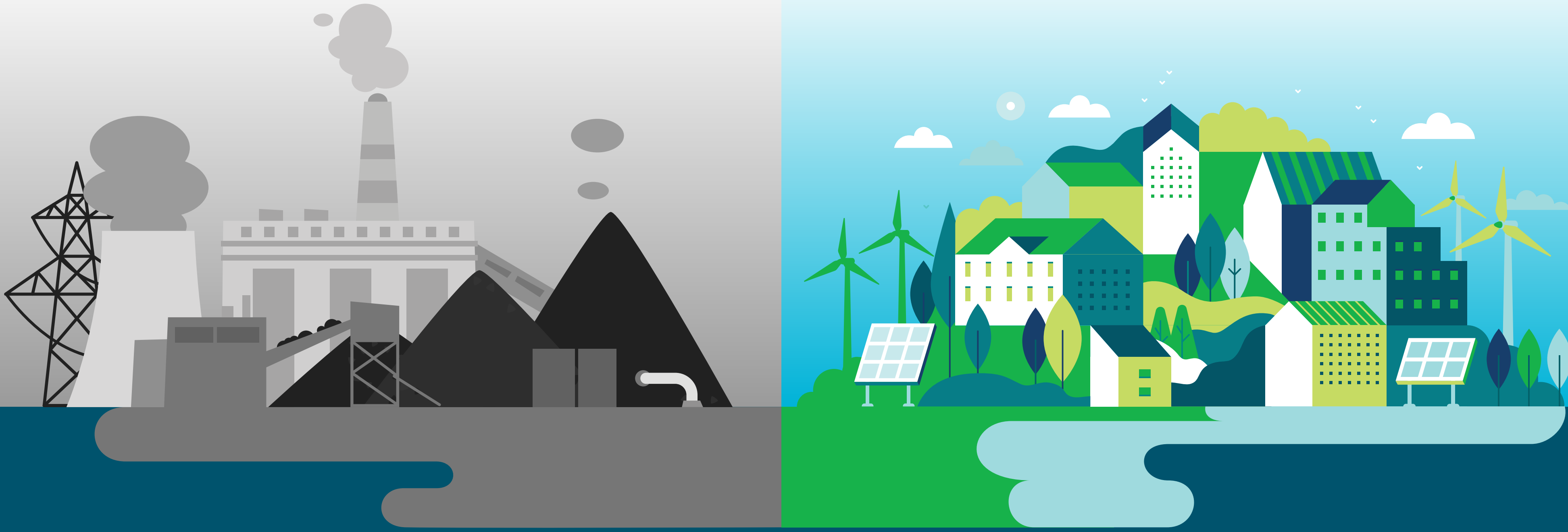


THE BUILDING DECARBONIZATION PRACTICE GUIDE

A Zero Carbon Future for the Built Environment

VOLUME 3:

Multifamily Residential, Hotels/Motels, and Similar Buildings

VOLUME 3 CONTENT LEADERSHIP

- **Katie Ackerly,** AIA, David Baker Architects
- **Sean Armstrong,** Redwood Energy
- **Steven Guttmann,** PE, BCxP, LEED Fellow, Guttmann & Blaevoet
- **Ryan Hamilton,** Consortium for Energy Efficiency
- **Heidi Lubin,** eSix Development
- **Ted Tiffany,** LEED AP BD+C, Building Decarbonization Coalition
- **Breana Wheeler,** BRE (BREEAM USA)

ACKNOWLEDGEMENTS

The William J. Worthen Foundation would like to thank the entire Working Group of experts behind the development of the Building Decarbonization Practice Guide.

RELEASE DATE

10/28/2021 (Updated 8/31/2023)

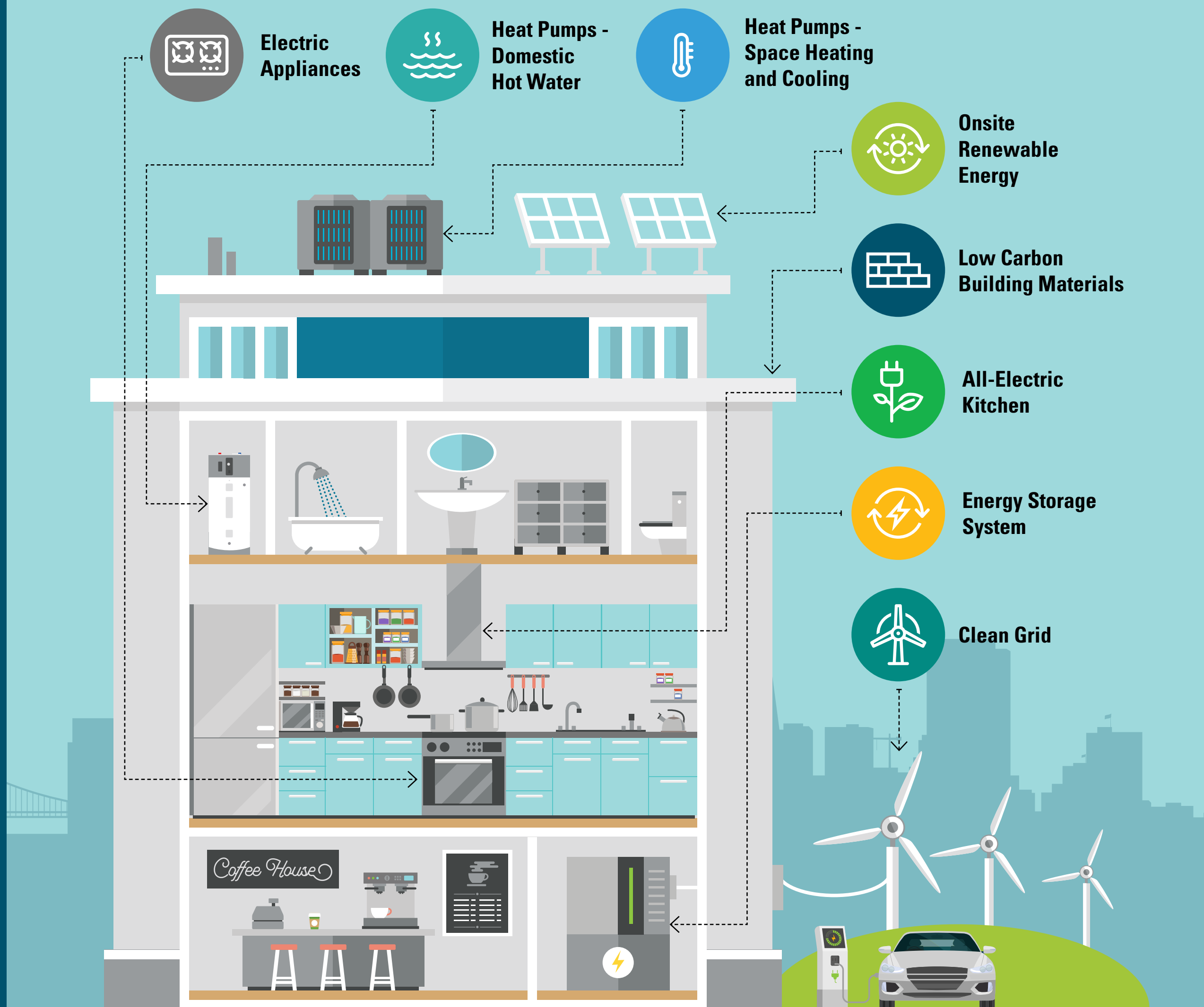


Table of Contents

VOLUME 3

Multifamily Residential, Hotels/Motels, and Similar Buildings

3.0_Multifamily Residential, Hotels/Motels, and Similar Buildings

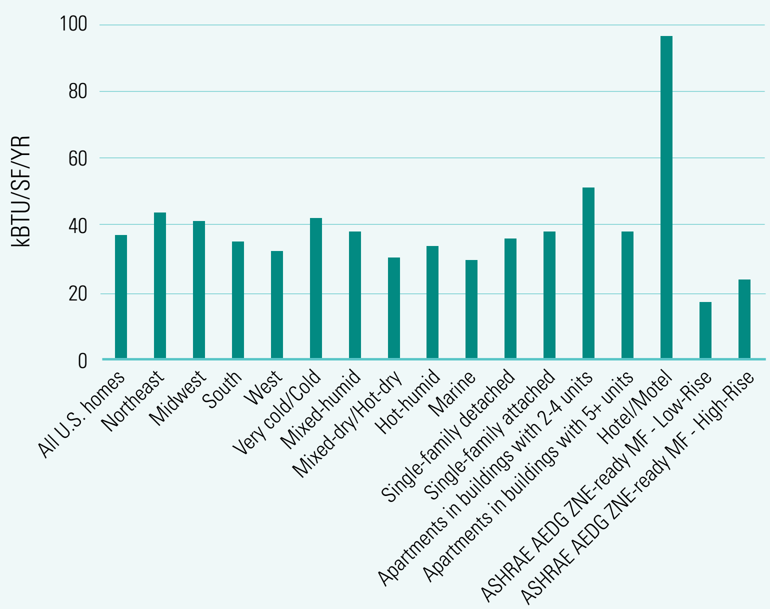
Residential communities form a cornerstone of a climate-adaptive, resilient future, and carbon reduction technologies and associated measures that improve health, equity, and resilience for people at home promise multiple benefits to society. Multi-family residential buildings, in particular, as well as hotel/motel and other housing types, present significant opportunities for decarbonization. Although not the most energy or carbon-intensive building type overall, the 24 hour/365 day operation of these buildings, coupled with high demand for new housing have great implications for decarbonization. In addition, decarbonization can have significant benefits for occupant health and comfort, which can help address growing concerns about indoor air quality in residential occupancies. This Volume lays out both the unique challenges and the technical considerations to create comfortable and healthy living spaces while moving along the path of decarbonization.

3.0.1_DIVERSITY OF BUILDING TYPES

This Volume focuses on buildings that people reside in: within this category, we consider multi-family residential such as apartments and condos, student housing, hotels, senior living, low-income housing, etc.

This Volume addresses primarily low- and mid-rise multifamily housing although many principles are transferable to other commercial building types with residential occupancies, such as dormitories and hotels. All-electric design for these buildings is characterized by the operational duration (24/7/365) as well as end uses such as domestic hot water, laundry and cooking, especially when these functions are centralized and commercial-scale. These buildings are also unified by the outsized impact that resident behavior and lifestyle have on the overall energy use of the building, complicating the use of existing energy use intensity (EUI) benchmarks to set energy performance targets. Within residential building types, data from the Energy Information Administration suggests that residential EUI varies from the national average by plus or minus 20% for most types of residences and most climates, except for apartment buildings with 2 to 4 units, where the deviation is more significant. Also, hotel/motel occupancies have a significantly higher EUI, most likely due to the prevalence of commercial kitchens and laundry facilities.

FIGURE 3.1: AVERAGE RESIDENTIAL ENERGY USE INTENSITY



Source of Data: Energy Information Administration, Residential Energy Consumption Survey (RECS) 2015, and Commercial Building Energy Consumption Survey (CBECS) 2012.

For multi-unit residential projects, it is important to be aware of how variables such as regional climate, dwelling unit mix, unit density, and number of stories impact an EUI target. Figure 3.1 illustrates EUI variations across residential project types and regions.

Many low-rise multifamily buildings, such as attached townhomes, may have systems and technical design challenges more similar to single-family residential buildings. Likewise, electrification of heating and service hot water systems for high-rise residential buildings may have more in common with high-rise commercial buildings. The main focus of this Volume is to capture the buildings that fall somewhere in-between.

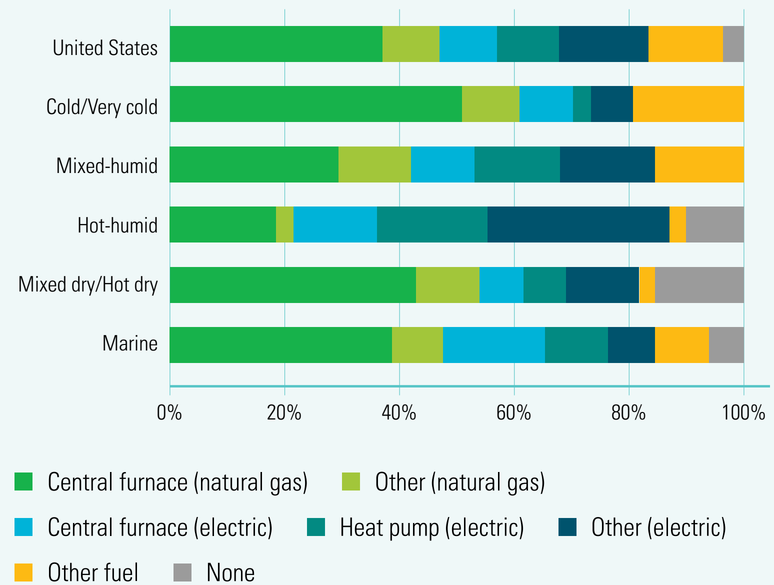
While this guide doesn't specifically address single family residential occupancies, many of the strategies defined herein would also be appropriately deployed in a single-family context as well.

3.1_Principles

On-site gas combustion is a key target for decarbonization efforts. According to the Energy Information Administration, over 50% of the energy consumed by residential occupancies is in the form of onsite fossil fuel combustion (over 80% of which is from natural gas).[1] Residential space and service water heating accounts for 60% of residential site energy use, and almost 60% of the homes in the US are heated using onsite fossil fuel combustion (see Figure 3.2).

While the proportion of homes built all-electric has almost doubled over the past 20 years, it still represented only 25% of the homes built in 2015 (see Figure 3.3). Accelerating the adoption of all-electric new construction and the retrofit of existing single family and multi-family housing could significantly reduce building sector GHG emissions.

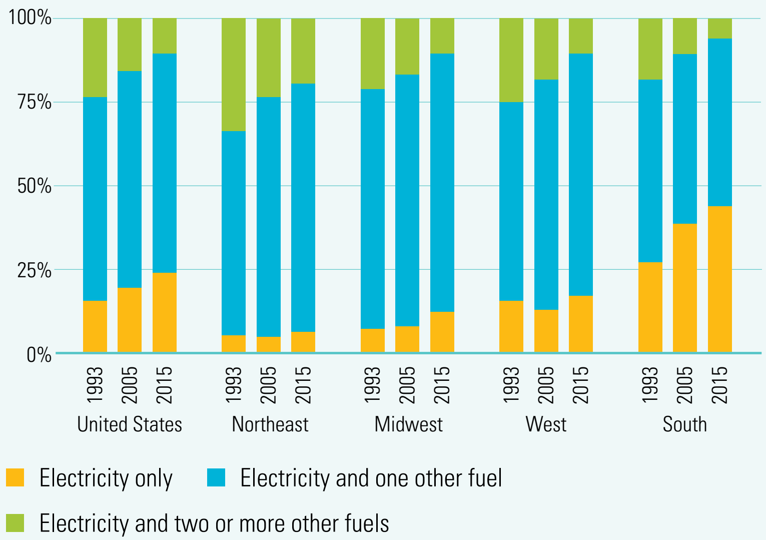
FIGURE 3.2: MAIN HEATING EQUIPMENT CHOICE BY CLIMATE REGION, 2015



Source: 2015 Residential Energy Consumption Survey, U.S. Energy Information Administration

1 https://www.eia.gov/consumption/residential/data/2015/index.php?view=consumption#by%20fuel

FIGURE 3.3: PERCENTAGE OF HOMES BY NUMBER OF FUELS USED IN THE HOME



Source: 2015 Residential Energy Consumption Survey, U.S. Energy Information Administration

It is important to recognize that decarbonization intersects with the multifamily building sector in a variety of ways. For any developer, designer or policy-maker, it is crucial to acknowledge that the relationship between housing development and greenhouse gas emissions includes more than fuel use, energy efficiency, and embodied carbon. These considerations along with housing demand, density and displacement, access to transit, energy and community infrastructure, and economic and social equity are all part of one crucial conversation.

This Volume does not address the regional emissions considerations of urban planning and housing density. It also does not delve deeply into how housing is tied to clean transit and micro-mobility. Nevertheless, denser housing situated amongst public transportation is well understood to be among the most effective weapons against climate change, while also significantly improving economic and health outcomes for people.

For example, "in an assessment of the carbon footprint of 700 California cities, experts with the Renewable and Appropriate Energy Laboratory at the University of California, Berkeley, found that, for most coastal California cities, 'infill' housing — that is, housing built in urban areas, near transit, jobs and services — can reduce greenhouse gas pollution more effectively than any other option."[2] This is equally true in Chicago or Philadelphia or Phoenix. There is great value in ensuring that the interconnected challenges of urban and community design, transit-oriented development, and barriers of housing access and long-term stability for people living in urban communities are holistically addressed in design for zero-carbon housing. Climate responsive and adaptive housing must address both where and how homes are built.

3.1.1_DECARBONIZATION AND SOCIAL EQUITY

Stable housing is a cornerstone of a sustainable society. As such, decarbonization and affordability should be coequal objectives. It is imperative that creating this new generation of housing does not increase inequities that could cause low-income communities to miss out on housing that improves climate resilience and energy security and positively impacts their health and wellbeing. Key inequities to avoid include higher energy cost burdens or construction costs that could make decarbonized housing unaffordable for most. Conversely, making provisions for back-up power protects residents who may be more vulnerable to disruptions caused by heat waves, storms, air quality hazards, or power failures. Prioritizing electric vehicle access in affordable housing helps low-income communities overcome a substantial barrier to accessing cheaper, cleaner mobility.

2 S. Wiener and D. Kammen, "Why Housing Policy is Climate Policy." *New York Times*, March 25, 2019

Decarbonization and affordability can both be achieved if the costs of transitioning our utility infrastructure are borne across the entire building sector — not just by those left to rely on site-burned fossil fuels. Since the negative impacts of climate change already disproportionately accrue to communities of concern, it is imperative that decarbonization in this sector places community health and resilience at the center of decision-making, rather than leading the conversation with greenhouse gas reduction targets. The health benefits of decarbonization are often maximized in communities of concern, and the corresponding reduction in public health costs would be a societal benefit shared by all. In addition, this new design paradigm must be delivered in a manner that maximizes affordability. In this way, the multiple benefits of low-carbon, net-zero housing — improved indoor air quality and lower utility bills — may be equitably shared.

3.1.1.1_Public Health Benefits

Harmful byproducts of onsite natural gas combustion can include carbon monoxide, nitrogen oxides, fine and ultrafine particulate matter, and formaldehyde. Each of these substances, alone and in combination, have been shown to have acute and chronic impacts on human health, including asthma and cancer.

As discussed in Volumes 2 and 5, indoor air quality has been shown to be compromised in residential occupancies. For example, the indoor air pollution caused simply by cooking on a gas stove has a far greater impact than most would imagine. Strategies to address this particular issue are explored in detail in Volume 5.

However, indoor fossil fuel combustion can also impact outdoor air quality. The same byproducts, once vented outside of buildings, further degrade air quality, impacting building residents and non-residents alike. Furthermore, once outside, nitrogen oxides can react with sunlight to form ground-level ozone. In addition to impairing lung function at even very low concentrations, ozone can stymie photosynthesis in shade trees and other plants, inducing a feedback loop of negative health and environmental effects. Refer to Volume 2, Section 2.2.1, "Societal Benefits", for more discussion on the public health benefits of decarbonization.

3.1.1.2_Risks to Affordability

There are many reasons why multifamily construction might lag behind other sectors in realizing cost-competitive electrification, despite the technology solutions being relatively affordable, low-hanging fruit. Building design and construction industry professionals — contractors, designers and developers and the systems upon which we rely to finance multifamily construction — all leverage familiarity (e.g. repetition and simplicity) to reduce cost and risk and minimize liability. Unfamiliar solutions can be subject to "risk pricing" by contractors or subcontractors who may have an implicit bias for seeing their "reliable" and familiar solutions preferred over more innovative ones.

