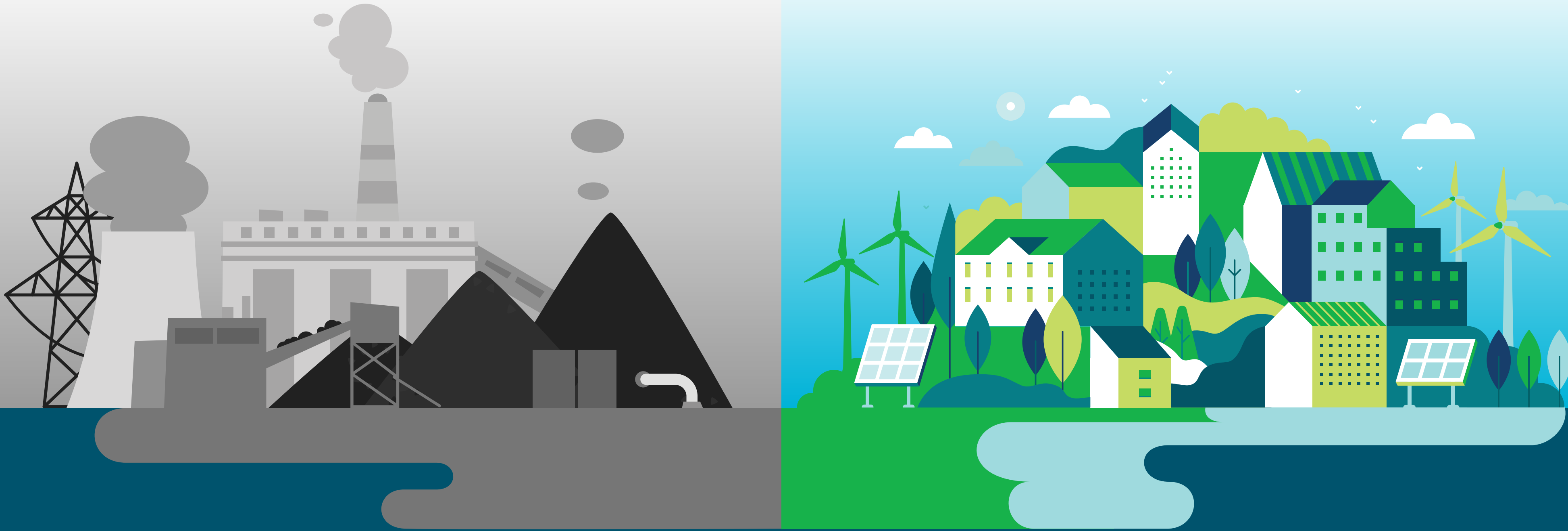

THE BUILDING DECARBONIZATION PRACTICE GUIDE

A Zero Carbon Future for the Built Environment

Google | Microsoft | Energy Foundation | UL | AIA California | WRNS Studio | Building Decarbonization Coalition | Guttmann & Blaevoet Consulting Engineers | Urban Fabrick | William J Worthen Foundation

VOLUME 1+2:

Introduction

Universal Design, Construction, and Operational Phase Considerationsl

VOLUME 1+2 CONTENT LEADERSHIP

- **Miranda Gardiner,** AIA, HKS
- **Steven Guttmann,** PE, BCxP, LEED Fellow, Guttmann & Blaevoet
- **Heidi Lubin,** eSix Development
- **Alice Sung,** AIA, LEED AP BD+C, SEA, Greenbank Associates
- **Wolfgang Werner,** AIA, LEED AP BD+C, CPHD, Urban Fabrick, Inc
- **Tamim Younos,** Green Water-Infrastructure Academy

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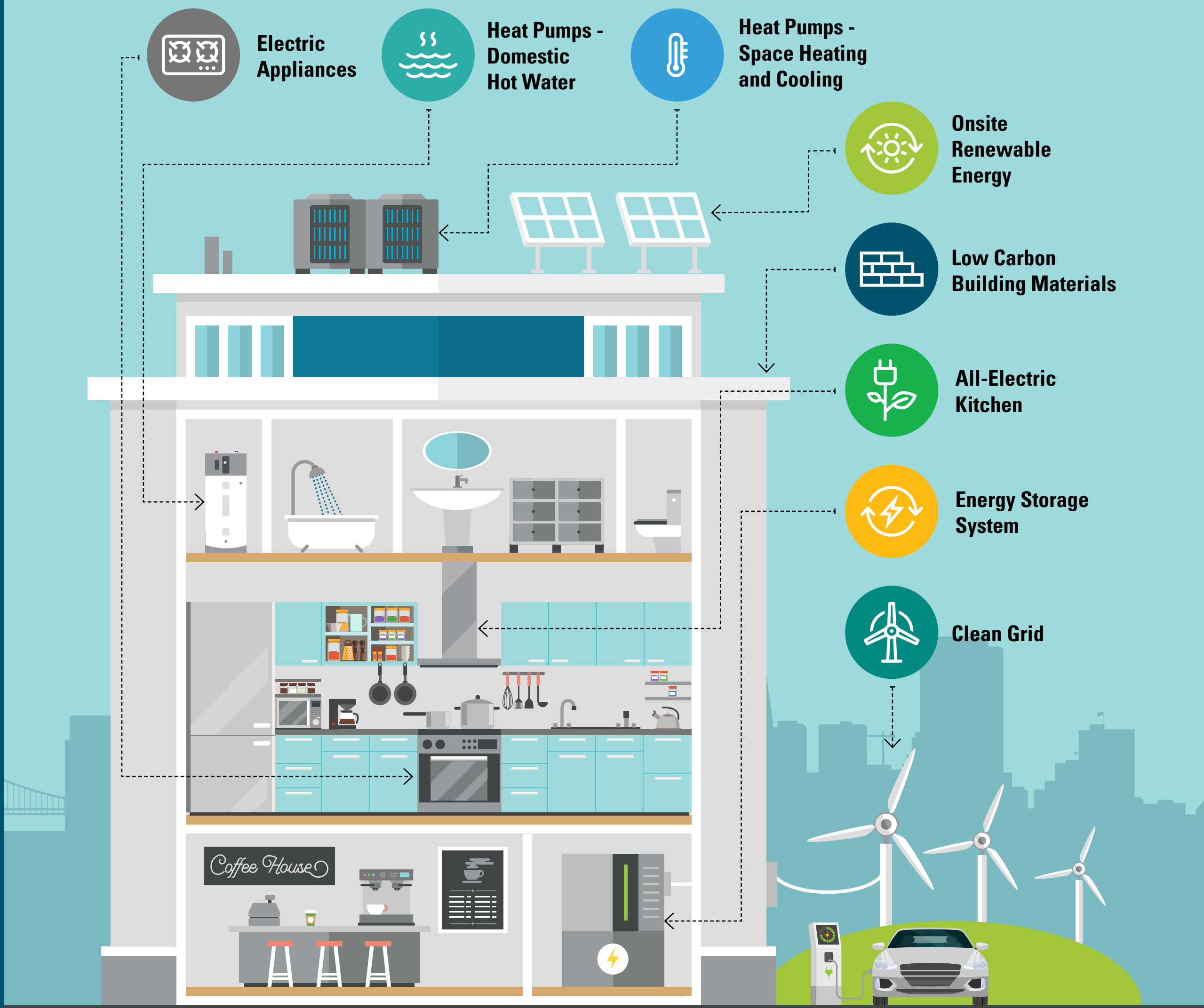

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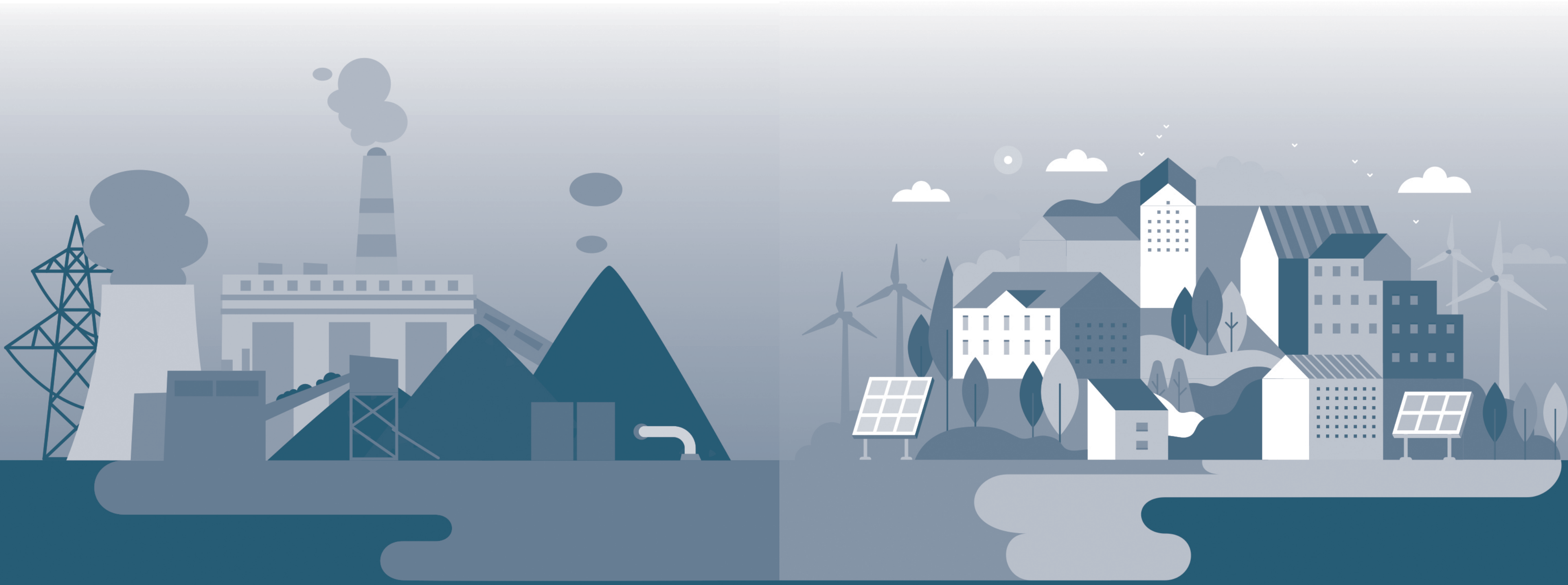


VOLUME 1

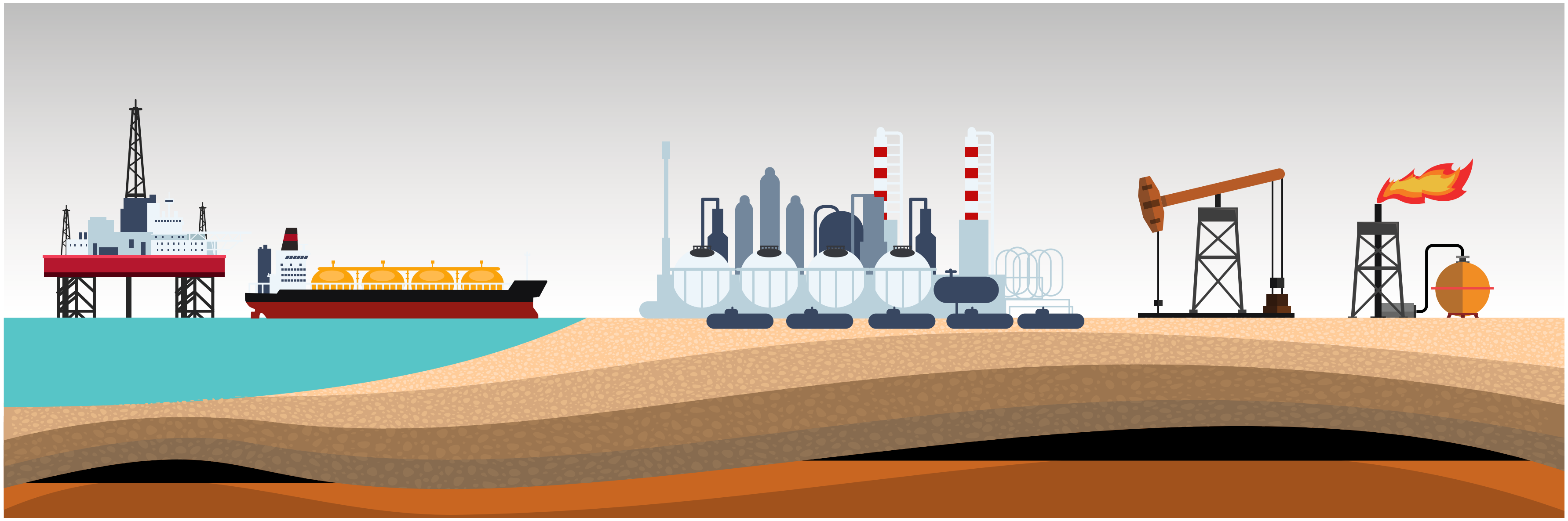
Introduction

1.1_The Background of the Global Climate Crisis

1.1.1_HOW DID WE GET HERE?

Since the onset of the Industrial Revolution a multitude of human activities has led to an inexorable increase in heat-trapping greenhouse gas concentrations in our atmosphere. In recent decades, this warming has accelerated at an alarming rate and threatens the survival of the biosphere that supports life as we know it. The unprecedented rate of industrial and population growth over the last two centuries and the near-complete transformation of the world from largely agrarian societies to highly urbanized and industrialized environments was made possible by the exploitation of one critical resource (aside from human ingenuity): fossil fuels.

Devising ways to harness the tremendous energy stored for millions of years in coal, oil, and gas deposits led to the modern world we live in. But the burning of fossil fuels comes with a hugely significant environmental impact: the release of carbon dioxide and other greenhouse gases, causing the warming of our planet. For much of the 19th and 20th centuries, it was easy to ignore this environmental impact, but as we move toward the middle of the 21st century our very survival depends on ultimately phasing out fossil fuel use.



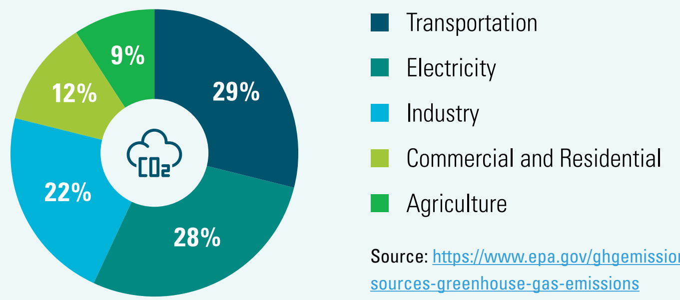
1.1.2_WHAT IS CLIMATE CHANGE AND GLOBAL WARMING

Climate change is attributed to global warming caused by increased concentration of greenhouse gases (GHGs) in Earth's atmosphere. GHGs warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space. Critical GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide, and refrigerants. CO_2 is considered the major GHG contributing to global warming. Recent focus has also been placed on methane leakage; due to Global Warming Potential (GWP) and recent data on leakage from its entire production and distribution cycle, cutting methane emissions may be the fastest opportunity we have to immediately slow the rate of global warming, even as we decarbonize our energy systems.

The Global Warming Potential of GHGs was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of CO_2. The time period usually used for GWPs is 100 years. For example, CH_4 is estimated to have a GWP of 28–36 over 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases. The US EPA tracks total U.S. emissions by publishing the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. This annual report estimates the total national greenhouse gas emissions and removals associated with human activities across the United States.[1]

In the US, GHG emissions from burning of fossil fuels are distributed across several economic sectors as categorized by the EPA (see Figure 1.1): electricity (generation, transmission and distribution), agriculture (crop and livestock production for food), industry (production of the goods and raw materials we use), transportation (the movement of people and goods by cars, trucks, trains, ships, airplanes, and other vehicles), and residential and commercial (both direct emissions from fossil fuel combustion, and indirect emissions that occur offsite but are associated with use of electricity consumed by homes and businesses).[2]

FIGURE 1.1: TOTAL U.S. GREENHOUSE GAS EMISSIONS BY ECONOMIC SECTOR



Source: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

1.2_Why Focus on the Built Environment?

Virtually all areas of human endeavor — agricultural and industrial processes, manufacturing, transportation and shipping, waste management, and the construction and operation of our entire built environment — rely to some extent on the energy of fossil fuels. This last sector is the focus of this practice guide. In the United States overall, approximately 35% of the nation's 2019 carbon footprint was a result of energy use in buildings[3] (and almost 50% when including embodied carbon), and in densely populated public-transportation-reliant cities this percentage can be a lot higher. For example, in New York City energy use in buildings accounts for almost 75%.[4]

1 https://www.epa.gov/ghgemissions/understanding-global-warming-potentials
2 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
3 https://www.eia.gov/environment/emissions/carbon/
4 https://www.hdrinc.com/portfolio/nyc-building-based-greenhouse-gas-emissions-reduction-targets-study

With global building stock projected to double in area by 2060,[5] it follows that reversing the growth of greenhouse gas emissions will require a coordinated, rapid, and scalable effort from the entire community of professionals that regulate, conceive, fund, design, construct, operate, maintain, and deconstruct the built environment.

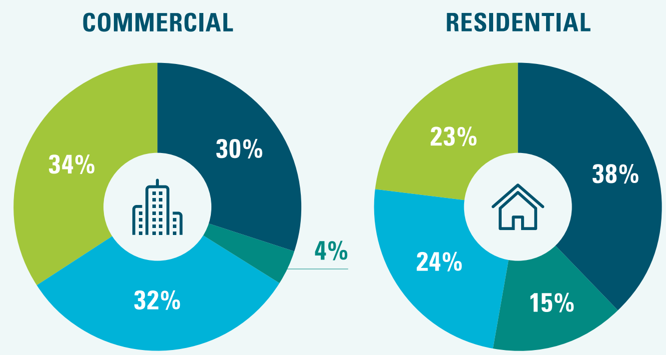
1.2.1_HOW BUILDINGS USE ENERGY: OPERATIONAL ENERGY + CARBON

Fossil fuels can be used either directly or indirectly in building operations. For example, a residential building may have a gas or oil-fired boiler in the basement combusting fossil fuel on-site to produce hot water. In this example, greenhouse gases are released directly by the building. Conversely, other end uses in buildings, such as lighting, air conditioning, or consumer electronics, typically use electricity as fuel. This electricity is generally supplied by a local utility company that operates remote power plants to generate electricity which is supplied to its customers through a network of transmission lines, transformer stations, and related infrastructure; the so-called "grid."

When plugging a television into a wall outlet, it is not apparent which mix of primary energy the utility company used in its network of power plants to generate the electricity feeding the TV. This primary energy fuel mix used by a utility for a certain region is referred to as the "grid mix". It is a safe bet that, in most locales, the grid mix is still reliant on fossil fuels (i.e. that the power plants are using coal or natural gas to generate steam that spins a turbine which generates the grid electricity). Thus, the greenhouse gas emissions associated with the TV's use of electricity are generated remotely at the power plant.

From 1990 to 2015, CO_2 emissions from fossil-fuel combustion attributed to the operation of buildings in general, and residential buildings in particular, increased 7.8 percent and 20.4 percent respectively. The majority of these emissions are indirect emissions from electricity generated off-site to power buildings. The remainder are direct emissions, primarily from on-site combustion of fossil fuels for heating, hot water, and cooking, and from leaks of compounds used in refrigeration and air conditioning (see Figure 1.2).[6]

FIGURE 1.2: TOTAL CO_2 EMISSIONS FROM THE COMMERCIAL AND RESIDENTIAL SECTORS (2016)



- Space Heating, Cooling, Ventilation
- Water Heating
- Cooking, Appliances, Electronics, Lighting
- Other*

*"Other" in both commercial and residential sectors includes items such as data servers, medical imaging equipment, ceiling fans and pool pumps which are categorized as "miscellaneous electric loads" by EIA

Source: U.S. Energy Information Administration, Annual Energy Outlook 2018 (Washington D.C.: U.S. Department of Energy, 2018), https://www.eia.gov/outlooks/aeo

5 https://architecture2030.org/buildings_problem_why/

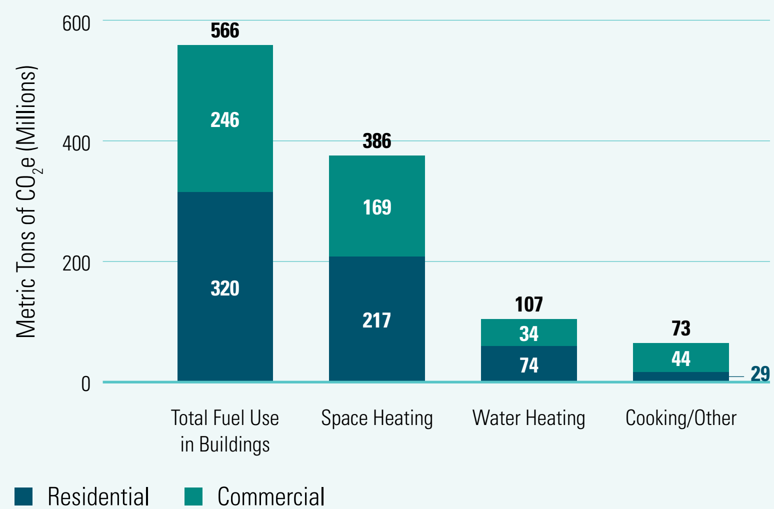
6 Center for Climate and Energy Solutions (C2ES) — Decarbonizing U.S. Buildings | https://www.c2es.org/document/decarbonizing-u-s-buildings/

In 2015, CO_2 emissions from on-site fossil-fuel combustion in the U.S. building sector generated 565.8 million metric tons of carbon dioxide equivalent (MMt CO_2e in direct emissions), or about 8.6 percent of total U.S. greenhouse gas emissions (see Figure 1.3). When indirect emissions (from the electricity generated off-site) are factored in, residential and commercial buildings generated 1,913.3 MMt CO_2e, or 29 percent of total U.S. emissions. The largest increases have been in indirect emissions, driven largely by population growth.

Emissions have been relatively flat since 2010. Thus, moving the U.S. electricity system to power generation that emits zero carbon will only reduce total US emissions around 30%. So, widespread electrification of buildings (new and existing) will be essential to achieving the aggressive goals necessary to significantly mitigate the effects of human-induced climate change.

A variety of residential and commercial end uses contribute to these sectors' energy demand, and corresponding CO_2 emissions. Space heating, cooling and ventilation, water heating, cooking, appliances, electronics, other plug loads, and lighting are the largest end uses (see illustration to the right). Satisfying these loads without direct or indirect emissions from fossil fuel use is the defining challenge of our time for the design and construction industry.

FIGURE 1.3: CARBON EMISSIONS OF FOSSIL FUEL END USES IN U.S. BUILIDINGS (2015)

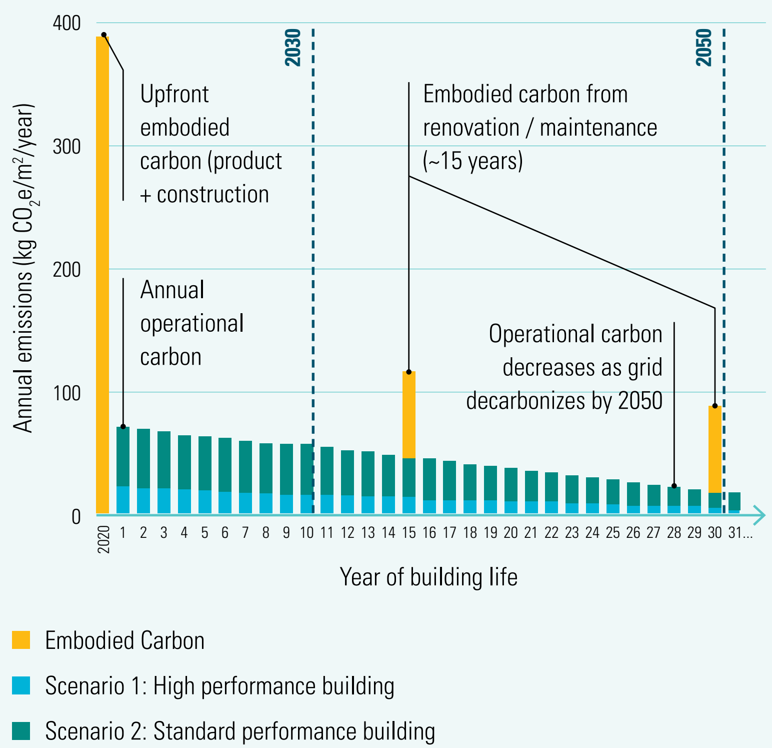


Source: The Economics of Electrifying Buildings, RMI 2018

1.2.2_HOW BUILDINGS USE ENERGY: EMBODIED ENERGY + CARBON

Embodied carbon refers to the greenhouse gas emissions arising from the manufacturing, installation, maintenance, and disposal of construction materials used in the construction of buildings, roads, and other infrastructure. It should come as no surprise that the materials needed for creating buildings are very energy-intensive (think about ore mining, steel mills, and cement plants, for example). As such, there is a substantial amount of carbon emissions "embodied" in these materials as a result of the energy used to extract, manufacture and deliver them to a construction project. The term "embodied carbon" reflects all the emissions resulting from the materials and construction processes that go into a specific building. Embodied carbon is an 'up front' cost that can be as large as multiple years of emissions from a building's operational energy, as the figure below demonstrates (see Figure 1.4).

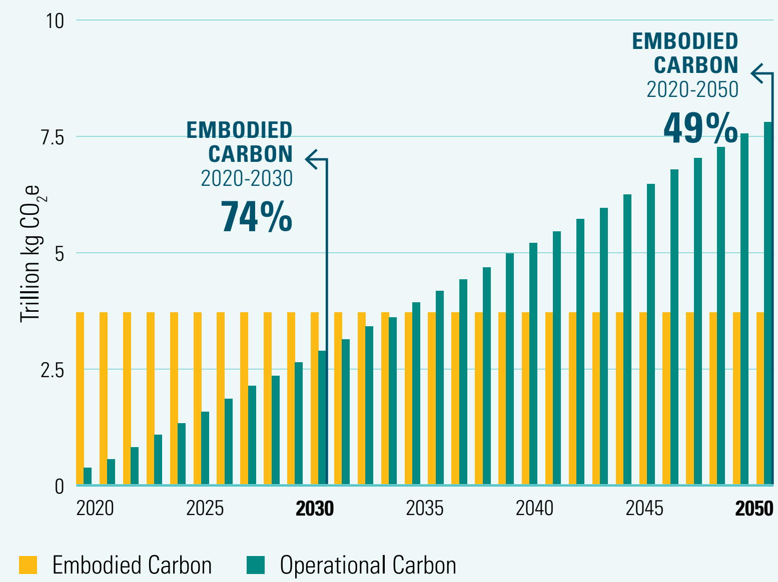
FIGURE 1.4: RELATIONSHIP BETWEEN EMBODIED CARBON AND OPERATIONAL CARBON OVER A BUILDING'S LIFECYCLE



Source: Carbon Leadership Forum

According to the statistics compiled by Architecture 2030, embodied carbon was responsible for 11% of global GHG emissions and 28% of global building sector emissions in 2017. Projections for the period 2020 to 2050, based on business as usual, suggest that embodied carbon may represent almost 50% of all the emissions from new construction over the next 30 years, and almost three-quarters of all construction-related emissions over the next decade (see Figure 1.5). Clearly, embodied carbon requires immediate and close attention if we are to meet the desired carbon emissions reduction targets in the next ten years.

FIGURE 1.5: TOTAL CARBON EMISSIONS OF GLOBAL CONSTRUCTION (2020–2050)



Source: Architecture 2030 (https://architecture2030.org/new-buildings-embodied/), using data from the U.N. Environment Global Status Report 2017: EIA International Energy Outlook 2017

Emissions from concrete manufacturing alone accounts for 8% of global greenhouse gas emissions,[7] and the embodied carbon intensity (embodied carbon content per square foot constructed) of each building material can change with each design decision. Sustainable manufacturing, material selection and reuse, local sourcing, and construction methods are all choices that have impacts on the embodied carbon intensity of a building.

Pairing the carbon impacts of material extraction, manufacturing, transportation, and end of life choices with operational carbon impacts from energy use and refrigerant selection is increasingly important to understand the total carbon emissions of each building.

WHAT DO WE MEAN WHEN WE TALK ABOUT BUILDING DECARBONIZATION?

Decarbonization: in the utility sector, it means reducing the carbon intensity of the emissions per each unit of energy which is generated. In the construction sector, it means reducing the greenhouse gas emissions that are attributable to the construction and operations of a building.

Electrification: in the context of this practice guide, this means relying on electricity as the only energy source used to power the equipment that enables a building to function and meet its intended use.

Operational Carbon: the carbon emissions attributable to the operations, the operational, or in-use phase of a building.

Embodied Carbon: the carbon emissions from the entire life cycle (e.g. manufacture, transport, erection, and disposal) of a material used in the construction of a building or other infrastructure of the built environment.

Carbon Negative: when a facility is removing more carbon from the atmosphere than it emits each year. Also referred to as "Climate Positive" and "CarbonPositive."

Carbon Neutral: having no net release of carbon dioxide to the atmosphere from a facility, especially through offsetting emissions (e.g. by planting trees or producing more solar energy than is used by the facility).

Emissions: in this document, "carbon emissions" and "GHG emissions" are shorthand for "carbon dioxide equivalent emissions" or CO_2e.

Zero Emissions: unlike carbon neutral buildings, which can still emit greenhouse gases, "zero emissions" buildings emit ZERO pounds of greenhouse gasses annually.

1.3_Decarbonization and Electrification

Decarbonization refers to the construction of a new building (or alteration of an existing one) in a manner that reduces the GHG emissions related to the building's erection and operation. This can be achieved in a number of ways, but, historically, the focus has been on reducing building-related energy use through energy efficiency measures, as well as satisfying the remaining energy use from renewable energy sources. In recent years, approaches have shifted to achieving "carbon neutral" construction through building electrification, material selections that reduce embodied carbon, and paying back the embodied carbon "debt" by producing more energy than the building consumes from renewable energy sources.

As the cost of photovoltaic (PV) systems drops, constructing all electric buildings served by electricity from 100% renewable energy sources can now be done cost effectively. Over the past decade, data compiled by the US DOE's National Renewable Energy Lab shows a steady decline in the cost of PV systems (a 65% reduction in the price of residential systems, and a 70% reduction for commercial systems). The U.S. DOE's Solar Energy Technologies Office (SETO) data demonstrates that the unsubsidized cost of producing electricity with PV systems (which was $0.10 per kW-hr in

7 Lehne, Johanna; Preston, Felix (June 2018). "Making Concrete Change: Innovation in Low Carbon Cement and Concrete" (PDF). Chatham House. *Chatham House Report*. ISBN 9781784132729. Retrieved 2021-04-17

2019) was cheaper than the average utility rate in at least 23 States. While the rates for all other forms of electricity are projected to increase over the next decade (as well as the relative cost of alternative fuels for onsite combustion, such as hydrogen, biofuels, etc.), SETO projects that by 2030 unsubsidized costs for PV systems will reach $0.04 per kW-hr, making solar energy cheaper than any other energy source.

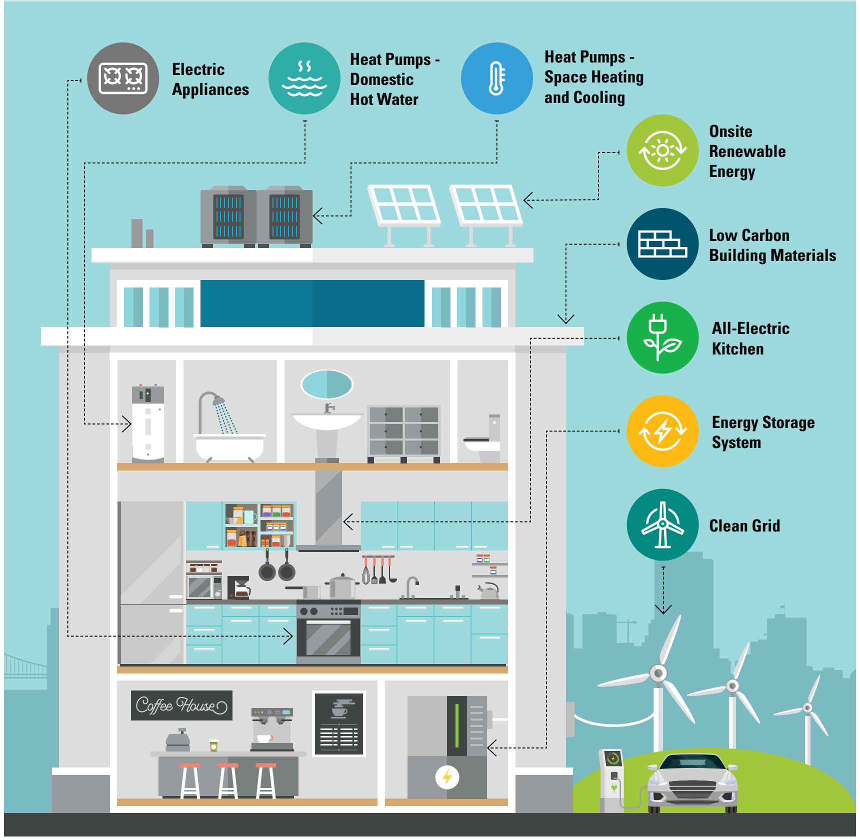
As a result of these source energy cost dynamics, anyone attempting to construct or renovate a building that is part of the global efforts to address climate change must recognize that the sensible path to decarbonize buildings is through electrification, low carbon material selection, and net-positive renewable energy production.

The purpose of the Building Decarbonization Practice Guide is to identify and explain these principles, to offer guidance to owners, regulators, and design and construction professionals, and to share helpful lessons learned so that our industry as a whole can help realize a zero net carbon future for the built environment.

1.4_How this Guide is Organized

The seven volumes of the practice guide will help readers to understand the context for building electrification and decarbonization, how strategies vary by building type, how to approach key systems and services that have traditionally been powered by onsite fossil fuel combustion, how to engage in addressing embodied carbon, and what implications for future decarbonization efforts result from the current Codes and Policy landscape.

FIGURE 1.6: COMMON ELEMENTS OF LOW CARBON CONSTRUCTION



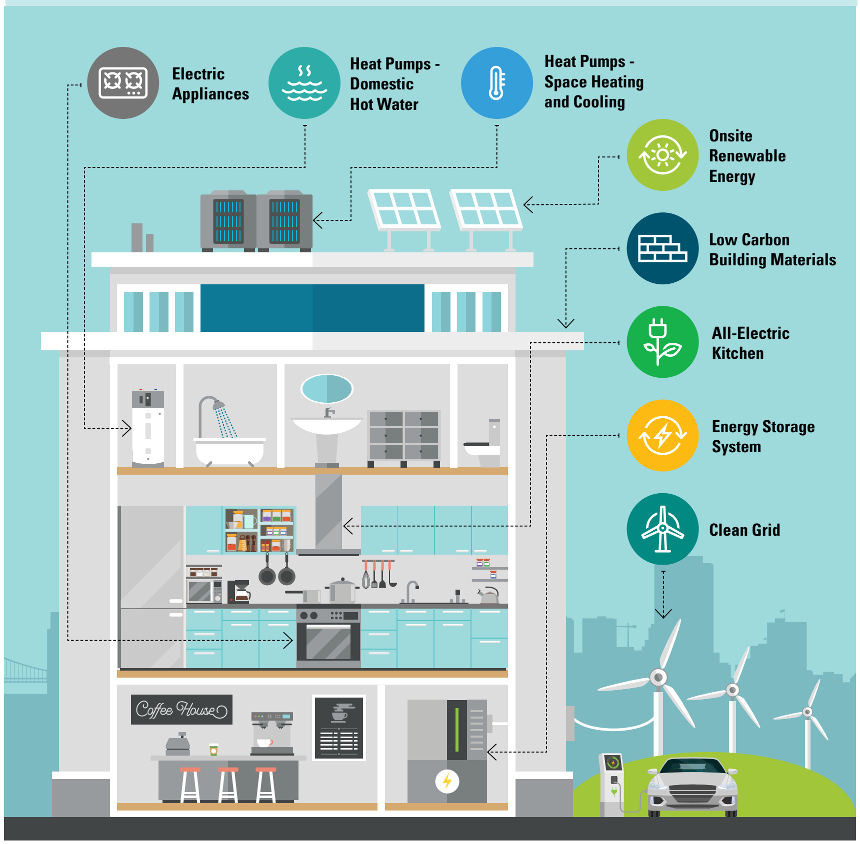
1. **Volume 1, Introduction:** this Volume provides context, background and definitions.
2. **Volume 2, Universal Design, Construction, and Operational Phase Considerations:** this Volume describes the factors related to electrification and decarbonization that are common to most, if not all, occupancy and building types.
3. **Volume 3, Multi-Family Residential, Hotels/Motels, and Similar Buildings:** this Volume discusses issues that are unique to this occupancy type, both new construction and existing building renovations. It addresses planning, budgeting, design, construction, and operations.
4. **Volume 4, Commercial Buildings:** this Volume discusses issues that are unique to commercial buildings, both new construction and existing building renovations. It addresses planning, budgeting, design, construction, and operations.
5. **Volume 5, All-Electric Kitchens — Residential and Commercial:** since kitchens, both commercial and residential, present some of the hardest design and operational paradigms to change, they warrant a Volume of their own. This Volume describes all-electric kitchen technologies, trade-offs between various options, and the potential barriers to adoption (including how to overcome them).
6. **Volume 6, Embodied Carbon:** the preceding volumes focus largely on operational carbon, so this Volume goes into depth on embodied carbon, including background, definitions, and information on design decisions and product selection that are applicable to all building types.
7. **Volume 7, Policy and Code Context:** this Volume addresses the current state of building Energy Codes, and the challenges of demonstrating the Code compliance of all-electric building designs. In addition, it discusses policies that both hinder and enable all-electric and low-embodied carbon buildings, while also exploring code and policy changes needed to enable and accelerate the technologies, human skills, and cost-effectiveness of decarbonized buildings. This Volume will also discuss the implications of the carbon content of regional electricity grids.

