Net Zero Village, Rotterdam, NY

zHomes, Issaquah, WA

The Grand Islander, Ilikai Hotel & Luxury Suites, Aston at the Executive Centre, Hilton Hawaiian Village, Waikiki Beach, HI

A Zero Emissions All-Electric Multifamily Construction Guide

The Battery, Philadelphia, PA

Mutual Housing at Spring Lake

REDWOOD ENERGY

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An all-electric kitchen in the Hilton Grand Islander Hotel in Hawaii.

Ryobi electric backpack blower

Opti-Myst electric fireplace

Kenyon electric grill

This report was produced for Menlo Spark, a non-profit, community-based organization that unites businesses, residents, and government partners to achieve a climate-neutral Menlo Park by 2025. Menlo Spark weaves together transformational energy, transportation, land use and building policies that promote community prosperity, bolster economic vitality, and protect civic heritage. The intent of this report is to help cities and developers everywhere embrace healthier, lower cost all-electric building construction practices.

Figure 1: The Ritz Carlton Residences, Waikiki, Hawaii

Figure 2: Veridian at Sandy Spring Apartments, North Atlanta, Georgia

Introduction

There is a growing trend of new multi-family developments going all-electric across the U.S. and globally, providing significant cost savings, reducing pollution, and improving tenant comfort, health, and safety. This guide shows examples of California's mixed-use mid-rises, Atlanta's pool-side rentals, luxury condos in Hawaii and Florida, *Passive House* apartments in the Northeast, and Vancouver's urban multi-unit residential buildings. Multifamily housing is more than half of California's new residential construction,[1] and 40% new residential construction in the U.S.[2] All-electric housing, both single-family and multifamily, has gained market share in the U.S. starting in 1993 and now accounts for 1 in 4 homes nation-wide.[3] Growth is strongest in the South, where all-electric comprised 46% of new homes in 2015. This booklet aims to explain the trend towards all-electric multifamily housing, summarize best practices and provide designers a useful catalogue of electric products.

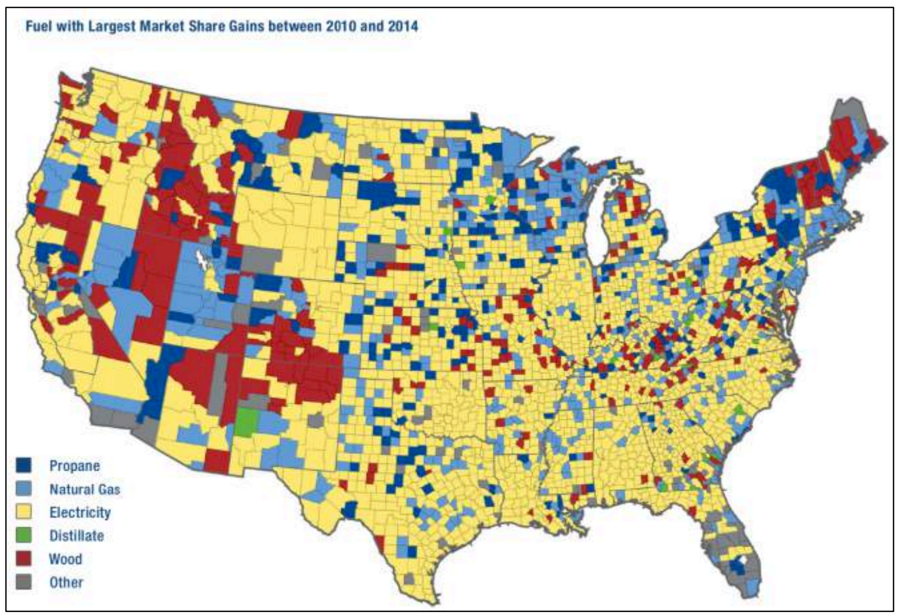

Figure 3: Electric heating, both heat pumps and resistance, has been the market share growth leader for heating energy in almost every county in the U.S. since 2010 (Propane Education Research Council, 2016. ICF-International)

All-Electric Construction costs less to build: In California developers save an average of $3,300/unit[4] of construction costs by avoiding gas use, or more than $20,000 per 8-plex for gas distribution, laterals, interior piping, appliances, and venting. In the downtown of a city like Los Angeles, just trenching and piping gas to an apartment building in a busy street can cost $140,000.[5]

1 Ft Journal. (2019). "The slowing trend in California construction starts." <https://journal.firsttuesday.us/the-rising-trend-in-california-construction-starts/17939/>
2 Salviati, C. (2018). "The Increasing Importance of Multifamily Construction." Apartment List. < https://www.apartmentlist.com/rentonomics/increasing-importance-multifamily-construction/>
3 Federal Energy Information Administration. "One in four U.S. homes is all-electric." May 1, 2019. https://www.eia.gov/todayinenergy/detail.php?id=39293
4 Bruceri, M. (2019)."Draft 2019 Energy Efficiency Cost-effectiveness Study: Low Rise Residential." For PG&E Codes & Standards, prepared by Frontier Energy. March 15, 2019
5 Walton Construction Services. "DHW Gas vs. Electric Study for Decro's Fermin Court." June 7, 2018. Gas services cost $63,000 for demolition, trenching, excavation, and paving; $20,000 for offsite main service; and $55,000 for site lateral service.

Plumbing piping to gas appliances is much of the additional cost, ranging from $200-$800 per gas appliance.[7] Figure 5 below summarizes the research on leakage of the natural gas infrastructure system serving California, from the wells to appliances.

Figure 4: Luxury condominiums in Pensacola, Florida are built all-electric to avoid significant gas infrastructure costs.[6]

Cleaner, Low Carbon Living: Buildings currently contribute roughly one third of global greenhouse gas (GHG) pollution from energy use. Multifamily housing construction can rapidly make a large reduction in carbon pollution by avoiding or replacing fossil fuels like gas, fuel oil, and propane with efficient all-electric construction.
Additionally, the Methane leaked from delivery of "natural" gas is an exceptionally strong GHG pollutant; according to an Environmental Defense Fund analysis of IPCC data, "about 25% of manmade global warming we're experiencing is caused by methane emissions,"[8] assuming a conservative 2.7% lifecycle leakage rate (*see Figure 5*).

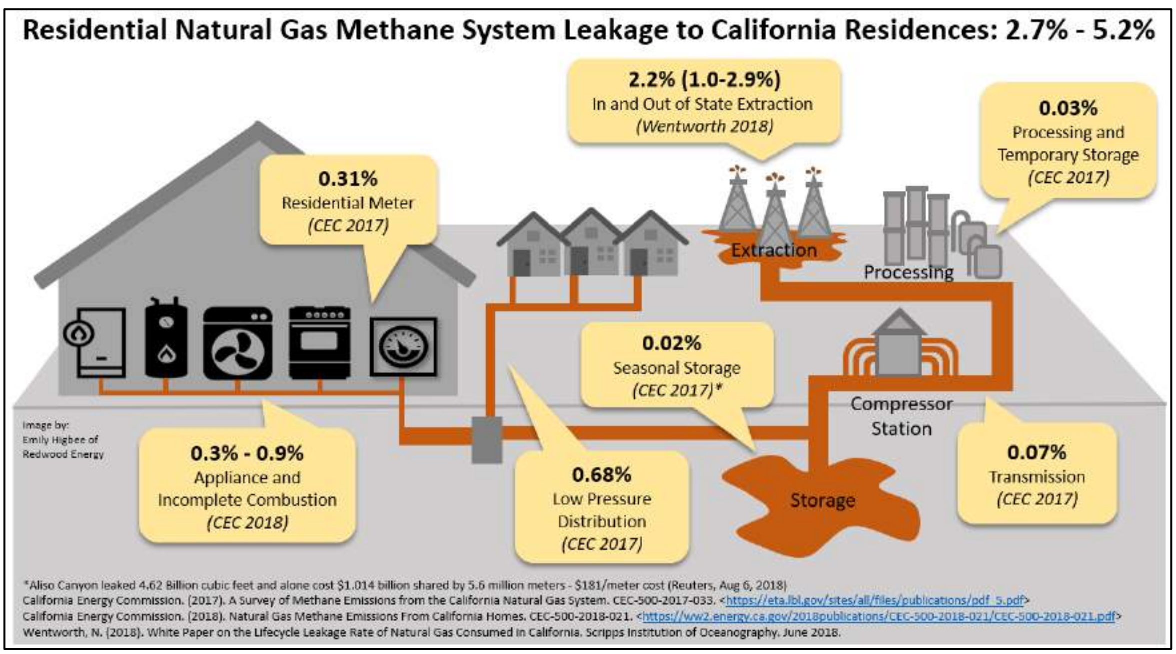

Figure 5: Research performed on the California gas delivery system reveals significant leaks at each step.

Even if the electricity in the grid comes from coal or gas powerplants, households with efficient electric space and water heating appliances (e.g. 315-400%) produce much less total air pollution than the most efficient (98%) gas furnaces and water heaters.[9] However, forty-eight utilities nation-wide have made renewable energy commitments, and many states

6 Jacobson, B, Shell, S., Schroeder, T., Young, R., Galarza, C., and Janssens, H. (2019). All Electric Commercial Kitchens.
7 Stone Energy Associates, Accounting for Cost of Gas Infrastructure, CEC Docket 17-BTSD-01 (May 4, 2017), https://efiling.energy.ca.gov/GetDocument.aspx?tn=217420&DocumentContentId=26959
8 "Methane, The Other Important Greenhouse Gas." *EDF calculation based on IPCC AR5 WGI Chapter 8." www.edf.org/climate/methane-other-important-greenhouse-gas. Note that other sources like livestock (e.g. cows) contribute to methane emissions also.
9 Department of Energy. "A Common Definition of Zero Energy Buildings." Table 1, 'National Average Source Energy Conversion Factors' shows 3.15 for Imported Electricity and 1.09 for Natural Gas. https://www.energy.gov/eere/buildings/downloads/common-definition-zero-energy-buildings

additionally mandate renewable energy. For instance, New York, Washington, Oregon and California, will have 100% carbon free power grids by 2045.[10]

Figure 6: Neighbors flee an out-of-control fire in San Bruno fueled by a damaged high-pressure gas pipeline[14]

Public Safety: Some cities have begun exploring a ban on new gas plumbing in buildings due to the fire, explosion, and public safety risks. For instance, gas line ruptures caused half of the fires after both the 1994 earthquake in Los Angeles, and the 1989 San Francisco earthquake. [11,12] Even in the absence of an earthquake, accidents have broken more than 9,000 pipelines between 1986 and 2016, almost one a day, and killed 548 people.[13] For example, in 2010 a major gas main in San Bruno, CA exploded into flames 1,000 feet high, killing eight people, wiping out 38 homes and damaging 70 other homes, and leaving behind a 40' deep crater.[14] Further, the National Fire Protection Association found that natural gas use in homes is responsible for almost half of residential house fires, each year directly causing 51 deaths and 194 injuries on average.[15]

Public Health: All-electric buildings improve *indoor* air quality and health by eliminating natural gas combustion inside homes. Burning of gas in household appliances produces harmful indoor air pollution, including nitrogen dioxide, carbon monoxide, nitric oxide, formaldehyde, acetaldehyde, and ultrafine particles.[16] The carbon monoxide produced by burning gas indoors can be lethal without proper venting; according to U.S. EPA, carbon monoxide poisoning results in roughly 15,000 emergency room visits and 500 deaths every year.[15] The California Air Resources Board warns that "cooking emissions, especially from gas stoves, have been associated with increased respiratory disease." (*see Smog in Your Kitchen sidebar*) In fact, the pollution from gas stoves doubles the odds of a home chef experiencing symptoms of lung and heart disease and triples the odds that a home chef will need to take asthma medication.[17]

"Routing a boiler flue up and down a tall building and fresh air requirements for boiler rooms can be challenging. Heat pumps give you flexibility in location, and there are significant safety benefits by eliminating gas. Water heaters pulling loose from gas connection is a major source of fires after earthquakes. We need to anticipate the future, the grid will be even cleaner, codes will be tighter." - ***Arup***

10 Interactive State Decarbonization Tracker at www.sepapower.org/decarbonization-tracker/
11 California Seismic Safety Commission. (2002). "Improving Natural Gas Safety in Earthquakes." SSC-02-03
12 Taylor, A. (2014) "The Northridge Earthquake: 20 Years Ago Today." The Atlantic.
13 Joseph, G. (2016). "30 Years of Oil and Gas Pipeline Accidents, Mapped." Citylab.
14 National Transportation Safety Board. (2011). Accident Report – San Bruno Pipeline Rupture. American Gas Association. https://www.aga.org/research/reports/ntsb-accident-report---san-bruno-pipeline-rupture---sept-2011/
Image from: Weiss, J. (2016) "Govt: PG&E ordered destruction of evidence after deadly blast" CNBC <https://www.cnbc.com/2016/01/13/govt-p-g-and-e-ordered-destruction-of-evidence-after-deadlysan-bruno-blast.html>
15 San Francisco Department of the Environment. (2017). Methane Math: How Cities Can Rethink Emissions from Natural Gas. <https://sfenvironment.org/sites/default/files/fliers/files/methane-math_natural-gas-report_final.pdf>
16 Singer, B. (2018). Healthy Efficient Homes: Research Findings. ACEEE 2018 Conference on Health, Environment and Energy. <https://aceee.org/sites/default/files/pdf/conferences/chee/2018/1b.singer.pdf>
17 Jarvis et al. (1996) "Evaluation of asthma prescription measures and health system performance based on emergency department utilization." https://www.ncbi.nlm.nih.gov/pubmed/8618483
All quote bubbles are from Scott Shell's Memo "Are We Ready for All-Electric Buildings?" < https://tinyurl.com/y3unn3r4>

All-Electric buildings are more efficient, and in most states produce lower utility bills. In California the number one use of payday loans is paying utility bills, with an average of 150 days of debt at a 400% APR.[18] Due to rapid gains in efficiency, electric appliances can lower home utility bills by up to $800 annually.[19] Even using the federal minimum efficiency heat pump, it will be at least double the efficiency of the most efficient gas appliance (Figure 7). The Department of Energy produces "yellow tags" showing the annual cost of operation using national average utility prices, and efficient heat pump water heaters are about 40% less expensive to operate than the highest performance gas water heaters using the national averages, about 30% less expensive than California averages (Figure 8).

