DISTRICT OF COLUMBIA

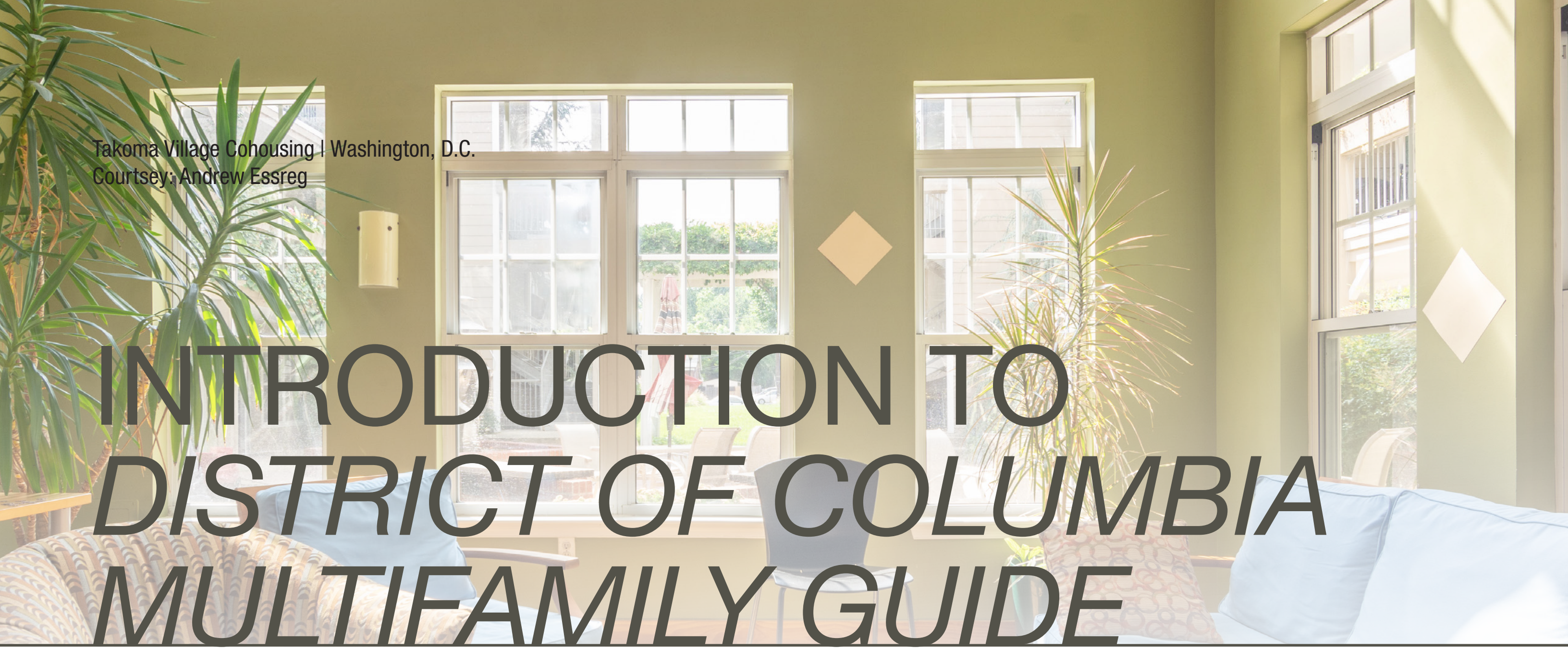
MULTIFAMILY GUIDE

AN ADVANCED GUIDELINE TO ACHIEVE SIGNIFICANT, PREDICTABLE ENERGY SAVINGS IN MULTIFAMILY BUILDINGS

NET-ZERO ENERGY DC

DISTRICT OF COLUMBIA MULTIFAMILY GUIDE

The Pearl, luxury apartments in Silver Spring, MD, owned and managed by The Tower Companies



Takoma Village Cohousing | Washington, D.C.
Courtsey: Andrew Essreg

INTRODUCTION TO *DISTRICT OF COLUMBIA MULTIFAMILY GUIDE*

The *District of Columbia Multifamily Guide* contains a comprehensive whole-building prescriptive guideline for achieving significant, predictable energy savings in new multifamily buildings. The Guide describes a set of simple, integrated design strategies and building features. When applied as a bundle, they result in significant energy savings over code for multifamily buildings of all types. Implementing the *District of Columbia Multifamily Guide* delivers 20-25% energy savings on average above the 2015 edition of the International Energy Conservation Code in climate zone 4A.

The DC Energy Conservation Code is one of the most stringent energy codes in the nation and is updated every 5 years to meet the District's GHG goals. The *District of Columbia Multifamily Guide* supports teams seeking greater energy efficiency and provides guidance of the most critical energy issues for multifamily buildings: domestic hot water, ventilation, site lighting and thermal bridging. General guidance on this topic is paired with specific guidance on meeting the related measures.

Background

With the District's continued building development, energy reduction in all new (and even existing buildings) is essential to meet the Clean Energy DC plan goals. Ultra-low energy multifamily buildings provide substantial business advantages to owners and developers, beyond the environmental benefits of reduced carbon and greenhouse gas emissions. Owners and developers who construct ultra-low buildings now are better prepared for changes in future energy codes, further setting them apart from the competition.

Energy efficiency multifamily buildings offer superior interior environments for tenants like improved thermal comfort, high-quality lighting, and better acoustics. Future tenants understand these attractive features and buildings lease-up quicker and have reduced vacancy and turnover rates. Energy efficient equipment often requires fewer repairs, reducing the number of call-backs

Figure 1: Even though these two buildings use similar construction types and similar equipment, the one on the left is subject to the residential code and the one on the right is subject to the commercial code.

and maintenance fees; further, ultra-low energy buildings provide reduced operating and equipment replacement costs. The benefits lead to an increased resale value which will grow developers' bottom line. As a bonus, customers will value buildings by the developer which is beneficial in a competitive market.

Multifamily buildings are subject to different sections of the commercial and residential energy codes, leading to confusion and missed opportunities in these buildings. High-rise multifamily buildings (those with four or more stories) are subject to the commercial code and low-rise multifamily buildings (those with three or fewer stories) are subject to the residential code. This split has created barriers to advancing the energy performance of this critical segment of the building market. Multifamily buildings are generally constructed like commercial buildings but used like residential buildings, meaning that neither the residential nor the commercial code adequately addresses the energy issues of multifamily buildings. Crafted for commercial loads and usage patterns, the commercial code doesn't really fit multifamily buildings with their residential usage patterns and loads. Crafted for the smaller size, lower density and generally simpler systems of single family homes, the residential code doesn't really fit multifamily buildings with their denser occupancy, common areas and frequently more complex systems. The code-minimum projects highlights some critical issues for energy efficiency caused by the way that the energy code addresses multifamily buildings.

These inconsistencies in energy code application have hampered the development and deployment of advanced performance strategies for the multifamily building sector. With their focuses on commercial and single family homes, the energy codes have not made as much progress advancing some multifamily issues, especially around ventilation, domestic water heating and infiltration.

The *District of Columbia Multifamily Guide* was crafted specifically to address these issues. The measure packages were chosen and calibrated to deliver savings regardless of whether the project is subject to the commercial or residential energy code. Developers and designers can use his guide regardless of what kind of multifamily project they are building. The accompanying guidance is crafted to address some of the most pressing issues facing multifamily projects, especially those issues that are most under-addressed by the energy code.

Note that the *District of Columbia Multifamily Guide* is not intended to completely replace the requirements of the energy code. Other requirements in current energy codes must still be addressed by any project using this Guide.

Guide Structure

The *District of Columbia Multifamily Guide* is divided into three parts: this Introduction, the Measures, and Guidance.

Introduction: The Introduction includes background information and a description of the purpose and content of the *Multifamily Guide*.

Measures: The Measures section includes the specific specifications for the bundle of measures that must be met in order to achieve the savings of the *Multifamily Guide*. It also includes additional energy options that can be pursued for greater savings.

Guidance: The Guidance Section includes guidance for four issues critical to the energy performance of multifamily housing: Domestic Water Heating, Site Lighting, Thermal Bridging, and Ventilation. This guidance will help design teams successfully implement the measures in the *Multifamily Guide* or any other multifamily project.

Measures

The Measures Section includes all of the measures that are a part of the *District of Columbia Multifamily Guide*. The measures are divided into two groups: the Integrated Bundle of Measures and the Additional Efficiency Options.

The integrated bundle is composed of thirteen measures, including:

1. **High Performance Windows:** Improved windows with above-code specifications for U-factor and Solar Heat Gain Coefficient (SHGC). These values generally correspond to the requirements for ENERGY STAR® windows. The measure includes some alternative specifications for windows that require greater structural strength, durability or ability to withstand wind loads; these windows are found almost exclusively in high rise buildings and were used to model savings for the high-rise prototype.
2. **Reduced Infiltration:** Reduced envelope infiltration verified by testing. The measure combines the (generally) more stringent

requirement from the commercial energy code with the testing requirement in the residential code, delivering savings above both codes.

3. **Reduced Thermal Bridging:** Improved detailing of the thermal envelope and better accounting for thermal bridges. The measure includes a straightforward list of prescriptive measures that will help reduce thermal bridging and standards for calculating the U-factor of the thermal envelope elements to better account for the impact of thermal bridges.
4. **High Performance HVAC Equipment:** Above-code levels of performance for HVAC equipment that generally correspond to the Consortium for Energy Efficiency's Tier 2 requirements for HVAC equipment.[1]
5. **High Performance Fans:** High efficiency fans, including specifications for both system and exhaust/ventilator fans.
6. **Efficient Ventilation:** Improved ventilation through the adoption of ventilation strategies that are both effective and efficient in multifamily buildings and that avoid some common inefficient configurations.
7. **Advanced HVAC Controls:** HVAC controls with better user interfaces that allow for greater ease of programming and access that are also more responsive to occupant needs and use patterns.
8. **High Performance Interior Lighting:** Reduced lighting power density in common areas and improved lamp efficacy in dwelling units.
9. **Interior Lighting Controls:** Occupancy and vacancy controls for common areas paired with implementation of bi-level lighting in some areas.
10. **High Performance Exterior Lighting:** Improved lamp efficacy for exterior site, landscape and architectural lighting.
11. **High Performance Water Heating Equipment:** Higher efficiency water heaters and boilers used for water heating.
12. **Hot Water Conservation:** Low-flow fixtures in kitchens and bathrooms.
13. **Efficient Appliances:** Energy Star appliances and other equipment.

There are 6 additional measures that offer additional savings above and beyond the bundle. These measures are meant to be implemented with the bundle of measures. They include:

1. **High Performance Thermal Envelope:** Reduced total U-factor for the thermal envelope that can be achieved through a combination of improved wall assemblies and windows and reduced window-to-wall ratio.
2. **Ground Source Heat Pump:** The use of GSHP for space heating and cooling.
3. **Radiant Heating/Cooling:** The use of radiant delivery systems for space heating and cooling.
4. **High Performance Heat Pump:** The use of high performance VRF or high-efficiency ductless mini-split systems for space heating and cooling.
5. **Heat Recovery Ventilation:** The inclusion of heat and energy recovery strategies in the ventilation system depending on climate zone.
6. **Heat Pump Water Heater:** Serve the hot water needs of the building with more efficient heat pump water heaters.