VOLUME 2

Universal Design, Construction, and Operational Phase Considerations

Regardless of the project type — be it a large multifamily residential development, a new or renovated office building, university housing with a big central kitchen, or a state-of-the-art public library — there will be numerous common design, construction and operational strategies, approaches, elements and technologies to consider when seeking to minimize operational and embodied carbon. This Volume will explore the key concepts that are relevant to all project types (see Figure 2.1).

FIGURE 2.1: COMMON ELEMENTS OF LOW CARBON CONSTRUCTION



2.1_To Build or Not

IS BUILDING NECESSARY?

This practice guide is focused on how to build "responsibly." Alternatives for building generally include renovation, adaptive reuse, and new construction. How to avoid building altogether (i.e. choosing whether to renovate, or adapt an existing building to a new use) is a topic for another practice guide. For the purposes of our focus on moving towards a carbon neutral future, this practice guide evaluates ways to eliminate operational carbon — through building systems electrification combined with the use of electricity from 100% renewable energy sources — and to significantly reduce embodied carbon. We will attempt to be clear where the strategies discussed in this Guide will be usable or best suited for only renovation or new construction. We will also attempt to be clear about what is required to adapt certain strategies for one building alternative or another. Otherwise, the following strategies should be seen as equally applicable to new construction and renovation/adaptive reuse projects.

EXISTING BUILDINGS

Choosing to decarbonize an existing building versus pursuing new, low-carbon construction requires a delicate balance between the embodied carbon benefits of an existing building and the potential for deep operational carbon improvements. The embodied carbon impact of renovating an existing building is usually lower, since the quantity of new virgin material is smaller and less waste is sent to landfills. However, providing a high performance envelope that allows for significant reductions in HVAC system capacities, or even elimination of some systems (e.g., perimeter heating systems), can often be extremely expensive in renovation projects.

In existing buildings, the easiest action — "the lowest hanging fruit" — is to ensure that lighting systems are replaced with very high efficiency, low wattage LED lighting: paybacks on lighting retrofits are extremely short in the context of building energy efficiency investment options (often less than two years). Heating and cooling systems represent the next largest energy savings opportunity, but these upgrades can be complex. If this upgrade is not in the cards as part of a facility improvement, it should be planned as a long-term or phased replacement project rather than abandoning this opportunity altogether. Upgrading these systems as part of an initial facility improvement is more easily justified when mechanical systems are at the end of useful life.

Replacing the building facade elements of existing buildings is another level of improvement that should be carefully evaluated with respect to carbon impacts. The long-term operational carbon benefits should outweigh the embodied carbon "costs," unless these changes are being driven by other factors such as improvements in occupant comfort or when the building skin is no longer weathertight. Investments in envelope improvements also can reduce the cost of new mechanical, electric, and plumbing (MEP) systems and mitigate some of the challenges associated with meeting heating loads in an all-electric building design.

2.2_Equity and Social Justice Considerations

Building "responsibly" **cannot** be accomplished without considering both the community that a building is intended to serve and the community in which the building will be located. How these "communities" are defined can significantly impact the outcomes of a project. "Enlightened" project development should be approached within a framework of "racial and 'spatial' justice[8], equitable development, sustainability, empathy and human-centered design, placekeeping and placemaking."[9]

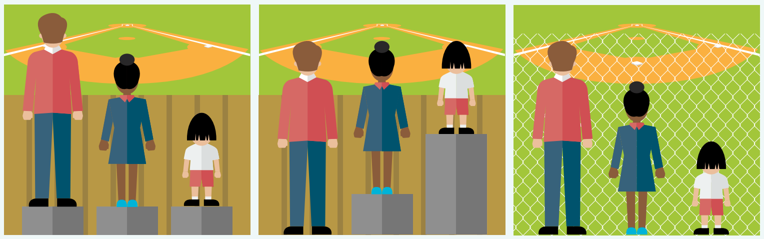
> "Equity means fairness. Equity…means that peoples' needs guide the distribution of opportunities for well-being. Equity… is not the same as equality… Inequities occur as a consequence of differences in opportunity, which result, for example in unequal access to health services, nutritious food or adequate housing. In such cases, inequalities…arise as a consequence of inequities in opportunities in life."

Adapted by Liz Ogbu from "Glossary of Terms," from the Public Health Agency of Canada, retrieved from http://www.phac-aspc.gc.ca/php-psp/ccph-cesp/glos-eng.php. The glossary was compiled by Dr. John M. Last in October 2006 and revised and edited by Peggy Edwards in August 2007. This quote has been edited to remove references to public health, since the belief is that the same notion applies to the design field and to society more broadly. For her full article, "Using Our Words: The Language of Design for Equity" see https://nextcity.org/daily/entry/using-our-words-the-language-of-design-for-equity.

8 See https://en.wikipedia.org/wiki/Spatial_justice and http://www.jssj.org/

9 From "Using Our Words: The Language of Design for Equity" | https://nextcity.org/daily/entry/using-our-words-the-language-of-design-for-equity

FIGURE 2.2: EQUALITY VS. EQUITY CONCEPT



In the first image, it is assumed that everyone will benefit from the same supports. They are being treated equally.

In the second image, individuals are given different supports to make it possible for them to have equal access to the game. They are being treated equitably.

In the third image, all three can see the game without any supports or accommodations because the cause of the inequity was addressed. The systemic barrier has been removed.

Note: A picture illustrating the concepts of equality, equity and justice.

Source: Courtesy of Courtesy Advancing Equity and Inclusion: A Guide for Municipalities, by City for All Women Initiative (CAWI), Ottawa

The concept of "equity" needs to be fully understood in order to develop solutions that enhance it (see Figure 2.2). There are significant opportunities in the design, construction, and operational phases to link sustainability, climate conscious design, equity and social justice. For example, residential construction provides opportunities for using decarbonization strategies to address the health impacts and resource deficits in marginalized communities. In addition, public investment in decarbonization (both public construction and public policy) can accelerate market transformation and demonstrate the technical feasibility and long-term societal benefits of deep decarbonization design strategies.

2.2.1_SOCIETAL BENEFITS

There is a growing awareness of the societal benefits (or co-benefits) of public sector actions focused on GHG emissions reductions (see Figure 2.3). As the public costs of extreme weather events grow, public expenditures for GHG emissions reduction strategies will have a positive return on investment while being essential to avoiding the worst impacts of climate change.[10] These returns will come primarily from the avoided costs of disaster mitigation and reductions in health care costs borne by the public health care system.

FIGURE 2.3: SOCIETAL BENEFITS OF BUILDING ELECTRIFICATION (FUEL-SWITCHING)

Health
no air pollutants from on-site combustion

Safety
reduced hazard risk, especially in earthquake territory

Resilience
all modern gas equipment requires electricity to operate, so gas equipment is not more resilient. In fact, after natural disasters, electricity is restored faster than gas. All-electric buildings are compatible with on-site generation and back-up power systems.

Short-term economic benefits
of job creation and training in an emerging market, influx of employment opportunities in communities

10 According to NOAA's National Center for Environmental Information, the U.S. has sustained 298 weather and climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion (including CPI adjustment to 2021). The total cost of these 298 events exceeds $1.975 trillion (https://www.ncdc.noaa.gov/billions/).

Public sector agencies around the United States have been investigating the impacts to disadvantaged and vulnerable communities in their climate-related planning and funding. The results of a 2018 study by the California Energy Commission, "Exploring Economic Impacts in Long-Term California Energy Scenarios" (https://ww2.energy.ca.gov/2018publications/CEC-500-2018-013/CEC-500-2018-013.pdf), suggest that the State's real gross product would increase due to the State's commitments to a new generation of lower-carbon energy infrastructure and use technologies. The study also concluded that the value of long-term economic benefits from averted deaths and medical care attributable to California's climate policy is comparable to the direct costs of the State's entire low-carbon infrastructure buildout. Thus, the state's climate initiatives — still controversial for some — could be justified solely on public health grounds.

Additional good news from this study is that these public health benefits would accrue to both disadvantaged and non-disadvantaged communities. For example, the study suggests that for every $1.00 saved from averted morbidity and mortality per disadvantaged community household, non-disadvantaged community households would also save $0.85. In other words, there are net benefits for all.

There is also clear evidence that disadvantaged households are disproportionately burdened by high levels of criteria pollutant (carbon monoxide, nitrogen dioxide, sulfur dioxide, ground-level ozone, particulate matter, and lead) exposure: for example, that same California study revealed 25 percent higher PM 2.5 particulate matter levels exposure on average. There are many diseases linked to higher exposures of these criteria pollutants: for example, California's disadvantaged households suffer from 55% higher than average rates of asthma.

Other potential benefits to all communities by increasing investments in decarbonization of the built environment include:

» Productivity increases from lower criteria pollutant concentrations (for example, work and school attendance and performance).

» Avoided local temperature increases due to lower GHG emissions. Higher temperatures have been found to negatively impact, among other things, agriculture, income, education, and crime rates.

» Job creation.

PUBLIC BENEFITS OF DECARBONIZATION

"The evidence is clear — burning less fossil fuel in power plants, cars and buses translates into less air pollution. Less air pollution can help reduce the risk for heart attacks, strokes, asthma attacks and lung cancer and improve pregnancy outcomes." — **George Daly, Dean Harvard Medical School**

Source: CEC Publication, CEC-500-2018-013, June 2018

2.3_Assembling the Right Team

Early in the life cycle of most construction projects, a team of design and construction professionals will be hired to help deliver a building that meets the needs of the owner. Some building owners/developers will use the same team over and over again, building relationships of trust and extracting value from the team's familiarity with an owner's expectations. Other owners may go through a selection process, searching for a team that will help bring the unique vision of a project to fruition.

Whatever process is used to build a team, it is critical to recognize that delivering a high-performance, all-electric, low embodied carbon building requires a different skill set and approach than "business as usual." The value of hiring architects, engineers, and contractors experienced with the new strategies required to deliver energy efficient, all-electric, low embodied carbon buildings cannot be overemphasized, even if it means that these people act in a supportive role to the "business as usual" team. Let's face it: people who have spent their career designing engines for Ferraris are not likely to be hired to develop the drivetrain for a Tesla. This is not a judgement about Ferraris or Teslas: it is just a fact of what it means to develop "expertise."

This practice guide is all about helping share knowledge, but owners should look for consultants with demonstrated expertise in this aspect of building type, just as they typically look for expertise in building function when hiring a team. Seek out MEP consultants who can show a history of using a variety of design approaches (to ensure that they are able to bring the right solutions to a project rather than justify their preferred solution yet again). Also, make sure that they are focused on informed consent from their clients rather than bringing a tendency to over-sell innovation without a track record and project-specific data and justifications. Equally important is to avoid the "safe" choice: MEP consultants who are low-cost, high perceived reliability, low-advocacy, low-innovation, highly-conservative and focused on repetition.

2.3.1_WHEN TO HIRE CONSULTANTS?

Design and construction efficiency flows from an optimized implementation process. Since the majority of clients are financially driven, the industry typically responds by looking to repeat proven, code-compliant delivery approaches.

Energy efficient, all-electric, low embodied carbon buildings often push the boundaries of a given jurisdiction's Building Codes, involve new technologies, and benefit from innovative delivery practices. These variances from conventional design and construction practice are most effectively addressed with an integrated project delivery process, where architects, engineers, contractors, and specialty consultants — all with the appropriate expertise — work together starting in early design. When the design and construction teams are integrated, and the major players are present throughout the project, this allows consideration of construction costs and cost effective practices to help optimize design decisions.

Furthermore, building projects that meet these decarbonization goals are created with whole building performance in mind. Although it is possible to reduce carbon emissions from operations with a widget approach, whole building energy and carbon modeling processes facilitate a team's ability to maximize low carbon strategies in cost effective ways. Thus, specialists in building performance modeling (both operational and embodied carbon performance) should be brought into the design process early. For an example of a desirable process, see Figure 2.4 on the following page from "The Architect's Guide to Integrating Energy Modeling in the Design Process," published by the American Institute of Architects. This same concept can be expanded from energy modeling to all the modeling that can help address full decarbonization goals.

FIGURE 2.4

	Concept Design	Schematic Design	Design Development	Construction Documents	Construction / Post-Occupancy
TEAM GOALS	Use early Design Performance Modeling to help define the goals of the project (Note: Design Performance Modeling could be with component modeling tools or a basic building energy model, but should at this stage address other performance parameters in addition to energy). Define the project requirements, as informed by modeling results	Review financial and performance energy information from model to guide design decisions	Review design alternatives based on initial goals, as informed by modeling results Create baseline and alternatives to choose from	Create documentation needed to accompany energy model results for code compliance Create documentation needed to accompany energy model results for commissioning and metering/ monitoring validation	Use results of the as-built model for commissioning Compare results of the as-built model against metered data to look for operating problems
ENERGY MODELING GOALS	Experiment with building siting and orientation Determine the effective envelope constructions Assess the effects of daylighting and other passive strategies Explore ways to reduce loads	Create rough baseline energy model Test energy efficiency measures to determine the lowest possible energy use Set up thermal zones and HVAC options	Create proposed models with system alternatives to choose from Refine, add detail, and modify the models, as needed Provide annual energy use charts and other performance metrics for baseline vs. proposed Evaluate specific products for project Test control strategies Do quality control check on the models	Complete the final design model Do quality control check on the models Create final results documentation needed to submit for code compliance	Complete the as-built model with installed component cut-sheet performance values Collect metered operating data to create a calibrated model to share with outcome-based database
BENEFITS TO CLIENT	Comfort that entire design team united around project goals Use modeling results to make design decisions informed by integrated system performance	Test different options before implementing them Determine the most efficient and cost effective solutions	Determine the most efficient and cost effective solutions Size mechanical equipment correctly	Use energy model as part of LEED or other sustainable design certification application Provide ability to better predict energy use in the building	Provide ability to refine operations to meet reduced energy use goals in the built project

Source: The Architect's Guide to Integrating Energy Modeling in the Design Process. AIA 2010.

2.3.2_COST ESTIMATING

Almost every construction project relies on close monitoring of the probable cost of construction during the design phase. Best practices include development of a cost model before design even begins, and estimates of construction cost are usually developed at major design milestones to ensure that the design is likely to continue to meet the target budget.

Early cost model development for all-electric buildings requires, by its nature, a substantially different allocation of resources between Divisions of work. Depending on the project delivery method, costs may be developed by the construction team, by professional estimators, or by both. Construction teams often rely on their past experience to inform cost estimates, as well as on subcontractors who may or may not have deep experience with the technologies and design solutions being used in all-electric building designs. Construction cost professionals can often bring a more realistic perspective when confronted with more innovative design solutions. The UK, Australia, and some other countries actually license individuals to provide these services; known as a Professional Quantity Surveyor (QS), these licensed individuals are construction industry professionals with expert knowledge on construction costs and contracts. The duties of a Quantity Surveyor can include:

» Cost estimate, cost planning, and cost management.

» Analyzing terms and conditions in contracts.

» Predicting potential risks in the project and taking precautions to mitigate such.

» Forecasting the costs of different materials needed for the project.

» Valuation of construction work.

» Life cycle cost analysis.

Until all-electric design is the norm, it may be appropriate to hire construction cost professionals to provide cost opinions, even if the construction team is preparing estimates. This second estimate can provide a valuable reference point to ensure that estimates are as accurate as possible, and the process of reconciling two estimates — while sometimes painstaking — can enforce a level of rigor that can help projects stay on budget.

In addition, whether it is a commercial, multifamily, for-profit, non-profit or public project, it is important to have an evaluative framework to analyze the cost of all-electric and decarbonized construction for a given property or development for both capital expense (or first cost) and operational expense. There is no building — even those that will be owned by public or non-profit entities — that would not be well served by lowering a building's first and operating costs. However, it is typical for owners to focus on the initial capital expense without placing adequate "value" on potential reductions in operational expenses over the life of a building that can result from building electrification and decarbonization.

Key elements to any development cost framework need to include:

» Capital Expenses and Savings (hard costs, as well as construction duration impacts and financing costs)

» Operating Expenses and Savings (ongoing cost)

» The Impact of Decarbonized and All-electric Construction on a Project's Exit Value

» The costs associated with utility connections

» Time for coordination with dual utilities versus one for all-electric design

While there is no "one-size fits all" solution to establishing a cost analysis framework, we recommend the following best practices:

- Establish a cost framework as a collaborative effort between project ownership and design and construction leadership to outline key parameters of the analysis
- Identify costs and benefits so they may be categorized by type and intent
- Calculate costs and benefits over the life of a project, and include (a) capital expenses; (b) operating cost, (c) replacement cost, and — where applicable — (d) exit value
- Compare costs and benefits by aggregating all of the defined inputs
- Compare life cycle costs using different assumptions about utility escalation rates and cost of carbon scenarios

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

Throughout this practice guide, we provide case studies and links to additional property comparables to help you review built examples and to assist your efforts to push back against any cost premium or "complexity premium" you may encounter for electrified and decarbonized construction and development methodologies.

2.3.3_ROLE OF COMMISSIONING AGENTS

Early ground-truthing[11] of the operational aspects of a building requires that the design team engage the commissioning agent early in the design process. This will better ensure the commissioning agent is familiar with the building's design intent well before the actual field-commissioning process begins, and it will serve to head off surprises related to equipment/system functionality. Among the important commissioning strategies in the early design phases of a project:

- Work with the owner to capture all electrification and decarbonization targets in the Owner's Project Requirements (OPR).
- Verify that the design team meets the OPR's goals in the Basis of Design (BOD) and design documents.
- Review design documents to ensure that the design intent reflected in the BOD is faithfully executed, maximizes clarity and minimizes ambiguity for the future bidders/builders, and provides features that can improve operational efficiency.

If performed by the right team, these efforts can be a key step towards reducing design team risks, schedule delays and construction cost change orders.

2.3.3.1_Building Enclosure Commissioning

Building Enclosure Commissioning (BECx) has become more widely embraced since the publication of guidelines such as the National Institute of Building Sciences Guideline 3, first published in 2006, and the incorporation of this NIBS Guideline into LEED standards in 2010.

11 "Ground truth" is a term used in various fields to refer to information provided by direct observation (i.e. empirical evidence) as opposed to information provided by inference.

Hiring a BECx professional, whose sole responsibility is to check that the project enclosure has been designed and installed to the client's project requirements, has been proven to significantly increase the client's chance of receiving an enclosure that helps to meet the project's overall performance goals.

Once fully installed, many layers of enclosure construction that are critical to performance (e.g. insulation, air-barriers, continuity strips at interfaces, etc.) are completely hidden. Design review remains the most cost effective measure to ensure that materials, components, and detailing will meet the performance intent once purchased. Qualified BECx professionals also help with specifying proper enclosure performance requirements and testing protocols, as well as witnessing that all of the soon-to-be-hidden performance control layers are installed properly and fully tested in an appropriate manner.

2.4_Owner's Project Requirements: The Value of Goal Setting

We all know that setting goals is important, but we often don't realize how essential they are. Goals help motivate us to develop strategies that enable us to perform at the required goal level. Setting goals helps trigger new behaviors, helps guide your focus and helps you sustain momentum. In the end, you can't manage what you don't measure and you can't improve upon something that you don't properly manage. Setting goals can help you do all of that and more.

Dr. Edward Locke and Dr. Gary Latham, co-authors of the 1990 book, "A Theory of Goal Setting & Task Performance," are leaders in goal-setting theory. Locke and Latham established five goal-setting principles that can help improve your chances of success:

Clarity » *Challenge* » *Commitment* » *Feedback* » *Task Complexity*

Clarity is important when it comes to goals. Setting goals that are clear and specific eliminate the confusion that occurs when a goal is set in a more generic manner.

Challenging goals stretch your mind and cause you to think bigger. This helps you accomplish more. Each success you achieve helps you build a winning mindset.

Commitment is also important. If you don't commit to your goal with everything you have it is less likely you will achieve it.

Feedback helps you know what you are doing right and how you are doing. This allows you to adjust your expectations and your plan of action going forward.

Task Complexity is the final factor. It's important to set goals that are aligned with the goal's complexity.

The objective of any project is to provide a facility that fulfills the functional and performance requirements of the owner, occupants, and operators. To attain this objective, it is necessary to establish and document Owner Project Requirements (OPR), forming the basis from which all design, construction, acceptance and operational decisions are made. Figure 2.5 provides a framework for the types of requirements that should be considered.

FIGURE 2.5: OWNER'S PROJECT REQUIREMENTS FRAMEWORK

Accessibility	Architectural Barriers Act Accessibility Standard (ABAAS)
Acoustics	Control of internal and external noise and intelligibility of sound
Comfort	Identify and document those comfort problems that have caused complaints in the past and which will be voided in this facility (i.e. glare, uneven air distribution, etc.)
Communications	Capacity to provide inter- and intra-telecommunications throughout the facility
Constructability	Feasibility of transportation to site, erection of components and assemblies, and health and safety during construction. Consider contractor means and methods and identifies risk in successful execution.
Design Coordination	Resolve all technical problems thoroughly and across disciplines to ensure durability and optimize facility life cycle performance.
Design Excellence	Concept development DE peer review process and incorporating peer guidance and adherence to approved design concept as design progresses
Durability	Retention of performance over required service life
Energy	Goals for energy efficiency (to the extent they are not called out in the Green Building Concepts)
Fire Protection & Life Safety	Fire protection and life safety systems. This includes active and passive fire protection and life safety systems and their interconnection with other building systems.
Flexibility	For future facility changes and expansions
Health & Hygiene	Protection from contamination from waste water, garbage and other wastes, emissions and toxic materials
Indoor Environment	Including hygrothermal, air temperature, humidity, condensation, indoor air quality and weather resistance
Installation evaluation, testing requirements, and sampling procedures	Evaluation, testing, integrated system design and testing and sampling criteria quantity identified.
Light	Including natural and artificial (i.e. electric, solar, etc.) illumination
Maintenance Requirements	Varied level of knowledge of maintenance staff and the expected complexity of the proposed systems, maintainability, access and operational performance requirements.
Security	Protection against intrusion (physical, thermal, sound, etc.) and vandalism and chemical/biological/radiological threats
Site Development	Systematic process of verifying that the dynamic systems built beyond a building's skin, perform in accordance with design intent and the property owner's operational needs including stormwater management, site utilities, irrigation, filtration, water harvesting systems and dynamic site security systems. (Background report for reviewers on this subject can be found at: https://www.gsa.gov/real-estate/design-construction/landscape-architecture/landscape-analytics-and-commissioning)
Standards Integration	Integration of approved Federal, State and local as well as GSA and Customer Agency standards and requirements
Structural Safety	Resistance to static and dynamic forces, impact and progressive collapse
Sustainability	Sustainability concepts including LEED certification goals
Training	Training requirements for the Owner's staff

Source: Adapted from "GSA Commissioning Guide," September 2020
https://www.gsa.gov/cdnstatic/GSA_Commissioning%20Guide_Sept_2020_Final_0.pdf

Obtaining the information and criteria for the Owner Project Requirements (OPR) necessitates input from all key facility users and operators.

The OPR should be expected to evolve throughout each project stage. As decisions are made throughout the planning, design, and construction phases, the OPR should be updated for use in validating, at the end of construction, that a facility fulfills the desired functional and performance requirements. It also serves as the primary tool for benchmarking success and should ultimately become part of the operations phase documentation.

OPR development is ideally led by a project ownership stakeholder in order to truly capture the owner's aspirational goals, especially when these goals challenge existing design and construction paradigms. However, this task is often assigned to an owner's representative such as the project's Commissioning Agent. The OPR should ideally be completed before the design and construction team are hired.

2.4.1_TRANSITION FROM A ZERO NET ENERGY TO A ZERO NET CARBON MINDSET

One of the paradigm shifts occurring with the developing focus on carbon is the transition from energy conservation to carbon emissions reduction goals. What will be seen throughout this practice guide is that design approaches for energy conservation are incomplete for addressing carbon emissions reduction strategies.

It is obvious that using less energy also reduces carbon. But, in a world where project cost budgets are finite, the lowest energy use strategy may not be achievable while the lowest carbon footprint strategy might be. In the extreme, imagine that every building project was all-electric, and one could include, in every project, enough onsite solar electricity generation to offset 100% of site energy use. Presto! Operationally, such a building is carbon neutral, regardless of overall energy consumption. Operational carbon neutrality could also be achieved if 100% of the grid purchased energy for this facility was from renewable energy sources.

With the cost of solar photo-voltaic (PV) systems nationally in the $2.50 to $3.00 range per installed watt for residential systems and $1.50 to $2.50 per installed watt for larger commercial systems, solar electricity can be produced at a lower cost onsite than utility company prices in many places in the U.S.[12, 13] Also, many owners have access to electricity from renewable energy sources without any investment of their own money. Buying solar electricity through a "Power Purchase Agreement" allows investors to essentially build an onsite utility source at their own expense, sell the electricity to the building owner/occupant, and make a healthy return on their investment in the process. Community choice aggregators and many utility companies also offer their customers access to 100% renewable energy from the local utility grid.

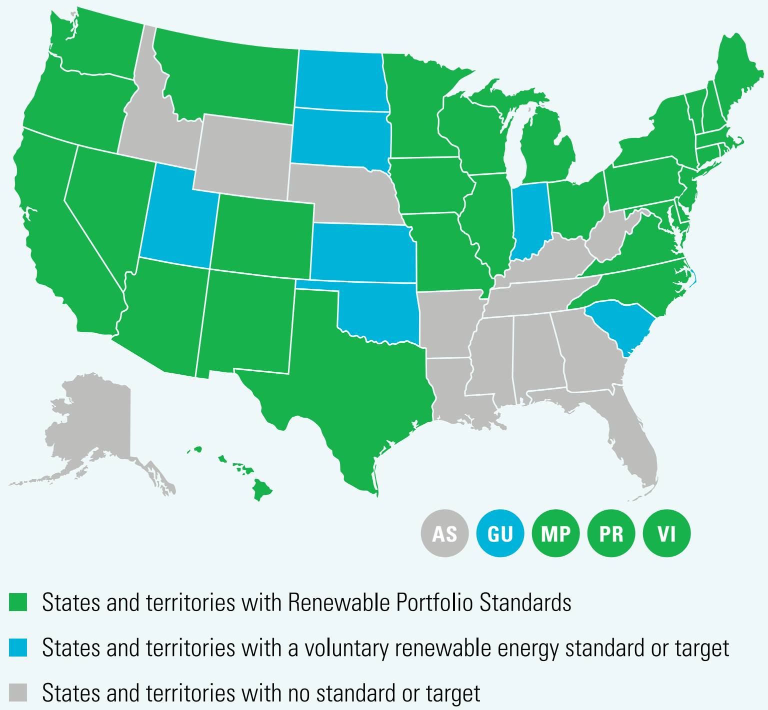
Thus, a real path to operational carbon neutrality is all-electric building design and operation, served by a 100% renewable energy source. This concept is the underpinning of the movement towards all-electric building design. In fact, State commitments to renewable energy have consistently grown since the first Renewable Portfolio Standard (RPS) was adopted by Iowa in 1983. Since then, more than half of U.S. states have established renewable energy targets. Thirty states, Washington, D.C., and three territories have adopted an RPS, while seven states and one territory have set renewable energy goals (see Figure 2.6). Although most state targets are between 10% and 45%, fourteen states — California, Colorado, Hawaii, Maine, Maryland, Massachusetts, Nevada, New Mexico, New Jersey, New York, Oregon, Vermont, Virginia, Washington, as well as Washington, D.C. Puerto Rico and the Virgin Islands — have requirements of 50% or greater. Guam also has a voluntary RPS goal of 50% by 2035 and 100% by 2045. In 2019, natural gas was the largest source of electricity in 20 states, while wind emerged as a leader in Iowa and Kansas. Coal remained the primary power source in only 15 states — about half as many as two decades ago.

12 See https://www.consumeraffairs.com/solar-energy/how-much-do-solar-panels-cost.html for average cost per State.

13 https://cleantechnica.com/2021/02/13/charts-a-decade-of-cost-declines-for-pv-systems/

With nine States committed to 100% GHG neutral power generation on or before 2050, the future of an electrical grid powered by 100% renewable energy is still not a certainty, so all-electric building projects would be well-advised to estimate a project's lifetime carbon emissions and develop and implement strategies to eliminate their projects' carbon debt during the project's lifetime.

FIGURE 2.6: RENEWABLE PORTFOLIO STANDARDS OR VOLUNTARY TARGETS



Source: https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx

As buildings are designed to consume less energy, and as the energy consumed becomes less carbon intensive, neglecting offsite carbon emissions associated with construction becomes increasingly problematic. The offsite emissions associated with producing materials, as well as emissions associated with transporting and installing materials, make up the "Embodied Carbon" of a building project. Ignoring embodied carbon results in an incomplete understanding of project-related carbon emissions. It also ignores areas where low cost carbon reductions may be achievable. After eliminating operational carbon, the reduction of embodied carbon becomes an essential strategy for achieving drastic reductions in overall carbon emissions associated with buildings, which will be key to a successful response to the climate change impacts of the built environment.

2.4.2_ALL-ELECTRIC BUILDING DESIGN

As stated above, operational carbon neutrality can be achieved through all-electric building design, and operations served by 100% renewable energy sources. It is this fact that has, by December of 2021, led 54 California jurisdictions, representing over 11% of the State's population, to adopt building codes and ordiannces to reduce their reliance on gas. The effort has spread to other parts of the country. The Massachusetts town of Brookline passed a prohibition on new gas connections, and municipalities near it are poised to do the same. Major cities, including Seattle, are in various stages of considering all-electric building legislation.

This movement to legislate all-electric construction — primarily focused at this time on new construction — comes from the recognition that the level of carbon emissions reduction required to avoid the worst impacts of climate change will be entirely unachievable if we continue to build buildings that are not operationally carbon-neutral. Every new building built with the onsite use of carbon-emitting fuels is just a future existing building that needs to be retrofitted. And future retrofit for all-electric operation is expensive, not cost effective, difficult to legislate, and represents the building sector's largest challenge when it comes to climate action.

Thus, when setting project goals, this is one of the most important decisions that an owner can make with respect to the future of their carbon footprint and our collective ability to combat climate change. OPR's should be clear about what is expected with respect to the onsite use of any fossil fuels. If these are not outright excluded from a project, owners should give extremely serious consideration to requiring their designers to enable future conversion to all-electric operation in a cost-effective manner. Such designs would include measures like increasing the capacity of electrical systems, allocating space for future equipment, and installing PV-ready infrastructure.

2.5_Using Building Performance Modeling as a Design Guidance Tool

Building performance modeling has traditionally been focused on energy modeling and has been used to predict the difference in energy use between alternate building and systems design strategies. It has also become common to use energy modeling in demonstrating compliance with Energy Code requirements. In the context of high-performance buildings overall, energy use is only one consideration, and energy models only tell one chapter of the story about a building's performance. Comfort, good access to daylight, thermal performance of building assemblies, and operational and embodied carbon footprint are all aspects of a building's full story that can be told through modeling. And, with a full complement of modeling analysis, truly optimal decisions can be made that allow for performance metrics to be prioritized and trade-offs recognized during building design. When done right, and given enough time and resources, modeling can be one of the most important steps in the successful delivery of all-electric building designs.

2.5.1_OPERATIONAL CARBON

2.5.1.1_Energy Efficiency is Still Important

For decades, the design and construction industry has focused on energy use reduction, whether due to Code compliance or for maximizing the financial return on infrastructure investments. The premise of this practice guide's approach for all-electric buildings is that all site fossil-fuel use is eliminated from a project, and source energy is from a grid fed by 100% renewable energy. Thus, energy use reduction would seem to have very little to do with emissions reductions. However, while minimizing the carbon emissions related to building design and construction is fundamentally a different focus, the synergies between carbon emissions and energy use reductions are significant. The biggest benefits from energy efficiency in an all-electric building come from:

1. Reduction of the electrical service size: electrical infrastructure cost (switchboards, utility connection charges, etc.) tends to vary in a fairly linear fashion with peak load until building ampacity gets very large.
2. Reduction of the peak capacity of HVAC systems: this can be especially beneficial if thermal energy is the primary method for distributing energy, as heat pumps can often occupy a lot more physical space than their conventional equipment counterparts.
3. Reduction in the size of onsite photovoltaic systems required to minimize carbon emissions related to grid-purchased energy.
4. Code compliance: States that have adopted ASHRAE 90.1 use energy cost as the compliance metric. So, saving energy reduces cost, and hence can help with the other Code-compliance challenges that are present for all-electric buildings (see the Codes & Policy Volume for more discussion of these issues).

Investing in efficiency first can help reduce or even eliminate the cost premiums of all-electric building designs and ensure that projects comply with their local Energy Code requirements. Traditional energy modeling has been extremely effective at evaluating the energy use reduction potential of various energy conservation measures. However, energy efficiency as the sole focus of advanced building design will not accomplish the urgent goals behind decarbonization of the built environment.

2.5.1.2_Building Enclosure Performance

Most successful high-performance buildings have placed significant emphasis on the role of the building enclosure in achieving their performance goals. This is even more important with all-electric building designs: the design, procurement, and construction of the building enclosure becomes an increasingly important system to develop, purchase, and construct for delivering a cost-effective all-electric, low operational, and embodied carbon building design.

Since the same systems (e.g. heat pumps) often serve both cooling and heating loads, load reduction strategies that impact the load during all seasons become more important in order to effectively reduce installed system costs. For example, heating with heat pumps can be a greater challenge in cold climates, where meeting heating loads will define the peak capacity required; thus, the reduction or elimination of perimeter heating using "super-insulated"[14] building enclosures can have significant cost and design benefits.

Limited modeling of enclosure construction is standard in all energy modeling. However, there can be value in detailed enclosure specific modeling early in the design phase to define achievable and specific enclosure performance goals. Parametric modeling, heat transfer modeling, and comfort modeling are all approaches to enclosure performance evaluation that can contribute significantly to the selection of an enclosure that is ultimately incorporated into an energy model.

Early, enclosure specific parametric models should include and document key assumptions regarding thermal breaks, continuity, etc. as well as specific wall material options (a level of detail that is not currently included in industry standard energy modeling services). It should be recognized that the type of advanced enclosure modeling discussed above is an area of expertise that is distinct from building energy modeling and requires that consultants who have this specific expertise be included on the design team.

Detailed definition of the enclosure construction and performance requirements can also help avoid performance and compliance issues when alternate materials or methods are considered during the construction phase. If designs are based on an enclosure that meets superior performance criteria, then it becomes extremely valuable to ensure that enclosure construction is thoroughly detailed and specified, and that quality control during construction is maintained.

2.5.1.2.1_THERMAL BRIDGING

Designing enclosure systems to avoid thermal bridging includes the use of continuous external insulation and providing thermal continuity at interfaces. Software tools such as THERM (free download at https://windows.lbl.gov/software/therm) can facilitate detailed evaluation of thermal discontinuities.

2.5.1.2.2_INFILTRATION

Assumptions about infiltration are often given very little consideration in energy models, yet studies have shown that the average building enclosure is much less airtight than often thought.[15] A poorly installed air barrier can offset all efforts at improving thermal insulation and mitigating thermal breaks, rendering the insulation essentially ineffective. Based on studies of existing buildings done in the 1970s and 1980s, the ASHRAE 1997 Fundamentals Handbook suggests that commercial office buildings were "leakier than expected." It is likely that construction practices have improved somewhat, but experience still suggests that air-tight enclosure construction does not happen without both intention and attention.

14 See https://en.wikipedia.org/wiki/Superinsulation.

15 See Steven J. Emmerich, Timothy P. McDowell, W Anis. "Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use." June 1, 2005 https://www.nist.gov/publications/investigation-impact-commercial-building-envelope-airtightness-hvac-energy-use-0

In terms of airtightness, the Passive House Standard[16] is considered best practice. While it may not be applicable to every project, it does shed light on what level of airtightness one might strive for to minimize heating and cooling loads related to air infiltration. A project can also gain additional benefits from air-tight construction, such as improved comfort and reduced energy consumption.