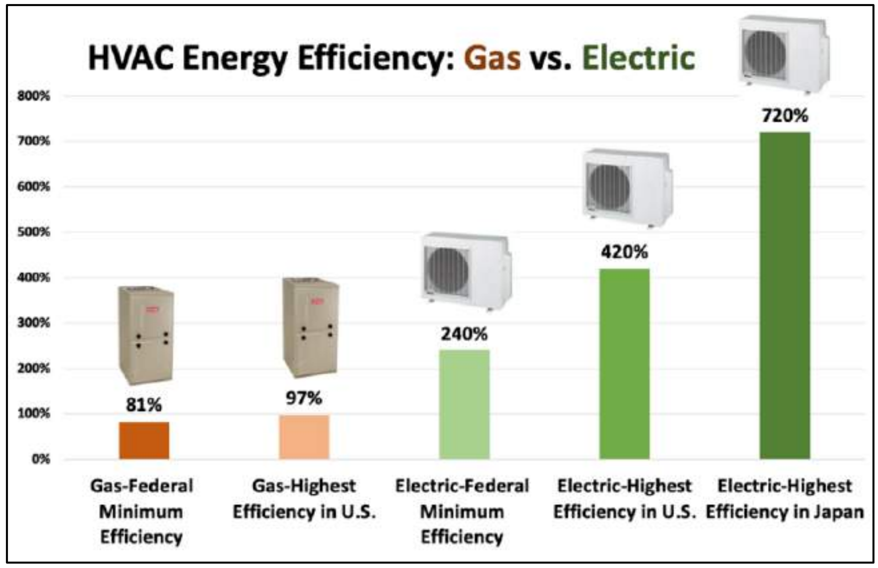

Figure 7: The relative efficiency of gas vs. electric Heating and Cooling products. Air source heat pumps collect more energy than they use. (Image by Redwood Energy).

Figure 8: Estimated yearly energy cost of an electric heat pump water heater (shown) vs. gas water heater.

Solar: Not only can multifamily developers lower tenant utility bills by building all-electric, owners of both affordable housing and market rate housing can study the debt required to install tenant-serving solar arrays (e.g. Community Solar) vs. increased rental revenue. In states with favorable solar feed-in rates, the payback is 4-8 years for installing solar to serve tenants. The option of profiting with solar power makes electrification of all end uses, paired with solar, a profitable practice for developers.

Civic Action: Since 2014, no new gas pipelines have been installed to 10 Massachusetts towns due to public opposition, and moratoriums on new gas hook-ups have led to all-electric multifamily developments.[20] In nearby New York State, utilities have twice been denied a permit to run a new gas pipeline north of the Bronx, leading to moratoriums on new gas connections and all-electric multifamily developments in Yonkers, White Plains and New Rochelle, with a further gas hook-up moratorium anticipated on Long Island in 2019.[21] In California, where gas power plants are being replaced with

18 Levy, R. and Sledge, J. (2012) A Complex Portrait: An Examination of Small-Dollar Credit Consumers. Center for Financial Services Innovation.

19 Synapse Energy Economics, Decarbonization of Heating Energy Use in California Buildings at 2, 39 (Oct. 2018), http://www.synapse-energy.com/sites/default/files/Decarbonization-Heating-CA-Buildings-17-092-1.pdf

20 Young, C. (2019). "Natural gas hookups off limits in more Mass. towns" Boston Business Journal. <https://www.bizjournals.com/boston/news/2019/02/19/natural-gas-hookups-off-limits-in-more-mass-towns.html>

21 West, D. (2019). "Con Ed Cuts Off New Gas Hookup in New York Suburb." The New York Times. <https://www.nytimes.com/2019/03/21/nyregion/con-ed-natural-gas.html>

wind and solar,[22] the electrification opportunity has been embraced by some utilities. For example, the Sacramento Municipal Utility District, for example, now offers up to $13,500 per house to electrify the existing gas appliances.[23]

The edited interview below by Sean Armstrong of Redwood Energy of Dr. Brett Singer of Lawrence Berkeley National Laboratories and Senior Fellow Bruce Nilles of the Rocky Mountain Institute was conducted via email between May 29th and June 1st, 2019 to generate the factual answers we came to and the title of our discussion:

"The Smog in Your Kitchen"

Sean Armstrong: A New Yorker article in April of 2019 about the hidden air pollution in our homes[26] said kitchen air during cooking was so dirty that there is actual smog formation after twenty to thirty minutes of cooking on a gas stove. Was that an exaggeration?

Dr. Brett Singer: If you add pollutants like NO2 from gas stoves to the cooking emissions, it is a mixture of pollutants deserving of a name like "smog," although that name is already taken by outdoor air pollution.

Sean Armstrong: Bruce, you wrote in the New York Times[27] in May of 2019 that NO_2 "can easily reach levels that would be illegal outdoors."

Bruce Nilles: NO_2 is one of the main pollutants from gas stoves, and it is both linked to childhood asthma in otherwise healthy children, and worsens pre-existing breathing problems.[28] That is why the EPA sets outdoor health-based standards for NO_2, but gas stoves cause indoor NO_2 levels that can be worse than outdoor air next to gas power plants and highways.

Sean Armstrong: What do you think is the significance of gas stove operation specifically on multifamily indoor air quality?

Dr. Brett Singer: In our research the issue is most acute in smaller homes. Just using a couple of gas burners got to problematic levels of NO_2 in all the smaller homes.

Sean: Are indoor levels of NO_2 from the gas stove as high as those found outside on photochemical, LA-style smoggy days?

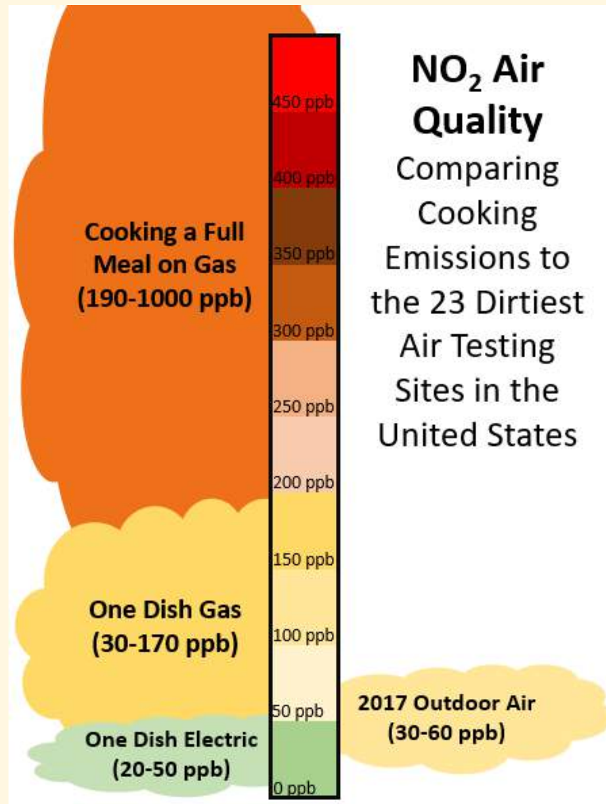

Figure 9: Comparison of 2017 outdoor NO2 air quality data[24] and cooking NO2 emissions for various tests: full meal on gas and single dishes (stir fry, tortillas, French fries)[25].

Bruce Nilles: Yes, the levels of NO_2 in your kitchen are often higher than the EPA's threshold of 100ppb outdoors. The California Air Resources Board found gas stoves producing 190 ppb to 1000 ppb of NO_2 in the kitchen after cooking a full meal, and even cooking individual dishes on gas stoves produced air quality that would be illegal outdoors.[29]

Sean: So cooking on a gas stove produces NO_2 pollution as bad as the dirtiest city air in the dirtiest 23 cities in the U.S.?

Bruce Nilles: Or worse. Every county in the U.S. today is in compliance with the EPA health-based NO_2 standards outdoors, but not our kitchens if we have a gas stove.

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22 Specht, M. (2019). "Natural Gas Power Plant Retirements in California" Union of Concerned Scientists. < https://blog.ucsusa.org/mark-specht/gas-retirements-california>

23 Sacramento Municipal Utility District. (2019). "A whole house approach to energy efficiency" <https://www.smud.org/en/Rebates-and-Savings-Tips/Improve-Home-Efficiency>

24 U.S. Environmental Protection Agency. (2018). Nitrogen Dioxide Trends. <https://www.epa.gov/air-trends/nitrogen-dioxide-trends>

25 California Air Resource Board. (2001) Indoor Air Pollution from Cooking. < https://ww2.arb.ca.gov/resources/documents/indoor-air-pollution-cooking>

Also see: issues: https://www.fresnobee.com/opinion/readers-opinion/article222726175.html and https://ehjournal.biomedcentral.com/articles/10.1186/1476-069X-13-71

26 Twilley, N. (2019). "The Hidden Air Pollution in Our Homes" The New Yorker. < https://www.newyorker.com/magazine/2019/04/08/the-hidden-air-pollution-in-our-homes>

27 Gillis, J. and Nilles, B. (2019). "Your Gas Stove Is Bad for You and the Planet" The New York Times. < https://www.nytimes.com/2019/05/01/opinion/climate-change-gas-electricity.html>

28 Kile, M. et al. (2014). "A Cross-Sectional Study of the Association between ventilation of Gas Stoves and Chronic Respiratory Illness in U.S. Children enrolled in NHANESIII." Environmental Health Journal.

29 California Air Resource Board. (2001) Residential Cooking Exposure Study Finds Unhealthful Levels. < https://ww2.arb.ca.gov/resources/documents/indoor-air-pollution-cooking>

Electric and Zero Carbon Building Policies

> *"Comparing high-performance design [construction costs] (LEED gold, better than Title 24) then electric is cheaper. There are significant code changes in California energy code in 2019 that will make electric even more cost competitive." - **Eric Solrain, Integral***

Electrification paired with cheap renewable energy is on a path to policy permanency, a practice first driven by developers and now supported by policies and buildings codes that seek both energy efficiency and accelerated carbon reduction. In New York City, where buildings larger than 25,000 square feet must cut carbon pollution 40% by 2030,[30] high performance electric heat pumps can out-perform the best gas devices. California is an example of a leading state in climate policy[31] including these three noteworthy laws:

- The Global Warming Solutions Act of 2006 (AB 32) requiring 20% of 1990 greenhouse gas pollution by 2050.
- California Renewables Portfolio Standards of 2018 (SB 100) requiring 100% carbon free electricity by 2045.
- The Low Emissions Buildings and Sources of Heat Energy Act of 2018 (SB 1477) providing direction to State energy agencies to pursue electrification of buildings as an essential strategy to curb climate and air pollution.[32]

Cities and Counties within California often provide early environmental leadership. Examples of local leadership electrification codes include:

- The University of California will no longer use fossil fuels, such as natural gas, for space and water heating, in new buildings or major renovations after June 2019, for all ten of their campuses.[33]
- The City of Berkeley plans to ban gas in new multifamily housing in 2020;[34]
- The City of Hayward has banned gas hook-ups for all new multifamily projects in the Downtown;[35]
- The City of Arcata's plan for a complete moratorium on gas hook-ups in all new construction and municipal rehabs in 2020;
- The City of Los Angeles policy is to no longer permit gas in new construction starting in 2030;
- The Silicon Valley City of Sunnyvale gives valuable development bonuses to all-electric buildings;[36]
- City of Carlsbad requires either an inexpensive electric heat pump water heater or a solar hot water array;[37]
- In 2016 the City of Palo Alto and the County of Marin adopted Green Building Ordinances that support electrification.[38]
- More than 40 California jurisdictions (LA County, Santa Monica County, San Jose, San Francisco) are working on reach codes for 2020 that support electrification.[39]

Decarbonization Goals. The efficiency of high-performance heat pumps (e.g. greater than 310% efficient) is an opportunity to reduce greenhouse gas pollution even when electrical power is created exclusively with fossil fuels, although many cities are swiftly moving towards carbon free power. The City of Vancouver, which uses clean hydro power, has a carbon standard for buildings that will effectively require all electric buildings by 2030,[40] while the City of