Life cycle costing (LCC) is discussed in Volume 2, and approaches to cost estimating are discussed later in this Volume. With respect to affordability, risk pricing can contribute to a lack of consistent, high-quality, life-cycle cost estimating. This can lead to uncertainty, confusion and skepticism for developers and builders.

Other risks to affordability can occur in urban sites, which often encounter constraints that pose challenges with electrical service planning. For example, there is a popular myth that switchgear must be upsized to accommodate the load of an all-electric building; this is inaccurate. Further, it is critical to note that, where electricity is more expensive than natural gas, electrification that does not increase utility bills can come with an additional investment in onsite renewable energy generation. This can provide a stabilizing impact on operating expenses for years to come. For more on the discussion of onsite generation, see Volume 2, Section 2.6.6, "Maximizing On-Site Renewable Energy Generation."

To reduce these risks:

» Include all-electric systems in any initial basis of design and budgeting exercise.

» Where there is a question of fuel choice, thoroughly account for the credit of eliminating gas infrastructure. Although this gas credit varies widely site to site, it can be more impactful than the added costs associated with the electrical service. Increasingly, gas is not being allowed in new construction in many municipalities; planning for all-electric service will also mitigate the potential impact of future code changes on a project while in the entitlement or pre-development phases.

» Consider alternate futures for natural gas pricing to uncover the impact of future natural gas rates on LCC. Perform sensitivity analyses to establish the cost of natural gas that tips the scales towards electrification, and evaluate the level of risk associated with this future. For more discussion about natural gas prices, see Volume 2, Section 2.5.1.3, "Energy Modeling, Carbon Emissions and Life Cycle Cost."

» Be careful with planning for electric vehicle charging capacity. Where local ordinances impose aggressive requirements, encourage local officials to consider the trade-offs between business as usual and electrification. Rules for electrical service and infrastructure sizing often favor adding charging capacity as a retrofit, rather than as part of new construction. Architects and engineers should be knowledgeable about these dynamics, code compliance issues, funding opportunities and technology options in order to manage cost barriers.

Section 3.2.3.3 herein, "Cost Estimating," includes further details regarding how to organize and complete more meaningful project cost analyses.

3.2_The Design Process

As with any successful building project, an all-electric building or decarbonization project benefits from early and intentional design decisions. Proper attention to the details of an all-electric, zero carbon building during the project's design phase can prevent unnecessary costs and delays during construction while also ensuring that the building operates according to the client's requirements.

There are many elements of the design process that are unique to all-electric building design that are not necessarily unique to multi-family housing projects (see Figure 3.4). However, this section attempts to identify design phase considerations specific to multifamily residential projects. It is organized according to specific professional disciplines and specialized building systems.

3.2.1_PRE-DESIGN

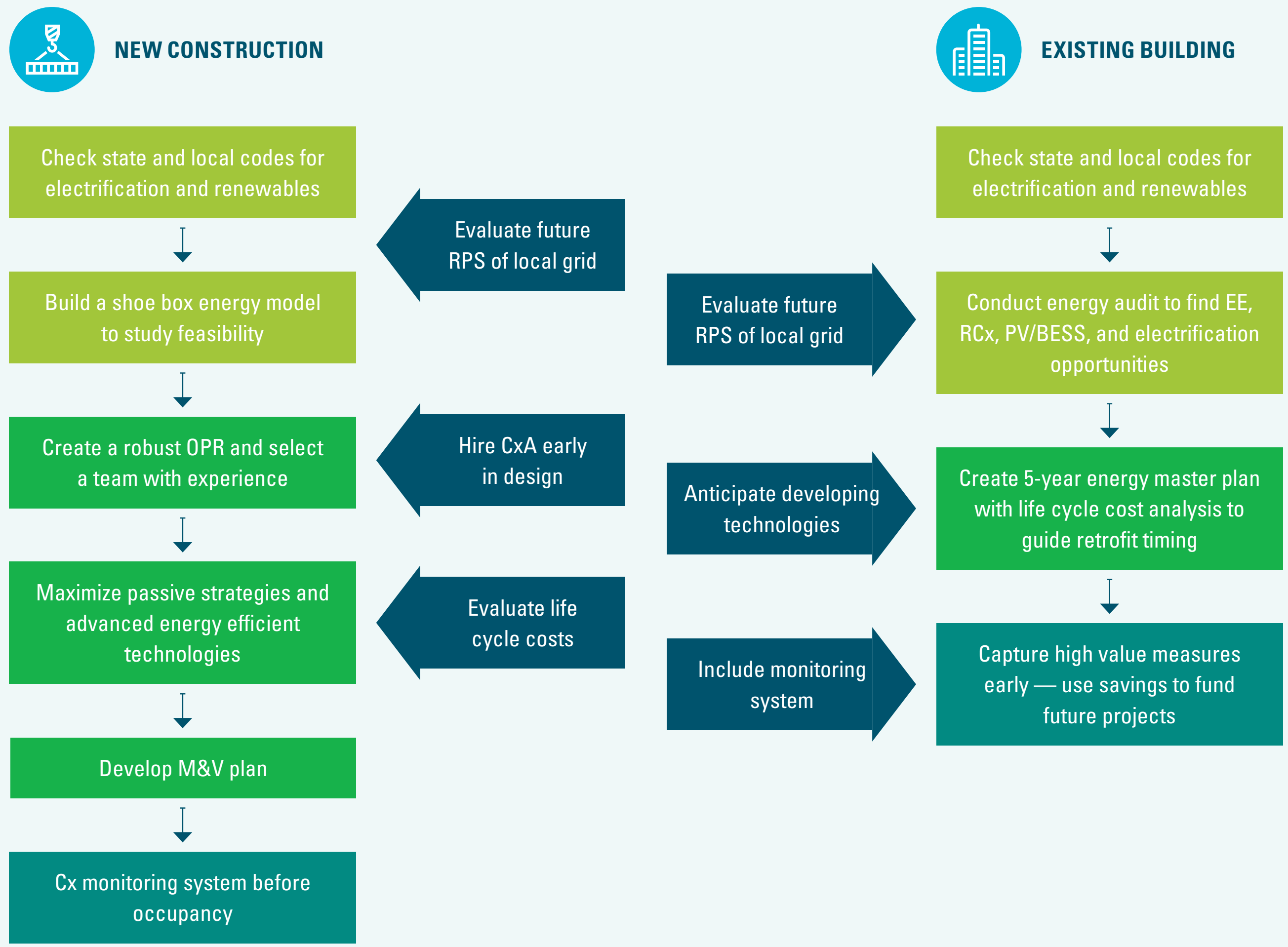
Some key tasks in the pre-design and early design phases include:

1. **Pre-Design:**

    a. Check for local Reach/Stretch Codes, funding and utility incentives, and local development standards that promote all-electric construction and/or onsite renewable energy generation. Consider using a "Power Purchase Agreement" for the funding of onsite generation in order to allow for funds to be diverted from this expense to other project enhancements.

    b. Build a consultant RFP scope that includes design-phase modeling and third-party design review and commissioning for all central heat pump water heater (CHPWH) systems. For more information see Volume 2, Section 2.3, "Assembling the Right Team."

FIGURE 3.4: COMMON ELEMENTS OF ALL-ELECTRIC BUILDING DESIGN PROCESS



c. Assemble a consultant team (Architect, Structural Engineer, MEP engineers, Energy Analyst, etc.) with experience designing all-electric and/or low-embodied carbon multifamily buildings. Make sure that the Energy Analyst is familiar with the challenges of demonstrating Code compliance for all-electric buildings (see further discussion in Volume 7).

d. Develop an operational energy and embodied carbon Owner's Project Requirement (OPR), either as a standalone document or as an amendment to the owner's generic design standards, that covers program-specific performance criteria not already addressed in the standards. Note that an existing design standard may be a more familiar and powerful basis for establishing requirements compared to a new OPR, depending on the client's experience (see Volume 2, Section 2.4, "Owner's Project Requirements: The Value of Goal Setting").

e. Develop a Cost-Benefit Analysis Framework as discussed in Section 3.5 herein, "Assessing Costs and Value."

2. **Early Design:**

   a. Identify a gross EUI target for your building (ASHRAE has resources for identifying a target EUI for a variety of Zero Net Energy residential project types).

   b. Maximize passive design strategies when evaluating site massing.

   c. Conduct a whole-building energy model and life-cycle cost analysis to evaluate measures required to meet compliance targets, the EUI target, and an optimal renewable energy investment target.

   d. Balance priorities of healthy indoor air quality, resilience, and simplicity alongside efficiency when selecting system options to evaluate.

   e. Hire a commissioning agent (see Volume 2, Section 2.3.3, "Role of Commissioning Agents" for more information).

3.2.2_SETTING UP A STRONG PROCESS AND TEAM

3.2.2.1_Create the Conditions for Intentional Goal-Setting

Housing has the opportunity to be transformative: these buildings have the potential to activate street life, benefit open space and ecology, shape the daily routine, safety, security, and health of residents, and facilitate ease of access to the neighborhood and the community. And yet projects are typically highly first-cost driven, and development goals tend to be narrow (i.e., unit yield, budget, schedule). So expanding the team's understanding of what a successful housing project looks like can be a critical early step in considering decarbonization strategies, even ones that are low- or no-cost.

It's easy for early milestones to fly by without taking a moment to pause and put a stake in the ground. Touring existing housing projects as a team can be a useful tool for building a foundation of shared experience and values. Here are some other key strategies:

1. **Emphasize co-benefits**

The market incentives to put emissions reduction high on the list of development priorities are still emerging. Electrification, grid-optimization and embodied carbon reduction strategies are more likely to gain traction on a project if they are attached to project certifications or funding, or framed in a way that leads with co-benefits such as resident health, property marketability and resident retention, resiliency benefits, or energy independence priorities.

2. **Head off uncertainty early**

There are specific points in the development process where there can be conflict between what a developer, designer, or contractor is accustomed to doing and what delivery of an all-electric building design would entail:

a. Budgeting (see also Section 3.5 herein):
   i. Funding criteria and deadlines
   ii. Uncertain magnitude and value of new soft costs
   iii. Uncertain up-front and life-cycle cost tradeoffs
   iv. Cost of onsite renewable energy generation
b. Programming
   i. Ground level service space planning
c. Design:
   i. Avoidance of the Guinea Pig syndrome (aka the natural tendency to avoid any solutions that seem too leading edge)
   ii. Utility connections, estimating transformer size/type and switchgear space
   iii. Domestic hot water system configuration and equipment location
   iv. HVAC systems options, envelope options, and energy modeling
   v. Electric Vehicle Charging Station (EVCS) options
   vi. PV system size
d. Permitting
   i. Energy Code compliance

These points, among others, can turn into extended conversations requiring coordination and/or analyses, which otherwise might not be required. These conversations add time, and you can bump up against cognitive bias, introducing more doubt and uncertainty for the owner.

3. **Be proactive with design standards**

Many multifamily property developers have a set of design standards that often supplement or replace an Owner's Project Requirements document and drive a lot of the specified systems and equipment. For large, market-rate developers, these standards can be relatively non-negotiable. Because such standards tend to be generic, project-specific goals and performance criteria can go undocumented. Designers can use project-specific documents as a helpful accountability tool, rather than an obstacle or administrative nuisance, if they are proactive about them. Design Team leaders should:

a. Encourage the addition of a programming document section to capture project-specific performance criteria, goals, and owner requirements.
b. Take the lead with scheduling coordination meetings that use the design standards and the project-specific criteria document to track progress and serve as a basis for project evaluation and discussion.

3.2.2.2_Hire the Right Team

Volume 2, Section 2.3, "Assembling the Right Team" discusses the value of hiring architects and engineers experienced with the new strategies required to deliver energy efficient, all-electric, low embodied carbon buildings. Specific things to consider when writing RFPs for multi-family housing projects include:

1. Requiring a team experienced with designing central heat pump water heaters and Energy Code compliance modeling for all-electric multifamily buildings.
2. Adding oversight scope from a consultant who specializes in central heat pump water heating systems. This scope might include: advising on the basis of design, evaluating/recommending concepts and sizing, peer review, system monitoring, and operator training.

3. Including in the energy consultant's scope a benchmarking energy model — distinct from the required Energy Code compliance model — that can help an owner evaluate energy performance and savings measures compared to an industry baseline, provide greater accuracy in hot water-related energy savings measures, allocate PV energy savings properly, and provide life-cycle cost analyses. Additional modeling scope is discussed in greater detail in Section 2.5, "Using Building Performance Modeling as a Design Guidance Tool".

4. In addition to basic testing and inspection scopes, include a request for team members that can provide some or all of the following:

   a. Services typically provided to meet the national or regional Energy Star for Homes program requirements and the Multifamily High Rise Program Testing and Verification Protocols, including the Thermal Enclosure System Field Checklist and fan pressure testing for compartmentalization.[3]

   b. Full systems commissioning, including envelope.

If these items get excluded, they are hard to include later in project development. If the scope is included from the start, it will be there to ensure a meaningful return on energy efficiency investments.

3.2.3_HIGH LEVEL DESIGN CONSIDERATIONS FOR MULTI-FAMILY HOUSING

Resources to assist in ensuring the appropriate consideration of electrification, energy efficiency, and renewable energy strategies are ubiquitous. For example, nonprofits such as the World Resources Institute (WRI), the New Buildings Institute (NBI), the Rocky Mountain Institute (RMI), Passive House Institute US, and ASHRAE, as well as the National Institute of Building Sciences, and the US Department of Energy (through various National Labs) have long been leaders in disseminating forward-thinking design guidance. For example, the WRI Working Paper, "Accelerating Building Decarbonization: Eight Attainable Policy Pathways to Net Zero Carbon Buildings for All," published in September 2019, highlights thirteen widely available energy efficiency (EE) technologies and eight widely available renewable energy (RE) technologies (see Figure 3.5). All these technologies are well-established and commercially available at reasonable cost, and they represent solutions that can be delivered by any number of qualified design and construction firms.

3.2.3.1_Architecture

Volume 2 addresses many of the universal architectural design considerations that are essential for the design of successful all-electric buildings, such as load reduction fundamentals: orientation, window sizing, envelope construction, and exterior shading devices.

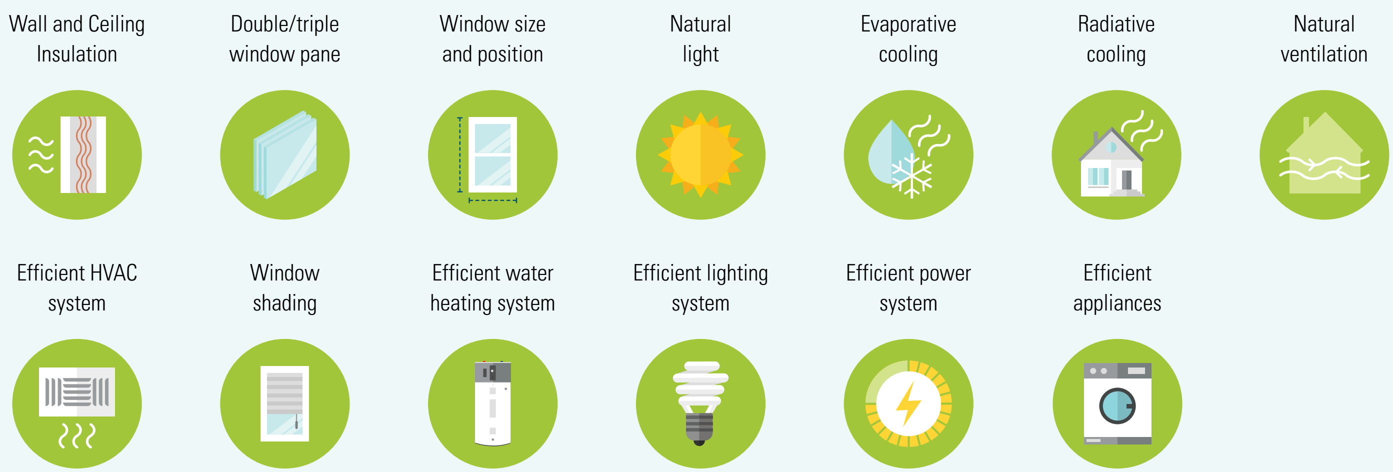
Although an all-electric design does not necessarily have a dramatic impact on space planning, it's worth highlighting that for this building type, basic building blocks for upper-floor residential and ground floor service areas are typically based on established rules of thumb that have evolved to maximize space efficiency over time. When transitioning away from historically mixed-fuel projects, some of these assumptions could be challenged, and should be confronted early.

A prime example of the impact of a shift in approach is the move to distributed hot water systems, which become appealing once gas is out of the building. This change of system type could lead to changes in basic unit dimensions. In fact, numerous systems in an all-electric, low-carbon apartment building could influence the basic building blocks that govern the allocation of roof and open space, ground floor space, and unit dimensions. As such, at the very earliest stages of design, it is important to take into consideration the type and location of domestic hot water systems, transformer size and location requirements, and any distributed energy resources such as PV and battery storage. This highlights the importance of

3 Forms can be found at https://www.energystar.gov/partner_resources/residential_new/homes_prog_reqs/national_page

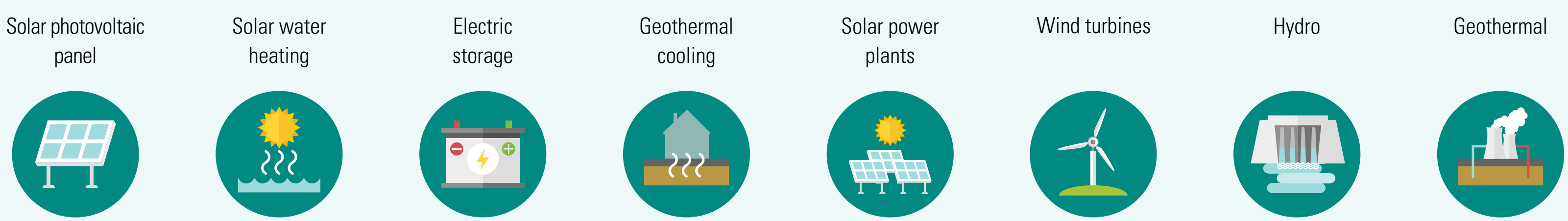
FIGURE 3.5: WIDELY AVAILABLE ENERGY EFFICIENCY (EE) AND RENEWABLE ENERGY (RE) TECHNOLOGIES THAT SUPPORT ZERO CARBON

ENERGY EFFICIENCY



OTHERS: Building form and layout to reduce cooling load, passive cooling through wall, window and roof massing/materials.

RENEWABLE ENERGY



OTHERS: Parabolic solar collectors, solar cooling, clean biomass for cookstoves, "thermal batteries."

Source: https://files.wri.org/s3fs-public/accelerating-building-decarbonization.pdf having high-level discussions about performance intentions and operations early on, or else build in some buffer — such as a slightly longer unit depth or comfortable service space allocation — so that the design remains flexible within a given unit yield and mix.

3.2.3.2_Structural Design

Volume 6 of this Guide is devoted to reducing the embodied carbon in buildings. It identifies the significant steps towards employing reduction opportunities:

1. **Quantifying the embodied carbon in your project**
2. **Familiarizing your team with high-impact materials and systems**
3. **Sourcing from lower-impact manufacturers**
4. **Optimizing the use of materials**
5. **Reusing materials**
6. **Using less Portland cement**
7. **Using more biobased and other carbon-sequestering materials**

Multi-family construction generally accommodates a wide range of embodied carbon footprint options, which are tied closely to the area of land impacted by the planned building, the size and height of the building, and the life-safety systems that go into the building.

Many framing options are possible for non-high-rise buildings (typically buildings with less than 75 feet elevation change from the entry to the highest occupied floor — the height of a fire ladder truck that usually defines the trigger point for high-rise construction requirements). For low and mid-rise construction, buildings with the lowest carbon footprint are often built with sustainably sourced lumber, in Type V combustible frame construction (stick framed with plywood shear walls). For high-rise buildings, fire/life safety systems and non-combustible construction become requirements, both of which significantly increase a building's embodied carbon footprint on a per unit basis.