2.5.1.3_Energy Modeling, Carbon Emissions and Life Cycle Cost

In spite of the shift towards renewables over the past decade, Energy Codes continue to compare a proposed all-electric building against a "standard design" that is, in most cases, fueled by a combination of electricity and natural gas. Simulations for annual building energy cost measured against a natural gas baseline can mask the benefits of saving low-cost/high-carbon fuels (e.g., natural gas) rather than electricity, which in most states is more expensive per BTU than natural gas. When evaluating the performance of an all-electric building with cost as the metric (typical in all States that use ASHRAE 90.1 as their Energy Code), the all-electric building design can be unfairly penalized in areas with high electricity cost, even though the carbon content of the electricity may be favorable for achieving emissions reduction goals. Energy Use Intensity (EUI) is a common metric used to evaluate high-performance buildings, but this metric fails to account for the carbon emissions impacts of design choices.

California has adopted a different metric — BTU per square foot per year, modified hourly based on a Time Dependent Valuation (TDV) multiplier (for more discussion of this see the Volume on Codes and Policy). However, neither cost nor TDV-adjusted energy use fully account for the carbon content of a fuel choice, and thus can inadvertently steer design choices away from all-electric building design. Thus, alternate metrics can be extremely useful in evaluating the performance of all-electric building designs.

2.5.1.3.1_CARBON EMISSIONS METRICS

If carbon neutrality is a key goal of your project, then comparing new construction to existing building reuse should investigate both first cost as well as short and long term carbon emissions reductions.

One can also look at a ratio between first cost (or life cycle cost) and avoided carbon emissions to arrive at a metric ($ per pound of avoided CO_2e emissions) that can be used to guide decision-making; this metric can help owners decide on how to maximize their investments in carbon emissions reduction.

Accounting for the carbon emissions related to grid-purchased energy can also be an important consideration in evaluating alternative design strategies. Carbon-related metrics for grid-supplied energy continue to evolve away from pounds of carbon per kilowatt hour based on the national average fuel mix to metrics based on regional grid averages. Data on hourly carbon content of grid sources in real time are becoming widely available, and can be used — instead of utility costs — to evaluate the performance of designs as well as manage system operations (for example, with loads that can be deployed based on marginal emissions on the grid, or with designs incorporating microgrid[17] control systems).

Data sets for simulation tools — to the extent that they are available — use predicted carbon profiles to evaluate the annual carbon emissions of proposed designs. This only allows project teams to make design decisions based on minimizing pro-forma carbon emissions on hourly and seasonal bases. Nevertheless, meeting carbon reduction goals based on pro-forma hourly metrics still encourages the use of load shifting technologies such as thermal storage and energy storage systems as well as load shifting and deployable load controls in building design. These technologies are critical in the short term to obtaining significant emissions reductions and to ultimately achieving zero emissions.

16 https://www.phius.org/what-is-passive-building/passive-house-principles

17 See https://www.energy.gov/articles/how-microgrids-work.

2.5.1.3.2 _CARBON EMISSIONS EQUIVALENT

While the burning of fossil fuels accounts for the vast majority of human-caused greenhouse gas emissions in the U.S. (in 2018, about 93% of total U.S. anthropogenic CO_2 emissions[18]), it only accounted for about 75% of total U.S. anthropogenic greenhouse gas (GHG) emissions in that same year. Other GHGs relevant to the building sector include methane and hydrofluorocarbons (HFCs).

Methane leakage from utility company natural gas distribution pipelines is a growing concern (natural gas is roughly 86 times more potent than CO_2 as a GHG over 20 years). Over 50% of the main pipelines in local natural gas distribution systems in the U.S. are more than 30 years old, and over 20% are more than 60 years old.[19] All told, based on the results of the natural gas industry's own study, the U.S. oil and gas industry is leaking 13 million metric tons of methane each year, which means the methane leak rate is 2.3 percent of total production. This leakage rate undermines the benefits of replacing many other "dirty" fuels (such as coal) with natural gas. And, this makes methane leakage almost 20% of all US GHG emissions. Avoiding the astronomical cost of upgrading the natural gas infrastructure is another benefit to universal building electrification.

HFCs are used as refrigerants in almost all electric-driven cooling systems and many modern electric-driven heating systems. Many of the HFCs used are potent GHGs (some thousands of times more potent than CO_2 as shown in Figure 2.7). Preventing the leakage of refrigerants is a fundamental goal of good equipment design, service, and maintenance. However, there has been an increasing focus both on leakage reduction due to the financial and environmental costs of leakage and on refrigerant selection as a method of reducing the environmental impact of refrigerant leakage.

When accounting for the climate impacts of system designs, all project-related emissions that have global warming impacts should be considered. To this end, the metric of "carbon dioxide equivalent" was developed.

A carbon dioxide equivalent (or CO_2 equivalent, abbreviated as CO_2e) is a metric used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

2.5.1.3.3_LIFE CYCLE COSTS AND CARBON

Financial decision-making that focuses on life cycle cost, rather than first cost, can support decarbonization efforts. Thus, it is important to understand any given owner's perspective on operations, maintenance, and replacement costs as part of making the case for specific decarbonization strategies.

Also, finding ways to factor in financial metrics related to carbon can be effective at promoting the adoption of decarbonization strategies. Large carbon emitters in California are already subject to the costs of the State's Cap-and-Trade Program. New York and ten other Northeastern and Mid-Atlantic States established the Regional Greenhouse Gas Initiative (RGGI), which subjects electric generation facilities to cap-and-trade rules similar to California's program. So, for emitters that fall under these programs, there are real costs associated with their carbon emissions. For others, planning for the day when carbon pollution has a regulatory cost can be a reasonable risk management need, whether these pollution costs are borne by owners directly, as in California and New York, or for when they become a larger component of utility costs that will affect all utility customers.

Until the cost of carbon pollution is reflected in the rate tariffs for fuels purchased for building operations, utility rates will not be an effective market driver for decarbonization. In the interim, one way to factor in the future cost of carbon can be through using artificial utility tariffs that correlate marginal emissions rates to cost. This artificial rate structure can then be easily used in the design team's "energy" modeling software to evaluate carbon reduction strategies; in this approach, minimizing utility costs will be directly correlated with minimizing carbon emissions (refer to Figure 2.9).

18 From U.S. Energy Information Administration data.

19 From "A National Estimate of Methane Leakage from Pipeline Mains in Natural Gas Local Distribution Systems", Zachary D. Weller, Steven P. Hamburg, and Joseph C. von Fischer, Environ. Sci. Technol 2020 (https://pubs.acs.org/doi/10.1021/acs.est.0c00437)

FIGURE 2.7: GLOBAL WARMING POTENTIAL OF COMMON REFRIGERANTS

Refrigerant Name	Trade or Common Name	CAS Name	Global Warming Potential (GWP) [3]
R-717	Ammonia	Ammonia	0
R-1224yd(Z)	AMOLEATM 1224yd	(Z)-1-Chloro-2,3,3,3-Tetrafluoropropane	1
R-744 [1]	CO_2	Carbon dioxide	1
R-1234zd(E)	Solstice zd	Trans-1-chloro-3,3,3-trifluoropropene	1
R-514A	Opteon XP30	HFO-1336mzzZ/trans-1,2-dichloroethylene (t-DCE) (74.7/25.3)	2
R-1270	Propylene	Propene, Propylene, Methyl Ethylene	2
R-290	Propane	Propane	4
R-1234yf [2]	HFO-1234yf	2,3,3,3-Tetrafluoropropene	4
R-1150	Ethene	Ethene, Ethylene	4
R-600a	Isobutane	Isobutane	5
R-1234ze(E)	Solstice ze	1,3,3,3-Tetrafluoropropene	6
R-170	Ethane	Ethane	6
R-601	Pentane	Pentane	11

Refrigerant Name	Trade or Common Name	CAS Name	Global Warming Potential (GWP) [3]
R-123 [4]	HCFC-123	2,2-Dichloro-1,1,1-trifluoroethane	77
R-152a	HFC-152a	1,1-Difluoroethane	124
R-32	HFC-32	Difluoromethane	675
R-401A	MP39	R-22/R-152a/R-124 (53/13/34)	1182
R-134a [7]	HFC-134a	1,1,1,2-Tetrafluoroethane	1430
R-407C	- -	R-32/R-125/R-134a (23/25/52)	1774
R-22 [5]	HCFC-22, Freon	Chlorodifluoromethane	810
R-410A	Puron, AZ-20	R-32/R-125 (50/50)	2088
R-407A	KLEA 60	R-32/R-125/R-134a (20/40/40)	2107
R-125	HFC-125	Pentafluoroethane	3500
R-404A	HP-62	R-125/R-143a/R-134a (44/52/4)	3922
R-11 [6]	CFC-11	Trichlorofluoromethane	4750
R-12 [6]	CFC-12	Dichlorodifluoromethane	10900

[1] As of May, 2021, CO2 heat pumps are available from Sanden, Mayekawa, Watts, and Mitsubishi. Other manufacturers have CO2 heat pumps under development (e.g. Nyle) due to growing market interest/demand.

[2] Proposed HFO replacement for R-134a (which is a popular high-GWP HFC that is being phased out under the EPA rules adopted in 2016). R-134a will no longer be available for new chillers starting on January 1, 2024.

[3] GWPs listed are IPCC AR4 (2007), 100-year GWPs.

[4] R-123 was phased out for new HVAC equipment on Jan. 1, 2020; it will continue to be produced for servicing equipment until 2030.

[5] Starting in 2020, R-22 was no longer produced or imported. After 2020, only recovered, recycled, or reclaimed supplies of R-22 will be available.

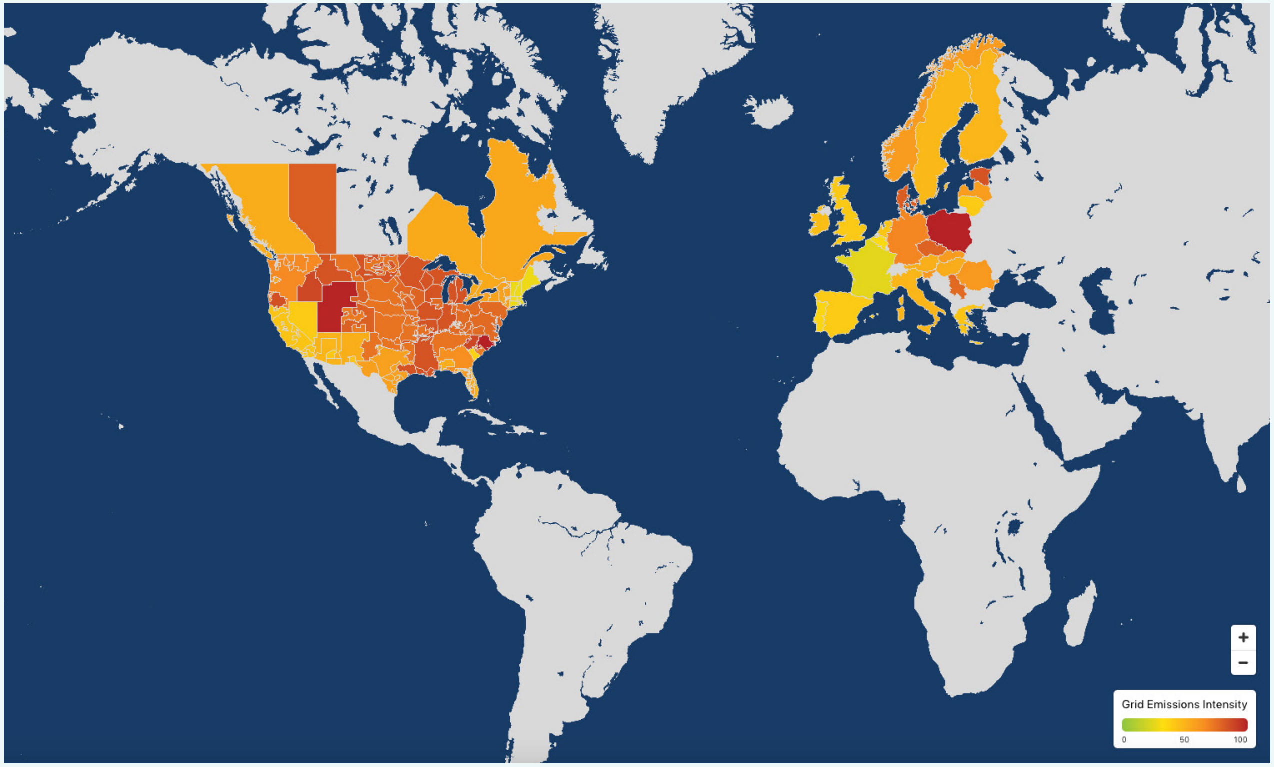
[6] R-11 and R-12 were completely banned from production in 1996 under the Montreal Protocol due to their ozone depletion characteristics.

[7] Refrigerants in red text are the most ubiquitous currently in use in new HVAC equipment. R-717 (CO2) is growing in popularity, albeit equipment options are currently limited.

Tools to assist with implementation of this methodology are currently being developed to be more accessible to the design community; robust data sets for modeling marginal emission rates in different utility sectors are available through non-profit entities like Watttime and by the National Renewable Energy Laboratory (NREL). The map below from Watttime (Figure 2.8) represents the electrical sub-regions in 2020 that track hourly marginal emission factors.

Refer to https://www.watttime.org/explorer/#3/41.23/-97.64 for real-time, location-specific information on marginal emissions rate from the grid in your area.

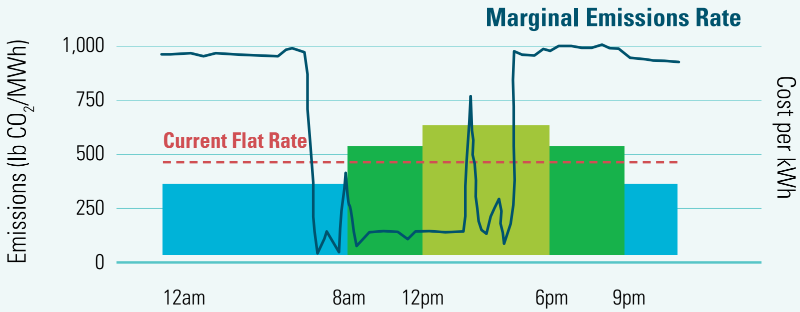
FIGURE 2.8: GRID EMISSIONS INTENSITY BY ELECTRIC GRID



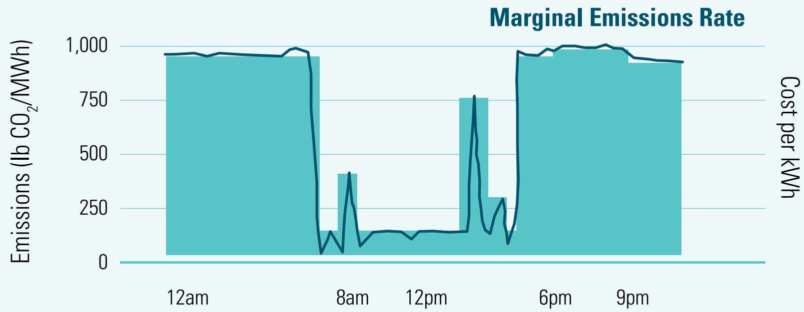
Grid emissions intensity on a scale of 1 – 100 relative to other electric grids. In other words, lower on scale is the cleanest any grid gets and higher on the scale is the dirtiest any grid gets.

Source: Watt Time
https://www.watttime.org/explorer/#3/41.23/-97.64

FIGURE 2.9: UTILITY COSTS ARE NOT ALIGNED WITH GRID EMISSIONS



Example above is what it looks like to have a tariff schedule that does not align with grid emissions



Example above is what it looks like to have a tariff schedule that perfectly aligns with grid emissions

Off-peak | Partial-peak | On-peak

Rate varies continuously throughout the day based on current marginal emissions rate

Source: Developed by Steve Guttmann, Guttmann & Blaevoet

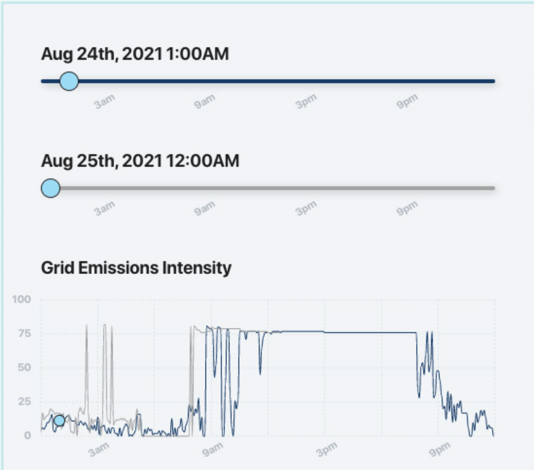
Access to the regional marginal emissions factors allows designers to fully understand electrification decisions based on the carbon emissions reduction potential versus operational costs. Since each subregion has different source mixes, grid emissions profiles can be significantly different on an hourly basis. California's solar access and heavy reliance on natural gas and nuclear power create a very different emission profile than Eastern Colorado or West Texas, which have higher uses of coal and large amounts of wind power (see Figure 2.10).

These tools allow future cost risks to be incorporated into a life cycle cost analysis or a risk management evaluation that looks at the sensitivity of financial performance metrics on a range of future emissions avoidance scenarios.

FIGURE 2.10: REAL TIME AND FORECASTED MARGINAL EMISSION RATE DATA IS AVAILABLE

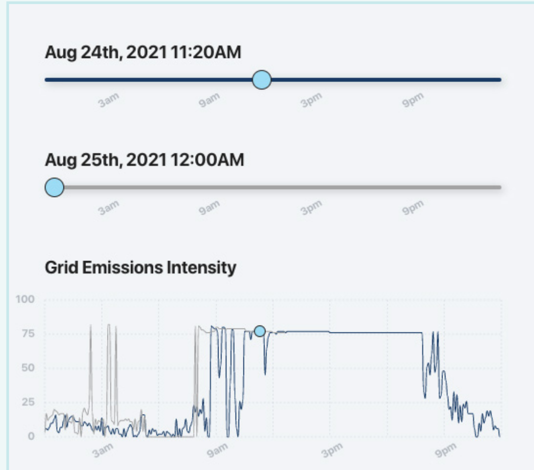
SPP North Texas

AUG. 24TH, 2021 1:00AM



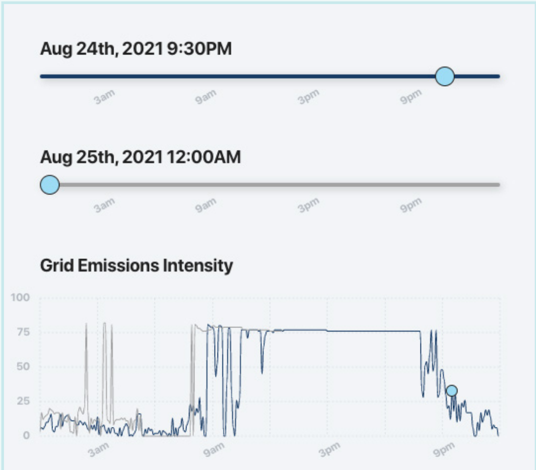
Grid Emissions Intensity = 17

AUG. 24TH, 2021 11:20 AM



Grid Emissions Intensity = 77

AUG. 24TH, 2021 9:30 PM

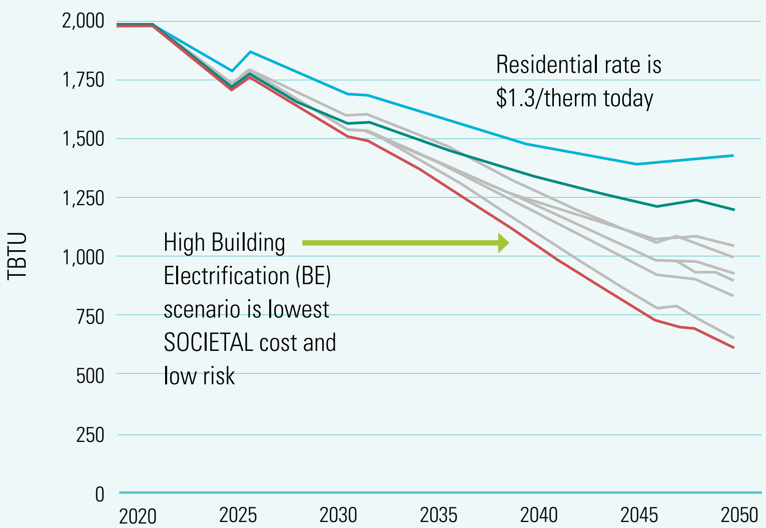


Grid Emissions Intensity = 33

Grid emissions intensity on a scale of 1 – 100 relative to other electric grids. In other words, lower on scale is the cleanest any grid gets and higher on the scale is the dirtiest any grid gets.

Source: Watt Time | https://www.watttime.org/explorer/#3/41.23/-97.64

FIGURE 2.11: PROJECTIONS OF CALIFORNIA GAS DEMAND AND NATURAL GAS PRICES IN VARIOUS GHG EMISSIONS REDUCTION SCENARIOS



- Current Policy Reference: $2.60/therm in 2050, 13 million gas customers remain
- No Building Electrification with Synthetic Natural Gas (SNG): $4-5/therm in 2050, 13 million gas customers remain
- High Building Electrification: $18/therm in 2050 with no gas transition strategy, 2 million gas customers remain

Notes: Rates are for residential customers; all results shown in 2018 (real). The analytics did not include customer price sensitivity feedback loops. Including price sensitivity modeling might lower the number of customers remaining on the system in 2050.

Source: Gridworks

Life cycle cost analyses also need to take a realistic look at the sensitivity of life cycle costs to the potential futures of natural gas prices in high-electrification scenarios. In an electrified future, a reduced ratepayer base will need to cover the cost of the natural gas distribution system maintenance, upgrade, and other operating costs. Studies by Gridworks and E3 performed for the California Energy Commision[20] showed costs per therm increasing from $1.30 in 2020 to as high as $18 per therm in 2050, based on a "high building electrification scenario," and as low as $4 per therm if an aggressive transition strategy is put in place (see Figure 2.11). The impacts of these possible escalations in future utility costs should be factored into any meaningful life cycle cost risk analysis.

2.5.2_EMBODIED CARBON

As discussed earlier, buildings produce greenhouse gases at every stage of the building lifecycle from extraction of virgin materials to disposition of construction waste. So as the electricity supply transitions to a greater percentage of renewable sources and operational carbon emissions are reduced, the pre-occupancy stage of a building's life begins to matter more as the contribution of carbon to the atmosphere "embodied" in the construction becomes a larger portion of the impact of a building's entire life span. It stands to reason, therefore, that the amount of construction required to meet the needs of projected population growth over the coming decades increases the urgency of addressing embodied carbon.

According to the non-profit organization Architecture 2030, "The embodied carbon emissions of building products and construction represent a significant portion of global emissions: concrete, iron, and steel alone produce ~9% of annual global GHG emissions; embodied carbon emissions from the building sector produce 11% of annual global GHG emissions. Embodied carbon will be responsible for almost half of total new construction emissions between now and 2050."[21]

20 "California's Gas System in Transition: Equitable, Affordable, Decarbonized and Smaller," pub. by Gridworks, and "Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model" pub. by the CEC on June 13, 2018.

21 See https://architecture2030.org/new-buildings-embodied/.

Volume 6 of this practice guide is devoted to reducing the embodied carbon in buildings. This Volume identifies reduction opportunities. Volume 6 recommends addressing high volume and carbon intensive building elements first:

a. **Concrete** accounts for more carbon emissions than any other material on the planet. Pretty much all buildings use concrete, if not in the structural frame and envelope, then in the foundations. Concrete usually accounts for more carbon emissions than any other material and often more than all other materials combined. For wood framed buildings, concrete can account for 75% of the total weight of the building.

    i. **What you can do:** Work with your structural engineer to minimize the amount of concrete on your project and specify low carbon concrete mixes that replace the Portland cement with supplementary cementitious materials such as fly ash and slag.

b. **Steel:** second only to concrete in global carbon emissions, not all steel is created equal. Steel from Electric Arc Furnaces (EAF) has high recycled content and a much lower carbon footprint than steel from Basic Oxygen Furnaces (BOF) that use more virgin ore and burn coal and coke. EAF products include structural steel shapes, reinforcing bars, flats, angles, rods and pipes. BOF products typically include sheet steel and metal studs.

    i. **What you can do:** Use steel sparingly and efficiently and select products produced in EAF's in areas with clean power grids.

Additional strategies for reducing embodied carbon include:

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

2.6_Design Approaches

2.6.1_HIGH PERFORMANCE ENVELOPES

While entire books have been written about high performance enclosures,[22] this practice guide focuses on a few key issues that can be the difference, between good and great performance.

The lack of continuity at the interfaces between enclosure systems and performance enhancing features (e.g. insulating materials, air-barriers, etc.) can seriously degrade overall enclosure performance. Rigorous review of design documentation for materials, layers, and interfaces can help clarify and define expectations for a contractor's installation. It is best if these reviews identify the detailing needed as well as the coordination of the interfaces between materials furnished by different trade partners.

Two aspects of enclosure design that are often overlooked but play a critical role in high performance enclosure design are thermal bridging and air barriers.

2.6.1.1_Thermal Bridging

Heat will transfer through a building's thermal envelope at different rates depending on the materials present throughout the envelope. Heat transfer will be greater at "thermal bridge" locations than where insulation exists because there is less thermal resistance.

"Super-insulated" enclosures (typically, walls with an effective R-value of 40 or greater and roofs with an effective R-value of 60 or greater) rely on strategies that incorporate thicker construction to accommodate insulation with increased R-value as well as a focus on the reduction of thermal bridging.

22 For example, see https://www.buildingscience.com/bookstore/books/high-performance-enclosures.

Designing enclosure systems to avoid thermal bridging includes the use of continuous external insulation and providing thermal continuity at interfaces. Rigorous design review for thermal continuity should be performed since poor continuity affects a significantly larger area of the wall's thermal performance than merely the line of the discontinuity, resulting in a more significant reduction in average overall thermal performance than would be intuitively anticipated.

There are several methods that have been proven to reduce or eliminate thermal bridging depending on the cause, location, and construction type. The objective of these methods is to either create a thermal break where a building component would otherwise span from exterior to interior or to reduce the number of building components spanning from exterior to interior.

Strategies include:

» A continuous thermal insulation layer in the thermal envelope, such as with rigid foam board insulation

» Lapping of insulation where direct continuity is not possible

» Double and staggered wall assemblies

» Structural Insulated Panels (SIPs) and Insulating Concrete Forms (ICFs)

» Reducing framing factor by eliminating unnecessary framing members

» Raised heel trusses at wall-to-roof junctions or other construction features that allow for increased roof insulation depth without compression

» Quality insulation installation without voids or compressed insulation

» Installing double or triple pane windows with gas filler and low-emissivity coating

» Installing windows with thermally broken frames made from low conductivity material

Details on many of these strategies can be found in the California Energy Commission (CEC) Residential Compliance Manual, published by the California Energy Commission.

2.6.1.2_Air Barriers

Air barriers are extremely important in controlling air infiltration between outdoors and conditioned interiors, providing both heating and cooling load control.

To ensure maximum air tightness of the construction, all fixed penetrations must be sealed properly and continuity must be provided at interfaces between systems and at all penetrations (e.g., windows and doors). The installation of the air barrier products requires oversight in order to ensure continuous adherence to the manufacturer's guidelines.

The Passive House Standard suggests a target for air tightness: a maximum of 0.6 air changes per hour at pressure of 50 Pascals (ACH50) or 0.2 inches of water, and verified with an onsite pressure test (in both pressurized and de-pressurized states).[23] This Standard is considered best practice and may not be applicable to every project. However, it does shed light on what level of airtightness one might strive for to minimize heating and cooling loads related to air infiltration, and also to gain additional benefits from air-tight construction such as improved comfort and reduced energy consumption. For contrast, under the DOE Zero Energy Ready Homes program, leakage criteria varies from 1.5 to 3 air changes per hour, depending on Climate Zone.[24]

23 A 50 Pascal pressure is roughly equivalent to the pressure generated by a 20 mph wind blowing on the building from all directions. CFM50 is the most commonly used measure of building airtightness and gives a quick indication of the total air leakage in the building envelope. ACH50 (Air Change per Hour at 50 Pascals) is a way of normalizing leakage test results so that leakage in buildings of different sizes can be compared.

24 https://basc.pnnl.gov/resource-guides/continuous-air-barrier-exterior-walls#edit-group-compliance

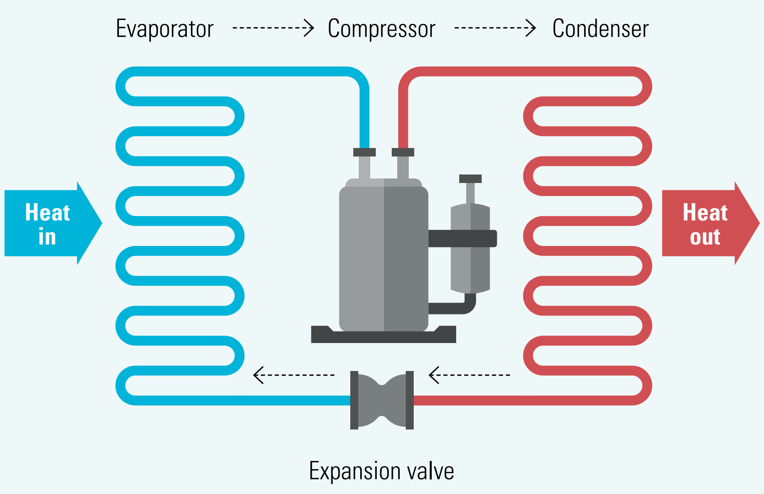
2.6.2_USE ELECTRIC-DRIVEN HEAT PUMPS

One of the most important tools in the toolkit for all-electric building design is the heat pump. Like your refrigerator, heat pumps use electricity to move heat from a cool space to a warm space, making the cool space cooler and the warm space warmer (see Figure 2.12). During the heating season, heat pumps can move heat from the cool outdoors into your warm building, and, during the cooling season, heat pumps move heat from your cool building into the warm outdoors. Because they move heat rather than generate heat, heat pumps can provide equivalent space conditioning at as little as one quarter of the cost of operating conventional heating or cooling appliances.

Heat pumps are not some mystery technology — they have been around for decades. In fact, the concept was first proposed by Lord Kelvin in 1852 and the first working system was created in 1855 by Peter von Rittinger. It is reported widely that modern heat pumps were "invented" in 1948 by a man named Robert C. Webber, who burned his hand on a condenser coil while working on a deep-freeze freezer in his cellar beneath his home. Not wanting to be wasteful, Robert thought about how to use this heat from his freezer. Large scale heat pump applications more likely go back to the 1920s, when Aurel Boleslav Stodola, a Slovak engineer, physicist, and inventor working as a professor of mechanical engineering at the Swiss Polytechnical Institute in Zurich, constructed a closed loop heat pump (using source water from Lake Geneva) to heat the City Hall in Geneva.

It wasn't until the oil crisis of the 1970s that the heat pump became a more popular choice for heating and cooling homes. Thus, heat pumps have been in large-scale commercial production for over 50 years. Unfortunately, many systems installed in the early periods of this technology did not perform very well. This was not a problem with the technology but with the industry. Heat pumps are not as forgiving as gas furnaces (e.g. correct sizing is critical to optimal performance), and HVAC contractors did not fully understand the technology (many still don't).

FIGURE 2.12: BASIC HEAT PUMP REFRIGERANT CYCLE



Source: On Air | https://www.lghvacstory.com/heat-pumps-the-new-high-tech-energy-source/

It is a myth that heat pumps only work in mild climates. This thinking stems from the fact that the performance of some heat pumps falls off as the ambient air temperature drops. Heat pumps have been used in extreme climates (like Alaska) for years. Today's air-source heat pumps easily perform down to 0 degrees F, and special low temperature units will work well to -15 degrees F and lower without electric resistance heat strips.

Heat pumps are designed to pull thermal energy from a "source" and deliver thermal energy to a "sink." Heat pumps come in multiple configurations for sources and sinks, which are generally either water or air. Heat pumps can be designed to move energy in one direction (i.e. always delivering heating energy or always delivering cooling energy to the sink); a chiller is, in essence, a heat pump that always takes heat out of the water being circulated through it and moves that heat to the outdoors via the air-cooled condenser or a cooling tower. With the inclusion of a reversing valve, heat pumps can change from delivering cooling energy to delivering heating energy. Heat pumps can also be designed to simultaneously deliver heating and cooling energy to separate sinks, and can use another dedicated component to act as a load balancing source or sink.

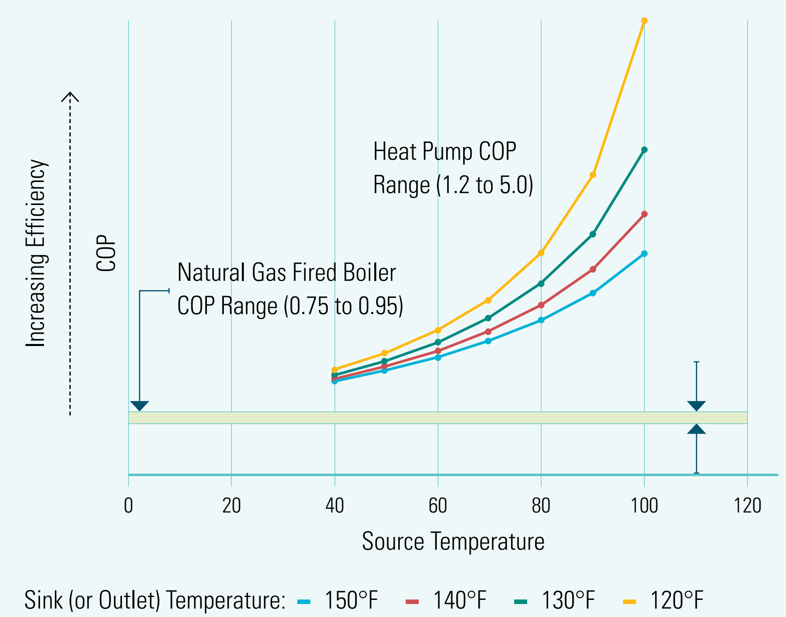
Thus, there are a number of configurations for heat pumps that allow for a wide application of equipment to the various heating and cooling needs of any facility.

Heat pumps are extremely effective at using electricity to move energy from a source to a sink. The efficiency ("coefficient of performance" or COP) of the system itself (the ratio between the electrical energy invested in order to run the heat pump and the heat pump's energy output) varies between the types of system used. To calculate COP, the unit of energy consumed must be the same in the numerator and denominator.

- **COP = Energy Output (kW) ÷ Energy Input (kW)**
- **COP = Energy Output (BTUH) ÷ Energy Input (BTUH)**

Theoretical efficiencies of heat pumps vary based on source and sink temperatures (as shown in Figure 2.13). Electrical resistance heating, by comparison, can only have a theoretical COP of 1.0, and, in application, typically has an effective COP of less than 1.0.

FIGURE 2.13: HEAT PUMP COEFFICIENT OF PERFORMANCE (COP) VS. SOURCE TEMP



Source: Steven Guttmann, Guttmann & Blaevoet

In real-world applications, heat pump system efficiency is dependent on many factors. Ground source heat pump systems tend to have a COP between 2.5 and 3. Air source heat pumps can be slightly less efficient, with an average COP of between 1.5 and 3. However, it must be noted that these values are increasing as technologies advance, and manufacturer's claims of a products' COP need to be carefully evaluated for source and sink assumptions.

Heat pumps are often paired with Dedicated Outdoor Air Systems (DOAS). A DOAS system removes the ventilation air load from the heat pump system, which can allow the heat pump to operate at higher efficiencies. DOAS systems often incorporate air-to-air heat exchangers for heat recovery from the exhaust air stream, further increasing the efficiency of the overall system.