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30 Durkin, E. (2019). "New York City unveils ambitions plan for local steps to tackle climate change." < https://www.theguardian.com/us-news/2019/apr/18/new-york-city-buildings-greenhouse-gas-emissions>
31 See https://www.climatechange.ca.gov/state/legislation.html for a more comprehensive list of California's climate legislation.
32 CEC. (2019). "Integrated Energy Policy Repot" <https://www.energy.ca.gov/2019_energypolicy/ Also see: https://www.sierraclub.org/articles/2019/02/california-energy-commission-prioritizes-building-electrification>
33 Gerdes, J. (2018). "California Universities Are Transitioning to All-Electric Buildings" <https://www.greentechmedia.com/articles/read/california-universities-are-transitioning-to-all-electric-buildings>
34 Berkeley City County. (2019). Berkeley City Council Facilities, Infrastructure, Transportation, Environment and Sustainability Committee Regular Meeting. <https://www.cityofberkeley.info/Clerk/City_Council/2019/03_Mar/Documents/03-07_Facilities_Committee_Agenda_Packet.aspx;
35 Placeworks. (2019). Hayward Downtown Specific Plan and Associated Zoning Code Update Draft EIR. <https://www.hayward-ca.gov/sites/default/files/documents/draft-environmental-impact-report.pdf>
36 Sunnyvale. (n.d.) "Green Building Program" <https://sunnyvale.ca.gov/civicax/filebank/blobdload.aspx?t=42455.06&BlobID=26418>
37 http://www.carlsbadca.gov/services/depts/pw/environment/cap/waterheat.asp
38 CEC, Local Ordinances Exceeding the 2016 Building Energy Efficiency Standards, https://ww2.energy.ca.gov/title24/2016standards/ordinances/
39 DelForge, P. (2019). "CA Local Governments Take Lead on Zero-Emissions Buildings" National Resource Defense Council. <https://www.nrdc.org/experts/pierre-delforge/ca-local-governments-take-lead-zero-emission-buildings>
40 City of Vancouver (2019). Vancouver takes next step to advance Renewable City Strategy. <https://vancouver.ca/news-calendar/vancouver-takes-next-step-to-advance-renewable-city-strategy.aspx>

San Jose is already promoting Zero Net Carbon (ZNC) commercial and residential buildings that source energy through their clean grid through its recently approved Climate Smart San José.[41]

The decades of energy efficiency codes, policies and programs have always been for the benefit of reducing energy costs and the upstream generation costs and environmental impacts. But it is the growing spotlight on the relationship between building's energy use and carbon, and the efficiency gains and cost reductions in renewable generation, that is making electrification the policy trend and our future.

All-electric design is better for Tenants as well as Builders

All-electric construction has benefits for developers, residents, the community and the environment- from GHG savings, to reduced energy usage and bills, and construction cost savings, as well as improved air quality, health, and safety. When on-site renewable energy and storage is included, all-electric projects also boost resilience for tenants and the community. Looking to the future where resiliency strategies will become the business as usual, all-electric project will have lower costs to include energy storage and other sustainable tactics.

Best practices for new developers of all-electric multifamily housing (particularly on the first project):

- Have an internal point person for all-electric construction to drive internal decision-making.
- Have a project team/consultant with technical expertise
- Engage asset managers in the design process to ensure the equipment will be properly maintained.

All-electric homes deliver on comfort, health, safety, and affordability for tenants. Higher performing homes with more efficient equipment are more comfortable to live in and more affordable to operate. Reducing utility costs for low income households can have tangible health impacts, such as having more money to pay for food, medicine and medical care; reduced stress related to finances; and being able to afford to operate heating and air conditioning systems. Also, reduced utility bills for tenants can boost the local neighborhood economy – less money spent on utility bills can lead to more spending at local businesses. As mentioned earlier, rate design will have a significant impact on the operating costs. Pairing all-electric homes with photovoltaics can offset usage and costs which reduces energy bills for residents further.

Considerations to Maximize Resident Benefits

- Explain benefits of comfort, health and safety. Occupants feel taken care off and safe in these homes.
- Explain the equipment and how it operates efficiently. This equipment is new to the design and construction teams and is definitely new to residents. Sometimes well-functioning equipment can be perceived as expensive to operate.
- Ensure that control strategies are accessible to user and make sense. Over-complicated strategies result in in-efficiency. Pre-program controls to support best operating conditions.
- Make tariff structures understandable. Provide estimates of expected utility costs as reference.

In addition to the indoor air quality benefits discussed above, studies of energy efficiency improvements found sound evidence that efficiency upgrades improved overall health, respiratory conditions, allergies, headaches, cardiovascular conditions and mental health.[42] Homes that are dry, clean, safe, well- ventilated, pest and contaminant-free, well-maintained, and thermally controlled are healthier for occupants. [43] In addition, induction cooking technology is safer than gas and electric resistance appliances resulting in fewer burns. Because this technology conducts heat magnetically directly to the pot, it heats up quickly and does not result in a hot surface after a pan is removed.

41 City of San José. (n.d.) Climate Smart San José. <http://sjenvironment.org/cssj>
42 E4TheFuture (2016). Occupant Health Benefits of Residential Energy Efficiency. <https://e4thefuture.org/wp-content/uploads/2016/11/Occupant-Health-Benefits-Residential-EE.pdf>
43 Harvard T.H. Chan School of Public Health. (2017). The 9 Foundations of a Health Building. <https://forhealth.org/9_Foundations_of_a_Healthy_Building.February_2017.pdf>

Multifamily Electrification Best Practices

Below is a list of recommendations for designing an all-electric multifamily development, either in new construction or when electrifying an existing gas load.

1. **Power and Energy**: In multifamily housing, design towards lower power demand (e.g. 15amp rather than 30amp heat pumps for both HVAC and Hot Water) and more energy efficient equipment (e.g. EF=3.7 Hot Water rather than EF=2.9 Hot Water) to:
    a. lower infrastructure costs (e.g. 100amp panel rather than 200amp panel leads to a smaller service and smaller transformer). However, in new development where each apartment has its own dedicated PV system, a 200 amp service panel is required.
    b. lower annual utility bills (e.g. a heat pump water heater uses 1/4th the energy of an electric resistance tank, enough electricity savings to drive 12,000 miles/year in an electric car), and
    c. allow for complete solar offset of multifamily housing up to six stories under the roof, taller with additional façade solar or solar on adjacent buildings.
2. **New Construction Hot Water**: Because multifamily housing has fewer exterior surfaces than single family homes, in new multifamily housing Hot Water is often the largest energy use rather than HVAC. Best Practices to consider in new construction of hot water systems include:
    a. The least energy use design is individual tanks per residence, which avoids recirculation energy loss 40% to 100% more energy than tanks, plus ~10% more pump energy. Drain-line heat recovery
    b. The least cost design is sharing individual 80-gallon tanks at 140F between two family units and up to seven senior studios. Solar offset is less expensive with PV than solar thermal.
    c. The least wait time is provided by a manifold with ½ or 3/8-inch copper piping, insulated, to each fixture. Note that PEX fittings lose more pressure (psi) than copper, sometimes lowering delivered pressure unacceptably at the fixtures. Use thermostatic shut-off shower valves for additional water and energy savings.
3. **Retrofit Construction Hot Water**:
    a. Install more efficient domestic hot water end uses--showerheads, faucets, dishwashers, and laundry washers--and insulate accessible pipes, which reduces the heat pump and storage tank costs, may avoid power upgrade costs, and lowers utility bills.
    b. Minimize any crossover in a central domestic hot water recirculation system by repairing or eliminating single handle shower and faucet valves and balancing the recirculation system. This will improve central heat pump water heater performance.
    c. For buildings with a central gas DHW plant with pipes running underground to multiple buildings, consider a retrofit of one HPWH system per building to dramatically reduce distribution energy losses.
4. **Insulation and HVAC**: HVAC energy use can be a small or large load, and comfortable or not, depending on the design of the building shell and equipment chosen.
    a. Energy Star for Homes construction standards for the building shell, appropriate to climate, are thorough and generally cost-effective.
    b. Choose inverter-controlled heat pumps rather than single speed heat pumps. The newer (~2001) inverter-controlled compressors are half as loud, ~30% more efficient and can produce their rated heat at -5 to -22F without electric resistance back-up.
5. **Solar Power**: Whenever feasible, incorporate onsite solar PV systems to provide low cost, clean energy to residents. Recommendations include:
    a. For a low-cost solar array, design for a large amount of unbroken/single plane, unshaded roof.
    b. If the ground is not available for heat pump compressors, avoid roof mounted compressors by using Packaged Terminal Heat Pumps (PTHP) or Vertical Terminal Heat Pumps (VTHP)
    c. If roof-mounted compressors are on a roof with parapet walls, hang mini-split compressors from the parapet walls to free roof space

d. Plumbing vents can be beneath solar panels with a 4" or greater airgap, but gas exhaust vents cannot.
e. If appropriate to the building type, a solar array with edge-to-edge panels produces the most energy per square foot of roof. It should be sloped at greater than 5% to shed rain and dust, while 45%+ is required to shed snow.

6. **Laundry** energy use can rise to become the number one load in an otherwise efficient apartment design. Many multifamily developers targeting Zero Net Energy move in-unit laundry to a central facility to cut laundry loads in half, while other use Condensing Washer/Dryers and Heat Pump Dryers to cut energy use 40%-60%.[44]

Case Studies

Developers generally pursue all-electric construction first because it lowers construction costs to not have additional, unnecessary gas infrastructure. All-electric multifamily housing has been built since the 1960s (e.g. Waikiki Beach region of Hawaii), and recently solar panels have been added to highly efficient electric developments in New York, California, Pennsylvania, Chicago, Denver, Washington D.C. and elsewhere, often with the goal of "Zero Net Energy" offset. Below are notable examples with a brief explanation of their electrification strategy.

Coliseum Place, Oakland, CA

Coliseum Place is a 6-story high-rise multifamily developed by RCD Housing and designed by David Baker Architects with Redwood Energy for 59 low-income families in Oakland, California. Savings related to the hot water design were significant--$32,000 from not installing gas piping to a boiler, and $200,000 from sharing one 80-gallon heat pump tank per two apartments, rather than a whole-building central system.[45] To provide hot water to all fixtures in less than 30 seconds, 3/8th inch and 1/2 inch piping from manifolds from the 80 gallon tanks provide hot water within 10 to 30 seconds.

Illustrated Design Principle: The "mini-plant" DHW design - where multiple residences share an 80-gallon HPWH - is estimated to cut the DHW energy in half – nearly the total amount of the projected HVAC energy use.

HVAC	LG PTHP + Resistance Backup
DHW	"Mini-Plant" 80-gal Rheem HPWH, 2.4 apts/tank
Cooking	Glass Top Electric
Envelope	R15 + R4

Rather than $13,000 ducted mini-split heat pumps, the apartments use $8,000 worth of efficient, whisper-quiet package terminal heat pumps (PTHPs) in the living room and master bedroom, with baseboard heating in additional bedrooms. The solar array has a profitably payback even with sized to 100% of the six-story building's demand with a canopy, but cost-constraints limited it to low cost 40% offset.

44 EPA Energy Star Product Finder Certified Clothes Dryer Results. June 2019. <https://www.energystar.gov/productfinder/product/certified-clothes-dryers/results>
45 Cost savings provided by lead Architect, Katie Ackerly, on June 26th, 2019 from pricing by Nibbi Brothers General Contracting.

Illustrated Design Principle: switching from a centralized hot water system to a "mini-plant" system was equal in energy savings to passive house design. (Image: footnote 46)

HVAC	Ducted mini-splits
DHW	Mini-Plant 80-gallon HPWH
Cooking	Induction
Envelope	Passive House

Hillandale Gateway, Silver Spring, MD

An eleven story tall, 500 unit, solar powered, Passive House apartment complex developed by Duffie Inc. with Redwood Energy and NK Architects will showcase Zero Carbon design to 250,000 commuters a day on the Washington DC Beltway. The apartments will serve low-income senior and market-rate households in Silver Spring, Maryland. While the developer committed early to Passive House design to minimize HVAC loads, in the design process it was discovered that *avoiding a hot water recirculation system saves an equal amount of energy* to the Passive House measures to save HVAC energy (~600kWh/year/apartment). Rather than a recirculation system, instead the apartments will share 80-gallon heat pump tanks among two to four apartments—centralized, but without the energy losses and additional costs of a recirculation system. The proposed HVAC is whisper-quiet, cold-climate ducted minisplit heat pumps located on the patios, rather than a "compressor garden" on the roof that would compromise the green roof goals and double installation costs.

Hollywood Palms, San Diego, CA (Retrofit)

Hollywood Palms illustrates how experienced green developers find the greatest net financial benefit from electrifying tenant gas loads and then providing 100% site solar offset. Redeveloped by Affirmed Housing with Redwood Energy's support, Hollywood Palms offers 94 affordable housing rental homes for families. No additional construction cost was associated with retrofitting from gas heating, water heating, cooking and dryers to all-electric equivalents. With low-cost, high-productivity rooftop solar, the increased cash-flow from solar-offset electric bills had a four-year payback and 20+ years of profit. In addition to being energy efficient, Affirmed Housing offers programs in education, healthy living, job readiness, life skills, after school homework help, an onsite fruit garden and a compost program that provides fresh produce to the residents.[47]

Illustrated Design Principle: In this retrofit scenario there were no additional costs to transition to electric stoves and heat pumps, and the project was able make a profit off the 100% solar offset array.