Mass timber and some hybrid structures are increasingly possible and code-compliant for high-rise construction. However, high-rise life/safety system requirements (e.g. additional structural encapsulation requirements for fire resistance, and redundant fire sprinkler systems) can cause increases in system sizing and hence embodied carbon, even with mass timber options.

High-rise construction often requires a more concentrated use of materials within the structure and the exterior enclosure. Together, these result in a higher embodied carbon footprint per area of building. But the type of systems used can lead to more durable, longer lasting buildings, as well as facilitating higher density programs for a smaller impacted land area.

Modular building options, both below and above the 75' height limit, offer unique opportunities for minimizing waste within the construction process. One challenge of volumetric modular construction is that the added structural materials that go into the modules for shipping and prior to final construction often increase their embodied carbon footprints over build-in-place alternatives.[4] One optimal modular approach, for both embodied carbon and cost, has been to flat-pack frame systems, where floor and wall panels are built using modular systems and final assembly either happens as the building goes up, or within an enclosed factory setting at the project site.

How to achieve the lowest embodied carbon footprint is not an easy question to answer and the variables are many. Trade-offs need to be considered carefully within a whole project life-cycle analysis in order to assess which is the lower carbon solution for a given site and targeted building lifespan.

4 Volumetric modular construction is the process of assembling fully enclosed, six-sided building modules in an offsite factory setting and then joining them together to construct one large building.

3.2.3.3_Cost Estimating

It is common for multi-family housing projects to be delivered through a design-assist[5] or design-build delivery method.[6] These methods often put the builder in the role of cost estimator since conventional wisdom has it that they are experienced at establishing quantities and productivity, so they should be well-positioned to establish the anticipated cost of any project.

Conventional wisdom has two potential pitfalls when it comes to relying on the builder to estimate construction costs for any project:

1. **"Filling in the gaps":**
   a. The process of developing opinions of probable construction cost is not the same activity as preparing a construction bid. Bidding typically involves measuring quantities shown on a set of drawings and applying material costs, productivity rates, and other factors as part of determining the total cost to build something. The art of estimating the cost of work when designs are not ready to be "measured" is critical to proper preparation of cost opinions during early design phases. Professionals who do nothing but estimate the cost of construction are often better suited to filling in the gaps, often based on extensive databases of similar work; the project design team — particularly the architect, engineers, and energy consulting professionals — should also be able to assist based on their most recent prior experiences.
   b. Moreover, development teams need to be supported to review life cycle cost and potential reductions in operational energy costs and related improvements in net operating income in order to fully evaluate the cost-benefit of a particular energy or embodied carbon decision. This process is more fully detailed in Section 3.5, and case study examples are provided in Section 3.6.
2. **"Risk Pricing" Pitfalls:**
   a. As stated previously, when contractors — and even most specialty subcontractors — are presented with unfamiliar design solutions, "risk pricing" can result. Contractors can have implicit biases for seeing their "reliable" solutions as preferred over more innovative ones.
   b. One strategy to mitigate risk pricing is to specify the most simple and elegant solution. In addition, offering strong support to contracting teams to ensure that they understand the systems — for example, installation mock-ups or training, prior to bidding — can reduce the fear of installing a "new" system for which they lack familiarity. It can also help to draw analogies to systems with which contractors and subcontractors are already familiar. For example, the install on today's packaged terminal heat pump (PTHP) units isn't appreciably different from yesterday's hotel-style heating and cooling unit (PTAC).

For general approaches to cost estimating that may improve the success of project cost control, see Volume 2, Section 2.3.2, "Cost Estimating". For a more focused discussion on cost control and value assessment related to Multifamily Housing projects, see Section 3.5 herein.

3.2.3.4_Electrical Design

For all-electric building designs, the electrical engineer takes on a critical role. Proper sizing of the electrical service is a key factor in these projects. While sizing of a building's electrical service is highly constrained by the national Electrical Code, engineering judgement is relied on in a number of ways that — if not exercised properly — can dramatically oversize electrical infrastructure. It is advisable to ensure that service sizing calculations are given robust peer review.

5 [Design-Assist: The Way to Really Fly [AIA course]] or https://files.klgates.com/files/publication/055ae3ba-ecb7-43d0-be9b-412fb235407b/presentation/publicationattachment/e4e0432e-8ae0-4656-824e-48d6a7619d36/design-assist-getting-contractors-involved-early_091912.pdf

6 What is Design Build? — Design-Build Institute of America Rocky Mountain Region

For example, National Electrical Code rules provide ways to discount various loads, including appliances, cooking equipment and laundry loads. In addition, experience shows that calculated demand loads always overestimate actual demand loads, and for good reason.

However, once a building is built and occupied, actual demand loads can be easily measured, and additional loads can be added without an increase in service or switchboard capacity. Thus, owners should be strategic about the possible phasing of work in order to take advantage of the inherent oversizing of electrical infrastructure even when good engineering judgement is exercised.

Areas where electrical engineers should pay close attention include:

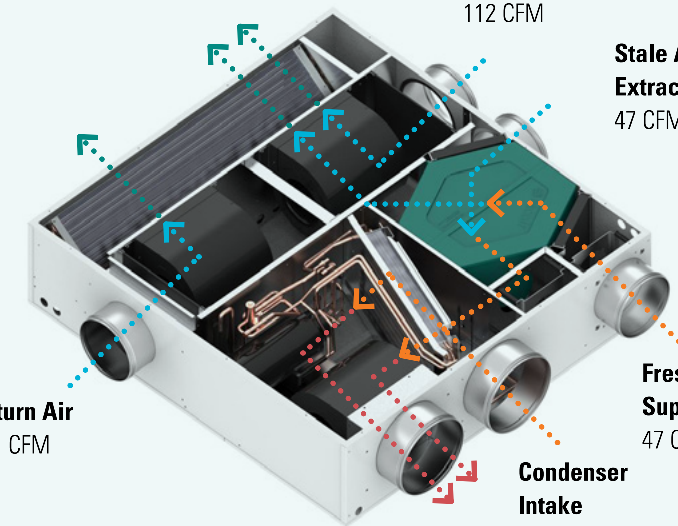
- Evaluating the anticipated connected load of heat pumps.
  - Even in mild climates, defrost heaters need to be considered, and heat pumps may need supplemental electric heat in order to handle low ambient conditions.
- Exercising reasonable engineering judgement when it comes to diversity, demand and derating factors.
  - Be careful in cases where Local Code provisions override the use of diversity factors, such as with the requirements for EVCSs in the California Green Building Standards Code (2019 CALGreen par. 4.106.4.2.4).
- Careful consideration of the service voltage.
  - These types of projects consist mostly of utilization voltages of 208 volts, so selection of the service voltage for smaller projects should be at 208 volts, in lieu of 480 volts, which reduces the need for interior step-down transformers to serve the load. Where projects might have difficulty siting a transformer (e.g. small, urban infill projects), work closely with the HVAC engineer to avoid the use of equipment requiring 460VAC. If all equipment can use 208V/1PH or 3PH power, a transformer can be avoided. For larger projects where transformers present cost and/or space issues, consider multiple utility services. Avoiding transformers also avoids the losses (+/-2% of the transformer's kW rating) that reduce overall electrical system energy efficiency.

3.2.3.5_HVAC Design

There are a number of cost effective all-electric HVAC approaches that provide good energy efficiency. ASHRAE is currently developing their Advanced Energy Design Guide for Zero Energy Multifamily Buildings, which will provide detailed guidance on optimal HVAC strategies.
In general, strategies include:

1. **Heat pumps:**
   a. Volume 2, Section 2.6.2, "Use Electric Driven Heat Pumps," discusses heat pumps in detail.
   b. Newer products are being developed for the residential market that incorporate many cost and energy efficiency measures, such as self-contained air-to-air heat pumps (i.e., no outdoor unit is required), and domestic hot water heat recovery options (see Figure 3.6).
   c. For certain projects, only specify — if possible — equipment that runs on 208 or 220 VAC. This can help the electrical engineer avoid the need for large service transformers, which can be costly as well as difficult to locate on some projects. This should be discussed with the electrical engineer and closely coordinated during the completion of the design.

FIGURE 3.6: AN EXAMPLE OF A HEAT PUMP ENERGY RECOVERY VENTILATOR WITH NO OUTDOOR UNIT



Source: Adapted from the Epocha's VHP2.0 brochure

2. **Efficient Packaged Terminal Air Conditioners (PTACs):**
   a. This is generally the least efficient option, but it is still a heavily used strategy in residential construction due to its relatively low cost.
   b. Be aware that many PTACs that have a heat pump option can only use the heat pump down to a relatively warm outdoor air temperature. Below this temperature, they switch to electric resistance heating, which can increase electrical infrastructure costs and be very expensive to operate.
3. **Dedicated outdoor air ventilation systems (DOAS):**
   a. Also discussed in Volume 2, Sections 2.6.2 ("Use Electric Driven Heat Pumps") and 2.6.3 ("Eliminate Reheat"), these systems can be paired with any number of heating and cooling strategies.
4. **Radiant heating and cooling systems:**
   a. More commonly seen in single family homes, there is no technical barrier to applying certain types of radiant systems to multifamily occupancies. However, the cost and complexity issues of these systems are often too significant to overcome for most multi-family projects.
5. **Refrigerant-based heat pump systems:**
   a. Variable refrigerant flow (or VRF) systems allow for energy to be exchanged between zones in heating and zones in cooling. VRF systems come in air-to-air and water-to-air heat pump configurations.
   b. VRF systems can also be equipped with an extra refrigerant-to-water heat exchanger that provides recovered energy for pre-heating domestic hot water.

6. **Electric resistance heating:**
    a. While this may be the least desirable type of system, there are some applications where it can be a reasonable choice: for example, when envelopes are built to Passive House standards, the vastly reduced size needed for space heating systems can make this technology an extremely cost effective choice.

Whatever systems are ultimately considered, final system selection needs to consider any number of project goals, including the ability of the property management staff to operate and maintain the systems.

3.2.3.6_Domestic Hot Water System Design

One of the systems undergoing the most radical transformation in design approach is the domestic hot water (DHW) delivery system. The onsite combustion of a fossil fuel to generate DHW has been the primary design paradigm for over 100 years; the first US patent for a storage type water heater was filed by Edwin Ruud in the 1880s.[7]

DHW (aka service hot water) heating is also a large energy end use in multifamily building types. These systems can be unitary (one or more per dwelling unit), unitary for multiple dwelling units, or — as is most commonly designed for large multifamily projects — a central water heater system with hot water storage and recirculation loops.

3.2.3.6.1_AIR-SOURCE HEAT PUMPS

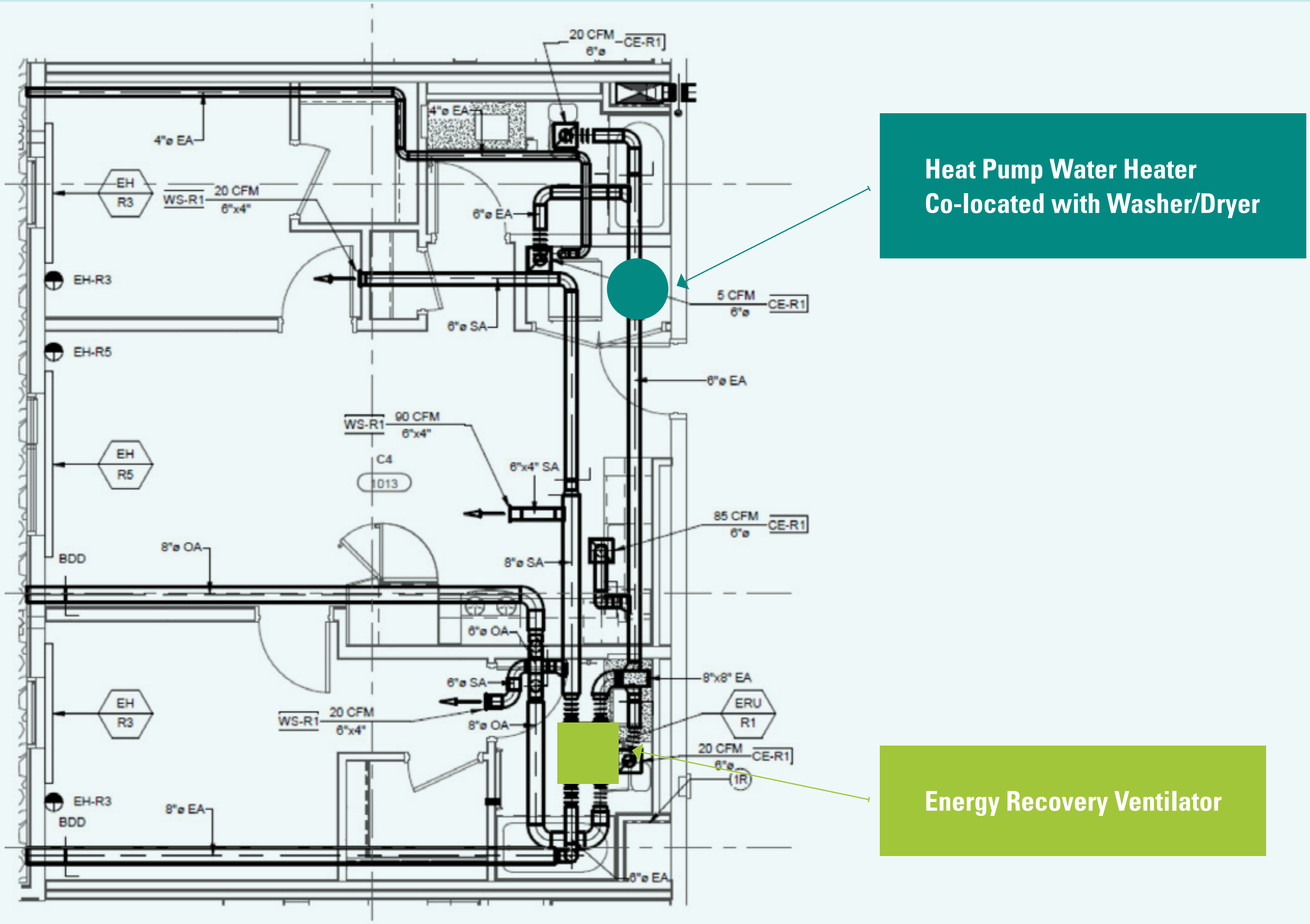
Efficient unitary systems are generally configured around air-to-water heat pumps (aka air-source heat pump or ASHP), and — if located close enough to all end uses — they can be installed in each unit to facilitate elimination of the recirculation loop and its associated energy losses. This requires a dedicated space for the equipment in the apartment or hotel room (see Figure 3.7), and the space must be adequately ventilated to prevent the space from becoming too cold as a result of the heat pump's operation. Some manufacturers allow the cold air emitted from a heat pump to be ducted, either to the outdoors or to a space that needs 24/7 cooling (such as an electrical or telecom room). Apartment laundry services can be co-located with the heat pump water heater to vent the cold air through the dryer exhaust vent as well as saving on materials and ductwork. There are also split heat pump units available on the market that place the condenser remotely (often outdoors) with a separate hot water tank that can be located wherever needed. This simplifies internal space layout and venting accommodations, but it does require outdoor space (roof or ground), a suitable exterior wall area for mounting the condenser, or a suitable, properly ventilated indoor space (e.g. a large parking garage).

Unitary equipment can also be configured for multiple dwelling units, linking multiple dwelling units to a singular heat pump water heater. While it may be harder to configure this type of system without a recirculation loop, designs have been completed that maintain compact domestic hot water piping without a recirculation loop. In this application, the system would typically require a larger storage tank volume to carry the larger loads of multiple units. Nevertheless, this design can save on space, cost per unit, and maintenance.

In larger buildings, especially in retrofits of existing buildings, central heat pump water heating (HPWH) systems may be the only viable approach, and this can be designed with highly efficient air-to-water heat pumps paired with storage tanks. Hot water storage tanks can be strategically placed in basements, parking garages, or dedicated mechanical spaces. ASHPs are typically located outdoors (roof or grade mounted) but can also be placed in open parking garages. Ideally heat generation and storage can be co-located, as in traditional boiler rooms. However, conventional boiler rooms are typically too small to house even the additional amount of water storage typically required for these heat pump systems, so space allocation is often an issue. A typical project layout that contrasts gas boiler and central heat pump water heating systems is shown in Figure 3.8, for a side-by-side comparison of the space needed for tanks and other equipment. Due to the relatively limited capacity of the largest ASHPs (when compared to conventional gas-fired water heaters), central HPWH systems should be designed to maximize storage and minimize heater capacity to ensure that adequate supplies of hot water are always provided. Early architectural

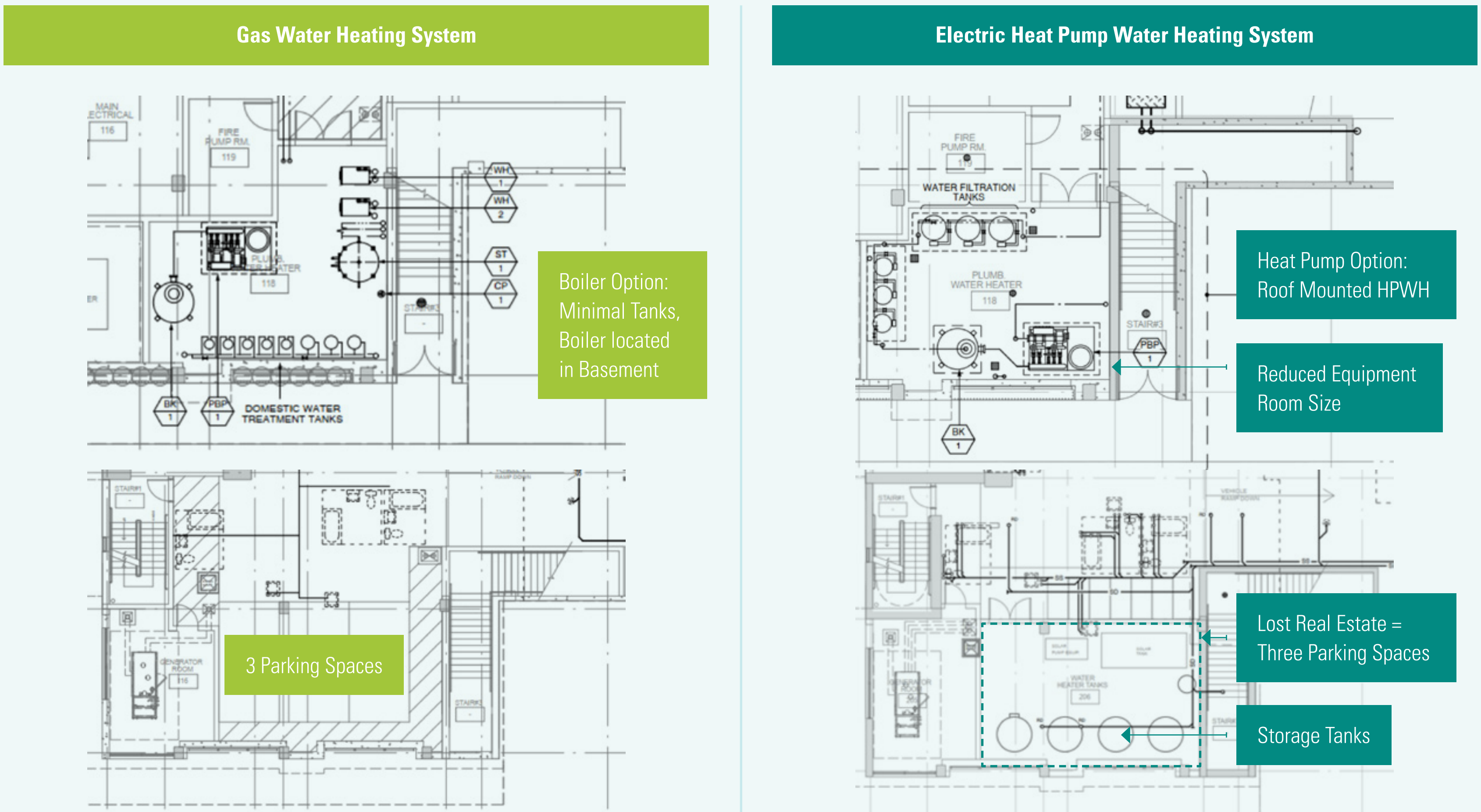
7 https://www.ruud.com/about/

FIGURE 3.7: TYPICAL APARTMENT LAYOUT INCORPORATING A HPWH



Source: Image courtesy of Guttmann & Blaevoet Consulting Engineers

FIGURE 3.8: CHANGES TO A FLOOR PLAN DUE TO CONVERSION FROM GAS TO ELECTRIC WATER HEATING SYSTEMS



Source: Image courtesy of Guttmann & Blaevoet Consulting Engineers design concepts should address the different space needs of central HPWH systems in order to ensure that all desired amenities can be accomodated.

