Accelerating Electrification of California's Multifamily Buildings

POLICY CONSIDERATIONS AND TECHNICAL GUIDELINES

STOPWASTE

ASSOCIATION FOR ENERGY AFFORDABILITY (AEA)

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Executive Summary

California aims to reduce its greenhouse gas emissions by 40% before 2030. While zero-carbon construction for new buildings could significantly cut the overall emissions of California's building stock, the majority of California's multifamily buildings are existing properties with natural gas–powered space heating and water heating. As explained in Part 1, The Value Proposition of Electrification in Multifamily Housing, electrifying these buildings so that they are compatible with zero-carbon infrastructure will be a necessary step in achieving California's goals.

While all-electric technologies and the solutions that make electrification of existing buildings possible have become increasingly prevalent, there is a lack of general knowledge about building electrification considerations and methods. A significant gap exists between the deep understanding held by many electricians and contractors and the knowledge required for decision making by building owners. As a result, going all-electric can be daunting to building owners who can't easily gauge the cost and extent of the upgrades required. This lack of information stands as a barrier to achieving decarbonization in California's existing building stock and may undermine the success of programs designed to encourage electrification unless it is quickly and widely addressed.

Part 2, Technical Considerations for the Electrification of Multifamily Buildings, provides an overview of electrical code, infrastructure, and technologies. A solid grasp of this information can enable building professionals to suggest and explain decarbonization methods appropriate to each building's situation. Such a preliminary assessment by a building professional can elucidate the options available to a building owner, bringing the concept of electrification to a tangible level.

Regardless of the specific programs adopted by California to reach its decarbonization goals, whole-building electrification assessments by building professionals and other program implementers will play a vital role in the ability of those programs to impact a wide sampling of buildings throughout the state.

Overview

This report, *Accelerating Electrification of California's Multifamily Buildings*, is a deliverable for the Accelerating Multifamily Building Upgrades project. This project was funded by the California Energy Commission's Local Government Challenge grant.

The report provides policy context (Part 1) and functional technical information (Part 2) to accelerate the electrification of California's existing multifamily buildings.

Part 1, The Value Proposition of Electrification in Multifamily Housing, reviews the historical and policy context for multifamily building electrification, addresses the significant carbon reduction and non-energy benefits of electrification, and addresses policy, social and economic challenges to converting existing multifamily buildings to all-electric. Part 1 is primarily intended for policymakers, program designers and implementers, funders and others interested in deepening their understanding of the value—and complexity—of electrifying this building sector.

Part 2, Technical Considerations for the Electrification of Multifamily Buildings provides a foundation for understanding the current conditions, considerations, processes and tradeoffs in implementing cost-efficient electrification retrofits in multifamily buildings. This information draws on data and experience from more than 30,000 multifamily units that participated in various building upgrade programs in California, including BayREN Multifamily, California Department of Community Services' Low-Income Weatherization Program (CSD LIWP), and others.

Making generalizations about electrification is challenging because of the diversity of multifamily building and system types. While energy auditors and contractors will face unique conditions during the electrification of specific buildings, Part 2 aims to provide a general framework for deciding if electrification is feasible, and if so, how to achieve it in a cost-efficient manner using available and emerging technologies.

PART 1: The Value Proposition of Electrification in Multifamily Housing

Introduction

In 2018, California emitted 425 million metric tons of CO_2 equivalent (MTCO2e), of which 6.1% was attributed to residential emissions associated with fossil fuels consumed onsite and electricity demand (California Air Resources Board, 2020). California had 13.1 million residential units, of which 3 million were apartments (United States Census Bureau, 2021). The California Energy Commission has found that space heating and water heating end uses contribute 88% of residential fossil fuel consumption. While a smaller share of the state's overall greenhouse gas emissions is attributable to residential buildings, the technologies to increase efficiency and transition to cleaner fuels are already developed and available for residential properties in the form of electrification. Natural gas systems and appliances are currently prevalent in existing multifamily buildings and their replacement represents a significant opportunity to reduce greenhouse gas emissions, potentially lower utility costs, and make buildings safer.

The primary natural gas end uses in multifamily buildings are the space heating components of heating, ventilation, and air conditioning systems (HVAC) and domestic hot water systems (DHW). Electrification of these systems will have the greatest impact on carbon reduction. However, because the benefits of electrification go beyond carbon reduction, electrification should span all fossil fuel–burning systems and appliances including stoves and ovens, clothes dryers, pool and spa heaters, and other miscellaneous equipment. For example, electrifying gas cooking appliances like ovens and stovetops can improve indoor air quality for residents, which is especially important for children's health (Weiwei Lin, 2013). Additionally, once a building is converted to all-electric, the property can be removed from the gas distribution network, a crucial part of California's long-term decarbonization strategy.

The electrification of existing multifamily buildings also provides an opportunity to address social and economic inequities. People with low incomes are often renters in marginalized communities disproportionately affected by air pollution. They also often have high rent and energy burdens. Efforts to electrify multifamily buildings in marginalized communities must focus on community engagement while aiming to maximize health benefits and energy cost reduction through pairing electrification with deep energy efficiency.

Electrification in the existing multifamily building sector faces the same obstacles inherent to the broader residential sector, including limited access to funds to offset upfront costs and retrofit challenges pertaining to electrical infrastructure upgrades and building modifications. However, the multifamily sector also faces unique challenges, such as the pervasive "split incentive" issue, which refers to the tendency of multifamily building owners to minimize in-unit energy upgrades that do not financially benefit them by reducing owner-paid utility bills. Additionally, multifamily buildings also have a wide variety of HVAC and DHW system types and configurations as well as infrastructural challenges related to limited panel capacity to add new electric load. Another obstacle to electrification arises from the diversity of multifamily building types, which range in size from low-rise buildings with less than 10 units to larger mid-rise buildings to high-rise buildings with many hundreds of units. A wide range of electrification measures and implementation strategies potentially come into play for the multifamily sector, including some that apply only to a specific area or single dwelling unit and others that apply only to large commercial central systems that serve whole buildings or larger areas.

Policy and technology developments pave the way for electrification

Since California enacted its building energy efficiency code in 1978, it has often emphasized the use of natural gas over electricity for space and water heating. This was partly because electric power plants were less efficient and their emissions created local air quality issues. It was also to curb peak demand on the state's electric grid. Additionally, the existence of natural gas power plants and associated storage and distribution infrastructure supported residential end uses. Furthermore, heat pump technology was nascent, and electric resistance systems and appliances were, and continue to be, inefficient. This made electric end uses expensive to operate, and their high power draw meant that adding electric appliances often required upgrades to electrical infrastructure. This led both to a prevalence of natural gas in California's existing building stock, and to the perception that electric appliances cost more to operate, require expensive infrastructure upgrades, and play a bigger role in climate change.

However, with California's Renewable Portfolio Standard Program, which set escalating renewable energy procurement requirements for utilities, and the falling cost of solar and wind generation in recent years, California's utility grid has been powered by an increasing portion of renewables. In 2019, 36% of its electric power came from renewables and over 60% from carbon-free sources (California Energy Commission, 2020). Further increases are anticipated as battery technology improves and the state fulfills its Senate Bill 100 mandate to be carbon neutral by 2045.

In addition to the increase in renewables, the other main driver of the shift to electrification has been the technological advancement of heat pumps. They have been in wide use in refrigerators and air conditioners for decades but only more recently have they been adapted for use in space and water heating. Heat pumps efficiently move heat instead of creating it, making them three to four times more efficient than electric resistance.

In the United States, this jump in efficiency paired with lower carbon electricity has redefined electrification: where electrification with electric resistance often meant infrastructure upgrades and high operating costs, electrification with modern heat pump technology requires less electrical capacity and has the potential to lower operating costs.

Decarbonization initiatives in California

Accelerating the electrification of multifamily buildings aligns with the direction of California's statewide decarbonization initiatives. The multifamily sector will help meet the efficiency and greenhouse gas reduction objectives of policies such as SB 350 (Clean Energy and Pollution Reduction Act, 2015), SB 1477 (Low-emissions Buildings and Sources of Heat Energy, 2017–2018), AB 3232 (Zero-emissions Buildings and Sources of Heat Energy, 2017–2018), and AB 1232 (Affordable Housing: Weatherization, 2019–2020).

The California Public Utilities Commission (CPUC) recently authorized electrification measures to be incentivized throughout their energy efficiency portfolio when those measures are in compliance with CPUC requirements documenting improved efficiency and reduced pollution compared to natural gas equivalent appliances. Additionally, the CPUC has included heat pump water heaters as an eligible measure in the Self Generation Incentive Program. With this important regulatory change, investor-owned utilities, community choice aggregators, and regional air districts across the state have launched electrification programs, with many of them focused on low-income households in multifamily buildings.

This report focuses on the electrification of existing multifamily buildings as there is large untapped potential in decarbonizing this sector. As California's codes and policies for newly constructed buildings approach requirements for net zero energy and carbon neutrality and local reach codes prohibit extension of new gas infrastructure, there is an even more pressing need to update the state's existing building stock, where there is far more potential for greenhouse gas emissions reductions. Over two-thirds of California's building stock in 2045 will be comprised of buildings already constructed today, with two-thirds of associated greenhouse gas emissions coming from residential buildings and one-third from commercial buildings (Building Decarbonization Coalition, 2019).

Electrification Readiness Factors Specific to Existing Multifamily Buildings

In addition to the technical feasibility factors detailed in Part 2, entities considering electrification readiness and electrification retrofits should take into account the factors that make multifamily housing distinct from other building sectors.

Multifamily housing is multifaceted

Decision making about multifamily residential building upgrades is different from single family and most commercial buildings in that it is subject to potentially divergent priorities of building owners and residents. Upgrade decisions are affected by system configuration (central or in-unit) and who is responsible for paying the associated utility bill (owner or tenants). This often leads to "split incentive" issues, where an owner is hesitant to make upgrades that do not benefit them directly in the form of reduced utility bills for common area meters. Residents, and in particular renters, on the other hand, typically lack the decision-making power to make upgrades but often have to pay higher utility bills associated with living in an inefficient building.

A central challenge to electrification of existing multifamily buildings arises from the fact that the sector consists of a number of subsectors based on ownership types and building configurations, such as:

- Size and configuration
  - High-rise, mid-rise, low-rise
  - Garden-style, double-loaded corridors, etc.
  - Mixed-use (commercial on the ground level with housing above)
- Ownership type and class
  - Market rate
  - Affordable
  - Deed-restricted
  - Naturally occurring affordable housing (NOAH)
  - Asset class (A, B, C)
  - Cooperative rental and condominium
- HVAC and DHW system types
  - Central (whole building)

    - Unitary (in-unit)

Additionally, differing building configurations and ownership structures influence:

- Which building and energy codes apply
- Who makes the decisions about upgrades
- What the financing and regulatory structures of the project are and how they might constrain electrification decisions
- Whether the common areas, dwelling units or both are the focus of the improvements

Affordable housing has its own subsectors

Renters typically have significantly lower incomes than homeowners (Borgeson, 2020). This is the case across the multifamily sector, for both market-rate and affordable properties. Affordable housing has traditionally been defined as deed-restricted or Section 8, but recently a new subsector has been identified as naturally occurring affordable housing.

Naturally occurring affordable housing

NOAH buildings are generally defined as market-rate residential rental properties where the rent is below the area median rent and is not formally subsidized by federal, state, or local programs. These buildings tend to be older, smaller (20 units or less), located in marginalized communities, and often owned by individual landlords or family trusts rather than larger real estate companies. The owners of NOAH properties may be more directly affected by local market conditions and rental non-payment issues than deed-restricted property owners and corporate housing portfolio owners. NOAH properties have historically been hard for upgrade programs to reach because owners are often individuals or family trusts who keep their properties at arm's length. Also, some tenants may have irregular work schedules or be undocumented, lowering their ability or desire to engage with electrification and energy efficiency program staff.

Deed restricted and Section 8 housing

Traditional affordable housing is considered to be deed restricted or Section 8. Deed restricted limits who is eligible to rent or buy a property and is typically determined by a maximum income requirement tied to area median income (AMI). In California, 80% of AMI is considered low income. The U.S. Department of Housing and Urban Development's Housing Choice Voucher Program, implemented by local public housing agencies and known as Section 8, helps very-low income families afford housing in the private market. In the case of deed restricted, regulated and government-subsidized low-income multifamily housing, the public funding sources utilized to finance their construction and operation generally determine the feasibility of electrification upgrades. Energy and decarbonization programs need to align with a project's primary funding requirements for scope and timeline. Subsidized housing also specifies the utility payment and rent payment structures between the owner and tenants that will play into the upgrade decision-making process.

It should also be noted that in NOAH, deed restricted, and Section 8 housing, low-income residents might be receiving discounted utility rates that can affect the payback calculations of in-unit upgrades, while tenants in master-metered properties might have their utilities paid by the property owner.

Policy Considerations for Multifamily Electrification Programs

These five policy considerations are intended for state-level policymakers and staff of regional programs and cities interested in promoting electrification of existing multifamily housing:

1. Incentivize electrical infrastructure upgrades
2. Offset capacity increases with energy efficiency gains
3. Take into account non-energy benefits of electrification
4. Continue to address improvement of in-unit spaces
5. Coordinate incentive offerings across a multitude of funding sources

Each of these considerations is discussed below.

Policy Consideration 1: Incentivize electrical infrastructure upgrades

Existing electrical infrastructure can be one of the biggest barriers to installing high efficiency electric space and water heating systems. The cost to upgrade electrical capacity, wiring and space configurations can often exceed the cost of the equipment and appliances themselves. Additional or increased incentives may be necessary to offset the cost of crucial electrical infrastructure upgrades need to complete an electrification project.

Policy Consideration 2: Offset capacity increases with energy efficiency gains

Existing electrical capacity is often not sufficient to support the installation of new electric heat pump HVAC and DHW systems. Increasing the energy efficiency of existing electrical systems like lighting and appliances is crucial to freeing up existing electrical capacity for new systems. Including energy efficiency incentives or layering incentives with existing energy efficiency programs should be heavily considered.

Policy Consideration 3: Take into account non-energy benefits of electrification

Converting each gas-powered system to a high efficiency electric equivalent has many benefits beyond energy savings and greenhouse gas reductions, including:

- Potential energy cost savings
- Improved indoor and outdoor air quality
- Increased resiliency and effectiveness of photovoltaic power and storage/battery systems
- More accessible electric vehicle charging
- Increased safety
- Effects on equity and jobs
- Added cooling

Potential Energy Cost Savings

Electrification does not automatically equate to lower utility bills, but studies suggest that utility bill cost savings are possible and likely. A recent building simulation study that modeled HVAC and heat pump water heater (HPWH) electrification retrofits of low-rise multifamily buildings showed marginal utility bill savings, while modeling electrification of cooking and clothes drying equipment showed increased utility bills (Energy + Environmental Economics, 2019).

Complicating factors include the uncertainty of gas and electric utility rate escalations, as well as the shift to time-of-use (TOU) electric utility rates. TOU rates charge more for electricity during times of high demand, generally May through October and late afternoon through evening, when air conditioning demand is high, solar photovoltaics decrease generation, and natural gas power plants increase generation. TOU rates complicate the calculation of utility bill savings but highlight the need for demand response, load shifting, and behavioral energy efficiency programs to reduce electric energy use when both rates and embodied greenhouse gas emissions are high. It should be noted that new heat pump HVAC and DHW equipment often come with demand response, load shifting, or programming capability to limit usage during peak demand.

Additionally, pairing electrification upgrades with solar PV and battery storage installation significantly reduces utility bills. Capital costs associated with installing PV and batteries remains high, although many financing mechanisms and incentive programs increase access to multifamily building owners.

Case studies from the Multifamily Low Income Weatherization Program (LIWP-MF), included at the end of Part 1 of this report, show reduced combined bill costs after electrification. Pre-installation modeling and post-installation bill analysis need to continue and be shared publicly to provide more insight on utility bill cost impacts.

Improved Indoor and Outdoor Air Quality

Removing combustion appliances from interior spaces reduces the opportunity for dangerous combustion gases to accumulate indoors. Older and improperly ventilated gas-combustion systems and appliances may backdraft flue gases into living spaces. All gas-combustion equipment can contribute to decreased ambient air quality levels, especially in areas already adversely affected by proximity to highways and industrial operations and associated fine particulate matter (PM2.5) and nitrogen oxides.

Additionally, gas cooking appliances have been linked to increased rate of asthma in children. A UCLA study found that if all residential gas appliances were converted to electric, monetized health benefits would be $3.5 billion per year (Weiwei Lin, 2013).

Increased Resiliency and Effectiveness of Photovoltaic Power and Battery Systems

Electrification paired with an appropriately sized photovoltaic and battery storage system allows for:

- Resilience to increasingly frequent power outages and shutoffs (if the system is capable of “islanding” from the grid)
- Reduced electric utility bill charges during peaks in TOU rates
- Potential for zero net energy use when combined with an all-electric building
- A hedge against electric utility rate escalation

Because preparing electrical infrastructure for PV systems and batteries often involves some of the upgrades necessary for building electrification and vice versa, pairing the two projects can reduce overall infrastructure upgrade costs.

More accessible electric vehicle charging

Electric vehicle (EV) market share has steadily increased in recent years, from 1.9% in 2016 to 5.8% in 2020 (California New Car Dealers Association, 2020). This trend is expected to continue thanks to the availability of state and federal incentives and a steady increase in public access to EV chargers. In California, this increase is further bolstered by Governor Newsom's executive order to phase out sales of internal combustion cars by 2035 (Office of Governor Gavin Newsom, 2020).

As with PV and battery systems, EV chargers and electrical infrastructure upgrades to support electrification become more cost efficient when installed simultaneously. This benefit can be amplified when incentive programs for solar, electric vehicle supply equipment (EVSE), and batteries are layered. As EV adoption increases, resident demand for EV charging stations in multifamily buildings will also increase, with many jurisdictions requiring EVSE installation for new construction. California's Civil Code § 1947.6(a) requires EV stations to be installed at the request and payment of tenants. Where EV charging may have been a perk in the past, it is now becoming a necessity, and buildings without it may not be able to compete with the rest of the market in coming years.

Increased safety

Combustion appliance safety testing is a costly component of gas appliance change outs and maintenance but is necessary to ensure hazardous conditions are not created by the presence of onsite combustion associated with gas furnaces, water heaters, and stoves. Removing combustion appliances from the site increases the safety of occupants by removing the potential for gas leaks and combustion venting issues that can lead to hazardous or unhealthy indoor air quality.

Combustion safety data from 99 properties that participated in the Bay Area Multifamily Building Enhancements (BAMBE) or LIWP programs reveal that central gas systems showed some sort of failure 10% of the time. Out of the 1,209 dwelling units tested, 49% had failed to comply with combustion safety standards. Completely removing gas systems and appliances through full building electrification equates to safer buildings for tenants and decreased liability for owners.

Effects on equity and jobs

Modernization and electrification of aging multifamily buildings can benefit low-income people in California by making their homes healthier, more comfortable and less costly and providing good jobs. However, program and policy support must substantially expand to ensure that low-income customers are not left to pay for the increasing costs associated with maintaining gas infrastructure.

Special attention must be given to utility bill effects of electrification. According to the U.S. Department of Energy's Low-Income Energy Affordability Data (LEAD) tool, the national average energy burden for low-income households is 8.6%, nearly three times higher than for non-low-income households (estimated to be 3%). This disparity is exacerbated in California because of the state's extremely high housing and energy costs. While well-planned electrification paired with deep energy efficiency may reduce utility bill costs, utility bill reduction cannot be assumed. Detailed upfront analysis should be completed to mitigate the risk of increased utility costs to both owners and low-income tenants.

In addition, policymakers should address the possibility of negative effects on low-income renters if owners are able to pass through electrification upgrade costs to renters in the form of higher rents.

As building electrification retrofits increase, demand will grow for HVAC, plumbing, and electrical contractors and workers to install and maintain heat pumps and electrical panels. This presents an opportunity for job growth benefiting low-income communities. Electrification programs and policies must be developed in concert with labor and workforce development agencies as well as training programs and contractors serving marginalized communities. Established end experienced contractors working in electrification should be incentivized to train and hire people from marginalized communities so they can benefit from and be an integral part of the growth of building electrification.