1 The Consortium for Energy Efficiency establishes three Tiers of above-code HVAC equipment efficiency.

Figure 2: A mixed-use mid-rise multifamily project with retail and offices on the ground floor.

Savings and Code Baselines

The measures in the Guide are designed to deliver an average of 20-25% savings over the 2015 edition of the International Energy Conservation Code, savings can vary more widely for projects depending on code baseline, climate, and multifamily project characteristics. Savings have also been calculated relative to the previous versions of the IECC and ASHRAE/ANSI/IESNA Standard 90.1.

Analysis Supporting the *Multifamily Guide*

An extensive energy modeling protocol has been implemented to support development of the *Multifamily Guide*. Thousands of individual energy modeling runs were generated using a batch protocol involving EnergyPlus and OpenStudio and then run using EnergyPlus. The analysis is based on the three multifamily prototypes developed by the Pacific Northwest National Lab for the Department of Energy code savings determination studies. The prototypes include:

1. A three-story, 18-unit low-rise multifamily building with open corridors and individual water heaters.
2. A four-story, 32-unit, mid-rise multifamily building with enclosed corridors and individual water heaters.
3. A ten-story, 80-unit high-rise multifamily building with enclosed corridors and a central water heating recirculation loop.

A baseline building that meets the requirements of each base code was defined for each permutation of the above prototypes in each of the ASHRAE climate zones. Note that the baseline building is defined using the prescriptive requirements of the applicable code. As a prescriptive standard, the *Multifamily Guide* is meant to be applied to buildings that would typically not complete energy modeling, and therefore the prescriptive requirements of code more accurately represent the target market.

Approximately 50 measures were considered for inclusion in the guideline and over 30 of those were included in the modeling. These were applied to each prototype and climate permutation to identify energy savings beyond the baseline models. Measures were only included in the Guide if they consistently demonstrated positive and substantial savings across permutations. Once these measures were identified, they were applied to the prototypes as a bundle. Some measures that demonstrated significant savings opportunities, but may not have been applicable or appropriate for all projects, were included as “additional efficiency options” that could be implemented in addition to the bundle for even greater savings.

Mixed-Use Buildings

The *Multifamily Guide* is intended for multifamily occupancies. This includes both the dwelling units and the common areas. However, many multifamily developments are actually mixed use projects that include both commercial and multifamily occupancies in a single building. The Guide can be used for the multifamily portion of the building, and many of the measures are applicable to the commercial sections as well. However, if the entire building is to achieve the high levels of performance that the Guide delivers for the multifamily portion, the commercial portion will need to follow a similar above-code standard intended for commercial buildings such as the *Advanced Buildings New Construction Guide*.

The *Multifamily Guide* and Energy Modeling

The *Multifamily Guide* is designed to provide a prescriptive option for achieving whole-building energy savings without energy modeling. However, the Guide can also be used to support a more effective energy modeling process. The Guide is based on an extensive energy modeling protocol to identify effective efficiency strategies. Therefore, the specific measures included in the Guide represent an excellent basis for any project undertaking energy modeling. Using the measures as a starting point in an energy modeling exercise allows projects to focus modeling resources on analyzing more advanced design strategies and design-specific issues rather than on answering basic performance questions. For projects targeting more aggressive savings, energy modeling can be used to help identify which additional efficiency options or combinations of options might be most effective.

The *Multifamily Guide* and the Energy Star Multifamily Standard

Historically, the US Environmental Protection Agency has maintained two separate ENERGY STAR® Standards for multifamily buildings. The Multifamily High Rise Standard was generally for high-rise multifamily projects subject to commercial energy codes, while low-rise multifamily projects subject to the residential energy codes generally used the ENERGY STAR® Homes Standard. This split has been an obstacle to greater success for ENERGY STAR® in the multifamily market.

In order to improve the impact of ENERGY STAR®, NBI and EPA collaborated in the development of the *Multifamily Guide* and EPA's forthcoming ENERGY STAR® Multifamily Standard. Both provide a single approach for both low-rise and high-rise multifamily buildings. As a result the *Multifamily Guide* is designed to align with the upcoming ENERGY STAR® Multifamily Standard (in development) and provides an option for even greater savings. The guidance included in the *Multifamily Guide* may also help projects successfully pursue the ENERGY STAR® Multifamily Standard when it is released.

Takoma Village Cohousing | Washington, D.C.
Courtsey: Andrew Essreg

The Pearl, luxury apartments in Silver Spring, MD, owned and managed by The Tower Companies

MEASURES

Fenestration:

The area-weighted average of all glazing assemblies shall meet the U-Factor and Solar Heat Gain Coefficient (SHGC) specifications shown below:

	CZ 4
Vertical curtain wall systems and metal site-built fenestration products	
Fixed Window U-factor	U-0.36
Operable Window U-factor	U-0.43
SHGC	0.35
For all other vertical fenestration except entrance doors	
U-factor	U-0.30
SHGC	0.35

Infiltration:

Verify that the envelope infiltration rate does not exceed 0.4 cfm/sf of envelope area when tested at 75 Pascals (or .3 CFM/sf at 50 Pa). Building testing shall comply with one of the following methods:

1. A whole-building blower door test verifying an infiltration rate of 0.4 cfm/sf of envelope area when tested at 75 Pa (0.3 cfm/sf at 50 Pa).
2. A floor isolation blower door test verifying an infiltration rate of 0.4 cfm/sf of envelope area for the specific floor when tested at 75 Pa (0.3 cfm/sf at 50 Pa).
3. Compartmentalization testing of individual dwelling units verifying an infiltration rate of 0.4 cfm/sf of the dwelling unit enclosure area when tested at 75 Pa (0.3 cfm/sf at 50 Pa). The dwelling unit enclosure area shall be the combined area of all floors, walls and ceilings that abut the exterior of the building, another dwelling unit, a common area space, an unconditioned space, or another occupancy in a mixed-use building.

Testing shall follow the protocol identified in ASTM Standard E779-10 as applicable. Leakage rates measured at another test pressure may be extrapolated in accordance with that standard. For compartmentalization testing, a sampling protocol in accordance with the following may be used:

- No fewer than seven total dwelling units shall be tested.
- Sample groups shall be no larger than seven dwelling units.
- Sample groups shall be composed of dwelling units with similar layouts and construction types.

- No less than one randomly selected dwelling unit from each sample group shall be tested. If the randomly selected dwelling unit fails, two additional dwelling units from the testing group shall be tested. If either of those dwelling units fails, the entire sample group shall be tested.
- During testing, all exterior doors and operable windows in the abutting spaces shall be open.
- If more than 25% of the dwelling units fail their first test, all of the dwelling units shall be tested.
- All failed dwelling units shall receive corrective measures and be retested until they pass.

Managing Thermal Bridging:

- The opaque envelope shall meet the U-factor requirements in the base code based on the Area-Weighted Average of the entire envelope component (eg Roofs, Above-Grade Walls, Floors, etc.). In calculating the U-factor of a building component, the U-factor shall be calculated as an area-weighted average of all points in the whole envelope component, not just a representative assembly. No points in the envelope shall be ignored, especially, but not limited to:
  - » Floor-to-wall interfaces.
  - » Wall-to-wall corner interfaces.
  - » Floor & slab edges.
  - » Other structural interfaces.
  - » Mechanical fasteners and structural connections that compose more than 0.5% of the assembly area.
- A minimum of R-3 continuous insulation shall be provided at all points in the thermal envelope.

Exceptions: 1. Structural connections that comprise less than .5% of the envelope component area
2. Structural connections provided with a thermal break of not less than R-3

- All window frames shall be installed with thermal breaks of not less than R-3 between the window and the opaque portions of the thermal envelope or the structure.
- All balconies shall a have a minimum R-3 thermal break between the balcony and the thermal envelope or be provided with R-3 continuous insulation.

Heating and Cooling System Efficiency:

- All space heating and cooling equipment shall meet the minimum efficiency specifications in Appendix A.
- Equipment not listed in the tables shall meet ENERGY STAR Criteria where available.

Ventilation:

All ventilation shall be provided by a system meeting the following guidelines:

- Sized in accordance with the 2016 or later editions of ASHRAE Standard 62.2 for dwelling units and ASHRAE Standard 62.1 for common areas.
- Balanced ventilation that is designed to provide make-up and exhaust air directly from and to the outdoors for the space being served and not through windows, infiltration or trickle vents. Supply airflow rate shall be within 15% of exhaust airflow rate.
- Corridors shall not be pressurized.
- Dampers shall not be used to reduce make-up or exhaust airflow. If make-up or exhaust airflow needs to be reduced, it shall be reduced through reducing fan speed or operating fans intermittently. This does not apply to dampers used or required to close air pathways when fans are not operating.
- Where make-up air is dehumidified, it shall not be heated before delivery to a conditioned space when the space conditioning system is in cooling mode.

Exception: Buildings designed to meet the requirements of ASHRAE Standard 62.2 and 62.1 either:

1. Without the use of any mechanical ventilation -or-
2. With an Energy Recovery Ventilation System.

Space Conditioning System Controls:

Provide all HVAC systems serving dwelling units and common areas with controls that meet the following:

- The capability of the controls to be accessed remotely (eg. wireless interface to laptop, smartphone or other network-enabled device).
- Seven-day schedule functionality that allows each day of the week to have unique operating settings.

Fan Efficiency:

All Fans used for heating, cooling or ventilation shall meet at least one of the following:

- A rated cfm/W of no less than 3.5 for range hoods and in-line (single–port & multi–port) fans and 6.0 for bathroom and utility fans.
- Served by an electronically commutated (brushless) motor.
- For fans attached to motors over 1hp, a Fan Efficiency Grade (FEG) of 71 or higher.

Interior Lighting Efficacy:

- The total installed lighting power density (LPD) in common areas shall not exceed 0.43 W/sf. The LPDs shall be calculated based on luminaire efficiency, including light sources, drivers and ballasts.
- For dwelling units, all rooms shall be provided with installed lighting.
- For dwelling units, all installed lighting shall be provided by Light Emitting Diode (LED) sources or other light sources with efficacy of no less than:
    1. 100 lumens per watt for lamps over 15 watts;
    2. 90 lumens per watt for lamps over 7 watts to 15 watts and
    3. 60 lumens per watt for lamps 7 watts or less.

Common Area Lighting:

- Occupancy Controls (automatic on/off) capable of reducing the lighting power of lobbies, corridors, stairways and other circulation paths by no less than 50% after 15 minutes of non-occupancy.
- Vacancy controls (manual on/off, automatic off) for all spaces over 50 sf.