Residential buildings tend to have a relatively predictable demand profile. Potable water use in residential buildings also normally adheres to a twin-peak profile, which is typically in near-perfect alignment with the typical electrical grid demand profile. These two factors allow for heat pump water heaters to be intentionally controlled to provide carbon reduction and grid harmonization benefits, making them useful in decarbonization beyond simply heating potable water with electricity instead of direct fossil-fuel combustion.

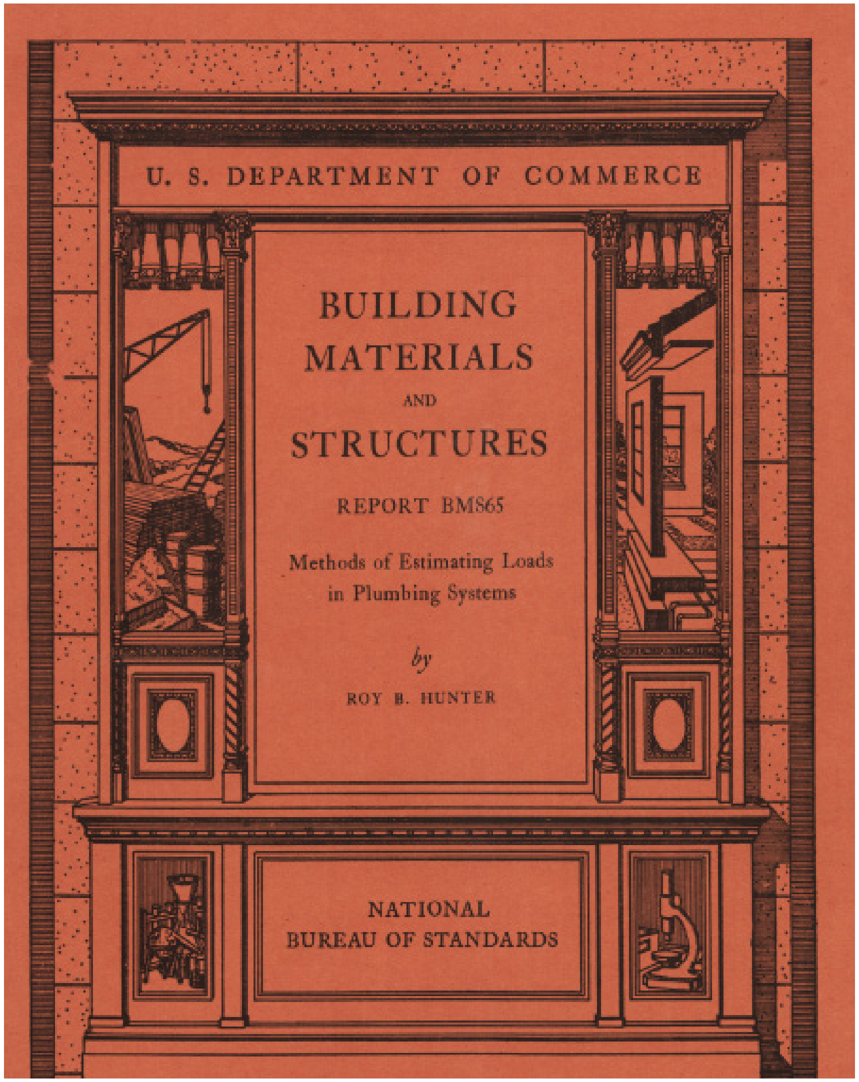
3.2.3.6.2_WATER-SOURCE HEAT PUMPS

Volume 2, Section 2.6.2.2 discusses water-source heat pumps (WSHPs) in detail. For decarbonization projects, these are typically connected to earth-coupled heat exchangers (e.g., working as ground-source heat pump systems) or applied in a heat recovery configuration, capturing waste heat from chiller systems, exhaust air streams, etc. The advantage of using a WSHP in a heat recovery application is the ability to take a "low-quality" heat source and boost it to a temperature suitable for DHW systems.

For ground-source systems, pulling heat out of the ground to create DHW should typically be combined with systems that put heat into the ground (e.g., chiller systems), to avoid annual thermal imbalances that can have significant adverse effects. Numerous resources on the proper design of ground-source heat pump systems are available.[8]

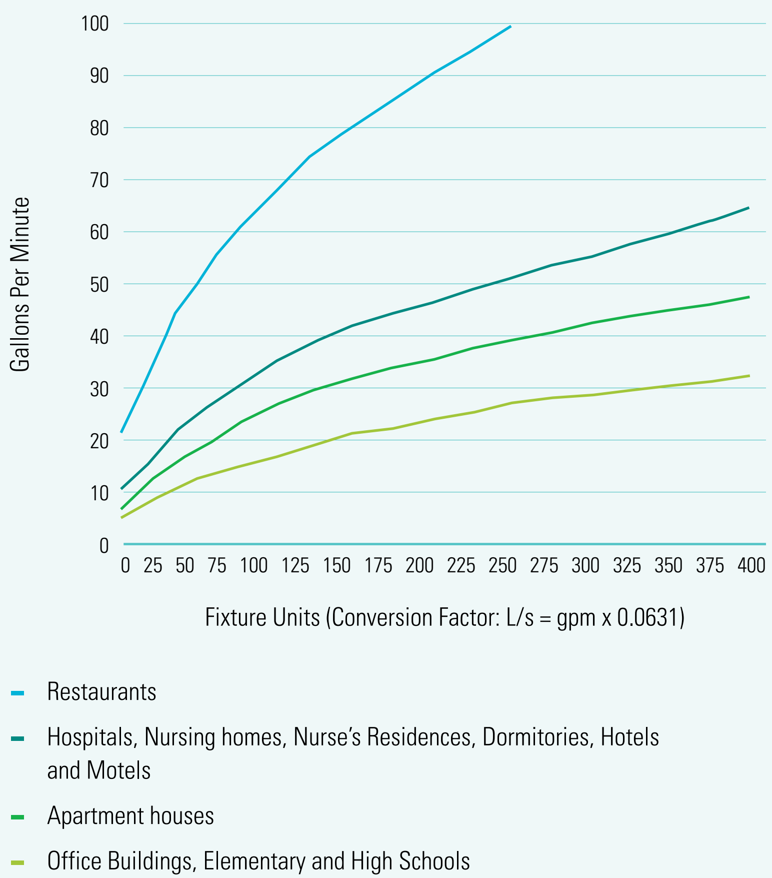
3.2.3.6.3_SIZING CONSIDERATIONS

The first consideration for designing and selecting a central HPWH system is to determine the peak demand and the usage profile over a twenty-four hour period.



8 For example, see *Geothermal Heating and Cooling: Design of Ground-Source Heat Pump Systems*, Steve Kavanaugh and Kevin Rafferty, published by ASHRAE, 2014.

FIGURE 3.9: MODIFIED HUNTER CURVES



Source: 1999 ASHRAE Handbook

While the buildings that are the focus of this Volume have similar demand characteristics (with some variation), the typical methods that are used for estimating peak demand in residential occupancies are based on outdated assumptions and data. These methods generally result in a significant oversizing of heating capacity. Many things have changed since 1940 when Roy B. Hunter's "Methods of Estimating Loads in Plumbing Systems" was published as a national standard in the United States.[9] Hunter's "curves" used for system sizing have been modified since the 1940s to develop curves that are tailored for different occupancy categories (see Figure 3.9). Nevertheless, Hunter's methodology is baked into current National Codes, and these curves still result in significant oversizing of systems.

Efforts have been made over the past decade to develop alternative methodologies for estimating peak demand that engineers can rely on to design systems that provide an adequate source of DHW at all times. For residential occupancies, numerous studies suggest that multi-family buildings (apartments and condominiums) share demand characteristics, with a tight correlation of daily volumetric consumption as well as time and duration of peak demand periods. Some manufacturers and industry-leading consultants have developed methodologies tailored to the residential market based on the fact that these demand profiles are more predictable than in many other occupancies. In addition, Appendix M of the Uniform Plumbing Code is being adopted by an increasing number of authorities; this alternate method has been shown to reduce calculated peak demand as well as pipe sizes that result from the traditional calculation methods.

Right sizing of heat-generating equipment is always important, but the challenges of designing HPWH systems are magnified by the oversizing of systems. Engineers need assurance that the methodologies they use will provide reliable results. Thus, this is a critical area for further tool development. The University of Cincinnati's Department of Environmental Engineering has been a leader in the research and development of new methodologies. However, until these new methods are objectively validated, engineers may prefer to compare manufacturers' recommended system capacities, capacities derived from tools developed by industry-leading organizations, and capacities developed using standard industry

9 Image from https://www.aspe.org/product/the-original-hunter-papers-the-foundation-of-plumbing-engineering/

methods to find ways to right-size these systems.[10] Acceleration of the development of new Standards, as well as the adoption by model Codes of more modern methodologies for system sizing, will be important steps in addressing this issue.

3.2.3.6.4_CONFIGURATION CONSIDERATIONS

Different configurations of central HPWH systems are available. The primary configurations in use today are:

- » Central Systems
  - Single-pass
  - Multi-pass
- » Distributed Systems
  - Residential-type HPWH with integral storage

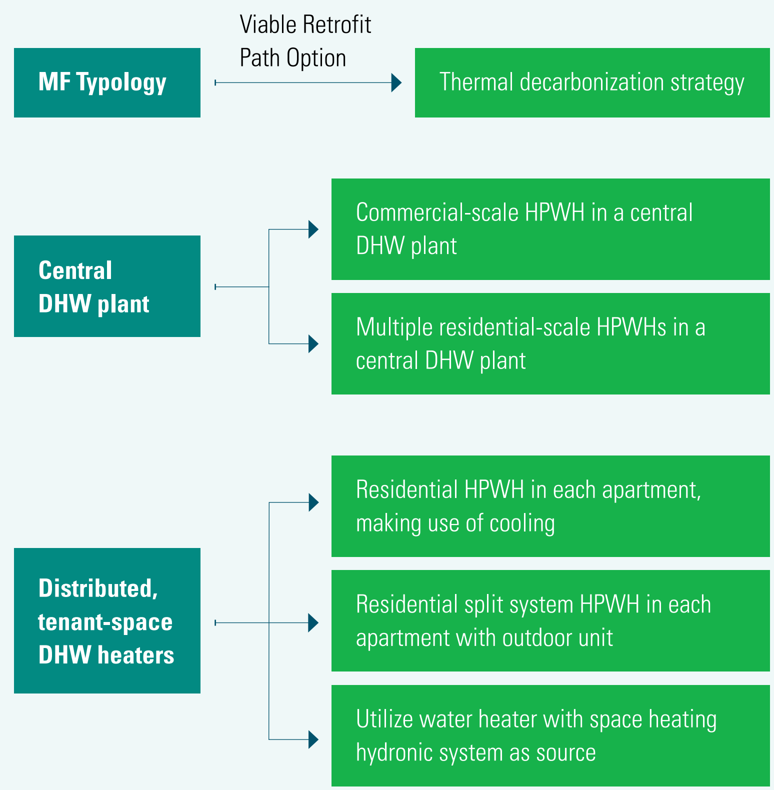
Design considerations for central HPWH systems are discussed in more detail in Volume 2, Section 2.6.2.4, "Single-Pass Versus Multi-Pass Domestic Hot Water (DHW) System Configurations".

3.2.3.6.5_UNIQUE CONSIDERATIONS FOR NEW MULTIFAMILY CONSTRUCTION

The importance of heat recovery cannot be overstated.

This is discussed throughout Volume 2 (e.g., see Section 2.6.2, "Use electric-driven heat pumps"). Heat pumps have the invaluable ability to take a "low-quality" heat source and boost it to a temperature suitable for effective use. There are a number of heat recovery opportunities in any building design, and every BTU recovered is usually delivered at a greater efficiency than a BTU pulled from outdoor air on cold days or from a typical geothermal ground loop. In multifamily residential projects, the main heat recovery source will be from the cooling systems, which can lead to HVAC system choices that allow for this feature.

FIGURE 3.10: RETROFIT STRATEGIES FOR DHW SYSTEMS IN MULIFAMILY BUILDINGS, DEPENDING ON EXISTING SYSTEMS AND COOLING NEEDS



Source: From "Heat Pump Retrofit Strategies for Multifamily Buildings", NRDC, April, 2019

10 Check out the "Ecosizer" tool at https://ecosizer.ecotope.com/sizer/.

3.2.3.6.6_UNIQUE CONSIDERATIONS FOR MULTIFAMILY RETROFITS

The NRDC funded the development of a very robust retrofit guide for heat pump water heating in various climate zones.[11] The report has a very useful decision tree for the various approaches (see Figure 3.10). The report also lays out potential design issues for retrofits, specifically noting the unique challenges for cold climate retrofits from existing space heating system systems to heat pump water heating systems.

3.2.3.7_Laundries

Appliance energy use can rise to become a dominant load in an otherwise efficient apartment design. Many multifamily developers targeting Zero Net Energy move in-unit laundries to a central facility to cut laundry equipment connected loads in half. Historically, equipment in central laundry facilities have been leased from third party vendors. However, the ease of installation and low capital expense for systems such as ShinePay make it highly feasible to purchase and install energy efficient laundry equipment that may not be available for lease while still facilitating a reimbursement-based system for which residents merely need a phone (no coins required!).

This approach opens up options for the use of condensing washer/dryers and heat pump dryers, which can cut energy use by 40%-60%. Another option that could be considered is upgrading from single function machines, which require tenants to move laundry from washer to dryer mid-process, to combined all-in-one washer/dryer machines that have built-in condensing drying capability. Central laundry room circuits can often be freed up by this upgrade, saving first cost or enabling opportunities for other increases in electrical loads.

3.2.3.8 _Fireplaces and Fire Pits

Electric fireplaces are less expensive than gas stoves, as well as safer and cleaner, and they plug into a normal 120V wall outlet. They provide heat in a more efficient and smokeless way: a 3,000-Watt electric fireplace can warm spaces up to 800 square feet. Outdoor electric space heaters are similarly versatile and ready to replace headache-inducing propane burners. And, unlike fireplaces that burn fossil fuels or wood, they do not emit CO_2 and can be controlled for optimal comfort and aesthetics.

What is a water vapor fireplace?

Ultra-fine water vapor, LED lights, and different air pressures allow "cold flames" to replace actual fire to reduce emissions in a building. LED lights illuminate the mist into a life-like flame effect. The depth of the flame can be customized as well by adjusting the opening where the water vapor comes out.

Why buy an LED fireplace?

LED fireplaces are a modern combination of an electric heater and refracted light. Depending on the model, the LED fireplace might have electric coils or use infrared technology to produce heat. An electric coil unit sends electricity through coils which heat up; fans then push the heat into the room. Infrared heaters use infrared lights to heat up a heat exchanger, such as copper coils, where fans distribute the heat. These fireplaces feel like a real fireplace, and they are the safest and cleanest electric fireplace technologies to put within a home or office.

3.2.3.9_Grills

Built-in electric grills or portable electric grills are great for outdoor cooking. Infrared electric grills heat up much more quickly than charcoal or gas grills, and infrared technology evenly disperses the heat over the entire grill area. Infrared cooking generates much higher temperatures than normal grills. These grills can generate surface cooking temperatures of up to 700 degrees in under 10 minutes.

With no charcoal fumes and no propane gas combustion, infrared electric grills can be cheaper to operate and easier to clean, need little maintenance, and are often smaller and easier to put away. There is no open flame or torrent of smoke, so they can also be used in high rise buildings, apartment complexes, or condos, where typical combustion grills may not be allowed due to fire code or insurance restrictions.

11 https://www.nrdc.org/sites/default/files/heat-pump-retrofit-strategies-report-05082019.pdf

3.2.3.10_Controls

In a world focused on decarbonization and electrification, it will be extremely important to address how our homes use electricity. We have become too comfortable with all of our appliances using milliamps of power all the time. For example, how many display clocks do we really need in our kitchens? The microwave, the coffee maker, the toaster oven, the refrigerator all want to tell the time, and they never quite agree!

The challenge of eliminating these "vampire" loads has been easily solved in the commercial construction world through plug load management devices and occupancy sensors, which are required by Code in many places.[12]

Applying plug load and lighting management technologies in residential construction has generally proven to be cost prohibitive. In addition, many of us have come to loathe the occupancy sensor that never seems to know we are there. However, newer technologies and tailored solutions are being developed for the residential market that will bring the cost down significantly and improve the efficacy. These devices provide a cost effective means to enhance occupancy-based control schemes (see Figure 3.11). They should also provide a means for grid responsive controls to be cost effectively incorporated into residential construction, allowing for the use of unitary HPWHs to be used as deployable loads.[13]

3.2.3.11_Swimming Pools

While already common world-wide and regionally in the U.S. (e.g., Florida, Hawaii), market demand for heat pump pool heaters is growing throughout the country. A common consensus is that heat pump pool heaters are simpler to install than natural gas pool heaters in new single-family and smaller multi-family residential construction because of the challenges of running gas lines compared to the simplicity of running a 40-Amp electrical circuit in residential settings.

FIGURE 3.11: STRATEGIES FOR OCCUPANCY-BASED ENERGY USE REDUCTIONS

Energy Efficiency Strategy	Single-family Houses	Multi-family Rentals	Vacation Rentals	Student Housing	Assigned Living	Hospitality
Occupancy Control 30% off lighting	●	●	●	●	●	●
Daylighting 10% off lighting	●	●	●	●	●	●
Dimming 10% off lighting	●	●	●	●	●	●
HVAC Integration 15% off heating/cooling	●	●	●	●	●	●
Water Heater Integration 30% off water heating	●	○	●	○	○	○
Plug Load Integration 15% off standby power	●	○	●	●	●	●
Demand Response 40% off during peaks	●	●	●	●	●	●

● Easily integrated strategy

○ Opportunity dependent on system design choices

Source: Rivieh

12 Plug load management requirements are included in the 2021 International Energy Conservation Code, the California Energy Code since 2013, the Washington State Energy Code since 2015, and ASHRAE 90.1 since 2010.

13 See Heat Pump Water Heaters as Clean-Energy Batteries or the publication "Evaluating Peak Load Shifting Abilities and Regulation Service Potential of a Grid Connected Residential Water Heater", published by the Electric Power Research Institute in 2012.

Heat pump pool heaters work well year-round since they can do both pool heating and pool cooling. Large outdoor pools that are kept warm during the winter can use multiple standard heat pumps that are designed to be integrated together to meet the higher heating demand. Generally, these are plumbed in parallel, with a logic system for automation.

Heat pump pool heaters save pool owners on their utility bills compared to gas because they can deliver up to five units of heat for every one unit of electricity used, while gas pool heaters use six times as much energy, delivering only 0.8 to 0.9 units of heat for every one unit that is burned.