Added Cooling

Electrification of existing gas heating systems through installation of heat pump HVAC systems has the benefit of adding efficient cooling where it did not previously exist. This significantly benefits the quality of life for residents living in warm climates and reduces health risks associated with hot weather to vulnerable populations like the elderly. In recent years, higher temperatures due to climate change have led to increased installations of standalone air conditioning system, including inefficient window units and packaged terminal air conditioners (PTAC), while leaving existing gas heating systems unaffected. Installation of efficient central or in-unit heat pump HVAC systems negates the need for installation of inefficient standalone air conditioning units and removes any existing natural gas heating systems. Adding air conditioning will increase electrical load and can increase associated electric utility bill costs, but this can be offset with efficiencies gained through the heating system and energy efficiency upgrades to the buildings envelope, lighting, appliances, and other energy systems.

Policy Consideration 4: Continue to address improvement of in-unit spaces

Serving tenants with energy efficiency and electrification programs continues to have specific challenges stemming from the aforementioned split incentive issues. Historically, energy programs serving multifamily buildings have focused on upgrades to central systems that financially benefit owners. In-unit or tenant spaces have been underserved by these programs. With electrification, common area and in-unit/tenant spaces must be comprehensively considered to reduce building load and free up electric panel space for new heat pump HVAC and DHW equipment.

Policy Consideration 5: Coordinate incentive offerings across a multitude of funding sources

Many programs offer support to California multifamily property owners for electrification. Some of these include BayREN’s Clean Heating Pathway, CPUC’s Energy Savings Assistance and Self-Generation Incentive Program, California Department of Community Services & Development’s LIWP-MF, and numerous electric vehicle charger installation programs offered by investor-owned utilities (IOUs) and community choice aggregators (CCAs).

Streamlining programs to promote layering will help property owners utilize these resources while reducing administrative costs. A successful example of this is MCE’s LIFT and BayREN’s Multifamily programs. These two programs aligned their outreach, intake, technical assistance, scope development, and attribution of savings to make it easier for both programs and their customers to layer incentives and achieve more comprehensive energy efficiency projects, lower project costs, and better customer experiences.

Case Studies

Numerous multifamily properties in California have completed electrification retrofits. Example projects include those assisted by the Electric Program Investment Charge (EPIC), LIWP-MF, and BAMBE programs. Table 1, which provides a savings snapshot of six electrification projects from the LIWP-MF program (Low-Income Weatherization Program for Multifamily Properties), is followed by two case studies with more detail.

Table 1. Savings from Example Multifamily Electrification Projects in California

Property Name	Combined Site BTU Savings	Electricity Savings	Gas Savings	Combined $ Savings	GHG Savings
205 Jones	40%	-82%	48%	31%	34%
Padre	37%	-6%	53%	27%	30%
Marlton Manor	27%	4%	35%	49%	23%
ArdenAire	64%	-33%	89%	36%	51%
Cascade Village	50%	-84%	66%	25%	41%
North Park	32%	18%	45%	23%	28%
Average	**42%**	**-31%**	**56%**	**32%**	**35%**

ALMOND COURT

Wasco, CA

Owner: Self-Help Enterprises
Year built: 1996
Type: Low-rise multifamily
Sector: Affordable rental
Units: 36
Size: 45,000 sq. ft.
Program participation: Low Income Weatherization Program (LIWP)

PROJECT SCOPE

- **Heat pump water heaters**
- **High efficiency ducted heat pumps**
- Ductwork sealed with Aeroseal
- Attic air sealed and insulated
- ENERGY STAR washing machines and refrigerators
- Dual-pane windows
- Comprehensive LED lighting upgrade
- Low-flow aerators and showerheads
- 110 kW solar PV system

ENERGY AND COST SAVINGS

(Confirmed efficiency savings plus projected PV savings)

- 44% reduction in actual resident energy use (combined BTU savings)
- 18% cost savings in resident utility bills from energy efficiency and electrification measures
- $830 average bill savings per unit
- 72% total site savings on BTU basis
- 91 metric tons CO2 reduced

LINK TO COMPLETE CASE STUDY:
https://camultifamilyenergyefficiency.org/case-studies/case-studies-almond-court/

Figure 1. Almond Court Case Study

Low-Rise Apartment Building

Central Valley, CA

Year built: 1995
Type: Low-rise multifamily
Sector: Affordable rental
Units: 52
Size: 57,716 sq. ft.
Program participation: Low Income Weatherization Program (LIWP)

**Image not available, owner requested anonymity*

PROJECT SCOPE

- **Heat pump water heaters**
- **Inverter driven heat pumps**
- Ductwork sealed with Aeroseal
- Attic air sealed and insulated
- ENERGY STAR washing machines and refrigerators
- Dual-pane windows
- Comprehensive LED lighting upgrade
- Low-flow aerators and showerheads
- 171.2 kW solar PV system, 90% allocated to tenant meters

ENERGY AND COST SAVINGS

(Confirmed efficiency savings plus projected PV savings)

- 45% reduction in site energy use, 79% with PV (combined BTU savings)
- 24% site utility bills savings from energy efficiency and electrification measures, 83% with PV
- 36% total site greenhouse gas savings (66.26 MTCO2e), 81% with PV (151.40 MTCO2e)

Figure 2. Low-Rise Apartment Building in Central Valley Case Study

PART 2: Technical Considerations for the Electrification of Existing Multifamily Buildings

Electricity Fundamentals

This report is not intended as an electricity primer; there are many publications and online sources that explain basic concepts. However, this page and the next one provide a brief overview of electricity fundamentals relevant to this report. If you don't need this refresher, skip ahead to the next section.

Alternating current

Electricity in California is in alternating current (AC), meaning the path of electrons in the electrical current alternate directions (+/-) at a certain frequency, measured in hertz (Hz). AC follows a sine wave pattern (Figure 4).

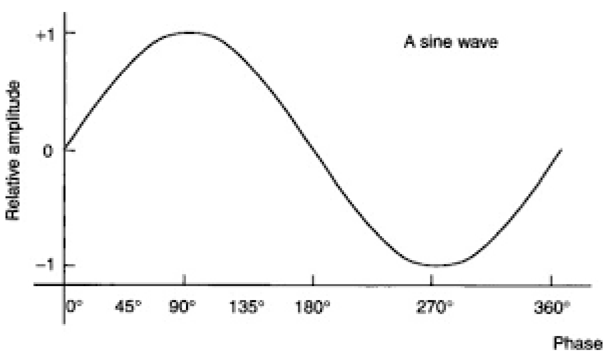

Figure 3. Sine Wave

(Elliot, 2000)

Electrical phases

Single-phase 240 V power (Figure 5) is commonly found in small multifamily residential buildings and single-family residences. It provides 120/240 voltages via three conductors: two 120 V supply conductors and one neutral conductor. The neutral conductor circles back, connects to the power source and completes the circuit. Each 120 V supply is 180 degrees out of phase from one another. When an appliance is connected to one supply conductor it receives 120 V, when connected to both supply conductors it receives 240 V.

***Three-phase 208 V* power** (Figure 6) commonly supplies larger multifamily buildings or commercial spaces and is how power is distributed on the electrical grid. Three-phase power is a four-wire system with a neutral conductor and three supply conductors, each 120 degrees out of phase from one another.

The supply conductors can have line voltages between 120 V and 347 V.

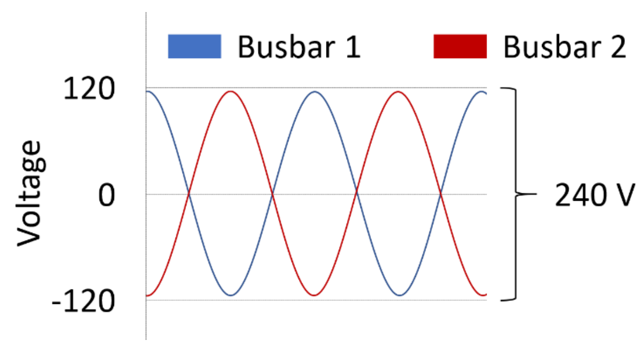

Figure 4. Single-Phase Power

(Electrical PE Review, 2016)

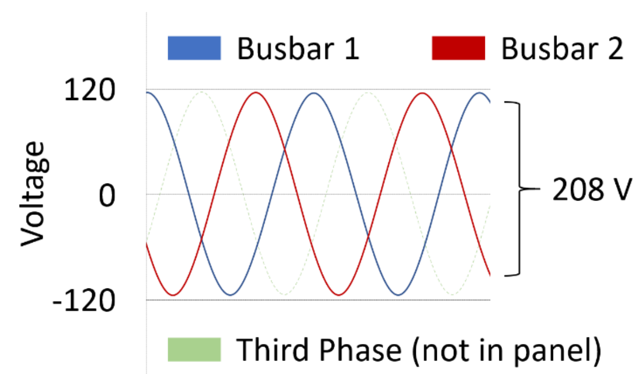

Figure 5 Three-Phase Power

(Electrical PE Review, 2016)

Typically, each supply conductor to a multifamily building is 120 V, so the line voltage between any two supply conductors is 208 V. While a building may be supplied with three-phase power, the feeders to the apartments will all be single phase; the only difference to downstream loads is that double-pole circuits will receive 208 V, rather than 240 V.

Load balancing

In both single-phase and three-phase power, the power traveling through each supply line is intentionally offset in phase to always be the opposite of the other supply line or lines. Therefore, if the power draw is equal on each line, the instantaneous voltages of the powered lines add up to zero. This means that the total current returning on the neutral line is zero.

If the power draw is not equal on each line, the neutral wire carries a non-zero current back to the utility. This current creates waste energy in the form of heat, decreasing the overall efficiency of power transmission to the building. This current can also become dangerous if it exceeds the neutral wire's capacity (Thiele, Balancing Electrical Loads, 2019). For these reasons, it is important to keep the net current as close to zero as possible; utilities may even require that a building balance its loads if the net current becomes too high.

Additionally, an unbalanced load may lead to reduced capacity available to add equipment for electrification. For example, if phase A has 100 kW on it, while phases B and C each have 70 kW on them, you would be required to use 100 kW in your calculations. If the loads can be balanced, with 10 kW moved to B and C for a total of 80 kW on each phase, that would allow an additional 20 kW of equipment to be added.

Line voltage

Line voltage is the effective voltage delivered to a load or electrical appliance from alternating current. Since AC alternates direction, the line voltage for a single AC conductor is the difference between the maximum amplitude or peak of the conductor's sine wave and zero. For appliances and loads that are connected to multiple AC conductors, the line voltage is the difference between the maximum amplitude of a single AC conductor to the other AC conductors (Electrical PE Review, 2016).

208/240 V rated appliances

Appliances with line voltage ratings of 208/240 V are designed to be connected to either single-phase or three-phase power. While they are able to operate in both, they may not be able to achieve their maximum function in a building with three-phase power due to the lower voltage reaching them, or they may operate at a higher amperage, which would reduce available capacity.

Cost-Efficient Electrification Process Overview

Making generalizations about the electrification of multifamily buildings is challenging because of the diversity of building and system types. While energy auditors and contractors will face unique conditions during the electrification of specific buildings, this report aims to provide a general framework for deciding if electrification is feasible, and if so, how to achieve it in a cost-efficient manner.

To carry out a cost-efficient electrification retrofit, the project team must take into account a building's existing electrical infrastructure and identify solutions that make the best use of that infrastructure. In this report, this process of analysis and strategic design is broken out into four main steps, which are shown in the decision tree in Figure 3 and discussed in detail in the following pages. The four steps are:

1. Evaluate existing conditions
2. Analyze electrical load
3. Select efficiency measures and appliances
4. Evaluate upgrade costs and consider emerging alternatives

Although many of the strategies presented here can inform the design of new all-electric buildings, the focus is to outline considerations and methods for cost-efficient electrification retrofits of multifamily buildings.

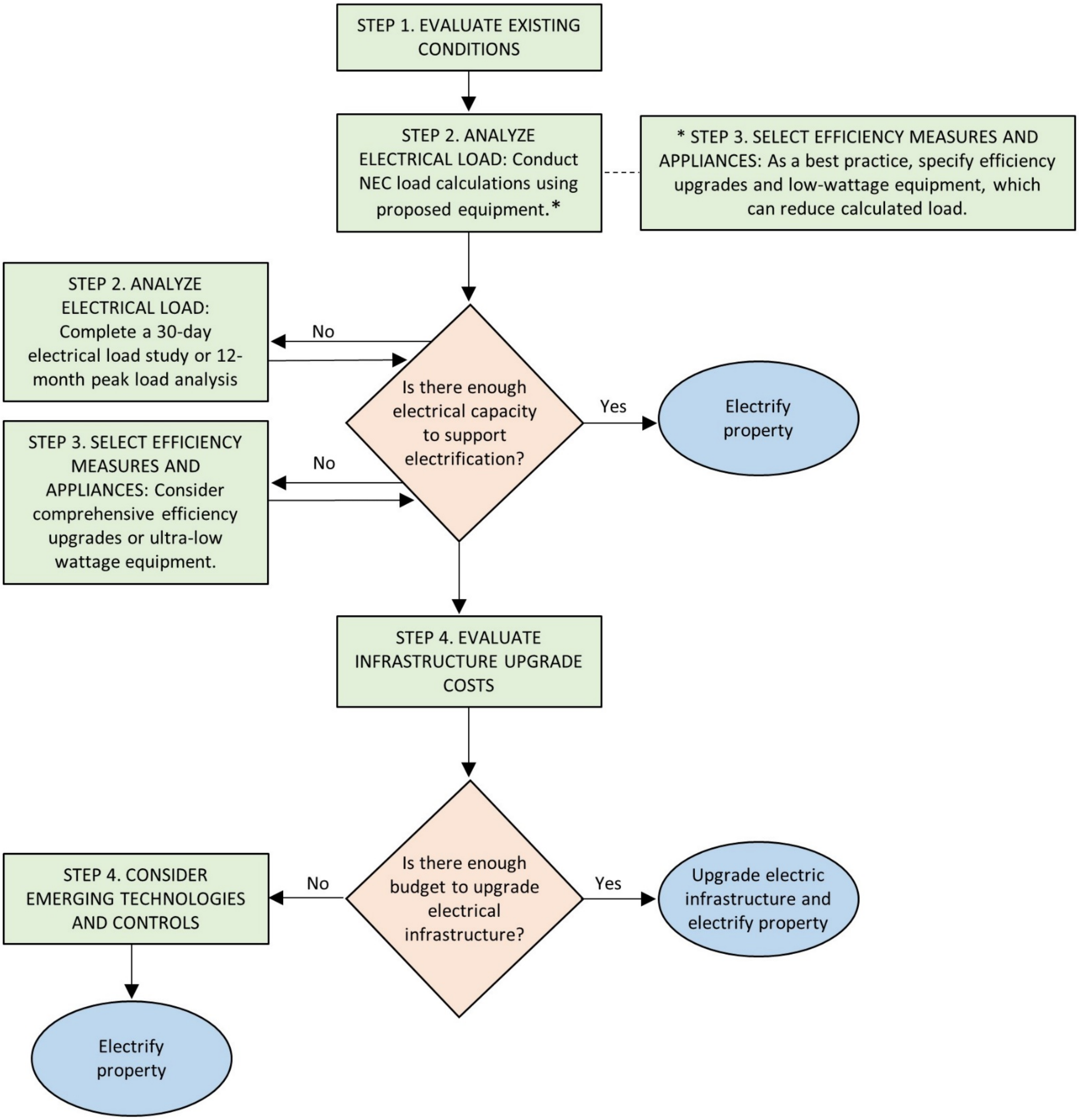

Figure 6. Electrification Decision Tree for Multifamily Buildings

STEP 1: Evaluate Existing Conditions

Information gathered during this stage will be used in Step 2 to calculate whether the building's existing electrical infrastructure can support the planned electric systems. Step 1 includes evaluating:

- Electrical infrastructure condition and capacity and electrical load
- Existing gas systems and/or appliances to be replaced during electrification
- General building construction, which will inform the ease of electrification and opportunities for efficiency measures and new electrical infrastructure

The results of this evaluation will be used to predict whether an electrification project can work within the existing electrical infrastructure capacity, if electrical infrastructure upgrades will be feasible and affordable, or if alternative solutions need to be investigated.

Typical existing infrastructure

Table 2 describes general amp ratings based on building age and where in the building the electrical infrastructure is located. This data is based on a sampling of properties that participated in multifamily efficiency programs throughout California. This generalization can be useful for understanding electrification constraints on a broad level but should never be used in place of a site-specific evaluation of an individual property's conditions.

Due to the variability of common area uses and sizes, Table 2 shows only electrical infrastructure serving the residential units of multifamily buildings.

Table 2. Electrical Infrastructure Conditions by Building Age

	Building Vintage and Capacity per Dwelling Unit			
Infrastructure type	**Pre-1950**	**1950–1974**	**1974–2010**	**2010–present**
Whole-building infrastructure (overall service size)	10–20 A per unit	15–45 A per unit	25–70 A per unit	25–70 A per unit
Dwelling unit infrastructure	30–40 A	30–60 A	60–90 A	100–150A
Appliances and end uses (branch/circuit) infrastructure	Two 15 A circuits	Two to six 15 A circuits and one to two double-pole* 20–30 A circuits	Five to seven 15–20 A circuits and one to three double-pole* 20–50 A circuits	Six to eight 15–20 A circuits and three to four double-pole* 20–50 A circuits

*Double-pole circuits are typically 208–240V circuits serving larger loads; see Branch Circuits and Breakers.

As the number of electrical appliances in buildings has increased over the years, so has the typical electrical capacity available. The National Electrical Code (NEC) has also been refined, adding more stringent requirements and accommodating modern technology.

Planned modernization

In some buildings built in the early 20th century, the existing electrical infrastructure may already be insufficient to support even basic modern appliances. The owners of these buildings will likely need to plan for electrical infrastructure upgrades simply to make their electrical systems usable. In these cases, proposed infrastructure capacity should be upsized to allow for full electrification, unless doing so would trigger a need to upgrade utility-owned infrastructure or would be infeasible due to physical space constraints. Otherwise, the cost difference between the minimum electrical infrastructure upgrades for modernizing systems (while maintaining gas equipment) and the upsized infrastructure to support full electrification is typically minimal if there is enough physical space for the new service equipment. Buildings where the owners are planning electrical modernization are ideal candidates for full electrification.

Data collection

The first step in any electrification project is an evaluation of the actual conditions onsite. An initial evaluation of a building's electrical infrastructure can be performed by an energy auditor. The auditor may wish to use or adapt the data collection template provided here. When using this template, keep in mind:

- Onsite conditions and all writing on electrical infrastructure should be photographed in addition to being recorded in a data collection sheet.
- Where capacity checks must be performed by an electrician or by the utility, the energy auditor may begin by making educated assumptions regarding the electrical infrastructure capacity. If the electrification project is deemed potentially feasible by the energy auditor, then a comprehensive evaluation of the property's electrical capacity should be completed with a licensed electrician or engineer and the utility.
- See Step 2: Analyze Electrical Load for details on how the information collected onsite is used. Be sure that the checks conducted are sufficient for both the NEC and local jurisdiction load calculation worksheets, which may require additional information. Always check with the local jurisdiction about additional requirements or specific load calculation worksheets.
- During the evaluation, the auditor may observe that the circuit breaker ratings in an apartment or common area subpanel sum up to a larger amperage than the main disconnect rating for that apartment. This is intentional, since not all circuits will be used at once, and is reflected by the demand factors used during the load calculation.

Some of the infrastructure or data referenced in this template may be unfamiliar. If so, refer to the Identifying Electrical Infrastructure section for more information.

In the template, some items are flagged with an asterisk due to their tendency to increase project complexity. Appendix E: Flagged Electrical Infrastructure has more information about these issues.