Exterior Lighting Efficiency:

- All luminaires with a total fixture wattage over 50W used for exterior lighting shall have a total luminaire efficacy of no less than 100 lumens/Watt including light sources, drivers and ballasts.
- All other luminaires used for exterior lighting shall have a total luminaire efficacy of no less than 60 lumens/Watt.

  Exception: solar-powered lamps not connected to any electrical service.

Water Heating Equipment:

- All Water Heaters shall have a minimum Uniform Energy Factor[2] of 0.95.
- All boilers used for domestic water heating shall meet the equipment standards of the efficiency tables of the HVAC Equipment Efficiency measure.
- Where a natural gas boiler reheats returning water in a recirculation loop, the loop shall be designed to return water to the boiler at a temperature below the threshold for condensing mode as stated by the boiler manufacturer.
- Air-Source Heat Pump Water Heaters shall not be located within conditioned space in locations with more Heating Degree Days than Cooling Degree Days.

  Exception: Heat Pump Water Heaters with ducted intake and exhaust air.

2 In 2014, DOE replaced the Energy Factor efficiency metric for water heaters with Uniform Energy Factor. The new metric is defined in the Department of Energy's test method outlined in 10 CFR Part 430, Subpart B, Appendix E.

Hot Water Conservation:

- All lavatory faucets shall have a flow rate no greater than 1.5 gallons per minute (gpm) at 60 psi.
- All showerheads shall have a flow rate no greater than 2.0 gpm at 80 psi.

Plug Load:

Plug-in equipment and appliances installed in the building shall meet the following:

- Be ENERGY STAR® certified when available.
- All task lighting shall utilize LED lamps.
- Water coolers shall be provided with timers capable of turning the power off during off hours. They are prohibited from having heaters that heat previously chilled water.

Additional Efficiency Packages:

Each of the measures below is intended to be deployed in addition to the bundle of measures above. These additional measures will allow for a higher tier of performance.

High-Performance Building Envelope

- The U-factors of the roof assembly, and the area-weighted average U-factor (UA) of the opaque walls and fenestration together shall meet the specifications in the table below.
- U-Factors for assemblies shall be calculated on an area weighted average basis for the whole wall assembly and calculated in accordance with ASHRAE Standard 90.1 Appendix A and the Thermal Bridging Measure.

U-Factors for High Performance Building Envelope

	CZ 4
Total area weighted average U-factor for opaque walls and fenestration	0.071
Roofs, Flat	0.023
Roofs, Sloped	0.017

Ground Source Heat Pump

Meet primary heating and cooling loads with an installed Ground Source Heat Pump (GSHP) system designed to meet the following:

- The ground heat exchange portion of any installed GSHP system shall be a closed-loop system in which all the fluid is re-circulated and there is no possibility of local ground water contamination.
- The ground loop heat exchanger shall be sufficiently sized to handle, at a minimum, the full heating and cooling load of the building or zone. Sizing calculations shall take into account future ground temperature shifts due to unbalanced heating and cooling energy extraction/rejection.
- Where multiple heat pumps are served by a single ground loop, ground loop pumping shall be provided by a variable speed pump.
- All pump systems serving the GSHP system shall cycle only on a call for heating or cooling; continuous pumping systems are prohibited. Systems with central pumping systems larger than 1 horsepower (hp) shall include variable speed pumping.
- The ground heat exchange portion of the piping shall be designed to attain a pressure drop no greater than 25 feet of static head under typical operation.
- Ground loop source side distribution system loss shall be no more than 40 feet of static head under typical operation.
- If the building includes a load-side water system, total load-side distribution system loss shall be no more than 40 feet of static head under typical operation.

- The fluid in the ground heat exchange portion of the piping shall be supplied with appropriate levels of antifreeze for the climate and design. Design to a minimum of no less than 30F fluid temperature (water temperature entering the ground loop).

Radiant Heating/Cooling

- Primary space conditioning shall be provided by radiant equipment. No more than 5% of the conditioned floor area may incorporate non-radiant, fan-based space conditioning. In the radiant areas, fans may only be used to distribute ventilation air (for "Active Chilled Beams" or similar systems that incorporate fan distribution systems directly into the design of the radiant system).
- All pipes conveying heated or cooled fluid to the radiant equipment shall be insulated to a thickness no less than the nominal diameter of the pipe.
- All pumps over 1 horsepower (HP) in the distribution system shall have variable speed drives (VSDs). Single phase pumps shall use electronically commutated motors (ECMs).
- Distribution pumps shall be controlled to eliminate continuous pumping. Pumps shall only cycle when there is a call for heating or cooling.
- Each separate zone shall have an independent method for zone control or balancing.

High Performance Heat Pump

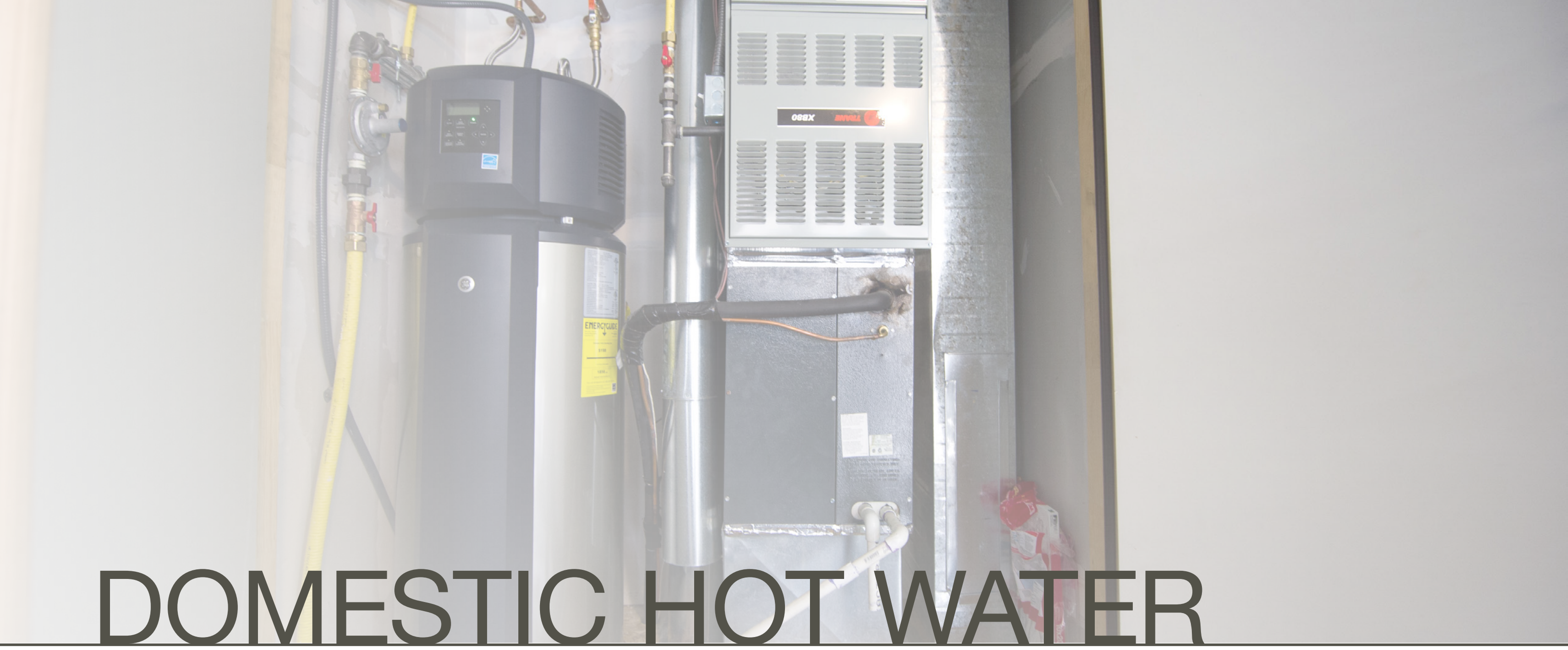
Provide all heating and cooling for the building with one of the following two high efficiency heat pump systems:

1. Ductless Heat Pump systems with a SEER of 22.4 and HSPF of 11.2.
2. Variable Capacity Heat Pump Systems (Variable Refrigerant Flow, Variable Refrigerant Volume) that include the following design features:
    - » The compressor shall be variable speed with capacity control that varies the amount of refrigerant flowing in the system based on the load in the zones.
    - » All indoor units shall include an electronic expansion valve that continually controls the flow rate of refrigerant.
    - » Maximum refrigerant piping lengths shall be limited to manufacturer specifications.
    - » In climates with low-temperature ambient conditions, frost protection shall be provided to defrost the outdoor heat exchanger when in heating mode.
    - » Utilize ductless fan coils whenever possible. If ducted units are used, only low/medium (no more than ¾" static pressure dirty filter) static models are allowed.
    - » No electric resistance heating is allowed in the ventilation system or as back up for the heat pump unless outside design temperatures drop below 20˚F. All electric heating shall be locked out until temperatures drop below 20˚F.
    - » Only one temperature control point (or a single average) shall be used per zone. No heating and cooling shall be allowed simultaneously in the same zone.
    - » Indoor-unit fans shall be set up to cycle on a call for heating or cooling only. Continuous fan operation shall not be used.

    Exception: Fan units that are also used to provide ventilation.

Heat Pump Water Heater

- Provide all domestic water heating loads with a Heat Pump Water Heater meeting the ENERGY STAR Specification.
- Air-Source Heat Pump Water Heaters shall not be located within conditioned space in locations with more Heating Degree Days than Cooling Degree Days.



DOMESTIC HOT WATER

Guidance

In typical multifamily buildings, water heating can account for up to 1/3 of the building's total energy load. The water heating system is therefore an essential component of the total efficiency of multifamily buildings. There are three primary components to the performance of the domestic water heating system: the efficiency of the water heating equipment, water conservation at the point of use, and the distribution system. High performance water heating requires careful consideration of all three of these components in the system design.

Integrated Design Considerations

The three components of the water heating system each have design implications for the others. These are discussed in full below. But the water heating system also has an impact on other buildings systems, especially the space heating system. Hot water storage in the conditioned space – in both hot water tanks and the the hot water distribution system – will have an impact on heating and cooling loads. New heat pump water heaters take heat from the surrounding area, also impacting heating and cooling loads when located in conditioned space. So, decisions about where to locate the water heating equipment and storage affects the space conditioning equipment. Combustion water heating equipment requires envelope penetrations for exhaust and make-up air, so decisions about electric vs gas water heating and central versus individual systems will impact air barrier detailing.

Water Heating Equipment

Code requirements for water heating equipment significantly lag the performance levels available on the market, and it is easy to specify high performance equipment like condensing gas or heat pump water heaters. But these more efficient technologies have special considerations for use in multifamily projects, especially in the central DHW systems often included in multifamily designs.

Water Heating Equipment

- All Water Heaters shall have a minimum Energy Factor of 0.95.
- All boilers used for domestic water heating shall meet the equipment standards of the efficiency tables of the HVAC Equipment Efficiency measure.
- Where a natural gas boiler reheats returning water in a recirculation loop, the loop shall be designed to return water to the boiler at a temperature below the threshold for condensing mode as stated by the boiler manufacturer.
- Air-Source Heat Pump Water Heaters shall not be located within conditioned space in locations with more Heating Degree Days than Cooling Degree Days.
- Exception: Heat Pump Water Heaters with ducted intake and exhaust air.