Furthermore, heat pump heating for pools can be paired with additional efficiency measures. Pool covers dramatically reduce heat loss, for example. Floor return lines, which prevent stratification (cold water at the bottom of the pool and hot water at the top), are common in older pool designs and are an important efficiency measure.[14]

3.2.3.12_Cold Climate Considerations

Designers want the ability to reliably produce 180°F water when it is 0°F outdoors. The good news is that they can!

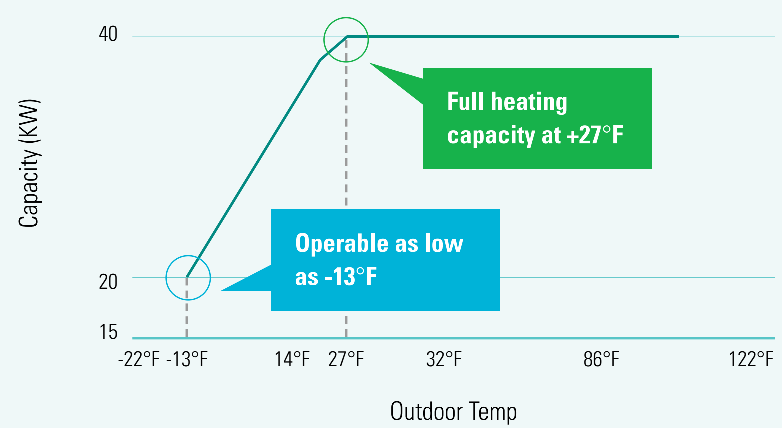
The barriers to producing hot water in cold climates are not technical, and there are a number of solutions available to tailor the design to a project's unique technical constraints. However, many of these solutions can be more expensive than business as usual. So, until market demand brings down the cost of these technologies, we will be relying on other market forces to encourage implementation of these solutions.

These solutions include:

» CO_2-based HPWHs:

- A number of manufacturers make heat pumps that use CO_2 as the refrigerant. In addition to the fact that CO_2 has the lowest GWP of any refrigerant on the market other than ammonia, this refrigerant is particularly well-suited to making very hot water in very cold climates (see Figure 3.12). New entrants are coming onto the market every month, driven in some part by the market demand created by California's initial requirement in December 2019 that all HPWH systems for DHW heating systems serving "multiple dwelling units" be able to (1) operate with a minimum ambient air temperature of-20°F and (2) be capable of providing hot water greater than 150°F when the ambient air temperature is between 5°F and 110°F. These criteria essentially mandated CO_2 heat pumps for all-electric multifamily housing projects in California.

FIGURE 3:12: SAMPLE CAPACITY CURVE FOR A CO_2 HPWH



Source: From Mitsubishi QAHV Hot Water Heat Pump Brochure

14 Adapted from Anderson, Dylan and Armstrong, Sean. Pool Heat Pump Design, Bay Area Strategies and Resources. May 2021.

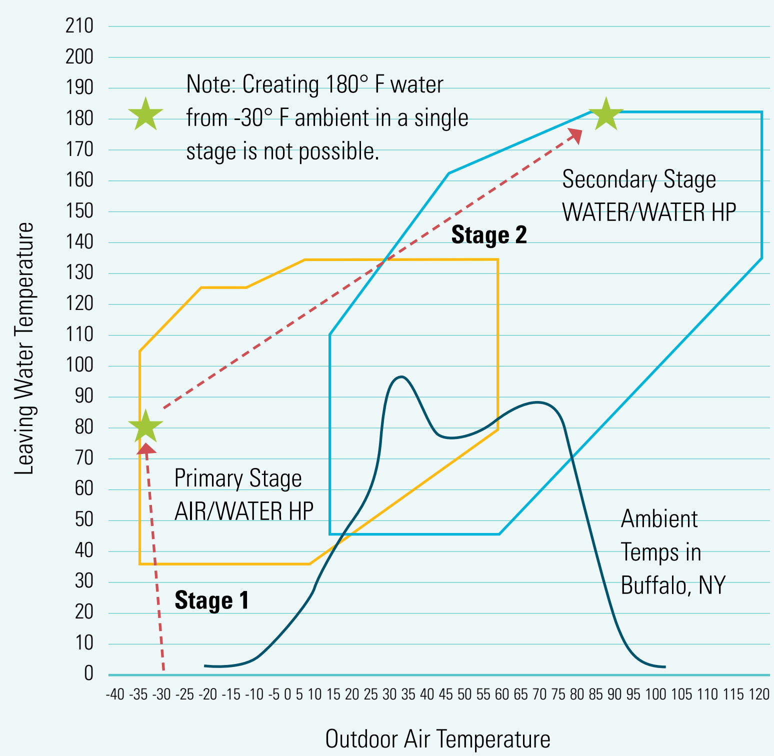
» Two-stage heat pump systems:

- Also known as "cascading heat pump systems," this configuration uses an air-to-water heat pump that can create water at an intermediate temperature (+/-80 to 100°F) when outdoor air temperatures are below 0°F as the first stage. Water leaving this first stage then enters a water-to-water heat pump that lifts the water from the entering temperature to the desired system supply water temperature (anywhere from 120°F to 180°F). See Figure 3.13 for a diagram of this two-stage process.

» Find a stable "source" at a temperature between 60 and 80°F to use for water-to-water heat pumps:

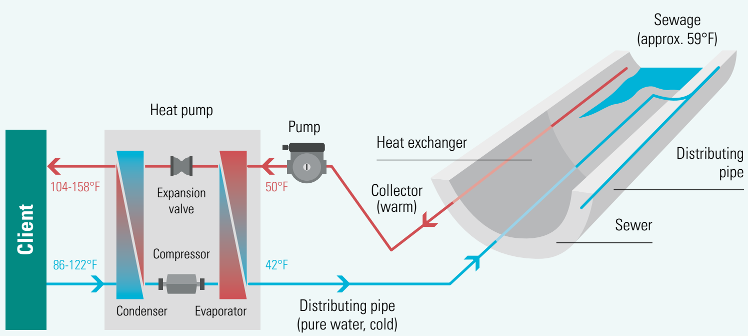
- Sewer Water Energy Exchange (SWEE): See the discussion of SWEE in Volume 2, Section 2.6.2.2, "Water-Source Heat Pumps" and refer to Figure 3.14.
- Earth-coupled heat pumps: ground temperatures at a depth of more than 10 feet below the surface tend to be very stable and relatively unaffected by ambient air temperatures. Bodies of water can also be excellent sources for heat, as long as a thermal balance is maintained: this usually comes from flowing water, extremely large bodies of water (like the ocean), or smaller bodies of water that serve as both a source (for heating) and a sink (for cooling).
- Cooling tower water: for projects that include water cooled chillers, condenser water can be effectively used; however, this requires that there be a significant cooling load during the heating season, which is less common in residential construction than it is in commercial construction. Also, these applications often require water storage to take advantage of heat produced when there is not enough load to use all the energy that is created, as well as supplemental heat sources to accommodate periods when cooling loads do not produce enough hot water to meet the loads.

FIGURE 3:13: COMPRESSOR ENVELOPE DIAGRAMS SHOWING A TWO-STAGE HPWH SYSTEM FOR COLD CLIMATES



Source: Transom Corporation, Barrie, Ontario, Canada

3.14: SANITARY WASTEWATER ENERGY EXCHANGE (SWEE)



Source: Rabtherm

There are several cold climate issues that designers need to bear in mind, which include:

- Defrost:
  - Don't think that a mild climate means that this issue can't affect your design; some equipment will frost up at temperatures as high as 40°F. Manufacturers of air-source products handle this issue in different ways. Be sure to incorporate, when needed:
    - Defrost heat sources
    - False cooling loads to allow systems to reject heat in the outdoor coil
    - Loss of capacity while units are taken out of service during a defrost cycle
- Capacity reductions:
  - The sample capacity curve shown in Figure 3.12 reflects a drop off in capacity starting at an outdoor air temperature of 27°F, and as much as a 50% loss in capacity at-13°F. Make sure manufacturers provide ratings at your most extreme expected operating conditions.
- Advantages of designing with lower water temps:
  - It is important to design for the lowest supply water temperature possible, especially in cold climates. Unless you are retrofitting an existing system that cannot provide adequate heating at less than the original design temperature, there are only a few reasons to design for hot water temperatures greater than approximately 120°F. Lower supply water temperature may also lower the overall design water temperature difference (aka "delta T"). While a lower delta T may increase pumping energy, the overall system efficiency reductions are more than offset by a heat pump's improved coefficient of performance (or COP) at lower supply water temperatures.
  - In addition, lowering supply water temperature avoids the first cost impacts of having to implement a two-stage system and, possibly, the decision to abandon electrification altogether.

3.2.3.13_Refrigerants

Refrigerants, other than CO_2 and ammonia, are potent greenhouse gases. With the growing availability of heat pumps using CO_2, choosing this refrigerant for as many uses as possible can be a good strategy to minimize the global warming impact of refrigeration systems. For further discussion about the relative impacts of other refrigerants, see Volume 2, Section 2.5.1.3.2 "Carbon Emissions Equivalent".

3.2.4_HOTEL/MOTEL OCCUPANCIES

Hotel and motel occupancies are not that different from multi-family building designs except for a few key features. The central heat pump domestic hot water loops are similar in design, controls, and piping configurations, but often with fewer fixtures to service as most hotel and motel rooms are designed without full service kitchens. Offsetting the reduction in kitchen fixtures is an increase in the density of showers, tubs, and bathroom fixtures compared to multi-family projects.

For smaller hotel/motel buildings, the electrified HVAC options are similar to what we would use in multi-family buildings, such as packaged terminal heat pumps, vertical heat pumps, VRF, and other strategies already discussed. For larger high rise hotels in dense urban areas, the system choices for high-efficiency designs tend towards central plants servicing 4-pipe fan coils at the guest rooms and larger/central air handlers for amenity spaces. These central plants can be based on heat recovery chillers, or central heat pumps (and are good candidates for combining with ground-source loops or sewer wastewater energy exchange).

One type of control strategy that is unique to the hotel/motel category is the "captive key card" system that automatically turns off the HVAC, lights, and controlled receptacles when the room is vacant. While this is a very efficient approach for hotels (and a Code requirement in many states), it is not currently a requirement for multi-family buildings. Some types of multi-family housing — such as student dormitories and co-living[15] facilities — might be appropriate types of projects to consider using this approach. New technologies are on the horizon that could make this type of "vacancy control" more suitable and cost effective in multi-family residential projects (e.g. see new technology from Rivieh[16] that is expected to become commercially available in the first quarter of 2022).

One of the last strongholds for natural gas is the hotel/motel kitchen. Suffice to say that the guest-support spaces, such as central kitchens and other more "commercial" spaces (including retail, ballrooms and conference centers), present the greater challenges for electrification of this occupancy type. Volume 5 busts the myths around gas as a superior fuel for cooking, and Volume 4 addresses commercial occupancies.

3.3_Construction Phase Considerations

In this practice guide, the primary discussion regarding construction practices and construction phase activities may be found in Volume 2, Universal Design Considerations, Section 2.7, Construction Practices, and Section 2.8 Post-Construction Practices. Nevertheless, a few key concepts bear repeating:

A study quoted in Volume 2, Section 2.7 suggests that substantial reductions in emissions during the procurement and construction process may be achieved if the following five actions are accomplished:

1. **using materials more efficiently**
2. **using existing buildings better**
3. **switching to lower-emission materials and low-emission construction machinery**
4. **using low-carbon cement, and**
5. **recycling building materials and components.**

15 The defining characteristic is that all co-living spaces offer at least a shared kitchen and living room.

16 https://rivieh.com/

It's critical to ensure that these goals are included in the OPR that will be subsequently memorialized in project specifications and contract documents. In addition, when contracting with design and commissioning professionals, make sure to include scope for these team members to spend time during the construction phase in order to:

» Ensure the building is built to specifications;

» Effectively manage the substitution process during construction (substitutions may be necessary to hold schedule or cost, but any such substitutions need to be evaluated against the OPR, predicted performance metrics, and building lifecycle goals);

» Ensure the building envelope is constructed from the specified materials or substitutions with identical performance specs and assembly compatibility, and that the enclosure is assembled properly from a performance perspective (air, moisture, and thermal);

» Create and memorialize an effective operation and maintenance manual before the building is turned over;

» Train property management and facilities staff during the process of commissioning the building.

See also Section 3.2.2 above to ensure that the right team is in place and empowered with appropriate processes to provide effective construction oversight for multi-family housing projects.

3.4_Operational Phase Considerations

A comprehensive approach to energy management can improve the energy efficiency of U.S. multifamily properties by 15-30% and save $3.4 billion in annual utility costs, according to ACEEE.[17] And yet, the multifamily sector has been slower than the commercial building sector to prioritize stewardship of energy and water use in buildings. There may be a number of unique reasons for this:

a. Commercial buildings increasingly require certifications such as LEED, WELL or BREEAM to meet corporate or Code-mandated sustainability goals. Meanwhile, residential development has generally not been required to certify to any sustainability standards, and residential property tenants are a diffuse, long-tail market and don't wield the same market influence as commercial tenants. As a result, sustainability has not been emphasized in multifamily projects.

b. In many multifamily buildings, tenants pay some or all of their utilities directly. Thus, the perception is that the initial capital expense for more efficient and sustainable building systems (e.g., solar, battery back-up and energy efficient building envelopes) would accrue to tenants — not to owners.

In both instances, conventional wisdom is rapidly changing. First, tenants increasingly want to understand the sustainability and wellness features of the building in which they will live. Additionally, and if properly communicated with tenants, decarbonized building systems can lower tenants' utility bills and improve their physical wellness. This, in turn, can enhance tenant retention and ease the operational burden and financial impact of managing tenant turnover.

Since decarbonized buildings are relatively new to the multifamily sector, owners, developers, and design professionals need to be prepared to take the actions described in the following subsections.

17 https://www.aceee.org/multifamily-project and https://www.energystar.gov/buildings/resources_audience/multifamily_housing

3.4.1_TRAIN FACILITIES STAFF AS PART OF COMMISSIONING

Many commercial building projects are pre-leased to tenants (or even built-to-suit for a single tenant). Conversely, the end of construction on a multifamily project can be a particularly busy time, often coinciding with pre-leasing, marketing, and move-in activities for a myriad of tenants, each of whom is likely to have different questions and needs. Understandably, the property management team at handover is likely focused on occupancy — and yet it's this crucial moment that also requires the team's attention to learning about and managing building systems that may be new to them.

One potential antidote to this time crunch is to begin the process of hand-over to the facilities operations and maintenance (O&M) and property management teams earlier in the construction process. Allowing these teams to interact with the design team and commissioning agent during construction can make them better prepared to operate their building as intended. For example, a lunch-and-learn overview of the building's sustainability features and review of the OPR with the property management team (especially if they didn't already participate in developing it — something highly recommended where feasible) can help facilitate a smoother handover. Allowing the facilities O&M team to attend commissioning meetings and testing activities can ensure that the operations staff become familiar with the specific building technologies used.

Ways to use the commissioning process to improve the handover of facilities from construction to operations are discussed in more detail in Volume 2, section 2.7.1. In addition, video recordings of training sessions (and even commissioning meetings and functional testing activities) can help to reduce the adverse impacts of staff turnover. While there are companies that will record and digitally organize these meetings, it is also possible (for projects with small budgets) to record the meetings on a smartphone or inside a video conference (e.g. Zoom) and to keep these digital files as part of the O&M records.

Ideally, the MEP team and/or commissioning agent should collaborate with the property management team to prepare a comprehensive O&M manual. While this may occur in the ordinary course of a project (and is often provided by the construction team), it is recommended that the MEP team and commissioning agent be required to effectively support property management in developing and reviewing any O&M manual prepared by the construction team.

3.4.2_MONITOR, MAINTAIN, AND VALIDATE BUILDING PERFORMANCE

As the old adage goes, "you can't manage what you don't measure." There are a number of ways to approach Measurement and Verification (M&V), each with varying levels of effort and benefit:

- **Energy Star Benchmarking:** the US EPA provides the "Portfolio Manager" tool as part of their Energy Star program. This free tool is used by hundreds of thousands of buildings to measure and track their energy use; multifamily properties with 20 or more units receive a score on a scale of 1–100, which is a rating of a facility's energy use compared to similar properties nationwide.[18] Projects can be "certified" under the program when receiving a score of 75 or greater. Energy Star certification can actually begin in the design phase, as the program has recently added the "Designed to Earn" certification.[19] It should also be noted that the US EPA has a similar program for water use called "WaterSense Labeled Homes."
- **Basic M&V:** this can be as simple as comparing utility bills to a site and building specific energy performance prediction. This prediction is materially different from Energy Code compliance calculations. Energy modelers with experience in preparing "predictive" energy use models can adapt Code compliance models to the needs of an M&V process.[20]

18 https://www.energystar.gov/buildings/resources_audience/multifamily_housing

19 https://www.energystar.gov/buildings/resources_audience/service_product_providers/commercial_new_construction/achieve_designed_earn_energy_star

20 For a more detailed discussion of this, see "An Architect's Guide to Integrating Energy Modeling into the Design Process," published by the AIA. | https://www.aia.org/resources/8056-architects-guide-to-integrating-energy-modeli

- **Advanced M&V:** since utility bills can only provide data on total energy use, deviations from predicted performance can be complicated to analyze and require careful evaluation in order to identify potential causes that can be acted upon. Advanced energy and water metering can make deviations easier to analyze. LEED, BREEAM and other rating systems encourage the use of such sub-metering. Check locally as well, since jurisdictions are increasingly requiring energy submetering. However, there can be a significant positive return on advanced M&V investments. No one would think twice about asking a car dealer to explain why the actual gas mileage of your new car was only 70% of the EPA window sticker mileage. This should be true of buildings as well.

- **Monitoring Based Commissioning (MBCx):** this robust process can evaluate building performance as well as enable a process of driving performance towards the expected result. For more discussion of this strategy, see Volume 2, Section 2.8.1.

Ideally an M&V process would be incorporated into regular, seasonal, or quarterly checks performed by property management teams. This can help ensure that equipment is operating within pre-identified performance criteria and that operational efficiencies are being maintained. For newly completed buildings, it's ideal to include seasonal check-ups in the initial building commissioning process.

It is also recommended that buildings be "recommissioned" after a few years of operation. Information on the value of this effort can be found in Volume 2, Section 2.8.2.

3.4.3_MARKET THE VALUE OF LIVING IN A DECARBONIZED BUILDING

Many multifamily developers have chosen to focus "sustainability" investments into a building's physical systems (e.g. solar panels or Energy Star rated appliances) rather than sustainability certifications (e.g. U.S.-based certifications such as LEED, GreenPoint, WELL, Fitwell, Green Globes, BREEAM, etc.). While each owner needs to make an individual choice about the value of certification, we recommend the following considerations:

- The challenge of communicating clearly to residents about the sustainable features of a building can be addressed by having a third-party framework in which to describe them. When carried through to certification, these frameworks also provide quantifiable achievements compared to an objective standard. Furthermore, having these accomplishments validated by a third party can help address any concerns about green-washing.

- The role of each tenant in ensuring the building achieves its sustainable performance potential can be more clearly explained.

- Participation in certification can help explain the myriad benefits to residents.