2.6.2.1_Air-Source Heat Pumps

Some of the available air-source heat pump configurations include:

1. **Air-to-air heat pumps:** a heat pump that either heats or cools the air stream circulated to the building by drawing heat from or dumping heat to another airstream.
    a. The most common air-source heat pump uses outdoor air to draw heat from or dump heat to. However, air-source heat pumps can also be successfully configured to use other air streams; for example, using the exhaust air from a building can be an extremely effective way of recovering energy that would otherwise be wasted.
    b. The newer generation of air-to-air heat pumps allow for the integration of a domestic hot water heat recovery system to dump heat from the system refrigeration circuit into a domestic hot water system.
2. **Air-to-water heat pumps:** a heat pump that either heats or cools the water stream circulated to the building by drawing heat from or dumping heat to an airstream.
    a. The most advanced air-to-water heat pumps have three water circulating loops: one for space heating hot water, one for space cooling water, and one for domestic hot water preheat. These heat pumps operate by moving energy from the chilled water loop and dumping that energy into the hot water loops, and vice versa. This "heat recovery" strategy allows these heat pumps to operate at COPs as high as 7.5. The air coil is used when there is not enough sink for one of the sources (in this case, the coil is used to dump excess heating or cooling energy to the atmosphere), or for periods when all the available heat recovery is not enough to meet one of the loop's demand (in this case, the coil is used to either draw heat from or reject heat to the atmosphere to supplement the recovered energy).
    b. Heat pumps that use CO_2 as a refrigerant are particularly well-suited to making hot water in cold climates. This is discussed in more detail in Volumes 3 and 4.

2.6.2.2_Water-Source Heat Pumps

Some of the available water-source heat pump configurations include:

1. **Water-to-air heat pumps:** a heat pump that either heats or cools the air stream circulated to the building by drawing heat from or dumping heat to a water source.
    a. Common sources for water-source heat pumps include:
        i. A water loop that is heated by an external heat source (historically, a natural-gas-fired boiler has been used, but all-electric designs would require another source), and cooled by a cooling tower, dry cooler, or other heat rejection device.
        ii. A water loop that is connected to a network of pipes buried in the ground. This is generally referred to as a geothermal or ground-source heat pump (see Figure 2.15). A variation on this type of configuration adds a cooling tower to the ground loop, so that the size of the ground loop does not need to be adequate to serve peak loads; this is typically referred to as a hybrid ground-source heat pump.

b. Other sources for water-source heat pumps include:

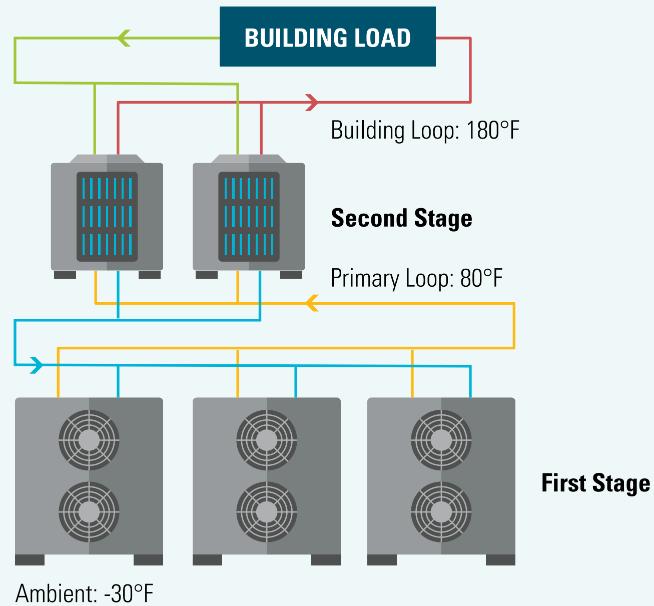
i. A water-loop that is connected to a body of water (river, lake, or ocean). This connection is typically accomplished via a heat exchanger. This heat exchanger can be a network of pipes submerged in the source. This can also be a conventional heat exchanger that has the heat pump's source water circulating in a loop on one side and water from the river/lake/ocean circulating on the other side. This is generally referred to as a geothermal or earth-coupled heat pump.

ii. A water loop that is connected to a coil in an airstream with a moderate, stable temperature, such as exhaust air from a building.

iii. A water loop that is connected to a heat exchanger that draws energy from water discharged into or flowing in a municipal sewer system. Typically referred to as Sanitary Wastewater Energy Exchange (or SWEE), this technology has been around for over 25 years, and there are more than 500 wastewater heat pumps in operation worldwide. One estimate is that Americans flush 350 billion kilowatt-hours of energy into the sewers each year — roughly enough to power 30 million U.S. homes.[25]

iv. A water loop that is connected to the discharge from an air-to-water heat pump. This configuration is typically used for applications of air-source heat pumps in cold climates that need to produce a hot water temperature over 90 to 100 degrees F. In this case, a water-source heat pump is used as a "second stage" (see Figure 2.14)

FIGURE 2.14: "CASCADING" OR TWO-STAGE AIR-SOURCE HEAT PUMP SYSTEM

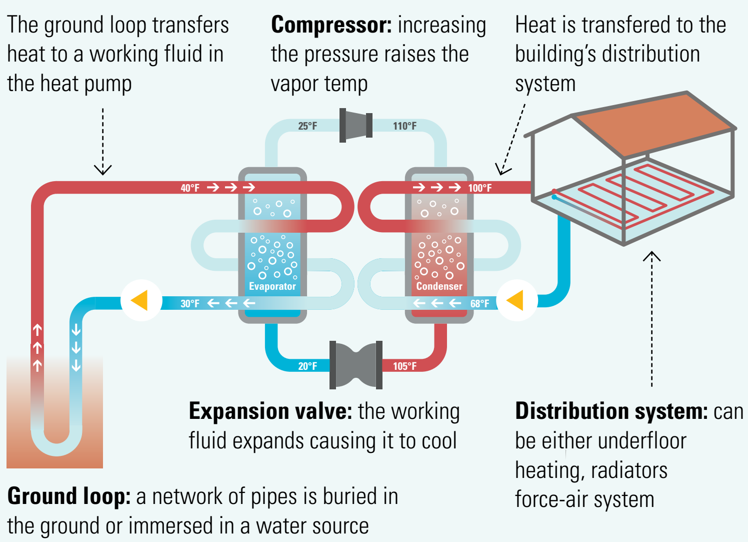


Source: Transom Corporation, Ontario, Canada
https://www.transomcorporation.com/products/hatch-air-source-heat-pump/

25 https://www.nationalgeographic.com/science/article/121211-sewage-heat-recovery

2. **Water-to-water heat pumps:** a heat pump that either heats or cools the water stream circulated to the building by drawing heat from or dumping heat to a water source.
   a. Source water for this type of heat pump can come from the same sources as water-to-air heat pumps. Similar to air-to-water heat pumps, water-to-water heat pumps can have four water circulating loops: one for space heating hot water, one for space cooling water, one for domestic hot water preheat, and one for load balancing. These can be combined with any number of space conditioning strategies, including fan coil units, air handlers, and radiant heating and cooling systems.

FIGURE 2.15: WATER-TO-WATER GROUND SOURCE HEAT PUMP (GSHP)—SYSTEM SHOWN IN HEATING MODE



Source: https://lakecountrygeothermal.com/geothermal-heat-pumps-and-ground-loops/

2.6.2.3_Refrigerant-Based Heat Pump Systems

Variable refrigerant flow (or VRF) systems allow for energy to be exchanged between zones in heating and zones in cooling. VRF systems come in air-to-air and water-to-air heat pump configurations, and many can be equipped with an extra refrigerant-to-water heat exchanger that provides recovered energy for pre-heating domestic hot water.

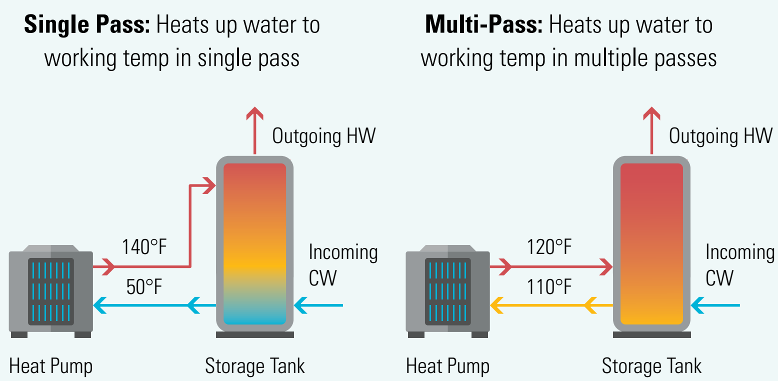
2.6.2.4_Single-Pass Versus Multi-Pass System Configurations

Different configurations of central Heat Pump Water Heater (HPWH) systems are available. The primary configurations that are being used today are (see Figures 2.16 and 2.18):

» Single pass

» Multi-pass

FIGURE 2.16: SINGLE AND MULTI-PASS HEAT PUMP SYSTEMS



2.6.2.4.1_MULTI-PASS SYSTEMS

Modeled on the design of conventional, natural-gas-fired, central water heating systems, "multi-pass" arrangements have been widely designed, installed, and operated.

Multi-pass systems are sensitive to:

1. The balancing of flows:

   a. Each heat pump wants to see the same amount of flow. For systems that bring on each heat pump in a staged manner, this can require rigorous commissioning of the controls that regulate the amount of water flowing between the heat pumps and the storage tanks.

   b. Water flow rates from the storage tanks to meet system demand should be balanced so that draw-off is relatively equally distributed.

   c. How recirculation water is tied into the storage system can affect the uniformity of tank temperatures. Recirculation water is colder than the storage temperature, especially in systems that store water at or above 140 deg. F and mix the temperature down to typical supply water temperatures (120 deg. F). Thus, poor configurations of return water connections can cause one or more tanks to drop in temperature quicker than the other tanks, with adverse impacts on heat pump system efficiency.

      i. The use of "loop" or "swing" tanks, developed in response to the same optimization efforts that have resulted in the promotion of single pass design configurations, may be a way to mitigate these adverse effects in multi-pass systems as well.

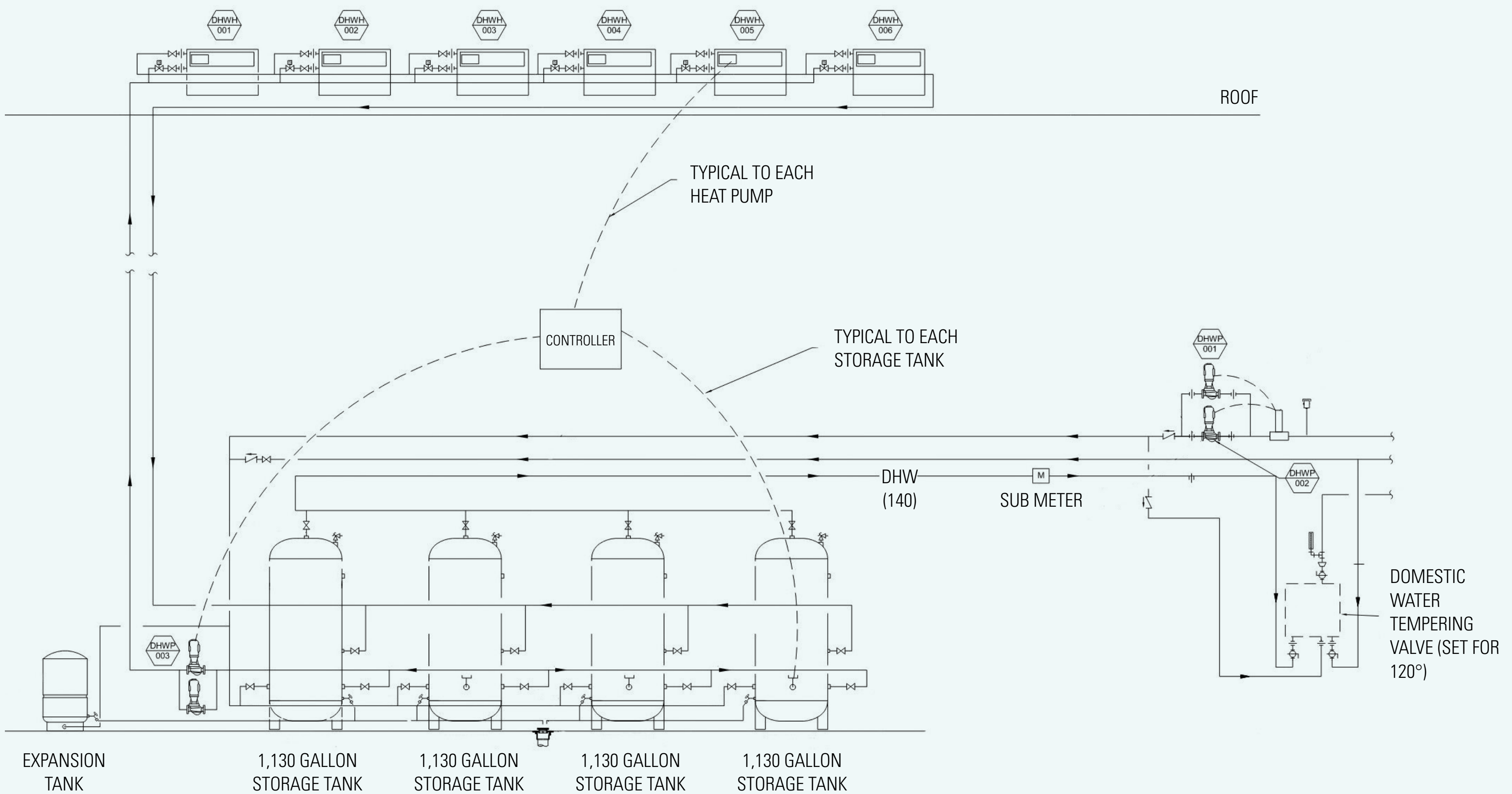
2. Piping design that does not maximize thermal stratification in the storage tanks.

See an example of the impacts from a number of these issues in Figure 2.17.

FIGURE 2.17: POORLY DESIGNED TANK CONFIGURATIONS CAN LEAD TO ADVERSE IMPACTS ON HEAT PUMP SYSTEM EFFICIENCY

Flow imbalances in this system are causing tank temperatures to vary significantly as well as causing excessive variations between storage tanks in the rate of charging and discharging.

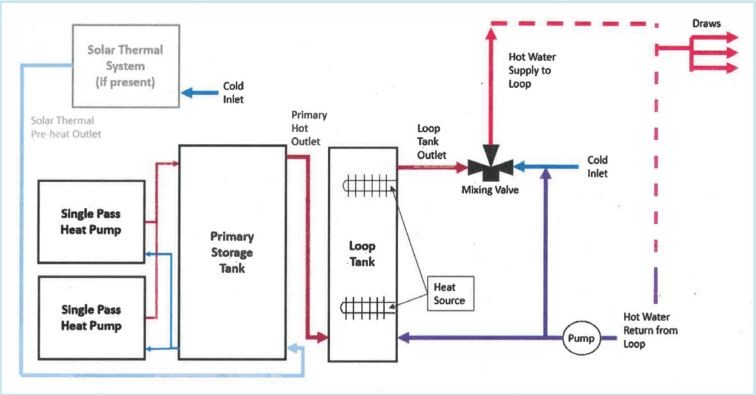
FIGURE 2.18: TYPICAL MULTI-PASS CENTRAL HPWH SYSTEM ARRANGEMENT WITH MULTIPLE AIR-SOURCE HEAT PUMPS AND MULTIPLE STORAGE TANKS



2.6.2.4.2_SINGLE PASS SYSTEMS

Studies on overall system efficiency suggest that "single pass" system arrangements may have advantages. Individual heat pump efficiency can be maximized by ensuring that the coldest water in the system (i.e. the make-up water) is what enters the heat pump(s).

FIGURE 2.19: PRESCRIPTIVE SIZING AND LAYOUT REQUIREMENTS FOR CENTRAL HEAT PUMP WATER HEATERS FOR MULTIFAMILY BUILDINGS



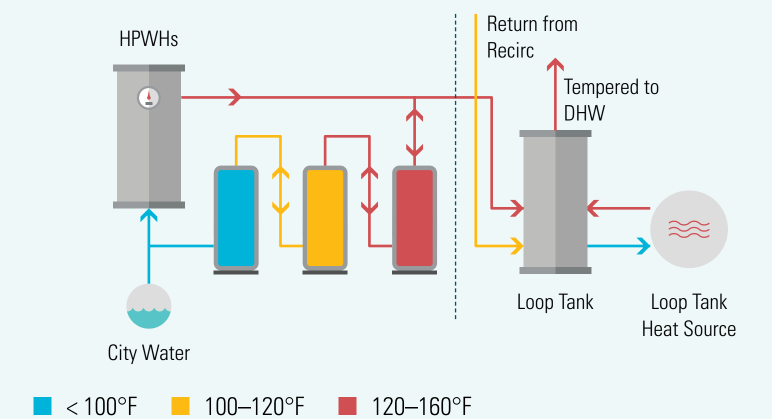
System schematic contained in the 2019 California Energy Commission's Executive Director Determination, which serves as the basis for Code compliance in multi-family housing in California.

Source: California Energy Commission

While there is still debate regarding the superiority of single pass over multi-pass configurations, California has decided to codify the single-pass approach into the Energy Code for projects with "multiple dwelling units."[26] The "Executive Director Determination," from the California Energy Commission issued on December 19, 2019 provides prescriptive requirements for the heat pump, storage tank, and "loop" or "swing" tank configurations (see Figure 2.19).

Multiple heat pumps and storage tanks can be used in single pass configurations. When multiple storage tanks are used, cold make-up water enters the heat pumps, and heated water leaves the heat pumps at the desired system delivery temperature (see Figure 2.20). The water leaving the heat pumps is connected to the last storage tank, which is arranged in a "cascade" arrangement so that the water stored gets colder and colder as the water flows from the last storage tank to the storage tank closest to the heat pump(s).

FIGURE 2.20: CONFIGURATION OF STORAGE TANKS IN A SINGLE PASS, MULTIPLE TANK ARRANGEMENT



26 https://efiling.energy.ca.gov/GetDocument.aspx?tn=231318

2.6.2.4.3_TEMPERATURE MAINTENANCE CONSIDERATIONS

As discussed above, there are some key design considerations related to how recirculation loops are configured, how recirculation pumping systems are configured and controlled, and how the heat loss from the piping distribution system is replaced. Furthermore, while recirculation systems that consist of a pump and piping loops are commonly used in multifamily buildings to reduce wait time for hot water at faucets — saving large amounts of potable water — there is a large body of evidence that recirculation systems in central HPWH system design significantly impact overall system energy efficiency. According to a study performed by the US DOE's National Renewable Energy Laboratory (NREL) in 2016, "distribution losses in multifamily buildings can account for 30%–50% of the energy input to the domestic hot water (DHW) system."[27] Recirculation pumps and controls also consume energy. Finally, the efficiency of the heat pump itself may be degraded due to the arrangement of the recirculation loop and tank design.

To address some of these challenges there are a few solutions that can minimize energy use (see Figures 2.21 and 2.22). When combined with electrification of these systems, significant reductions in carbon emissions associated with these systems can be realized.

1. **Controls for recirculation pumps:**
    - The NREL study mentioned above evaluated three control strategies for recirculation pumps: "Demand" controls, "Temperature Modulation" controls, and the simultaneous operation of both. The results of the study — shown in the Table to the right — showed a significant energy savings potential from these alternate control strategies when used in combination.

FIGURE 2.21

Energy Use Reductions and Costs Saving by Technique

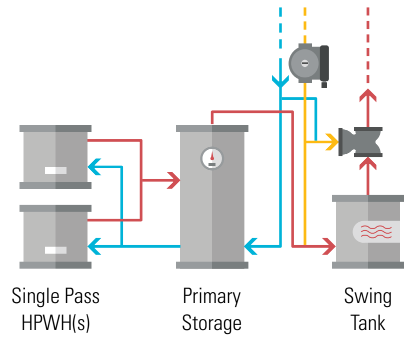
Technique	Annual Energy Savings	Annual Cost Savings
Demand Control	7%	8%
TM	2%	1%
TM & Demand Control	15%	14%

Source: "Control Strategies to Reduce the Energy Consumption of Central Domestic Hot Water Systems," Dentz et al, June, 2016.

2. **Minimizing recirculation flows:**
    - Methods for determining the flow rate and head requirements for recirculation pumps are fairly well established. However, large buildings can end up with a lot of horsepower dedicated to recirculation flows. In addition, without proper water balancing, proper recirculating system performance cannot be ensured. Means for minimizing the flow rate required to ensure that hot water is readily available throughout the system have been developed, such as thermostatic balancing valves. These devices can help avoid the added cost of water balancing for these systems.

27 "Control Strategies to Reduce the Energy Consumption of Central Domestic Hot Water Systems," Dentz et al, June, 2016.

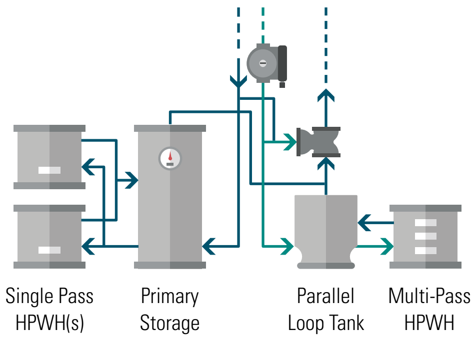
FIGURE 2.22: TEMPERATURE MAINTENANCE SYSTEM ALTERNATIVES FOR SINGLE PASS SYSTEMS



SWING TANK

Primary plant with temperature maintenance plant in series

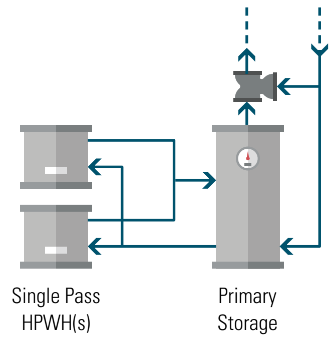
A Swing Tank design is a proven technique to use the primary heat pumps to support the temperature maintenance loads (banks et al., 2020), while keeping the heat pump equipment isolated from the warm water returning from recirculation loop. This design strategy is best suited for buildings with low temperature maintenance loop losses (<60W/apt) and relies on increased storage volume (with tanks piped in series) to ensure storage stratification. Swing tank systems have an electric resistance element in the temperature maintenance tank as a backup safety factor. Sizing a swing tank system also means increasing the heating capacity and storage volume of the primary system. The temperature maintenance storage volume for the swing tank can be small.



PARALLEL LOOP TANK

Primary plant with temperature maintenance plant in parallel

Single-pass heat pump water heaters are most efficient when heating cool city water to hot storage temperatures, whereas multi-pass equipment can still operate efficiently when incoming water temperatures are around 120°F.
A parallel loop configuration is one strategy used to isolate the temperature maintenance task from the task of heating the primary storage. A parallel loop tank is an electric resistance element or a multi-pass heat pump that is piped in parallel with the primary system, specifically to handle the temperature maintenance load.



PRIMARY: NO RECIRCULATION

Just the primary plant without a temperature maintenance load

Primary: no recirculation is used for sizing a primary plant only.

Source: Ecotope

3. **Loop tanks:**

   » As discussed above, there are design and operational challenges from the impacts of mixing cool return water back into multi-pass systems. Also, in single pass systems, the desire is to ensure that only the coldest water enters the heat pumps and only the hottest water leaves the storage system. Thus how to put heat back into the system that is lost in the distribution piping is a matter of some debate. The idea of the separate "loop" or "swing" tank that is provided with its own heat source is an approach that is gaining traction. Loop tank heat sources appear to be less critical from an overall efficiency standpoint: they can be a dedicated HPWH, a unitary tank-type HPWH, or even an electric resistance water heater (either standalone or tank-type).

4. **Pipe insulation:**

   » Energy Codes generally specify the minimum insulation required for all piping in a DHW system. Since water is essentially stagnant in DHW circulating systems for long periods of time, minimizing the rate of heat loss to the ambient air can be effective at reducing overall heat losses. So, using an insulation thickness one size larger than required by Code can be a cost effective measure to reduce energy use in DHW systems.

2.6.3_ELIMINATE REHEAT

Reheat is the energy transfer process where heat is added to air that has already been cooled. Central HVAC systems typically employ reheat so that one system can be used to serve a number of zones with different loads and load profiles. Such zones need different amounts and/or temperatures of air at any given hour of the day to meet their load. The energy crisis of the late 1970s made central variable air volume (VAV) systems with reheat one of the most common types of HVAC systems employed in commercial buildings over the past forty years. While this type of system was developed in order to reduce the energy used by its predecessor — constant volume systems with reheat — a significant amount of energy in VAV systems is still used to reduce the amount of cooling by reheating air.

By its nature, reheat is a waste of energy, since energy has been previously invested to cool down the air stream. Elimination of reheat can be accomplished by a variety of design strategies. Available configurations either "decouple" the energy used to meet zone heating and cooling loads from the energy used to condition ventilation air or bring in ventilation air at the zone level. Decoupled zonal heating and cooling systems typically rely on "dedicated outdoor air systems" for meeting ventilation requirements. Air from a DOAS system is usually delivered to each space at a "neutral" temperature (i.e. somewhere between 68 and 72 degrees F) in order to allow the zone heating and cooling system to respond to zone loads only. Examples of these systems include:

1. **Decoupled systems**

   » Two-pipe or four-pipe fan coil units

   » Unitary air-source or water-source heat pumps (ASHPs or WSHPs)

   » Variable Refrigerant Flow (VRF) systems (also known as Variable Refrigerant Volume, or VRV systems)

   » Passive or active chilled beams

   » Radiant heating and cooling

2. **Systems that can bring in ventilation air at the zone level**

   » Two-pipe or four-pipe fan coil units

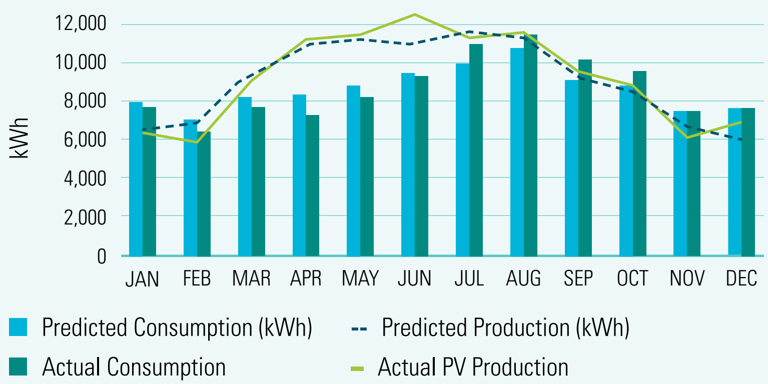
   » Unitary ASHPs or WSHPs

   » VRF systems

2.6.4_SUB-METERING

Zero Net Energy (ZNE) is an energy accounting strategy for zeroing out emissions caused by demand for grid electricity. The most effective ZNE buildings are those that reduce annual energy consumption through passive design and other energy efficiency techniques, and then match or slightly exceed that annual consumption with annual output from on-site renewable energy sources (most commonly photovoltaic or PV systems). In the most basic systems, utility companies that allow for net energy metering[28] (NEM) will report the net monthly grid energy used or net site energy delivered to the grid, allowing an owner to track annual energy usage in order to ensure that the net amount of grid energy consumed is zero. Such a system will monitor energy demand and energy output, and that data can be compared to the results of a predictive energy model created during the design phase. See Figure 2.23 for an example of what those comparisons look like.

FIGURE 2.23: ALPINE BRANCH LIBRARY YEAR ONE ZNE



Source: Courtesy of Energy & Sustainability Program, County of San Diego

28 Net energy metering is a mechanism that allows domestic or commercial users who generate their own electricity using solar panels or photovoltaic systems to export their surplus energy back to the grid.

Achieving this annual balance, however, cannot be confirmed until the end of each year. Thus, methods that help to ensure that this balance is achieved are extremely useful. The graph on this page reflects a "well-behaved" building, but operational or design issues can result in actual monthly consumption and production values that vary significantly from predicted values. Even well-behaved buildings can go through a start-up period that can last for months in order to get the building to operate as intended. The installation of electricity sub meters that measure end uses (e.g. lighting, HVAC, plug and process loads, elevators, etc.) can provide more granular energy use data that can be compared against a predictive energy model: this can both facilitate the identification of specific energy usage that significantly deviates from predicted values and assist in quickly establishing corrective measures to bring actual energy use into conformance with predictions. Thus, the use of submetering systems can significantly reduce the effort and time needed to respond to issues that may undermine the attainment of a ZNE goal.

Submetering can have benefits beyond managing ZNE goal achievement. A report by the National Science and Technology Council on submetering of building power usage found that: "Numerous case studies provide evidence that the ROI [on installing submeters] can be significant...Further, submetering provides the necessary infrastructure for more advanced conservation and efficiency techniques."[29] In this report and others, submetering is hailed as the new gold standard because of its potential for increasing the sustainability of building operations by reducing waste and cost, changing user behavior in positive ways, and improving operations efficiency. A General Services Administration study on the business case for submetering discusses the financial implications of using submetering as a means of energy cost management and reduction in federal facilities or commercial leased buildings;[30] it introduces the concept of submetering and its "value added" applications, and it provides key metrics needed for making a business case for submetering efforts as part of new construction or retrofit projects.

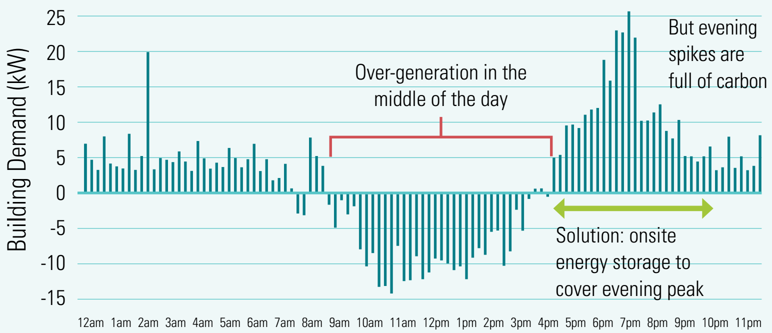
29 "Submetering of Building Energy and Water Usage: Analysis and Recommendations of the Subcommittee on Buildings Technology Research and Development", National Science and Technology Council Committee on Technology, Subcommittee on Buildings Technology Research and Development, October 2011.

30 "Submetering Business Case: How to calculate cost-effective solutions in the building context" https://www.gsa.gov/governmentwide-initiatives/federal-highperformance-green-buildings/resource-library/energy-water/submetering.

2.6.5_GRID RESPONSIVE DESIGN

Electrification is a strategy to eliminate greenhouse gas emissions from the load side of the meter. However, regardless of the percentage of renewables in the fuel mix of your local grid, when the sun is not shining and the wind is not blowing grid managers rely for the most part on fossil fuels to meet demand. This is why the time of day that energy gets used matters. Figure 2.24 shows the demand profile at a typical ZNE building. Facilities that stay open into the evening and nighttime hours experience the same profile; demand, during these hours of energy use, that is met by grid-supplied energy will have higher carbon content than hours when renewable energy sources are at peak production.

FIGURE 2.24: ALPINE LIBRARY ENERGY PROFILE



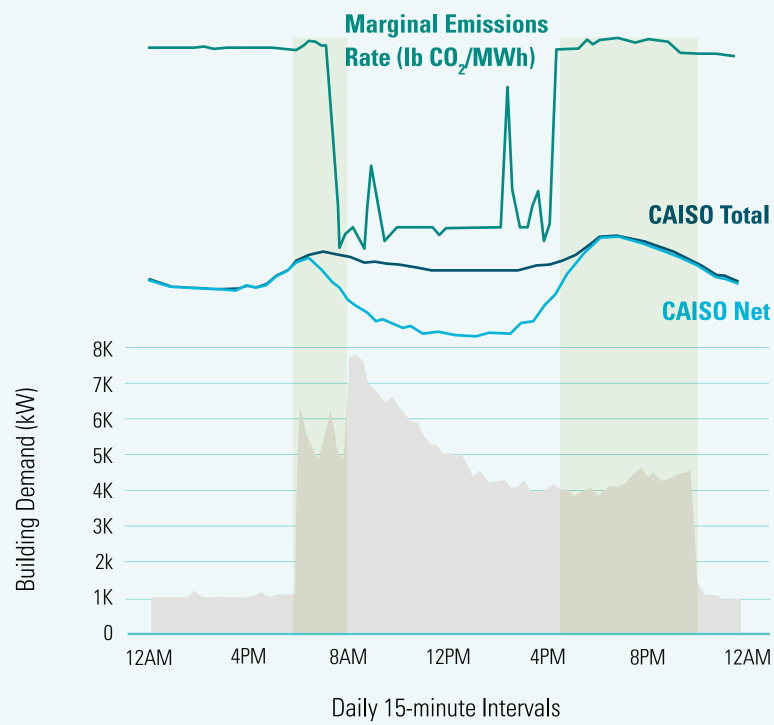
Source: Courtesy of Energy & Sustainability Program, County of San Diego

On the grid side, a typical emissions profile for a day may look like Figure 2.25[31], which shows the Marginal Emissions Rate (MER) of grid-supplied energy over the California Independent System Operator's (CAISO) daily load profile above a building demand profile.

31 From a Grid Optimal Pilot Project report prepared by the New Buildings Institute, October, 2018.

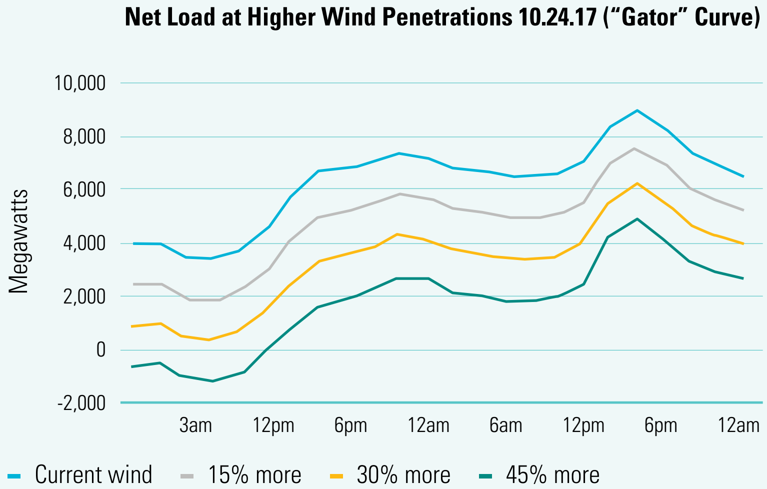
Energy suppliers on different regional grids experience different power generation management issues based on the different types and amounts of renewable energy connected to their grid (see Figure 2.26). Thus, building system design strategies for grid harmonization will be different in each grid "climate." Harmonization design strategies will allow for the timing of loads to be targeted to periods with a low marginal emissions rate, whenever they occur on any particular grid.

FIGURE 2.25: MARGINAL EMISSIONS RATES AND BUILDING ENERGY DEMAND

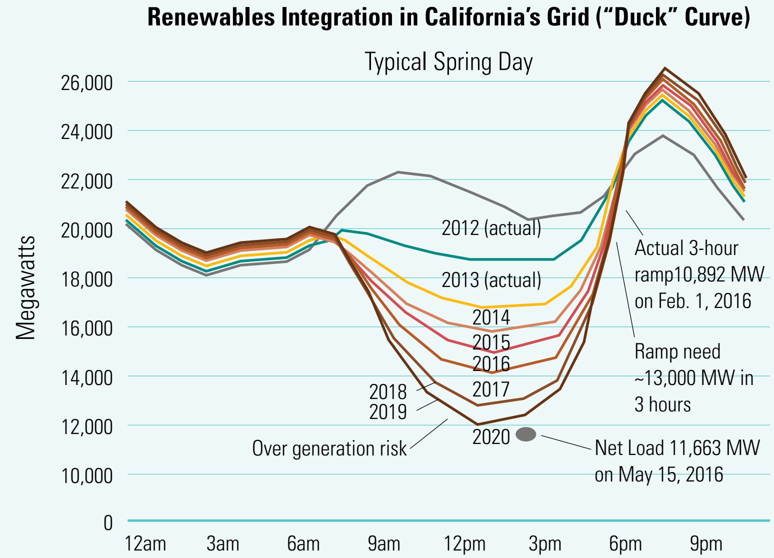


Source: New Buildings Institute

FIGURE 2.26: EFFECTS OF DIFFERENT RENEWABLES MIXES ON REGIONAL GRID LOAD PROFILES



Source: Fresh Energy



Source: California ISO

CAISO experiences a "Duck Curve" in power plant demand based on a large amount of solar energy on the grid, while the Midcontinent Independent System Operator (MISO) experiences a "Gator Curve" due to a large amount of wind energy supplied to the grid.