Figure 7. Data Collection Template for Electrification Feasibility Survey

Data Collection	**Data Applications**
APARTMENT AND COMMON AREA LOADS	
□ Wall construction: __ inches of insulation ☐No cavity/difficult access (brick, lath+plaster, etc.)* □ Ceiling construction: __ inches of insulation ☐Has accessible cavity* □ Floor: __ inches of insulation ☐Slab □ Window glazing: ☐Single pane ☐Dual pane □ Window frame: ☐Metal ☐Wood ☐Vinyl or fiberglass	
□ Primary lighting type: ☐Incandescent ☐Fluorescent ☐LED (1) □ Do residents report tripping electrical breakers? ☐Yes ☐No □ If so, when? ____ (2) □ Range: ☐Gas ☐Electric □ Water heating BTU output: ______________ ☐Gas ☐Electric ☐In unit ☐Central □ Heating type: ☐Gas ☐Electric ☐Hydronic ☐Steam ☐Ducted □ Heating output: __________________ □ Cooling output: __________________ (3)	(1) Extra capacity may be gained by upgrading to LEDs if lights are not already efficient. (2) If certain breakers frequently trip, their circuits may be overloaded or have safety issues. (3) Knowing which appliances use gas, and how much they use, can help inform calculations of how much electricity use will be added once these appliances are converted to electric. Keep in mind, existing gas appliances tend to be oversized, so the best practice is to resize when installing new electrical appliances.
□ Square footage of apartment units by type:__________________ (4) □ Nameplate VA and amperage rating for all electric appliances that are fixed in place or always use a dedicated circuit. For each appliance: Appliance Type: ________________VA:_______A:_______ (5) □ Nameplate VA rating for all electric heating and cooling equipment, including both compressor and supplemental heat ratings for heat pumps. For each appliance: Appliance Type: ________________VA:_______A:_______ (6) □ If heating equipment is a heat pump, can its auxiliary heat be run at the same time as the compressor? ☐Yes ☐No ☐No auxiliary heat (7) □ Number of separately controlled space heating units: _________ (8)	(4) Square footage will later be multiplied by a deemed volt-amp (VA) value to determine lighting and appliance load (NEC 220.12, 2017). (5) VA for all recorded appliances will be totaled and multiplied by demand factors as given by the NEC (see Step 2: Analyze Electrical Load). Note that some NEC sections allow watts to be used interchangeably with VA. (6) 100% of the heating or cooling rating (whichever is higher) will be added to total load (NEC 220.51, 2017). (7) When using optional calculations, if auxiliary and compressor heating cannot run at the same time, the compressor load may be omitted (NEC 220.82(C), 2017). (8) When using optional calculations, a smaller demand factor may be applied to instances of four or more separate space heaters (for example, electric baseboards in each room) (NEC 220.82(C), 2017).

<table>
<tr><th>Data Collection</th><th>Data Applications</th></tr>
<tr><td colspan="2">IN-UNIT AND COMMON AREA SUBPANELS</td></tr>
<tr><td>◻ Panel brand: _________* Breaker brand: ____________*
☐Fuse box*
◻ Panel location: ☐Closet* ☐Over stairs* ☐__________
◻ Front clearance: ☐36” or greater ☐Under 36”*
◻ Side-to-side clearance of panel space:
☐30” or greater ☐Under 30”*
◻ Height clearance of panel space:
☐78” or greater ☐Under 78”*
◻ Panel catalog number: ____________________
◻ Number of slots in panel: ________________
◻ Main breaker/disconnect in panel? ☐Yes ☐No
◻ If branch circuit wiring is visible, record using Feeder Cables and Branch Circuit Wiring section below.</td><td></td></tr>
<tr><td>◻ Panel amperage rating: ______________
◻ Panel/breaker voltage:
☐120/240 Vac ☐120/208 Vac ☐Not listed (9)
◻ Amp rating of main breaker (if in subpanel): __________
◻ For each breaker in the subpanel:
Amps: ____ Load served: _____________ ☐Single pole
☐Dual pole (10)</td><td>(9) Voltage is multiplied by amperage in order to compare available capacity with the VA of downstream loads.
(10) The capacities of panels, breakers, feeder cable, secondary disconnects, and service disconnects will be compared with load calculations to determine whether the infrastructure can support downstream loads. It is also best to note the number of unused breaker spaces in a subpanel.</td></tr>
<tr><td colspan="2">FEEDER CABLES AND BRANCH CIRCUIT WIRING</td></tr>
<tr><td>◻ Wiring location: ☐Attic ☐Crawlspace ☐Slab* ☐Plenum
☐Other: _______________ ☐Unknown
◻ Conduit type: ________ Diameter: ____
☐No Conduit ☐Unknown
◻ Alternative Paths for New Wiring (if needed):
☐Attic ☐Crawlspace
☐Other: _______________ ☐Unknown
Wiring Type: ☐NM ☐MC ☐Copper ☐Knob + Tube*
☐Aluminum* ☐Cloth/Rubber Insulated*
☐Other: _______________ ☐Unknown</td><td></td></tr>
<tr><td>◻ AWG Rating/Wire Labeling (if visible without opening panels, conduit, or covers):
______________________________ (10)</td><td></td></tr>
</table>

Data Collection	**Data Applications**
METER BANK	
◻ Secondary disconnects near meters? ☐Yes ☐No ◻ Meter ID numbers	
◻ If secondary disconnects are near meters, sample secondary disconnects for all typical apartment types and for a common area. For each typical disconnect: Amp rating of secondary disconnect: _________ (10)	
SERVICE DISCONNECT	
◻ Main breaker amperage rating: ___________(10) ◻ Main bus amperage rating: ___________(10) ◻ Voltage: ___________(10) ◻ Phase: ___________(10) ◻ Enclosure rating: ________ (10) ◻ Service size: _______ (10)	
TRANSFORMER	
◻ Type: ☐Pad mounted ☐Pole mount ☐Subsurface ◻ Utility transformer is: ☐Shared with adjacent properties ☐Dedicated ◻ Transformer number, if present ________ ◻ Number of transformers, for larger properties: _________	

*Items with asterisks are flagged due to their tendency to increase project complexity. Appendix E: Flagged Electrical Infrastructure provides more details.

Identifying electrical infrastructure

During the site evaluation, it is important to understand what each piece of infrastructure is and how to collect relevant information about it. As each piece of infrastructure is observed, its condition, type and labeling should be recorded using photos and notes. It is also helpful to document the size and condition of the areas in which infrastructure is located; wide-shot photographs are recommended for this.

If you are familiar with electrical infrastructure components, you may wish to skip ahead to Step 2: Analyze Electrical Load.

While individual electrical systems may vary among buildings, the overall layout of electrical infrastructure is usually similar to what is shown in Figure 8. As a general rule, conductors or cables (branch circuits and feeder cables in Figure 8) transfer electricity from one place to another and are protected by an upstream breaker or disconnect that will shut off power if loads exceed the breaker rating.

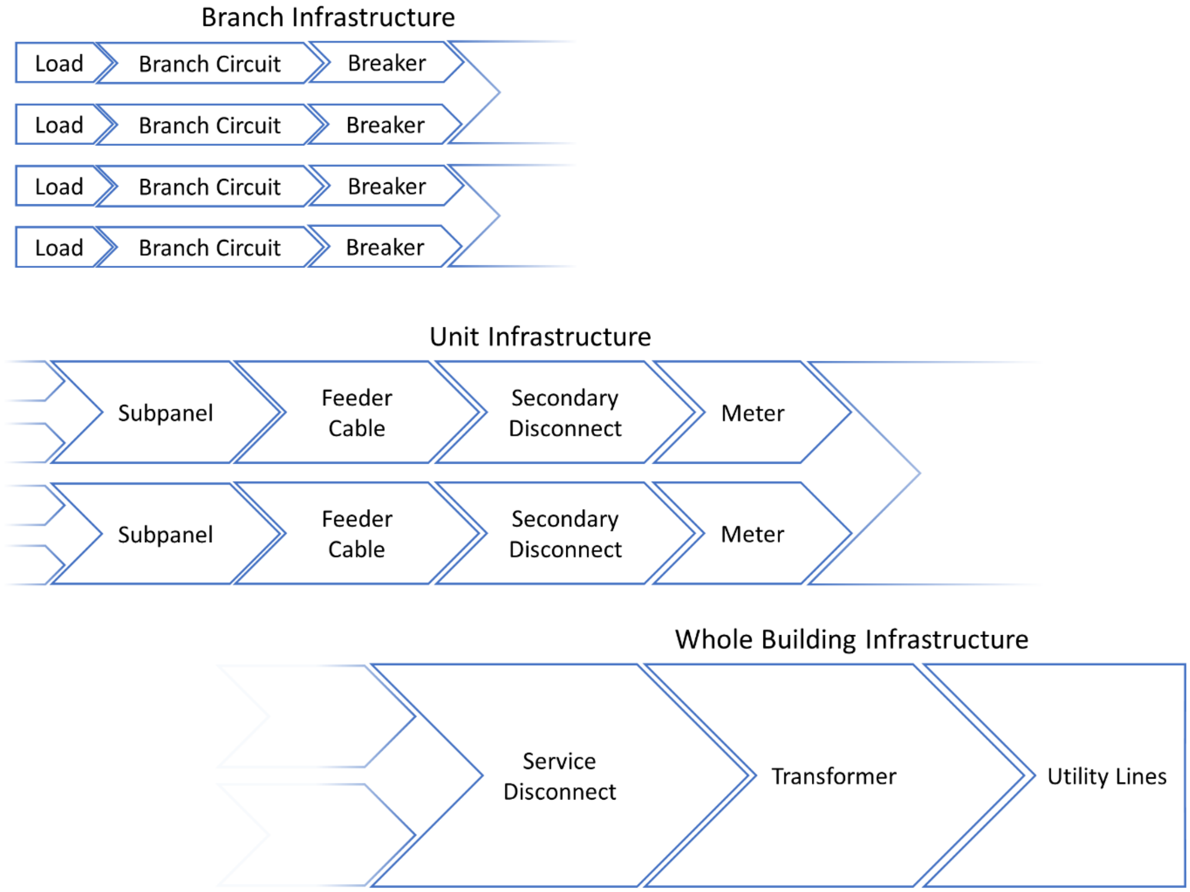

Figure 8. Electrical Infrastructure Sequence

In an electrification project, every piece of the electrical infrastructure must have the capacity to support the existing electrical loads and new electrical loads added during electrification.

The following pages summarize the function and capacity of each system along this infrastructure path.

Loads

Loads are the end uses of electricity in a building. A building's electrical loads may include lighting, small appliances that may be plugged into various receptacles (outlets), and larger appliances with dedicated receptacles.

Documenting Loads

Recording the power ratings of existing electrical appliances will inform calculations of how much capacity is needed to support existing load.

Load calculations generally require the nameplate rated volt amps (VA) of larger appliances (see Figure 9). The presence of non-electric appliances that may later be electrified will inform the amount of additional load added during electrification.

Tips

- If no volt amp rating can be found, watts (W) can typically be recorded instead. (UCF Facilities Planning and Construction, 2002) (NEC, 2017).
- If neither VA nor W can be located, the values can be calculated using the voltage and amps of the equipment.

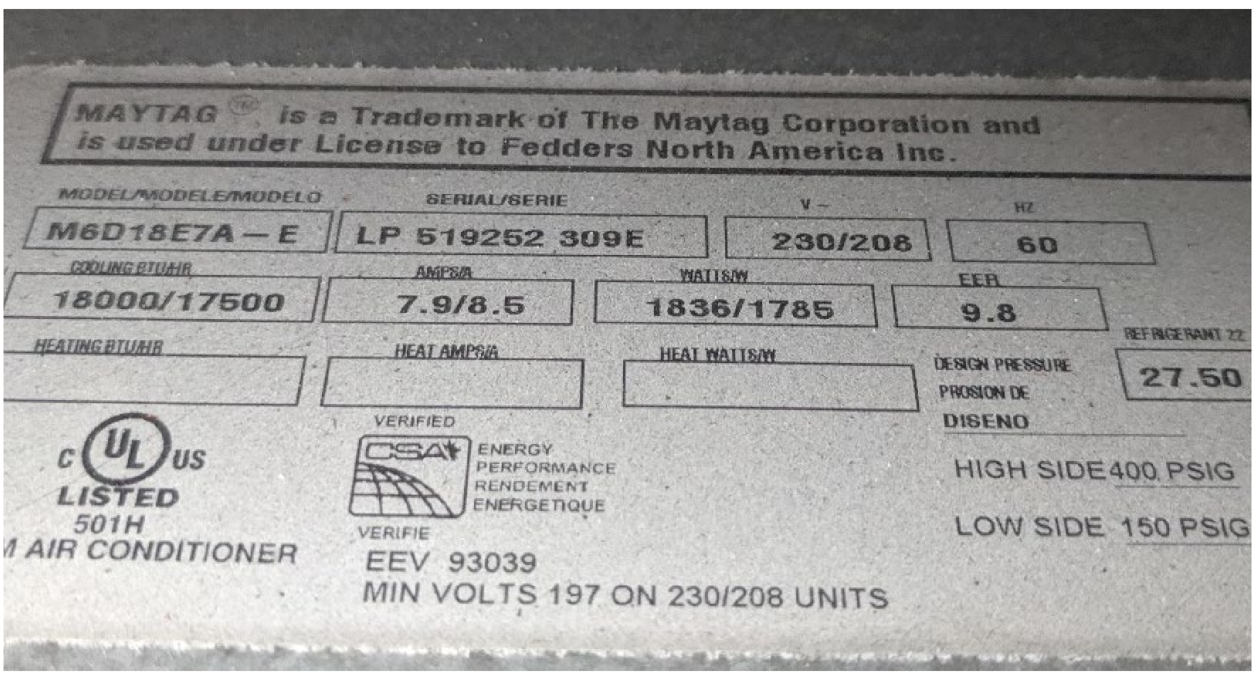

Figure 9. Air Conditioner Name Plate Information

This air conditioning unit uses 1836 W at 230 V, or 1785 W at 208 V.
Refer to the Meter section to determine voltage.

Branch Circuits and Breakers

Branch circuits are the circuits from which loads draw power. They are the most “downstream” circuits in a building; in other words, they are closest to the electricity’s end use.

Breakers are located at the “upstream” ends of branch circuits. Each breaker protects its corresponding circuit by cutting off the flow of electricity if the current exceeds the breaker’s amperage rating, which is generally sized based on electrical capacity of the wire attached to it. Breakers can also be manually turned off by electricians, maintenance personnel, or tenants to deactivate downstream circuits.

Documenting Branch Circuits and Breakers

Breaker and circuit electrical capacity will be compared with their proposed and existing loads to determine whether they can adequately support their end uses.

Breakers can often be found by opening the door of a unit or common area’s subpanel (see next section), though they may be located centrally near the meters in some buildings. To identify each circuit’s load, look for labeling near the breaker (Figure 10).

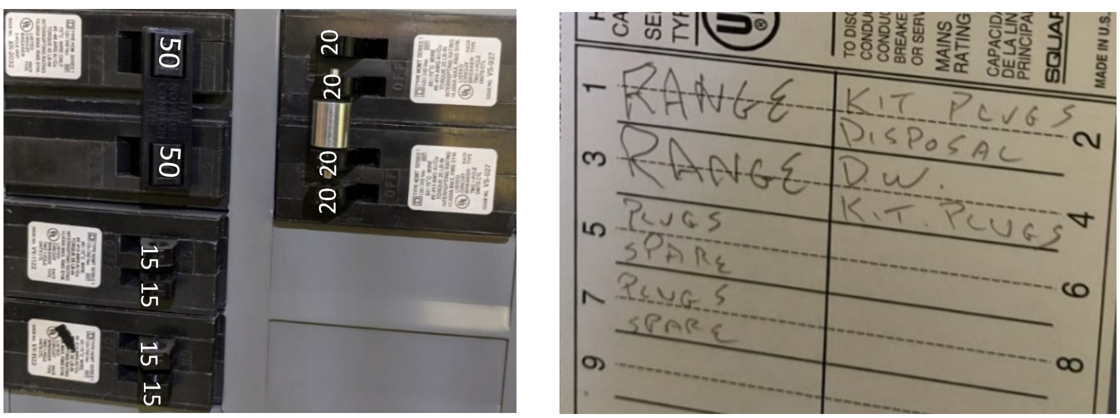

Figure 10. Subpanel Labeling

In Figure 10, the labels on the subpanel’s door indicate that:

- The 50 A breaker serves the range.
- The 20 A breakers serve the small appliance receptacles in the kitchen, as well as the dishwasher and garbage disposal.
- The 15 A tandem breakers each serve receptacles throughout the apartment with one switch, leaving the other switch spare. The fact that the spare switches are on may indicate that these circuits are in use, though they may have initially been installed out of convenience if only tandem breakers were available (standalone “spare” circuits are more likely intentional).

If the panel door does not have labels, make an educated guess using these guidelines:

15–20 A circuits commonly support lights or receptacles (outlets) for small appliances. Multiple lighting or receptacle loads may share a circuit, or the circuit may power a single appliance like a refrigerator.

30–50 A circuits lead to larger loads and 208/240 V appliances such as stoves, dryers, or heating, ventilation and air conditioning (HVAC) appliances. Generally, these appliances require dedicated circuits shared with no other loads and will have amperage ratings slightly lower than their breaker amperages. (Thiele, Dedicated Electrical Circuits, 2019)

>50 A circuits are typically connected to large mechanical equipment in multifamily common areas and central systems.

These circuits may be served by two main types of breakers:

Single-pole breakers typically have a single switch and provide 120 V and 15–20 A to branch circuits whose loads require less power.

Dual-pole breakers occupy two slots in the electrical panel and provide 208/240 V to branch circuits (see more information in the Subpanels section). Dual-pole breakers are typically rated for 20 A or higher and serve large appliances that require more power. (Thiele, What are Double Pole Circuit Breakers?, 2020)

Tandem breakers are specialty breakers that provide two switches and take the space of a single breaker. Tandem breakers can often be used to replace existing standard size breakers to expand the number of available breakers when adding new loads. There are some limitations to this approach; not all panels are rated for tandem breakers, and they are typically only allowed in specific sections of the panel.

Figure 11 shows one 50 A dual-pole breaker, four 15 A single-pole breakers, and four 20 A single-pole breakers, two of which are tied together (see Tips). All but the 50 A breaker are tandem breakers.

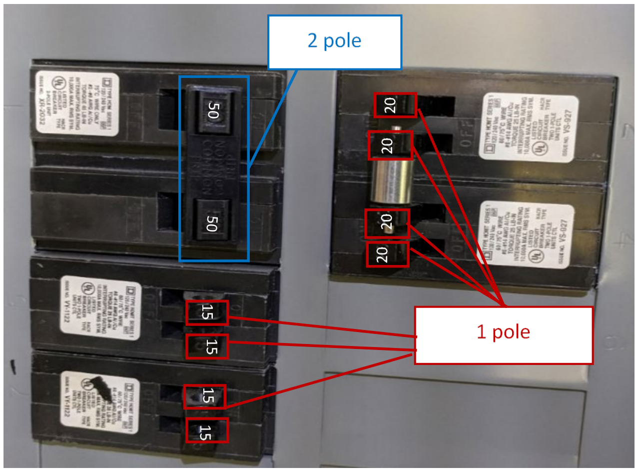

Figure 11. Panel Showing Single- and Dual-Pole Breakers

Since tandem breakers are not available in AFCI/GFCI versions (see below), they can only replace circuits that do not require this added protection. In Figure 11 the upper left dual-pole breaker is standard size and the remaining breakers are tandem.

AFCI/GFCI

Arc fault circuit interrupters are specialty breakers installed in an electrical panel that detect dangerous arcing conditions in the downstream circuit and shut down power if needed, in order to prevent fires (NEMA, 2020). AFCI protection is now required for circuits in most residential rooms (NEC 210.12).

Ground fault circuit interrupters are specialty receptacles/electrical outlets designed to shut off the flow of electricity in the receptacle if the input and output current are not balanced (Holt, 2001). This can prevent electric shock as well as overheating of appliances that may cause fires. GFCI receptacles are required in specific areas where water may be present (NEC 210.8).

Tips

- [x] Dishwasher and garbage disposal circuits may consist of two single-pole breakers that are tied together. This is not a 208/240 V circuit; in this case one breaker serves the top plug and the other the bottom in the same receptacle. This ensures that power to the entire receptacle is shut off when either breaker opens.

Subpanels

In many buildings, all circuits serving a unit or common area trace back to that area's **subpanel**, which hosts the area's breakers.