Key benefits that can be effectively tracked via certification and then marketed and communicated to residents include:

- **Wellness Benefits:** there are significant wellness benefits to living in a sustainably designed and built building. For example, residents should learn about the improved indoor air quality from switching out natural gas for electric cooking appliances (Volume 5 of this practice guide provides a deep dive into all-electric kitchens). We also recommend checking out the Well Building Standard for additional ideas and guidance.[21]

21 https://resources.wellcertified.com/tools/multifamily-residential-checklist-well-v1/

- **Financial Benefits:** Decarbonized and all-electric buildings can be less expensive to operate, particularly if electricity use patterns maximize the benefits of a utility's time of use rates and water fixture efficiency is maximized. We recommend communicating the value of these savings, and — if you feel comfortable — providing a sample utility bill comparison. LEED, for example, provides a framework for quantifying cost savings from energy and water use reductions.[22]

- **Resiliency Benefits:** Decarbonized and all-electric buildings can offer crucial resiliency benefits, particularly if solar and battery back-up systems were installed. For example, if the building provides back-up power for refrigerators, select plug loads, building wifi, or even some limited air-conditioning (critical to vulnerable populations during extreme heat events), the benefits of these systems operating during power outages should be communicated to every resident. RELi 2.0 is the most comprehensive certification rating system currently available for socially and environmentally resilient design and construction.[23]

Increasingly, and thankfully, people want to participate in actions and choices that can help avert the worst impacts of climate change. Sharing with tenants the anticipated benefits of choosing to live in a decarbonized, all-electric residence, and how emissions reductions were achieved by the design and construction process can be especially positive and beneficial. Furthermore, property managers benefit from being clear about how tenants can participate in ongoing environmental and resource stewardship through their individual actions.

3.4.4_PROACTIVELY ENGAGE TENANTS TO BE STEWARDS OF ENERGY AND WATER RESOURCES

Effective stewardship of resources in a sustainably designed multifamily building requires the direct engagement of tenants. They are the primary users of the building, and their actions may have a meaningful impact on the outcome. We recommend a program of activities, planned in concert with and carried out by property management, that includes the ability to educate, communicate, and playfully remind and engage tenants in good stewardship practices.

- **Educate:** There are myriad opportunities to educate residents. For example, consider signage in the lobby that memorializes the sustainability features incorporated in the design and construction process. Share an overview of building systems with residents upon move-in and post the overview in the building (e.g. in a laundry room). Another opportunity is to post regularly updated or rotating reminders about the impact of timing energy use to low cost and low carbon periods, including how to use the programmable features of different appliances (like dishwashers and thermostats) to assist in this effort. Residents need information in order to actively support efficient and sustainable operation.

- **Communicate:** Data visualization can be a really powerful tool. When the building is planned, designed, and constructed, make sure to install monitoring equipment that will allow you to share real-time visualizations of energy consumption (and energy production, if renewable energy generation was incorporated). Many solar providers furnish the equipment that can be used to aggregate building electricity demand and production in a summary visualization. These graphics can be shared with residents either via a custom application, a sheet of FAQs, a website, or on a welcome screen when they enter the building. Sharing with residents real-time access to energy and water use data can serve as an invitation for them to reduce consumption.

22 https://www.usgbc.org/resources/leed-homes
23 https://c3livingdesign.org/?page_id=13783

- **Remind and Engage:** Residents increasingly want to participate in sustainability efforts, but we need to give them the tools to do it. It also helps to make sure that engagement is fun and rewarding. Teach them about how time of use impacts the grid, their energy bill, and carbon emissions — and then host a competition to see which units in the building can reduce their energy consumption the most in a given month. Include sustainability in tenant engagement programming and provide shared rewards — for example, residents can get to know one another over pizza after a successful effort. Energy Star provides helpful guidance about hosting energy saving competitions, and their resources include activity kits for children. Perhaps you can even help one of your young tenants win the local science fair!

3.4.5_MANAGE REFRIGERANTS RESPONSIBLY

Many of the systems, equipment, and appliances that may be considered for multi-family residential projects currently use refrigerants R-134a or R-410a. Unfortunately these refrigerants are very powerful global warming agents. For context:

- A release of all the R-134a refrigerant in a typical residential storage-type heat pump water heater would be equivalent to the climate change impacts from a typical gas water heater with ~3% methane leakage per year.
- A typical refrigerator using R-134a can contain 0.25 kg of refrigerant, which if released into the environment would result in the emissions equivalent of driving 2,130 miles per year (3,427km) in an average family-sized car.

Roughly 90% of refrigerant emissions occur at an equipment's end of life, according to Project Drawdown. This means that proper disposal is essential.

At the beginning of 2020, the atmosphere's remaining "global carbon budget" was approximately 340 billion tons.[24] Appropriate management and reuse of refrigerants is projected to slash 100 billion tons of equivalent global CO_2 emissions between 2020 and 2050.[25] Proper refrigerant management should be taken extremely seriously, and all EPA requirements under Section 608 of the Clean Air Act should be followed. There are at least five parts to a successful leak reduction program:

1. **Leak Detection**
2. **Leak Repair**
3. **Leak Prevention**
4. **Performance Measuring / Tracking**
5. **Goal Setting**

The new EPA Section 608 regulations attempt to keep ozone depleting substances — and other chemicals related to climate change — in check (see Figure 3.15). These regulations will also help drive value from the point of view of maintenance. The record-keeping required to track and maintain these systems will provide great insight into systems that are performing poorly and costing operators money.

While all organizations are expected to have a solution that keeps them in compliance, establishing a process that highlights poor performing equipment is where the most value in an improved maintenance regimen can be found. Refrigerants have become a double-edged sword, as they can leave operators open to regulatory fines and increase repair and replacement costs when not well monitored.

Many jurisdictions are looking into applying their own regulations to keep ozone depleting substances in check. California has been utilizing its own rules since 2011. New York and Maryland have been creating their own regulations as well. Managing refrigerants is a responsibility that is not going away any time soon and delaying the process will only open organizations to legal risks, negative PR, and fines. The following website provides information on refrigerant management requirements in over 30 States in the U.S: https://www.blr.com/Environmental/Air/RefrigerantsODS.

24 Immediate Action Required: An Open Letter to the UNFCCC Secretariat – Architecture 2030

25 Search Reuse & Destroy | https://us.eia.org/report/20190214-search-reuse-destroy/, Environmental Investigation Agency | https://eia-global.org/about

FIGURE 3.15: SECTION 608 REGULATORY REQUIREMENTS — STATIONARY REFRIGERATION AND AIR CONDITIONING

Source: https://www.epa.gov/section608/section-608-clean-air-act

3.5_Assessing Costs and Value

This section is intended to empower the users of this practice guide with the evaluative framework and questions necessary to analyze the cost of all-electric and decarbonized construction in your (or your client's) subject property or development; case studies and links to additional property comparables are also provided. This information is intended to demonstrate that decarbonization is feasible, that the electrification and decarbonization of residential structures can be the norm, and that it is cost beneficial.

Overview — Addressing Concerns & Fears: The fields of architectural design and construction are a primary home for innovation with respect to climate adaptation and resilience for buildings. On the other hand, many would postulate that it's harder to take risks in construction because of the great cost of any development or retrofit and that, as a result, the real estate industry can be risk-averse and slower to adapt. For example, some of the understandable fears expressed by owners and developers about all-electric and decarbonized construction include:

- It's too expensive
- It's too risky, it won't work, and the technology isn't proven
- Development is difficult already — don't add further complexity
- My staff doesn't know how to maintain this stuff
- What if it requires more maintenance than is typical?
- I'm used to what I already do, and so are my debt and equity investors

All-electric, decarbonized construction is not a new phenomenon; moreover, not only is it feasible, but in some parts of the U.S., all-electric construction has been the norm for many years. For example, the U.S.Energy Information Administration (EIA) estimates that in the Southeast, nearly 45 percent of homes use only electricity.[26] Further, the results of the EIA's 2015 Residential Energy Consumption Survey indicate that 25% of homes nationwide rely solely on electricity, and the share of all-electric homes has risen in each census region, particularly in the Midwest and in the South.[27] Heat pump technology has led to a more than 20% increase in the share of homes using electricity to power the main heating equipment, and there are similar increases in the market share of homes relying on electricity for domestic hot water.

While the EIA data is somewhat more focused on the single-family home market, the data remains significant because it demonstrates that: (1) consumers are accustomed to all-electric construction, appliances, and mechanical and plumbing equipment, and (2) the technology, market, and personnel required to service this design approach is increasingly robust and stable. As such, the all-electric construction market is poised for significant growth. The increase in market size should drive down cost as manufacturers achieve economies of scale in production and installers and subcontractors further increase their familiarity with these products and systems.

Alignment of the regulatory framework to encourage electrification and decarbonization is growing. In Washington, DC, the December 2018 passage of the Clean Energy DC Omnibus Act greatly expanded the market for energy efficiency retrofits by mandating efficiency standards in existing buildings. New building regulation is increasingly mandating all-electric construction, as is now the case, for example, across 40 municipalities in California or as reflected in the regulatory battles in Massachusetts.[28] However, while support for building decarbonization is expanding at the local level, the role of natural gas use in the built environment is still a hotly debated topic in many State Legislatures (see Figure 3.16).

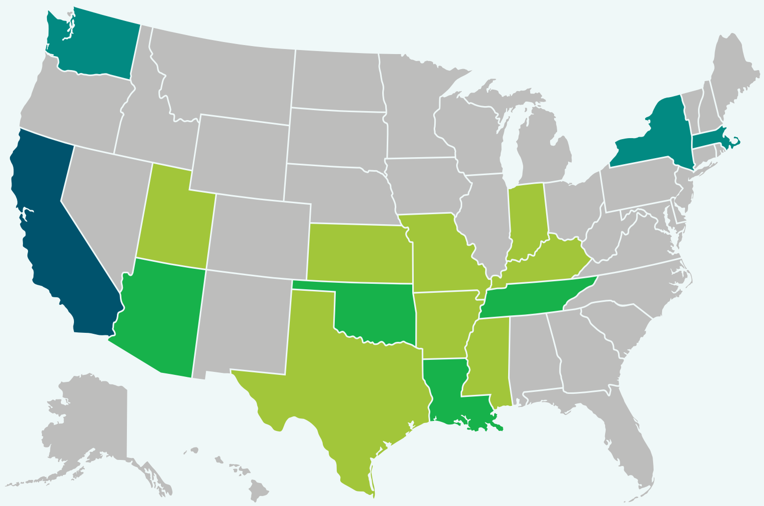
While this context may assuage concerns about risk, maintenance, and the regulatory landscape, how do we dispel concerns about cost? Are all-electric and decarbonized buildings really a financial risk, or is the real financial risk choosing not to electrify and decarbonize a subject development? A thoughtful framework for the evaluation of the requisite capital expense (or first cost) and operating expense (or ongoing cost) yields a surprising outcome for the skeptics among us.

26 https://www.eia.gov/todayinenergy/detail.php?id=39293

27 https://www.eia.gov/consumption/residential/index.php

28 https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/mass-building-gas-ban-movement-expands-after-2020-setback-62026427

FIGURE 3.16: THE BATTLE OVER THE ROLE OF NATURAL GAS IN THE BUILT ENVIRONMENT (AS OF JANUARY 25, 2021)



State legislation prohibiting local governments from restricting natural gas utlity service

Passed   Introduced in current session

Local gas bans and electrification codes on new buildings

Adopted   In development

Source: S&P Global Market Intelligence

3.5.1_A RECOMMENDED COST-BENEFIT ANALYSIS FRAMEWORK

As the building code and regulatory environment rapidly shift to require all-electric new construction, all-electric renovation, and/or high standards for energy efficiency and carbon reduction, discussion of the costs and benefits for all-electric or low embodied carbon construction must also be advanced. Increasingly, all-electric construction is a regulatory requirement and there is no alternative — one must simply optimize the capital expense and operational cost for all-electric construction. When you have a choice, a cost-benefit analysis is helpful to guide the decision-making process when considering to build decarbonized and all-electric. It can also help to evaluate smaller decisions during the design and construction phases, including how to optimize decarbonized and all-electric construction within the context of programmatic goals.

One of the challenges to guiding an analysis of cost is that there is no "one-size fits all" solution. We recommend the following best practices:

- Establish a cost framework as a collaborative effort between project ownership and design leadership to outline the key parameters of the analysis;
- Identify costs and benefits so they may be categorized by type and intent;
- Calculate costs and benefits to include not only first cost but also operating cost and exit value across the assumed life of a project or initiative;
- Compare cost and benefits by aggregating all of the defined inputs.

3.5.1.1_Sample Ground-Up Multifamily Development Cost Framework

It may be obvious that key elements to any development cost framework need to include:

- Capital Expenses/Savings (or first costs – including construction time and financing costs)
- Operating Expenses/Savings (or ongoing cost)
- Impact of Decarbonized and All-electric Construction on a Project's Exit Value

The "key" however, is to perform a sufficiently comprehensive analysis. There is great risk in not giving adequate attention to all of the cost elements, particularly because it is easy to overweight the capital expense of decarbonized all-electric construction if one is not rigorously analyzing the benefits (e.g. decreased construction time, reduction in infrastructure expenses, improved operating income, etc.).

As reported by the EIA, in many jurisdictions — including cold-weather jurisdictions — decarbonized construction methodologies and equipment have already achieved cost parity with "traditional construction" (even based solely on the cost of building materials and installation). Once you include the reduction in operating expenses typically achieved by decarbonized construction practices, all-electric construction quickly becomes accretive with respect to financial performance as well as occupant retention, health, and well-being.

3.5.1.2_Capital Expenses/Savings: Hard Costs, the Cost of Building Materials, and the Installation Thereof

As we've said, there is no one-size fits all solution to reducing hard costs in decarbonized buildings, but there are best practices to achieving hard cost reductions:

Step 1: Optimize the structural design. It is important to bring structural engineers into planning conversations early, as optimization of structural systems can be heavily influenced by structural bay sizing that is often assumed in the development of test fits for dwelling unit layouts. Also, alternatives to conventional concrete podium construction should be evaluated (e.g. cross laminated timber (CLT) can often be much less costly). Structural design considerations for multifamily housing are discussed in Section 3.2.3.2, and embodied carbon considerations, in general, are discussed in Volume 6.

Step 2: Set an overarching goal to drive down the energy use intensity by maximizing the performance and insulative capacity of the building envelope. The use of exterior insulation, for example, may also have additional benefits by increasing the amount of net rentable space. Further, the reduction in overall building heating and cooling loads will subsequently reduce the size and cost of systems ranging from photovoltaic arrays to switchgear and electrical infrastructure. Opportunities to increase envelope performance are also discussed in greater detail in Volume 2, Section 2.6.1.

Step 3: Carefully evaluate the use of centralized vs. decentralized mechanical and plumbing systems. Decentralized systems have recently emerged that can save first cost. For example, at Coliseum Place — a 59-unit, 6-story high rise building in Oakland, California — the project team chose to deploy a "mini-plant" domestic hot water design where multiple residences share an 80-gallon heat-pump water heater. This approach is estimated to have cut the domestic hot water use in half — saving an amount of energy nearly equal to the total amount of the projected HVAC energy use. There were also first cost savings related to the domestic hot water design; specifically, a $32,000 savings from not installing the gas piping to a boiler system, and a $200,000 savings from sharing one 80-gallon HPWH per two apartments as compared to a whole-building central system. This design approach did not reduce the quality of the DHW service: 3/8" and 1/2" piping from manifolds at the 80 gallon tanks provides hot water to all fixtures within 10 to 30 seconds. In the same project, rather than installing ducted mini-split heat pumps in each apartment (at the cost of $13,000 per unit), the units each use $8,000 whisper quiet package terminal heat pumps (PTHPs) in the living room and master bedrooms with baseboard heating in the additional bedrooms.

Step 4: Exercise patience, examine holistically, and iterate. Even in situations where the hard cost of labor and materials is more expensive, the savings in reduced infrastructure and time can still net the project overall first cost savings; operational cost savings can create further benefits.

Step 5: Leverage existing case studies to push back on the myth of the "complexity premium." This is particularly important during the bidding and estimation phases. While the techniques, technologies, and systems for decarbonized all-electric construction aren't new, general contractors and subcontractors may still express unfamiliarity or impose a "complexity premium" (referred to in previous sections as "risk pricing"). These premiums should be challenged by leveraging the case studies in this practice guide and by comparing them to traditional technologies. For example, the PTHPs deployed today are actually easier to install than the PTACs of yesteryear. Also, when heating systems only rely upon electricity, there is less infrastructure (i.e. no natural gas) to coordinate and install.

3.5.1.3_Capital Expenses — The Benefits of Reduced Infrastructure

Taking natural gas out of the building provides many benefits. Chief among these are faster permitting, lower utility installation costs, and reduction in design and coordination costs. Furthermore, for rural projects, where the natural gas infrastructure can be far away from the subject development, the savings are likely to be even greater. Pricing for recent projects in San Francisco yielded per-unit infrastructure cost savings — from removing the gas from the building — ranging from $75/unit to $800/unit.[29]

Perhaps even more importantly, the reduction in infrastructure saves time at critical junctures of a project. For example: the reduction in joint trench coordination can speed time to issuance for utility permits; the reduction in the amount of installed utility infrastructure can accelerate the time-to-install for utility power (since the electric utility no longer has to coordinate with the gas utility); and the simplicity of a single energy source can reduce the inspection timeframe, particularly just before the project is finalized for a certificate of occupancy when the carrying-costs of a construction loan are highest.

SPECIAL HIGHLIGHT: HOW TO WORK WITH YOUR LOCAL UTILITY TO ELIMINATE OR REMOVE ONSITE GAS INFRASTRUCTURE:

There are private and public equity benefits to the reduction in gas infrastructure. The true cost of new gas infrastructure is not fully passed on to developers or owners when a new service is installed; cost is recouped over several decades and amortized over the utility's entire customer base. In certain jurisdictions, a utility company is allowed to charge customers a gas removal fee if the gas infrastructure was installed within 10 years. As such, it is often in the owner's best financial interest to start with an all-electric building instead of converting the building to all-electric operation within the first 10 years of operation. As the regulatory environment quickly shifts to favor all-electric construction, there may be even more imminent disincentives to planning mixed-fuel projects.

Since all-electric buildings are still in the early stages of adoption as a design paradigm, there are neither national nor consistent state-wide policies, and many utility companies do not have fully standardized protocols for existing gas infrastructure removal for a decarbonized retrofit project. Thus, it is highly advisable to contact the gas utility company servicing the project's jurisdiction well ahead of time to determine the proper steps to remove and cap existing gas infrastructure to ensure public safety. The discussions should define

29 Based on data collected by David Baker Architects from five urban housing projects between 2016 and 2020.

the scope of work, the split of responsibility between the gas utility, owner, and contractors, and whether there are fees charged by the utility company for infrastructure removal and safe-off.

The questions below were excerpted from a utility-provided FAQ outlining basic questions that the owner or owner's representative should consider discussing with the utility company in order to create a formal agreement on the terms of service for opting out of gas connection and any future gas-related utility charges.

1. When, if at all, does the customer need to inform the utility company that they will no longer need a gas service?
2. What specific information does the customer need to communicate to the utility company?
3. What steps must the customer take to ensure that they no longer pay a gas bill?
4. What happens to the gas infrastructure at the customer's site? Will the meter be removed? Will any facilities be left in place?
5. Can the customer or their contractor perform the work? What work, if any, can only be done by the utility company?
6. Does the customer have to pay any fees to have the gas meter removed and/or gas infrastructure on the property capped or removed?
7. If the utility is going to conduct any work at the property, such as removing a gas meter, does the customer have to arrange for a city inspector to be present?
8. Is any permitting needed for the removal of a gas meter and related utility infrastructure?

3.5.2_HOW ELECTRIFICATION CAN BENEFIT FINANCING COSTS

3.5.2.1_Capital Expenses

Any thorough analysis of the expenses or savings from all-electric and decarbonized construction must be completed as a partnership between the design/construction team and the project's ownership. For example, there may be savings in overall construction time that the design/construction team can claim. This reduction in the time to completion can reduce the carrying cost of loans. Also, insurance companies may be willing to provide a discount on the course of construction or general liability insurance policies due to the lower risk of fire by removing natural gas infrastructure. Finally, the ownership team may be able to access alternative or improved construction financing in recognition of the "sustainability" features of the construction; lenders may recognize projected reductions in operating cost (as discussed herein) or improved resilience, and give the project credit in the form of a slight reduction in the interest rate of a loan.

