions by 2045. This includes the first of its kind 2019 ban of natural gas in new buildings.[xliii]
- Washington, DC: Committed to carbon neutrality by 2050, with an interim target of a 50% GHG reduction by 2032. Washington DC also passed what is considered by some as the nation's strictest climate law passed by a U.S. City. The Clean Energy DC Omnibus Act, which includes the building energy performance standard (BEPS). BEPS requires all existing buildings 50,000 SF and larger to meet minimum performance standards (at least median performance) by 2026 or receive financial penalties.[xliv]
- Boston, MA: Updated its Climate Action Plan in 2019 to reduce emissions from buildings, including constructing new municipal buildings to a zero net carbon standard, adopting a zero net carbon standard for city-funded affordable housing, and developing a carbon emissions performance standard to reduce emissions from existing large buildings.
- St. Louis, MO: Passed the fourth building performance standard in the country, requiring 65% of buildings by property type to improve performance. The law contributes to the city's goal of eliminating GHG emissions by 2050.[xlv]
- Rhode Island: commissioned a study on decarbonizing the state's building heating systems as part of 80x50 targets.[xlvi]

# 4. PHASING

Rollout of an electrification program for newly constructed buildings in Arlington County should focus on both GHG impact and technology availability. Systems should be prioritized in the following order:

1. Heating and Cooling Systems
    a. Heating and Cooling constitute the largest end uses in Arlington's buildings; improvements to these systems have the highest potential for GHG reductions.
    b. These loads are usually provided by the same equipment, savings on up front equipment costs.
    c. The technology is most mature as compared to DHW and cooking. Technology is available as are qualified installers and vendors with experience with these systems.

2. Central Ventilation Systems
    a. Where present, central supply ventilation systems should be designed in conjunction with heating and cooling systems to ensure equipment is sized appropriately. Central ventilation systems impact heating and cooling loads and may be required to condition outdoor air themselves.

3. DHW Systems
    a. DHW is a smaller load than heating and cooling.
    b. These systems can be incorporated in more of a plug and play manner, resulting in less disruption to building design.
    c. Technology is still in development for more effective and affordable large scale options.

4. Cooking
    a. Cooking loads are a small percentage of overall building energy usage within multifamily buildings.
    b. Technology is available.
    c. Health benefits are well documented, however user adoption may be slow.

## OTHER CONSIDERATIONS

Other elements of an electrification program should be considered to improve effectiveness.

### Encourage Futureproofing of Buildings

Buildings without electrified systems can still be encouraged to accommodate for future system upgrades.

- Electrical distribution within the building should be upsized for an electrified building where sensible and allowable per code, and space should be left for additional feeders and panels for future loads, even if using natural gas in the immediate term.
    - Buildings are served by electric service(s) where the building's power infrastructure connects to the grid. The service(s) feed switchgear, which then serves the building's various end uses. From here, electric feeders connect switchgear, meters, and panels serving spaces, and wiring finally connects the subpanels to equipment in a space. These feeders are affixed with meters to measure usage.
    - Electrification of any load impacts this whole chain, meaning all components must be sized appropriately to provide the correct voltage and current for specific equipment. New construction designs may have adequate capacity in some areas but not in others, determining what incremental increases are needed and where.
    - Costs for increased service is hugely variable site by site but should be investigated at the initial design phase. Depending on the design, only some or many elements may need to be upgraded to meet future loads. At the start of the chain, the electric service

itself may need to be increased, or it may be necessary to add a new additional service. Initial research indicates that this cost is often less than 10% of overall project cost in a comprehensive electrification retrofit for existing buildings, however the cost of service modifications varies greatly depending on the size of the change and the service location. The cost of upgrades in new construction projects is incremental for upsizing the service as needed and is therefore a lower percentage of project cost. Overall, electrical service upgrades are much more expensive in existing building retrofits, since it is an entirely new scope of work as compare to preparing a new building with moderately larger wires and panel slots where most labor and material costs are already sunk.
    - Electric service needs are also dependent on the type of building. Multifamily buildings and hotels may have higher heating loads than office buildings, but office buildings tend to have higher cooling loads. Unique loads such as commercial kitchens may have their own considerations.
    - Increases in electrical load may also impact the sizing of utility infrastructure. This planning should be coordinated with the utility in advance to potentially reduce upgrade costs later.
- Leave access for mechanical spaces. Large equipment will be needed on rooftops under electrification scenarios and heat pump units will need to be replaced. Ensure ease of access for large equipment to the roof.
- Install submetering to drive behavioral change if direct metering not already in place.
- Encourage installation of low temperature hydronic systems that can utilize central heat pumps later
- Provide enough structural support to carry ~15-20 gallons of water stored per apartment unit in the future; DHW heat pump plants require storage.
- Central DHW systems in particular can be planned for:
    - Provide structural support and space for storage tanks in/near the boiler room.
    - Clear chase space from the boiler room to the outdoor heat pump location for easy installation of a riser pair with insulation.
    - Design for a low recirculation flow rate with balanced risers. Balanced low flow recirculation is best for heat pumps.
    - Leave spare breakers in the boiler room for additional pumps and controls for the heat pump system.
    - Consider leaving valved off and capped futures for easier heat pump connections to the existing piping.
    - Put valves in everywhere to make it easier to isolate portions of the system for installing new components.

## Refrigerant Leak Detection

Refrigerant leakage can be reduced through oversite of installation.

There are two main resources in the industry for systems containing refrigerant; 1) Chapter 11 of the International Mechanical Code and 2) ASHRAE Standard 15.