HVAC	Heat pump heating and cooling
DHW	Heat pump water heater
Cooking	Electric Glass Top
Envelope	Existing

46 Email Correspondence with Goyer Roberts, PMP at The Duffie Companies.
47 Affirmed Housing (2019). <https://affirmedhousing.com/completed/hollywood/>

HVAC	Combined HVAC and DHW with Geothermal Heat Pump
DHW	
Cooking	Electric Radiant Glass Top
Envelope	Passive House

Phase III of The Battery, Philadelphia, PA

The Battery project is Phase III of Capital Flats. Developed by Onions Flats in 2017, it provides sustainable and market rate housing for Northern Liberties, a community in Philadelphia, PA. This project offers 25 "micro" 500 sf zero net energy units of all-electric PHIUS + certified multifamily housing for young professionals looking for an affordable housing option, with rent that includes utilities. To achieve this affordability and density – maximized zoning allowances, density bonus incentive for green roof, solar orientation and two 1,000-foot deep geo-thermal wells providing heating, cooling and hot water to all apartments.[48] The envelope is prefabricated and super insulated with triple pane windows. With a 72 kW PV canopy array, it consumes 80% less than a similar code building. All-electric and passive house design are now the standard for construction for Onion Flats.

Belfield Townhomes, Philadelphia, PA

This project was developed by Onion Flats and serves as an example of affordable and sustainable housing in Philadelphia and received the 2014 International Passive House award presented by the Passive House Institute (PHI) in Darmstadt, Germany and a 2nd Place Award in Affordable Housing by the Passive House Institute US (PHIUS) as well as being the first Passive House and zero net energy project in Pennsylvania.[49] The building components include an air tight envelope, triple glazed windows, rotary wheel heat exchanger for ventilation and frost protection, an Ultimate Aire ERV with a GE PTAC, and a 50 gallon GE heat pump water heater.[50,51]

HVAC	Ultimate Aire ERV + GE PTAC
DHW	Individual 50-gal HPWH
Cooking	Induction
Envelope	Passive House

48 Onion Flats. (2017). "Phase 3: The Battery" <http://www.onionflats.com/projects/all/phase-3-the-battery.php>
49 Onion Flats. (2012). "Belfield Townhomes" <http://www.onionflats.com/projects/affordable/belfield-townhomes.php>
50 Passive House Institute. (2014). Passive House Projects the 2014 Passive House Award Winners. <http://www.onionflats.com/pdf/PHi_award_publication_belfield.pdf>
51 Email correspondence with Timothy McDonald Onion Flats President. 5/9/2019.

Edwina Benner Plaza, Sunnyvale, CA

Illustrated Design Principle: While it saves space, even an efficient central domestic hot water system loses as much heat as it delivers from the additional piping for recirculation. (Image: Keith Baker Photography)

HVAC	Individual unit mini splits, ducted heat pump for common spaces
DHW	Central heat pump
Cooking	Electric Resistance Coils
Envelope	R21 / CMU + R8

Edwina Benner Plaza, by MidPen Housing, is a 4-story multifamily residential building, with ground floor parking, common areas, and playground, and three stories of units above. The 66-unit family housing development completed construction Q4 2018, and has been fully-occupied since Q1 2019. The building sits on a 1.3 acre lot, and includes significant outdoor amenities for residents. Apartments are heated and cooled with ductless mini-split heat pumps, while common areas are heated and cooled via ducted heat pumps (17-20 SEER). Domestic hot water is provided by two innovative central heat pump water heating plants with Sanden heat pumps that utilized super-climate-friendly CO_2 refrigerant, paired with large storage tanks to shift heat pump loads away from peak periods. Edwina Benner Plaza has a solar PV system on the roof that is projected to offset 50% of the annual energy use of the entire building.

The Colonial House Apartments, Oxnard, CA

This LEED Platinum, ~66% solar offset affordable housing complex was developed by The Pacific Companies in 2014 with Redwood Energy's support. The building is mixed use and 3-stories where the bottom floor is commercial space, and the top floors contain 44 apartments including one to four-bedroom units with a total of 46,552 square feet. For each apartment heating is provided by electric resistance baseboard heaters and no cooling. Heat pump water heaters provide water heating with a 2.35 EF and all hot water piping is insulated. In addition to the mechanical systems, the building also has a radiant barrier in the attic and a cool roof.

Illustrated Design Principle: Almost Passive House performance can be achieved in coastal CA with an Energy Star good envelope and ceiling fans - only two apartments turned on space heating in the first year of operation.

HVAC	Electric resistance heating, no cooling
DHW	Individual HPWH
Cooking	Electric Resistance Coils
Envelope	Energy Star certified

Napa Creek Village, Napa, CA

Napa Creek Village, developed by Thriving Communities with Redwood Energy's support, offers a mix of higher end and workforce townhomes for sale – with a 100% solar PV offset paired with battery storage. The design of Napa creek includes high standards of green building materials, off site metal framed panelized construction that will be assembled on site. In addition, the development will include grey water recycling, LED lighting, passive heating and cooling with an HRV, optimization of building orientation, living walls and tight building envelope, recycled steel framing (recycles 6 cars per unit), electric car charging stations, and edible community gardens. It also features a rent to own program along with other financial assistance (down payment assistance, loan, mortgage).

Illustrated Design Principle: In high cost construction areas there are benefits to offsite, modular construction. Image: footnote 52)

HVAC	Ductless Mini-Split + HRV
DHW	50 gal individual HPWH
Cooking	Induction
Envelope	Passive House

Illustrated Design Principle: Comprehensive retrofit, including central domestic hot water to electric heat pump alternative. (Image: footnote 53)

HVAC	Existing Gas Hydronic Boiler
DHW	Central HPWH CO2 Sanden Plant
Cooking	Electric Resistance Coils
Envelope	Existing Masonry

205 Jones Street, San Francisco, CA (Retrofit)

205 Jones Street Apartments was built in 1920, remodeled by Mercy Housing in 1995 and is a National registered historic building in downtown San Francisco. Mercy Housing is the largest affordable housing nonprofit in the country, and redeveloped the building into 50 studio apartments with ground floor commercial uses.[54] In 2018 Mercy performed a deep energy retrofit and replaced the central gas boilers with central CO2 heat pump domestic water heaters, reducing the dependency on natural gas and the associate GHG emissions of the property, resulting in the 205 Jones St Apartments being spotlighted by DOE's Better Building Challenge and winning the National Apartment Association's Return on Energy Retrofit Award. These projects were also included in a larger retrofit effort funded in part by the Affordable Community Energy Services Company (ACE) "pay from savings" approach, which will provide O&M for the installed measures.

52 Napa Creek Village. (2019). <http://www.napacreekvillage.com/>

53 U.S. Department of Energy. (2018). "Mercy Housing Wins NAA's ROE Energy Retrofit Award." <https://betterbuildingssolutioncenter.energy.gov/beat-blog/mercy-housing-wins-naa%E2%80%99s-roe-energy-retrofit-award>

54 Mercy Housing. (2019). "Mercy Housing Makes Affordable Housing Green Through Energy and Water Efficiency Upgrades" <https://www.mercyhousing.org/2017/09/mercy-housing-makes-affordable-housing-green-through-energy-and-water-efficiency-upgrades/>

St. Marks Hotel, Oakland, CA (Retrofit)

St. Marks Hotel is a historic hotel originally built in 1906 that hosted then President Taft in 1909. It has since been remodeled into permanent housing and contains 102 apartments. The 2018 deep energy remodel with the support of Redwood Energy and the Alliance for Energy Affordability has reduced site energy by 44%. The 80% efficient boilers were replaced with 400% efficient centralized heat pumps to meet 95% of the load, with the existing gas boiler retained due to lack of power supply to complete the electrification of Hot Water and Space Heating. An economic analysis showed that replacing the gas hot water boiler with a heat pump boiler was a more cost-effective strategy than retrofitting the windows, which are not only expensive to replace, but are also not as beneficial in this type of temperate climate due to the minimal space heating loads in the building.

Illustrated Design Principle: Retrofit single largest gas appliance with electric heat pump alternative, reduce consumption of other electric end uses, and offset with Solar PV.

HVAC	Existing Gas Hydronic Boiler
DHW	Central HPWH CO2 Sanden Plant
Cooking	Electric Resistance Coils
Envelope	Existing Masonry

Waikiki Skytower, Honolulu, HI

Waikiki Skytower is an example of the dozens of all-electric high-rises on the island of Oahu. These luxury condos and apartments were built in 1978, and later retrofitted with a Colmac heat pump for central domestic hot water and the swimming pool. Inside the condos, each kitchen has a radiant glass-top electric range, and electric dryers. The poolside lifestyle also is all-electric, including electric BBQs and an electric sauna. The building has 102 units and 30 floors, where each 694 sf room is a corner unit.[55]

HVAC	Multi-Head Ductless Mini-Split
DHW	Colmac Central Heat Pump - for hot water and pool
Cooking	Electric Glass Top
Envelope	Existing

55 Hawaii Living. (2019). Waikiki Skytower Condos Overview <https://www.hawaiiliving.com/oahu/honolulu/metro/waikiki-skytower-waikiki-condos-for-sale/>

The Eureka Homeless and Veterans Housing, Eureka, CA

This project is being built by Danco Communities in Eureka, California with Redwood Energy's support with 50 one-bedroom, 550 sf residences. The 100% solar offset apartments were built for $315,000/unit, at a cost of $572/square foot and a density of 84 units/acre. To lower costs by $3000/apt and maintain high efficiency, an 80 gallon heat pump tank run at 135F is shared among four to five apartments, rather than one smaller tank per apartment. To save $4000 per apartment the apartments use electric resistance wall heaters and Energy Recovery Ventilators (ERVs) instead of heat pumps—the cool summers in Eureka, just five blocks from the Humboldt Bay, rarely call for air conditioning.

Illustrated Design Principle: From the lessons learned at Colonial House - electric resistance heating and ceiling fans can achieve an energy efficient and comfortable design.

HVAC	Electric resistance heating, no cooling
DHW	Mini plant, 1 80 gal per four apartments
Cooking	Radiant Glass Top
Envelope	Energy Star equivalent

Casa Adelante, San Francisco, CA

Casa Adelante in San Francisco by Tenderloin Neighborhood Development Corporation, Chinatown Community Development Center and the architecture firm Mithun will provide family affordable housing and transition age youth housing with retail space on the first floor. The energy consultants, AEA, assisted in the 9 story 100% electric design which will have central Colmac air source heat pumps for hot water heating and resistive heating with no cooling.[56] The façade of the building is high performance – with 3 inches of continuous insulation and fiberglass clips with shading. Instead of centralized ductwork running down each hallway, there are Zender heat recovery ventilators (HRV) for each residence. No centralized ducting reduces pest infestation but the filters for each HRV will be replaced twice a year - timed with a health and wellness check in with each family. Additional building components includes the variable refrigerant flow systems to the common spaces, solar PV to cover all loads, and solar thermal for domestic hot water, and a highly stratified storage tank for the hot water.

Illustrated Design Principle: The combination of the high-performance façade, HRVs, and resistive heating was 1.5 million less than the cost of a traditional hydronic system.[56] (Image: footnote 57)

HVAC	Resistance Heating, No Cooling + HRV's, VRF for Common Spaces
DHW	Central HPWH Colmac + Solar Thermal
Cooking	Glass Top Electric
Envelope	3" CI, Fiberglass Clips, Shading

56 Email correspondence with Stet Sanborn of Smith Group, 2019.
57 Mithun. (2019). <http://mithun.com/2019/01/31/groundbreaking-at-2060-folsom/>

Mutual Housing at Spring Lake, Woodland, CA

Illustrated Design Principle: Combined systems can have large energy losses due to failed control system (in this case - misplacement of the temperature gauge caused the HVAC system to run constantly). This led to the design decision to transition to ductless split heat pumps and individual tank HPWH's for Phase II. (Image: footnote 59)

HVAC **DHW**	***Phase 1:*** Daikin Altherma air to water heat pump for heating, cooling and hot water ***Phase 2:*** Ductless Split Heat Pumps + Individual HPWH
Cooking	Electric Resistance Coils
Envelope	Energy Star Certified

This award-winning two-phase farmworker housing complex in Woodland, California was Developed by Mutual Housing California. It was the first 100% Zero Net Energy rental housing development in the USA to be Certified by the US Department of Energy (U.S. DOE) and has received several awards including the U.S. DOE Housing Innovation Award in 2015 and United Nations World Habitat Grand Prize in 2017. [58] Phase I was completed in 2015 and provides 62 apartments across 64,600 square feet of conditioned space. Individual units utilize air-to-water heat pumps for space heating (13 SEER, 11 HSPF) and water heating (2.4 EF).[59] Phase II will be completed in 2019 and includes 38 units across 35,000 square feet. Apartments will be heated and cooled with highly efficient ductless split heat pumps (18 SEER, 9.3 HSPF) and have individual NEEA-Rated heat pump water heaters. Phase II will perform as a Net Positive development, producing 105% of the annual energy loads on-site with rooftop solar and 5% on-site storage.

Quetzal Gardens, San Jose, CA

Illustrated Design Principle: It was determined that individual DHW systems and tanks would be more cost effective and energy efficient than a central DHW system.