Hot Water Conservation:

- All lavatory faucets shall have a flow rate no greater than 1.5 gallons per minute (gpm) at 60 psi.
- All showerheads shall have a flow rate no greater than 2.0 gpm at 80 psi.

Heat Pump Water Heaters

Heat Pump Water Heaters (HP-WH) are the highest efficiency water heating equipment available on the market today. The primary consideration when choosing a HP-WH is that the tank temperature recovery time for the heat pump is much slower than electric resistance or gas water heaters. Most HP-WHs have a backup resistance heating element that will kick in when the primary heat pump cannot keep up with demand. However, this significantly decreases the actual efficiency of the water heater since the resistance element is far less efficient than the heat pump. Therefore, the standard tank sizes specified for traditional water heaters may be too small for a HP-WH and a larger tank may be necessary to ensure that the HP-WH stays in heat pump mode and out of the less efficient back-up resistance mode. The design team should size the tank according to the hot water loads and recovery time of the equipment selected to ensure efficiency. Many HP-WHs have an efficiency or “ECO” mode that uses the resistance element as sparingly as possible. When available, this setting should be chosen during installation.

Air-Source Heat Pump water heaters extract heat from the surrounding air and concentrate it in a water tank, effectively lowering the surrounding air temperature. When located within a conditioned space, this will have an impact on space heating and cooling loads. If heat pump water heaters are located within conditioned space in climates dominated by cooling, this is beneficial as it decreases the cooling load in the conditioned space. But in climates dominated by heating loads, heat pumps located in the conditioned space take the heat produced by the space heating system, decreasing the true operating efficiency of the HP-WH. The water heating energy savings relative to traditional water heating equipment far outweigh the space heating impact, but that impact should still be considered when making decisions about equipment placement. Some HP-WHs are equipped with direct ducting for supply and exhaust air that allow them to be located in conditioned space while utilizing unconditioned air for water heating. Other HP-WHs are split-systems and the compressor can be located outside of conditioned space while the tank is located inside. When HP-WHs (or just their compressors) are not located in conditioned space, it is best to locate them in unconditioned spaces such as garages. In addition to protecting the equipment, these spaces generally provide more favorable operating conditions than a sheltered exterior location.

Not all heat pump water heaters are air-source. Some models extract heat from a refrigerant or water loop instead of the surrounding air. These HP-WH can always be located within the conditioned space. Another advantage of these models is that it is possible for them to use the same refrigerant or water loop used by the space conditioning system. When configured properly, this can allow the waste heat produced by space cooling to be utilized by the water heater.

Other HP-WHs extract heat from an exhaust air stream. This approach is mutually exclusive with Energy or Heat Recovery Ventilation, but could be especially useful in mixed use buildings where commercial occupancies might provide hot exhaust sources.

Hot Water Recirculation Loops and Equipment Efficiency

Many multifamily buildings utilize centralized water heating equipment rather than a water heater for each dwelling unit. Centralized systems generally require a hot water loop with a recirculation pump to ensure that hot water is close to the points of use and that wait times for hot water are minimized. The decision to use a central hot water plant with a recirculation loop is generally driven by concerns other than energy such as space, but it has significant energy impacts. Larger distribution losses from the distribution system are addressed more below. But pairing a hot water recirculation loop can also have an impact on the efficiency of the water heating equipment itself. Most high-efficiency equipment does not operate as efficiently when reheating warm/hot water as it does when heating cold water, and that is a significant issue for multifamily buildings with a central system with a recirculation loop.

Condensing water heaters and boilers achieve higher efficiency through the use of a secondary heat transfer coil in the flue exhaust stream. The coil extracts additional energy from the hot flue gases by condensing water vapor in the exhaust. For this to work, the heat transfer coil needs to be cool enough to allow condensation of flue gasses and subsequent transfer of heat to the water. In a water heater, this is simple since the condensing coil contains the cold make up water entering the water heater. If the condensing coil contains the return water from the recirculation loop, and that return water is too hot, the flue gases won’t condense and the boiler will operate similarly to a boiler without condensing technology. HP-WHs have a similar issue. HP-WHs operate much less efficiently when reheating hot/

warm water than when heating cold water. This issue can be addressed through a few strategies, including:

Minimize return water temperature: Cooler return water can be achieved through effective control of the recirculation loop and water heating equipment. This starts with the water temperature. Domestic water can safely be set at much lower temperatures than some typical practices, as low as 120 degrees Fahrenheit according to the Consumer Product Safety Commission. This is below the condensing temperature of most condensing boilers and water heaters. By controlling the pump with temperature controls, the loop can be controlled so that it only recirculates and reheats the loop when the return water is within a temperature range that allows the water heating equipment to run efficiently.

Secondary loop reheat system: A secondary system can be used to maintain the recirculation loop temperature. With this approach, the primary water heating equipment only heats cold makeup water and will run at full efficiency while another heat source is then used to maintain the recirculation loop temperature. Since these secondary systems are typically less efficient than the central plant, is it important to maximize pipe insulation in order to minimize operation of the equipment. Below are two examples of this approach.

- Trace Heating. Resistance heat strips are attached to the pipes, maintaining a minimum temperature in the water through directly heating the pipes.
- Temperature maintenance water heater. A conventional water heater is placed on the return of the recirculation loop to maintain the temperature and allow the high-efficiency water heater to only heat the incoming cold water.

Best Practices

Due to the high water heating load of multifamily buildings, project teams should consider additional means of reducing water heating loads. Two very effective ways to do this are to provide the building with solar thermal or waste heat recovery systems. Waste heat can be recovered from wastewater drains or air exhaust systems to pre-heat water. Mixed-use buildings provide particular opportunities for waste heat recovery since commercial spaces are much more likely to be dominated by cooling loads or to have process loads with available waste heat. Even if a whole building system is not installed, efficient unit systems targeted in high-intensity water heating load applications such as showers and laundry rooms can have a big impact.

Hot Water Conservation

One of the most effective ways to reduce hot water energy consumption is to reduce hot water demand. In multifamily buildings, the most direct way to achieve this is through the installation of low-flow faucets and showerheads. The low-flow specification above save energy by reducing the amount of hot water that is consumed at the point of use. EPA's WaterSense program provides an easy way to find fixtures that perform effectively at lower flows.

These strategies have the additional benefit of reducing all water usage, which in turn saves the significant energy expended in purifying and distributing water. While the savings from this water-energy nexus are difficult to claim at the building level, they are an important part of the total energy picture of water use in buildings.

Water Metering

An important element of conservation is awareness of consumption. Metering water use is a powerful feedback tool for tenants to self-regulate their energy use. Having the water heating energy use on their individual utility bill provides another strong feedback mechanism and incentive to conserve. Central DHW systems make water metering more difficult, but there are solutions that can be implemented.

Efficient Hot Water Distribution

Low-flow plumbing fixtures have wide market penetration and are even included in code, and this has made great strides in reducing average hot water consumption in multifamily housing. Likewise, as water-heating equipment has become more efficient, the energy use they represent has decreased. While the efficiency of distribution systems has been improved somewhat by increased pipe insulation and demand control recirculation code requirements, this element of total system efficiency has not seen the same kinds of advances. As a result, distribution losses can represent 30-50% of the hot water load in central hot water systems.

Due to heat losses through pipes, the hot water distribution system is effectively a hot water consumer. Every time hot water fills the system and then cools, it is wasting energy. Many distribution pipes are oversized for modern, low-flow fixtures. Flow rates have been reduced at the plumbing fixtures themselves by regulations, but distribution piping is often still sized for the flow rates of fixtures used before the advent of low-flow fixtures. These fixtures could have up to three times the flow rate of current fixtures. This problem is exacerbated for projects following the *Multifamily Guide* since it requires even lower flow rates. This has three serious impacts on the water heating system:

- It lengthens wait times for hot water. The same volume of water in the pipe has to be displaced in order to deliver hot water to the fixture, but the flow rate at the fixture is much lower, so it takes longer to get hot water to the point of use.
- It wastes hot water. Oversized pipes create a much larger volume of water that needs to be displaced in order to deliver hot water to the point of use. Each time water is used, that total volume sits in the pipe and eventually cools, wasting the energy used to heat it.
- It loses more heat. Pipes with larger surface areas are effectively larger radiators capable of losing more energy.

The following design strategies can be employed to reduce the volume of the hot water distribution system and with it the hot water energy waste:

Pipe size: Reduce wasted hot water energy in the distribution system by reducing pipe sizes to correspond to the actual flow rates of the fixtures. Old guidelines should be revised and actual volume calculations for the fixtures installed in the system should be used to calculate the necessary pipe sizes. However, it is important to not be too aggressive on pipe size reductions, especially on recirculation loops or other pipes with active pumping. If the pipe is constricted too much, increased pressure drops and turbulence will increase the pumping energy.

Locating Hot Water Uses: Plumbing design should be incorporated into the conceptual design phase so that efficient pipe layouts can be integrated into the project early in the design. Central locations for hot water equipment and clustering of hot water points of use all decrease the pipe runs between hot water production and hot water use. Configuring hot water points of use toward the center of the building also allows them to be served by a shorter recirculation loop.

Pipe Layout: Often, pipe layouts are described in terms of “trunks” and “branches.” Branches supply one or more plumbing fixtures and trunks supply multiple branches. The pipes that compose the branches and trunks are sized to accommodate the additive loads of the downstream plumbing fixtures. However, it is useful to think in terms of “trunks” “branches,” and “twigs.”[3] The difference between a branch and twig is that a twig only supplies one plumbing fixture instead of the multiple fixtures a branch might supply. A branch is sized large enough to accommodate multiple loads, but frequently only one load will be active. As a result, a volume of hot water meant to serve multiple fixtures needs to be displaced in order to deliver hot water to the single active load. With only one fixture on a twig, a much smaller volume of water needs to be displaced in order to deliver hot water to the fixture. Utilizing twigs instead of branches therefore reduces the amount of hot water that is wasted for each hot water draw.[4]

Pipe Insulation

The distribution system also consumes water-heating energy due to heat losses through the piping. The 2015 IECC requires that most pipes used for domestic hot water be insulated to only R3 in low-rise multifamily and R3-5 in most in high-rise multifamily applications. When we consider that the same code requires more than five times that insulation in walls, most hot water pipes are going significantly under-insulated. Insulation on hot water pipes should therefore be increased substantially, especially on recirculation loops that always contain hot water. Additionally, joints and valves need to be addressed with adequate insulation that can accommodate their unique shapes.

All of these strategies have the side benefit of reducing wait times for hot water, which will in turn contribute to occupant satisfaction and reduced water use. They also all reduce pipe and pipe insulation cost through reducing pipe size and pipe length.

3 This is the approach advocated by Gary Klein of Gary Klein and Associates, a national expert in efficient hot water systems.