Documenting Subpanels

Subpanel electrical capacity will be compared with the loads on downstream circuits to determine whether the existing subpanel is sufficient. Look for subpanels in or near individual apartment units and in common areas. In some buildings, outdated fuse boxes may be present instead of subpanels with breakers. Figure 12 shows a fuse box above a breaker panel.

Figure 12. Comparison of Fuse Box and Breaker Panel

Tips

- Some buildings built before the mid-1970s may not have subpanels; instead, apartment breakers may be located under each individual utility meter.
- Note that the amperage rating of a panel does not necessarily determine existing capacity, and upstream infrastructure may have a lower amperage rating than the panel.

Inside the door of most subpanels will typically be a nameplate that lists important information about the panel including brand, model number, amp and voltage ratings, and compatible breakers (Figure 13).

If the nameplate isn't present but a catalog number is listed for the cover, looking up the catalog number may reveal the amperage rating.

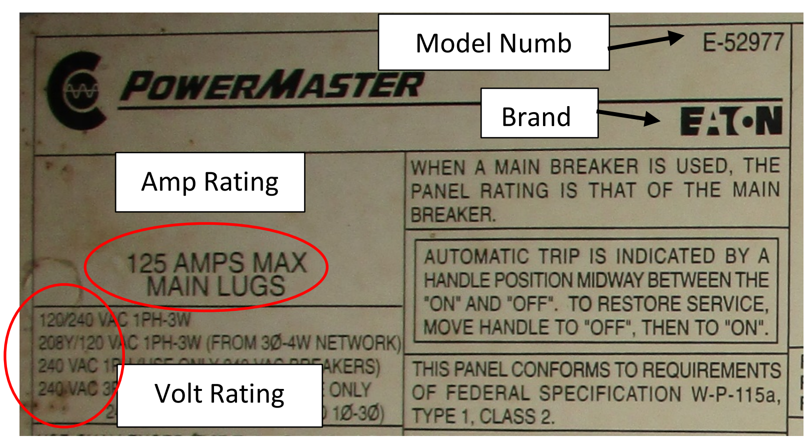

Figure 13. Example of a Subpanel Nameplate

Behind a subpanel's door is a deadfront, which is the faceplate that covers all of the internal components (breaker switches are exposed through openings in the deadfront).

This deadfront should not be opened except by a licensed electrician. Behind the deadfront, two powered busbars run vertically down the center of the panel, with neutral and ground busbars running along the sides of the panel. Figure 14 shows how breakers connect to the panel's busbars. The busbar legs corresponding to each breaker slot alternate, such that every other breaker in a vertical column draws from the same busbar. Dual-pole breakers, as depicted in the lower right of Figure 14, draw from both busbars to obtain 208 V or 240 V.

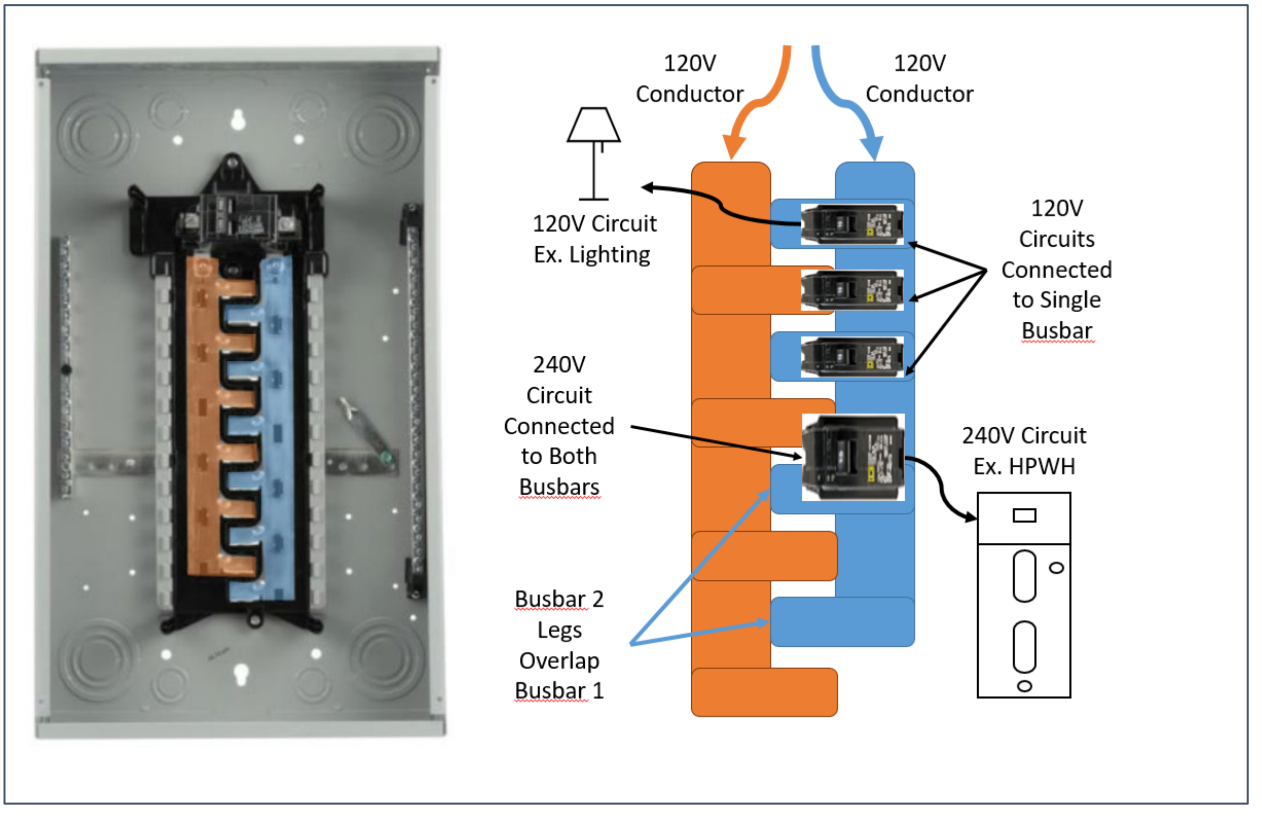

Figure 14. Photograph and Diagram of Inside of a Subpanel

(Square D, 2020) (Square D, 2020) (Saltzman) (Murray, 2020)

Feeder Cables

A **feeder cable** is a grouping of feeder conductors (wires), which brings power to a subpanel from the service connection. Distribution to panels can be managed using a centrally located meter bank or main distribution panel. The latter configuration is usually seen in centrally metered properties and properties with large common area loads.

Documenting Feeder Cables

Feeder cable capacity will determine a building's ability to support downstream loads, and the location of feeder cables can influence ease of replacement should upgrades be necessary. Feeder cables can be run through attics (Figure 15), crawlspaces, slabs or in between floors and walls.

Capacity should only be checked by a licensed electrician, unless the wire type and AWG rating are clearly visible on the cable, as shown in Figure 16 without removing panel deadfronts or conduit. The writing on these cables may also reveal wire material such as AL (aluminum) or CU (copper). Otherwise, the electrician will open the subpanel to observe the wire gauge size of the cable or will observe the other end of the cable by opening the secondary disconnect at the meter.

Tips

- ☑ It may be possible to establish where feeder cables run by observing where the cables leave the meter bank or main panel, checking the attic, or looking at electrical plans for the building.

Figure 15. Feeder Cables in an Attic

Figure 16. AWG Rating Visible on Exposed Feeder Cables

Knob and tube wiring can be a fire risk when in contact with flammable material and cannot support modern electrical appliances. Figure 17 shows knobs (circled) supporting the wires in knob and tube wiring.

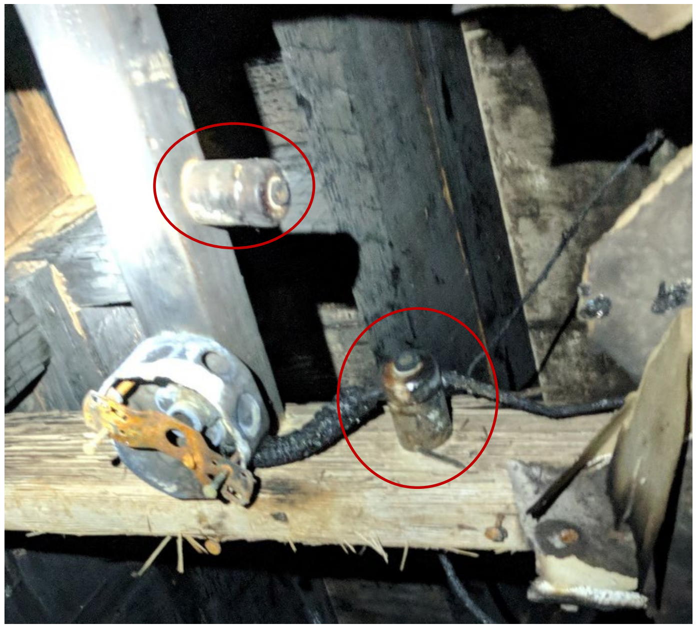

Figure 17. Knob and Tube Wiring

Wire Types

Conductors are single wires that transfer electricity. American wire gauge (AWG) is the standard indicator of a conductor's diameter used by the NEC. Larger wire sizes are measured in thousands of circular mils (MCM or kcmil). As conductors decrease in diameter, their resistance to the flow of electrical energy increases. Table 3 Table 3. Types of Conductors describes the types of conductors and the locations where they are typically installed. Note some of the conductor types in the table may also be referred to as cables (Thiele, Understanding Electrical Wire Lettering, 2019).

Table 3. Types of Conductors

Type	Location
NM (nonmetallic)	Indoors
MC (metal clad)	Indoors
SE (service entrance)	Between service point and main panel
UF (underground feeder)	Outdoor/wet locations
THHN (high heat resistant thermoplastic)	In conduit, high heat areas
THWN (wet location thermoplastic)	In conduit, outdoor/wet locations

Cables are groupings of wires or conductors, often with protective outer coatings or additional support members added. They are designed to organize and protect conductors traveling to the same location. Cables are often color coded to indicate the capacity of the conductors inside.

Conduit is a protective channel through which conductors and cables are run. Depending on the strength and water tightness needed for each location, conduit of varying types can be selected (Electrical Conduit Types, 2020).

Table 4. Types of Conduit

Metal (from least to most protection)	**Non-metal**
Electrical metallic tubing (EMT)	Polyvinyl chloride (PVC)
Intermediate metal conduit (IMC)	High density polyethylene (HDPE)
Rigid metal conduit	Electrical non-metallic tubing (ENT or Smurf tube)
Flexible metal conduit (FMC)	
Liquid tight flexible metal conduit (LMFC)	

Secondary Disconnect

A **secondary disconnect** is a breaker that protects the subpanel and all loads downstream of it. In multifamily buildings it is typically located at the central meter bank but can be located in each apartment directly on the subpanel.

Documenting Secondary Disconnects

Secondary disconnect capacity can determine the downstream loads that can be supported and has likely been sized based on the feeder cable size and capacity.

Figure 18. 30 A Dual-Pole Secondary Disconnect Next to a Meter

Tips

- Secondary disconnects may be covered or locked. Flip up the covers to observe the disconnects.
- If a secondary disconnect is directly on the subpanel, it will typically be a large dual pole breaker (Figure 17) at the top of the panel, separated from the rest of the breakers. Or it may be mounted with the branch circuit breakers and labeled as “Main.”

Meter

All electricity that passes through a secondary disconnect is also monitored by a utility-owned **meter**, located directly upstream of the disconnect.

Documenting Meters

Meters are typically the responsibility of the utility; however, recording the meter number can be useful for tracking energy use of the metered area later on.

Sometimes a meter will display either 208 V or 240 V, which reveals the voltage available to double-pole circuits downstream. Single-pole circuits will almost always use 120 V. In Figure 19, the voltage and meter number are circled in red.

Tips

Buildings with central meters may still have a secondary disconnect for each apartment.

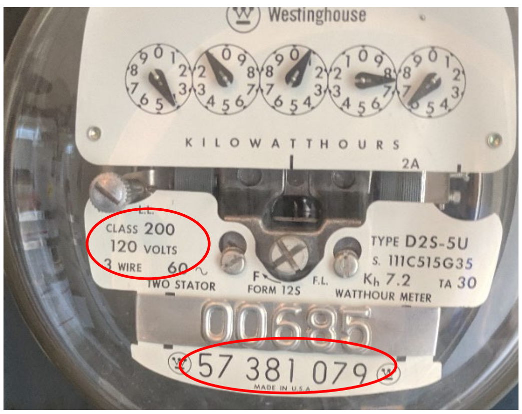

Figure 19. Meter Showing Voltage and Meter Number

Even though downstream circuits in apartments are all single phase, their voltage depends on the phase of the power initially supplied to the building. If three-phase, four-wire service is supplied to a building, it will be split into single-phase 120 V/208 V service downstream, while buildings with single-phase, three-wire service can be expected to supply single-phase 120 V/240 V to downstream loads. For more information about single-phase and three-phase power, see Electricity Fundamentals in Part 2.

If voltage is not displayed on the meter, check the switchboard or service disconnect (see below).

In a typical multifamily building, the main power supply to the building is split through multiple meters:

- **Tenant meters** measure the power consumption of each apartment.
- **Common area meters** measure the power consumption of common area systems. These include all common area lights, outlets and appliances.
- **Central meters** measure the power consumption of an entire building. These are installed in buildings that do not have tenant meters.

Service Disconnect/ Switchboard

The **service disconnect** is the largest disconnect in a building and can cut off the flow of electricity to the entire property. Like secondary disconnects and breakers, the service disconnect shuts off when current gets too high and can also be manually switched off. It protects utility service lines from drawing too much power and ensures the safety of firefighters responding to emergencies or electricians working on the building's wiring. In larger buildings, service disconnects may be located on a **switchboard**, which distributes power to various infrastructure throughout the building.

Documenting Service Disconnects/Switchboards

The capacity of a service disconnect informs the total load allowable in a building. This can give insight into the capacity of the utility-owned infrastructure supplying the entire building's loads.

Service disconnects are centrally located near where power first enters a building (Holt, Electrical Services — Part 2, 2009). The amperage rating of a service disconnect is usually written near the disconnect switch or can be found on the manufacturer's label on the breaker. In some cases, it may be obscured by the deadfront around the disconnect; in these cases, only a licensed electrician should check it.

The type of power supplied to the building (single phase or three phase) can also typically be found on the switchboard nameplate or near the disconnect.

Tips

- A building electrical service that serves under six units might have up to six service disconnects, which replace secondary disconnects. (Holt, Article 230: Services Part 1, 2007)
- The switchboard bus may be larger than the main breaker, such as installations where there is already PV installed.

In Figure 20, the photo on the left shows the service disconnect of a large multifamily building, with amperage rating circled. Amperage rating on the disconnect may differ from that shown on the switchboard. The switchboard (photo on the right) reveals that this building is supplied with three-phase power.

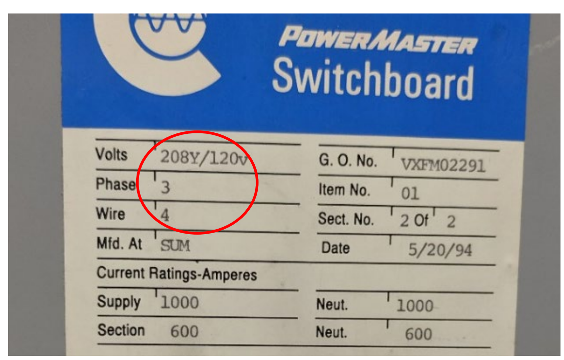

Figure 20. Service Disconnect and Switchboard of a Large Multifamily Building

Service Entrance Cable

A utility-owned cable containing three to four conductor wires connects each property to the utility's distribution system. A **service entrance cable** owned by the building connects to the utility service cable where it contacts the building.

Documenting Service Cables

The capacity of service cables (Figure 21) must be checked by the utility.

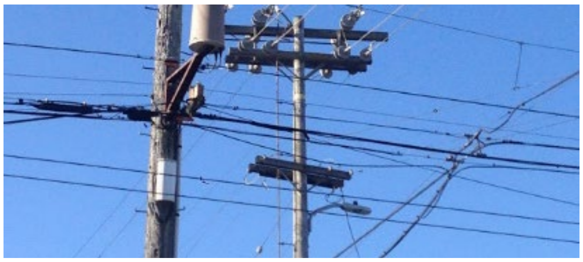

Figure 21. Overhead Service Cables

Tips

The cable from the distribution system to the property is called a service drop if connecting to overhead service, or service lateral if connecting to an underground distribution system (Holt, Article 230: Services Part 1, 2007).

Figure 22 shows a service drop that is spliced to the service entrance cables as it enters the building. This connection is known as the service connection point and delineates the building's property from that of the utility. The splices and service drop are utility property, and the service entrance cable belongs to the building. (Stallcup, 2001)

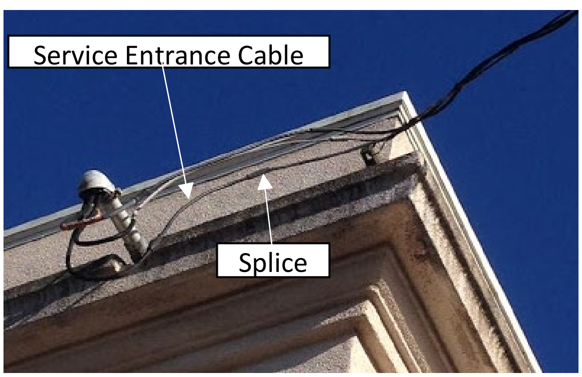

Figure 22. Service Drop Spliced to Service Entrance Cables

Transformer

Before reaching a building, high voltages used in the transmission and distribution of power throughout the utility service area are “stepped down” by a utility-owned **transformer** to be usable by residential systems.

Documenting Transformers

The kVA rating of a transformer must be checked by the utility. However, noting the transformer type can help identify whether the building uses single-phase or three-phase power.

Pole-mounted transformers serve smaller buildings, typically under 12 apartments. They step down high voltages and typically provide single- or three-phase service up to 400 A. Figure 23 shows an example of a pole-mounted transformer for overhead service.

Tips

- The cost of upgrading a transformer may vary depending on whether it is shared with other properties.

Figure 23. Pole-Mounted Transformer

Step-down (pad mounted) transformers serve larger properties. They step down high voltages and typically provide three-phase service above 400 A. Figure 24 shows a pad-mounted transformer in the yard of a large multifamily building with underground service.

Figure 24. Pad-Mounted Transformer

STEP 2: Analyze Electrical Load

After completing the infrastructure walkthrough and data collection, the next steps are to:

1. Analyze the data collected during the walkthrough and determine the existing electrical infrastructure capacity at different locations in the building. For example, what is the in-unit electrical capacity, common-area electrical capacity, and building-wide electrical capacity?

2. Using the electrical appliance nameplate information gathered in the units and common areas, use the NEC Deemed Electrical Load Calculation (below) to determine how much electrical capacity is currently being used to support the existing electrical loads.

3. Select properly sized electrical appliances to replace existing gas appliances. Using the NEC Deemed Electrical Load Calculation, add these new electrical loads to the existing electrical loads and determine if there is sufficient electrical capacity to support 100% electrification.

4. If there is a capacity deficiency, identify alternate appliance, equipment and efficiency combinations to determine if capacity can be met. See Step 3: Efficiency Measures and Electrification Appliance Selection for electrification appliance considerations and Appendix A for specific electrification appliance recommendations.

5. If there is still a capacity deficiency, determine if using the NEC Electrical Load Monitoring Study, which utilizes monitoring or historical utility data, has the potential to allow for electrification using the existing infrastructure.

6. If, after all efforts above have been exhausted, there is still a capacity deficiency and electrical infrastructure upgrades are infeasible due to complications of the existing infrastructure, explore Emerging Alternatives to Upgrading Electrical Infrastructure.

NEC deemed electrical load calculation

The NEC Deemed Electrical Load Calculation is a code-mandated methodology for determining electrical capacity. It utilizes demand factors, nameplate wattages (or volt amps), and deemed values to determine the electrical infrastructure capacity of subpanels, disconnects, feeder wires, service wires and transformers required to support electrical loads.