HVAC	Mr. Slim Mitsubishi Mini – ducted mini splits
DHW	HPWH 65-gal tank per family apartment
Cooking	Radiant Glass Top
Envelope	R 21, R30 floor, R38 roof

Quetzal Gardens is a 6-story mixed-use, solar powered affordable family rental apartment building in the works in San Jose, California with Redwood Energy's support. The project includes a parking garage, ground-level commercial tenant spaces and 5-stories containing 71 residential units, with 21 set aside for chronically homeless individuals alongside 50 units designated for low-income residents in a mix of one, two and three-bedroom apartments. Quetzal Gardens will begin construction in 2019 on a 0.7 acre lot and will contain 66,000 square feet of conditioned space, including puzzle lifts to maximize parking and a community garden space on the 6th floor. This project will be Green Point Rated Certified and will have solar panels on the rooftop to cover 45% of the Net Energy for the entire site. Apartments will be heated and cooled with ducted split heat pumps (16 SEER, 12 EER, 9 HSPF) and the water heating will be provided by NEEA-Rated, Rheem heat pump water heaters in 50, 65 and 80-gallon tanks, for each bedroom type.

58 World Habitat. (2017). "Mutual Housing at Spring Lake- Winner 2017 United States of America" < https://www.world-habitat.org/world-habitat-awards/winners-and-finalists/mutual-housing-at-spring-lake/#award-content>

59 Mutual Housing California. (2018). *Mutual Housing at Spring Lake a Zero Net Energy Rental Housing Community*. < http://www.mutualhousing.com/wp-content/uploads/2012/02/Mutual-Housing-at-Spring-Lake-White-Paper.pdf>

Additional All-Electric Case Studies[60]

Maceo May Veterans Apartments
Treasure Island, CA
(Chinatown Community Development Center, Mithun)

Balboa Upper Yard Family Apartments
San Francisco, CA
(Mission Housing Development and Related California, Mithun)

Hunters Point Shipyard Block 52
San Francisco, CA
(McCormack, Mithun)

Hunters Point Shipyard Block 54
San Francisco, CA
(McCormack, Mithun)

681 Florida
San Francisco, CA
(Tenderloin Neighborhood Development Corporation and Mission Economic Development Agency, Mithun)

Linda Vista
Mountain View, CA
(Palo Alto Housing, Van Meter Williams Pollack, Integral)

Stoddard Housing
Napa, CA
(Burbank Housing, Dahlin Group Architects)

St. Paul's Commons
Walnut Creek, CA
(Resources for Community Development, Pyatok Architects)

2437 Eagle Ave
Alameda, CA
(Housing Authority of the City of Alameda, Anne Philips Architecture)

UC Santa Cruz
Student Housing West
(Capstone, HED Architects)

UC Riverside
Dundee Residence Hall
(American Campus Communities, SCB Architects)

UC Irvine
Student Housing West
(American Campus Communities, KTGY Architects)

UC Davis
Student Housing
(DPR GC, HKS Architects)

Station House
Oakland, CA
(City Venture, Baran Studio Architect)

Ice House
Oakland, CA
(City Venture)

60 Shell, S. (2019). Multi-Family Building Electrification Current Examples. <https://drive.google.com/file/d/1BUCtAHS0fs6CiJ1Y9lN_EOwJxPPCSQN7/view?usp=sharing> Listed under name and location of each project is the developer and architectural firm.

All-Electric Product Guides

The following product guides provide an overview of electric products on the market as guidance to electrify all the end uses in multifamily buildings. This guide includes the basics – space heating and cooling and domestic hot water – as well as cooking, laundry drying, and accessory end uses like electric fireplaces, electric cars, electric car chargers, landscaping and pool heating. This guide provides a range of sizes as well, from large centralized heating and cooling systems to commercial kitchens which offer strategies and products for larger mixed-use buildings to small systems like individual heat pump water heater tanks and tankless water heating to single burner induction stoves.

Heat pumps are the solution to meeting our largest energy demands in multifamily buildings. Heat pumps go by many names depending on their applications like “refrigerators,” “air conditioners,” “air source heat pumps,” and “reverse chillers.” The history of chemical refrigeration dates back to the 1550’s when saltpeter baths were first used to chill wine. Ice manufacturing was a booming business by the late 1700’s, and the first true “refrigerator” was built to chill beer at the nation’s largest brewery, S. Liebmann’s Sons Brewery in Brooklyn, New York in 1870. Willis Carrier is credited with inventing the air conditioner compressor in 1902[61] also in Brooklyn, NY. Residential refrigerators were common by the 1920’s, and reversible air conditioners (aka “heat pumps”) came on the market in the 1950’s.

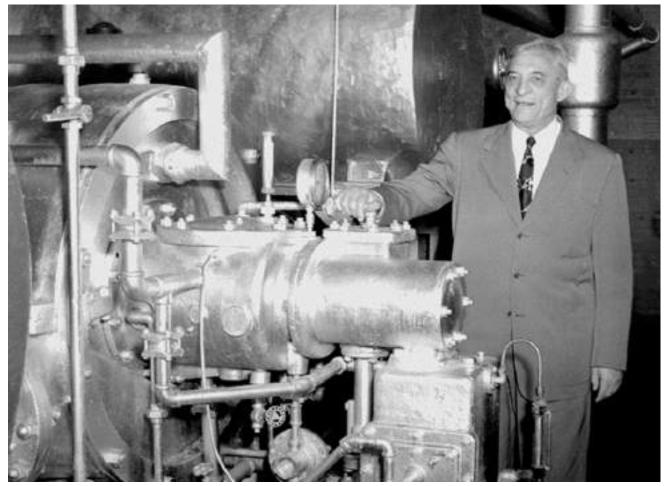

Figure 10: Willis Carrier (1922) proudly standing next to the first chiller.[61]

Heat pumps can draw their energy from three main sources --the air, the ground and water - this energy is then moved into either air, water, or refrigerants which are cycled through the building to meet heating and cooling needs. The most common and flexible heat pumps are “air source”, like that in your refrigerator or your air conditioner. Ground source and water source are a little less common and are usually used on larger scale and use the soil and bodies of water to move heat around. Sometimes, “water source heat pump” refers to a two-stage process, where there is a central air source heat pump that chills or heats water, then that water circulates through the building instead of air.

Heat pumps can move heat from one substance to another so well because of the compression and expansion of chemicals called refrigerants. There are many types of refrigerants, but the most common for heating and cooling are the Hydrofluorocarbons r410 and r134a which are newer versions of refrigerants like R22 but do not contribute to ozone depletion. However, the industry has been moving toward “natural” refrigerants like CO2 (R744), Ammonia (R717) and Propane (R290) that do not deplete the ozone and do not contribute to global warming.

Figure 11: Fujitsu heat pump in the snow (image footnote 62).

Cold Climate Heat Pumps can now collect heat down to low temperatures (-20°F)[63], where early models were limited to warmer climates. With the use of inverters, heat pumps can now accelerate their compressor pump so they can operate in below freezing temperatures. In addition to inverter technology, cold climate heat pumps have a heating element to defrost the outside unit to keep ice from forming on it.

Coldest operating heat pumps are in bold text and blue highlight in the product tables below.

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61 Long, T. (2019). “July 17, 1902 An Invention to Beat the Heat, Humidity” Wired. <https://www.wired.com/2009/07/dayintech-0717/>
62 Refrigeration Kings. (2019). “Protect Your Heat Pump From the Harsh Atlantic Weather” <https://www.kingsrefrigeration.com/residential/heat-pump-accessories>
63 Sanden. (n.d.) Heat Pump Water Heater. <https://www.sandenwaterheater.com/sanden/assets/File/SANDEN_CO2WaterHeaterG3_3_17.pdf>

Domestic Hot Water

The following section provides electric alternatives to gas water heaters, from tiny tanks to water heaters for high rises. This list includes tankless water heaters one might use in commercial bathrooms, heat pump water heaters with integrated tanks (common in new homes), heat pump water heaters using remote tanks (helpful for retrofits), and larger water heaters for whole-house hydronic HVAC.

Large Building Applications (240V-480V)

> *On the cost of large central heat pumps: "It is very difficult to get contractors to provide pricing for subsets of work within a larger scope, below is some of the best data we have to date—$1,359/Apt, an incremental cost of $600/apartment more than using a gas boiler, but the estimate does not include the savings from eliminating gas service, which can be $600-$1000/apartment."*
> ***– Shawn Oram, Ecotope***

Apartment buildings, hotels and large commercial facilities usually heat water in a central plant and plumb it throughout the building. These large heat pumps range from 10 tons to 260 tons (1 ton = 12,000 BTUh) and like any central system they require careful design of the pumps, heat exchangers and storage tanks to optimize energy use and heat pump operation. The range of operating temperatures is important—each product has a different maximum output temperature, between 120F and 180F, and a minimum operating temperature between 5F and 45F before it switches off the heat pump and uses resistance to heat the water. Resistance heating, which is 100% efficient vs. the heat pump which is 200-400% efficient should be minimized in order to get the maximum efficiency of heat pump water heaters. Distributed central systems offer an alternative to larger central systems, they are more flexible and reduce the size of heat pumps and the distribution system.

Large Applications Domestic Hot Water (240V-480V)

	Colmac CxA 	***Colmac CxV*** 	**Mayekawa Unimo "Eco Cute"** HE-HWA-2HTC 	**Aermec ANK** (030,045,050) 	**AO Smith** CHP-120 	**Nyle** (C25A-CSA250A) 
Description	Air source heat pump water heater	Air source heat pump water heater	Water source heat pump water heater	**Multipurpose heat pump -** single unit	Heat pump water heater w/ 112 gal tank	Air source heat pump water heater
Voltage (V)	230/460	230/220	400	208/230	208/240	208/230
Dimension (ft)	3W	-	4.1W x 6.2L x 6.8H	4.2H x 4.8W x 1.5D	5.7H x 1.91W x 3.25D	7L x 4.6W x 5.6H
Ref. Type	R134a	R134a	R744 (CO2)	R134a	134a	134a
Ambient Temp. Range (F)	10 (low)	**-4 – 120 (cold climate)**	14 - 110	45 - 113	20 - 110	40 - 120
Power (W)		4,900 – 6,300		2,810 – 4,520	2,350	-
Amps (A)	21.1 – 86.5	36.8	120	45	67	6.2 -23.9
Heating Cap. (BTUh)	137,500 – 419,400	31,200 – 77,900	200,600 – 284,200	37,670 – 57,598	37,977	27,450 – 272,450
Cooling Cap. (BTUh)	109,700 – 334,100	17,300 – 60,700	-	30,120 – 48,240	-	21,200 – 218,000
Heating (COP)	4.0 - 4.2	1.8 – 3.7	3.40 – 3.89	3. 1 – 4.4	4.2	4.45 - 5.18
Cooling (COP)	3.2 – 3.5	1.0 – 2.9	2.62 – 3.28	-	-	3.88 - 4.20

Individual Heat Pump Water Heaters (240V)

The below water heaters all rely upon heat pumps - no resistance models are shown due to their inefficiency. These products rely on 30-80 gallons of water storage and collect 2.4 – 3.8 units of heat for every one unit of electricity powering the air source heat pump. Some have a 4000 BTU compressor integrated on top of the tank, others use a 12,000-36,000 BTU separate compressor outside that produces more BTUs at a higher efficiency. These models can be used as either serving one dwelling unit or can be combined in a distributed central plant to feed multiple units.

	Sanden CO2 	**Rheem** Prestige Hybrid 	**AO Smith** Voltex Hybrid 	**Bradford White** AeroTherm 	**Steilbel Eltron** Accelera 
Description	Split heat pump water heater	Hybrid (WIFI option adds $150/tank)	Hybrid	Hybrid	Hybrid
Gallons	43, 83	50, 65, 80	50, 66, 80	50, 80	58, 80
Voltage (V)	208/230	208/240	208/240	208/240	220/240
Dimension (ft)	27.5H x 35W x 11D	74H x 24Diam.	69H x 27Diam.	71H x 25Diam.	60H x 27Diam.
Ref. Type	R744 (CO2)	R134a	R134a	R134a	R134a
Ambient Temp. Range (F)	**-20 – 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 (BTUh)	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

Small Demand and Low Voltage Applications (120V)

Electric resistance water heaters are best used where hot water is needed in small amounts or when a project requires strict voltage limitations. Tankless water heaters can be used in a restaurant or office bathroom, or a 120 sf tiny house that has no room for a 50-gallon tank or that is not sharing water system with other tiny homes. Electric resistance uses 2 - 4 times more energy than a heat pump but can be the right size for the right demand and they are helpful when there is no 220V electricity available. The 2 to 7-gallon tanks on the market use 120V, while anything larger uses 240V for more heating capability.

	Stiebel Eltron Mini-E Series 	**Stiebel Eltron** SHC Series 	**Bosch Tronic** 3000 Series 
Description	Tankless, Point of use	Mini tank, Point of use	Mini tank, Point of use
Gallons	0.21 (gpm)	6, 4, 2.7	7, 4, 2.7
Voltage (V)	120/110	110/120	120
Dimension (ft)	6H x 7W x 3D	20H x 15W x 15D	17H x 17W x 14D
Power (W)	1,800	1,300	1,440
Max Amps (A)	15	11.3	12
Heating (COP)	0.98	0.98	0.98

Best Practices for Heat Pumps Central Domestic Hot Water Systems[64]

Using heat pumps to provide space cooling dates to the 1920s, for space heating to the 1940s, but using compressors to heat domestic hot water for cafeterias, apartment complexes, dairies[65] and other large uses dates only to the 1970s, and has advanced further in Asia where efficiency is more valued. Consequently, there is less familiarity among North American designers of both the products and practice of designing commercial hot water systems using heat pumps. Below is helpful guidance from the engineers at Ecotope of Seattle, the most experienced designers (25 systems so far) of central domestic hot water heat pumps in North America.