4 One issue to consider with this approach is that sub-metering hot water loads becomes more difficult when each fixture has dedicated piping to the recirculation loop. One simple solution is to cluster the points of use in each dwelling unit and serve the entire dwelling unit from a metered manifold connected to the recirculation loop.

SITE LIGHTING

Guidance

Light Emitting Diode (LED) lighting had some of its earliest and broadest successes in exterior lighting applications. The substantially better energy performance of LED light sources allowed for significant energy savings in exterior applications, especially considering the long operating hours and large areas that often characterized many exterior lighting installations. The long service life and resulting lowered maintenance costs only contributed more cost savings. And the better color rendering LED offered over the High Pressure Sodium (HPS) lamps that dominated exterior lighting applications was a non-energy benefit that just made another strong selling point for many projects.

However, the early and rapid adoption of exterior LED lighting did have some bumps along the way. LED lighting was sometimes criticized as being too bright, too white (or even too blue), too harsh, etc. LED lighting and its relatively high color temperature intensified general concerns about the impact of nighttime lighting on human circadian rhythms and sleep patterns. Concerns were significant enough that in 2016, the American Medical Association (AMA) Council on Science and Public Health issued a warning about the potential negative health impacts of LED site lighting. These issues are especially pertinent for multifamily projects since site lighting is in such close proximity to bedrooms.

There are some simple and important steps that designers can take to minimize any negative impacts of LED lighting while still reaping the significant energy savings and other benefits. These approaches fall into a few categories: luminaire shielding, color temperature, site light levels and lighting controls.

Luminaire Shielding

Luminaire shielding is a well-established solution to light trespass (the encroachment of light into areas that are not intended or needed to be lit). Light shields are installed on luminaires to block the light in one direction. Many exterior luminaire manufacturers offer light shields specifically for their products

Measure:

- All luminaires with a total fixture wattage over 50W used for exterior lighting shall have a total luminaire efficacy of no less than 100 lumens/Watt including light sources, drivers and ballasts.
- All other luminaires used for exterior lighting shall have a total luminaire efficacy of no less than 60 lumens/Watt.

Exception: solar-powered lamps not connected to any electrical service.

Figure 2: LED site downlight. An array of individual LEDs allow for very directional light.

and third-party after-market solutions are also available for many luminaires.

Luminaires with a higher cut-off angle that direct light in a more downward direction can also help reduce light trespass. LEDs are inherently a directional light source, so they are well suited to creating luminaires with higher cut-off angles. Higher cut-off angles are also a good approach to reducing light pollution in general by limiting upward light. (For more on the issue of light pollution, see the International Dark-Sky Association's resources at www.darksky.org.) LEDs are also intense light sources, so specifying luminaires with higher cut-off angles will help shield people from glare and even discomfort of having a direct line-of-site exposure to the LED light source.

Color Temperature

Concerns about the impact of site lighting on human circadian rhythms and sleep patterns can also be addressed through specifying LED lighting with a lower color temperature. The AMA recommends that site lighting should have a color temperature no higher than 3000K. Color temperature is the way that the color of light is graded. Color temperature is measured in degrees Kelvin (K.) Lower numbers like those in the 2000s denote a "warmer" light that is more orange and yellow, a light more like traditional incandescent lamps. Higher numbers denote "cooler" temperatures that tend more toward blue. Most fluorescent lamps used in interiors are in the 3000s, with some "daylight" models in the 4000s or even 5000s. White LEDs are actually blue LEDs with special coatings, and they can have very high color temperatures. Many of the LED site lighting products available have a color temperature of 5000K, well within the range of what is considered "daylight" products.

Specifying lights with higher color temperatures exacerbates their negative impact on sleep. Lighting with a higher color temperature resembles sunlight more, and therefore its potential to disrupt the circadian rhythm and sleep is greater. Some studies indicate that white LEDs have five times the circadian rhythms disruptive capacity as High-Pressure Sodium (HPS) lamps.[5] A very simple way to address this issue is to specify lighting with a lower color temperature and a "warmer" light quality. The options for lighting are not as broad for exterior lighting as interior, but many LED site lighting products are available in 3000K configurations, right in line with the recommendation of the AMA. Color temperature is also an important consideration in the discussion of light levels below.

Figure 3: Color temperatures of white light varying 2700K, 3000K, 3500K, and 4100K from left to right. (Image courtesy of the Energy and Technology Center, Sacramento Municipal Utility District.)

Light Levels

The light from LEDs is different from previous technologies like High Pressure Sodium and Mercury Vapor. As such, the adoption of LED lighting presents the opportunity to rethink light levels completely. Some of the issues with some early LED site lighting applications were not due to LED lighting, but to design approaches like luminaire-for-luminaire swap-outs that ignored the fact that different light sources need different design approaches.

5 Falchi F, Cinzano P, Elvidge CD, Keith DM, Haim A. Limiting the impact of light pollution on human health, environment and stellar visibility. J Environ Manage. 2011;92:2714-22.

Figure 4: High Pressure Sodium site lighting luminaire.

LED lighting can seem brighter than HPS light sources because of their generally superior color rendering and color temperature. When LED lighting is used in luminaire-for-luminaire retrofits, even if lumen output is kept constant, the resulting lighting can seem brighter. And this is because not all lumens are created equal when it comes to low light applications (See “Light and the Human Eye” in the sidebar for more). To address this issue in LED lighting designs, it is important to design for the light characteristics of LED sources. Using old guidelines that were developed over years for the particular light characteristics of HPS risks poor outcomes with LED light sources. Designs with LED lighting should be calculated from the target foot-candle.

Site lighting brightness should actually be reconsidered in general. Higher light levels are often desired for safety reasons. However if care is not taken, increases in luminaire brightness can have a negative impact on safety. Bright light sources in the landscape cause the pupil to contract and let less light into the eye. These overlit pools of light deepen shadows in the landscape and create glare, potentially hiding hazards and dangers. Making the fixtures brighter does not address this problem, and may in fact exacerbate it. The human eye does not adapt well or quickly to large light level changes, so if the person moves from a well-lit area of the site to a less well-lit area, it can take 10-60 minutes for their eyes to fully adapt. The best strategy for security lighting is to design for lower, but uniform, light levels that avoid the creation of high-contrast dark zones.

The Illuminating Engineering Society (IES) recommends only 0.2-0.5 foot-candles for parking lots. See the IES publications RP-20: Lighting for Parking Facilities and RP-33: Lighting for Exterior Environments, as well as the Federal Energy Management Program resource Guide to FEMP-Designated Parking Lot Lighting for more information on appropriate light levels for exterior lighting applications.

Controls

Even highly efficient light sources like LEDs can benefit from good control strategies. The energy code requires controls that turn site lighting off during daylight hours, but there are opportunities to turn site lighting off or down during nighttime hours as well. Most sites see a period with little to no activity each night. During these hours, site lighting can be turned down while landscape and accent lighting can be completely turned off. LED light sources are very well suited to dimming, making step down strategies very feasible. Consider implementing the following control strategies for all site lighting:

- For all landscape and accent lighting: astronomical time clock controls capable of turning off lighting during set nighttime hours.
- For parking structure and parking canopy lighting: occupancy sensing controls capable of reducing lighting power by no less than 50% after 30 minutes of inactivity. Each control zone should be no larger than a single luminaire or 1000sf, whichever is larger.
- For all other site lighting: astronomical time clock or occupancy controls capable of reducing input power by no less than 50%.

These strategies can also reduce complaints in multifamily projects from occupants about bright site lighting at night without sacrificing security and safety.

The efficiency gains from LEDs in site lighting can be considerable. But like many new technologies it takes some attention to the details to ensure a successful transition to this lower energy consumption future.

Light and the Human Eye

Light Color

Humans perceive light from different parts of the color spectrum differently. The human eye has two different kinds of light receptor cells: cones and rods. Rods dominate low light (scotopic) vision and are more sensitive to light from the blue end of the spectrum (most sensitive to blue-green, and not at all from the red portion). Rods are also sensitive to lower light levels overall. Cones dominate our perception of colors and fine detail (photopic vision) and are more sensitive to light from the red end of the spectrum (most sensitive to the green-yellow range). Cones are less sensitive than rods and require higher light levels. Pure scotopic vision corresponds roughly with starlight, so most site lighting applications result in the use of both rods and cones (mesotopic vision).

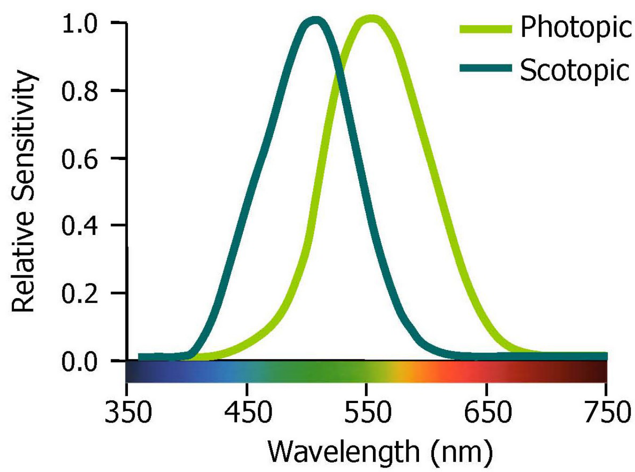


Figure 5: The sensors in the human eye respond at different intensities and colors of the light range.

HPS light is composed of a spectral mix of light with the greatest output concentrated in the green-yellow to red portion of the spectrum. This means that in order to supply sufficient light in low-light conditions, HPS-based exterior lighting designs actually has to have higher lumen output than whiter/bluer light sources to ensure that the human eye is in the mesotopic or photopic range. It effectively requires fewer white/blue-dominated lumens than yellow/red-dominated lumens to provide enough light for the visual cells in the human eye to be effective. The same amount of lumens from a blue-biased light source like most LEDs in an otherwise low-light condition is perceived as brighter than red/yellow-biased sources like HPS.

This difference is exacerbated by how lumens are measured. The lumen measurement for light output was created for interior applications. It biases light in the yellow part of the spectrum since that is the light most useful to rod cells for detail in visual tasks. But that part of the spectrum is less useful for less detail-dominated, low-light applications like exterior nighttime lighting. HPS lamp output also happens to have spikes in the green-yellow and yellow-orange portions of the spectrum, giving them a somewhat misleading lumen output rating.

These factors make “lumen for lumen” LED replacement strategies for traditional HPS site lighting prone to over-lighting.

LIMITING THERMAL BRIDGES

Guidance

Thermal bridges are created when a relatively high thermally conductive material “bridges” through the insulating materials in the thermal envelope. Whether they penetrate all the way from the exterior to the interior of the building or only partially through the thermal envelope, thermal bridges make it easier for heat to travel in or out of the building. This has an impact on the heating and cooling loads of the building, as well as on the perceived comfort of space occupants. Humans perceive heat primarily through conduction, then radiation, then convection. So the presence of hot or cold surfaces due to thermal bridges can have a significant impact on thermal comfort. When the thermal envelope has hot or cold spots from thermal bridges, occupants are more likely to feel uncomfortable and respond by over-conditioning the air in the space, creating another source of energy loss.