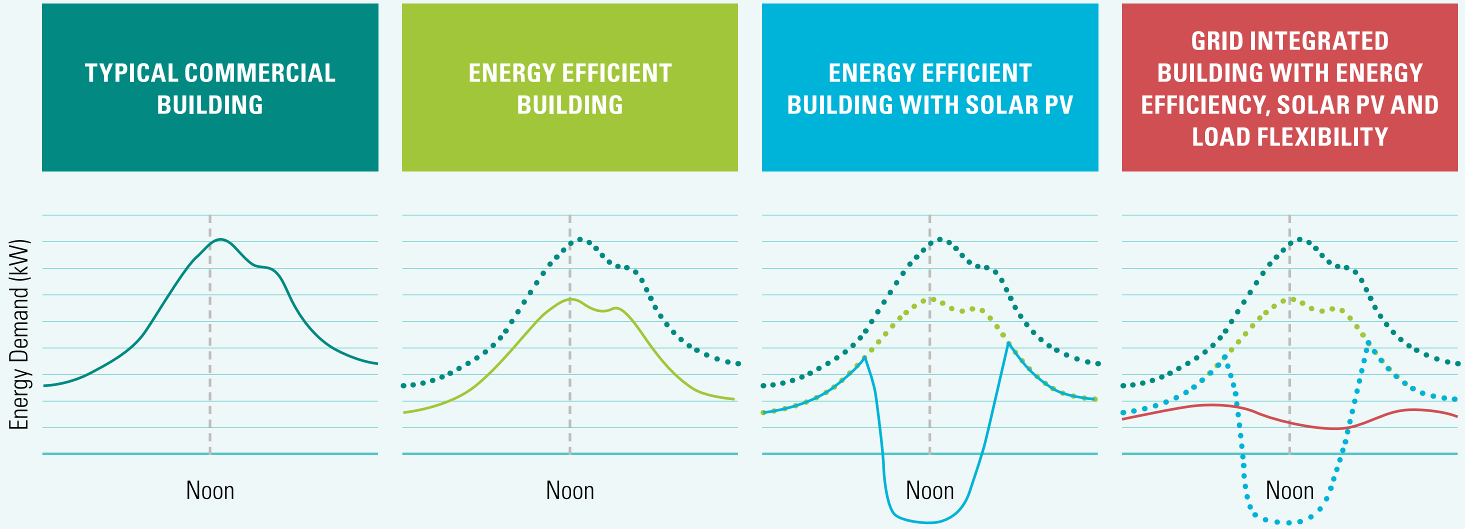
Building system solutions that can facilitate the timing of loads include load shifting strategies (such as thermal storage), energy storage systems that charge and discharge based on grid MERs, demand limiting strategies (such as dimming lights and resetting building temperature setpoints), and load deployment strategies (such as limiting domestic hot water heat pump operation or car charging to hours when MERs are low). Figure 2.27 shows the differences in the load profiles of a conventional energy efficient building, one with a PV system added, and a truly "grid-integrated" building.

The New Building Institute's GridOptimal Initiative[32] has developed new metrics by which building features and operating characteristics that support more effective grid operation can be measured and quantified.

So, while conventional, energy efficient, and even ZNE designs fall short when it comes to decarbonization, a grid integrated or "grid harmonized" building design can address both energy efficiency and carbon emissions reductions.

32 https://newbuildings.org/resource/gridoptimal/

FIGURE 2.27: GRID INTEGRATED BUILDING: LOAD PROFILES



Source: Cara Carmichael, RMI

Efficiency improves curve (lowers and flattens)

+ Reduces energy consumption and demand changes

Adding solar offsets significant loads, often coincident with utility peak loads

+ Reduces energy consumption and demand changes
+ Can cause steep ramping of loads and utility issues

Grid integration combined with the other strategies shifts building loads to match generation, further reducing peaks

+ Optimizes energy consumption and demand charge savings while supporting grid stability and resilience
+ Demand response capability during grid peak scenarios provides additional revenue

2.6.5.1_Energy Storage

The increasing availability of renewable energy on electrical grids creates challenges for grid managers. The problem with most renewables is that their generation is variable in nature. One solution to solve that variability is to use energy storage, effectively decoupling the need to match the timing of energy generation and use.

Utility scale energy storage systems are expensive and complicated to deploy in order to maintain grid stability. Nevertheless, "driven by steeply falling prices and technological progress that allows batteries to store ever-larger amounts of energy, grid-scale systems are seeing record growth in the U.S. and around the world. California is currently the global leader in the effort to balance the intermittency of renewable energy in electric grids with high-capacity batteries. But the rest of the world is rapidly following suit. Recently announced plans range from a 409-megawatt system in South Florida, to a 320-megawatt plant near London, England, to a 200-megawatt facility in Lithuania and a 112-megawatt unit in Chile."[33]

Onsite energy storage systems, by comparison, are relatively easy to install and manage. Building-scale battery energy storage systems (BESS) are becoming more readily available and adaptable. While still relatively expensive, they can be used to reduce utility costs (consumption and demand charges) as well as reduce a building's carbon footprint. Distributed energy storage in buildings is expected to play an increasing role in the future energy transition, and BESS are not the only type of energy storage system that can be applied at the building scale. Other options, some commercially available and some that are still in the early stages of commercialization, include:

SYSTEM THAT CAN STORE "POTENTIAL ENERGY"

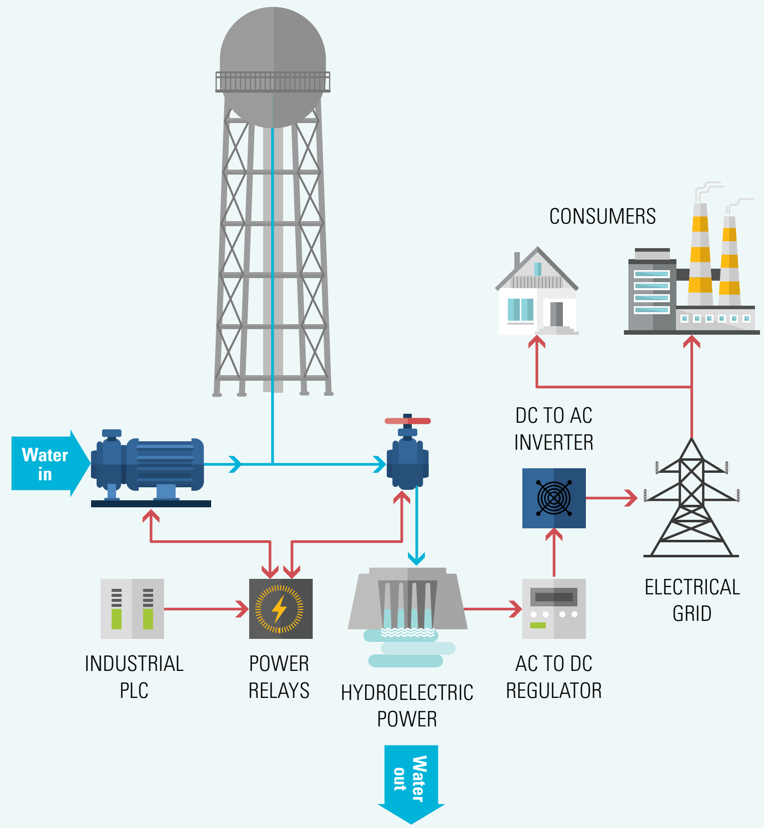
1. **Flywheels**
   - These are being used at both the utility and building scale. Flywheel energy storage (FES) works by accelerating a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy. When energy is extracted from the system, the flywheel's rotational speed is reduced as a consequence of the principle of conservation of energy; adding energy to the system correspondingly results in an increase in the speed of the flywheel. Beacon Power opened a 5 MWh (20 MW over 15 mins) flywheel energy storage plant in Stephentown, New York in 2011, and a similar 20 MW system at Hazle Township, Pennsylvania in 2014. A 2 MW (for 15 min) flywheel storage facility in Minto, Ontario, Canada also opened in 2014. Amber Kinetics, Inc. has an agreement with Pacific Gas and Electric (PG&E) for a 20 MW / 80 MWh flywheel energy storage facility located in Fresno, CA with a four-hour discharge duration.

2. **Elevated water storage**
   - A 2015 article from IEEE Spectrum notes that "pumping water uphill to store energy in hydropower reservoirs is an idea that, by power grid standards, is as old as the hills that such 'pumped storage' plants are built on. But with the rise of intermittent solar energy and wind power, this technology could soon experience a revival, experts say."[34]
   In 2015, Citibank estimated that the cost of power from pumped hydroelectric was about 5 percent of the cost of grid-scale battery-stored electricity. Pumped storage hydro is by far the most successful energy storage technology, representing most of the installed storage capacity worldwide, although for large installations. This prompts the question of whether such technology could be used on a much smaller, building scale (see Figure 2.28). Design of cost-effective, small-scale pumped storage hydroelectric systems can be a challenge.

33 https://e360.yale.edu/features/in-boost-for-renewables-grid-scale-battery-storage-is-on-the-rise

34 https://spectrum.ieee.org/energy/policy/a-pumped-hydro-energystorage-renaissance

FIGURE 2.28: RETROFITTING WATER TOWERS FOR HYDROELECTRIC POWER

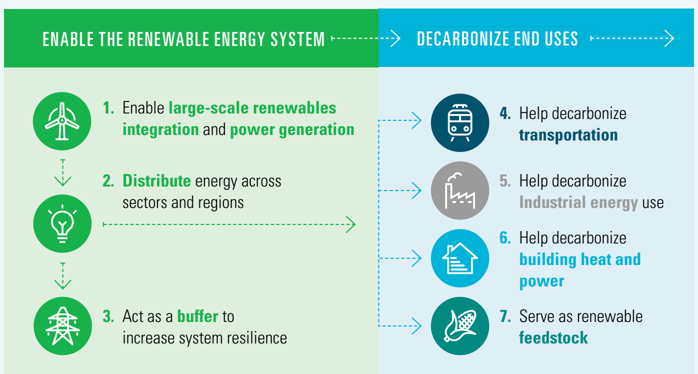


Source: From "Retrofitting Water Towers for Hydroelectric Power Generation," Viorel Miron-Alexe, Valahia University of Targoviste, Institute of Multidisciplinary Research for Science and Technology, Targoviste, Romania. Published online: 30.12.2019.

3. **Creating green hydrogen from excess solar energy**

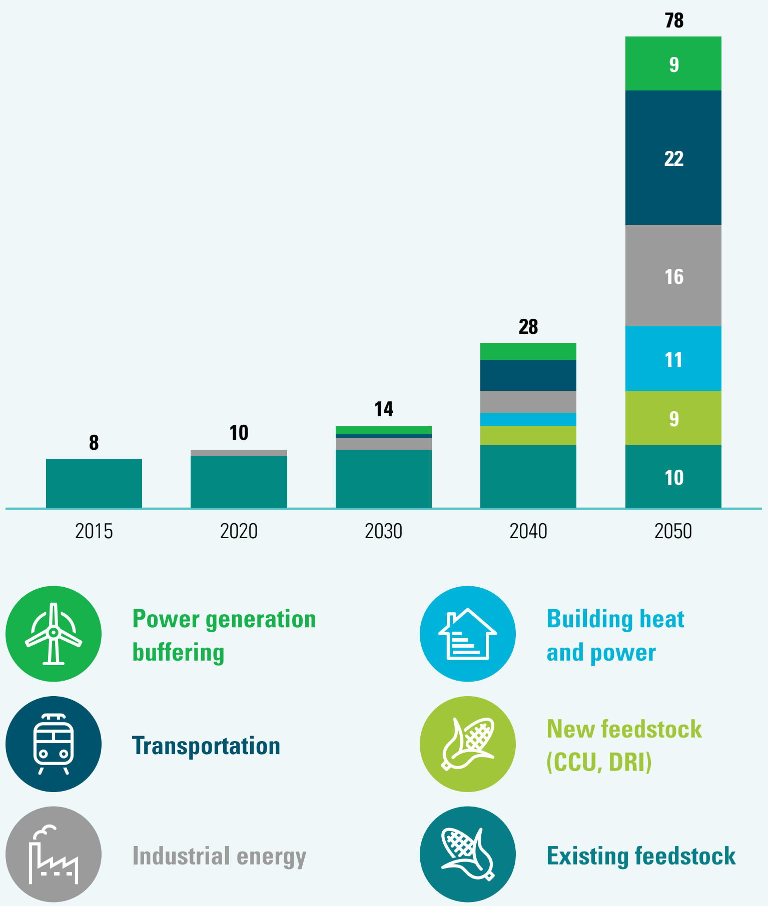
» There is a growing international consensus that clean hydrogen will play a key role in the world's transition to a sustainable energy future (see Figures 2.29 and 2.30). While the cost-effectiveness of using electricity to create hydrogen (via electrolysis of water) is debatable, the ability to create and store hydrogen gas using solar energy that might otherwise be "wasted" allows hydrogen to act as an energy storage medium. Such stored gas could be used to power fuel cells or even direct combustion. The world's first hydrogen-powered domestic boiler was put into operation in Rozenburg, the Netherlands in 2019 (https://www.bdrthermeagroup.com/en/products-and-services/products/hydrogen-boilers). Mixing hydrogen with methane for delivery through existing utility infrastructure, as well as other ways to create a more "green" alternative for methane, are increasingly seen as strategies that cannot be developed fast enough and at an adequate scale to be serious contributions to decarbonization goals.

FIGURE 2.29: HYDROGEN CAN PLAY MANY ROLES IN A DECARBONIZED ENERGY SUPPLY TRANSITION



Source: Hydrogen Council
https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

FIGURE 2.30: POTENTIAL DEMAND FOR HYDROGEN



Source: CleanTech | https://www.enapter.com/media-coverage/cleantech-com-the-role-of-green-hydrogen-in-global-decarbonization

2.6.5.2_Demand Response and Deployable Loads

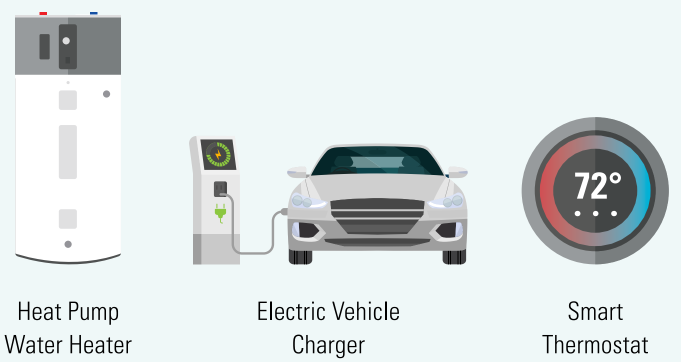
Managing building energy use in a manner that is responsive to grid capacity and stability is known as "Grid Harmonization." Strategies that accomplish this can also be used to take maximum advantage of renewable energy when it is available on the grid.

Demand response programs can serve as a major tool for accelerating the use of renewable energy and balancing electricity load on a grid (see Figure 2.31). When there is excess energy on the grid (for grids that incorporate solar PV capacity, this is primarily during the middle of the day when solar generation peaks), utility companies can encourage participating smart devices to charge, pre-cool, or pre-heat themselves. When there is demand for electricity and available sources are being fully utilized, utility companies can slow or delay participating smart devices until the grid is cleaner, preventing the need for electricity generated by the dirtiest fossil fuels. These smart devices represent loads that can be deployed by grid operators when they want to increase usage to take advantage of available excess renewable energy as well as when decreasing usage is necessary for grid load management.

The Energy Independence and Security Act of 2007 (EISA) gave the National Institute of Standards and Technology (NIST) the primary responsibility to coordinate development of a framework that includes protocols and model standards to achieve interoperability of smart devices and systems that interact with the electricity grid. Many utility companies are developing programs for controlling electric vehicle charging stations, domestic hot water heat pump water heaters, and smart thermostats located in residences, and equipment manufacturers are incorporating software to make these devices interoperable with demand response signals from utilities. Building automation systems can also be used to control the deployment of these loads, allowing owners to maintain control over their assets.

Changes are happening rapidly, and everyone should be watching for this decarbonization strategy to become business as usual in order to facilitate the transition of regional grid supplies to 100% renewable energy.

FIGURE 2.31: TYPES OF DEPLOYABLE LOADS THAT CAN BE INTEGRATED INTO A UTILITY DEMAND RESPONSE PROGRAM



Source: Sonoma Clean Power's "Grid Savvy" Demand Response Program Brochure

2.6.5.3_Load Shifting and Thermal Storage

Traditionally, load shifting has been implemented to save money by reducing peak electricity demand (hence, reducing demand charges) and by shifting energy use to hours when less expensive, non-peak rates apply; this creates thermal energy that can be stored and used at a later time to avoid electricity use during peak rate hours. Under a decarbonization paradigm, load shifting will use energy when electricity is available with low or no marginal emissions to create thermal energy that can be stored and used during periods when marginal emissions rates are high.

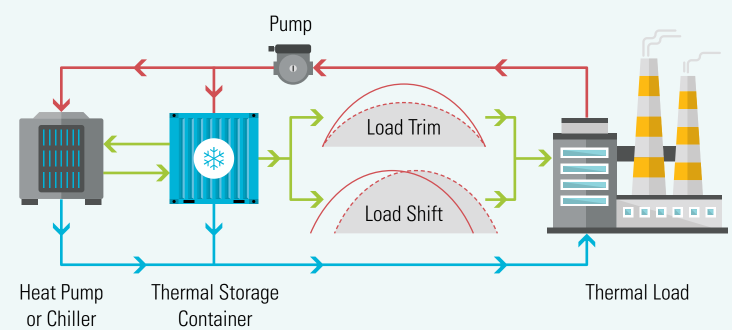
Some of the technologies that enable systems to shift the time that peak loads occur can also facilitate the timing of grid-purchased energy (see Figure 2.32) in order to utilize electricity with the lowest marginal emissions rate (i.e. loads that can be "deployed" for maximum grid harmonization).

With respect to all-electric buildings, 24/7 facilities have unique and expanded opportunities for load shifting and thermal storage, allowing for significant reductions in the capacity of heating and cooling plants.

Technologies available to accomplish load shifting and demand reduction include:

1. **Thermal storage (ice or water):** this is one of the most effective load shifting technologies available that also contributes to grid harmonization because it produces chilled water (or ice) and hot water at times when the source of electricity has low or no marginal emissions.

FIGURE 2.32: TYPICAL THERMAL STORAGE SYSTEM



Source: BioPCM

2. **Super-insulated envelopes (e.g. Passive House design):**

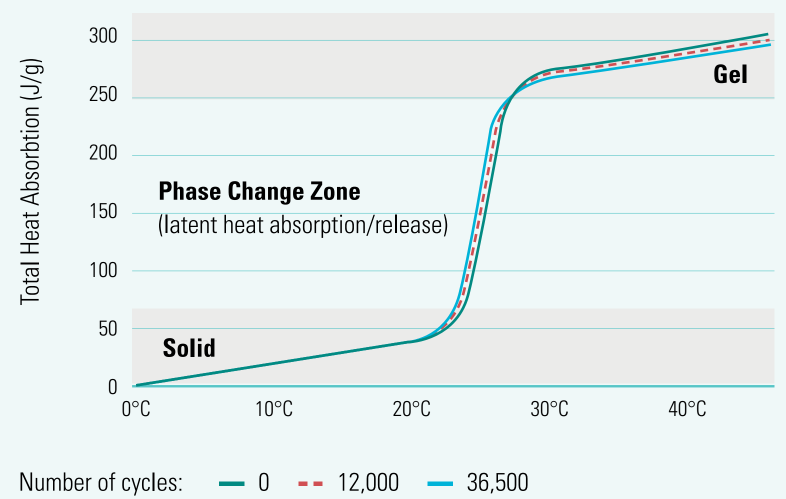
    » Super-insulated envelopes delay the transfer of energy from the outdoors to the indoors. This has the benefit of reducing peak loads as well as shifting the time of day that systems see the maximum impact from exterior loads to a later hour of the day.

3. **Phase change materials embedded in the construction:**

    » Phase change materials (PCMs) are substances that store and release thermal energy as they transition from one phase to another (e.g. solid to liquid). During a phase change, molecules rearrange themselves and cause an entropy change that results in the absorption or release of latent heat, meaning the temperature of the material itself remains constant as a great deal of energy is absorbed before melting and released before freezing (see Figure 2.33). For example, when heat is applied to a block of ice, the ice and resulting melted water remain at or near 32°F until the phase change is complete (i.e. there is no more ice). The heat is absorbed as latent heat until the ice completely changes phase into water. Conversely, when heat is removed from a pool of water, the temperature of the water and resulting ice will not fall below 32°F until the water completely changes phase into ice. When a PCM is installed, it absorbs heat (melts) when ambient temperature exceeds target room temperature, and it releases heat (freezes) when ambient temperature falls below target room temperature. Through this recurring process, ambient temperature within the managed environment is stabilized around the target room temperature. As a result, less mechanical cooling is required, and HVAC power consumption is greatly reduced.

    » While this technology can be "tuned" to a project's specific needs (i.e. the temperature at which the phase change occurs can be adjusted based on the properties of the PCMs used), deployment cannot necessarily be timed to coincide with low marginal emissions rates.

FIGURE 2.33: LATENT HEAT (ABSORPTION AND RELEASE)



Enthlapy of BioPCM® (Q25) demonstarte excellent energy storage performance through thousands of phase change cycles.

Source: BioPCM | https://phasechange.com/enrgblanket/

4. Thermal mass

» Thermal mass is a property of the materials in a building to store energy (heat), providing "inertia" against temperature fluctuations. Thermal mass will absorb thermal energy when the surroundings are at a higher temperature than the mass itself, and give thermal energy back when the surroundings are cooler. The use of materials with high thermal mass is most advantageous where there is a big difference in outdoor temperatures from day to night; flushing a building with outside air at night can cool down the mass, which allows the mass to absorb significant amounts of heat during the day.

» Thermal mass has similar characteristics with respect to grid harmonization that PCMs do, but without the PCMs' ability to "tune" the energy transfer.

» Materials commonly used for thermal mass include:

- Concrete, clay bricks and other forms of masonry: the thermal conductivity of concrete depends on its composition and curing technique. Concretes with stones are more thermally conductive than concretes with ash, perlite, fibers, and other insulating aggregates.
- Clay brick.
- Adobe brick or mudbrick.
- Earth, mud and sod: dirt's heat capacity depends on its density, moisture content, particle shape, temperature, and composition.
- Rammed earth: rammed earth provides excellent thermal mass because of its high density and the high specific heat capacity of the soil used in its construction.
- Natural rock and stone.
- Water: water has the highest volumetric heat capacity of all commonly used materials. Typically, it is placed in large containers (for example, acrylic tubes as shown in Figure 2.34), in an area with direct sunlight.

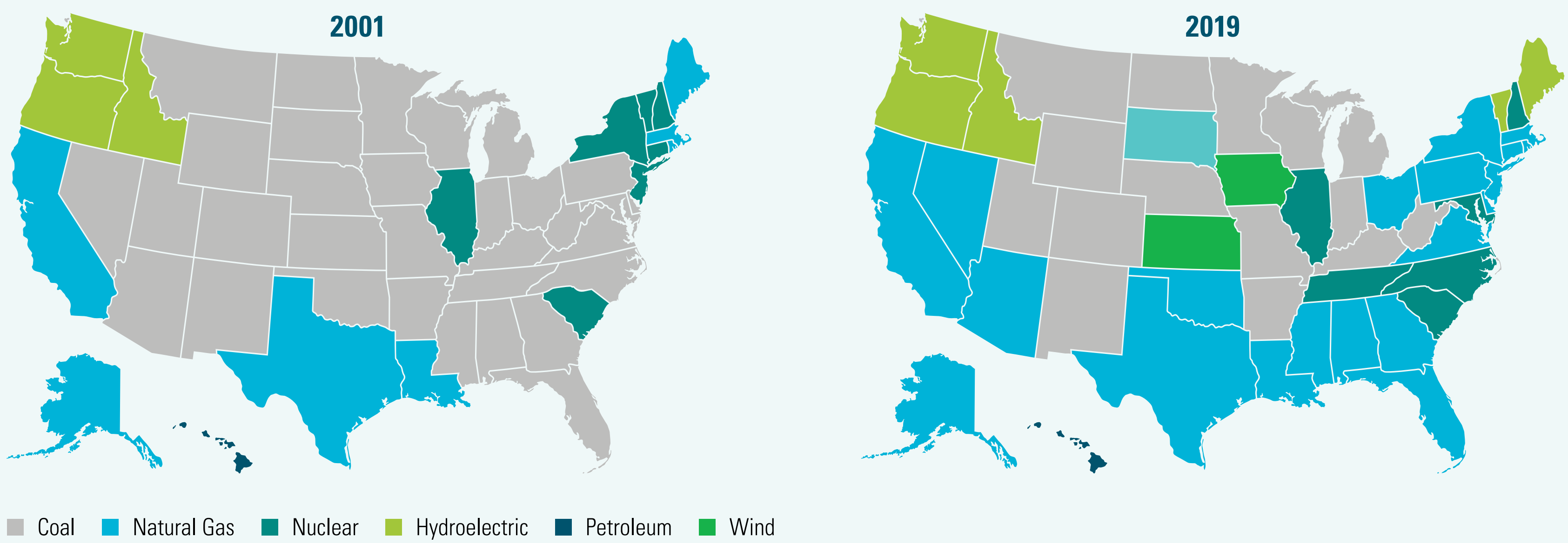
FIGURE 2.34

Source: Trombe wall | https://www.thenaturalhome.com/heatstorage/

2.6.6_MAXIMIZING ON-SITE RENEWABLE ENERGY GENERATION

The biggest immediate concerns with electrification tend to be centered around the potential to stress local grid capacity and potential short term increases in operational-energy related carbon emissions due to the local utility feeding "dirty" energy onto the grid. As discussed in Volume 7, "Policy and Code Context," many U.S. states still use large amounts of coal for generating electricity (see Figure 2.35). In Iowa for example, coal produced 35% of the state's electricity in 2019 (down from 85% in 2001). Data for 2019 suggests that, nationally, 23% of total electricity generation was still done with coal (a reduction of over 50% since 2008),[35] and the EIA estimates that coal use was further reduced to producing only 19% of total electricity generation in 2020.[36]

FIGURE 2.35: PRIMARY POWER SOURCE BY STATE



Source: United States Energy Information Administration

35 How Does Your State Make Electricity?

36 Electricity in the US - US Energy Information Administration

Rather than take the position that all-electric buildings are a bad choice for reducing operational GHG emissions, Section 2.4.1 suggests that projects develop strategies to offset emissions from utility-purchased energy that occur between completion and decommissioning. Options include, where available, purchasing electricity from a provider that can supply 100% renewable energy to incorporating onsite or offsite renewable energy generation to offset emissions.

With paybacks on investments in PV systems currently ranging from a low of 5 years (e.g. in Hawaii and Massachusetts) to as long as 16 years (e.g. in Louisiana and North Dakota), these investments will always pay themselves back over the life of a building, even without factoring in the utility price risks if a cost of carbon emissions is ever established. In 2010, the U.S. DOE Solar Energy Technology Office (SETO) announced unsubsidized PV price targets for 2020. Per their 2020 benchmarking, residential systems were 93% of the way towards achieving the target of 10 cents per kilowatt-hour (kWh) and commercial systems were 97% of the way towards the target of 8 cents/kWh. Systems met 2020 price targets three years early, and are progressing towards SETO's 2030 target for commercial PV of 4 cents/kWh (5 cents/kWh for residential PV systems). So, there is no question that, from an operational energy carbon emissions reduction perspective, PV systems are a cost effective and reliable choice.

Also, in States that allow investors to pay for the development of a solar system on someone else's property and then sell them the power that the system generates (aka Power Purchase Agreement, or "PPA"),[37] access to solar-generated electricity no longer has to be an "investment" decision. As long as the PPA provider can sell a customer electricity at a lower rate than the local utility company and can guarantee an escalation rate lower than the historical average for the local utility, owners have access to investment-free, risk-free solar systems. Thus, there are very few locations or projects that, given the current economics of PV systems, can justify not including the maximum amount of onsite solar generation resources.

2.6.7_RESILIENCY

Onsite energy generation, in addition to many of the other decarbonization strategies discussed below, can help buildings "to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events."[38]

Increases in the interruption of local utility supplies and excessive escalation of utility rates can adversely affect a property's asset value. So, many of the strategies that make buildings better able to cope with the constant increase in the frequency of adverse events, also make a property more "valuable" to the occupants and, hence, the property owners.

Resiliency is a growing concern for many occupancy types. Design and construction strategies are needed to address disaster mitigation and recovery as well as passive operations: 24/7 facilities are especially ripe for benefiting from passive operational strategies (e.g. operable windows, exterior shading, super-insulated envelopes).

The National Infrastructure Advisory Council determined that resilience can be characterized by four key features: Robustness, Resourcefulness, Rapid Recovery, and Redundancy.[39] The interrelationship between these four features and sustainability is shown in Figure 2.36 on the next page.

According to the National Association of Insurance Commissioners, "The economic cost of natural disasters has an immense impact on the U.S. economy. Natural catastrophes topped $232 billion in total costs in 2019, with insured losses covering $71 billion. In terms of insured losses, 10 of the nation's costliest catastrophes have occurred in the past two decades. Insurance plays a large part in helping with the economic recovery following catastrophic events. However, according to a 2019 Aon report, the portion of economic losses not covered by insurance (insurance gap) was $161 billion."[40]

Thus, one might argue that sustainable design and decarbonization strategies could be an effective form of "insurance" against the cost of adverse events.

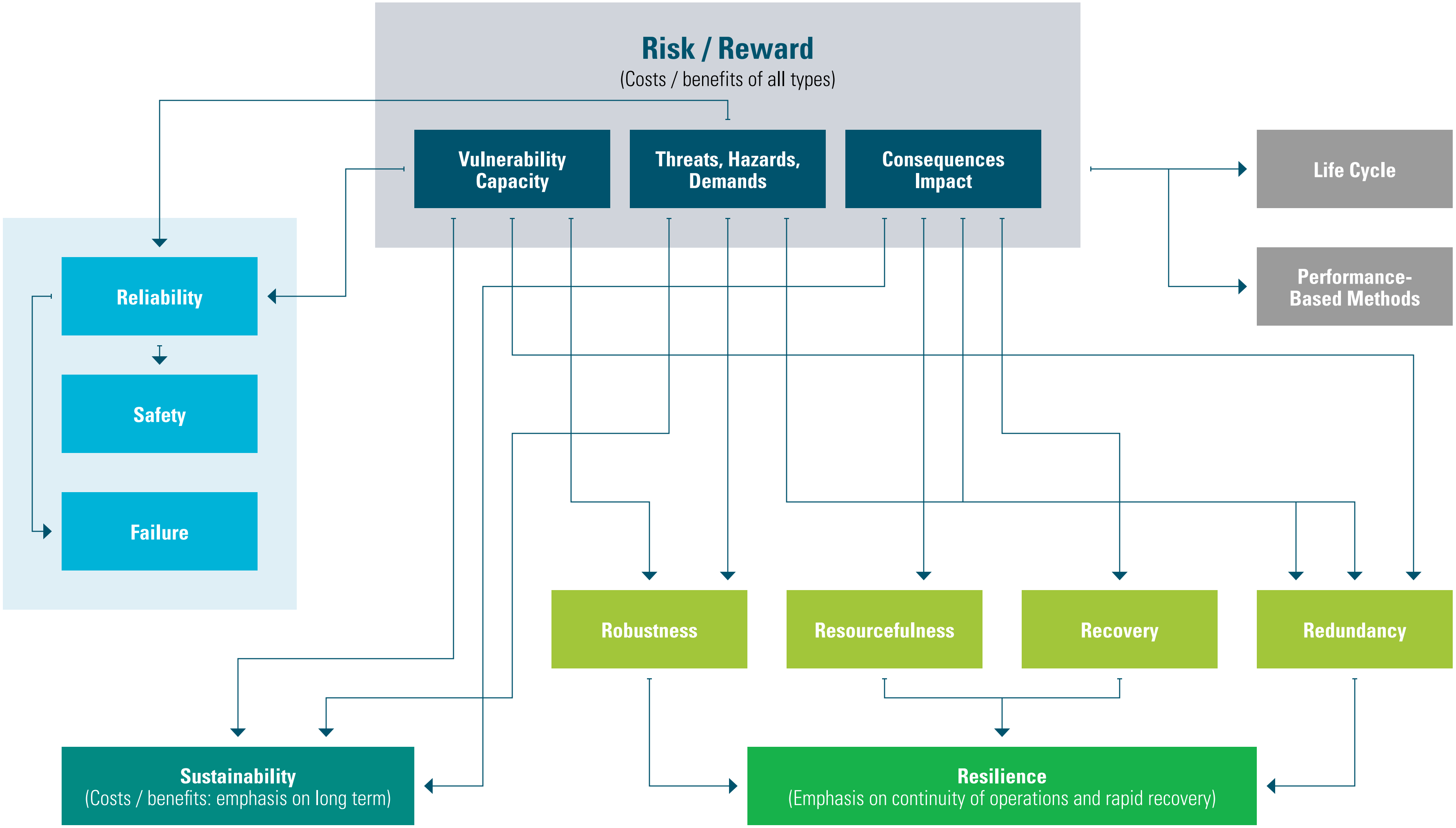
37 https://www.seia.org/research-resources/solar-power-purchase-agreements

38 The definition of resiliency from the National Research Council publication "Disaster Resilience: A National Imperative" 2012.

39 https://www.cisa.gov/publication/niac-critical-infrastructure-resilience-final-report

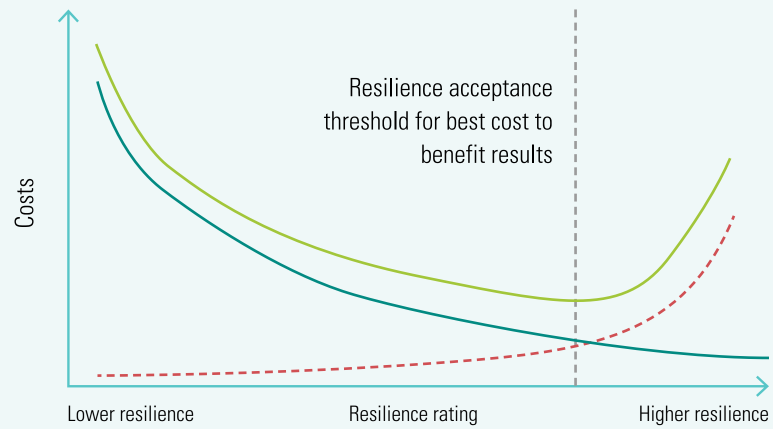
40 https://content.naic.org/cipr_topics/topic_climatenatural_catastrophe_risks_and_resiliency.htm

FIGURE 2.36: RISK, RESILIENCE, AND SUSTAINABILITY INTERRELATIONSHIPS



Source: https://www.wbdg.org/resources/building-resiliency

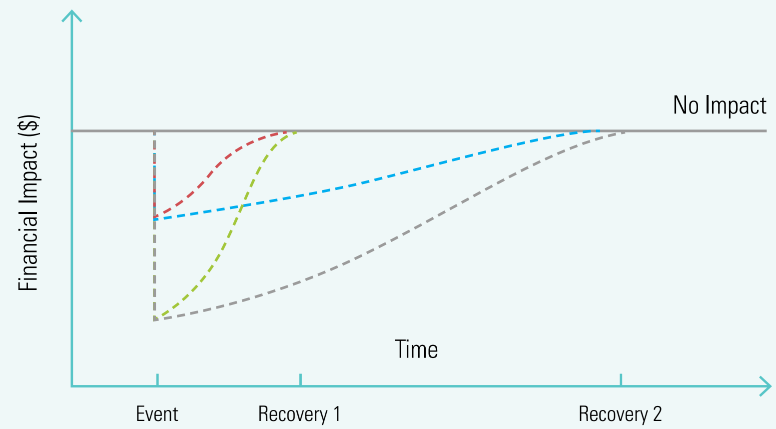
FIGURE 2.37: THE BUSINESS CASE FOR RESILIENCY INVESTMENTS



- Total costs
- Natural/man-made hazard costs: decrease for higher resilience
- Resilience improvement (retrofit) costs: increase for higher resilience

Source: The Business Case for Resiliency | https://www.wbdg.org/resources/building-resiliency

FIGURE 2.38: SCENARIOS OF IMPROVED RESILIENCE



- Smaller impact, faster recovery
- Smaller impact, slower recovery
- Larger impact, faster recovery
- Baseline scenario

Source: https://www.resources.org/common-resources/the-role-of-insurance-in-promoting-resilience/

Going all-electric has proven to be a healthier and more resilient approach than conventional mixed-fuel designs. Insurance companies traditionally view resilience as a function of reduced impact from a natural disaster or increased speed of recovery (see Figures 2.37 and 2.38).

Data from recent disasters suggest that the speed of recovery of the utility infrastructure can be a severely limiting factor in a facility's resiliency, even if the facility itself is designed for maximum disaster preparedness.

Data also suggests that utility companies' electrical infrastructure is inherently more resilient than their natural gas infrastructure (see Figure 2.39).

It turns out that many of the resiliency strategies promoted for decades as part of the "green building movement" can, indeed, increase a building's resiliency. In addition, the growing availability and popularity of building-scale battery energy storage systems make new strategies available for increasing the resilience of buildings.