An NEC load calculation will need to be completed at the subpanel level where electrification is occurring and for all electrical infrastructure upstream. For dwelling unit electrification, the NEC provides two methods, standard and optional. The optional method can be chosen to size whole-building feeder wire and service size if all dwelling units have electric cooking per NEC Table 220.84. Appendix B shows an NEC deemed load calculation example utilizing the optional method.

In either case, the NEC deemed load calculation typically provides a conservative estimate of required electrical capacity and does not allow actual existing conditions to be used. For example:

- For some electrical appliances, if the watts or volt amps rating is less than the deemed watt or volt amp values outlined in the NEC, then the deemed value must be used (NEC 220.54, 2017).

- Deemed lighting wattages or volt amps are required to be used for in-unit and common area lighting, even if the lighting has undergone efficiency measures (NEC 220.12, 2017).
- The NEC requires two small kitchen appliance plug load circuits, as well as a laundry circuit, to be added into the calculation for sizing dwelling unit electrical infrastructure, regardless of whether the dwelling unit is too small to have multiple small appliance circuits (NEC 210.11(C), 2017).

This conservative approach is in place to ensure a safe (and future proofed) electrical system. In doing so, however, it may fail to reflect significant load reductions achieved through increased efficiency or fewer end uses.

NEC Deemed Load Calculation Example

This example illustrates using the NEC Deemed Load Calculation for a single dwelling unit undergoing electrification. (For NEC Deemed Load Calculation examples to size a service line disconnect for a whole multifamily building and to size a subpanel, secondary disconnect and feeder wire for a house load laundry room, refer to Appendix B.)

This example includes the following assumptions:

In a single dwelling unit in a multifamily building, the owner is planning to replace the existing central 3-ton forced air furnace with a mini-split high efficiency 3-ton heat pump. Other electrical appliances and circuits include a single kitchen appliance circuit, a single laundry appliance circuit, two small appliance circuits required by NEC (NEC 210.11(C), 2017) and an electric cooking range and stovetop. The example assumes the existing electrical infrastructure shown in Figure 25.

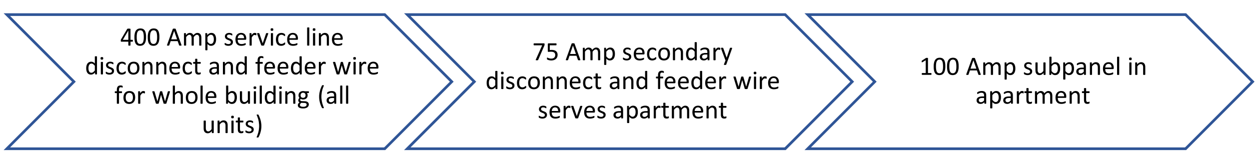

Figure 25. Electrical Infrastructure Assumptions for Example Calculation

Example A. NEC Deemed Load Calculation

In this example the calculation results in the secondary disconnect not having sufficient capacity to support electrification of the in-unit space heating. Note the service line disconnect calculation is not included in this example.

Residential Dwelling Unit Load Calculation - NEC Section 220					
Dwelling Unit Area	800 ft^2				
Step 1 - General Loads Per NEC 220.16					
Deemed Lighting Load Value: 3.0 Volt Amps (VA) per square foot			=	2,400	VA
	Quantity	NEC Deemed VA Value			
Kitchen Appliance Circuit	1	1,500	=	1,500	VA
Laundry Appliance Circuit	1	1,500	=	1,500	VA
Small Appliance Circuits	2	1,500	=	3,000	VA
Demand factors:					
First 3 KVA have a demand factor of 100%				3,000	VA
3.1 KVA - 120KVA have a demand factor of 35%				1,890	VA
> 120 KVA has a demand factor of 25%				-	VA
		Total	**=**	**4,890**	**VA**
Step 2 - HVAC Loads Per NEC 220.83b					
Load added during	Quantity	Appliance Name Plate VA			
3-Ton Mini-split Heat Pump for Heating and Cooling	1	+ 4,000	=	4,000	VA
Demand factors:					
Electric heating or cooling (whichever is larger) has a demand factor of 100%				4,000	VA
Remaining appliance loads first 8 KVA have a demand factor of 100%				-	VA
Remainder of all other appliance loads > 8 KVA have a demand factor of 40%				-	VA
		Total	**=**	**4,000**	**VA**
Step 3 - Electric Cooking Loads Per NEC 220.55					
	Quantity	Appliance Name Plate VA			
Electric Cooking Range and Stovetop	1	14,000	=	14,000	VA
Demand factors:					
Electric Cooking Appliance has a demand factor of 80%				11,200	VA
		Total	**=**	**11,200**	**VA**
Step 4 - Add the Results from Step 1 through 3 to Calculate Required Volt Amps and Amps					
		Total Existing Volt Amps for the Dwelling Unit		16,090	VA
		Total Proposed Volt Amps for the Dwelling Unit with the 3-Ton Mini-split Heat Pump		20,090	VA
Secondary Disconnect and Feeder Wire Cannot Support the Added Electrical		**Single Phase Amp Capacity Requirements**		**83.71**	**A**
		In-unit Subpanel Amp Rating		**100.00**	**A**
		Secondary Disconnect and Feeder Wire Amp Rating		**75.00**	**A**

Notes for Example A

Step 1: General Loads are required by the NEC. These are intended to serve small plug-in appliances throughout the dwelling unit.

Demand factors: For each load type, demand factors are applied to help simulate the coincidence that all loads will be on at the same time. Different load types have different demand factors deemed by the NEC.

Step 2: HVAC Loads have different demand factors and must be calculated separately from general loads. For all NEC load calculations, the calculation must represent the final conditions. In this example, the 3-ton heat pump replaces the existing furnace during electrification.

Step 3: Electric Cooking also has different demand factors and must be calculated separately from HVAC Loads and General Loads.

Step 4: Sum all loads after demand factors have been applied to determine the total volt amps for the dwelling unit. Divide this number by the volt ratings of the panel/secondary disconnect to determine required amps. In this example, it is being divided by single phase 240V.

NEC electrical load monitoring study

The NEC Deemed Load Calculation often overestimates the peak electrical load used to size electrical infrastructure. As an alternative the NEC allows for a load study that uses historical *actual* peak energy demand when calculating whether additional new loads can be safely added to the existing infrastructure. Under this method the actual consumption profile determines the baseline, and NEC deemed load calculations are used to calculate the additional load.

There are two approved load study methods to determine the electrical load baseline (Miller C. R., 2011):

- A 30-day electrical load monitoring study utilizing a power meter or recording ammeter. Figure 26 shows load monitoring equipment attached to each leg of a three-phase service wire.
- A peak-demand meter or smart meter with 15-minute interval data has been in place at the feeder or service for at least a year and has at least a year of recorded data. If the property's utility provides maximum demand data, a year's worth utility bills may be utilized to satisfy this requirement.

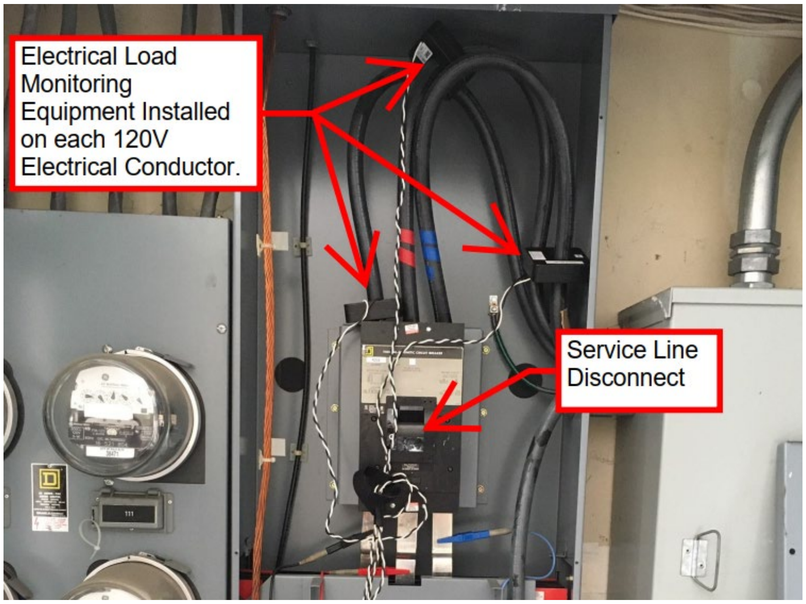

Figure 26. Load Monitoring Equipment

If considering using the approved NEC load monitoring method, take into account the following:

- If a 30-day electrical load study is being implemented, the load monitoring period must reflect the highest electrical usage season. For example, if a property has electric cooling and gas heating, then the load monitoring period should occur in the summer when the electric cooling is in use (Miller C. R., 2011) (NEC 220.87, 2017).
- A power meter or recording ammeter should be installed on the highest loaded phase (Miller C. R., 2011) (NEC 220.87, 2017). Since the highest loaded phase is usually unknown, all phases should be metered.
- Power meters and recording ammeter must be installed by a licensed electrician.

- The install location of the power meter or recording ammeter is determined based on where electrification is occurring at the property and where a limitation in infrastructure has been identified.
- Monitoring all dwelling units that are undergoing in-unit electrification is the preferred method. However, some electrical engineers and building officials may approve monitoring a sample of units as long as all variations of dwelling unit types and unit areas at the property are monitored.

After the load monitoring study has been completed, it must be analyzed to determine peak load and electrical infrastructure size. The following guidelines should be used during this analysis:

- A 125% safety factor applied to the maximum demand measured should be included when sizing the feeder or service ampacity rating (Miller C. , 2011).
- Engineering principals must be applied to ensure future proofing. Examples of these principals include:
  - Monitoring the electrical load during peak electrical use season. For example, if there is existing air conditioning and gas heating at the property, monitoring during the hottest season is recommended to capture the peak electrical draw.
  - Consideration of unoccupied units and applying factors to simulate all units are occupied when monitoring a whole building's consumption.

Example B. NEC Peak Load Monitoring Study Calculation

Example B uses the same dwelling unit and electrification scenario as Example A, but uses the NEC approved 12-month load study to determine the existing load and an NEC deemed load calculation for the proposed added electrical load. The added electrical load has been reduced as a result of envelope efficiency measures.

> **Tips**
>
> ☑ When completing a 30-day load study, the peak load draw captured during the load monitoring period would be used, not utility data.

Determining the 12-Month Peak Electrical Draw for a Single Dwelling Unit

The initial step in performing the NEC Peak Load Monitoring Study is to determine the peak electrical draw over the 12-month period. As mentioned above, dwelling units connected to a peak-demand meter or smart meter for at least 12 months are eligible for the 12-month peak electrical load study to determine baseline. For this example, it is assumed that the dwelling unit is connected to a utility-owned smart meter. The maximum demand recorded by the smart meter for each billing period is shown in the utility bill (see Figure 27).

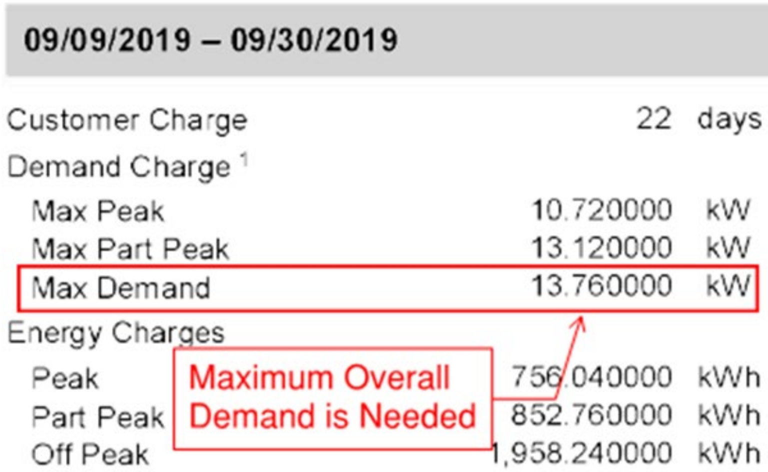

Figure 27. Example Smart Meter Utility Bill with Peak Demand

This should be done for each utility bill, so that the maximum demand over the 12-month period can be determined. In Table 5, the maximum demand occurs during the 12/7/19 – 1/6/20 billing period.

Table 5. Twelve Months of Peak Electrical Draw

Billing Period	Maximum Demand kW
9/9/2019 - 9/30/2019	11.73
10/1/2019 - 11/5/2019	12.13
11/6/2019 - 12/6/2019	12.19
12/7/2019 - 1/6/2020	12.55
1/7/2020 - 2/5/2020	11.68
2/6/2020 - 3/8/2020	11.15
3/9/2020 - 4/6/2020	11.08
4/7/2020 - 5/6/2020	11.02
5/7/2020 - 6/7/2020	10.98
6/8/2020 - 7/6/2020	10.75
7/7/2020 - 8/5/2020	10.56
8/6/2020 - 9/3/2020	10.20

The maximum annual demand is converted from 12.55 kW to 12,550 VA and is included in the NEC load calculation example below as the existing baseline electrical load.

Residential Dwelling Unit Load Calculation with Envelope Efficiency Measures and a 12-Month Load Analysis

Dwelling Unit Area 800 ft^2

Step 1 - General Loads Per NEC 220.16

Replaced by 12-Month Load Analysis - No Calculations Necessary

Step 2 - Adding New HVAC Loads Per NEC 220.83b

Added load during electrification reduced through efficiency measures

	Quantity	Appliance Name Plate VA			
2-Ton Mini Split for Space Heating and Cooling	1	2,000	=	2,000	VA

Demand factors:

Electric heating or cooling (whichever is larger) have a demand factor of 100%	2,000	VA
Remaining appliance loads first 8 KVA have a demand factor of 100%	-	VA
Remainder of all other appliance loads > 8 KVA have a demand factor of 40%	-	VA
Total =	**2,000**	**VA**

Step 3 - Electric Cooking Loads Per NEC 220.55

Replaced by 12 Month Load Analysis - No Calculations Necessary

Alternative to Step 1 and 3 - 12 Month Load Analysis

Existing load reduced by replacing deemed load calculation with 12-month load analysis

From 12-month load study above

Peak Volt Amp Load over the Past 12 Months	12,550	VA
Existing Furnace Name Plate Volt Amp	-1,050	VA
Peak Volt Amp Load over the Past 12 Months Subtracting Existing Furnace Volt Amps and 125% Safety Factor Applied	14,375	

Step 4 - Add the Results from Step 1 through 3 to Calculate Required Volt Amps and Amps

Total Existing Volt Amps for the Dwelling Unit	14,375	VA
Total Proposed Volt Amps for the Dwelling Unit	16,375	VA
Single Phase Amp Capacity Requirements	**68.23**	**A**
In-unit Subpanel Amp Rating	**100.00**	**A**
Secondary Disconnect and Feeder Wire Amp Rating	**75.00**	**A**

Notes for Example B

Step 1: General Load calculations are replaced by an approved NEC 12-Month Load Analysis. The maximum annual demand is determined in Table 5 above.

Step 2: HVAC Loads. The NEC approved 12-Month Load Analysis does not capture proposed loads. The additional load from the mini-split heat pump must be calculated.

Efficiency Measures: In this example, envelope efficiency measures have allowed a 2-ton heat pump to be installed rather than a 3-ton heat pump, reducing required electrical capacity.

Step 3: Electric Cooking Load calculations are replaced by an approved NEC 12-Month Load Analysis.

Removing Existing Furnace Volt Amps: It is acceptable to remove the furnace load from the peak volt amp draw because it is being replaced by the heat pump and the peak load draw is shown to occur when the furnace was on. Preferably the volt amp draw from the furnace would be measured, but nameplate volt amps is acceptable.

Step 4: Sum the results of the load analysis and the proposed load added during electrification.

STEP 3: Select Efficiency Measures and Appliances

As shown in Example B above, managing new electrical load can be pivotal when adding new electrical appliances within the constraints of the existing electrical infrastructure. This section describes efficiency measures and equipment selection that can decrease added and existing electrical load to support electrification of different appliances.

This section discusses efficiency and equipment considerations for HVAC systems, domestic hot water systems, and lighting, cooking and other appliances, and miscellaneous equipment.

HVAC efficiency and equipment

Electrical load reduction measures for heating and cooling systems can be accomplished using three strategies:

- **Building envelope efficiency.** Reduces heating and cooling loads through decreased heat transfer through the building envelope.
- **Air distribution efficiency.** Reduces heating and cooling loads through increased efficiency of conditioned air distribution.
- **Equipment selection.** Higher efficiency, low amperage appliances reduce the added electrical load on panels. In some cases, selection of 120V equipment over 208/240V equipment can free up electrical infrastructure.

Implementing these three strategies can make cost-efficient electrification more accessible.

Building Envelope Efficiency

Increasing insulation levels, installing dual pane windows, and reducing envelope air leakage lowers heating and cooling loads. This allows for lower capacity heating and cooling equipment that has smaller electrical demand to properly condition the building and improve resident comfort.

The installation of window films or window shading devices, cool roofs or attic radiant barriers have the benefit of reducing cooling loads but may increase wintertime heating loads. In cooling-dominated climates this increase in winter heating load is usually more than offset by a reduction in cooling loads, and the net impact can still result in smaller HVAC equipment and electric loads.

> **Tips**
>
> It is not recommended to cover knob and tube wiring with insulation, and some jurisdictions prohibit it. If there is active knob and tube wiring throughout the property, consult an electrician if insulation is in the scope of work (Armanda, 2004).

Air Distribution Efficiency

The majority of existing ductwork in heating and cooling systems have been shown to be poorly sealed and insulated. Due to these inefficiencies, significant amount of air that is heated or cooled, is lost in addition to negatively impacting indoor air quality (Minimizing Energy Losses in Ducts, n.d.). Pairing envelope upgrades as indicated above with properly sealing and insulating existing ductwork can allow for smaller HVAC systems, which require less electrical capacity. For smaller dwelling units, ductless HVAC systems can be used to the same effect.

Heating and Cooling Equipment Selection

High efficiency HVAC equipment can deliver the same amount of BTUs as a less efficient system while using less input power. For example, when moving from an existing 100% efficient electric resistance heater to a moderately efficient heat pump the BTU output can remain the same while reducing input power by a factor of three. This major leap in efficiency somewhat tapers off when comparing heat pump to heat pump, but efficiency gains of 10 to 20% across models can still be achieved.

> **Tips**
>
> ☑ A list of high efficiency, 120V, and low amperage heating and cooling equipment can be found in Appendix A.

In addition to reducing power draw through efficient equipment selection, it may also be useful to select equipment that uses fewer circuits to power the equipment, either to work with the number of available breaker spaces in a panel or to free up breaker spaces for another new electrified load like a water heater. For example:

- Consider using 120V instead of 208/240V heat pump equipment. Single zone through-the-wall heat pumps and ductless mini-splits are currently available in 120V.
- For ducted heat pump systems, consider selecting equipment where the indoor air handler receives its power from the outdoor compressor instead of requiring a separate dedicated electrical circuit, which is typical.

Figure 28 and Figure 29 provide examples of how optimized heat pump equipment selection can reduce electrical capacity requirements and free up breaker space in electrical panels. Figure 30 shows how further electrical capacity reduction can be achieved when HVAC selection is combined with envelope improvements.