Thermal bridging is an especially significant issue for multifamily buildings. Many multifamily buildings include balconies for all or most of the units. It is easy to simply extend a structural concrete slab or other structural member out of the building and through the thermal envelope to create a balcony. However, this creates a massive thermal bridge, allowing unwanted heat flow in and/or out of the building. Other common areas for thermal bridges are where structural members meet the building envelope, at window and door perimeters, and anywhere that multiple framing elements come together at a single location such as at wall junctions and corners.

Integrated Design Considerations

Careful envelope assembly detailing and construction is needed to manage thermal bridging in building envelopes. Controlling thermal bridging has a significant impact on design decisions about the rest of the building envelope. Interfaces between the building structure, opaque envelope assemblies and fenestration, as well as building penetrations, all create opportunities for thermal bridging that must be managed to achieve the intent of this measure. Therefore decisions about the components of the building cannot be made in isolation; these and the intersections between them require extra attention in construction details and construction.

Measure:

- The opaque envelope shall meet the U-factor requirements in the base code based on the Area-Weighted Average of the entire envelope component (eg Roofs, Above-Grade Walls, Floors, etc.).
- In calculating the U-factor of a building component, the U-factor shall be calculated as an area-weighted average of all points in the whole envelope component, not just a representative assembly. No points in the envelope shall be ignored, especially, but not limited to:
  - Floor-to-wall interfaces
  - Wall-to-wall corner interfaces
  - Floor & slab edges
  - Other structural interfaces
  - Mechanical fasteners that compose more than 0.5% of the assembly area.
- A minimum of R-5 continuous insulation shall be provided at all points in the thermal envelope (except mechanical fasteners).
- All window frames shall be installed with thermal breaks of not less than R-5 between the window and the opaque portions of the thermal envelope or the structure.
- All balconies shall a have a minimum of R-5 thermal break between the balcony and the thermal envelope

Figure 6: Interior concrete slabs extending unbroken through the thermal envelope and thermally un-broken structural connections turn this multifamily development's balconies into significant thermal bridges

Thermal bridges can also have an impact on HVAC design and thermal comfort. When thermal bridges exist, they can become sources of thermal discomfort and unexpected heat loss or gain. More fully controlling thermal bridges in the building envelope will help ensure that the HVAC system is accurately sized and the occupants are comfortable.

Reducing Thermal Bridging

The impact of thermal bridges in a thermal envelope far outweighs their relative area. Building assemblies are rarely composed of a homogenous material. They are built up of many various components with different characteristics and some of those components conduct heat much more than others. The first step to reducing thermal bridges is to be cognizant of this heterogeneity when designing building envelopes. The energy code allows three methods to comply with opaque envelope requirements—the R-value method, the U-factor method and the Component Performance Alternative—and all three allow projects to largely ignore the thermal bridges between envelope components and between the envelope and the structure. Using the specifications for an assembly that composes only the "field" part of the assembly to meet code requirements neglects envelope and structural interfaces. These can have very different characteristics and that difference can have a significant impact on heat flow in and out of the building.

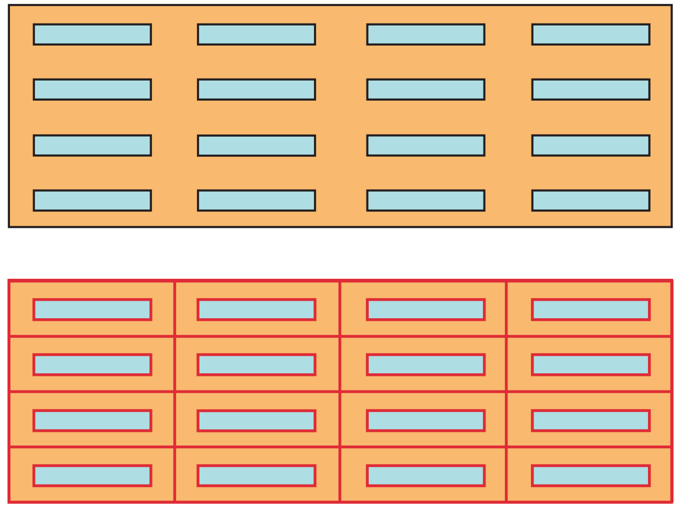


Figure 7: A weighted-area U-factor calculation needs to account for more than just the field assembly (top). It also needs to include the U-factor that results from building component intersections – such as window jambs, walls and floors (bottom) – in the resulting area-weighted U-factor.

Figure 8 below shows an area-weighted U-factor calculation for a wall from the prototype mid-rise building used in the analysis of the *Multifamily Guide* measures. The U-factor specification for wood-framed walls in climate zone 4 is 0.064, which corresponds generally to a wood frame wall with R-13 cavity insulation and R-3.8 continuous insulation or a metal frame wall with R-13 cavity insulation and R-7.5 continuous insulation. If only the field portion of the wall is considered, this wall meets the code target. However, if the U-factor accounts for

Envelope Component	U-factor	Area	Percent of total
Wall Field Assembly	0.064	3,324	89%
Floor-Wall Intersection	0.177	82	2%
Interior-Exterior Wall Intersection	0.177	50	1%
Outside Corner	0.039	20	1%
Roof-Wall intersection	0.289	104	3%
Fenestration-wall intersection	0.083	172	5%
Area Weighted average	**0.075**	**3,751**	**100%**

Figure 8: An Area-Weighted U-Factor Calculation that accounts for the entire wall. Projects pursuing the High Performance Building Envelope Additional Efficiency Package would also include the fenestration in this weighted area calculation.

the entire wall and not just the field assembly, the weighted-average U-factor is only 0.075. That's a 17% difference, enough to make a notable difference on energy performance.

Accounting for the interfaces between the parts of the thermal envelope results in a better overall envelope. In order to meet the target U-factor, the envelope will need to be improved overall to counteract the weak points in the envelope. It also forces designers to pay attention to these weak points, and hopefully address them directly.

A more careful evaluation, detailing, and construction treatment of thermal bridging conditions should be included in the design and construction process. Implementing design details like continuous insulation can go a long way to minimizing thermal bridges in the assembly by moving the entire assembly within an insulating material. Also, through using thoughtful structural details that minimize contact between structural members in the thermal envelope and that utilize thermal breaks when possible, thermal bridges can be further reduced.

Beyond U-Factor

Designers can go further than just better weighted-area U-factor (UA) calculations. The UA method assumes that all heat flow in an assembly is parallel, when in reality heat also flows laterally within the assembly as well. This lateral movement intensifies the impact of thermal bridges on heat flow. Thermal bridges don't just transmit heat along their length, they transmit it through their surfaces to adjoining materials. The result is that thermal bridges contribute far more heat transmission than a UA calculation captures.

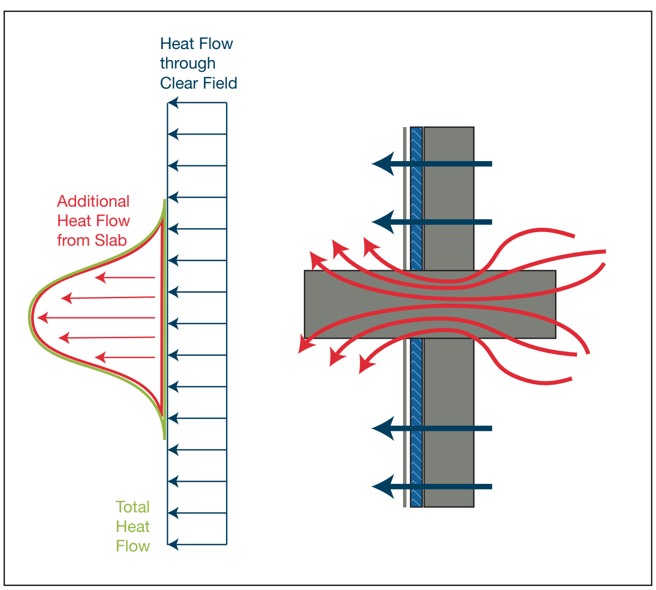


Figure 9: This diagram illustrates how lateral heat flow between assembly components allows additional heat flow through the thermal bridge that is not captured by U-factor.

Excellent guidance and information about better calculating the thermal performance of envelopes and better addressing thermal bridging can be found in *Building Envelope Thermal Bridging Guide – Analysis, Applications, and Insights*.[6] The calculation method in this guide captures heat flow far more comprehensively, but it is more complex. Computer tools like Flexio[7] and Therm[8] can also capture heat flow more comprehensively and can help identify and eliminate thermal bridges. Although the *Multifamily Guide* does not require one of these more sophisticated approaches, projects employing novel or complex building assemblies would be well-advised to make use of a more sophisticated approach to thermal transmittance calculations to more accurately characterize the loads in the building.

Through using different structural details, these thermal bridges can be significantly reduced and even nearly eliminated. Like all thermal bridges, this requires greater attention to the construction details of the thermal envelope.

6 http://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/power-smart/builders-developers/building-envelope-thermal-bridging-guide-1.1.pdf (06/2017)

7 http://www.flexo.com

8 www.windows.lbl.gov/software/therm/therm.html

VENTILATION

Guidance

Indoor air quality is one of the more pressing issues facing multifamily buildings, especially within modern new construction. Historically, ventilation in residential buildings was provided through the building envelope, through both windows and high infiltration rates. As envelopes have been tightened by code and further tightened by above-code standards, balanced mechanical ventilation with dedicated paths for make-up and exhaust air has become necessary to ensure sufficient fresh air in multifamily buildings. The ventilation measure in the Multifamily Guide ensures that proper ventilation is being provided to the building in a manner that is energy efficient.

Integrated Design Considerations

In multifamily HVAC systems, the ventilation system (the “V”) is frequently decoupled from the heating and cooling system(s) (the “H” and “AC”). Therefore, ventilation system design decisions need to be made in tandem with the space conditioning system selection. One of the most important considerations for decoupled systems is whether the space conditioning or the ventilation system will be handling humidity control.

There are also important interactions between ventilation and the thermal envelope. Modern, tight building enclosures make mechanical ventilation essential in most multifamily buildings in order to maintain acceptable indoor air quality. In turn, design decisions about ventilation impact the air barrier system in the building envelope. Providing outdoor air to the individual dwelling units can result in multiple envelope penetrations with increasing opportunities for air leakage through the air barrier. Central ventilation systems can create vertical pathways that promote the stack effect in tall buildings, which can drive greater infiltration. Therefore, the choice of a central or unitized ventilation system has an impact on infiltration and air barrier construction details.