1. ***Heat pumps are not boilers***. Do not oversize the central heat pump for faster recovery, which leads to both higher construction costs and equipment failure. Instead use a series of dispatchable 5-15 ton heat pumps, rather than one larger (e.g. 60 ton) heat pump, and favor hot water storage over hot water production.
2. When designing hot water systems, ***split the pipe recirculation heat loss load from the usage load***. Temperature maintenance of recirculating water is ideal for "multi-pass" heat pumps that handle 110F incoming water (e.g. Aermec, Daiken) and perform 10F temperature bump-ups, while meeting peak loads is best done with a "single pass" heat pump (e.g. Sanden, Colmac) that uses cold incoming water, not recirc water, to efficiently lift temperatures from 50F to 150F.
3. ***Install "heat traps"*** on both hot and cold water sides of storage tanks to prevent migration and mixing.
4. ***Reduce pipe surface area*** to greatest extent possible. Insulate remaining pipes with 1"-4" of foam, depending on space availability. Insulate tanks to at least R-19, same as an outside wall, due to the even more extreme heat loss than found in a wall.
5. ***Design diagnostics into crucial points in the heat plant and distribution system***—electrical gauges to measure power quality, temperature gauges to monitor heat gain and loss, and control valves on the discharge side of pumps to measure pump flow
6. ***Provide redundancy in heat pumps and choose electric resistance storage tanks*** for a durable, dependable design for the eventuality that system components need maintenance.
7. ***Consider adding drain line heat recovery*** to save energy while improving the hot water delivery capacity. This is a simple heat exchanger to transfer heat from the drain line to the incoming cold water input to the water heater.

Figure 12: Ecotope Case Study "RCC" system for 194 unit Multifamily building, using best practices in central heat pumps for domestic hot water, from ACEEE presentation by Shawn Oram.[64]

64 Several Presentation Links from Sean Oram of Ecotope are provided: Heat Pumps Are Not Boilers, Shawn Oram Presentation ZNE Retreat July 2018, RCC Pilot Project: Multifamily Heat Pump Water Heaters in Below Grade Parking Garages in the Pacific Northwest, Central Heat Pump Water Heating with 3 Case Studies

65 C&I Case Studies in Beneficial Electrification (2018): Agribusiness: Dairy Water Heating. Retrieved from: www.cooperative.com/programs-services/bts/documents/techsurveillance/ts-beneficial-electrification-dairy-water-heating-april-2018.pdf

Heating, Ventilation and Air Conditioning

The following guide gives an overview of heating and cooling electric systems that are widely used in multifamily buildings. The sample of products shown includes large central heat pumps, mini-split heat pumps and small packaged terminal heat pumps.

Large Application Heat Pumps (240V – 480V)

Larger application heat pumps are most typically used for central air and water systems. In some cases, apartment heating, cooling and ventilation needs are met by individual units (like PTHP's). These larger systems are used for the common space loads.

	Mitsubishi City Multi Y-Series (PUHY: P72TKMU, P96TKMU, P120TKMU, P144TKMU) 	**Mitsubishi** City Multi W-Series (PQRY: P72TLMU, P96TLMU, P120TLMU, P144TLMU) 	**Mitsubishi** City Multi S-Series (PUMY: P36NHMU, P48NHMU, P60NKMU) 	**Spacepak** Solstice (Extreme) 
Description	Air source heat pump, variable refrigerant flow	Water source heat pump, variable refrigerant flow, (use w/ air source to reach ideal temps.)	Air source heat pump	Air to water, hydronic heating and cooling
Voltage (V)	208/230	230	460	230
Dimension (ft)	5.4H x 5.7W x 2.4D	3.6H x 2.9W x 1.8D		4.0H x 4.5W x 1.5D
Ref. Type	410A	410A	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-13 – 60 / 12 – 115 (cold climate)**	50 – 113 / 50 - 113	**0 – 60 (cold climate)**	**-8 – 105 (cold climate)**
Power (W)	5,700 - 12,200	3,000 – 8,100	12,000 – 16,100	3,880 – 5,963
Max Amps (A)	23 - 53	12 - 35		23.5 - 31
Heating Cap. (BTUh)	80,000 - 160,000	80,000 – 137,00	42,000 – 66,000	42,240 – 66,480
Cooling Cap. (BTUh)	72,000 - 144,000	72,000 – 144,000	36,000 – 60,000	40,000
Heating (COP)	3.56 - 3.95	4.90 – 5.77	3.30 – 3.90	2.12 – 3.26
Cooling (COP)	3.72 - 4.22	5.50 – 6.05	3.25 – 4.16	2.43

Mini-Splits (240V)

Mini split systems are comprised of a compressor outside the building and a fan inside the building. Mini split systems can also have many fans inside the building, commonly referred to as multi split systems, where one outside unit serves multiple fans or zones inside the building. Having multiple zones in the building allows for a more controlled, versatile arrangement of installations and temperature settings compared to a typical split HVAC system. Zones can be at different temperature settings while still being served by one outside unit. Multi/mini split systems can be ductless (where refrigerant lines move heat around the building) or they can have mini ducts where air is moved around the building. There are pros and cons of ducts versus no ducts - having no ducts prevents duct leakage energy losses but having many refrigerant lines running through the building can cause problems if they leak. In general, mini/multi split systems are more efficient than typical HVAC systems. No ducting also has an advantage because of reduced fan loads. Larger variable refrigerant flow systems are also a form of a multi split system but on a larger scale (Mitsubishi City Multi Y-Series above).

	Fujitsu Halcyon Series 	**Mitsubishi** HyperCore FH50 	**LG** LMU18CHV 	**Gree** TERRA 09HP230V1AO 
Description	2 – 4 indoor units, XLTH models		2 zones	1 zone
Dimension (ft)	39H x 38W x 14D	36H x 9W x 12D	2.08H x 2.83W x 1.17	2.25H x 2.92W x 1.19D
Ref. Type	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-15 – 75 / 14 – 115 (cold climate)**	**-15 / 115 (cold climate)**	-4 – 64 F / 14 – 118 C	5 – 75 / 5 - 118
Power (W)	1,330 – 2,700	1,380 – 1,480	1.31 – 2.04	60 - 65
Max Amps (A)	16.4 - 26	13.6	11.09	7.0
Heating Cap. (BTUh)	22,000 – 36,400	10,900 – 30,700	17,000	9,800
Cooling Cap. (BTUh)	18,000 – 35,200	8,500 – 26,600	15,600	9,000
Heating (COP)	3.60 – 4.04	3.07 - 4.85	3.0	3.2 - 3.8
Cooling (COP)	3.52 – 3.60	3.31 – 5.10		3.66 – 4.25

This is an interview from 2018 between Sean Armstrong of Redwood Energy and Jonathan Moscatello of the Heat Pump Store in Portland, Oregon. Jonathan had just returned from China where he has direct import relationships for ductless mini-split heat pumps, with decades in the business.

Sean: A lot of people are not clear about how heat pumps are sold in the market. Could you explain to us?
Jonathan: Sure, it's not that complicated, but it's true that most people aren't exactly sure how it works. The process starts with the Manufacturer--they sell to Distributors. I don't know what the Manufacturer pricing is, and generally it's not possible to buy directly from the Manufacturer. When you are a Contractor who wants to install a heat pump, you buy from the Distributor. Then you sell it the Client, and at each step there is a markup of 25 to 50%.

Sean: If the contractor is fair and the labor is well-trained and fairly paid, what is the total cost of installing a ductless mini-split with one fancoil?
Jonathan: The lowest cost for a 1 ton, with one fancoil, that you'll see where someone can stay in business is $4,200. For a 2-ton, $5,500 is the lowest price you would see. I did this business for a number of years, and contractors take a lot of risks and work hard in difficult work environments.

Sean: How much does it cost to buy just the materials for a 1 ton mini split heat pump?
Jonathan: What the Contractor pays from the Distributor is $800 and $1,400 a ton, with the average around $1,200. Mitsubishi is an example of a $1,400 per ton product, while $1,200 a ton is found in products from Daikin, Panasonic, LG, and Aurora. What the contractor charges a client is 40% (e.g. Mitsubishi's written recommendations to contractors) to 50% more than their price. So $800-$1400 to the Contractor is $1100--$2100 to the Client, plus labor and additional materials.

Sean: Can you tell us about the cost for buying and installing a heat pump with multi-zone system, where there are 2-5 fan coils scattered in different rooms?
Jonathan: Well, if a 1-ton mini-split cost about $1,200, a 1.5 ton with two fan coils cost $1,600 to $1,800, and a 2-ton compressor with three fancoils cost about $3,200. Of course, this is marked up 40%-50% when sold to a client. The inside fancoils each cost about $450, while the compressor goes up in cost at about $800/ton.

Sean: What about the Labor costs for installing a ductless mini-split?

Jonathan: Labor is a constrained resource. For a full-time job, labor is paid $25 an hour to $35 an hour, and sold to the client at $42 an hour to $60 an hour. To install a 1 ton heat pump by market leading contractors takes 2 to 4 hours, and for contractors who do not install ductless on a daily basis that same work takes 4 to 8 hours because of contractor inefficiency, likely due to their relative inexperience.

Ducted Heat Pumps (240V)

Ducted air conditioning systems are usually driven by a central compressor that pumps air through ducts to vents in different areas throughout the building. These systems pair an outdoor heat pump unit with an indoor evaporator coil and air handler unit, with exception of the Friedrich (G.E. not pictured) product below, which is a packaged system that has all components in one box.

	Friedrich VRP12K 	**Goodman** GSZC180481C 	**Fujitsu** FO2414R 	**York** YZH02412C 	**Carrier** Infinity 25VNA036A003 
Description	Packaged and Ducted	Split and Ducted	Split and Ducted	Split and Ducted	Split and Ducted
Dimension (in)	26W x 25D x 50H	35W x 35D x 38H	26.25H x 23.63L x 23.63D	34H x 42W x 23D	35W x 44H x 28D
Ref. Type	R410a	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	15 - 70	**-5 – 115 (cold climate)**	55 - 125	**-10 – 115 (cold climate)**	**-4 – 68 (cold climate)**
Power (W)	923 - 991	4,830 – 4,840	7,030	2,500 – 3,412	1,050 – 1,240
Heating Cap. (BTUh)	7,100 – 115,00	22,000 – 59,500	17,060 – 60,053	18,000 - 59,000	25,000
Cooling Cap. (BTUh)	4,000 – 23,524	23,000 – 56,500	17,300 – 60,500	19,000 – 58,000	36,000
Heating (COP)	0.64 - 1	1.47 – 6.77	3.6 – 3.8	2 -4	2.3 - 4
Cooling (COP)	3.22 – 3.81	3.66 – 4.10	3.37	4 – 4.4	4 – 4.4

Packaged Terminal Air Conditioners and Heat Pumps (PTACs and PTHPs) are all-in-one HVAC units that are used to heat and cool 1 to 3 rooms. These types of units are ductless, and can be hung from a wall and ducted through (e.g. Innova, Sakura), mounted in a window or placed into a cutout in the wall. Packaged units deliver heating or cooling directly to the space, avoiding energy losses from ductwork but introducing potential leaks around the product if it is not sealed.