Existing through-the-wall AC w/ Electric Resistance Heater

Proposed through-the-wall 120v and Heat Pump

	Existing	Proposed	Capacity & Infrastructure Savings
Cooling Capacity (Btu/hr)	9,300	8,500	-
Heating Capacity (Btu/hr)	11,000	11,500	-
Watts	3,500	1,630	+ 1,870 Watts
Breaker	240V 20 Amp	120V 15 Amp (dedicated circuit may not be required)	+ 1 Single Pole Breaker Slot

Figure 28. Through-the-Wall AC with Electric Heat Replaced with Through-the-Wall Heat Pump

Images and data: (Amana, 2020) (AC Wholesalers) (Gallery 2.0) (Ehpoca, 2020)

Existing 3 Ton Split AC + 3 Ton Natural Gas Fueled Furnace

Proposed 3 Ton Mini-split Inverter Driven Heat Pump with Indoor Air Handler

	Existing	Proposed	Capacity & Infrastructure Savings
Cooling Efficiency (SEER)	13.0	16.0	-
Heating Efficiency	80%	320%	-
Cooling Capacity (Btu/hr)	36,000	35,800	-
Heating Capacity (Btu/hr)	32,000	36,000	-
Watts (VA)	5,610	3,720	+1,890
Breaker Size	• 240V 30 Amp Breaker (Outdoor Unit) • 120V 15 Amp Breaker (Indoor Unit)	240V 20 Amp	+120V 25 Amp

Figure 29. 1.5 to 3 Ton Split AC Replaced with Heat Pump

Images and data: (Goodman, 2020) (Goodman, 2020) (Mitsubishi Electric, 2020)

Existing 3 Ton Split AC + 3 Ton Natural Gas Fueled Furnace

Proposed 2 Ton Mini-split Inverter Driven Heat Pump with Indoor Air Handler

Smaller proposed heat pumps can be installed when envelope efficiency measures are in the scope of work

	Existing	**Proposed**	**Capacity & Infrastructure Savings with Smaller Proposed Heat Pump**
Cooling Efficiency (SEER)	13.0	18.0	-
Heating Efficiency	80%	285%	-
Cooling Capacity (Btu/hr)	36,000	28,000	-
Heating Capacity (Btu/hr)	32,000	24,000	-
Watts (VA)	5,610	1,910	+ 3,700
Breaker Size	• 240V 30 Amp Breaker (Outdoor Unit) • 120V 15 Amp Breaker (Indoor Unit)	240V 20 Amp	+ 120V 25 Amp

Figure 30. 1.5 to 3 Ton Split AC Replaced with Heat Pump with Efficiency Measures Applied

Images and data: (Goodman, 2020) (Goodman, 2020) (Mitsubishi Electric, 2020)

Heating and Cooling Equipment Design Considerations

Envelope Penetrations

All packaged terminal heat pumps require sleeves or small ducts to access outside air. Ask the local building department if there are any restrictions on the visibility or location of the envelope penetration.

Location of Outdoor Compressor

General Installations: Outdoor compressors cannot encroach on setback requirements and may need to be screened in some high visibility locations so they are easily not visible from the street. Ask the local planning department if there are property setback line restrictions and visibility restrictions.

Roof top installations: Ensure the roof has the structural capacity to handle the additional weight load of the compressor and that the equipment can be easily maintained after installation. The onsite maintenance team may not be allowed to access the roof for maintenance.

Refrigerant Line Sets

Title 24 requires that line set insulation be physically covered to protect it from UV damage. Additionally, building departments may require that refrigerant line covers be painted to match the building. Attempt to minimize exterior-mounted refrigerant line sets by running them through an attic or crawlspace. Consider using existing envelope penetrations such as abandoned flues or duct work to run refrigerant line sets.

Cold Ambient Temperature Performance

For air-to-air heat pumps, when ambient outdoor temperatures fall below a certain threshold (depending on the refrigerant used), the heating capacity and efficiency performance are reduced. Refer to the specification sheet and performance curve of the proposed heat pump to determine if it can meet the required heating load at design conditions.

Defrost Cycle

In heating mode, the heat pump outdoor coil may develop frost depending on the outdoor humidity and temperature levels. Heat pumps manage this by reversing back into cooling mode and sending warm refrigerant over the coil to melt the ice build-up. To reduce cold-air complaints during defrost, traditional heat pumps were typically designed with electric resistance backup heat that engages during defrost, although this backup heat was and is not required for the system to operate. Inverter-based heat pumps and ductless mini-splits typically manage defrost by slowing the indoor unit fan speed and adjusting fan direction where possible; this helps reduce cold-air complaints. When selecting equipment, research how defrost is managed and confirm electric resistance backup heat can be eliminated.

Domestic hot water systems

Water heating is often the largest energy load in California buildings (California Energy Commission, 2010). Unlike heating and cooling systems, existing domestic hot water systems are typically fueled by gas in California (California Energy Commission, 2010), which presents no opportunity to increase available electrical capacity through efficiency measures. (One exception is in-unit existing electric resistance tank-type water heaters present in some multifamily properties.)

However, there are still strategies to reduce the electrical impact for new electric water heating systems. This section outlines these opportunities and previews design considerations when converting from gas water heaters to electric heat pump water heaters (HPWH).

Hot Water Demand Reduction

The primary variable affecting the sizing of a water heating system and the amount of energy it uses is the amount of hot water consumed. While consumption profiles can be significantly influenced by each household's needs and habits, consumption of hot water can be reduced by installing low-flow kitchen and bathroom faucet aerators, low-flow showerheads and water-efficient appliances, and by fixing leaks in tub diverters and other locations. Poor quality low-flow fixtures may result in tenant complaints and removal of the fixtures. For low-flow fixtures to be successful, consider installing Water Sense Certified low-flow aerators and showerheads. Also consider pairing installation of low-flow fixtures with distribution improvements to ensure users do not experience a reduction in hot water wait times or temperature.

Hot Water Distribution Efficiency

In both central and in-unit water heating systems, a significant percentage of the water heating load is from distribution losses due to uninsulated hot water pipes or underground hot water piping. In central water heating systems, distribution losses can occur from distribution riser imbalance, domestic hot water crossover, or recirculation pumps that continuously circulate hot water throughout the building (Ansanelli, 2015) (Ayala & Zobrist, 2016).

Water heating distribution load can be reduced in a number of ways for both central and in-unit water heating systems:

- Install pipe insulation
- Install thermostatic balancing valves on each riser or return loop to balance distribution
- Repair crossover issues to reduce cold water intrusion into hot water distribution lines and vice versa
- Install recirculation pump controls and variable speed recirculation pumps

Residential Heat Pump Water Heater Equipment

Electrical Requirements

Residential heat pump water heaters historically require 208/240 volts, range from a storage size of 40 to 80 gallons and either require a 15 amp or a 30 amp breaker. The 15 amp models that are currently available either do not require electric resistance backup or use smaller elements than 30 amp models; selecting this equipment may help reduce peak electrical demand when running an NEC Deemed Load Calculation. Appendix A has a partial list of currently available equipment; 120V models are expected to be available in the United States in the near future.

For small DHW load applications like leasing offices, studios and maintenance shops, small storage or on-demand electric resistance water heaters can be installed. However, electric resistance water heaters do not comply with Title 24 prescriptive code (CEC, 2018).

Equipment Selection

Residential heat pump water heaters should typically be selected to have larger storage volumes when possible because in heat pump mode the BTU output is lower. The larger volume of water provides the heat pump more time to recover the tank before needing to use less efficient electric resistance backup (where present). As one would expect, the 15 amp models have a longer recovery time than 30 amp models.

The use of a thermostatic mixing valve installed at the water heater can provide a similar function. The water heater can be set to a higher temperature (holding more heat in the tank) because the delivered water is mixed down to a safe temperature after leaving the water heater and prior to reaching end-use fixtures. This essentially provides a greater volume of hot water than actual tank size would indicate.

The Northwest Energy Efficiency Alliance (NEEA) has developed a list of residential heat pump water heaters that have been tested for performance and are favored by California Title 24 performance code (CEC, 2018). A link to their comprehensive list is in Appendix A.

Equipment Location

Ensure the location will fit the proposed heat pump water heater including all required manufacturer's clearances. Where the selected water heater cannot meet listed clearances, look for an alternative product that meets all requirements or receive a variance from the manufacturer in writing prior to install.

Tank-type heat pump water heaters move heat from the surrounding environment to the tank. The byproduct of this process is cool, dehumidified air that leaves the compressor during operation. For this reason, it is recommended to:

- Ensure sufficient makeup air is available for the heat pump, typically provided by locating the water heater in a large room (700 ft^3 is typical), providing a fully louvered door to the water heater location, or ducting intake (or exhaust) air to the water heater.
- Avoid installing a tank-type HPWH in a location that will result in tenant discomfort when exhausting cold air or duct the exhaust when necessary.

In heat pump water heaters, the heat pump is a compressor located at the top of the tank. While the sound produced from the equipment is comparable to other household appliances, take care when replacing an existing water heater that is in a location where added sound could disturb residents (for example in a closet adjacent to a bedroom). In this situation it may be preferable to duct the water heater and weatherstrip the door to the bedroom to reduce sound transfer.

Cold Ambient Temperature Performance

Cold ambient outdoor temperatures can affect the performance of air-to-water residential heat pumps and tank-type models. When the heat pump's compressor can't satisfy the load due cold ambient temperatures, some models employ auxiliary electric resistance elements to add supplemental heat. HPWH models that use CO2 as a refrigerant are able to operate at very low ambient temperatures and likely would not need supplemental resistance heat in any California climate zones. Refer to the specification sheet and performance curve of the proposed heat pump to determine the effect of cold ambient temperatures.

Commercial HPWH Equipment

Electrical Load Considerations

Like residential heat pump water heaters, commercial heat pump water heaters require larger storage tanks than commercial gas water heaters to achieve high efficiency and to meet the building's hot water demands. As a general rule for central or commercial heat pump water heaters, the larger the storage (to an extent), the less heat pump capacity is required to meet the domestic hot water load.

Figure 31 plots power requirements for central heat pump water heaters, given varying amounts of domestic hot water storage and number of occupants served. Designing central heat pump water heaters with larger storage volumes can decrease the amount of electrical capacity required to adequately deliver hot water. An example of this is clear at the 100 occupants served data point in Figure 31.

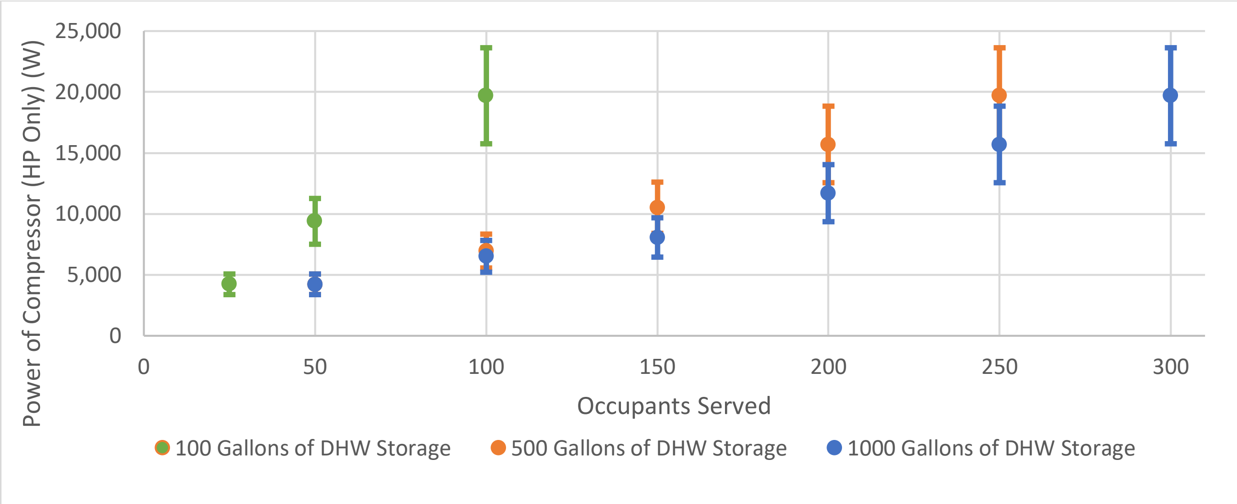

Figure 31. Central HPWH Power Consumption Data

(Nyle, 2020)

Electrical Requirements

Some commercial HPWHs are available in single phase, while larger equipment may only be available in three phase. When an existing site is limited to single-phase power but has available electrical capacity, multiple single-phase HPWHs can be used in a combined plant to meet water heating needs. Switching from single phase to three phase can be done but requires a number of electrical infrastructure replacements and the cost to do so can significantly increase the overall project cost (see Infrastructure Upgrade Costs).

Equipment Location

When considering the location of a central heat pump water heater, there are a variety of factors and tradeoffs to be considered, including:

- Available space for increased storage
- Location for heat pumps and new storage
- Noise produced

As a general rule, heat pump compressors should be located in areas where the noise produced does not impact occupants or neighbors or violate local codes. When equipment will not meet decibel level requirements, consult with the manufacturer to determine if modifications can be made to their system to reduce noise levels.

If locating the compressors indoors such as in a boiler room or parking garage, be sure that adequate makeup air will be provided to ensure consistent heat pump performance year round. Provide ducted exhaust and makeup air when needed.

Cold Ambient Temperature Performance

Cold ambient outdoor temperatures can affect the performance of air-to-water commercial heat pumps and result in less capacity and less efficiency and may require auxiliary electric resistance elements to supply supplemental heat. Refer to the specification sheet and performance curve of the proposed heat pump to determine the effect of cold ambient temperatures. Work with commercial heat pump manufacturers to properly select equipment for each application being considered.

Lighting, cooking and other appliances, and miscellaneous equipment

This section presents additional multifamily efficiency measures that can be evaluated to increase available electrical capacity for electrification. While these upgrades will reduce electrical demand and consumption, they may or may not have an effect on the deemed NEC electrical load calculation, as described below.

Lighting

Lighting technology has drastically changed over the last 40 years. Through the use of LED technology, individual light bulbs and light fixtures have become more and more efficient. Table 6 illustrates how LEDs have reduced the electrical load of an average bulb.

Table 6. Typical Residential Light Bulb Wattages

(Efficiency Maine, 2020)

	Type of Bulb			
Lumens	**Incandescent**	**Halogen**	**CFL**	**LED**
450	40 W	29 W	9 W	7 W
800	60 W	43 W	14 W	10 W
1,100	75 W	53 W	19 W	17 W
1,600	100 W	72 W	23 W	20 W

LED bulbs significantly reduce the energy consumed while each light is on, and lighting controls reduce the amount of time that each light draws power. These strategies together make up a comprehensive lighting retrofit. Lighting retrofits in common areas are especially effective in reducing a building's electrical load because common areas like parking garages, corridors and exterior areas require large quantities of lights that operate for most of the night and sometimes throughout the day.

In-unit lighting retrofits, while still recommended to reduce energy use, have a smaller impact on the electrical infrastructure, since lighting is less frequently used and there are fewer fixtures in dwelling units.

The NEC load calculator uses deemed wattage values for lighting (NEC 220.12, 2017), so LED lighting retrofits will only affect the load calculations if load monitoring strategies are used. Although there are different deemed wattage values for lighting in different areas of a multifamily building, the effect of oversizing electrical infrastructure is the same. Because of this, lighting retrofits can be performed prior to load monitoring so that the reduction in load can be acknowledged.

Cooking and Other Appliances

Increasing the efficiency of existing electrical appliances may make more electrical capacity available for electrification of other appliances and will help reduce electricity use in general and lower electricity bills.

The largest electrical appliances that are common in multifamily units include:

- Refrigerators
- Dishwashers
- Electric cooktops
- Electric dryers
- Washing machines

Electrical infrastructure is sized based on peak electrical demand and in many cases efficient in-unit appliances have similar peak electrical draws to non-efficient in-unit appliances. In these cases, the improved efficiency is a result of reduced time of use rather than reduced peak electrical draws. Refer to specification sheets and look for recommended circuit sizes or rated wattages to see if the replacement appliance will result in increased available electrical capacity.

For specific appliances, the NEC has deemed volt amp values; if the existing or proposed appliance has a rated wattage or volt amp value, then the larger deemed value must be used (NEC 220.54, 2017).

Cooking

There are two main appliance options when electrifying cooking appliances:

- Electric resistance oven and cooktop
- Electric resistance oven and induction cooktop

Induction cooktops can save energy by reducing runtimes and transferring heat more effectively (Livchak, Hedrick, & Young, 2019); however, based on an NEC deemed load calculation, the electrical requirements of an electric resistance cooktop and an induction cooktop are comparable if they have the same number of burners (NEC 220.55, 2017). Induction cooktops may not be compatible with certain cookware; if installing induction cooktops, ensure that tenants have appropriate cookware.

There are a few ways to reduce electrical load from electric cooking appliances that are reflected in the NEC deemed load calculation method. Decoupling the electric oven and cooktop can open opportunities to apply smaller demand factors to reduce calculated peak electrical load. Electric cooking appliances that have kilowatt ratings less than or equal to 1.75 kW (NEC 220.55, 2017) can apply general NEC dwelling unit appliance demand factors that are more generous than electric cooking demand factors (NEC 220.53, 2017). Plug-in two-burner (or less) induction cooktops may be allowed to be included as an NEC small-appliance circuit load and would be removed from the NEC deemed load calculation (NEC 220.52 (A), 2017). Discuss this with the local building official to determine their interpretation of this NEC section.

For feeder wires and service sizing, the NEC has an optional load calculation for multifamily buildings that have three or more dwelling units and electric cooking (NEC 220.84, 2017). The optional load calculation has significant demand factors that may allow a property to avoid electrical infrastructure upgrades for their feeder wire and service infrastructure while electrifying cooking appliances.

Laundry Appliance Efficiency Example

Figure 32 provides an example of how actual volt amps of a dryer and washing machine combination can free up capacity. If using a deemed NEC load calculation, a deemed volt amp value must be used instead of the actual rated volt amp or wattage for the electric dryer in this example. Since the NEC deemed values fail to reflect significant load reductions achieved through increased efficiency, load monitoring may be necessary to demonstrate the increased available capacity.

Existing Residential Washing Machine and Electric Resistance Clothes Dryer

Proposed Residential Condensing Dryer/Washer Combination

	Existing	Proposed	Capacity & Infrastructure Savings
Total Watts	5,700	1,200	+ 4,500
Breaker	• 240V 30 Amp (Dryer) • 120V 15 Amp* (Washing Machine)	120V 15 Amp*	+ 1 Single Pole Breaker Slot

Figure 32. Residential Washer and Electric Dryer Replaced with Condensing Washer/Dryer Combination Unit

Images and data: (LG Electronics) (Electrolux Home Products Inc.) (Frigidaire Affinity Series, 2020)

Miscellaneous Equipment Efficiency

Fan Efficiency

In-unit exhaust fans have a relatively small electrical load, but buildings with central exhaust systems (such as bathroom/kitchen stacks, hallways, and garages) can provide meaningful load reduction opportunities for fans that often operate continuously. Typical efficiency measures include:

- Downsizing and converting belt driven fans to direct-drive electronically commutated motor (ECM) fans
- Sealing ducts and shafts
- Reducing fan speeds (where the system is overventilated compared to current code requirements)
- Installing carbon monoxide sensor controls and variable frequency drives (VFD) in garages

Reduction in fan power requirements will increase available electrical capacity and will be reflected in the deemed NEC load calculation (NEC Section 220, 2017).

Pumps

Large pumps are typically seen in multifamily buildings that have central heating and cooling, or in taller multifamily buildings that need to boost city water pressure to satisfy upper floors. The pumps in both systems typically operate continuously throughout the year.

Cold Water Booster Pumps. Most existing cold water booster pumps are single speed or staged pump systems that include controls that restrict or control pressure but do not limit energy use when demand is low. On the other hand, modern variable speed cold water booster pump systems vary pump speed as needed to maintain pressure, allowing the pumps to operate at very low power draws for most of the time.

When scoping replacement booster skid system projects, most manufacturers can provide a short-term instrumented pump monitoring study to measure actual demands in the building that will inform replacement equipment sizes. Almost without exception the results of these studies have indicated that the existing booster pump systems were oversized, or were designed with excess capacity to provide redundancy, and the new cold water skid system can be much smaller (with a corresponding lower peak electrical demand). This results in an increase in electrical capacity based on NEC deemed electrical load calculations (NEC Section 220, 2017). If the existing system has a variable frequency drive installed on the existing pumps this will not allow for a reduction in the NEC deemed load calculation as the nameplate power draw for the system will not change

Hydronic Pumps. Central heating and cooling systems rely on circulators (pumps) to move heated or chilled water to radiators, fan coils, or water source heat pumps located throughout a building. Most of these circulators in multifamily properties are single speed, and flow is relatively constant through the use of three-way (bypass) valves located at each emitter or through the use of one or more bypasses located elsewhere in the system.