Balanced ventilation

Balanced ventilation ensures that ventilation fans are only working as hard as necessary to move sufficient air changes into the occupied space. There

Measure:

All ventilation shall be provided by a system meeting the following:

- Sized in accordance with the 2016 or later editions of ASHRAE Standard 62.2 for dwelling units and AHRAE Standard 62.1 for common areas.
- Balanced ventilation that is designed to provide make-up and exhaust air directly to the space being served and not through infiltration or trickle vents.
- Corridors shall not be pressurized.
- Dampers shall not be used to constrict make-up or exhaust airflow. If make-up or exhaust airflow needs to be reduced, it shall be reduced through reducing fan speed or operating fans intermittently. This does not apply to dampers used or required to close air pathways when fans are not operating.
- Where make-up air is dehumidified, it shall not be heated before delivery to a conditioned space. If air tempering is required, it shall be accomplished passively or through air mixing.
- Exception: Buildings designed to meet the requirements of *ASHRAE Standard 62.2 and 62.1 without the use of any mechanical ventilation.*

are two sides to every ventilation system: exhaust air and supply (or make-up) air. An unbalanced ventilation strategy uses a fan on either the exhaust or supply side of the system to pressurize or depressurize the space in order to draw air for the other side through indirect, often constricted, paths like envelope infiltration or trickle vents. Fans are subject to the cube-square law, where changes in the energy consumption of the fan are cubed relative to the changes in the flow rate. In a very simplified example, increasing fan speed by 50% in order to pressurize/depressurize the space results in an 87.5% increase in energy consumption. Therefore, any ventilation strategy that effectively relies on pressurization will require more fan power to provide the same level of ventilation as a balanced, non-pressurized strategy. In many cases, the fans will simply lack sufficient power to actually move enough ventilation air through the restricted pathways, leaving the space under-ventilated. But even in that case, working against pressure will decrease the efficiency of the fan, resulting in both insufficient ventilation and increased energy consumption. As buildings get tighter and infiltration is further reduced, the energy penalty of relying on infiltration and pressurization for ventilation only exacerbates the under-ventilation and fan power issues.

Balanced ventilation systems are really the only sufficient means of providing mechanical ventilation to modern, tighter, code compliant buildings. This is why they are starting to be required by code in some states. “Balanced ventilation” is sometimes taken as a synonym for central ventilation strategies or for designs with fans on both supply and exhaust sides of the system, but there are other strategies available. Balanced ventilation can be implemented on a unit-by-unit basis and the market has numerous ventilation options designed for multifamily units available. Balanced ventilation can also be implemented with a fan on only the supply or exhaust path and a passive inlet or outlet on the other. When there is a fan on both the supply and exhaust sides of the system, it is easy to oversize the fans. A common pitfall is to specify a fan for each side of the ventilation system that is sized to provide the proper ventilation rate on its own, effectively oversizing the fan power by a factor of two. It is important to remember that these fans are working together and each only has to provide approximately half of the ventilation fan power.

Providing balanced ventilation also solves a number of air quality issues. Forcing air through the envelope creates the opportunity to also draw moisture into the envelope assembly where it can condense and promote pathogen growth such as mold and mildew. Where make-up air is being drawn through the envelope, these pathogens can be carried into the space with the moving air. Another risk of an unbalanced system is that supply air will be drawn through unintended routes such as other exhaust routes with less powerful fans, through sewer ventilation paths, and even as backdraft through the exhaust flues for combustion appliances. All of these can create unhealthy or even dangerous air quality conditions.

Heat and Energy Recovery Ventilation systems are inherently balanced and provide a straightforward means of implementing balanced ventilation while also achieving additional savings. These systems are discussed further below.

Pressurized Corridors

Pressurized corridors have been a popular way to provide mechanical ventilation in multifamily buildings. The corridor HVAC system is configured to provide more supply than exhaust air to the corridor. The pressurized corridor then drives air into the dwelling units where it can be exhausted through exfiltration or exhaust fans. In addition to being a simple method to provide ventilation, pressurizing the corridor can help control odors by keeping them in the dwelling units, and these factors have made this strategy common. However, it is a problematic approach to ventilation and therefore pressurized corridors are prohibited by projects following the *Multifamily Guide*.

This approach to ventilation suffers all of the complications from pressurization mentioned above; however, they have several other issues. The fan energy penalty isn’t the only energy issue for pressurized corridors. When the corridor is pressurized, all of the intake air has to be conditioned by the corridor space conditioning system. This unit effectively has to condition the air changes for the entire building. Corridor pressurization typically results in very uneven ventilation in the dwelling units. Corridor pressurization strategies also generally require undercuts to the doors between the corridor and the dwelling units. This causes issues for sound and odor control in the building, but more importantly is prohibited by the fire code in most states.

Central Ventilation

Historically, one of the most common strategies for the implementation of balanced ventilation has been through a central ventilation unit. A central unit provides supply and/or exhaust ventilation air to each unit. Where only supply or exhaust air are provided centrally, unit-level fans usually provide the other (although some systems rely on assumed window operation or envelope in/exfiltration). These systems can be very simple, with continuous operating fans on each side, or can be quite sophisticated, with energy recovery or demand-control strategies.

When central suppply air and exhaust are paired, they create the opportunity for building-level heat or energy recovery ventilation. With a single or limited number of units, this can be a cost effective way to implement ERV/HRV in multifamily buildings. (Although unit-level ERV and HRV units are becoming more widely available and cost effective.)

Pairing a central make-up or exhaust systems with individual, unit-level fans for the other side creates different energy efficiency opportunities. For example, a central make-up air system can be combined with simple fans like bath fans, utility room fans and range hood fans to provide exhaust air. When the exhaust fans are controlled intermittently, with careful staging of operations between units, the central make-up system can be downsized. Since it does not have to provide make-up air to all of the units simultaneously, it does not need to be as large. A configuration like this also creates an opportunity to implement demand-control ventilation. Exhaust fans can be controlled by CO2, contamination or occupancy sensors to detect ventilation demand. The central make-up air unit can then be provided with variable speed drives to adapt to the changing ventilation demand as the exhaust fans in different units cycle on and off. Since the ducts for the central system would need to be sized for a simultaneous load, but the system would generally be operating at only a partial load nearly all the time, the ducts would be oversized for most loading conditions, reducing turbulence and pressure drops in the system. Lowering pressure drops, in turn, allows for lower fan energy.

A very important consideration with central systems is the impact of stack effect. Most central units are located on the roof and vertical central ventilation risers can create the opportunity for stack effect in taller buildings. Stack effect is driven by rising warm air and causes air to be forced out the top of the building and sucked in the bottom. The greater the air temperature differential and the taller the vertical path in the building, the more pronounced the stack effect will be. Stack effect can actually reduce the energy consumption of a roof-mounted central exhaust-only system as it can help draw the air out, but it will increase the energy consumption of a similar system providing supply air since the fans will have to overcome the stack effect. Since stack effect has greater impact toward the top and the bottom of the building, designs will need to account for different pressure impacts at different stories of the building.

Energy/Heat Recovery Ventilation

When Energy or Heat Recovery Ventilation is implemented as an additional energy option, no less than 90% of the building's ventilation shall be provided by a system that meets the following:

- An Energy Recovery Ventilator with a Total Recovery Efficiency (TRE) of not less than 50.
- Electric resistance heat shall not be included for outside air pre-heat in climates with outdoor design temperatures of 20° F or greater. For colder climates electric resistance shall be locked out at temperatures greater than 20° F. Capacity shall be limited to that necessary to deliver 55° F air.
- Defrost cycles shall only be implemented in climates where defrost is required.
- A bypass that can route the supply and exhaust airstreams around the ERV unit when the temperature difference between the supply and exhaust airstreams is less than 10° F.
- The HVAC system capacity shall be calculated and sized to account for the reduced loads resulting from the ERV or HRV.

Energy Recovery Ventilation (ERV) and Heat Recovery Ventilation (HRV) systems transfer energy between the supply and exhaust airstreams. When there is a cooling load, heat in the supply airstream is transferred to the cooler exhaust airstream, lowering the temperature of the supply air. When there is a heating load, heat in the exhaust airstream is transferred to the cooler supply airstream, raising the temperature of the supply air. Unlike its simpler HRV cousin, an ERV system can transfer both sensible and latent heat through transferring moisture between the exhaust and supply air streams with an enthalpy wheel. This makes ERVs far more effective in transferring heat under cooling loads than HRVs. In hot, dry climates, it is more cost effective to utilize HRVs than ERVs. In these climates, the efficiency gains of ERVs are reduced, even though the price is higher.

The design of ERV systems must account for several additional design and air quality concerns. It is important for ERV systems to avoid cross-contamination of the make-up and exhaust airstreams. This is one reason that the pressure drop on the supply and exhaust sides needs to be limited. The design should also account for frost protection in cold climates. ERVs save energy, but those savings are offset somewhat by the energy needed to run the ERV system itself and the pressure drop created by the ERV unit. As a result, it is essential for ERVs to have a bypass that allows the ERV to be powered down and the airstreams to be routed around the ERV unit.

Energy Recovery Ventilation can be implemented on either central or unit-level ventilation systems. When implementing energy recovery ventilation, central systems offer some cost savings as a single or limited number of energy recovery units can be used to serve multiple individual units. Central ERV/HRV systems also simplify routine maintenance such as filter changes, a critical issue for the ongoing efficiency of these units. However, the lower installation cost is balanced against the possibility of higher fan energy usage from the longer duct runs in and against the greater space requirements for central systems. Additionally, the recent rapid advancement of energy recovery ventilation equipment specifically designed for multifamily dwelling units and small homes has narrowed the cost differential between central and unit-level systems.

Figure 10: An enthalpy wheel in a central ERV at the Brooks School, North Andover, MA. (Photo credit: Architerra)

Appendix A:

Warm Air Furnaces

Equipment Type	Size Category (Input)	Minimum Efficiency	Test Procedure
Warm-air furnaces, gas fired	< 225,000 Btu/h	97% AFUE	DOE 10 CFR Part 430
	≥ 225,000 Btu/h	81% Et	ANSI Z21.47
Warm-air furnaces, oil fired	< 225,000 Btu/h	95% AFUE	DOE 10 CFR Part 430
	≥ 225,000 Btu/h	81%Et	UL 727

Unitary Air Conditioners and Condensing Units, Electrically Operated

Equipment Type	Size	Heating Type	Subcategory	Minimum Efficiency	Test Procedure
Air Conditioners, Air Cooled (Cooling Mode)	<65,000 Btu/h	All	Split System	15.0 SEER 12.5 EER	AHRI 210/240
			Single Package	15.0 SEER 12.0 EER	
	≥65,000 Btu/h and <135,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	12.2 EER 14.0 IEER	AHRI 340/360
		All Other	Split System and Single Package	12.0 EER 13.8 IEER	
	≥135,000 Btu/h and <240,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	12.2 EER 13.2 IEER	
		All Other	Split System and Single Package	12.0 EER 13.0 IEER	
	≥240,000 Btu/h and <760,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	10.8 EER 12.3 IEER	
		All Other	Split System and Single Package	10.6 EER 12.1 IEER	
	≥760,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	10.4 EE 11.6 IEER	
		All Other	Split System and Single Package	10.2 EER 11.4 IEER	
Air Conditioners, Water Cooled	<65,000 Btu/h	All	Split System and Single Package	14.0 EER	AHRI 210/240
	≥65,000 Btu/h and <135,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	14.0 EER 15.3 IEER	AHRI 340/360
		All Other	Split System and Single Package	13.8 EER 15.1 IEER	
	≥135,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	14.0 EER 14.8 IEER	
		All Other	Split System and Single Package	13.8 EER 14.6 IEER	
Air Conditioners, Evaporatively Cooled	<65,000 Btu/h	All	Split System and Single Package	14.0 EER	AHRI 210/240
	≥65,000 Btu/h and <135,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	14.0 EER 15.3 IEER	AHRI 340/360
		All Other	Split System and Single Package	13.8 EER 15.1 IEER	
	≥135,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	13.5 EER 14.3 IEER	
		All Other	Split System and Single Package	13.3 EER 14.1 IEER	