Packaged Terminal Heat Pumps (120V)

	Innova (8,10,10DC,12DC, 12DC Elect) 	**Frigidaire** FFRH0822Q1 	**Friedrich** YS10N10C 	**Gree** 26TTW09HP115V1A 
Description	Twin ducts through the wall, dehumidification, ER back-up	Noise 50.2 dB (low) Heat pump with ER	Heat pump model – no back up ER	Heat pump model with ER + dehumidification
Voltage (V)	230	115	115	115
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
Ambient Temp. Range (H/C) (F)	**14 – 64 / 23 – 109 (cold climate)**	**-5 – 75 / 5 – 110 (cold climate)**	40 – 115	29 - 125
Power (W)	545 – 730	780 – 1,290	917 - 978	830 – 1,150
Heating Cap. (BTUh)	0.7 – 3.05 kw @-7 (0.79 – 1.11) kw	3,500 (ER) 7,000 (HP)	8,000	3,900 (ER) 6,600 (HP)
Cooling Cap. (BTUh)	0.8 – 3.1 kw	8,000	10,000	9,000
Heating (COP)	2.84 – 3.22	2.63	2.6	3
Cooling (COP)	3.12 – 3.28	2.87	3.19	2.87

*ER = electric resistance, HP = heat pump

Packaged Terminal Heat Pumps (240V)

	Amana (AH093E35AX, AH123G35AX, AH183E35AX) 	**Friedrich** (YS12N33C, YM18N34C, YL2N35C) 	**Gree** (W07HP230V1A, W09HP230V1A, W12HP230V1A) 	**LG** (LP073HDUC, LP093HDUC1, LP123HDUC1, LP153HDUC) 
Description	Heat pump model	Heat pump model – no back up ER	Heat pump model with ER + dehumidification	Smaller inverter - cold climate ready for tiny homes
Voltage (V)	208/230	230/208	230	208/230
Dimension (in)	16H x 26W x 27D	20H x 28W x 35D	15H x 26W x 16D	16H x 42W x 21D in
Ref. Type	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	61 - 86	60 - 115	29 - 125	**-4 - 75 / 54 – 115 (cold climate)**
Power (W)	920 – 3,680	1,101 – 2,391	680 – 3,500	2,300 - 4,700
Max Amps (A)	4.2 – 16.0	4.9 – 19.5	20	15,20,30 amp cord
Heating Cap. (BTUh)	10,700 – 9,000 (ER) 8,100 – 16,00 (HP)	11,300 – 22,000	3,900 – 11,000 (ER) 6,600 – 11,400 (HP)	1,250 - 13,400
Cooling Cap. (BTUh)	9,200 – 17,300	12,000 – 24,00	7,200 – 11,700	7,100 – 14,900
Heating (COP)	2.6 - 2.9	2.6 -2.7	2.9 – 3.1	3.1 – 3.5
Cooling (COP)	2.63 – 2.93	3.02 – 3.19	2.81 – 3.11	3.28 – 3.90

*ER = electric resistance, HP = heat pump

Energy Management Systems and Electric Car Charging

Limited transformer, service and breaker panel capacities are often found in older neighborhoods and buildings, and can be expensive to upgrade, or delay construction to address. In response, multifamily design teams may select lower power draw equipment (e.g. 15 amp HVAC vs. 30 amp HVAC), reduce energy loads (e.g. more insulation = less HVAC power need), or put some loads on a battery and use power management systems. Batteries are also important for essential services like elevators in multifamily buildings and are being used in high-end condo housing as a sale feature. Below are case studies and a variety of technical solutions.

Electricity is delivered to plug-in electric vehicles to ensure the safe recharge of depleted batteries. Chargers have three levels of power supply:

- **Level 1** plugs into a regular home outlet (120V/15Amps) and charge 8-11 miles/hour. It is the least cost solution.
- **Level 2** requires the 240V electricity used by most laundry dryers and electric stoves. With 20amps the car charges at 11-15 miles/hour, 30 amps charges at 16-23 miles/hour, and 40 amps at 22-30 miles/hour.
- **Level 3** requires commercial grade electricity at 480V at 125amps, but can charge 200-300 miles/hour.[66]

EVBOX		ChargePoint	
	• Elvi model: designed for every electric car • Commercial line: load balancing, peak shaving,		• lower capacity (<40A) to each port, avoid panel upgrade • Dynamically share current 40,30,20 Amp • network to allow for demand response

Some chargers have capabilities especially attractive to multifamily developers-- ChargePoint's dynamic charging of multiple vehicles avoids panel upgrades, while EVOBOX's Elvi model is designed to charge all types and brands of electric vehicles. When Alameda County's vehicle fleet garage ran out of power capacity in 2017 to support charging the existing 70 vehicles, let alone another 30 to be delivered later that year, they installed ChargePoint products to cost-effectively schedule, prioritize and balance charging demands rather than invest in a new power supply.[67]

Utilizing Electric Vehicles for Building Back-Up

was deployed in Japan after the 2011 tsunami closed the nation's nuclear power plants. Nissan pioneered the "Vehicle-to-Home" practice with a charger that isolates a building from the grid while it relies on vehicle battery power. This can be enough to operate a building for days, or longer if rooftop solar is available to recharge the vehicle, like the Sol Lux example above. The island of Maui, with its constrained grid, and the Los Angeles Air Force Base[69], with its need for resilience during emergencies, began using Nissans for Vehicle-to-Building and Vehicle-to-Grid chargers in 2014.[70] Honda, Mitsubishi, Toyota and other car manufacturers with standard CHAdeMO-certified Level 2 charging plugs can now support bi-directional charging. Tesla is also expected to release a V2B charging system for its cards in late 2019 or early 2020.

Figure 13: Nissan unveils the U.S. commercial offering of Vehicle to Home charging in Los Angeles for 2019 deployment in the U.S., using battery-powered Leaf cars and Fermata Energy bi-directional charging. 68

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66 Kettles, D. (2015). Electric Vehicle Charging Technology Analysis And Standards. Electric Vehicle Transportation Center. <http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1996-15.pdf>

67 Dao, T. (2017) "EV Charging Pilot Minimizes Calif. County's Energy Use Spikes. Government Fleet. <https://www.government-fleet.com/142785/ev-charging-pilot-minimizes-calif-countys-energy-use-spikes>

68 Lambert, F. (2018). "Nissan launches 'Nissan Energy' to commercialize vehicle-to-home/building with the Leaf. Electrek. <https://electrek.co/2018/11/28/nissan-energy-leaf-vehicle-to-home-building/>

69 Princeton Power Systems (2014). Case Study, L.A. Air Force Base EV Charging Stations. Retrieved from Princeton Power: https://www.princetonpower.com/pdf-new/LAAFB_Case_StudyC.pdf

70 Hawaiian Electric (2018). Electrification of Transportation: Strategic Roadmap. Retrieved from Energy and Environmental Economics: https://www.ethree.com/wp-content/uploads/2018/04/201803_EOT_roadmap.pdf

Sol Lux Alpha[71] is a four story, all-electric, "nanogrid" condo development built in San Francisco in 2018 that can go off-grid indefinitely during spring, summer and fall with (Figure 14):

- Three "Tesla Powerwall 2" batteries for each condo (42kWh)
- Pre-wiring for "Vehicle to Home/Building" bi-directional electric car chargers planned for installation in the fall of 2019, which allows an electric car to provide battery back-up to each condo and also common loads, tripling on-site battery storage in an emergency. Each long-range electric car stores 60kWh-120kWh of available battery per car.
- 12kWh of Blue Ion batteries for the elevator and incidental common loads.
- 8kW PV of solar array wired to each apartment's dedicated battery system, making 32 kWh/day on average, but usually more during the 8 sunniest months of the year in San Francisco
- Passive House design, high performance heat pumps and Bosch induction ranges

Figure 14: The Sol Lux Alpha apartment complex can operate as a "nanogrid" using the Tesla Powerwall 2, and vehicle to home charging.

Energy Management Systems

One recent innovation in circuit breaker panels is the addition of small computers to monitor and control electricity use. Addressing loads in all-electric multifamily developments is particularly important because there can be multiple large power draws happening simultaneously (like EV charging and laundry) that can be prioritized, rather than upgrading power to supply both.

Eaton[72] Energy Management Circuit Breaker (EMCB)	**Thermolec**[73] DCC-9
	
Smart Panel, Smart Circuit Breaker	EV Power Management
• Programmable breakers to prioritize loads in power outage scenarios, control shedding of lighting and plug loads • Remote cycling of HVAC, WH, to offset energy demands and save money • Can connect with solar monitoring, home networks and demand response • In the future could simplify EV charging.	• Connects EV charger to panel to manage energy loads • real-time reading of total power consumption of electrical panel; if the panel exceeds 80% rated loading, then the it temporarily de-energizes the vehicle charger. Reconnects automatically when other loads allow.

71 Passive House Buildings. (2018). "Sol Lux Alpha – Carbon-Neutral Nanogrid Living" <https://passivehousebuildings.com/magazine/fall-2018/sol-lux-alpha-carbon-neutral-nanogrid-living/>

72 Eaton. (2019). "Energy management circuit breaker" <https://www.eaton.com/us/en-us/markets/innovation-stories/energy-management-circuit-breaker.html>

73 DCC. (2018). "DCC-9" < https://dcc.technology/dcc-9/>

Electric Cooking

The LED “flame” of a Samsung induction stove (at left) is an example of how intuitive it can be to transition to cleaner, faster and safer all-electric cooking. Gas stoves cause unhealthy levels of Nitrous Oxides that would be illegal if it were from a gas power plant. After just twenty minutes of cooking and a sunny window, a kitchen can have actual smog and trigger asthma and lung ailments. Gas cooking appliances are 25-40% efficient, while electric cooking appliances are 70-95% efficient, meaning electric kitchens use 1/3rd as much energy and require only 1/3rd as much cooling. Using electric appliances avoids the construction costs and costs to run extra gas venting equipment. In addition to being more efficient, induction cooking appliances are faster, provide more temperature control and cause less kitchen fires than gas or radiant electric stoves.[74] Multifamily housing comes in all sizes and layouts, as do the commercial kitchens found in mixed-use apartment buildings. Below are products that facilitate both retrofits and new construction with high performance cooking equipment. Countertop products do not require any installation retrofits and plug into a standard wall outlet. Drop-in cooktops, on the other hand, are installed into a cut-out of the countertop and hard-wired to a 120V or 240V outlet. Electric cooking comes in a variety of technologies, standard electric, glass top radiant electric, and induction.

Glass Top Radiant Range (Less than $550)

Make/Model	**Amana** AER6303MFS 	**Whirlpool** WFE320M0ES 	**Frigidaire** FFEF3052TS 	**GE Appliances** JBS60DKBB 
Wattage	1,800	3,000	100-3,000	3,100
Price	$450	$500	$500	$510
Oven space (cu. ft)	4.8	4.8	4.9	5.3

Glass Top Radiant Range (Greater than $500) (9600W, 240V using a 40amp circuit)

Make/Model	**Kenmore** 92612 	**Frigidaire** Gallery FGIF3036TF 	**Samsung** NE58K9560WS 	**LG** LSSE3026ST 	**Bosch** 800 Series 
Price	$700	$ 1,075	$1,400	$1,700	$2,500

Slide-In Induction Range (9600W, 240V using a 40amp circuit)

Make/Model	**Frigidaire** Gallery FGIS3065PF 	**LG** LSE4617ST 	**GE** Profile PHS930SLSS 	**Café** CHS985SELSS 	**Samsung** NE58K9560WS 
Price	$2,760	$3,000	$2,440	$3,420	$2,240

74 See the Induction Cooking Fact Sheet by Tom Lent: https://docs.google.com/document/d/1qiGX6-tFdawfA6Nqp8SYifRbtucX9RzqAdjZ_5NdwBE/edit

Single Burner Countertop Induction (1800W, 120V and using a 15amp circuit)

Make/ Model	**Avantco** ICBTM-20 Light Duty	**Avantco** IC1800 Heavy Duty	**Eurodib** C1823	**NuWave** PIC Platinum	**Vollrath** Mirage Cadet 59300
					
Price	$50	$120	$160	$200	$270
Temp. Range	140°F - 460°F	140°F - 460°F	150°F - 450°F	100°F-575°F	100°F - 400°F

Single Burner Drop-In Induction (1800W, 120V and using a 15amp circuit)

Make/Model	**True Induction** TI-1B	**Avantco** DC1800	**Adcraft** IND-DR120V	**Spring** SM-651R	**Bon Chef** 12083
					
Price	$140	$170	$190	$440	$500
Temp. Range	150°F-450°F	140°F-464°F	Up to 464°F	145°F-185F°	150°F-450°F

Double Burner Countertop Induction (1800W, 120V and using a 15amp circuit)

Make/Model	**Eurodib** S2F1	**Cuisinart** ICT-60	**Inducto**	**Avantco** IC18DB	**NuWave** PIC Double
					
Price	$200	$200	$150	$150	$200
Temp. Range	150-450 F	140F-460F	176° F-460° F	140-460 F	100 – 575 F

Multi Burner Induction Stovetops (9600W, 240V using a 40amp circuit)

Make/Model	**Empava** IDC-36 36”	**KitchenAid** KCES556 HSS 36”	**Bosch** NETP068SUC 30”	**Samsung** NZ36K7880UG 36”	**Frigidaire** FPIC3677RF 36"
					
Price	$900	$1,300	$1,300	$2,300	$2,500

Figure 15: All-Electric Culinary leaders in New York City include many diners, an upscale oyster bar, induction ranges for each customer's Mongolian hot pot and fine Italian dining made with induction woks.

Commercial Electric Kitchens in Mixed Use Buildings

Urban multi-family buildings often have restaurants on the ground floor that benefit from faster, cleaner safer, more efficient all-electric equipment.[75]

- Electric cooking equipment delivers heat three times as effectively than gas equipment—heat delivery efficiency is between 60% and 90%, compared to gas equipment at 25-35% efficient. [76] In addition, energy star commercial electric cooking equipment can reduce loads.
- Faster heat delivery is important during rush hours—at a fast food restaurant an electric fryer produces six more baskets of fries per hour than a gas fryer, directly impacting sales, labor efficiency and profitability.
- Gas inefficiency triples kitchen air conditioning and ventilation loads, and gas combustion pollution (NO2, Formaldehyde) makes kitchens inherently less healthy for chefs.
- Induction electric cooking offers precise temperature control, while gas burns at 3400F and then relies upon inefficiencies in heat transfer, or liquids in the pan to cool it. Induction stoves protect chefs from high temperature burns when they bump cookware.