Here are some key questions to ask:

1. How much time can we save, and at what phase(s) of the project, by choosing decarbonized construction or by removing gas from the development?
2. Is the anticipated form of construction financing a "drawdown" structure?
   - If so, the construction loan becomes more expensive as the project nears completion and the loan principal is highest. Under this structure, savings in the duration of construction are particularly valuable.
3. Has anyone spoken to the owner's insurance team about potential discounts for all-electric and decarbonized construction?

4. Have life cycle cost analyses included the specific equipment replacement time horizons relevant to the project's local climate?
   » If you are able to design an all-electric building using equipment with a longer life expectancy than the mixed-fuel designs, as appropriate to your location and local climate, this can reduce the life cycle cost impact of equipment replacement costs.
5. Has anyone spoken with the project's lender or brokerage team to see if there may be lower rates available on construction financing?

3.5.2.2_Operating Expenses and Savings

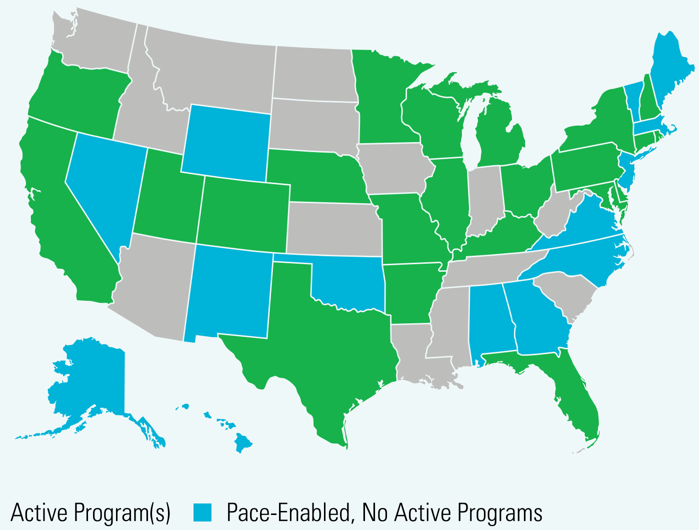
While many for-profit and not-for-profit owners are rightfully focused on the hard costs of construction, the importance of maximizing operational savings cannot be overstated; it's the key driver of financing for both for-profit and not-for-profit projects, because as operating expenses go down net operating income goes up. An increase in net operating income is a key indicator of the project's ability to service debt, pay back its investors or turn a profit upon sale. Furthermore, as the projected energy usage indicates lower operating expenses, that data may then support increases in construction debt in the event that the hard costs are higher.

Energy use intensity is a particularly effective tool for analyzing operating expenses or savings. Generally, when EUI goes down, the cost to operate the building also decreases. This is irrespective of the local utility's price structures and whether or not the owner will include the utility expenses in bulk rent or pass along utility expenses to residents.

In addition, careful thought and planning to align split incentives between ownership and tenants (i.e., who pays for utilities versus who uses the energy or water), can further support managing operational energy consumption to the benefit of all stakeholders (see further discussion of split incentives in Section 3.5.2.3).

Quick Tip: For more information regarding financing programs that leverage improvements in net operating income (NOI), speak to your lender. Some programs offer rate reductions for building sustainability initiatives. Your lender may also have access to PACE or C-PACE (Commercial Property Assessed Clean Energy) Financing Programs. To see if PACE programs are active in your jurisdiction, check out Figure 3.17 and find a resource like https://www.assetenvironments.com/pace-financing.html. Please note: in some jurisdictions, contractors may offer PACE financing directly to clients. In such instances, we encourage owners to seek financial guidance from a PACE lender to confirm that projected savings from any PACE upgrades will be sufficient to cover the costs of servicing the debt created by the PACE financing.

FIGURE 3.17: PACE FINANCING (PROGRAMS AS OF 2020)



Source: Asset Environments. Note: This file is licensed under the Creative Attribution-Share Alike 4.0 International.

3.5.2.2.1_ADDITIONAL OPERATING COST BENEFITS OF DECARBONIZED CONSTRUCTION

In addition to lower utility expenses, there are other benefits to all-electric and decarbonized construction. These include:

» Decreased maintenance cost and complexity; heat pump equipment is often resilient and low-maintenance when compared to combustion based heating systems (e.g. furnaces or boilers). Boilers and furnaces often have many unrelated parts that need attention (gas supplies and flues), and lack of maintenance of these features can cause safety issues.

» The reduction in maintenance costs over time allows for the project's ownership (whether non-profit or for-profit) to reduce the maintenance reserves for the property, increasing the project's ability to service debt.

» Decarbonized construction is more resilient; while the benefits of resilience are difficult to quantify (see discussion in Volume 2, Section 2.6.7), they may include:

- Lower insurance rates, particularly as insurance rates increase in the wake of extreme weather events.
- Higher tenant retention rates or even higher rent (or sale prices, if condos), particularly in regions prone to extreme weather events, such as wildfires, hurricanes, or tornadoes. Consumers today understand more intuitively the intrinsic value of living in resilient buildings and the myriad benefits of onsite, back-up power.

3.5.2.3 _Navigating Split Incentives — First Cost versus Operating Costs

Historically, in multifamily rental and office projects, the owner paid to construct the building, but operational utility costs were passed along to the tenants. This set up a situation where the owner was incentivized to reduce capital expenses but was less incentivized to minimize energy-related operating expenses. Conversely, if utility bills are included in a lease, there is strong data to suggest that residents are not particularly focused on energy conservation. According to a study from ACEEE, the U.S. multifamily housing sector alone represents a $3.4 billion energy cost savings opportunity.[30] Other studies have found that annual costs for landlords were 20 percent higher relative to when tenants directly paid the bills or when there was a "green lease."[31]

There are a number of best practices to resolve these inherent conflicts:

1. In instances where ownership will pay for utility expenses and/or where the building is substantially incentivized to improve energy efficiency, owners should remember that any reduction in energy usage will accrue to the project's overall benefit. However, if owners are paying the bulk of the utility bills, tenants shouldn't be given a blank check:
    a. Software is available that will show owners and tenants what building energy consumption is on a month-to-month basis (as energy benchmarking laws expand, this may become a requirement and not merely a best practice). "Virtual Grid" software can be an alternative to traditional sub-metering methods for cost recovery. These platforms ensure that multi-unit properties' solar benefits are distributed by comparing resident "behavior" (often using proprietary algorithms) to equitably distribute the benefits of solar based on real time usage, solar availability, and avoided utility cost.

30 https://www.greentechmedia.com/articles/read/multifamily-housing-a-3-4b-u-s-energy-efficiency-opportunity

31 https://www.greentechmedia.com/articles/read/a-graphic-that-illustrates-the-problem-with-split-incentives

   b. Gamify good energy efficiency practices by engaging tenants in reducing utility bills and offering prizes or rewards.
   c. Include only a maximum, annually adjusted/reviewed, energy or water amount in a tenant's utility allowance, and hold the tenant responsible for usage in excess of the allowance.

2. If tenants are paying the bulk of the utility bill, owners may be additionally able to:
   a. Explore the use of a "green lease," an agreement between landlord and tenant to share the cost (and savings) of an efficiency upgrade or highly efficient building systems whereby the owner makes an investment in upgraded efficiency and the tenant shares in the savings.
   b. Achieve higher rental rates by lowering resident's utility costs through investments in highly efficient buildings. There are ways to structure leases so that owners don't assume undue risk and tenants have confidence in their overall cost exposure when relying on predictive energy models for selling this approach.
   c. Virtual Grid software can help owners capture some of the benefits of reduced energy cost while allowing tenants to share in the cost reduction benefits of energy efficiency measures.

3.5.3_NAVIGATING UTILITY PRICING FRAMEWORKS

A growing percentage of grid-supplied electricity throughout the country is from renewable energy sources (see detailed discussion of this in Volume 2, Section 2.4.1, "Transition from a Zero Net Energy to a Zero Net Carbon Mindset"). Combined with the growth of distributed solar energy systems and the growing number of electric vehicles in garages, more and more utilities are making time-of-use (TOU) rate structures available to their residential customers. While these rate structures don't always incentivize the use of grid electricity with the lowest carbon content, these pricing structures may offer utility cost savings opportunities for all-electric projects. These opportunities come from using strategies that reduce overall energy consumption, compared to conventional building design, as well as designs that employ load shifting strategies or technologies that shift energy use to hours with lower electricity rates (see more detailed discussion of this in Volume 2, Section 2.6.5.3, "Load Shifting and Thermal Storage"). In order to take advantage of these opportunities:

- » Hire a team with demonstrated experience in designing, installing, and commissioning the strategies that will deliver these results.
- » Engage a solar power provider early, preferably one that also has expertise in the installation of battery energy storage systems (BESS). Energy Storage Systems are discussed in greater detail in Volume 2, Section 2.6.5.1.
  - Operating costs can be substantially reduced by maximizing the physical space available for solar system installation and by including battery energy storage technologies for load management.
  - The resiliency benefits of solar systems combined with a BESS can be a significant enhancement to a project (see also Volume 2, Section 2.6.7.1, "Microgrids, 'Islanding', and Resiliency").
  - A good solar provider will calculate both physical space needs and capital expense payback periods for PV and PV+battery installations. A qualified energy or engineering consultant can often help with this as well.

3.5.4_IMPACT OF DECARBONIZED AND ALL-ELECTRIC CONSTRUCTION ON A PROJECT'S EXIT VALUE

Fundamentally, the value of a property upon sale is a function of location (as the old adage goes). However, location — just like operating expenses, resilience, or any other quantifiable or qualitative benefit — ultimately manifests in the rental rate achieved (or sales price, in the case of condominium developments), the project's net operating income (or cost-to-own), and tenant retention (or time to sale).

It is critical that we make design teams, developers, owners, investors, lenders and appraisers more aware of the positive impact of decarbonized and all-electric construction on a project's exit or appraised value. For example, these positive impacts include:

- **All-electric options can reduce both maintenance expense and reserve requirements in many cases,** enabling increases in net operating income to be achieved. We encourage developers and design team members to iterate to the solution in your respective climate that facilitates these savings.
- **Lower utility expenses can increase net operating income.** This improvement in net operating income provides a stronger cash stream for the duration of the project. It can also lead to greater opportunity to finance or refinance debt, in either case improving leverage ratios (based on either predictive or actual EUI).
- **Many tenants are increasingly attracted to healthy, sustainable buildings;** above-market rents may be achieved, and tenants may stay longer. Moreover, because the building may be more attractive to potential tenants, lease-up may proceed more quickly: while this is one-time income, it's an important metric for developers as critical early income helps achieve initial investor preferred returns.
- **Any increase in net operating income will increase the exit value of the property by a multiple of the capitalization rate.** The prices for most multifamily-rental properties, when sold, are based upon a capitalization rate applied to the NOI.
- **Consider requesting a whole building life-cycle assessment to review and validate both the operational and embodied carbon savings as well as the potential improvements to NOI.** This assessment process is discussed further in Volume 6, Section 6.2, "Estimating Embodied Carbon".

3.5.5_HIRING PROFESSIONALS TO ANALYZE COST

Volume 2, Section 2.3, as well as Section 3.2.2.2, include guidance on how to assemble a team to design, estimate and build energy-efficient, all-electric, low-embodied carbon buildings. Here are some key steps that we wish to emphasize here:

- **Consider assembling key professionals earlier in the development and entitlement process than you might typically.**
  - Early planning can save time and effort later in the design development and construction drawing process, so this does not necessarily add cost. Key professionals to consider engaging in schematic design include: architects (this is conventional), as well as structural engineers, MEP engineers, and the energy/carbon consultant. Please note, the structural and MEP firms may be able to provide a very limited, low cost consulting engagement at these early phases of the project.
  - The architect and energy/carbon consultant may be able to serve the earliest needs in brainstorming and schematic phases of the project. Alternatively, some MEP firms provide integrated design and energy/carbon consulting services.

» **There are often more comparable all-electric projects in your area than you realize.**

- Please cross-reference our case-study database at http://www.electrifiedbuildings.org/. Each case-study includes a list of the key development, design and construction professionals that worked on the project. We recommend you reach out to learn and share best practices and to find resources that may help you along the way.

3.6_Case Studies

3.6.1_THE UNION (SMALL SCALE)

Source: Benedicte Lassalle, OpenDoor, PBC, eSix Development

Project Location: West Oakland, CA

Completion Year: 2019

Project Size: 6,400 SF

What: This project is designed to be a benchmark for affordable, sustainable, and equitable workforce housing, putting people back to work and providing stable long-term financial assets. It's also specifically relevant as an example that these strategies are not out of reach for smaller developers and small to midsize housing projects. Affordable and sustainable housing is possible and accretive. This project shows that it can be done.

The Union is a first of its kind, ground-up co-living development featuring all-electric construction. This state-of-the art, highly sustainable co-living property is transit-oriented, located approximately 1.5 blocks from BART, and was achieved as a lot-split, which increased density without any displacement. The 7,527 sq.ft. empty lot was entitled for three detached condo units totaling 6,420 built sq.ft. The development features a "common house" with a large kitchen/dining area and sufficient cooking and dining space to house the residents from all three condo units (though each unit has its own kitchen). All three units are connected via second floor "skybridge" balconies and share a common roof deck and rear patio barbeque area. The project is all-electric. Rents are approximately 79% of area median income (AMI), as compared to Oakland rental limits for studios. This project is an important proof-of-concept to demonstrate that sustainable, missing middle housing is possible.

HVAC	Hydronic systems with air-to-water reverse cycle heat pumps that alternate between heating and cooling (SpacePak); individual fan coils in each room provide customizable comfort
DHW	Rheem ProTerra Electric hybrid heat pump electric water heater (1 per unit); 3.75 uniform energy factor
Cooking	Electric Resistance
Building Envelope	Spray foam; insulation
Electrical Load Offset	20.24 kW PV (combined) Rooftop System; 355w solar modules with integrated micro inverters
Actual EUI	--
Building Code	2016 California Building Code
Developer	eSix Development Partners, in partnership with OpenDoor Coliving
Structural Engineer	ONE Design
Architect	Baran Studio Architecture
MEP Engineering	Design/Build by Architect & GC
General Contractor	Design Draw Build, Inc.

Trade-offs and Challenges:

» The 2016 California Energy Code (aka Title 24) did not provide clear compliance pathways for an all-electric project; we had to resolve confusion with the Authorities Having Jurisdiction and the building inspection teams. We had to demonstrate that we were allowed to exclude a natural gas connection for the project. Additionally, we had to overcome preferential scoring for solar thermal hot water systems even though there were more energy efficient combinations for our project (and more widely available strategies in the marketplace).

» This is an example of how the pace of technology development has quickly outpaced building code development. Regulators need to account for the ongoing technology development as we look ahead toward the transition to all-electric building codes.

» While heat pump technology is growing in its market dominance, the labor pool available that was also certified by the manufacturer to install the hydronic HVAC equipment was limited and, therefore, in very high demand. There still remains opportunity to develop the workforce pool that is knowledgeable about the installation of green building systems, which would scale the capacity to install such systems and create good jobs.

Lessons Learned:

» All-electric affordable housing in California can be cost neutral or a lower cost to build than conventional design.

» The cost of resilience features can be offset through savings from sustainability measures.

- Going all-electric did not significantly increase capital costs; the first cost elimination of natural gas saved money. As important — if not more so — it saved precious time coordinating inspections for both electric and natural gas; these inspections often become part of the critical path for achieving the certificate of occupancy.
- Programmable heat pump based hot water heaters may serve a dual purpose as one of the most cost effective energy storage methodologies; the water can retain sufficient heat even if it's programmed to decrease the temperature during the utility's peak load time frame.
- The solar PV array has a significant cost-stabilizing effect.

3.6.2_MACEO MAY VETERANS APARTMENTS (LARGE SCALE)

Source: Mithun

Project Location: Treasure Island, San Francisco, CA

Completion Year: 2022

Project Size: 104,500 SF

What: Maceo May is a modular, all-electric and affordable residential development currently under construction in San Francisco. Climate-responsive design contributes economic value for Maceo May's owners and delivers a stable, healthy living environment for its residents, who are formerly homeless veterans and their families. Developed by two nonprofits, Chinatown Community Development Center and Swords to Plowshares, Maceo May will be the second all-electric affordable building in San Francisco. The $55 million development will be six stories tall with 105 units — 24 studios, 47 one-bedroom units and 34 two-bedroom units — when construction is completed in 2022. The development is designed to be protected from sea level rise and to continue operations and remain safe and comfortable during periods of extreme heat, power outages, wildfire smoke, and seismic events. The Maceo May resilience approach also includes all-electric systems (no natural gas), solar photovoltaic (PV) energy generation, and readiness for net-zero carbon operations as the California grid continues to meet carbon-reduction targets. Maceo May also features passive design strategies and backup power. Natural gas is a vulnerable infrastructure asset in San Francisco because earthquakes can damage gas infrastructure and lead to explosions and methane leaks.

Net-zero capable, Maceo May is designed to maximize energy efficiency with an anticipated energy use intensity (EUI) that will be about 70 percent lower than an average multifamily building in the United States. Air-source heat pumps provide hot water three to five times more efficiently than a typical boiler. A high-performance building envelope that incorporates 1.5 inches of rigid-mineral-wool continuous insulation minimizes heating and cooling loads, allowing smaller residential heating equipment and cutting costs.

Occupancy sensors and daylight dimmers also limit electricity use. The development team also chose to install an energy recovery ventilator (ERV) with a MERV 13 filter for every residential unit. The ERV reduces HVAC electricity consumption, and the MERV 13 filter exceeds conventional practice and will help filter particulate matter and airborne debris to maintain better indoor air quality, which is a considerable concern during wildfire events.

Given that a significant amount of construction will occur on Treasure Island for a long time after the building opens, and that we're housing a population who bears disproportionate health issues such as compromised immune systems and other effects from having endured trauma, designing to limit solar heat gain while providing for good indoor air quality is paramount. Accordingly, at Maceo May, passive design strategies and superior ventilation also serve to limit energy use, create good air quality, and support the thermal comfort of residents, especially during potential power outages. Maceo May is oriented to take advantage of San Francisco Bay breezes. Windows are operable and have a low u-value (resistance to thermal conduction) and solar heat gain coefficient (resistance to direct solar heat gain) by using double-pane, argon-filled, low-E glazing (indicating a high level of insulation and resistance to heat transfer). South- and west-facing windows are shaded. In residential units, ceiling fans and operable windows located at different heights maximize airflow.

A rooftop 123-kilowatt solar PV array with on-site battery storage is designed to prioritize power for a first-floor community room that doubles as a "resilience hub." Inverters link the array to both battery storage and the local grid so Maceo May has the ability to be self-sustaining. The battery backup system is located on the top floor to prevent problems in the event of flooding.

The back-up systems power critical building features that support resident well-being, such as refrigeration (for storing essential daily medications), basic light and power (including for charging devices), and cooling for data and wi-fi closets that are specifically circuited for the ground-floor community space. The resilience hub's operability during power outages is a means of minimizing disruption in residents' lives, a key resilience goal in a home for veterans.

HVAC	Common Areas: VRV Split Systems; Residential Units: ERVs and Small Cadet Electric Resistance Wall Heaters
DHW	Central Heat Pump Hot Water System (Colmac) with recirculating loop
Cooking	Electric Resistance, Energy Star
Building Envelope	Rain Screen with Fluid Applied Waterproofing Membrane above 1½" Continuous Insulation (Rigid Mineral Wood) and R-19 batts in Type IIIA Construction (Wood Stud above Metal Stud on Level 1). Thermally-broken Aluminum Frame dual-pane argon-filled low-E glazing with U-Factor of 0.26, SHGC of 0.23 and VLT of 0.51
Electrical Load Offset	123 kW pV Rooftop System with 34 kWhr / 20 kW Lithium Ion Battery Backup
Actual EUI	18.2 EUI (anticipated)

Building Code	2016 California Building Code
Developer	Swords to Plowshares and Chinatown Community Development Corp
Architect	MITHUN
MEP Engineering	Engineering 360 and Integral Group

Trade-offs and Challenges:

» The all-electric building design faced challenges to achieve and exceed the 2016 California Energy Code, which required natural gas boilers as a baseline and did not provide an approved modeling pathway for a heat pump DHW system, as well as a number of other weighted calculations, such as preferential scoring for solar thermal hot water systems.