FIGURE 2.39

EARTHQUAKES

Earthquake Damage to Services	Loma Prieta SF Bay Area (1989)	Northridge LA Area (1994)
# of Electricity Outages	1.4 million	2.3 million
Electricity — Time to Restoration	70% restored same day Most habitable structures restored in 5 days	99% restored in 7 hours Remaining habitable structures in 2 days
# of Gas Outages	156,000	151,000
Gas — Time to Restoration	80% restored in 10 days	80% restored in 14 days
# of Gas Fires	30	158

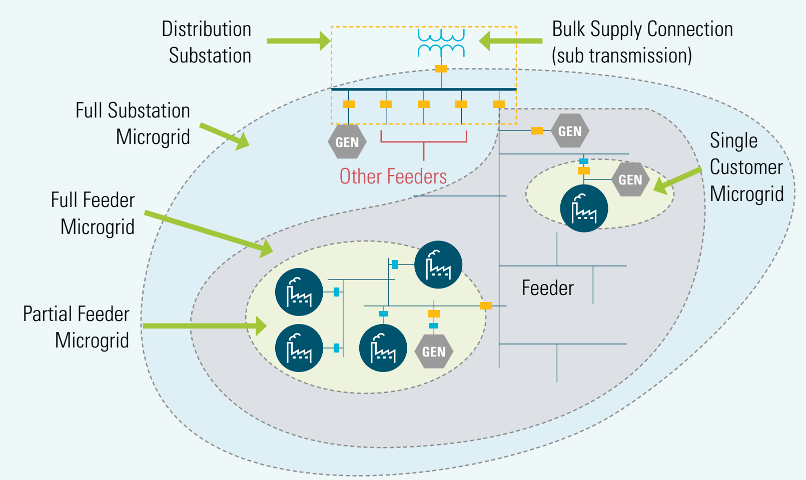
HURRICANES & FLOODS

Flood Damage to Services	Hurricane Katrina New Orleans (2005)	Super Storm Sandy NY, NJ, WV (2012)
# of Electricity Outages	2.5+ million 28,900 utility poles destroyed	8.5 million
Electricity — Time to Restoration	10% restored within 3 days 75% restored after 23 days	95% restored within 13 days in NY Restored quicker in NJ and WV
# of Gas Outages	105,000	87,000 +1,700 large buildings without steam service (in NY only)
Gas — Time to Restoration	10 years to replace 162 miles of degraded piping 316 total miles repaired	2-3 weeks for full restoration of gas and steam 4 hospitals closed (no steam, but had power)

2.6.7.1_Microgrids, "Islanding," and Resiliency

With the growing availability of building-scale Battery Energy Storage Systems (BESS), the ability to combine solar PV systems, batteries, generators, and other energy generation systems into an integrated system that can work in tandem with conventional utility power expands the opportunities for development of single-customer microgrids (see Figure 2.40). A byproduct of this configuration of systems is the ability to continue building operations despite a loss of grid-supplied power: when a building operates on a microgrid without utility power connected, this is called "islanding."

FIGURE 2.40: MICROGRIDS AT DIFFERENT SCALES



Source: https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/role-microgrids-helping

Microgrids have traditionally been deployed to provide backup for the grid in case of emergencies. A microgrid can also be used to cut costs by replacing grid-sourced electricity with onsite generated electricity when onsite generation can be provided at a lower cost or when demand charges can be significantly reduced by lowering the demand from the utility grid. This approach has grown in popularity with decreases in the costs of solar and BESS coupled with rapidly advancing data processing capabilities.

Also, a microgrid can be used to connect to a local utility resource that is too small or unreliable for traditional grid use. Most importantly for the readers of this practice guide, a microgrid allows communities to be more energy independent and, in some cases, more environmentally friendly.[41] The availability of real-time and forecasted marginal emissions rates for utility power can be combined with weather and solar production forecasting to create opportunities to use a microgrid controller's optimization algorithms for managing microgrid resources in order to reduce the GHG emissions from operational energy use. Also, "the recent increase in natural and human-triggered threats like wildfires and severe storms has added urgency to microgrid development"for improved resiliency of buildings.[42] However, operating a microgrid in island mode is still subject to local utility company approval and may not currently be allowed in many locations. Growing interest in microgids is now forcing utilities and regulators to rethink how the grid of the future will be designed and operated.

2.6.7.2_Operable Windows and Natural Ventilation

The purpose of this section is not to claim that operable windows and natural ventilation are the solution to reducing the energy intensity of building operations. However, it is common sense that if outdoor conditions are favorable and the building is properly designed to take advantage of it, natural ventilation can allow a building to be "comfortable" without a lot of energy use for mechanical cooling, heating, or ventilation. "Properly designed" means that the building is intentionally configured to be well-suited for natural ventilation. It is a fact that operable windows alone do not make a building "naturally ventilated." Yet, research suggests that under the right conditions, operable windows can increase an occupant's sense of comfort.[43]

But why are we talking about natural ventilation in a practice guide about all-electric buildings? It is as important to consider the use of operable windows to allow for maintaining comfort without using electrical energy for HVAC systems, as it is to recognize that improper use of operable windows can be problematic for energy use reduction and may even warrant active controls to ensure they are not used when HVAC systems are running.

When it comes to resiliency, however, it is also important to recognize that, increasingly, owners may need to figure out how to keep their buildings in operation during power failures, and operable windows can be extremely handy in these situations in lieu of more expensive and complex alternatives like generators and other advanced microgrid configurations.

2.6.7.3_Passive Heating and Cooling Strategies

As discussed in Section 2.5.1.1, reducing energy consumption has benefits for all-electric building design, cost, and GHG emissions performance. The most reliable form of energy efficiency is to turn off energy consuming systems. So, to the extent that, during certain times of the year, and under certain outdoor conditions, a building could achieve a passive energy balance that allows the indoor environment to remain "comfortable," passive heating and cooling strategies can potentially save significant amounts of energy.

Furthermore, when grid utilities are not available to run a building's heating and cooling systems, passive strategies tend to improve the habitability of the indoor environment over a broad range of outdoor conditions.

41 https://www.energy.gov/articles/how-microgrids-work

42 https://www.utilitydive.com/news/microgrids-are-coming-will-they-increase-inequities/593133/

43 For example, see ASHRAE RP-1161, "Operable Windows, Personal Control, and Occupant Comfort", 2004.

Passive cooling actions generally include the following:

1. **Storing of cold mass or air within building envelope**
   » Night pre-cooling combined with thermal mass
2. **Avoidance of direct external solar radiation heat gain**
   » High performance glass in fenestration units
   » Shading glazed areas
   » Using landscape design
   » Design of self-shading forms
   » Color and reflectivity of external surfaces and interior surfaces exposed to direct solar radiation
3. **Removal of gained heat from the interior or exterior sources**
   » Night pre-cooling
   » Natural or whole-house exhaust ventilation
   » Earth tubes, rock beds, basement labyrinths (all ways to use thermal mass strategically)
4. **Slowing heat transfer from the external climate through the building envelope**
   » Super-insulation (e.g. Passive House)
   » Double or triple glazed fenestration units

Passive heating relies on many of the same strategies, applied in ways that tend to maximize the use of direct solar radiation for heating interiors during winter, while limiting the solar radiation impacts in summer.

Passive design strategies are covered extensively in a number of excellent design resources, and these resources should be sought out and applied when considering incorporation of passive design strategies in your project. For example, *Lo-TEK: Design by Radical Indigenism* by Julia Watson, does an amazing job of cataloguing "sustainable, adaptable, and resilient technologies that are borne out of necessity," although by no means is the book intended to be a manual on passive design strategies for the built environment. Similarly, *Architecture without Architects* by Bernard Rudofsky, published in 1964, acknowledges that the wisdom to be derived from the "art of building" practiced centuries ago "goes beyond economic and aesthetic considerations, for it touches the far tougher and increasingly troublesome problem of how to live and let live, how to keep peace with one's neighbors, both in the parochial and universal sense." Both books reveal the richness of indigenous science that emerges from the lessons of place, climate, and survival, provide insight into the effectiveness of passive design strategies, and help us gain a perspective on why equity must be a central consideration in achieving the larger goals of a decarbonized built environment.

2.6.8_WATER USE REDUCTION AND BUILDING ELECTRIFICATION SYNERGIES

While the focus of this practice guide is on decarbonization of the built environment through the all-electric design of buildings, we need to remember that the consequences of climate change and the current lifestyle of modern societies adversely impacts our most precious resource: potable water, which is truly "the stuff of life." In fact, incorporating water conservation has a number of synergies with building electrification.

2.6.8.1_Reduced Domestic Hot Water Usage

Reducing domestic hot water (DHW) use has the benefit of reducing potable water consumption and, at the same time, reducing energy consumption and water heating system first cost.

Strategies for reducing DHW use include:

1. **Low flow shower heads:**

   » If supply water pressures are adequate, shower heads are available that can provide a "comfortable" shower at flow rates as low as 1.25 GPM,[44] or half the flow rate of most "high-efficiency" shower heads on the market today.

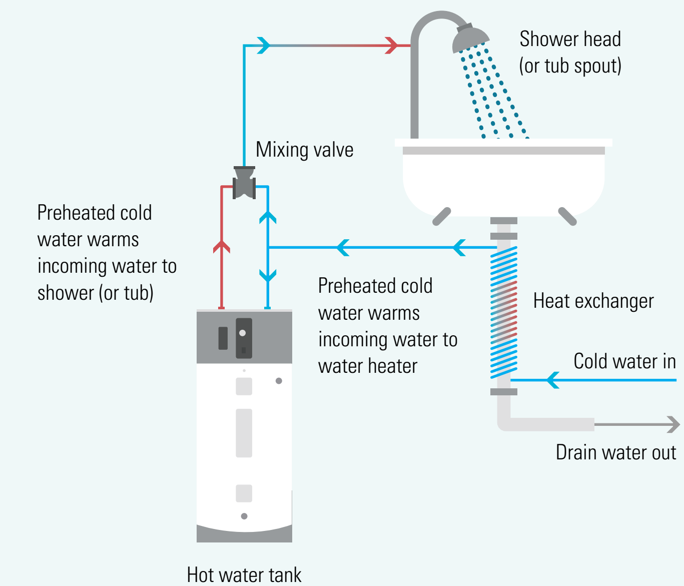
2. **Sewer water energy exchange (SWEE):**

   » Discussed as a building scale technology in Sections 2.6.2.2, there are point of use technologies that can preheat cold water before it is mixed with hot water at an outlet for creating the right use temperature. Often referred to as "drain water heat recovery," this application uses engineered heat exchangers installed in wastewater piping from fixtures and appliances (e.g. showers and dishwashers) to exchange energy between the hot water in the wastewater piping and the cold water inlet to various fixtures (see Figure 2.41). The increased temperature of the cold water used at the fixture allows for a reduced amount of hot water to be used to achieve the same outlet temperature.

3. **Appliances:**

   » Look for appliances that have the lowest water use and are rated by a national standard such as EPA's EnergyStar and WaterSense standards, or ratings of Tier 2 and higher by the Consortium for Energy Efficiency if performance superior to the EPA Standards are of interest.

FIGURE 2.41: DRAIN WATER HEAT RECOVERY



While other Volumes of this practice guide discuss ways to electrify DHW production, as well as reduce energy use for other aspects of the DHW system, water conservation strategies are not the primary focus herein. Look instead to other water conservation resources for further discussion on usage reduction strategies.

44 For example, see Niagara showerhead products at https://products.amconservationgroup.com/browse-products/water/showerheads.

2.6.8.2_Recognition of the Water-Energy Nexus

For the vast majority of buildings, potable water arrives via a series of pipes from a local water treatment plant. Most drinking water treatment plants utilize energy-intensive processes to treat, pump and distribute high volumes of water to their customers. Researchers at the University of Texas at Austin have attempted to quantify the energy embedded in the U.S. public water supply, which is the primary water source of residential, commercial, and municipal users. One such analysis concluded that energy use associated with the public water supply is 4.1% of the nation's annual primary energy consumption and 6.1% of national electricity consumption, but this analysis excluded energy requirements associated with water for agriculture, industrial, and self-supplied sectors (e.g. thermoelectric and mining).[45] The American Water Works Association Research Foundation reported energy use for potable water treatment and delivery in the U.S. to be in the range of 0.07 – 0.92 kWh/m^3, with an estimated average of 0.38 kWh/m^3."[46] Furthermore, the energy demand for water infrastructure is projected to increase by approximately 30 percent over the coming decades.

All of this data suggests that a significant amount of GHG emissions are "embedded" in the water we use in our buildings. So, in addition to reducing the impact of droughts and general resource scarcity, water efficiency can reduce GHG emissions related to fossil-fuel use within the water service system.

While this practice guide is focused on decarbonization of the built environment, we must recognize the essential role that water plays in sustaining life. Thus, the most sensible water conservation strategy (regardless of energy use considerations) is to preserve the highest quality drinking water for human consumption, and to use lower quality water resources for as many "non-contact" uses as possible. This usually means developing onsite water treatment and reuse systems, unless a building happens to be situated in one of the few areas serviced by municipally-supplied reclaimed water.

2.6.8.3_Onsite Water Treatment and Reuse

Different reuse strategies and technologies have a range of space and energy use requirements. The more natural or passive water reuse and recycling pathways, such as constructed wetlands, require little energy to operate but a great deal of space. On the other hand, a membrane bioreactor system may require considerable energy to operate but can occupy a relatively small footprint in the building. It is incumbent upon the design team to balance the competing goals of potable water use reduction, increased resilience, and energy use reduction when exploring onsite water reuse options.

The first practice guide produced by the William J. Worthen Foundation (known then as the Urban Fabrick Collaborative) was the "Onsite Non-Potable Water Reuse Practice Guide," published in January 2018 and available for free download at https://www.collaborativedesign.org/water-reuse-practice-guide. The Top 10 reasons why the A/E/C community should care about onsite non-potable water reuse, as outlined in the Water Reuse Practice Guide, have not changed much in the years since its publication:

1. **It reduces a building's need for potable water.**
2. **It extends our water supply.**
3. **It increases the resiliency of our cities and urban neighborhoods.**
4. **It can reduce the costs of expanding and upgrading water and sewage infrastructure.**
5. **It can allow projects to better achieve green building certifications without altering the architectural design.**
6. **When done right, it is safe, cost-effective, and publicly acceptable.**

45 "Energy-Water Nexus: The Water Sector's Energy Use", Congressional Research Office, January 24, 2017

46 See https://roanoke.com/opinion/commentary/younos-carbon-footprint-of-community-water-consumption/article_3359937d-ab7c-5f65-9f7f-c54490831d52.html

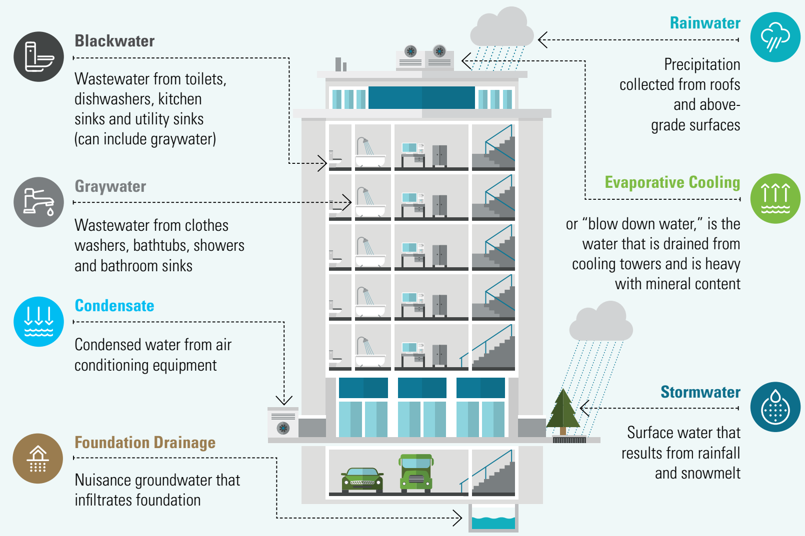
7. **It can be a cost-effective strategy to move your project closer to net-zero energy and water use.**
8. **It can be used as a tool to shorten planning and entitlement reviews.**
9. **Understanding how to address the water-energy nexus in practice is a great way to demonstrate professional leadership and environmental stewardship.**
10. **Eventually, onsite non-potable water reuse will not only be allowed but may be required in your jurisdiction.**

Implementing small-scale decentralized water-reuse infrastructure combined with renewable energy systems is both carbon-responsible and resource-responsible, and all available alternative water sources should be considered for collection and reuse (see Figure 2.42). Reducing the use of potable water for everything other than human consumption should be a part of a project's decarbonization strategies.

2.6.8.4 _Be Careful About Trading Water Use for Energy Use

Evaporative cooling is a very energy efficient source of cooling when the local climate enables this technology to be used. However, this can become an extremely large potable water use in a building. For regions where water supplies come from local watersheds and are abundant, a decision to use evaporative cooling — climate permitting — may be a good trade-off for refrigerant-based cooling systems. However, as more and more regions become water stressed, and adequate clean drinking water resources become harder to maintain, all-electric buildings powered by 100% renewable energy will need to be the primary strategy for the building sector's response to climate change mitigation, and potable water will need to be preserved for its most important uses.

FIGURE 2.42: ALTERNATIVE WATER SOURCES



This diagram shows the main alternative water sources available in a typical urban building.

Source: Taken from "Onsite Non-Potable Water Reuse Practice Guide"

2.7_Construction Practices

According to a study by the University of Leeds and C40 Cities (the international cities network), "a 44% reduction in emissions could be achieved in the procurement and construction process if the industry did five things: 1) used materials more efficiently; 2) used existing buildings better; 3) switched to lower-emission materials; 4) developed and used low-carbon cement; 5) recycled building materials and components."[47]

Buildings and Infrastructure Category Interventions	GHG Emission Reduction Potential
+ material efficiency + enhance building utilization + material switching + low-carbon cement + reuse building components	44%
Source: "Building and Infrastructure Consumption Emissions," August 2019	

In addition, the use of low-emissions construction machinery is another intervention whose benefits are undisputed, but the data to quantify all of them is currently not available. These emissions are local and thus have a greater impact on air and noise pollution in dense urban environments. For example, it has been estimated that 14.5% of PM2.5 matter in London is due to local construction sites.[48]

The same report identifies and analyzes interventions to reduce consumption emissions from buildings and infrastructure construction, and scenarios are presented to show how consumption-based emissions in C40 cities may evolve if no action is taken, if limited action is taken, and if ambitious action is taken.

An approach to quantifying a construction program's impacts on lifetime carbon emissions for a project can be found in "Whole Life Carbon Assessment for the Built Environment," published by the Royal Institution of Chartered Surveyors (RICS) in 2017.[49]

One of the hidden barriers to decarbonizing construction practices is the impacts to construction schedules from alternate materials and alternate approaches. For example, to the extent that the use of low carbon cement substitutes require longer curing times, this can adversely impact construction costs if not properly accounted for during the planning phases.

Furthermore, properly executed building enclosure commissioning (BECx) will require interruptions in erection sequences so that inspection and testing can be performed at a time when construction assemblies are still exposed to view, and when testing can inform the need for modifications to the design or installation methods before errors are repeated. BECx in combination with MEP systems commissioning is a vital strategy for ensuring that the decarbonization goals embedded in the design documents are faithfully delivered.

2.7.1_COMMISSIONING

Commissioning is a quality assurance strategy that has benefits for any modern construction project. A commissioning agent with prior experience in the design, start-up, and turn-over of the strategies that are common in all-electric buildings can be a valuable asset for navigating the unique challenges encountered in the design and construction of these projects.

47 "Building and Infrastructure Consumption Emissions", August 2019. Available from https://www.c40.org/networks/clean-construction-forum.

48 "Zero Emission Construction Sites: The Possibilities and Barriers of Electric Construction Machinery", Bellona Europa, 2019. Available at: http://innovativeanskaffelser.no/wp-content/uploads/2018/12/bellona-report-on-zemcons.pdf.

49 Available at: https://www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf

Among the most important aspects of commissioning these project types are:

1. **Verify that contractors build per the design, purchase the correct equipment, and know how to install and start-up the equipment.**

   » An example of an item to pay particular attention to is the configuration and start-up of central domestic hot water heating systems.

   - For a discussion of configuration considerations, see Section 2.6.2.3.

   - Central HPWHs require a sophisticated start-up that may be unfamiliar to plumbing contractors. The refrigeration circuit of a heat pump water heater requires the verification, and possible adjustment of, expansion valves as well as superheat and subcool settings of the system, checking for adequate refrigerant charge, and adding refrigerant if necessary (which requires a technician with an EPA 608 certification, more commonly found amongst HVAC contractors).

2. **Ensure that facility operations staff are fully trained, especially on systems they do not have extensive prior experience with.**

3. **Make sure a Systems Manual is provided**. Systems Manuals (see the LEED v4 for Building Design and Construction Enhanced Commissioning credit for more detail on Systems Manuals) compile documents critical for the proper operation and ongoing maintenance of systems. When dealing with new technology, Systems Manuals can be a key resource for operations staff.

4. **Ensure the envelope performance of the building:** validating that the installed enclosure meets performance expectations requires both witnessing installation (especially observing that performance control layers are installed properly before they are concealed within the construction) and testing the installed systems for proper performance (thermal, air, water control, etc.).

   » Properly witnessing installation and testing requires coordinating trade schedules and sequencing to allow for these tasks at appropriate milestones in the overall enclosure installation. It's important to note that the current standard of practice for enclosure installation (a "continuous" installation sequence) typically needs to be modified to a non-traditional "start-stop-start" installation sequence to accommodate these commissioning tasks.

   - Enclosure system installation should stop after an initial installation, in order to test the initial install and identify modifications that may be needed to pass thermal, air and water control tests. Only then should installation restart, and subsequent system and component installations must incorporate the required modifications.

   - Start-stop-start sequencing, when properly coordinated into the General Contractor's installation schedule in advance, will usually be perceived as inefficient and costly. However, the added cost should be seen as a reasonable "insurance policy" against the potential costs and delays in the event that the envelope systems fail their performance tests. These added costs typically include:

     › the additional time and materials for de-installing, remediating, and re-installing work that may have been installed before testing could be accomplished, and which now needs post-test modifications, and

     › the financial hardship and potential litigation costs for enclosure remediation and repairs to address interior damage if issues are not found until after project handover.

   - System/components testing needs to occur before interior finishes are installed, to allow for:

     › proper viewing of any water or air infiltration issues, and

› limiting damage to and therefore removal and replacement of interior finishes if there is a problem (i.e. wetting and degradation of sheetrock, wetting and potential for mold in interstitial insulation, etc.).

- Even when agreeing to start-stop-start erection sequencing, when schedule challenges occur (as they often do) General Contractors will typically want to modify previously agreed enclosure erection sequencing. They may offer to "continue at risk" and/or "accept full responsibility during the warranty period." Owners would be well-advised to resist these "concessions." Due to the multiple trades involved in an enclosure, if issues arise there will be finger pointing and litigation before issues are resolved. This may leave the owner or occupants with a building that is partially or totally unusable until these problems are resolved.

5. **Oversee the proper handling of substitutions during construction:**

» The critical features of equipment may not always be recognized or understood by the contractors or their vendors. Ensuring the "equivalency" of all aspects of substituted equipment can be important to avoid surprises at the end of a project. It is disappointing, and possibly even negligent, when key goals of the owner have been unknowingly sacrificed as a result of acceptance of substitutions by the Engineers of Record.

» When onsite renewable energy systems are sized to produce a certain amount of electricity annually — based on the predicted consumption of the building's all-electric systems — equipment substitutions can adversely affect both energy consumption and production, and hence the carbon footprint of the final facility.

2.8_Post-Construction Practices

2.8.1_MONITORING-BASED COMMISSIONING AND RETRO-COMMISSIONING

Commissioning during the post-construction or operations phase of a building's life cycle is fundamentally different from the commissioning that occurs during the construction phase.

MONITORING-BASED COMMISSIONING (MBCX)

During the first year of operation and beyond, utilizing data collected about building system and equipment performance can be extremely effective in identifying and addressing the operational issues that cause systems to operate in manners that diminish performance, increase energy use, and cause operator and end user dissatisfaction.

Many terms are used for this activity: data analytics, fault detection and diagnostics (FDD), data-driven facilities management, etc. All these terms have at their core the fundamental concept of gathering data from systems that control and monitor building equipment to provide an on-going methodology for identifying and correcting system performance issues. Thus, Monitoring-based Commissioning is a term that encapsulates the process of collecting and analyzing data and responding to system anomalies with corrective actions.

MBCx helps identify operational issues that can be hard to discover during the construction phase commissioning work that is done prior to building turn-over to an owner. Construction phase commissioning tends to look at the operation of systems through demonstration of changes to specific, short-term operational conditions that need to result in appropriate systems responses. However, the dynamic operation of systems in response to the occupants' use of a building results in more complex system interactions than can be created during initial testing. Thus MBCx can be an essential step towards successful and efficient building operations.

Key steps for maximizing the benefits of MBCx include:

1. **Engage the building operations team early.**
   - The operations team is the ultimate stakeholder of monitoring-based commissioning. The end goal should be to train the operations team to facilitate monitoring-based commissioning, and to commit to taking action on identified issues.
2. **Look into incentive programs.**
   - Federal funds, state grants, and utility incentives may be available to offset the first costs of monitoring-based commissioning. Where formal programs don't exist, municipalities and utilities are usually willing to entertain a pilot program when you work with an approved service provider.
3. **Choose Automated Fault Detection and Diagnostics (AFDD) software that is customizable and capable of integrating with a Building Automation and Control System.**
   - MBCx can be implemented very cost-effectively by employing any of a variety of well-developed platforms that "automate" the collection and analysis of the large amounts of data available in most modern commercial buildings.
   - ASHRAE Guideline 36, "High-Performance Sequences of Operation for HVAC Systems," has integrated many automated FDD functions and is a good resource for understanding how FDD can be used for maintaining proper system performance.
   - A vast number of third-party automated FDD providers offer both open protocol and platform-specific products.

2.8.2_RETRO-COMMISSIONING AND RECOMMISSIONING

Retro-commissioning is generally considered a process to improve an existing building's performance. Opportunities for performance improvement are identified, quantified, implemented, and demonstrated to result in energy savings or other operational improvements. According to a 2005 study by Lawrence Berkeley National Laboratory, PECI and the Energy Systems Laboratory at Texas A&M University, median payback for retro-commissioning was 8.5 months (https://www.bcxa.org/ncbc/2005/proceedings/19_Piette_NCBC2005.pdf), and was at the time the most cost-effective means of improving energy efficiency in commercial buildings.

Recommissioning is another type of commissioning that occurs when a building that has already been commissioned undergoes another commissioning process. The decision to recommission may be triggered by a change in building use or ownership, the onset of operational problems, or some other need. Ideally, a plan for recommissioning is established as part of a new building's original commissioning process. The Enhanced Commissioning credit in LEED v4 BD&C requires the Commissioning Agent to develop an "Ongoing Commissioning Plan," providing the building's operating staff with procedures, blank test scripts, and a schedule for recommissioning activities.

The growth of interest in recommissioning stems from a study by Portland Energy Conservation, Inc. (PECI) completed decades ago, suggesting that the benefits of new construction commissioning do not always persist.[50] The study identified three main reasons that the benefits did not persist:

1. **Limited operator support and high operator turnover rates**
2. **Poor information transfer from the new construction commissioning process**
3. **A lack of systems put in place to help operators track performance**

50 Available at: https://www.aceee.org/files/proceedings/2002/data/papers/SS02_Panel3_Paper11.pdf

The persistence of commissioning benefits were found to be highly dependent on the working environment that included adequate operator training, dedicated operations staff with the time to study and optimize building operations, and an administrative focus on building performance and energy costs. Four methods for improving persistence were proposed:

» **Providing operators with a high level of training and support.**

» **Providing a complete Systems Manual at the end of the commissioning process.** The systems manual is the institutional memory for the building, and this information assists the staff in ensuring that the benefits of commissioning persist. If the knowledge gained from the commissioning process is not available to the current operators, the value of commissioning is decreased in the long term.

» **Tracking building performance.** While not common at the time the PECI study was completed, this can best be done through an MBCx process using automated FDD platforms.

» **Starting commissioning in the design phase.** The most cost effective benefits of commissioning often occur during the design phase, when changes can be made on paper, rather than during construction or after construction is complete.

2.8.3_DECONSTRUCTION

Deconstruction is the final chapter in the life cycle of a building. Proper and thoughtful planning for the entire life of a building project — from the initial design to the end of its useful life — can ensure that the entire lifetime carbon impact of a construction project is minimized, with the ultimate goal that construction projects achieve lifetime carbon neutrality.

While carbon neutrality is a laudable goal, it is but one positive effect of deconstruction (which is sometimes called "construction in reverse" or "unbuilding") instead of outright demolition (which typically uses mechanical equipment like bulldozers and wrecking balls, resulting in limited reusability). Other positive impacts, according to Building Reuse, a non-profit organization focused on reusing building materials, include fewer trips to landfills, job creation and workforce development, and aftermarket opportunities to reuse or recycle building materials. Public health is also served by deconstruction, considering that demolition can release harmful lead dust, asbestos, and other toxic materials into the community.[51]

Green building certifications also encourage and reward deconstruction and building material reuse and recycling efforts. Moreover, municipalities are implementing deconstruction policies to achieve their triple-bottom-line sustainability goals.[52] The deconstruction industry has the potential to create stable jobs with low training thresholds, foster community connections, and contribute to more sustainable construction practices.

51 From Build Reuse.

52 See https://www.portland.gov/bps/decon/deconstruction-requirements and https://www.c40knowledgehub.org/s/article/How-to-start-deconstructing-and-stop-demolishing-your-citys-buildings?language=en_US

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BUILDING DECARBONIZATION COALITION

The Building Decarbonization Coalition unites building industry stakeholders with energy providers, environmental organizations and local governments to help electrify California's homes and work spaces with clean energy. Through research, policy development, and consumer inspiration, the BDC is pursuing fast, fair action to accelerate the development of zero-emission homes and buildings that will help California cut one of its largest sources of climate pollution, while creating safe, healthy and affordable communities. The Project Team gives special thanks to the BDC for its leadership in this endeavor and for the generous support of its Membership.

WRNS STUDIO

Guttmann & Blaevoet CONSULTING ENGINEERS

CONNECTING POLICY AND PRACTICE WITH DESIGN URBAN FABRICK

WILLIAM J WORTHEN FOUNDATION

Contributors

Building Decarbonization Practice Guide Content Leadership

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

Project Manager

- **Brett Rosenberg**, LEED AP, Treeline Strategy, LLC

WJWF Intern

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

Graphic Design

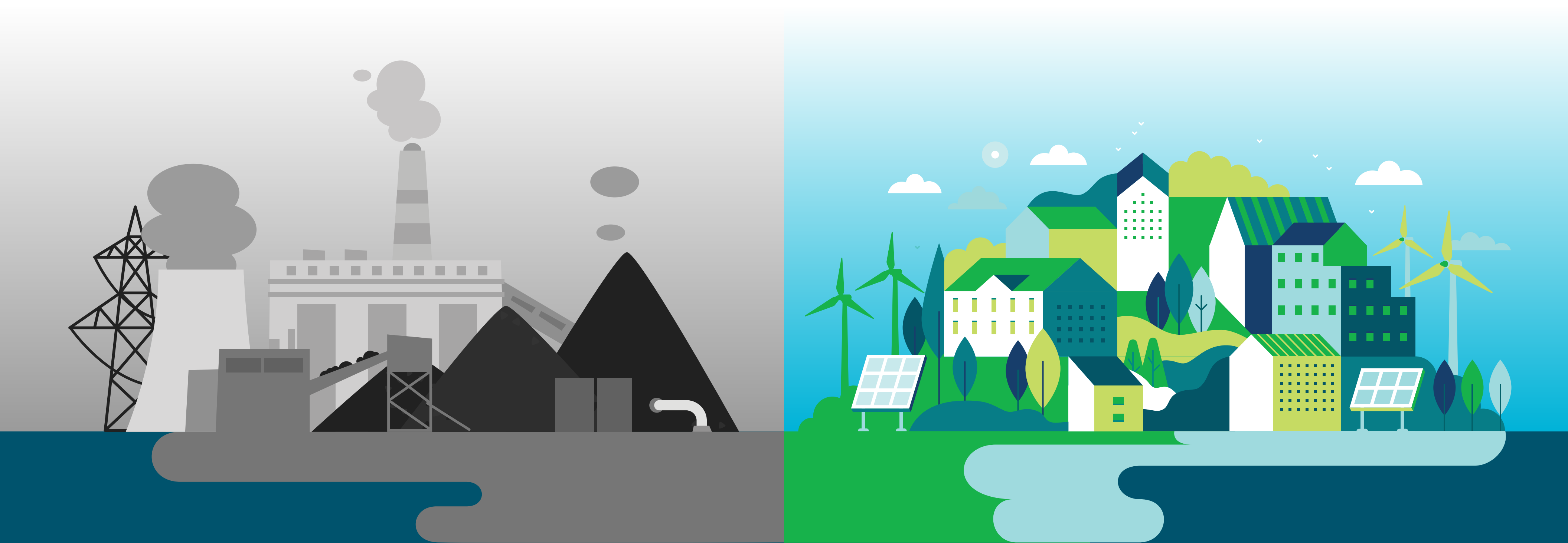
- **Stoller Design Group**

Copy Editor

- **Geoff Martin,** Wheelhouse Writing Services

Working Group Members and Content Contributors

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



THE BUILDING DECARBONIZATION PRACTICE GUIDE

A Zero Carbon Future for the Built Environment

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VOLUME 3:

Multifamily Residential, Hotels/Motels, and Similar Buildings

VOLUME 3 CONTENT LEADERSHIP

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

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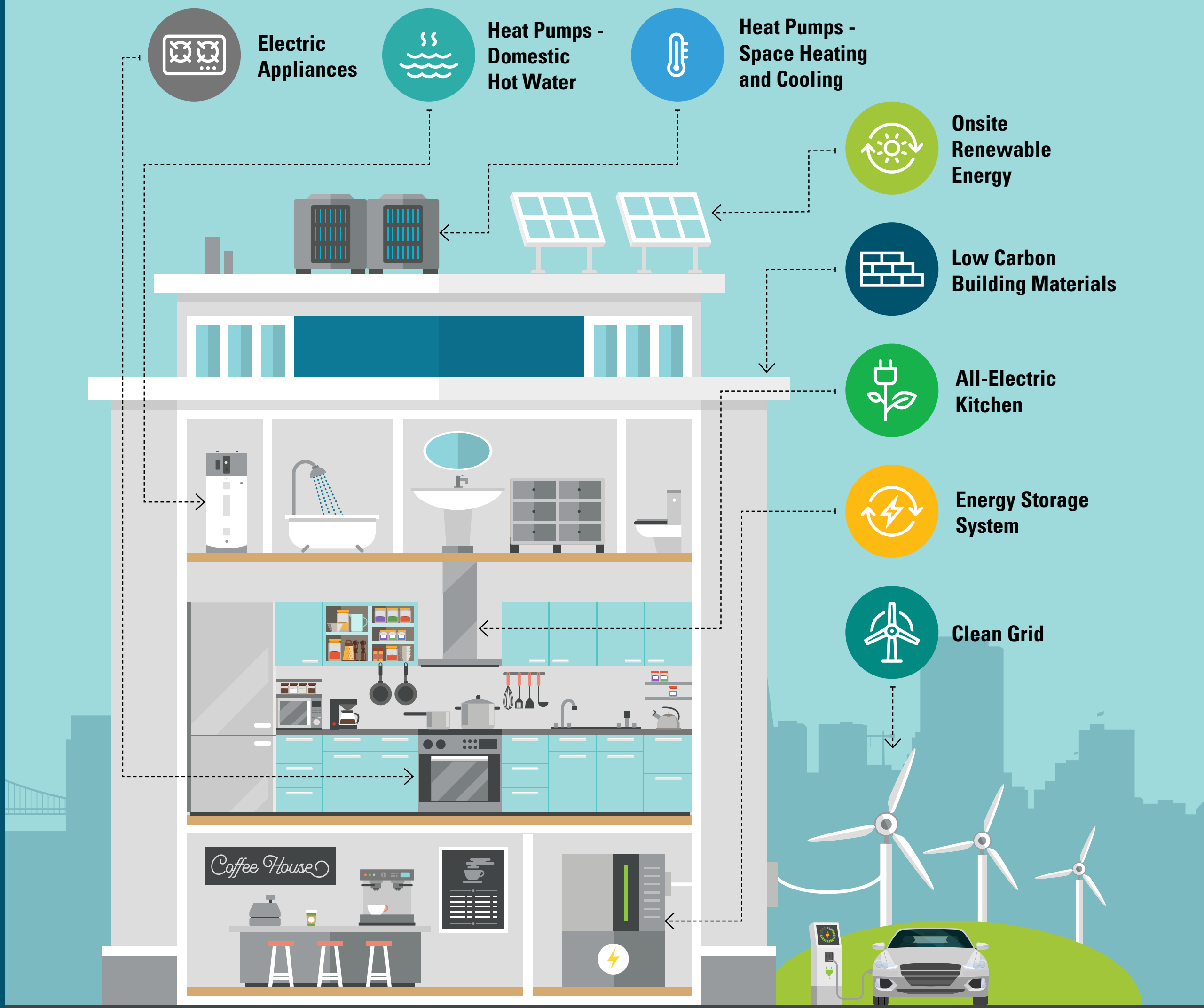

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VOLUME 3: MULTIFAMILY RESIDENTIAL, HOTELS/MOTELS, AND SIMILAR BUILDINGS

VOLUME 3

Multifamily Residential, Hotels/Motels, and Similar Buildings

3.0_Multifamily Residential, Hotels/Motels, and Similar Buildings

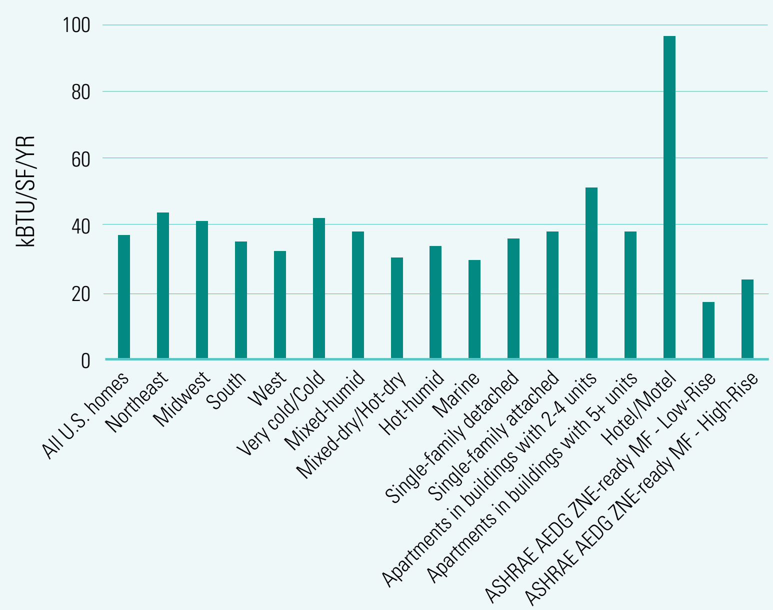
Residential communities form a cornerstone of a climate-adaptive, resilient future, and carbon reduction technologies and associated measures that improve health, equity, and resilience for people at home promise multiple benefits to society. Multi-family residential buildings, in particular, as well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

3.0.1_DIVERSITY OF BUILDING TYPES

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

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

FIGURE 3.1: AVERAGE RESIDENTIAL ENERGY USE INTENSITY



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

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

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

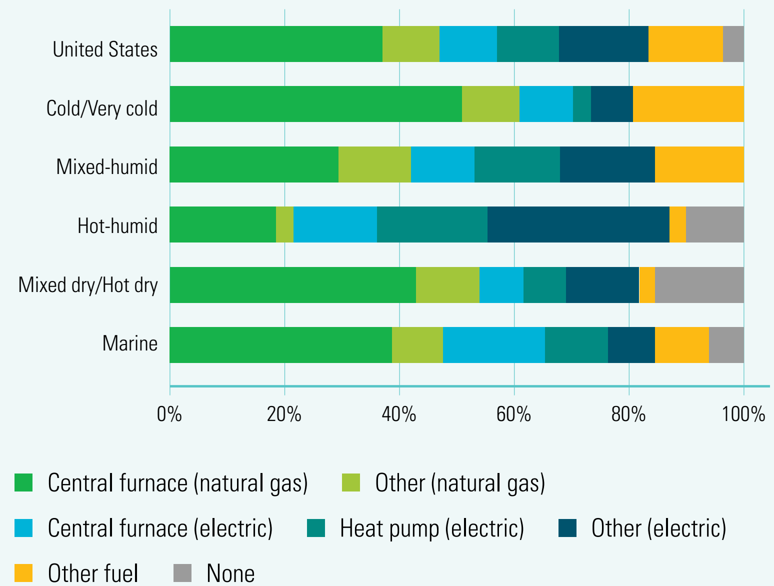
While this guide doesn't specifically address single family residential occupancies, many of the strategies defined herein would also be appropriately deployed in a single-family context as well.