Unitary and Applied Heat Pumps, Electrically Operated

Equipment Type	Size Category	Heating Section	Subcategory	Minimum Efficiency	Test Procedure
Air Cooled (Cooling Mode)	<65,000 Btu/h	All	Split System	15.0 SEER 12.5 EER	AHRI 210/240
			Single Package	15.0 SEER 12.0 EER	
	≥65,000 Btu/h and <135,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	11.3 EER 12.3 IEER	AHRI 340/360
		All Other	Split System and Single Package	11.1 EER 12.1 IEER	
	≥135,000 Btu/h and <240,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	10.9 EER 11.9 IEER	
		All Other	Split System and Single Package	10.7 EER 11.7 IEER	
	≥240,000 Btu/h	Electric Resistance (or none)	Split System and Single Package	10.3 EER 10.9 IEER	
		All Other	Split System and Single Package	10.1 EER 10.7 IEER	
Air Cooled (Heating Mode)	<65,000 Btu/h	All	Split System	9.0 HSPF	AHRI 210/240
			Single Package	8.5 HSPF	
	≥65,000 Btu/h and <135,000 Btu/h		47 F db/43 F wb Outdoor Air	3.4 COP	AHRI 340/360
			17 F db/15 F wb Outdoor Air	2.4 COP	
	≥135,000 Btu/h		47 F db/43 F wb Outdoor Air	3.2 COP	
			17 F db/15 F wb Outdoor Air	2.1 COP	
Water Source (Cooling Mode)	<135,000 Btu/h		86 Entering Water	14.0 EER	ISO 13256-1
Water Source (Heating Mode	<135,000 Btu/h		68 Entering Water	4.6 COP	ISO 13256-1

Variable Refrigerant Flow Air Conditioner

Equipment Type	Size Category	Heating Section Type	Minimum Efficiency	Test Procedure
VRF Air Cooled (Cooling Mode)	< 65,000 Btu/h	All	15.0 SEER	AHRI 1230
			12.5 EER	
	> 65,000 Bth/h and < 135,000 Btu/h	Resistance or None	11.7 EER	
			14.9 IEER	
	> 135,000 Btu/h and < 240,000 Btu/h	Resistance or None	11.7 EER	
			14.4 IEER	
	> 240,000 Btu/h	Resistance or None	10.5 EER	
			13.0 IEER	

Boilers

Type	Fuel	Size Category	Minimum Efficiency	Test Procedure
Hot Water	Gas	< 300,000 Btu/hr	97.3% AFUE	DOE 10 CFR Part 430
		300,000 - 2,500,000 Btu/hr	94.5% Et	DOE 10 CFR Part 431
		> 2,500,000 Btu/hr	94.5% Ec	
	Oil	< 300,000 Btu/hr	88.6% AFUE	DOE 10 CFR Part 430
		300,000 - 2,500,000 Btu/hr	85.3% Et	DOE 10 CFR Part 431
		> 2,500,000 Btu/hr	86.2% Ec	
Steam	Gas	< 300,000 Btu/hr	83.4% AFUE	DOE 10 CFR Part 430
		300,000 - 2,500,000 Btu/hr	80.6% Et	DOE 10 CFR Part 431
		> 2,500,000 Btu/hr	80.5% Ec	
	Oil	< 300,000 Btu/hr	85.6% AFUE	DOE 10 CFR Part 430
		300,000 - 2,500,000 Btu/hr	83.0% Et	DOE 10 CFR Part 431
		> 2,500,000 Btu/hr	83.5% Ec	

Et = thermal efficiency, Ec = Combustion Efficiency

Chillers

Equipment Type	Size Category	Minimum Efficiency		Test Procedure [c]
		Path A	Path B	
Air-Cooled Chillers	< 150 Tons	≥10.100 EER	≥9.700 EER	AHRI 550/590
		≥13.700 IPLV	≥15.800 IPLV	
	≥150 Tons	≥10.100 EER	≥9.700 EER	
		≥14.000 IPLV	≥16.100 IPLV	
Air-Cooled without Condenser, Electrically Operated	All Capacities	Air-cooled chillers without condenser must be rated with matching condensers and comply with air-cooled chiller efficiency requirements		
Water-Cooled, Electrically Operated Positive Displacement	< 75 Tons	≤0.750 kW/ton	≤0.780 kW/ton	
		≤0.600 IPLV	≤0.500 IPLV	
	≥ 75 tons and <150 tons	≤0.720 kW/ton	≤0.750 kW/ton	
		≤0.560 IPLV	≤0.490 IPLV	
	≥ 150 tons and < 300 tons	≤0.660 kW/ton	≤0.680 kW/ton	
		≤0.540 IPLV	≤0.440 IPLV	
	≥ 300 tons and < 600 tons	≤0.610 kW/ton	≤0.625 kW/ton	
		≤0.520 IPLV	≤0.410 IPLV	
	≥ 600 tons	≤0.560 kW/ton	≤0.585 kW/ton	
		≤0.500 IPLV	≤0.380 IPLV	
Water Cooled, Electrically Operated Centrifugal	< 150 Tons	≤0.610 kW/ton	≤0.695 kW/ton	
		≤0.550 IPLV	≤0.440 IPLV	
	≥ 150 tons and <300 tons	≤0.610 kW/ton	≤0.635 kW/ton	
		≤0.550 IPLV	≤0.400 IPLV	
	≥ 300 tons and <400 tons	≤0.560 kW/ton	≤0.595 kW/ton	
		≤0.520 IPLV	≤0.390 IPLV	
	≥ 400 tons and <600 tons	≤0.560 kW/ton	≤0.585 kW/ton	
		≤0.500 IPLV	≤0.380 IPLV	
	≥ 600 tons	≤0.560 kW/ton	≤0.585 kW/ton	
		≤0.500 IPLV	≤0.380 IPLV	
Air-Cooled Absorption, Single Effect	All Capacities	≥0.600 COP	NA[d]	AHRI 560
Water-Cooled Absorption, Single Effect	All Capacities	≥0.700 COP	NA[d]	
Double-Effect, Indirect-Fired	All Capacities	≥1.000 COP	NA[d]	
		≥1.050 IPLV		
Absorption Double-Effect, Direct-Fired	All Capacities	≥1.000 COP	NA[d]	
		≥1.000 IPLV		

1. FL is the full load performance requirements and IPLV is for the part load performance requirements

2. Both the full load and IPLV requirements must be met or exceeded to comply with this standard. When there is a Path B, compliance can be with either Path A or Path B for any application.

3. The requirements for centrifugal chiller shall be adjusted for non-standard rating conditions per C403.2.3.1 of the IECC and are only applicable for the range of conditions listed in C403.2.3.1. The requirements for air-cooled, water-cooled positive displacement and absorption chillers are at standard rating conditions defined in the reference test procedure.

Variable Refrigerant Flow Air Multisplit Heat Pump

Equipment Type	Size Category	Heating Section Type	Subcategory	Minimum Efficiency	Test Procedure
VRF Air Cooled (Cooling Mode)	< 65,000 Btu/h	All	Multisplit	15.0 SEER	AHRI 1230
				12.5 EER	
	> 65,000 Bth/h and < 135,000 Btu/h	Resistance or None	Multisplit	11.3 EER	
				14.2 IEER	
			Multisplit with Heat Recovery	11.1 EER	
				14.0 IEER	
	> 135,000 Btu/h and < 240,000 Btu/h	Resistance or None	Multisplit	10.9 EER	
				13.7 IEER	
			Multisplit with Heat Recovery	10.7 EER	
				13.5	
	> 240,000 Btu/h	Resistance or None	Multisplit	10.3 EER	
				12.5 IEER	
			Multisplit with Heat Recovery	10.1 EER	
				12.3 IEER	
VRF Air Cooled (Heating Mode)	< 65,000 Btu/h	-	Multisplit	9.0 HSPF	
	> 65,000 Bth/h and < 135,000 Btu/h	-	47°F db/43°F wb Outdoor Air	3.4 COP	
		-	17°F db/15°F wb Outdoor Air	2.4 COP	
	≥ 135,000 Btu/h	-	47°F db/43°F wb Outdoor Air	3.2 COP	
		-	17°F db/15°F wb Outdoor Air	2.1 COP	
VRF Water Source (Cooling Mode)	< 135,000 Btu/h	All	Multisplit System 86° Entering Water	14.0 EER	
			Multisplit System 86° Entering Water	13.8 EER	
VRF Water Source (Heating Mode)	< 135,000 Btu/h		68° Entering Water	4.6 COP	

Takoma Village Cohousing | Washington, D.C.
Courtesy: Andrew Essreg

New Buildings Institute (NBI) is a nonprofit organization driving better energy performance in commercial buildings. We work collaboratively with industry market players—governments, utilities, energy efficiency advocates and building professionals—to promote advanced design practices, innovative technologies, public policies and programs that improve energy efficiency. We also develop and offer guidance and tools to support the design and construction of energy efficient buildings.

Throughout its 20-year history, NBI has become a trusted and independent resource helping to drive buildings that are better for people and the environment. Our theory of change includes setting a vision and defining a path forward. We then set out to create the research that serves as the basis for tool and policy development necessary to create market change.

623 SW Oak St., 3rd Floor, Portland, OR 97205
503 761 7339 | newbuildings.org

nbi new buildings institute

The Department of Energy and Environment (DOEE) is the leading authority on energy and environmental issues affecting the District of Columbia. Using a combination of regulations, outreach, education, and incentives, DOEE administers programs and services to fulfill our mission to improve the quality of life for the residents and natural inhabitants of the nation's capital by protecting and restoring the environment, conserving our natural resources, mitigating pollution, increasing access to clean and renewable energy, and educating the public on ways to secure a sustainable future. We work collaboratively with other government agencies, residents, businesses, and institutions to promote environmentally responsible behavior that will lead to a more sustainable urban environment.

WE ARE WASHINGTON DC GOVERNMENT OF THE DISTRICT OF COLUMBIA MURIEL BOWSER, MAYOR

DEPARTMENT OF ENERGY & ENVIRONMENT
GOVERNMENT OF THE DISTRICT OF COLUMBIA

SUSTAINABLE DC

NET-ZERO ENERGY DC

CLEAN ENERGY DC