» A lack of developer/owner familiarity with heat-pump technology as well as energy recovery ventilator systems demanded that the design team lead more in-depth conversations about system selection. This need to create developer/owner familiarity was addressed by presenting case studies and existing project precedents and going on tours of other all-electric multifamily buildings. Including the facilities management and operations staff in this effort was critical to achieving final sign off by the owners.

Lessons Learned:

» All-electric affordable housing in California can be cost neutral, or a lower cost to build than conventional design. According to the non-profit developer, CCDC, the big takeaway is that "all-electric multifamily affordable housing is cost neutral at a minimum."

Going all-electric did not significantly increase capital costs; in fact, the design helped avoid some infrastructure expenses, such as $242,000 saved in first costs by eliminating natural gas. Those savings were reinvested into the design in the form of the ERVs in every residential unit (approximately $1,200 premium per unit over conventional trickle-air "z-duct" vents) and the battery-back up system (approximately $80,000). Construction costs, which were $472 per square foot, were on the high end but not far outside the normal range for San Francisco. Operational energy savings are anticipated, and utility bills are expected to be much lower than for a typical multifamily building once the solar PV array is installed.

» The cost of resilience features can be offset through savings from sustainability measures.

» Engagement between the building owner and the design team in setting outcome-based design goals preserved essential design features, saved time through the process, and illuminated opportunities to achieve co-benefits.

» The solar array is designed to cover approximately 85 percent of the common-area loads of the building. This means that the project is approaching near-net zero energy for common area loads, which provides a significant long-term economic boost to the owners by reducing strain on limited operating budgets. Additionally, the development team sees the solar PV array as insurance against future utility cost increases and against the perceived risk of adopting new technology (namely, the air-source heat pump hot water system). Because there is not yet robust building performance and benchmarking data on air-source heat pump hot water systems from buildings of this scale in the region, the ability to produce on-site electricity provides the co-owners a sense of a safety net should the domestic hot water demands surge beyond the modeled performance.

Source: Mithun

3.6.3_WAIKIKI SKYTOWER (RETROFIT)

Source: Redwood Energy

Project Location: Honolulu, Oahu, HI

Completion Year: 2015

Project Size: Not available

What: Waikiki Skytower is an example of the many all-electric high-rises on the island of Oahu, including both multifamily and hotel projects. The luxury condos at the Skytower were originally built in 1978. The building has 102 units over 30 floors; each of the approximately 694 square foot, one-bedroom, one-bath units are all corner units.[32 33]

This renovation retrofitted the domestic hot water system with a Colmac heat pump serving both central domestic hot water and the swimming pool. Inside the condos, each kitchen features a radiant glass-top electric range and electric dryer. The poolside amenities are also achieved in a sustainable manner, featuring all-electric barbeques and an electric sauna.

AHW	Colmac central heat pump
Building Envelope	Pre-existing; completed in 1978
HVAC	Multi-head Ductless Mini-Split
Cooking	Electric glass top range

32 https://www.hawaiiliving.com/oahu/honolulu/metro/waikiki-skytower-waikiki-condos-for-sale/

33 Redwood Energy, A Zero Emissions All-Electric Multifamily Construction Guide

3.6.4_THE BATTERY — PHASE III OF CAPITAL FLATS

Source: Onion Flats Architecture

Project Location: Philadelphia, PA

Completion Year: 2017

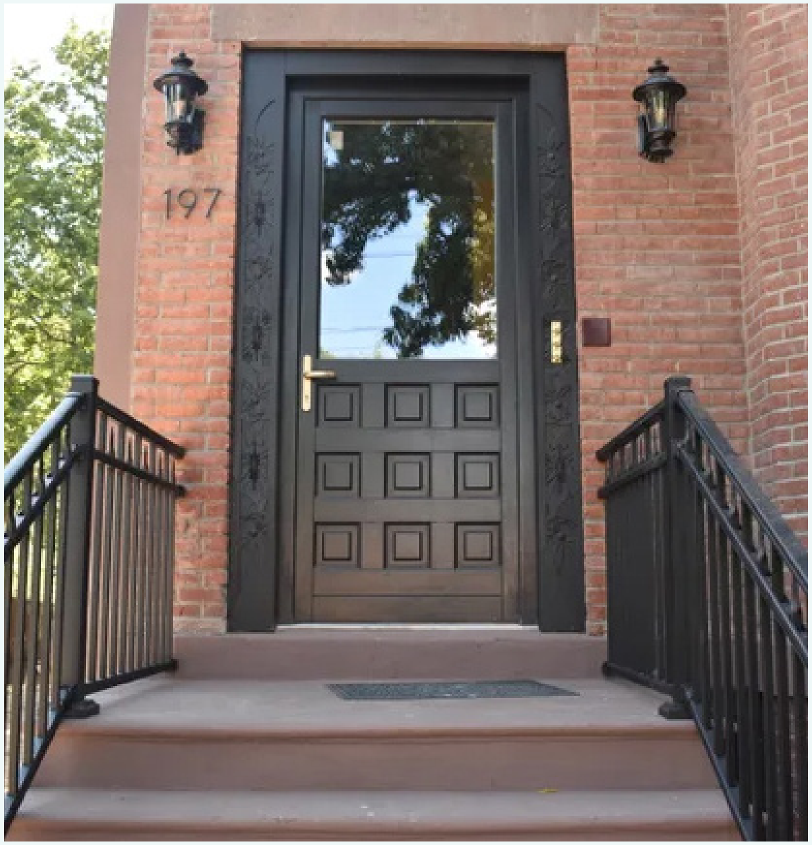
Project Size: 16,782 SF

What: The Battery provides sustainable and market rate housing for residents of Northern Liberties, a community in Philadelphia, PA. The project offers twenty-five 500 sq. ft. "micro" units in an all-electric, zero-net-energy building. Intended for young professionals in need of affordable housing in a rapidly gentrifying neighborhood, the rents start at $1,200 per month and include all utilities. To achieve this affordability and density, the project maximized zoning allowances using a density bonus incentive for green rooftops and deployed water-source heat pumps using two 1,000 foot deep geo-thermal bores to provide heating, cooling and hot water to all apartments. The envelope is prefabricated and super insulated with triple pane windows, and air-tight construction. With a 72 kW photovoltaic canopy on the roof, the project is Passive House certified, and was designed to consume 80% less energy than a similar minimally-code-compliant building.[34]

HVAC and DWH	Combined HVAC and DHW with Geothermal Heat Pump
Cooking	Electric Radiant Glass Top
Building Envelope	Passive House standard; Prefabricated; triple pane windows
Electric Load Offset	72 kW PV Rooftop Canopy
Developer/Architect	Onion Flats

34 https://www.onionflats.com/the-battery-phase3

3.6.5_NORTH MILLER MULTIFAMILY PROPERTY (SMALL-SCALE, GUT REHAB)



Source: Lana Bellamy, Times Herald-Record

Project Location: Newburgh, NY

Completion Year: 2020

Project Size: Not Available

What: This New York State Energy Research and Development Authority (NYSERDA) Buildings of Excellence project aimed to alleviate utility cost pressure for low- to moderate-income residents. The all-in rental model keeps tenants' monthly expenses affordable and predictable, while reducing appliance plug load, enabling the building owners to benefit from reduced energy consumption. The gut rehab put a condemned building onto the performance path to achieving Passive House PHIUS+ 2018 and PHIUS Source Zero standards. The passive design uses the building's orientation to reduce electric load by capturing solar energy to retain heat in the winter while exterior shading blocks the sun in the summer. The HVAC system was converted to all-electric by installing high-efficiency heat pumps, each of which is tied into a central energy recovery ventilation unit to minimize energy losses. Great attention was paid to the building envelope to minimize air leakage — the envelope meets an airtightness of 0.06 cubic feet per minute (CFM50), which can reduce heating demand by 75%. The onsite 9 kW solar photovoltaic array on the roof satisfies much of the building load, while the balance of load is met by an off-site solar PV system. LED lighting, high-efficiency windows, and ENERGY STAR rated appliances collectively serve to reduce the balance of the energy load.[35 36 37 38]

35 https://www.nyserda.ny.gov/All-Programs/Programs/Multifamily-Buildings-of-Excellence/Winners, Round 1 winning project in the "Under Construction" category

36 https://www.nyserda.ny.gov/About/Publications/Case-Studies-and-Features, under "New Construction"

37 https://www.recordonline.com/story/news/2020/06/28/efficient-affordable-housing-coming-north-miller-newburgh/3263075001/

38 https://www.pha-hv.org/north-miller-passive-multifamily-ribbon-cutting/

HVAC and DWH	Air source heat pumps for HVAC and domestic hot water
Building Envelope	Passive House PHIUS+ 2018, PHIUS Source Zero standards
Electric Load Offset	9 kW PV Rooftop Canopy and offsite PV
Architect/Design Team Lead	The Figure Ground Studio (AOR); Northeast Projects LLC (design team lead)
Developer	Steven Taya Property Development
Project Cost	$325,000; $81.82 per gross sq ft
Project Specs	1 building; 3 Stories; 3 units; 3,972 sq ft

Trade-offs and Challenges:

- The SiteSage Energy Management system analyzes occupant energy needs and pinpoints any mechanical or electrical system problems or design flaws.
- Five wall sensors were installed to measure relative humidity and temperature in the building for maximum comfort.

Lessons Learned:

- Exceptionally low-cost gut and rehabilitation is feasible and can deliver a building that achieves very low energy usage while providing high-quality affordable, decarbonized housing.

ACKNOWLEDGMENTS

Project Sponsors, Contributors, and Terms of Use

Project Sponsors

Google	At Google, sustainability is at the core of everything we do. We tackle environmental sustainability projects because they reduce our company's environmental impact, and also because they help our bottom line. But mostly we do it because it needs to be done and it's the right thing to do. And we're not just saying that. Google has been carbon neutral since 2007. We believe this Building Decarbonization Practice Guide is a great tool that will help enable design and engineering teams everywhere to deliver water innovation for residential and office-space projects of all scales.
Microsoft	At Microsoft, we believe sustainability is critical for meeting the economic, societal, and environmental needs of today and of future generations. We also believe sustainability is good for business.
ENERGY FOUNDATION	Energy Foundation supports education and analysis to promote non-partisan policy solutions that advance renewable energy and energy efficiency while opening doors to greater innovation and productivity — growing the economy with dramatically less pollution. For nearly 30 years, Energy Foundation has supported grantees to help educate policymakers and the general public about the benefits of a clean energy economy. Our grantees include business, health, environmental, labor, equity, community, faith, and consumer groups, as well as policy experts, think tanks, universities, and more.
UL	UL is the global safety science leader. We deliver testing, inspection and certification (TIC), training and advisory services, risk management solutions and essential business insights to help our customers, based in more than 100 countries, achieve their safety, security and sustainability goals. Our deep knowledge of products and intelligence across supply chains make us the partner of choice for customers with complex challenges. Discover more att UL.com.
AIA California	AIA California represents the interests of more than 11,000 architects and allied professionals in California. Founded in 1944, the AIA California's mission supports architects in their endeavors to improve the quality of life for all Californians by creating more livable communities, sustainable designs and quality work environments. For more information, visit aiacalifornia.org.
BUILDING DECARBONIZATION COALITION	The Building Decarbonization Coalition unites building industry stakeholders with energy providers, environmental organizations and local governments to help electrify California's homes and work spaces with clean energy. Through research, policy development, and consumer inspiration, the BDC is pursuing fast, fair action to accelerate the development of zero-emission homes and buildings that will help California cut one of its largest sources of climate pollution, while creating safe, healthy and affordable communities. The Project Team gives special thanks to the BDC for its leadership in this endeavor and for the generous support of its Membership.

WRNS STUDIO

Guttmann & Blaevoet CONSULTING ENGINEERS

CONNECTING POLICY AND PRACTICE WITH DESIGN URBAN FABRICK

WILLIAM J WORTHEN FOUNDATION

Contributors

Building Decarbonization Practice Guide Content Leadership

» **Panama Bartholomy,** Building Decarbonization Coalition
» **Rachelle Boucher,** Kitchens to Life
» **Glenn Friedman,** PE, FASHRAE, Taylor Engineers
» **Christopher Galarza,** Forward Dining Solutions
» **Miranda Gardiner,** AIA, iMasons Climate Accord
» **Steven Guttmann,** PE, BCxP, LEED Fellow, Guttmann & Blaevoet
» **Teresa Jan,** AIA, LEED AP, WELL AP, Multistudio
» **Heidi Lubin,** eSix Development
» **Kyle Pickett,** William J. Worthen Foundation
» **Katie Ross,** Microsoft
» **Pauline Souza,** FAIA, LEED Fellow, WELL AP, LEED AP BD+C, LFA, WRNS Studio
» **Alice Sung,** AIA, LEED AP BD+C, SEA, Greenbank Associates
» **Ted Tiffany,** LEED AP BD+C, Building Decarbonization Coalition

Project Manager

» **Brett Rosenberg**, LEED AP, Cushman & Wakefield

WJWF Intern

» **Laura Barbosa,** Construction Industry Workforce Initiative

Graphic Design

» **Stoller Design Group**

Copy Editor

» **Geoff Martin,** Wheelhouse Writing Services

Working Group Members and Content Contributors

» **Katie Ackerly,** AIA, David Baker Architects
» **Sean Armstrong,** Redwood Energy
» **Heather Burpee,** University of Washington Integrated Design Lab
» **Don Davies,** PE, SE, Magnusson Klemenic Associates
» **Pierre Delforge,** Natural Resources Defense Council
» **Patrick Doss-Smith,** HGA
» **Susan Freed,** County of San Diego
» **Andreas Gyr,** Google
» **Ryan Hamilton,** Consortium for Energy Efficiency
» **Barry Hooper,** SF Environment
» **Josh Jacobs,** LEED AP+ BD&C, UL
» **Dirk Kestner,** PE, LEED AP BD+C, ENV SP, Walter P Moore
» **Bruce King,** Ecological Building Network
» **Candice Kollar,** Kollar EcoCreative and William J. Worthen Foundation
» **Meghan Lewis,** Carbon Leadership Forum
» **Lisa Fay Matthiesen,** FAIA, LEED Fellow, Amazon
» **Maurya McClintock,** McClintock Facades Consulting, LLC
» **Hilary Noll,** AIA, LEED AP BD+C, Mithun
» **Kelsey Rose Price,** PE, Hines
» **Cole Roberts,** PE, LEED AP, WELL AP, Arup
» **Henry Siegel,** FAIA, LEED AP, Siegel + Strain Architects
» **Stacy Smedley,** Skanska
» **Larry Strain,** Siegel + Strain
» **Mark Webster,** PE, LEED AP BD+C, Simpson Gumpertz & Heger
» **Wolfgang Werner,** AIA, LEED AP BD+C, CPHD, Urban Fabrick, Inc.
» **Breana Wheeler,** BRE (BREEAM USA)
» **Tamim Younos,** Green Water-Infrastructure Academy

Terms of Use

Please read the following Terms of Use ("the Terms") carefully before accessing or using "The Building Decarbonization Practice Guide: A Zero Carbon Future for the Built Environment" ("the Book"). These Terms govern your use of the Book, and by accessing or using it, you acknowledge and agree to be bound by these Terms. If you do not agree with any part of these Terms, you should not access or use the Book.

1. Intellectual Property Rights:

a. All intellectual property rights in the Book, including but not limited to copyrights, trademarks, and any other rights, belong to the William Worthen Foundation ("the Publisher") or have been appropriately licensed by the Publisher. The Book is protected by applicable copyright and other intellectual property laws.

b. The Publication and its original content, features, and functionality are owned by the Publisher and are protected by international copyright, trademark, patent, trade secret, and other intellectual property or proprietary rights laws.

c. You may not reproduce, distribute, modify, create derivative works of, publicly display, publicly perform, republish, download, store, or transmit any part of the Book without the prior written consent of the Publisher, except as expressly permitted by applicable law and as outlined in these Terms.

2. Permitted Use:

a. You are granted a non-exclusive, non-transferable, limited license to access and use the Book solely for your personal informational and educational purposes.

b. You may make copies of the Book for your personal use, such as storing it on your personal devices or printing a copy for personal reading. However, you may not distribute or share these copies with others.

c. You are granted a non-exclusive, non-transferable, limited license to place a link on your own website to the Worthen Foundation website (https://worthenfoundation.org/get-the-guide-bdpg), where the Book can be downloaded by others who will also be required to be bound by the Terms.

d. You may use the text from the Book for personal, non-commercial purposes with the appropriate attribution substantially in the form of: "Material presented is taken from 'The Building Decarbonization Practice Guide' published by the William Worthen Foundation, and is reprinted with permission of the Foundation."

3. Prohibited Use:

a. You may not use the Book in any way that violates applicable laws or regulations.

b. You may not use the Book or its contents for any commercial purpose without the explicit written consent of the Publisher. Should uses other than those permitted above be desired by the user, the Publisher will consider written requests, and the Publisher may require monetary and/or in-kind compensation in order to grant such a request. Use of material from the Book for commercial purposes is not permitted unless a separate agreement is executed between you and the William Worthen Foundation.

c. You may not modify, adapt, reverse engineer, decompile, or disassemble the Book or any part of it.

Terms of Use (continued)

d. You may not remove, alter, or obscure any copyright, trademark, or other proprietary notices contained in the Book.

e. You may not use any images, including photographs and graphics, in the Book without the explicit written consent of the Publisher.

f. You may not host links to downloadable copies of the Book on any website. All copies of the Book shall be exclusively acquired by direct download from the William Worthen Foundation website (https://worthenfoundation.org/get-the-guide-bdpg).

4. Limitation of Liability:

a. The Book is provided on an "as is" basis, without warranties of any kind, either expressed or implied. The Publisher disclaims all warranties, including but not limited to, warranties of title, merchantability, fitness for a particular purpose, and non-infringement.

b. In no event shall the Publisher be liable for any direct, indirect, incidental, special, exemplary, or consequential damages arising out of or in connection with the use of the Book, even if advised of the possibility of such damages.

5. Indemnification:

a. You agree to indemnify and hold harmless the Publisher and its affiliates, officers, agents, employees, and partners from any claim or demand, including reasonable attorneys' fees, made by any third party due to or arising out of your use of the Publication, your violation of this Agreement, or your violation of any rights of another.

6. Termination:

a. The Publisher reserves the right to suspend or terminate your access to the Book at any time, without prior notice, for any reason or no reason, in their sole discretion. If access to the Book is suspended or terminated, you agree to stop accessing the Book and/or delete all copies of the Book as instructed by the Publisher.

7. Changes to the Terms:

a. The Publisher reserves the right to modify or update these Terms at any time without prior notice. The most current version of the Terms will be posted on the Publisher's website or provided with the Book. Your continued use of the Book after any modifications or updates to the Terms constitutes your acceptance of such changes.

8. Governing Law and Jurisdiction:

a. These Terms shall be governed by and construed in accordance with the laws of the State of California. Any disputes arising out of or in connection with these Terms shall be subject to the exclusive jurisdiction of the courts located in California.

By accessing or using the Book, you acknowledge that you have read, understood, and agree to be bound by these Terms. If you do not agree to these Terms, you should not access or use the Book.

For questions or licensing requests, please contact **Kyle Pickett** at kyle@worthenfoundation.org, or **Candice Kollar** at candice@worthenfoundation.org.