3.1_Principles

On-site gas combustion is a key target for decarbonization efforts. According to the Energy Information Administration, over 50% of the energy consumed by residential occupancies is in the form of onsite fossil fuel combustion (over 80% of which is from natural gas).[53] Residential space and service water heating accounts for 60% of residential site energy use, and almost 60% of the homes in the US are heated using onsite fossil fuel combustion (see Figure 3.2).

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

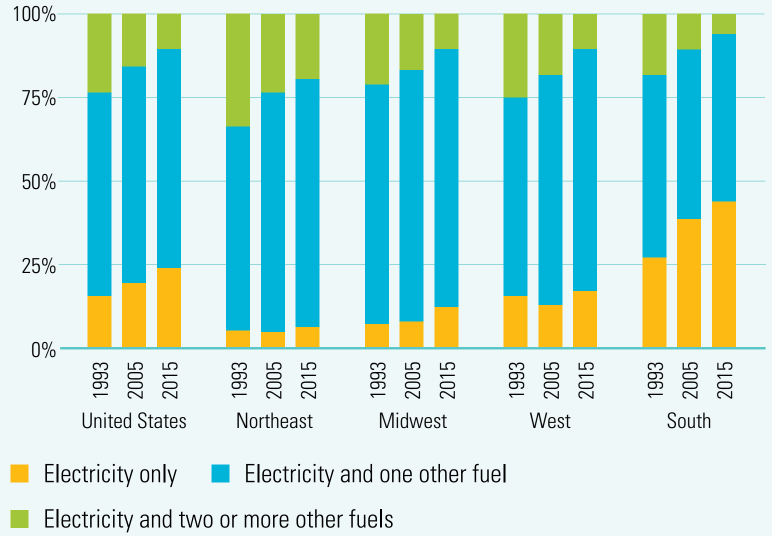
FIGURE 3.2: MAIN HEATING EQUIPMENT CHOICE BY CLIMATE REGION, 2015



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

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

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



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

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

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

For example, "in an assessment of the carbon footprint of 700 California cities, experts with the Renewable and Appropriate Energy Laboratory at the University of California, Berkeley, found that, for most coastal California cities, 'infill' housing — that is, housing built in urban areas, near transit, jobs and services — can reduce greenhouse gas pollution more effectively than any other option."[54] This is equally true in Chicago or Philadelphia or Phoenix. There is great value in ensuring that the interconnected challenges of urban and community design, transit-oriented development, and barriers of housing access and long-term stability for people living in urban communities are holistically addressed in design for zero-carbon housing. Climate responsive and adaptive housing must address both where and how homes are built.

3.1.1_DECARBONIZATION AND SOCIAL EQUITY

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

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

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

3.1.1.1_Public Health Benefits

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

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

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

3.1.1.2_Risks to Affordability

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

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

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

To reduce these risks:

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

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

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

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

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

3.2_The Design Process

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

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

3.2.1_PRE-DESIGN

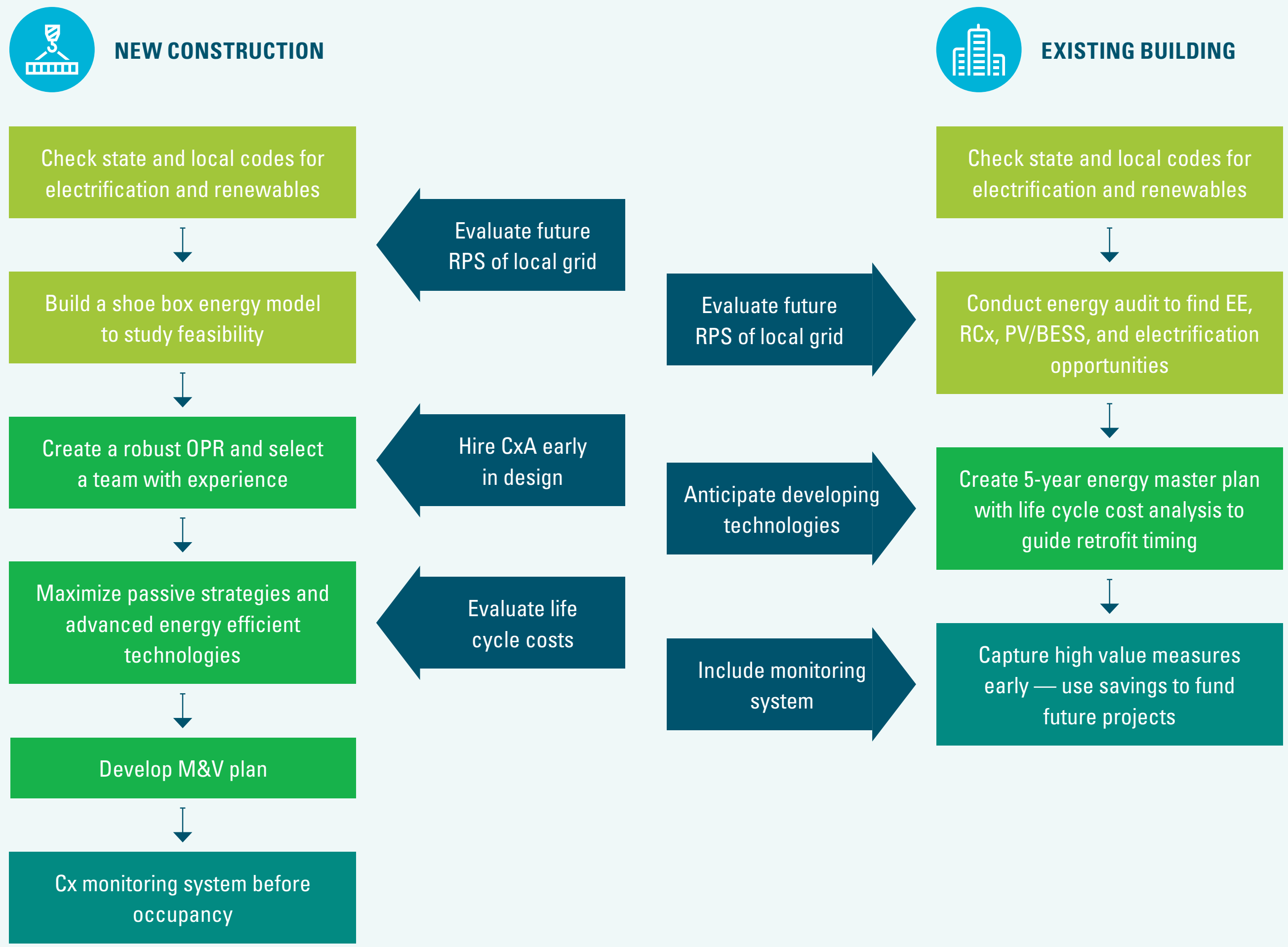
Some key tasks in the pre-design and early design phases include:

1. **Pre-Design:**

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

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

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



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

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

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

2. **Early Design:**

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

   b. Maximize passive design strategies when evaluating site massing.

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

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

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

3.2.2_SETTING UP A STRONG PROCESS AND TEAM

3.2.2.1_Create the Conditions for Intentional Goal-Setting

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

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

1. **Emphasize co-benefits**

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

2. **Head off uncertainty early**

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

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

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

3. **Be proactive with design standards**

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

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

3.2.2.2_Hire the Right Team

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

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

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

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

   a. Services typically provided to meet the national or regional Energy Star for Homes program requirements and the Multifamily High Rise Program Testing and Verification Protocols, including the Thermal Enclosure System Field Checklist and fan pressure testing for compartmentalization.[55]

   b. Full systems commissioning, including envelope.

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

3.2.3_HIGH LEVEL DESIGN CONSIDERATIONS FOR MULTI-FAMILY HOUSING

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

3.2.3.1_Architecture

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

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

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

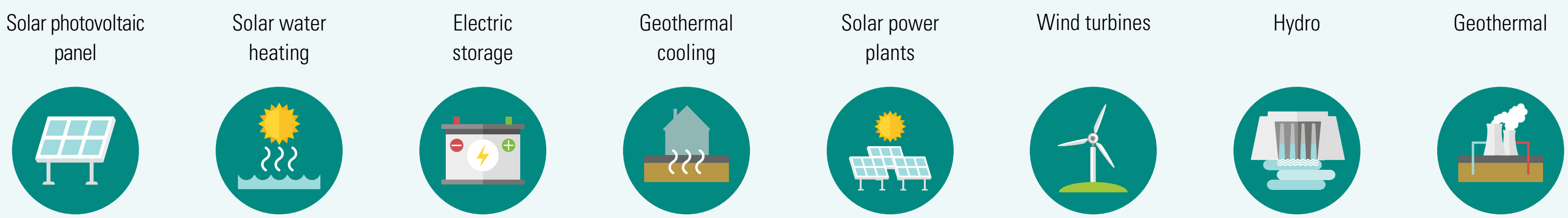
55 Forms can be found at https://www.energystar.gov/partner_resources/residential_new/homes_prog_reqs/national_page

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

EE

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

RE



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

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

3.2.3.2_Structural Design

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

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

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

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

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

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

Modular building options, both below and above the 75' height limit, offer unique opportunities for minimizing waste within the construction process. One challenge of volumetric modular construction is that the added structural materials that go into the modules for shipping and prior to final construction often increase their embodied carbon footprints over build-in-place alternatives.[56] One optimal modular approach, for both embodied carbon and cost, has been to flat-pack frame systems, where floor and wall panels are built using modular systems and final assembly either happens as the building goes up, or within an enclosed factory setting at the project site.

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

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

3.2.3.3_Cost Estimating

It is common for multi-family housing projects to be delivered through a design-assist[57] or design-build delivery method.[58] These methods often put the builder in the role of cost estimator since conventional wisdom has it that they are experienced at establishing quantities and productivity, so they should be well-positioned to establish the anticipated cost of any project.

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

1. **"Filling in the gaps":**
    a. The process of developing opinions of probable construction cost is not the same activity as preparing a construction bid. Bidding typically involves measuring quantities shown on a set of drawings and applying material costs, productivity rates, and other factors as part of determining the total cost to build something. The art of estimating the cost of work when designs are not ready to be "measured" is critical to proper preparation of cost opinions during early design phases. Professionals who do nothing but estimate the cost of construction are often better suited to filling in the gaps, often based on extensive databases of similar work; the project design team — particularly the architect, engineers, and energy consulting professionals — should also be able to assist based on their most recent prior experiences.
    b. Moreover, development teams need to be supported to review life cycle cost and potential reductions in operational energy costs and related improvements in net operating income in order to fully evaluate the cost-benefit of a particular energy or embodied carbon decision. This process is more fully detailed in Section 3.5, and case study examples are provided in Section 3.6.

57 Design-Assist: The Way to Really Fly [AIA course] or Design-Assist: Getting Contractors Involved Early

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

2. **"Risk Pricing" Pitfalls:**
    a. As stated previously, when contractors — and even most specialty subcontractors — are presented with unfamiliar design solutions, "risk pricing" can result. Contractors can have implicit biases for seeing their "reliable" solutions as preferred over more innovative ones.
    b. One strategy to mitigate risk pricing is to specify the most simple and elegant solution. In addition, offering strong support to contracting teams to ensure that they understand the systems — for example, installation mock-ups or training, prior to bidding — can reduce the fear of installing a "new" system for which they lack familiarity. It can also help to draw analogies to systems with which contractors and subcontractors are already familiar. For example, the install on today's packaged terminal heat pump (PTHP) units isn't appreciably different from yesterday's hotel-style heating and cooling unit (PTAC).

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

3.2.3.4_Electrical Design

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

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

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

Areas where electrical engineers should pay close attention include:

» Evaluating the anticipated connected load of heat pumps.

- Even in mild climates, defrost heaters need to be considered, and heat pumps may need supplemental electric heat in order to handle low ambient conditions.

» Exercising reasonable engineering judgement when it comes to diversity, demand and derating factors.

- Be careful in cases where Local Code provisions override the use of diversity factors, such as with the requirements for EVCSs in the California Green Building Standards Code (2019 CALGreen par. 4.106.4.2.4).

» Careful consideration of the service voltage.

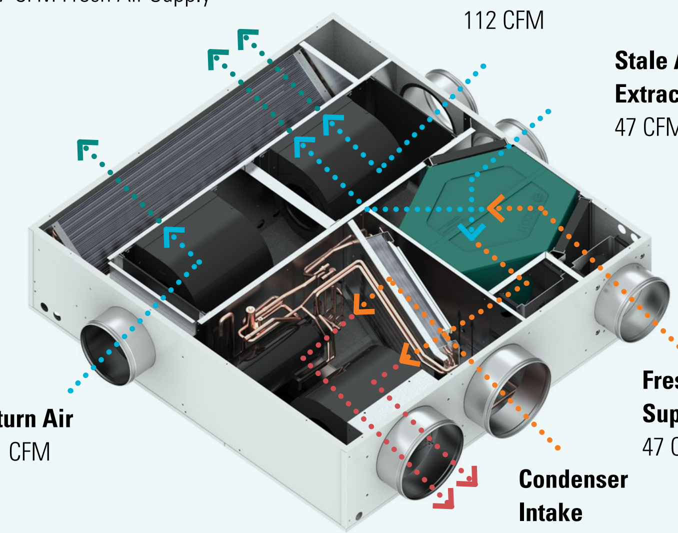
- These types of projects consist mostly of utilization voltages of 208 volts, so selection of the service voltage for smaller projects should be at 208 volts, in lieu of 480 volts, which reduces the need for interior step-down transformers to serve the load. Where projects might have difficulty siting a transformer (e.g. small, urban infill projects), work closely with the HVAC engineer to avoid the use of equipment requiring 460VAC. If all equipment can use 208V/1PH or 3PH power, a transformer can be avoided. For larger projects where transformers present cost and/or space issues, consider multiple utility services. Avoiding transformers also avoids the losses (+/-2% of the transformer's kW rating) that reduce overall electrical system energy efficiency.

3.2.3.5_HVAC Design

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

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

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



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

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

6. **Electric resistance heating:**

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

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

3.2.3.6_Domestic Hot Water System Design

One of the systems undergoing the most radical transformation in design approach is the domestic hot water (DHW) delivery system. The onsite combustion of a fossil fuel to generate DHW has been the primary design paradigm for over 100 years; the first US patent for a storage type water heater was filed by Edwin Ruud in the 1880s.[59]

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

3.2.3.6.1_AIR-SOURCE HEAT PUMPS

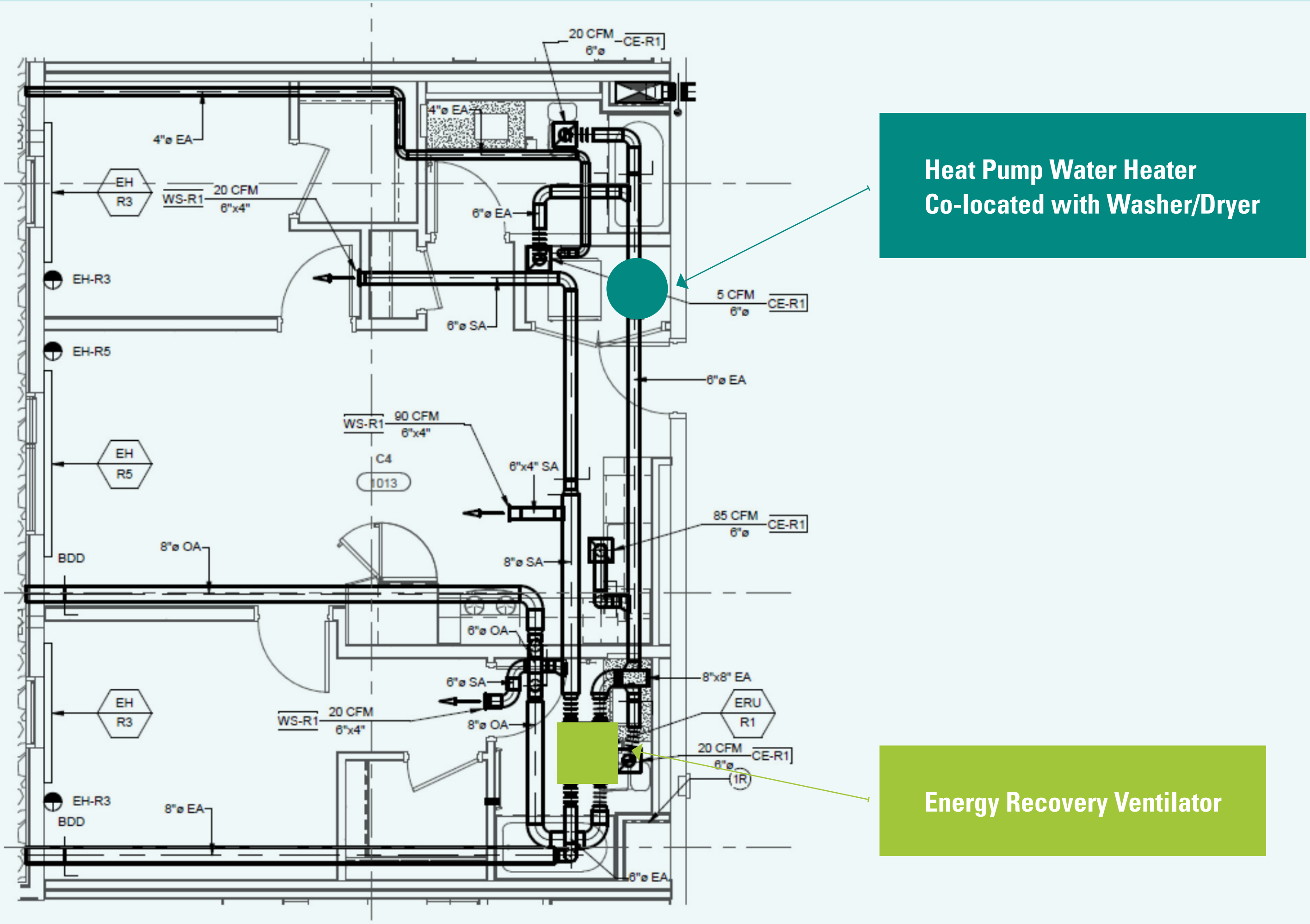
Efficient unitary systems are generally configured around air-to-water heat pumps (aka air-source heat pump or ASHP), and — if located close enough to all end uses — they can be installed in each unit to facilitate elimination of the recirculation loop and its associated energy losses. This requires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

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

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

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

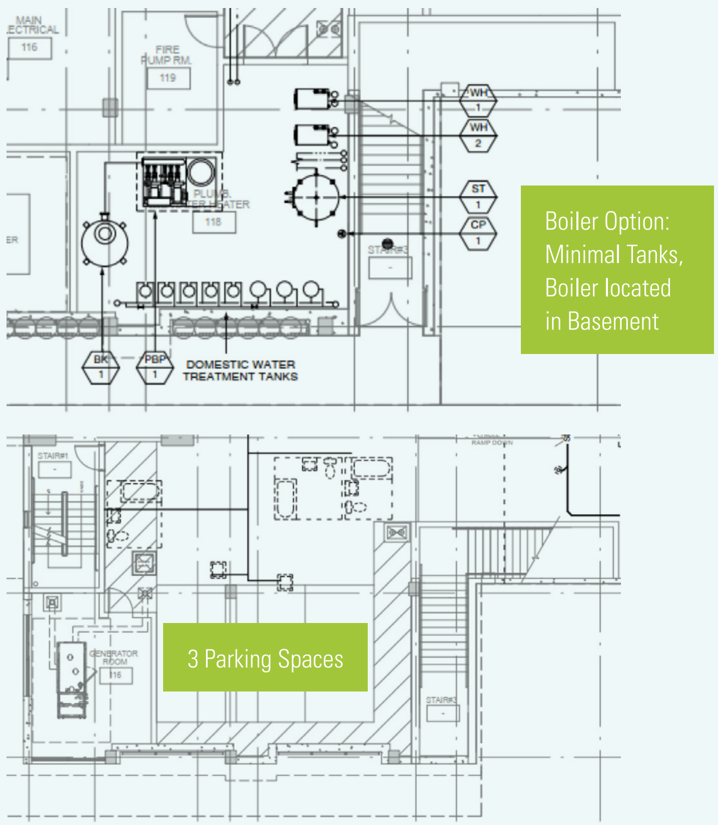
FIGURE 3.7: TYPICAL APARTMENT LAYOUT INCORPORATING A HPWH



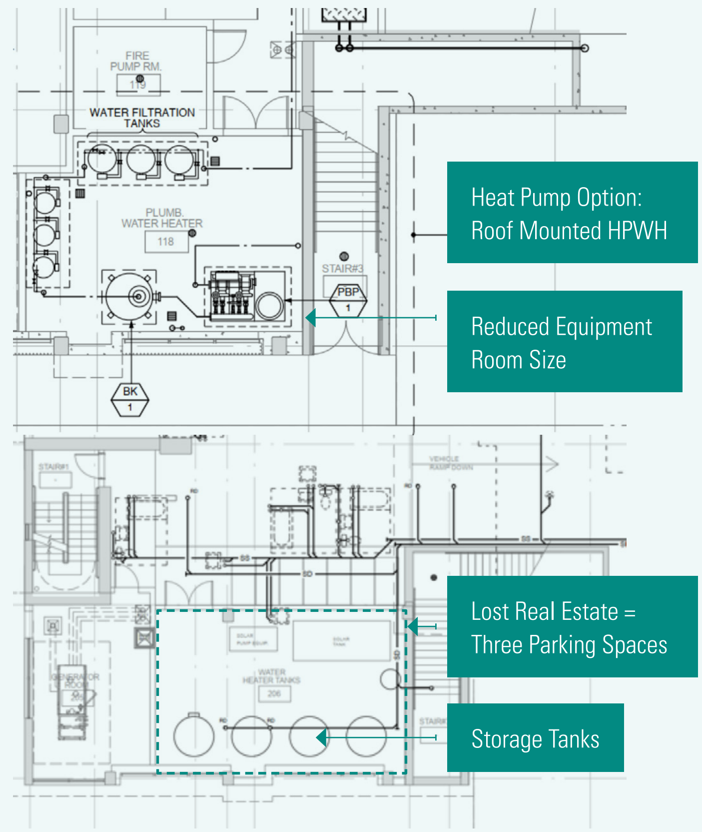
Source: Image courtesy of Guttmann & Blaevoet Consulting Engineers

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

Gas Water Heating System



Electric Heat Pump Water Heating System



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

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

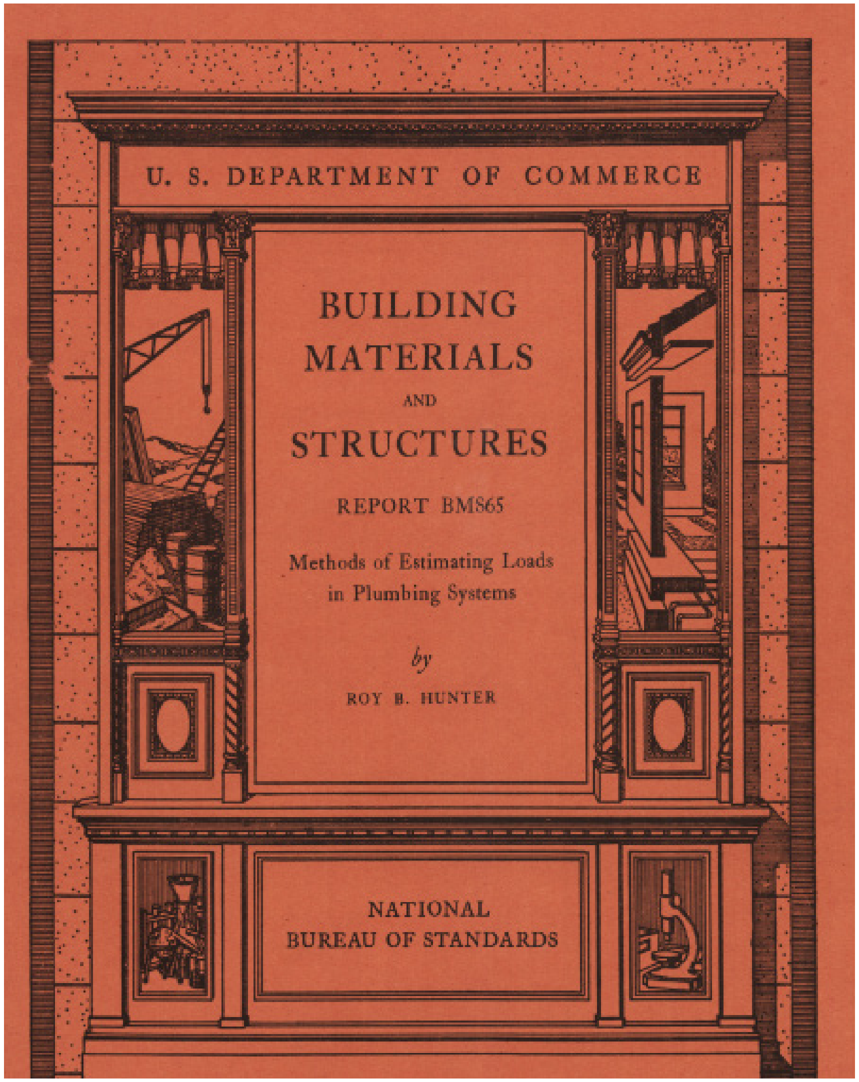
3.2.3.6.2_WATER-SOURCE HEAT PUMPS

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

For ground-source systems, pulling heat out of the ground to create DHW should typically be combined with systems that put heat into the ground (e.g., chiller systems), to avoid annual thermal imbalances that can have significant adverse effects. Numerous resources on the proper design of ground-source heat pump systems are available.[60]

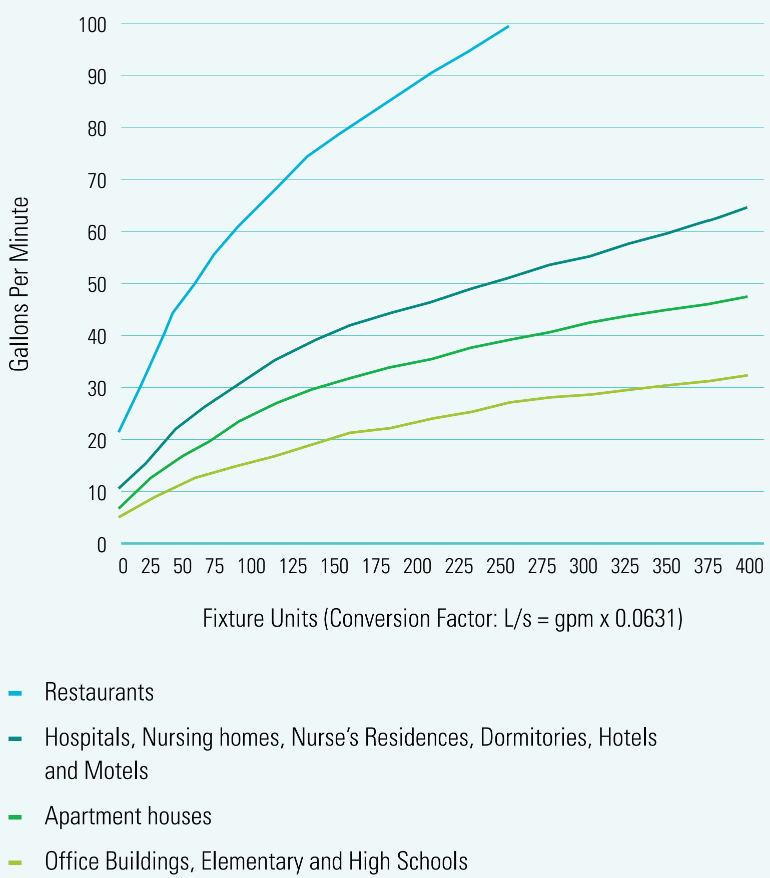
3.2.3.6.3_SIZING CONSIDERATIONS

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



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

FIGURE 3.9: MODIFIED HUNTER CURVES



Source: 1999 ASHRAE Handbook

While the buildings that are the focus of this Volume have similar demand characteristics (with some variation), the typical methods that are used for estimating peak demand in residential occupancies are based on outdated assumptions and data. These methods generally result in a significant oversizing of heating capacity. Many things have changed since 1940 when Roy B. Hunter's "Methods of Estimating Loads in Plumbing Systems" was published as a national standard in the United States.[61] Hunter's "curves" used for system sizing have been modified since the 1940s to develop curves that are tailored for different occupancy categories (see Figure 3.9). Nevertheless, Hunter's methodology is baked into current National Codes, and these curves still result in significant oversizing of systems.

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

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

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

methods to find ways to right-size these systems.[62] Acceleration of the development of new Standards, as well as the adoption by model Codes of more modern methodologies for system sizing, will be important steps in addressing this issue.

3.2.3.6.4_CONFIGURATION CONSIDERATIONS

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

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

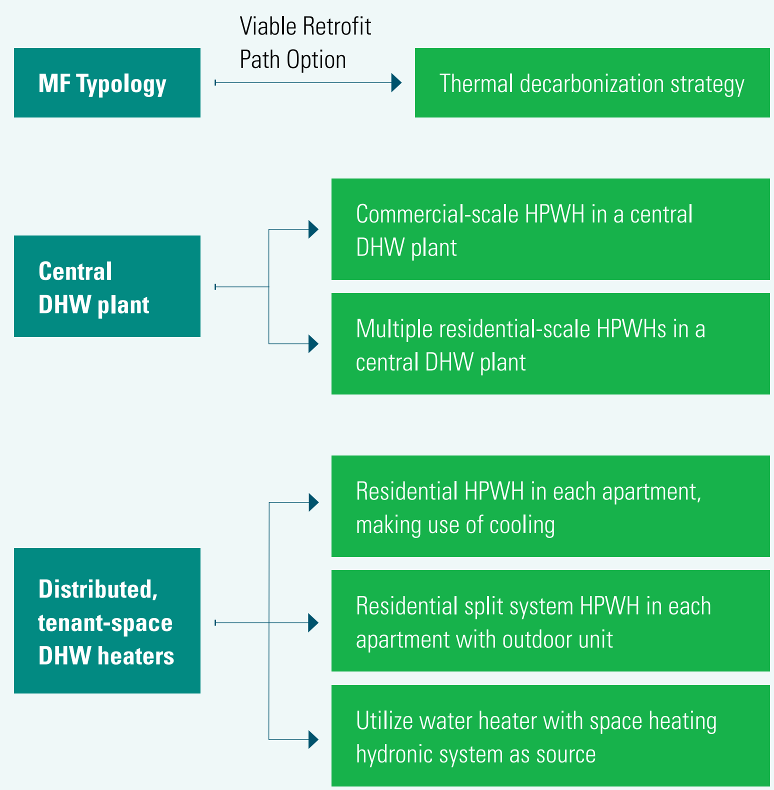
Design considerations for central HPWH systems are discussed in more detail in Volume 2, Section 2.6.2.4, "Single-Pass Versus Multi-Pass Domestic Hot Water (DHW) System Configurations".

3.2.3.6.5_UNIQUE CONSIDERATIONS FOR NEW MULTIFAMILY CONSTRUCTION

The importance of heat recovery cannot be overstated.

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

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



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

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

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

3.2.3.6.6_UNIQUE CONSIDERATIONS FOR MULTIFAMILY RETROFITS

The NRDC funded the development of a very robust retrofit guide for heat pump water heating in various climate zones.[63] The report has a very useful decision tree for the various approaches (see Figure 3.10). The report also lays out potential design issues for retrofits, specifically noting the unique challenges for cold climate retrofits from existing space heating system systems to heat pump water heating systems.

3.2.3.7_Laundries

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

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

3.2.3.8 _Fireplaces and Fire Pits

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

What is a water vapor fireplace?

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

Why buy an LED fireplace?