Commercial Electric Ranges

Make/Model	**Bertazzoni** PRO304INMXE 	**Garland** SS686 	**Vulcan** EV36S4FP1HT2 	**AGA Elise** AEL48IN-SS 	**Lang** R36C-APA 	**Garland** SS684 
Price	$3,000	$6,490	$8,440	$8,930	$10,100	$10,400
Amp/Wattage	45.5 / 12.4	78 /19	13kW	50 / 14.9	103.8/21.6	33kW
Volts	240	240	208	240	208-240	208-240
Heating Type	Induction	Radiant	Radiant	Induction	Radiant	Radiant
Temp. Range	NA	150°F - 550°F	200°F-500°F	NA	150°F - 450°F	150°F - 550°F
Burner Diameter	7"(2x)/ 5"/ 8"	6 ½"(x3)/ 8 ½"(x3)	NA	Flattop	24" griddle/8" element(x4)	NA

75 Kostuch Media Ltd. (2017). Why Induction Cooking is the Hottest Trend to Hit Restaurant Kitchens. Food Service and Hospitality. <https://www.foodserviceandhospitality.com/why-induction-cooking-is-the-hottest-trend-to-hit-restaurant-kitchens/>

76 Source: Andre Saldivar, Foodservice Technology Center, Southern California Edison

Commercial Ovens (208V)

Make/Model	**Bakers Pride** BCO-E1 	**Vulcan** VC5ED-11D1 	**Blodgett** BDO-100-E 	**Garland** SUME-100 
Price	$3,324	$3,715	$3,810	$4,630
Kilowatts	10.5kW	12kW	11kW	10.4kW

Commercial Single Burner Countertop Induction Cooktops (1800 W / 15 Amps / 120V)

Make/Model	**Update** International IC 	**Eurodib** C1813 	**Waring** WIH200 	**ChangBERT** 	**Vollrath** 6950020 
Price	$200	$90	$150	$250	$610
Temp. Range	140°F-460°F	150°F-450°F	Up to 450°F	NA	NA

Electric Induction Woks (240V / 15A)

Make/Model	**Spring** SM-351WCR-8 	**Garland** GI-SH 	**APW** Wyott IWK 	**Vollrath** 6958301 	**Garland** GI-SH/WO/IN 
Price	$1,470	$1,760	$1,950	$2,200	$2,440
kW	3.5	3.5	3	3	5

Electric Fryers

Make/Model	**Dean** SR114E 	**Imperial Range** IFS-40-E 	**Frymaster** RE14C-SD 	**Anets** AEH14X 	**Garland** 36ES11 	**Vulcan** CEF40 
Amp/Wattage	14kW	14kW	39A/14kW	58.3A/14kW	51A/12kW	47A/17kW
Volts	208V	208-240V	208V	240V	240V	208V
Price	$1,650	$1,820	$5,280	$4,140	$5,960	$4,340

Induction Catering / Buffet Equipment

Make/Model	**Garland** GI-HO 1500 Induction Warmer 	**Spring USA** QS7230 Warming table 	**Vollrath** 7552280 60" Buffet Table 	**Bon Chef** 50120 Induction Buffet Case 	**Bon Chef** 50102 96" Buffet Table 
Price	$2,250	$5,700	$6,520	$11,630	$16,120
Amp/ Wattage	NA / 1500W	20A/650W	11.25A / 1350W	50A/NA	30A / 3200W
Voltage	120	120V	120V	220V	110 V

Electric Laundry Dryers

As our building systems become more efficient, the energy use of appliances becomes more apparent. Laundry loads in multifamily housing can sometimes be the largest load, so ensuring that the most efficient equipment is used is important. More surprising may be that the first cause of high consumption is convenience—households with in-unit laundry run twice as many loads as households with only access to a central laundromat.[77] While washing machines and clothes dryers use about the same amount of motor energy per load, boiling the water out of wet laundry uses 81% of all the energy in an average laundry load in 2010[78], assuming one is using a standard ~30% efficient gas dryer, rather than a ~250% efficient electric heat pump dryer.

Energy Star Electric Dryers

Energy Star, a building science program led by the US Environmental Protection Agency (EPA), aims to inform consumers and businesses on how to cut down on operating costs by listing and ranking energy efficient products[79]. Until recently, both residential and commercial/coin-operated clothes drying machines were excluded from the list of Energy Star rated appliances because of their consistently high-power demand between all products available on the market. Innovative technologies like moisture sensing, heat pumps and condensation drying have led to a rise in the availability of residential-grade Energy Star rated dryers[80], although there are no commercial-grade Energy Star listings as of 2019. Some examples of residential-grade Energy Star washers and dryers are shown below. Commercial grade, coin-operated products must be independently evaluated for efficiency, often by requesting that of the company placing laundry machines on-site as a service. All products below are Energy Star.

Standard Electric Dryers

Energy Star ranked Laundry Dryers use a variety of strategies to better eliminate water from clothes, such as fans, humidity sensors and heating technologies. Electric resistance dryers require a vent, while condensing dryers do not. The following products use electric resistance to dry clothes.

	Samsung DV45K76E	LG DLE1501	GE GTD65EB	Maytag MED3500W	Whirlpool WED75HEFW	Electrolux EFME417
						
Price	$400	$450	$500	$650	$650	$700
Drum Capacity (cu. ft)	7.4	7.4	7.4	7.4	7.4	8.0
kWh/year	607	607	608	608	608	608

77 Baylon et. al. (2013). "Residential Building Stock Assessment: Multifamily Characteristics and Energy Use." Ecotope, Inc. for NEEA.

78 Korn & Dimetrosky. (2010). "Do the Savings Come Out in the Wash? A Large Scale Study of In-Situ Residential Laundry Systems." The Cadmus Group. ACEEE Summer Study on Energy Efficiency in Buildings

79 U.S. Department of Energy. (2017). "Saving Energy and Money with Appliance and Equipment Standards in the United States" <https://www.energy.gov/sites/prod/files/2017/01/f34/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet-011917_0.pdf>

80 Janeway, K. (2014). "Finally, the lowly dryer can reach for Energy Star" <https://www.consumerreports.org/cro/news/2014/05/finally-the-humble-dryer-can-reach-for-energy-star/index.htm>

Combination Condensing Washer & Dryer

Condensing Washer/Dryer combine both space and energy efficiency and are ventless—laundry water instead goes down the drain. They are most common in retrofitted apartments in Europe, and run on 120V outlets, using as much energy as a hair dryer on medium and stresses fabrics less. After washing the clothes, the same machine dries the laundry using a condenser. A laundry cycle, from loading to unloading, takes 2-3 hours.

	Magic Chef MCSCWD20W3	**Haier** HLC1700AXW	**Summit** SPWD2201SS	**Deco** DC4400CV	**LG** WM3488HW	**Whirlpool** WFC8090GX
						
Price	$720	$1,000	$1,000	$1,200	$1,300	$1,500
kWh/year	85 kWh/year	65kWh/year	65kWh/year	96kWh/year	120 kWh/year	180kWh/year
Drum Capacity (cu. ft.)	-	2.0	2.0	3.5	2.3	2.8
Volts/Amps	-	120V/10A	115V/12A	110V/15A	120V/15A	240V/30A

Heat Pump Dryers

Heat pump dryers are also ventless but maintain a higher temperature than a condensing dryer and lower than that of electric resistance, and therefore dry clothing at a rate between the two. Note that smaller drum sizes hold less clothes, and consequently take less time to dry.

	Samsung DV22N685H	**Blomberg** DHP24400W	**Kenmore** Elite 81783	**Beko** HPD24412W	**Whirlpool** WED9290FC	**Miele** TWI180WP
						
Price	$1,000	$1,100	$1,100	$1,300	$1,700	$1,900
kWh/year	145kWh/year	149kWh/year	-	149kWh/year	531kWh/year	133kWh/year
Drum Capacity (cu. ft.)	4.0	4.1	7.4	4.1	7.4	4.1
Cycle Time (min)	60	46	-	46	75	35

Electric Landscaping


Powerful commercial-grade electric landscaping equipment uses lightweight batteries and efficient motors that are half as loud as gas equivalents, produce no local air pollution, and are easier to maintain. Modern batteries now offer comparable length of operating time to gas tanks, and batteries are safer to store than gasoline, oil and rags.

	Blower	**Chain Saw**	**Pole Pruner**	**Trimmer**	**Hedge Trimmer**	
STIHL[81]	BGA 100 ($350) 	MSA 160 C-BQ ($350) 	HTA 85 ($490) 	FSA 130 R ($400) 	HAS 94 R ($500) 	RMA 510 ($520) 
Husqvarna[82]	550iBTX ($500) 	T536Li XP ($400) 	536LiPT5 ($500) 	536LiLX **($300)** 	536LiHD60X ($430) 	LE221R ($430) 
RYOBI[83]	RY40440 ($270) 	P549 ($200) 	RY40561 ($200) 	RY40250 ($160) 	RY40610A ($150) 	RY48ZTR100 ($4100) 

*Prices will vary – visit retailers for the most current cost information.

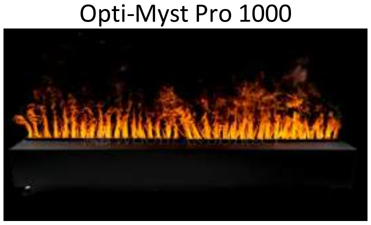
81 STIHL. (2019) “AP Series” <https://www.stihlusa.com/products/battery-products/ap-series/>
82 Husqvarna. (2019). “Battery Series” https://www.husqvarna.com/us/products/battery/
83 RYOBI. (2019). “Lawn and Garden” https://www.ryobitools.com/outdoor

Electric Fireplaces

Swirling, fire-like mist lit with LEDs and a log fire's worth of heat: these are the new electric fireplaces. They're less expensive than gas stoves, safer, cleaner, and plug into a normal 120V wall outlet. They provide heat in a more efficient and smokeless way – a 3,000-Watt electric fireplace can warm spaces up to 800 feet and look great doing it. From convincing to dramatic, electric fireplaces are ready to match the tastes of any owner. Outdoor electric space heaters are similarly versatile and ready to replace headache-inducing propane burners.

Indoor Electric Fireplaces

	ClassicFlame Felicity	**Amantii** Zero Clearance	**Modern Flames** CLX Series
			
Size	46.6"W, 19.75"H,5"D	29.5"W, 38.75"H, 8.5" D	144" W,25.5" H, 5.3" D
Price	$350	$1,300	$7,500
Voltage/Amps	120V/12.5A	120V/12.5A	120V
Heat Output	1,500W	1,500W	1,500W

	Dimplex Opti-Myst Pro 1000	**Napoleon** See-thru	**Dynasty** DY-BT79
			
Size	40.1" W, 9.5"H, 12" D	50"W, 18.4"H, 9"D	80"W, 19.3" H, 7" D
Price	$2100	$2,000	$1,300
Voltage/Amps	120V	120V/240V	120V/10.8A
Heat Output	460W	3,000W	1,300W

Outdoor Electric Fireplaces/Heaters

	Dimplex Opti-Myst Pro 500	**Touchstone** Sideline	**EnerG+** Patio Heater
			
Size	20" W, 9.5"H, 12" D	50"W,17.9"H ,6"D	11" W, 4'3"H,11"D
Price	$1300	$574	$186.99
Voltage/Amps	120V/3.83A	120V/11A	110V/13A
Heat Output	230W	1,500W	1,500W

Electric Barbeques

Electric BBQ grills heat up much more quickly than charcoal or gas grills and distribute heat more evenly over the entire grill area. With no charcoal fumes and no propane gas burning, they are safer and can be used indoors in inclement weather. Electric grills are cheaper to operate, clean up easier, need little maintenance and can also be used in high rise buildings where typical combustion grills are not allowed due to fire code restrictions.

	Electri Chef The Safire 115V 	**Electri Chef** Emerald 24” 	**Electri Chef** Ruby 32” Built-in 	**Kenyon** B70590 	**Kenyon** B70060 
Size (sq. in.)	224	336	448	115	115
Price	$700	$3,600	$3,500	$1200	$650
Voltage	115V	220V	220V	120V	120V

	Weber 55020001 	**Char-Broil** 804142 	**Kuma** Profile 150 	**Americana** 9359U8.181 	**Maverick** E-50S 
Size (sq. in.)	280	240	145	200	173
Price	$320	$200	$220	$245	$180
Voltage	120V	120V	110	120V	120V

Electrically Heated Swimming Pools and Hot Tubs

Many commercial buildings (e.g. hotels, corporate campuses) have swimming pools and hot tubs. Utilizing a heat pump can be an efficient way to address the energy demands of heating a pool. To size a heat pump pool heater, assume the heat pump must produce 4 to 6 BTUs/Hour for each gallon of heated pool water, with higher productivity needed when the incoming water is colder in the winter. In addition, solar thermal can an efficient way to heat pools.

Figure 16: Pacific Companies Zero Net Energy apartment complexes built in 2014 with heat pumps for the hot tub and swimming pools. (left King Station Apartments, King City, CA and right Belle Vista Senior Apartments, Lakeport, CA.)

Pool and Hot Tub Heat Pumps

Listed briefly below are heat pump specifically designed for pools and cost $2400-$4200 for 90,000 BTUs/Hr to 140,000 BTUs/Hr of heating, about 1/10th the price of a similar-sized solar thermal pool heater. Heat pumps significantly reduce construction costs compared to solar thermal while providing the same ~80% offset of energy use by using ambient heat in the air, while working all 12 months of a year, compared to 5 to 8 months of renewable pool heating with solar thermal panels.

Hayward Heat Pro

Pentair

PHNIX

Aquacal Heatwave