ICC requires systems like VRF heat pumps with refrigerant piping that is erected on-site to be tested for refrigerant leaks after it has been completed and before start-up. ASHRAE 15 provides some additional guidance on where and how to install the piping like leaving joints exposed for visual inspection before covering them. The ICC already includes/references most of ASHRAE 15 so it is not recommend to include ASHRAE 15 as a referenced standard separately.

Even though the code requires systems be leak tested and a certificate of doing so be "made part of the public record" it is recommend taking this verification portion a step further by bringing the Commissioning Agent in to oversee the process and specifically require them to verify the following which is currently also not required in energy code (IECC) commissioning:

- Collect as-built refrigerant piping line length calculations (as-designed lengths would not be acceptable as too many changes are made to the often overly simplified designed runs)
- Collect and review the detailed refrigerant pipe pressure and vacuum testing reports that have been based on the as-built calculations for completeness and accuracy
- Collect the charge confirmation documentation

## Data Tracking

Direct and submetered properties can provide a wealth of data for analyzing county-wide energy usage. The availability of this data can assist in separating resident usage from central usage, and heating and cooling loads as compared to baseloads. This granularity allows for a better understanding of the county's energy profile and can better inform future county policy and utility initiatives. Access to this data should be encouraged.

## Designing for Equity

Arlington's 2019 CEP defines Energy Equity as "the fair distribution of the burdens and benefits from energy production and consumption; including but not limited to how accessible and affordable the energy supply is across a population and sensitivity to its socio-economic complexity." It specifies that that Arlington's energy and climate strategy should ensure equity is an established focus of its efforts.[xlvii]

Electrification can contribute to equity by giving residents controls of indoor comfort and potentially ownership of utility expenses.

More efficient equipment and control over indoor temperatures could positively impact resident's monthly costs. Improved individual controls can ensure resident's temperature needs are met as needed.

Removal of fossil fuels at buildings eliminates emissions on site and improves air quality.

# APPENDIX A: GHG REDUCTION CALCULATIONS

Whole building GHG and EUI reductions by equipment type as compared to a baseline case were estimated.

SWA identified expected average natural gas EUI for the three building types using data from the United States Energy Information Administration's Commercial Buildings Energy Consumption Survey (CBECS). This national survey collects information on commercial buildings to draw conclusions on common energy usage patterns. SWA adjusted this data using guidance from the *Arlington County Building Energy Study* prepared by Leidos Inc. in March 2015. SWA estimated 85% efficient natural gas plants for heating and DHW production as the baseline scenario.

Efficiency improvements for the modeled equipment, measured in COP, was estimated based on a combination of rated equipment efficiencies, field testing, and industry research. For comparison, a standard natural gas system estimated at 85% efficiency would be roughly the equivalent of a COP of 0.85. Electric resistance technology is assumed 100% efficient, or a COP of 1:

| VRF | Mini-Split | Electric PTHP | Central Heat Pump w/ Hydronic Distribution | Ground Source Loop w/ Hydronic Distribution | DHW – Central Heat Pump Plant | DHW – Decentralized Heat Pumps |
|---|---|---|---|---|---|---|
| 3 | 3 | 2.5 | 3 | 3.25 | 2.2 | 2.2 |

Associated GHG reductions were based on electrifying the resulting more efficient load. The Environmental Protection Agency's eGRID coefficients were used to estimate GHG impact. The average emissions factors for the SRVC subregion were selected and applied to natural gas and electricity. The average factors estimate the annual total generation for electricity through the mix of different fuel sources. The following factors were used:

- Natural Gas: 0.05311 kgCO2e/kBTU
- Electricity: 0.107681 kgCO2e/kBTU

Note that these GHG savings are based on the current estimates of the associated emissions from electricity production for Arlington's electricity grid. These savings will increase as the grid because cleaner and more reliant on renewable energy.

# APPENDIX B: COST RESEARCH

A growing number of studies show that new construction buildings with all-electric systems can have lower upfront construction costs as compared to those with natural gas-fired systems, largely due to elimination of gas infrastructure and piping. Operating costs can also be reduced in comparison to this baseline scenario.

Cost comparisons in this research are between discussed electrification technologies and are based on equipment first-costs. All HVAC and DHW systems will include soft costs for appropriate design, sizing, and layout that is not necessarily provided by installers.

Cost estimates are provided in a scale of Low (**$**), Medium (**$$**), and High (**$$$). ** Estimates were based on available market research and supporting information from known designers and installers in the Arlington market.

Heating & Cooling

- Electric PTHP units have the lowest upfront costs, but the least efficient of the options.
- Minisplit systems and VRF systems are estimated within the mid-range cost scenario, with VRF systems being the more expensive option. In a retrofit scenario (different than the new construction research here), research has shown costs over $20/ SF
- Central heat pumps configuration cost information is limited. However, costs are not expected to be as high as ground source heat pumps.
- Ground source heat pump loop systems are estimated to have the highest costs due to permitting and required geological work. In a retrofit scenario (different than the new construction research here), interviews and research has shown costs over $25/ SF.

Domestic Hot Water

- Centralized DHW heat pump plant cost information is limited. One individual study saw roughly a 50% cost increase as compared to a standard natural gas boiler.
- Individual heat pump water heaters are more expensive than standard electric resistance models (research and interviews show increased cost of 50%-100%), however operating expenses are lower.

Cooking

- Induction stoves carry a higher cost than standard electric models or gas-fired models, but a less significant cost to the overall building as compared to heating or DHW systems.

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