Upgrading these circulators to variable speed models requires a careful assessment of the existing distribution system. Significant energy savings (not electrical load reduction) will only be achieved if flow can be reduced as demand reduces in the building. This requires that existing bypasses can be closed and emitters use two-way valves that are fully off when closed.

Electrical load reduction is feasible if replacement variable speed pumps are more efficient, or if a pump audit determines the existing pump is oversized.

Pool and Spa Heating

Table 7, Table 8 and Table 9 give typical heating capacity ranges of air source heat pump pool heaters rated for various breaker sizes. As available BTU capacities are typically smaller than most multifamily pool and spa equipment, it is important to work with manufacturers to properly size and select replacement heat pump equipment. Efficiency measures like the use of covers may be helpful in reducing heat loss. Adjusting existing operating hours may be necessary to give the heat pump more time to recover heat loss. For example, a spa turned off at night may only need one hour to recover in the morning with a gas heater but may need four hours with a heat pump.

Table 7. Single-Phase (208/240) Inverter-Driven Pool Heat Pumps

Maximum Breaker Amps	Capacity Range (Btu/hr)
15	≤ 32,600
20	32,601–43,600
25	43,601–59,300

Table 8. Single-Phase (208/240) Typical Pool Heat Pumps

Maximum Breaker Amps	Capacity Range (Btu/hr)
35	≤ 47,000
50	47,001–78,500
60	78,501–136,500

Table 9. Three-Phase (208/240) Typical Pool Heat Pumps

Maximum Breaker Amps	Capacity Range (Btu/hr)
30	≤ 72,000
50	72,001–136,500
70	136,501–162,500

STEP 4: Evaluate Upgrade Costs and Consider Emerging Alternatives

Infrastructure upgrade costs

Efficiency measures to reduce existing and proposed electrical demand should always be considered as a first step toward cost-efficient electrification, as discussed in Step 3. After efficiency measures are identified, a general estimate of the budget required for electrical infrastructure upgrades can help building owners make decisions on whether to upgrade infrastructure, consider alternative solutions, or both.

> **Attention**
>
> Electrical infrastructure upgrades are highly dependent on specific building conditions. The costs shown here may not reflect the actual electrical infrastructure upgrade costs for specific buildings.

ABOUT THE COST TABLES

Table 10 and Table 11 show typical cost ranges for upgrading electrical infrastructure. These estimated costs include ancillary costs such as drywall repair. Adding circuits may be an unavoidable electrical infrastructure upgrade expense due to NEC and local building code restrictions on appliance-dedicated circuits (Miller C. , 2011).

Electrical infrastructure upgrades are very building specific. The estimated costs presented here may not reflect actual costs for specific buildings.

In the cost ranges, the lower limit represents a typical multifamily building that has 20 or fewer units and doesn't have major upgrade hurdles. The upper limits of the cost ranges represent more complicated upgrades typically associated with commercial or large multifamily properties.

Table 10. Estimated Costs for Electrical Infrastructure Upgrades

Electrical Infrastructure Upgrades	Cost
Add circuits for a new electric appliance	\$500–\$2,000
Upgrade subpanels	\$1,000–\$7,000
Replace disconnects at meter bank	\$1,000–\$3,000
Upsize feeder cable	\$1,000–\$10,000
Convert from single to three phase	\$10,000–\$100,000 (depends on building size)

Table 11. Estimated Costs for Utility Service Upgrades

Utility Service Upgrades	Cost
Service line disconnect	\$500–\$5,000
Overhead service connection	\$3,000–\$10,000
Underground service connection	\$10,000–\$50,000
Pole-mount transformer	\$3,000–\$5,000
Pad-mount transformer	\$10,000–\$30,000
Subsurface transformer	\$40,000–\$80,000

Phased Electrification

In many existing multifamily buildings, full electrification will necessitate upgrading electrical infrastructure. The cost of these upgrades paired with installing new electric appliances may be too burdensome for many building owners. Completing electrification in phases may be less cost-efficient overall, but it may lower the immediate cost burden and make electrification more accessible.

Phased electrification projects should be treated as a comprehensive electrification project when completing an infrastructure walkthrough and load analysis. These two steps will help define the scope of work needed to achieve 100% electrification, which then can be broken down into cost-efficient phases.

Emerging alternatives to upgrading electrical infrastructure

For some properties, it may not be possible to reduce the electrical consumption of existing or new loads enough to fit within existing electrical capacity, and electrical infrastructure upgrades may seem unavoidable. In these cases, alternatives to upgrading infrastructure may be considered. Alternative solutions may be less expensive than upgrading electrical infrastructure; however, the majority of these solutions may require compromise, such as limited flexibility of use for the appliances they control.

This section discusses currently available technologies that can help reduce the load on existing infrastructure through control and monitoring strategies. Available solutions include smart panels, smart splitters, and dynamic load management for buildings with multiple electric vehicle (EV) chargers. These technologies focus mainly on load shifting and prioritization (changing when loads occur); this can reduce simultaneous power draw to lower the effective load on an electrical system.

However, these technologies do not increase actual capacity as required by the NEC and would not be reflected in deemed NEC calculations (NEC Section 220). It is not yet clear if local code officials will allow new electrical loads to be installed when paired with load shifting technology. Always get approval from the authority having jurisdiction before using these strategies as a solution for demand reduction.

Appendix A includes examples of each technology discussed in this section.

Smart panels

Smart panels are electrical equipment that replace or connect to existing electrical panels. They are currently used to manage loads in residential applications that incorporate battery backup and solar PV systems. They do this by monitoring and controlling the circuits downstream of the panel in order to limit coincidental load.

Smart panel manufacturers have identified that their technology could also be modified to effectively increase electrical capacity for new electrical loads in a non-battery backup scenario without having to alter feeder or other upstream equipment. The minimum service capacity that would be needed to support full electrification across different apartment types has yet to be evaluated. This approach does not currently appear to be supported by the NEC and would need advance approval from the local authority having jurisdiction.

Smart panel future use cases

Smart panels are currently targeted more toward single-family applications, so some may be oversized for in-unit apartment installation. Future innovation of these products may lead to smaller multifamily-specific subpanels. While some smart panels are already capable of load triage in response to large simultaneous draw, this capability must be proven reliable and incorporated by the NEC as a load reduction strategy before it can be relied upon for infrastructure sizing. Should the NEC be modernized to allow for load shifting as a demand reduction strategy, smart panels could be used at scale as an alternative to infrastructure upgrades.

SMART SPLITTERS

Like smart panels, smart splitters reduce the need for upstream infrastructure upgrades by limiting the amount of energy that downstream loads can draw at any given time. However, instead of managing many loads at once, they simply divide the use of a dedicated circuit between two appliances. If the priority appliance is in use, the smart splitter will limit or cut power to the other appliance, so that too much power is never drawn.

Smart splitters are less flexible than smart panels when it comes to managing load, because they can only "triage" load between two or more appliances. Because of this, smart splitters should never be used for appliances that must run continuously or at the same time. Instead, appliances with less time-dependent operation (such as EV chargers, water heaters or HVAC) should be paired with priority appliances such as stoves or dryers, which run briefly and intermittently. In these cases, smart splitters might work as an alternative to wiring a new branch circuit and may be more affordable than a smart panel.

There are a number of existing smart splitters used to divide power between a dryer and an EV charger (which can both be located in a garage). However, their availability has expanded such that they can now be found in a few slightly different form factors and use cases.

Smart splitter future use cases

Permitting the installation of smart splitters may be necessary if they are used at scale. If a permit is required by the authority having jurisdiction, it may be necessary to educate building department officials on the new technology to facilitate the permit process. Since there is no explicit code language related to smart splitters, the reliability of their logic and their resistance to tampering may need to be demonstrated before building departments are willing to allow them as a load management solution at scale.

Future innovation of these products may lead to communication with the appliances that are sharing the circuit and the smart splitter, allowing for partial draw from both appliances, and supporting load triage for more than two appliances.

DIALOGUE WITH LOCAL CODE ENFORCEMENT

Because load management technology is a relatively new advancement, its use for appliances is not currently addressed by the NEC.[1] Building officials for each jurisdiction may have different interpretations of how appliance load management devices should be handled by code. The

[1] Automatic load management has been acknowledged and approved as a demand reduction strategy, but only as it applies to EV charging (NEC 625.42, 2020).

following questions illustrate some of the ambiguity that may arise when considering load management technology. These are only some of many questions that may need to be addressed:

- Can the results of load monitoring or utility bill analysis be used for infrastructure sizing if the impacted area is managed by a load management device?
- Can the load on an individual branch circuit be defined as the maximum managed load through a smart splitter?
- Is automatic load management acceptable if we can demonstrate that the failure mode of the equipment would not result in an overloading of the electrical system?

If an electrician or electrical engineer determines that load management devices could be an effective part of the electrification strategy for a building, a conversation with the local jurisdiction's building department is recommended. This can help establish a basic understanding of what the building department expects and can approve, as well as how they would handle solutions left ambiguous by the NEC. In addition to guiding the overall approach of the electrician or engineer, this conversation can help clarify the details of sizing and installing infrastructure that includes load management devices.

EV DYNAMIC LOAD MANAGEMENT

A major hurdle of electrifying vehicles in California is the limited amount of EV chargers in multifamily buildings. Multifamily tenants often cannot park their car in a personal garage or near their apartment, where an EV charger can be installed on their individual electrical meter. EV charging station installation and management is thus left up to multifamily property owners, property managers or homeowners' associations. A recent study found that half of residents located in the Bay Area live in multifamily properties; however, only 10% of multifamily residents own electric vehicles. Residents of single-family homes in the Bay Area are three times more likely to own electric vehicles (Bryan & Aldridge, 2020).

With the push for electric vehicles in California, installing EV charging stations is becoming more beneficial for multifamily building owners since it may improve their property's marketability. However, limited existing electrical capacity can be a hurdle to cost-efficiently installing EV charging stations. In the same study mentioned above, 23 properties were evaluated for the installation of EV chargers and less than half had common area electrical capacities to support EV charging (Bryan & Aldridge, 2020).

EV dynamic load management has emerged as a solution to reduce electrical capacity requirements to support EV chargers, making installation of EV chargers more cost efficient. Multifamily building electrical infrastructure is designed to support the peak electrical load of the electrical appliances and electric mechanical systems it is connected to, which is a rare occurrence. EV dynamic load management connects an EV charger to existing electrical infrastructure and avoids drawing power during peak load events. For example, a multifamily building's central laundry room has the electrical infrastructure to support several electrical appliances like washing machines and dryers. When the laundry room closes at night, the existing electrical infrastructure can be used to support EV chargers because the washing machines and dryers will not be drawing electricity.

Solar photovoltaic systems

Solar photovoltaic (PV) systems when combined with electrification produces cost-efficient multifamily building operation by offsetting the electrical loads and decreasing utility bills. There are two ways to connect PV to a multifamily building's electrical infrastructure: line-side tap at the service overhead wire and load-side tap at the service switchboard or service panel, where the service line disconnect exists.

Line-side tap. With a line-side tap, the PV connection ties directly into the service line. All energy produced is sent to the energy grid and the property receives energy credits for the electricity generated. This connection allows for virtual net energy metering (VNEM), a billing mechanism that allows the property to allocate the energy credits received to different areas in the building including common area loads and dwelling unit loads.

Load-side tap. With a load-side tap, the PV connection occurs at the busbar behind the panel or switchboard. The busbar must exceed the size of service line disconnect. The additional capacity of the busbar will need to be sized to support the PV. Also, the PV system's breaker amp rating cannot exceed 20% of the service line disconnect amp rating (NEC Section 705.12).

A load-side tap allows for net energy metering (NEM), a billing mechanism that allows the property to use the electricity produced by the solar PV system directly. Excess energy is sent back to the grid and the multifamily building receives energy credits or VNEM if a utility-owned electricity meter is installed on the PV feeder wire to record the PV system's energy production.

If PV system is included in the future plans for the multifamily building, determining the optimal PV connection for the property is the first step in determining the effect of the PV system on the existing electrical infrastructure. When upgrading electrical infrastructure to support electrification, PV connections should be considered to avoid replacing newly installed electrical infrastructure for the PV system.

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Appendix A: Product Guides

Retrofit Equipment Product Guide

A list of NEEA Rated Residential Heat Pump Water Heaters is available at https://neea.org/img/documents/HPWH-qualified-products-list.pdf. This comprehensive list is aligned with California's Title 24 building code and is updated frequently.

The following product guides are provided courtesy of Redwood Energy. They show products available at the time this report was written. An updated list is available here: https://www.redwoodenergy.tech/wp-content/uploads/2020/04/SF-Guide-4-10-2020.pdf

Technologies, products and availability are constantly changing. When choosing products and systems for building electrification, be sure to consult with a building professional experienced with electrification. Inclusion of products and brands in this report does not imply endorsement or recommendation.

Table 12. Individual (Per Apartment) Heat Pump Water Heaters (240 V)

(Redwood Energy, 2020)

Manufacturer and Product Image	**Eco2 Systems** 	**Rheem** Prestige Hybrid 	**AO Smith** Voltex Hybrid 	**Bradford White** AeroTherm 	**Steilbel Eltron** Accelera 
Description	Large Volume Cold Climate CO2 Refrigerant	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance
Gallons	43, 83, 119	40, 50, 65, 80	50, 66, 80	50, 80	58, 80
Voltage (V)	208/230	208/240	208/240	208/240	220/240
Dimension (in)	27.5H x 35W x 11D	74H x 24Diam.	69H x 27Diam.	71H x 25Diam.	60H x 27Diam.
Ref. Type	R744 (CO_2)	R134a	R134a	R134a	R134a
Ambient Temp. Range (F)	**-30 – 110 (cold climate)**	37 – 145	45 - 109	35 – 120	42 – 108 / 6 – 42
Power (W)			4,500	550 – 4,500	650 - 1500
Max Amps (A)	13	15 – 30	30	30	15
Heating (BTU/h)	15,400	4,200	-	-	5,800
Heating (COP)	5.0	-	-	-	-
Energy Factor	3.09 – 3.84	3.55 – 3.70	3.06 – 3.61	2.40 – 3.39	3.05 – 3.39

Table 13. Individual Heat Pump Water Heaters (240 V and 120 V)

Availability Pending (Redwood Energy, 2020)

Manufacturer and Product Image	**Nulite** NERS-FR1.5F 	**GE** GeoSpring 	**Nulite** NE-BZ2/W200 
Description	Hybrid Heat Pump with Resistance	**Retrofit Ready** Heat Pump-Only	DC inverter heat pump water heater
Gallons	18.5 (70L)	40, 50	53 (200L)
Voltage (V)	220 @ 50 Hz	120V	220 @ 50 Hz
Dimension (in)		To be released in 2020	
Ref. Type	R134A		R410A
Ambient Temp. Range (F)	5 - 68		
Power (W)	860 - 1500		
Max Amps (A)	Pending		250V/20A (50Hz)
Heating (BTU/h)	12,500		27,000
Heating (COP)	1.36 - 5.34		
Energy Factor	Pending		Pending
Additional Comments	UL Certification Pending		UL Certification Pending

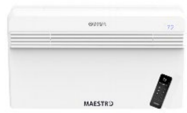
Table 14. Ductless Mini-Split Heat Pumps (120 V)

(Redwood Energy, 2020)

Interior Wall-Mounted Fan Coil 	**GE** Caliber Series AS12CRA 	**LG**[i] Mega (115v) LS-120HXV 	**Mitsubishi** MZ-JP12WA 	**Gree** LIV (09,12) HP115V1B 	**Carrier** 38MAR 	**Haier** 
Description	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil
Dimension (in) (HxWxD)	21 x 31 x 10	19 x 28 x 10	22 x 32 x 11	33 x 21 x 13	32 x 21 x 13	28 x 35 x 14
Ref. Type	R410a	R410a	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-4 - 115**	14 – 65 / 14 – 118	**-4 - 115**	**0 - 115**	**-13 - 122**	**-4 – 115**
Power (W)		1,140 – 1,090	800 – 1,300	1,955	1,725	2,100
Max Amps (A)		10.4	11.8	17	15	18
Heating Cap. (BTU/h)	12,000	13,000	12,200	9,600; 12,500	12,000	16,000
Cooling Cap. (BTU/h)	12,000	12,000	12,000	9,000; 12,000	12,000	12,000
Heating (COP)	2.92	2.6	2.9	3.3	2.03 - 3.80	3.2
Cooling (COP)	2.92	3.1	2.9	4.67		3.75

Table 15. Packaged Terminal Heat Pumps (120 V)

(Redwood Energy, 2020)

	Innova 10DC 	**Olimpia** Maestro 	**Frigidaire** FFRH0822Q1 	**Friedrich** YS10N10C 	**Gree** 26TTW09HP115V1A 
Description	Twin ducts through the wall, dehumidification, optional resistance back-up	Twin ducts through the wall, dehumidification	Heat pump with Resistance	Heat pump model – no back up Resistance	Heat pump model with Resistance
Voltage (V)	120	120	120	120	120
Dimension (in)	1.8H x 3.3W x 0.5D		15H X 22W x 23D	15H x 25W x 29D	15H x 26W x 16D
Ref. Type	R410a	R410a	R410a	R410a	R410a
Minimum Heat Pump Operating Temp (F)	**14F (cold climate)**	**5F (cold climate)**	40F	40F	29F
Power (W)	545 – 730	830-850	780 – 1,290	917 - 978	830 – 1,150
Heating Capacity (BTU/h)		10,600 (Heat Pump only)	7,000 (Heat Pump) 3,500 (Resistance)	8,000	6,600 (HP) 3,900 (ER)
Cooling Cap. (BTU/h)	0.8 – 3.1 kw	11,600	8,000	10,000	9,000
Heating (COP)	2.84 – 3.22	3.8	2.63	2.6	3
Cooling (COP)	3.12 – 3.28	3.8	2.87	3.19	2.87

*ER = electric resistance, HP = heat pump

Emerging Alternatives Product Guide

The following three tables provide information about emerging technologies that may have applications in the electrification of multifamily housing. This is neither a comprehensive list nor an endorsement of any products or manufacturers. The products listed here have not been evaluated for functionality. While specific products are discussed as examples of certain technologies, these technologies are constantly evolving and products may have changed since the publication of this report.

Table 16. Summary of Smart Panel Products and Use Cases

Manufac-turer	Product Summary	Current Use Case
Lumin	The Lumin Smart Panel device can be installed on any existing electrical panel. It works by intercepting each circuit and running the circuits through a smart controller, which can be accessed by residents via an online portal or any Android or IOS device. The smart controller allows an owner/resident to input schedules which limit power draw for different circuits at different times of the day. It also features smart controls which limit concurrent energy draw from electrical appliances. The Lumin device can handle 12 poles and additional Lumin panels can be stacked to control additional circuits where needed. The physical size of the currently available Lumin Smart Panel may be a concern in smaller units with limited space. (LuminSmart, 2020) (O'Shea, 2020)	Load schedules can help occupants optimize their electrical usage to align with lower time of use rates, and to effectively utilize on site solar PV and/or energy storage systems. Smart controls allow load shifting of existing and added loads to keep peak usage down. Users can also monitor existing electrical load to determine whether there is available capacity for electrification.
Eaton	In Q4 2020, Eaton released their smart breakers (marketed as Energy Management circuit breakers), which are currently rated to be installed in most existing Eaton panels. The smart breakers are designed to both monitor the energy used by downstream circuits and to control the circuit based on user input schedules or third-party applications. Eaton smart breakers also include an EV charging variant which integrates EV charging	As they exist currently, Eaton smart breakers must be connected to the internet, and paired with software that enables monitoring and control, in order to achieve full functionality. To minimize electrical use during high time of use rate periods, owners can schedule certain breakers to shut off. Users can also monitor existing electrical load to determine whether there is available capacity for electrification. To manage coincidental load, Eaton smart breakers would need to be paired with a whole home energy management system that aggregates information from the smart breakers

Manufac-turer	Product Summary	Current Use Case
	functionality in the panel itself, making EV charging retrofits more feasible by limiting the amount of power that each charger may draw. (Eaton, 2020) (Eaton, 2017) (Katarki, 2020)	and manages coincidental load by turning certain loads ON/OFF. Because the breakers currently accomplish this using an internet connection, they are not able to instantly triage loads to guarantee a limited peak draw. This makes Eaton products best suited for monitoring and time of use rate control.
Span	Span's smart panel includes fully controllable breaker spaces and allows electrical load to be monitored, controlled, and recorded, using an Android and iOS app. Because it is designed to interface with the entire home (including solar PV systems, battery systems, EV chargers, and smart appliances), Span's panel can limit the amount of electrical infrastructure required for applications with solar/storage or EV charging. The Span smart panel that is currently available can be rated between 100-200A, with a 225A bus to support on-site generation. (Span.io, n.d.) (Law, 2020)	The Span panel can be used to improve resiliency by selecting which electrical systems should be operable during an outage; users can also monitor existing electrical load to determine if there is available capacity for electrification. Span can intelligently control which loads are using power at any given time, reducing peak load and responding to time-of-use rates. For multifamily building use cases, Span is best used for small multifamily common areas, and apartment units with dedicated PV.

Table 17. Summary of Smart Splitter Use Cases

Manufac-turer	Product Summary	Current Use Case
EV-PowerShare	The EV-PowerShare splitter is designed to allow for EV charging to be more accessible and avoid electrical infrastructure upgrades. The product plugs into an existing electric dryer receptacle and splits its power between the dryer and a new EV charger. It also incorporates a power monitoring screen to monitor energy use of the two loads. Includes a 25A breaker as well as surge and short circuit protection for added safety (Hu, 2020) (EV - Powershare, n.d.)	Circuit sharing of an EV charger and an electric dryer. The EV-PowerShare will shutoff power to the EV charger when the electric dryer is in use.
Dryer Buddy	The Dryer Buddy splitter is a more versatile splitter that can be purchased in various configurations to plug into a number of different receptacles and provide various output receptacles. It is available in a manual switch configuration, as well as an automatic configuration that will shut off the secondary load when the primary load is running. It also has a power monitoring screen. (Dryer Buddy, 2020)	Generally, it is designed to plug into a dryer receptacle and split its power between the dryer and an EV charger. Given its various configurations and ability to have a manual or automatic switch configuration its current use case is fairly robust
NeoCharge	The NeoCharge splitter is a small, portable splitter designed to plug into a receptacle and split power to its two built-in receptacles. All configurations are UL listed, Wi-Fi enabled, and include an app through which usage can be monitored. The splitter itself does not need Wi-Fi and has internal control logic which cuts power to the non-priority appliance when the total load on the circuit approaches maximum capacity. This logic allows it to power two appliances at once, if the total draw remains under the circuit capacity maximum, or power only the priority appliance otherwise. (NeoCharge, n.d.) (Harrison, 2020)	It was originally intended to allow shared power between a dryer and an EV charger, and this remains its most common use case. However, it is available in various configurations designed to split power between two EVs, two appliances, or an EV and an appliance.

Table 18. Summary of EV Load Management Use Cases

Manufac-turer	Product Summary	Current Use Case
EverCharge	EverCharge is a dynamic EV load management system that has the potential to install EV charging at scale while avoiding major electrical infrastructure upgrades. While installing multiple traditional “unmanaged” EV chargers would require sufficient electrical infrastructure to support the peak loads of all chargers operating simultaneously, EverCharge modulates all connected chargers based on available load on the panel(s). Additionally, the EverCharge system can be tied into an existing building monitoring system to help support electrical load shifting, lower utility rates, and increase the cost effectiveness of EV chargers. All chargers connected to an EverCharge system are level 2 chargers, and multiple chargers can be connected to a single circuit. (EverCharge, 2019) (Berman, 2020) (Appelbaum & Kostiner, 2020)	EverCharge is used to expand EV charging capabilities in buildings looking to install multiple car chargers with limited electrical capacity.

Appendix B: NEC Deemed Load Calculations

Calculation Process Overview

Section 220 of the NEC outlines all sizing and safety requirements for dwelling unit and house electrical loads for multifamily buildings. There are a variety of methods to calculate electrical loads utilizing different demand factors depending on the appliances and intend use of the space (dwelling units, laundry rooms, etc.). Refer to NEC Section 220 for more details. A summary of the general process for calculating a dwelling unit's electrical load is as follows:

1. Calculate the square footage of the apartment units.
2. Count small appliance loads. (A small appliance load is any electrical appliance that does not sit in place or require a dedicated circuit. A minimum of two must be included in the calculations for each unit to account for connection of appliances such as microwaves and other kitchen appliances.)
3. Count small laundry loads. (A small, dedicated circuit is required to be included in the calculations for each unit for connection of small appliances like irons.)
4. Count appliances that require a dedicated circuit and record their rated wattage/volt amps. (If an appliance has a rated wattage or volt amps that is less than the default wattage/volt amps of that appliance listed in the NEC, use the default value.)
    a. Laundry washing machine
    b. Electric laundry dryer (NEC 220.54)
    c. Air handler with gas furnace
    d. Electric space or water heater
    e. Electric range (NEC 220.6)
    f. Air conditioner (Some room air conditioners, if small enough, can count as a small appliance load.) (NEC 440.62)
5. Apply demand factors. (Demand factors are factors that you multiply the load by since it is assumed not all appliances will be on instantaneously.)
    a. Lighting demand factors (NEC 220.42):
        i. A 100% demand factor is used for the first 3,000 VA of the load.
        ii. A 35% demand factor is used for the next 117,000 VA.
        iii. A 25% demand factor is used for the remaining load.
    b. Appliance demand factors (NEC 220.53):
        i. A 75% demand factor is used when there are four or more appliances fastened in place (excluding electric ranges, clothes dryers, space heating equipment or air conditioning equipment).
    c. Electric range demand factors (NEC 220.55):
        i. Demand factor ranges from 80% to 16%, depending on quantity of ranges and rated wattage of range.
    d. Optional load calculation and demand factors for multifamily dwellings (NEC 220.84):
        i. Each dwelling unit is supplied by only one feeder.
        ii. Each dwelling unit is provided with electric cooking equipment.

iii. Three or more dwelling units.
iv. Demand factor ranges from 45% to 23%, depending on quantity of units.

6. Exceptions to demand factors and rated VA include:
    a. Default in-unit electric dryer rating is 5,000 VA, unless the nameplate rating is higher. If the nameplate rating is lower, then 5,000 VA must be used (NEC 220.54).
    b. Air conditioning has a demand factor of 100%, unless small enough to be considered a small appliance (NEC 440.62).
    c. For in-unit laundry, there is always one laundry circuit that must be rated at 1,500 VA (NEC 220.82(B)). This includes the washer and gas dryer. If the dryer is electric, then it must have its own dedicated circuit. Some building officials interpret this requirement differently and the code does not explicitly state that this circuit is only included when there is in-unit laundry. It would be best to initially include it in the load calculations and if it pushes the electrical capacity beyond the existing infrastructure, check with the local building official to determine if it is required.
    d. All heating systems have a demand factor of 100% (NEC 220.82(C)).
    e. Cooking load is included in NEC load calculator if it exceeds 1.75 kW (NEC 220.55), which means all electric stovetops/ovens, and some gas stovetops/ovens.
    f. Count the loads of the appliances in the units that are fastened in place (the NEC specifies which appliances do not count). If there are four or more appliances in each unit, a demand factor of 75% can be applied.
    g. Lighting load is calculated to be 3 VA/square foot for in-unit applications. Different common areas of a multifamily building will require different default VA/square foot values, regardless of whether the lighting has undergone efficiency measures (NEC 220.12).
    h. There is also an optional load calculation method in the NEC for buildings with no more than one feeder per dwelling unit, electric space heating or air conditioning, and electric cooking in each unit (an exception is included if the electric cooking requirement is not met) (NEC 220.83(B)). This calculation is similar to the standard method but may allow for smaller electrical capacity due to the number of electrical appliances and a decrease in the possibility of all electrical appliances running at once. This optional load calculation method may result in smaller electrical capacities required to support the electrical load in dwelling units after electrification.

NEC Load Calculation References

Tom Kabat, with contributions from Redwood Energy, a leader in zero net carbon design and electrification in California, has created a "Watt Diet Calculator," an Excel-based tool that provides a dynamic NEC load calculation to help determine the effect of efficiency measures on the available electrical capacity. The Watt Diet Calculator is intended for single-family dwellings but can be easily converted for multifamily. It can be downloaded at: https://redwoodenergy.net/wp-content/uploads/2020/10/Watt-Diet-Calculator-2020-10-22.xlsx (Kabat, Higbee, & Anderson, 2020).

Example Dwelling Unit Load Calculation Worksheet

2000 Main Street 3rd Floor
Huntington Beach, Ca 92648
714/536-5241

Optional Method Service Load Calculation for a Single Dwelling Unit (CEC 220.82)

1. **General** Lighting and Receptacle Loads **220.82(B)(1)** **Do not** include open porches, garages, or unused or unfinished spaces not adaptable for future use.	**3 x** ________________ = (sq ft using outside dimensions)	1	
2. Small-Appliance **Branch Circuits** 20.82(b)(2) **At least two** small-appliance branch circuits must be included. 210.11(C)(2)	**1500 x** ________________ = (minimum of two)	2	
3. Laundry Brach Circuit(s) 220.82(B)(2) **At least one** laundry branch circuit must be included. 210.11(C)(2).	**1500 x** ________________ = (minimum of one) ***NOTE: 1500 VA shall be included for each laundry branch circuit.***	3	
4. Appliances 220.82(B)(3) and (4) **Use nameplate rating of all appliances (fastened in place, permanently connected, or connected to a specific circuit), ranges, ovens, cooktops, motors, and clothes dryers. Convert any nameplate rating given in amperes to volt-amperes by multiplying the amperes by the rated voltage.**	**Do not include any heating or air-conditioning equipment in this section.** water heater/ ____ dishwasher / ____ clothes dryer/ ____ disposal / ____ range / ____ EV / ____ — **Total volt-amperes of all appliances. LISTED BELOW** ____ / ____ (×6)	4	
5. **Apply** 220.82(B) demand factor to the total of lines 1 through 4. ________ **- 10,000 =** ________ **x 40% =** ________ **+ 10,000 =** (total of **line 1** through **4**)		5	
6. Heating or Air-Condition System 220.82(C) **Use the nameplate ratings in volt-amperes** for all applicable systems in lines '**a**' through '**c**'.	A) **Air-Conditioning and cooling systems, including heat pumps without any supplemental electric heating:** ________ **x 100% =**	A	
B) **Electric thermal storage and other heating systems where the usual load is expected to be continuous at full nameplate value. Systems qualifying under this section shall not be figured under any other selection in 220.82(C).** ________ **x 100% =** B ____	C) **Supplemental electric heating equipment for heat-pump systems. Include the heat-pump compressor(s) at 100%. If the heat-pump compressor is prevented from operating with the supplement heat, omit the compressor.** ________ **x 65% =**	C	
7. **Total Volt-Ampere Demand Load**: ________ + ________ = (largest VA rating from line **6a** through **6c**) (**line 5**)		7	
8. Minimum Amperes **Divide the total Volt-amperes** by the voltage. ________ ÷ ________ = (line 7) (voltage) 8 ________ (minimum amperes)	9. Minimum Size Service or Feeder 240.6(A)	9	(minimum is 100 amperes)
10. Size the Service of Feeder Conductors. **Use** 310.15(B)(6) to find the **service conductors up to 400 amperes**. Ratings in excess of 400 amperes **shall comply with Table 310.16**. 310.15(B)(6) also applies to feeder conductors serving as the main power feeder.	**Minimum Size Conductors**	10	
11. Size the Grounding Electrode Conductors. **Use line 10** to find the grounding **electrode conductor in Table 250.66**. **Size** the Equipment Grounding Conductor (for Feeder). **250.122**. **Use line 9** to find the equipment grounding conductor in **Table 250.122**. Equipment grounding conductor types are listed in **250.118**.	**Minimum Size Conductors**	12	

Figure 29. Huntington Beach Building Department Load Calculation Worksheet

(City of Huntington Beach)

Example NEC Deemed Load Calculation: Laundry Room

Residential House Load Laundry Room Calculation - NEC Section 220					
Area of Laundry Room 500 ft^2					
Step 1 - General Lighting Per NEC 220.42					
Deemed Lighting Load Value: 1.0 Volt Amps (VA) per square foot			=	500	VA
Demand factors:					
First 3 KVA have a demand factor of 100%				500	VA
3.1 KVA - 120KVA have a demand factor of 35%				-	VA
> 120 KVA has a demand factor of 25%				-	VA
			Total =	**500**	**VA**
Step 2 - House Receptacle Loads Per NEC 220.44					
	Quantity	NEC Deemed VA Value			
Small Appliance Circuits*	2	1,500	=	3,000	VA
Load added during electrification		Appliance Name Plate VA			
Heat Pump Water Heater	1	+ 5,000		5,000	VA
Washing Machines	5	1,550		7,750	VA
Demand factors:					
First 10 KVA have a demand factor of 100%				15,750	VA
Remainder over 10 KVA at have a demand factor of 50%				-	VA
			Total =	**15,750**	**VA**
Step 3 - Electric Clothes Dryers Per NEC 220.54					
	Quantity	Appliance Name Plate VA - if Name Plate Value is less than 5 KVA, then 5 KVA must be used			
Electric Clothes Dryers	5	5,000	=	25,000	VA
Demand factors:					
5 Dryers have a demand factor of 85%				21,250	VA
			Total =	**21,250**	**VA**
Total Existing Volt Amps for the Laundry Room				32,000	VA
Total Proposed Volt Amps for the Laundry Room with the Heat Pump Water Heater				37,000	VA
Single Phase Amp Capacity Requirements				**154.17**	**A**
Laundry Room Subpanel Amp Rating				**200.00**	**A**
Secondary Disconnect and Feeder Wire Amp Rating				**175.00**	**A**

Figure 33. Example NEC Load Calculation: Laundry Room

Example NEC Deemed Load Calculation: Whole Multifamily Building

Whole Building Residential Load Calculation - NEC Section 220					
Total Dwelling Unit Area	4,937 ft^2				
Number of Dwelling Units	4				
Step 1 -Lighting Loads Per NEC 220.12					
Deemed Lighting Load Value: 3.0 Volt Amps (VA) per square foot			=	14,811	VA
Step 2 - Sum up General Loads and HVAC Loads					
	Quantity	NEC Deemed VA Value			
Small Appliance Circuits (2 per apartment)	8	1,500	=	12,000	VA
Laundry Circuits (1 per apartment)	4	1,500	=	6,000	VA
		Appliance VA Value			
Electric Cooking Randge and Stove Top (1 per	4	7,680	=	30,720	VA
Load added during electrification					
New Space Conditioning Heat Pumps (1 per apartment)	4	9,000	=	36,000	VA
Garbage disposals (1 per apartment)	4	1,200	=	4,800	VA
Step 3 - Apply Whole Building Demand Factors per NEC Table 220.84					
Demand factors:					
Total VA has a demand factor of 45% because the property has 3-5 dwelling units				46,949	VA
		Total	**=**	**46,949**	**VA**
		Total Existing Volt Amps for the Mulitfamily Building		30,749	VA
		Total Proposed Volt Amps for the Multifamily Building with New Space Conditioning Heat Pumps		46,949	VA
		Single Phase Amp Capacity Requirements		**195.62**	**A**
		Service Line Disconnect and Feeder Wire Amp Rating		**200.00**	**A**

Figure 34. Example NEC Load Calculation: Whole Multifamily Building

Appendix C: Flagged Electrical Infrastructure

In the Data Collection Template (Figure 7), electrical infrastructure conditions that may increase a project's complexity are flagged with an asterisk. This table provides more information about those conditions and the relative ease or difficulty they present for electrification.

Key to electrification complexity: ○ Relatively easy ◑ Standard complexity ● Difficult

Flagged Electrical Infrastructure	**Description**	**Action**
APARTMENT UNITS, COMMON SPACES		
Brick or lath and plaster wall assemblies and ceiling assemblies with no cavities	Wall and ceiling assemblies that are solid or that have a cavity but are difficult to open and repair (such as lath and plaster or walls and ceilings with decorative finishes) make it difficult to conceal new circuits added during electrification.	○ Wall and ceiling assemblies with inaccessible cavities require new circuits to be surface mounted or run through attics and crawlspaces. This makes adding new circuits easier but less aesthetically pleasing. ◑ Walls and ceilings with cavities give the option of surface mounting, attic or crawlspace runs or through wall or ceiling cavities.
IN-UNIT AND COMMON AREA SUBPANELS		
Panel brand	Some panels installed in buildings have been recalled due to their potential for causing fires. Recalled panels include (Energy Today, 2016) (US CPSC, n.d.) (Gromicko, n.d.): • Zinsco • GTE-Sylvania • Federal Pacific Electric • Challenger Note: This is not an exhaustive list and there may be more recalled panel brands.	◑ Recalled panels not present ● Recalled panels present, will likely need to be replaced
Breaker brand	Similar to panels, some breakers brands installed in buildings have been recalled due to their potential for causing fires. Recalled breakers include (Energy Today, 2016) (US CPSC, n.d.) (Gromicko, n.d.):	◑ Recalled breakers not present ● Recalled breakers present, may not need to be replaced but can add complexity to the project

Flagged Electrical Infrastructure	**Description**	**Action**
	• Zinsco • GTE-Sylvania • Federal Pacific Electric • Challenger Note: This is not an exhaustive list and there may be more recalled panel brands.	
Fuse boxes	Fuse boxes are prevalent in buildings built before 1965 (Thiele, How Electrical Service Panels Have Evolved, 2019) and are often present in buildings with knob and tube wiring. When a fuse trips in a fuse box, the fuse must be replaced. If not replaced with the correct fuse type or correct rated amp fuse, then a fuse box can become a fire hazard.	◑ Modern panel present ● Fuse box present, will need to be replaced to support modern electric appliances
Subpanel location	Subpanels located in the following areas may need to be relocated during electrical infrastructure alterations (NEC 220.52 (A): • In closets • Under stairs • < 36” of forward clearance • < 30” of side-to-side clearance • < 78” of height clearance	◑ Panel located in approved area with proper clearance ● Panel located in unapproved area or without proper clearance, panel may need to be relocated
FEEDER CABLES		
Feeder cable running through slab	When feeder cables run through the slab and are inaccessible, it may impossible financially or physically to replace them. Instead, they may need to be run through a different path, increasing costs.	◑ Feeder cable run in accessible area ● Feeder cable runs located in slab and are inaccessible, may require new runs or alternative solutions to avoid upgrade

Appendix C: Flagged Electrical Infrastructure

Flagged Electrical Infrastructure	**Description**	**Action**
Knob and tube wiring	Knob and tube often does not have a ground wire and the insulation, which may have become brittle over time, can fall off if the wiring is moved or disturbed. It can be more dangerous than current wiring standards because it does not have a ground wire and is unable to properly connect to modern appliances. Modifications like improperly adding insulation can create a fire hazard, because knob and tube wiring cannot come in contact with flammable material (Armanda, 2004). However, insulation may still be allowable if properly installed, after wiring is inspected and deemed safe.	◑ Knob and tube wiring is not present ◑ Knob and tube wiring is present but modern appliances will not connect to the knob and tube wiring ● Knob and tube wiring is present and modern appliances are planned to connect to it. Modern appliances cannot connect to knob and tube and it must be replaced.
Aluminum wiring	Aluminum wiring installed with terminations (end connections) that have not been rated for use with aluminum can cause corrosion, which later leads to arcing and fires (Carson Dunlop, 2015). Older alloys also have a tendency to expand and contract, leading to loose connections; newer alloys help mitigate this problem with better expansion and contraction coefficients.	◑ Aluminum wiring is not present ◑ Aluminum wiring is present but connected to proper terminations ● Aluminum wiring is present with improper terminations. Improper terminations can create a fire risk and the aluminum wiring should be replaced
Cloth/rubber wire insulation	Outdated wire insulation, which is present in some older buildings, if is cracked or damaged can be a fire hazard. (Whitt Inspections, n.d.).	◑ Cloth/rubber wire insulation is not present ◑ Cloth/rubber wire insulation is present and in good condition ● Cloth/rubber wire insulation is present but cracker or damaged. Cloth/rubber wire insulation when cracked or damaged can be a fire hazard and should be replaced.