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

3.2.3.9_Grills

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

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

3.2.3.10_Controls

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

The challenge of eliminating these "vampire" loads has been easily solved in the commercial construction world through plug load management devices and occupancy sensors, which are required by Code in many places.[64]

Applying plug load and lighting management technologies in residential construction has generally proven to be cost prohibitive. In addition, many of us have come to loathe the occupancy sensor that never seems to know we are there. However, newer technologies and tailored solutions are being developed for the residential market that will bring the cost down significantly and improve the efficacy. These devices provide a cost effective means to enhance occupancy-based control schemes (see Figure 3.11). They should also provide a means for grid responsive controls to be cost effectively incorporated into residential construction, allowing for the use of unitary HPWHs to be used as deployable loads.[65]

3.2.3.11_Swimming Pools

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

FIGURE 3.11: STRATEGIES FOR OCCUPANCY-BASED ENERGY USE REDUCTIONS

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

● Easily integrated strategy

○ Opportunity dependent on system design choices

Source: Rivieh

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

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

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

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

Furthermore, heat pump heating for pools can be paired with additional efficiency measures. Pool covers dramatically reduce heat loss, for example. Floor return lines, which prevent stratification (cold water at the bottom of the pool and hot water at the top), are common in older pool designs and are an important efficiency measure.[66]

3.2.3.12_Cold Climate Considerations

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

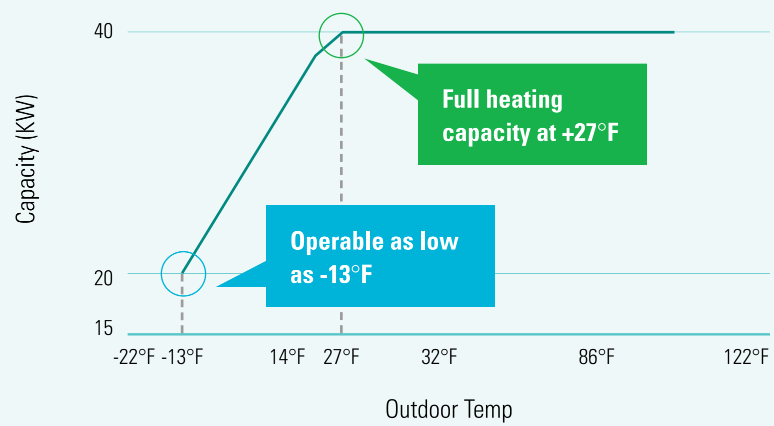
The barriers to producing hot water in cold climates are not technical, and there are a number of solutions available to tailor the design to a project's unique technical constraints. However, many of these solutions can be more expensive than business as usual. So, until market demand brings down the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

These solutions include:

» CO_2-based HPWHs:

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

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



Source: From Mitsubishi QAHV Hot Water Heat Pump Brochure

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

» Two-stage heat pump systems:

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

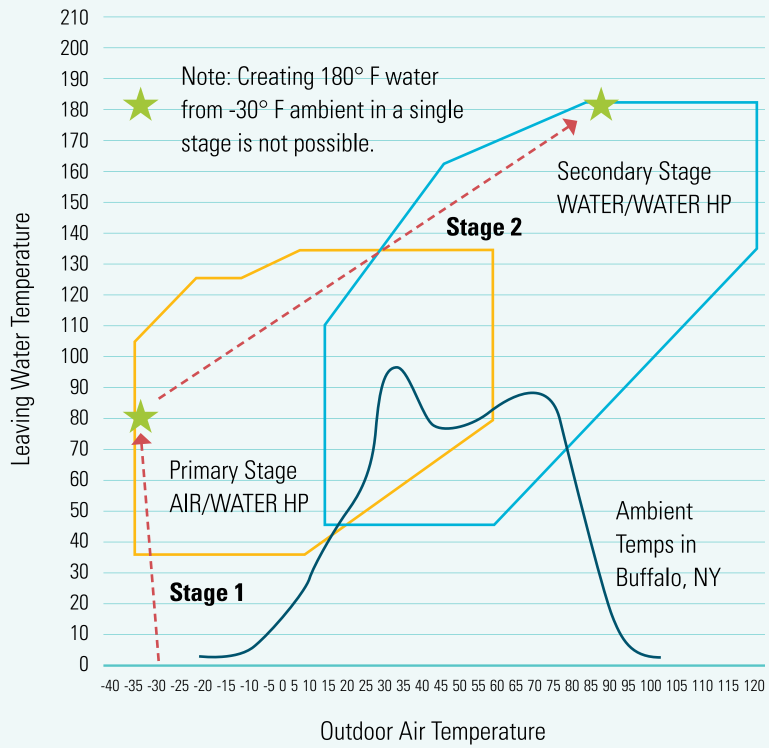
» Find a stable "source" at a temperature between 60 and 80°F to use for water-to-water heat pumps:

- Sewer Water Energy Exchange (SWEE): See the discussion of SWEE in Volume 2, Section 2.6.2.2, "Water-Source Heat Pumps" and refer to Figure 3.14.

- Earth-coupled heat pumps: ground temperatures at a depth of more than 10 feet below the surface tend to be very stable and relatively unaffected by ambient air temperatures. Bodies of water can also be excellent sources for heat, as long as a thermal balance is maintained: this usually comes from flowing water, extremely large bodies of water (like the ocean), or smaller bodies of water that serve as both a source (for heating) and a sink (for cooling).

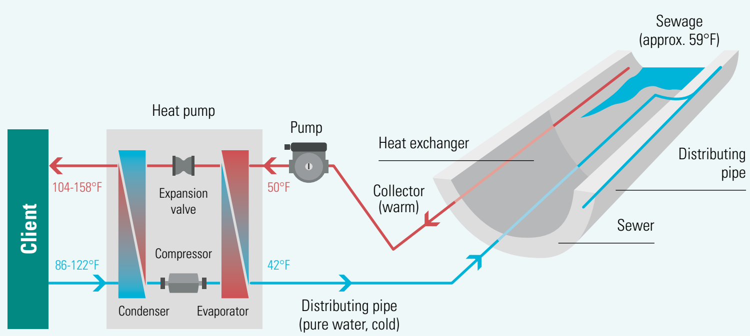
- Cooling tower water: for projects that include water cooled chillers, condenser water can be effectively used; however, this requires that there be a significant cooling load during the heating season, which is less common in residential construction than it is in commercial construction. Also, these applications often require water storage to take advantage of heat produced when there is not enough load to use all the energy that is created, as well as supplemental heat sources to accommodate periods when cooling loads do not produce enough hot water to meet the loads.

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



Source: Transom Corporation, Barrie, Ontario, Canada

3.14: SANITARY WASTEWATER ENERGY EXCHANGE (SWEE)



Source: Rabtherm

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

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

3.2.3.13_Refrigerants

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

3.2.4_HOTEL/MOTEL OCCUPANCIES

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

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

One type of control strategy that is unique to the hotel/motel category is the "captive key card" system that automatically turns off the HVAC, lights, and controlled receptacles when the room is vacant. While this is a very efficient approach for hotels (and a Code requirement in many states), it is not currently a requirement for multi-family buildings. Some types of multi-family housing — such as student dormitories and co-living[67] facilities — might be appropriate types of projects to consider using this approach. New technologies are on the horizon that could make this type of "vacancy control" more suitable and cost effective in multi-family residential projects (e.g. see new technology from Rivieh[68] that is expected to become commercially available in the first quarter of 2022).

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

3.3_Construction Phase Considerations

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

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

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

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

68 https://rivieh.com/

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

- » Ensure the building is built to specifications;
- » Effectively manage the substitution process during construction (substitutions may be necessary to hold schedule or cost, but any such substitutions need to be evaluated against the OPR, predicted performance metrics, and building lifecycle goals);
- » Ensure the building envelope is constructed from the specified materials or substitutions with identical performance specs and assembly compatibility, and that the enclosure is assembled properly from a performance perspective (air, moisture, and thermal);
- » Create and memorialize an effective operation and maintenance manual before the building is turned over;
- » Train property management and facilities staff during the process of commissioning the building.

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

3.4_Operational Phase Considerations

A comprehensive approach to energy management can improve the energy efficiency of U.S. multifamily properties by 15-30% and save $3.4 billion in annual utility costs, according to ACEEE.[69] And yet, the multifamily sector has been slower than the commercial building sector to prioritize stewardship of energy and water use in buildings. There may be a number of unique reasons for this:

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

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

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

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

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

3.4.1_TRAIN FACILITIES STAFF AS PART OF COMMISSIONING

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

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

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

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

3.4.2_MONITOR, MAINTAIN, AND VALIDATE BUILDING PERFORMANCE

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

- **Energy Star Benchmarking:** the US EPA provides the "Portfolio Manager" tool as part of their Energy Star program. This free tool is used by hundreds of thousands of buildings to measure and track their energy use; multifamily properties with 20 or more units receive a score on a scale of 1–100, which is a rating of a facility's energy use compared to similar properties nationwide.[70] Projects can be "certified" under the program when receiving a score of 75 or greater. Energy Star certification can actually begin in the design phase, as the program has recently added the "Designed to Earn" certification.[71] It should also be noted that the US EPA has a similar program for water use called "WaterSense Labeled Homes."
- **Basic M&V:** this can be as simple as comparing utility bills to a site and building specific energy performance prediction. This prediction is materially different from Energy Code compliance calculations. Energy modelers with experience in preparing "predictive" energy use models can adapt Code compliance models to the needs of an M&V process. [72]

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

71 https://www.energystar.gov/partner_resources/residential_new/program_reqs/mfnc_cert_process/designed_earn_multifamily

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

- **Advanced M&V:** since utility bills can only provide data on total energy use, deviations from predicted performance can be complicated to analyze and require careful evaluation in order to identify potential causes that can be acted upon. Advanced energy and water metering can make deviations easier to analyze. LEED, BREEAM and other rating systems encourage the use of such sub-metering. Check locally as well, since jurisdictions are increasingly requiring energy submetering. However, there can be a significant positive return on advanced M&V investments. No one would think twice about asking a car dealer to explain why the actual gas mileage of your new car was only 70% of the EPA window sticker mileage. This should be true of buildings as well.
- **Monitoring Based Commissioning (MBCx):** this robust process can evaluate building performance as well as enable a process of driving performance towards the expected result. For more discussion of this strategy, see Volume 2, Section 2.8.1.

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

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

3.4.3_MARKET THE VALUE OF LIVING IN A DECARBONIZED BUILDING

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

- The challenge of communicating clearly to residents about the sustainable features of a building can be addressed by having a third-party framework in which to describe them. When carried through to certification, these frameworks also provide quantifiable achievements compared to an objective standard. Furthermore, having these accomplishments validated by a third party can help address any concerns about green-washing.
- The role of each tenant in ensuring the building achieves its sustainable performance potential can be more clearly explained.
- Participation in certification can help explain the myriad benefits to residents.

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

- **Wellness Benefits:** there are significant wellness benefits to living in a sustainably designed and built building. For example, residents should learn about the improved indoor air quality from switching out natural gas for electric cooking appliances (Volume 5 of this practice guide provides a deep dive into all-electric kitchens). We also recommend checking out the Well Building Standard for additional ideas and guidance.[73]

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

- **Financial Benefits:** Decarbonized and all-electric buildings can be less expensive to operate, particularly if electricity use patterns maximize the benefits of a utility's time of use rates and water fixture efficiency is maximized. We recommend communicating the value of these savings, and — if you feel comfortable — providing a sample utility bill comparison. LEED, for example, provides a framework for quantifying cost savings from energy and water use reductions.[74]
- **Resiliency Benefits:** Decarbonized and all-electric buildings can offer crucial resiliency benefits, particularly if solar and battery back-up systems were installed. For example, if the building provides back-up power for refrigerators, select plug loads, building wifi, or even some limited air-conditioning (critical to vulnerable populations during extreme heat events), the benefits of these systems operating during power outages should be communicated to every resident. RELi 2.0 is the most comprehensive certification rating system currently available for socially and environmentally resilient design and construction.[75]

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

74 https://www.usgbc.org/resources/leed-homes

75 https://www.usgbc.org/resources/reli-20-rating-guidelines-resilient-design-and-construction

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

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

- **Educate:** There are myriad opportunities to educate residents. For example, consider signage in the lobby that memorializes the sustainability features incorporated in the design and construction process. Share an overview of building systems with residents upon move-in and post the overview in the building (e.g. in a laundry room). Another opportunity is to post regularly updated or rotating reminders about the impact of timing energy use to low cost and low carbon periods, including how to use the programmable features of different appliances (like dishwashers and thermostats) to assist in this effort. Residents need information in order to actively support efficient and sustainable operation.
- **Communicate:** Data visualization can be a really powerful tool. When the building is planned, designed, and constructed, make sure to install monitoring equipment that will allow you to share real-time visualizations of energy consumption (and energy production, if renewable energy generation was incorporated). Many solar providers furnish the equipment that can be used to aggregate building electricity demand and production in a summary visualization. These graphics can be shared with residents either via a custom application, a sheet of FAQs, a website, or on a welcome screen when they enter the building. Sharing with residents real-time access to energy and water use data can serve as an invitation for them to reduce consumption.

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

3.4.5_MANAGE REFRIGERANTS RESPONSIBLY

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

» A release of all the R-134a refrigerant in a typical residential storage-type heat pump water heater would be equivalent to the climate change impacts from a typical gas water heater with ~3% methane leakage per year.

» A typical refrigerator using R-134a can contain 0.25 kg of refrigerant, which if released into the environment would result in the emissions equivalent of driving 2,130 miles per year (3,427km) in an average family-sized car.

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

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

77 Search Reuse & Destroy, Environmental Investigation Agency | https://eia-global.org/about

At the beginning of 2020, the atmosphere's remaining "global carbon budget" was approximately 340 billion tons.[76] Appropriate management and reuse of refrigerants is projected to slash 100 billion tons of equivalent global CO_2 emissions between 2020 and 2050.[77] Proper refrigerant management should be taken extremely seriously, and all EPA requirements under Section 608 of the Clean Air Act should be followed. There are at least five parts to a successful leak reduction program:

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

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

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

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

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

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

3.5_Assessing Costs and Value

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

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

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

All-electric, decarbonized construction is not a new phenomenon; moreover, not only is it feasible, but in some parts of the U.S., all-electric construction has been the norm for many years. For example, the U.S.Energy Information Administration (EIA) estimates that in the Southeast, nearly 45 percent of homes use only electricity.[78] Further, the results of the EIA's 2015 Residential Energy Consumption Survey indicate that 25% of homes nationwide rely solely on electricity, and the share of all-electric homes has risen in each census region, particularly in the Midwest and in the South.[79] Heat pump technology has led to a more than 20% increase in the share of homes using electricity to power the main heating equipment, and there are similar increases in the market share of homes relying on electricity for domestic hot water.

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

Alignment of the regulatory framework to encourage electrification and decarbonization is growing. In Washington, DC, the December 2018 passage of the Clean Energy DC Omnibus Act greatly expanded the market for energy efficiency retrofits by mandating efficiency standards in existing buildings. New building regulation is increasingly mandating all-electric construction, as is now the case, for example, across 40 municipalities in California or as reflected in the regulatory battles in Massachusetts.[80] However, while support for building decarbonization is expanding at the local level, the role of natural gas use in the built environment is still a hotly debated topic in many State Legislatures (see Figure 3.16).

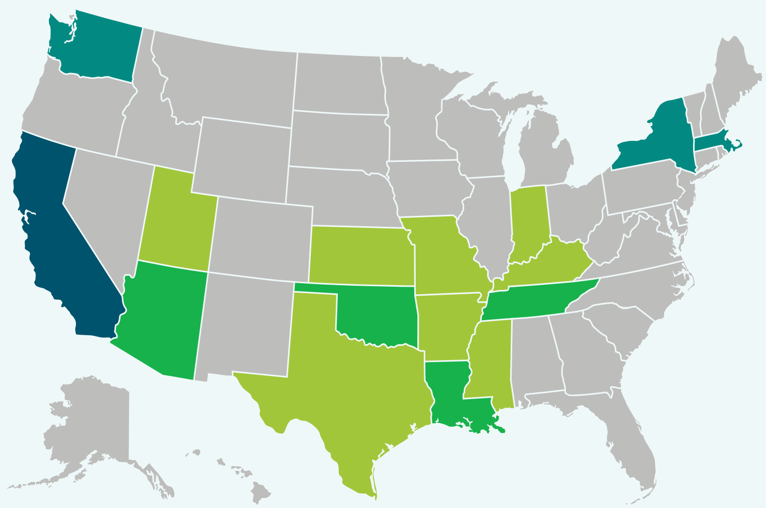
While this context may assuage concerns about risk, maintenance, and the regulatory landscape, how do we dispel concerns about cost? Are all-electric and decarbonized buildings really a financial risk, or is the real financial risk choosing not to electrify and decarbonize a subject development? A thoughtful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

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

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

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

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



State legislation prohibiting local governments from restricting natural gas utlity service

Passed   Introduced in current session

Local gas bans and electrification codes on new buildings

Adopted   In development

Source: S&P Global Market Intelligence

3.5.1_A RECOMMENDED COST-BENEFIT ANALYSIS FRAMEWORK

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

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

» Establish a cost framework as a collaborative effort between project ownership and design leadership to outline the key parameters of the analysis;

» Identify costs and benefits so they may be categorized by type and intent;

» Calculate costs and benefits to include not only first cost but also operating cost and exit value across the assumed life of a project or initiative;

» Compare cost and benefits by aggregating all of the defined inputs.

3.5.1.1_Sample Ground-Up Multifamily Development Cost Framework

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

» Capital Expenses/Savings (or first costs – including construction time and financing costs)

» Operating Expenses/Savings (or ongoing cost)

» Impact of Decarbonized and All-electric Construction on a Project's Exit Value

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

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

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

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

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

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

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

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

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

3.5.1.3_Capital Expenses — The Benefits of Reduced Infrastructure

Taking natural gas out of the building provides many benefits. Chief among these are faster permitting, lower utility installation costs, and reduction in design and coordination costs. Furthermore, for rural projects, where the natural gas infrastructure can be far away from the subject development, the savings are likely to be even greater. Pricing for recent projects in San Francisco yielded per-unit infrastructure cost savings — from removing the gas from the building — ranging from $75/unit to $1,040/unit.[81]

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

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

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

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

81 Per email w/K. Ackerley. Maceo May had a $1040/unit savings and D. Baker Architects has seen savings of $75/unit to $125/unit for eliminating gas.

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

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

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

3.5.2_HOW ELECTRIFICATION CAN BENEFIT FINANCING COSTS

3.5.2.1_Capital Expenses

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

Here are some key questions to ask:

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

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

3.5.2.2_Operating Expenses and Savings

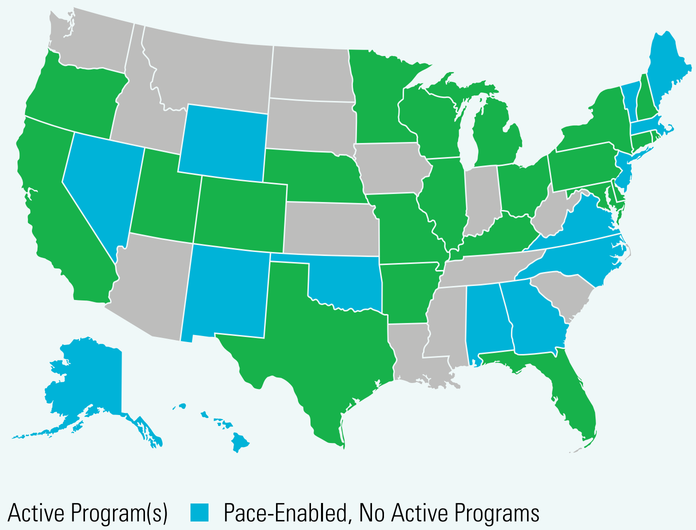
While many for-profit and not-for-profit owners are rightfully focused on the hard costs of construction, the importance of maximizing operational savings cannot be overstated; it's the key driver of financing for both for-profit and not-for-profit projects, because as operating expenses go down net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

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

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

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

FIGURE 3.17: PACE FINANCING (PROGRAMS AS OF 2020)



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

3.5.2.2.1_ADDITIONAL OPERATING COST BENEFITS OF DECARBONIZED CONSTRUCTION

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

- Decreased maintenance cost and complexity; heat pump equipment is often resilient and low-maintenance when compared to combustion based heating systems (e.g. furnaces or boilers). Boilers and furnaces often have many unrelated parts that need attention (gas supplies and flues), and lack of maintenance of these features can cause safety issues.
- The reduction in maintenance costs over time allows for the project's ownership (whether non-profit or for-profit) to reduce the maintenance reserves for the property, increasing the project's ability to service debt.
- Decarbonized construction is more resilient; while the benefits of resilience are difficult to quantify (see discussion in Volume 2, Section 2.6.7), they may include:
  - Lower insurance rates, particularly as insurance rates increase in the wake of extreme weather events.
  - Higher tenant retention rates or even higher rent (or sale prices, if condos), particularly in regions prone to extreme weather events, such as wildfires, hurricanes, or tornadoes. Consumers today understand more intuitively the intrinsic value of living in resilient buildings and the myriad benefits of onsite, back-up power.

3.5.2.3 _Navigating Split Incentives — First Cost versus Operating Costs

Historically, in multifamily rental and office projects, the owner paid to construct the building, but operational utility costs were passed along to the tenants. This set up a situation where the owner was incentivized to reduce capital expenses but was less incentivized to minimize energy-related operating expenses. Conversely, if utility bills are included in a lease, there is strong data to suggest that residents are not particularly focused on energy conservation. According to a study from ACEEE, the U.S. multifamily housing sector alone represents a $3.4 billion energy cost savings opportunity.[82] Other studies have found that annual costs for landlords were 20 percent higher relative to when tenants directly paid the bills or when there was a "green lease."[83]

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

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

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

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

b. Gamify good energy efficiency practices by engaging tenants in reducing utility bills and offering prizes or rewards.

c. Include only a maximum, annually adjusted/reviewed, energy or water amount in a tenant's utility allowance, and hold the tenant responsible for usage in excess of the allowance.

2. If tenants are paying the bulk of the utility bill, owners may be additionally able to:

   a. Explore the use of a "green lease," an agreement between landlord and tenant to share the cost (and savings) of an efficiency upgrade or highly efficient building systems whereby the owner makes an investment in upgraded efficiency and the tenant shares in the savings.

   b. Achieve higher rental rates by lowering resident's utility costs through investments in highly efficient buildings. There are ways to structure leases so that owners don't assume undue risk and tenants have confidence in their overall cost exposure when relying on predictive energy models for selling this approach.

   c. Virtual Grid software can help owners capture some of the benefits of reduced energy cost while allowing tenants to share in the cost reduction benefits of energy efficiency measures.

3.5.3_NAVIGATING UTILITY PRICING FRAMEWORKS

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

» Hire a team with demonstrated experience in designing, installing, and commissioning the strategies that will deliver these results.

» Engage a solar power provider early, preferably one that also has expertise in the installation of battery energy storage systems (BESS). Energy Storage Systems are discussed in greater detail in Volume 2, Section 2.6.5.1.

  - Operating costs can be substantially reduced by maximizing the physical space available for solar system installation and by including battery energy storage technologies for load management.

  - The resiliency benefits of solar systems combined with a BESS can be a significant enhancement to a project (see also Volume 2, Section 2.6.7.1, "Microgrids, 'Islanding', and Resiliency").

  - A good solar provider will calculate both physical space needs and capital expense payback periods for PV and PV+battery installations. A qualified energy or engineering consultant can often help with this as well.

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

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

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

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

3.5.5_HIRING PROFESSIONALS TO ANALYZE COST

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

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

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

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

3.6_Case Studies

3.6.1_THE UNION (SMALL SCALE)

Source: Benedicte Lassalle, OpenDoor, PBC, eSix Development

Project Location: West Oakland, CA

Completion Year: 2019

Project Size: 6,400 SF

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

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

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

Trade-offs and Challenges:

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

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

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

Lessons Learned:

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

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

» Going all-electric did not significantly increase capital costs; the first cost elimination of natural gas saved money. As important — if not more so — it saved precious time coordinating inspections for both electric and natural gas; these inspections often become part of the critical path for achieving the certificate of occupancy.

» Programmable heat pump based hot water heaters may serve a dual purpose as one of the most cost effective energy storage methodologies; the water can retain sufficient heat even if it's programmed to decrease the temperature during the utility's peak load time frame.

» The solar PV array has a significant cost-stabilizing effect.

3.6.2_MACEO MAY VETERANS APARTMENTS (LARGE SCALE)

Source: Mithun

Project Location: Treasure Island, San Francisco, CA

Completion Year: 2022

Project Size: 104,500 SF

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

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

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

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

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

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

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

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

Trade-offs and Challenges:

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

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

Lessons Learned:

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

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

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

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

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

ACTIVE SYSTEMS

- All electric building with 123kW solar PV and battery storage
- Air Source Heat Pump water heating, dryers and mechanical systems
- Battery backup power for islanding
- Heat-Recovery Ventilators with MERV 13 air filtration in residential units
- Electric vehicle charging

PASSIVE SYSTEMS

- Enhanced building insulation and ventilation
- Building oriented to capture bay breezes
- High performance glazing
- Recessed windows and shading to mitigate solar heat gain
- Site elevated for Sea Level Rise by 42"

COMMUNITY ROOM RESILIENCE HUB:

- Backup power during blackouts
- Refrigeration for essential medications
- Free wi-fi (server on backup power)
- Large Ceiling Fans for Cooling

HEALTH & SOCIAL RESILIENCE

- Community spaces to build social cohesion
- Bicycle storage + repair station
- Healing forest grove and landscaped gathering areas
- On-site resident health services
- Garden Way: active transit street
- Future adjacent neighborhood park
- Active design stair

Source: Mithun

3.6.3_WAIKIKI SKYTOWER (RETROFIT)

Source: Redwood Energy

Project Location: Honolulu, Oahu, HI

Completion Year: 2015

Project Size: Not available

What: Waikiki Skytower is an example of the many all-electric high-rises on the island of Oahu, including both multifamily and hotel projects. The luxury condos at the Skytower were originally built in 1978. The building has 102 units over 30 floors; each of the approximately 694 square foot, one-bedroom, one-bath units are all corner units.[84 85]

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

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

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

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

3.6.4_THE BATTERY — PHASE III OF CAPITAL FLATS

Source: Onion Flats Architecture

Project Location: Philadelphia, PA

Completion Year: 2017

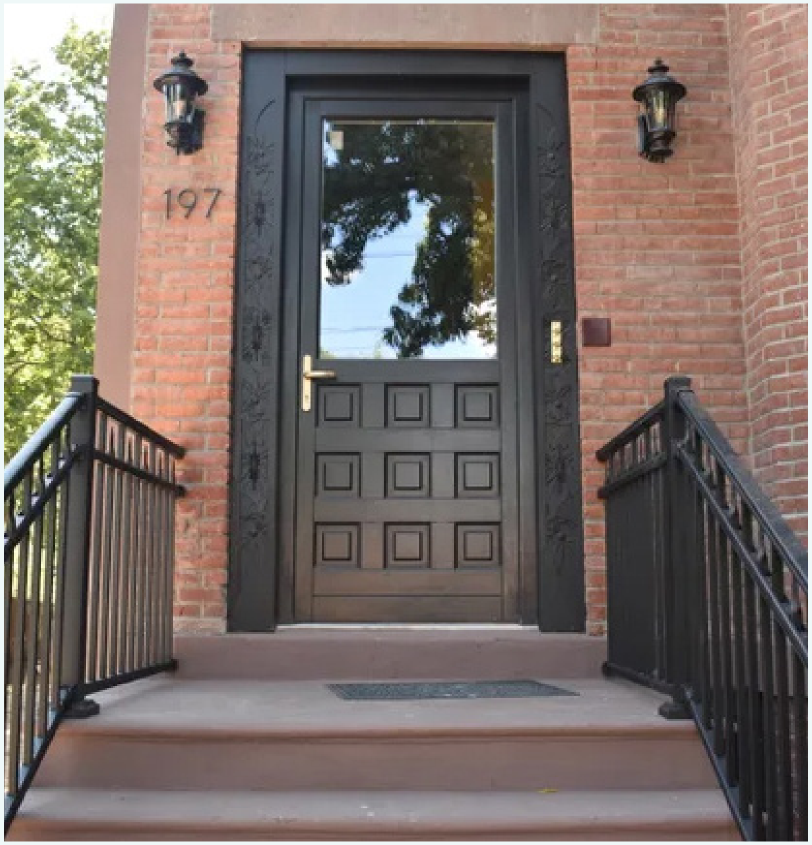
Project Size: 16,782 SF

What: The Battery provides sustainable and market rate housing for residents of Northern Liberties, a community in Philadelphia, PA. The project offers twenty-five 500 sq. ft. "micro" units in an all-electric, zero-net-energy building. Intended for young professionals in need of affordable housing in a rapidly gentrifying neighborhood, the rents start at $1,200 per month and include all utilities. To achieve this affordability and density, the project maximized zoning allowances using a density bonus incentive for green rooftops and deployed water-source heat pumps using two 1,000 foot deep geo-thermal bores to provide heating, cooling and hot water to all apartments. The envelope is prefabricated and super insulated with triple pane windows, and air-tight construction. With a 72 kW photovoltaic canopy on the roof, the project is Passive House certified, and was designed to consume 80% less energy than a similar minimally-code-compliant building.[86]

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

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

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



Source: Lana Bellamy, Times Herald-Record

Project Location: Newburgh, NY

Completion Year: 2020

Project Size: Not Available

What: This New York State Energy Research and Development Authority (NYSERDA) Buildings of Excellence project aimed to alleviate utility cost pressure for low- to moderate-income residents. The all-in rental model keeps tenants' monthly expenses affordable and predictable, while reducing appliance plug load, enabling the building owners to benefit from reduced energy consumption. The gut rehab put a condemned building onto the performance path to achieving Passive House PHIUS+ 2018 and PHIUS Source Zero standards.
The passive design uses the building's orientation to reduce electric load by capturing solar energy to retain heat in the winter while exterior shading blocks the sun in the summer. The HVAC system was converted to all-electric by installing high-efficiency heat pumps, each of which is tied into a central energy recovery ventilation unit to minimize energy losses. Great attention was paid to the building envelope to minimize air leakage — the envelope meets an airtightness of 0.06 cubic feet per minute (CFM50), which can reduce heating demand by 75%. The onsite 9 kW solar photovoltaic array on the roof satisfies much of the building load, while the balance of load is met by an off-site solar PV system. LED lighting, high-efficiency windows, and ENERGY STAR rated appliances collectively serve to reduce the balance of the energy load.[87 88 89 90]

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

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

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

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

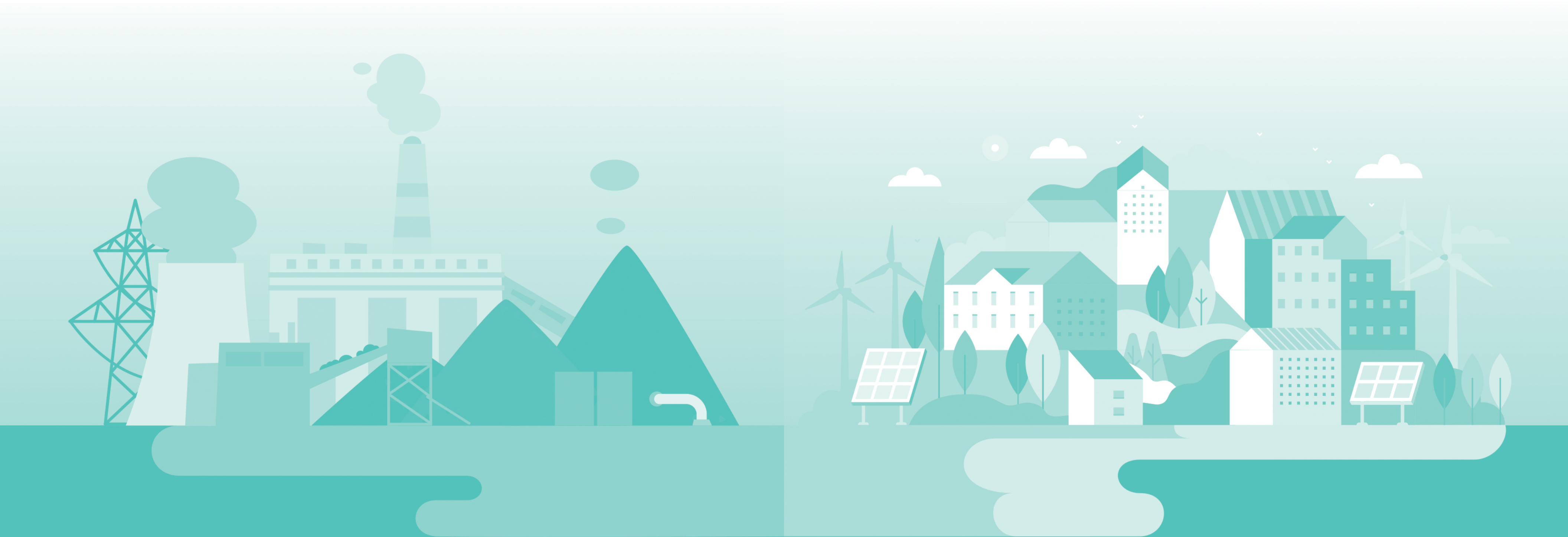
HVAC and DWH	Air source heat pumps for HVAC and domestic hot water
Building Envelope	Passive House PHIUS+ 2018, PHIUS Source Zero standards
Electric Load Offset	9 kW PV Rooftop Canopy and offsite PV
Architect/Design Team Lead	The Figure Ground Studio (AOR); Northeast Projects LLC (design team lead)
Developer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

Trade-offs and Challenges:

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

Lessons Learned:

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



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At Microsoft, we believe sustainability is critical for meeting the economic, societal, and environmental needs of today and of future generations. We also believe sustainability is good for business.

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The Building Decarbonization Coalition unites building industry stakeholders with energy providers, environmental organizations and local governments to help electrify California's homes and work spaces with clean energy. Through research, policy development, and consumer inspiration, the BDC is pursuing fast, fair action to accelerate the development of zero-emission homes and buildings that will help California cut one of its largest sources of climate pollution, while creating safe, healthy and affordable communities. The Project Team gives special thanks to the BDC for its leadership in this endeavor and for the generous support of its Membership.

Contributors

Building Decarbonization Practice Guide Content Leadership

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

Project Manager

- **Brett Rosenberg**, LEED AP, Treeline Strategy, LLC

WJWF Intern

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

Graphic Design

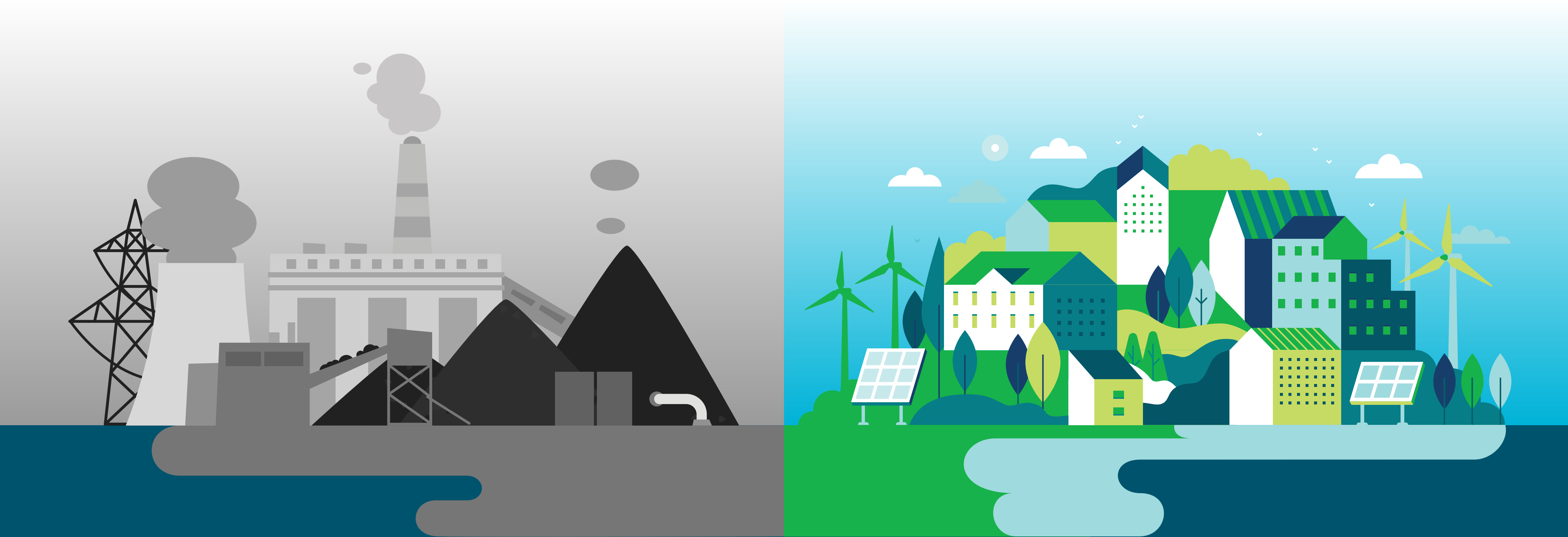
- **Stoller Design Group**

Copy Editor

- **Geoff Martin,** Wheelhouse Writing Services

Working Group Members and Content Contributors

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



THE BUILDING DECARBONIZATION PRACTICE GUIDE

A Zero Carbon Future for the Built Environment

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VOLUME 4:

Commercial + Institutional Buildings

VOLUME 4 CONTENT LEADERSHIP

- » Susan Freed
- » Glenn Friedman
- » Miranda Gardiner
- » Steve Guttmann
- » Ryan Hamilton
- » Teresa Jan
- » Katie Ross
- » Pauline Souza
- » Breanna Wheeler

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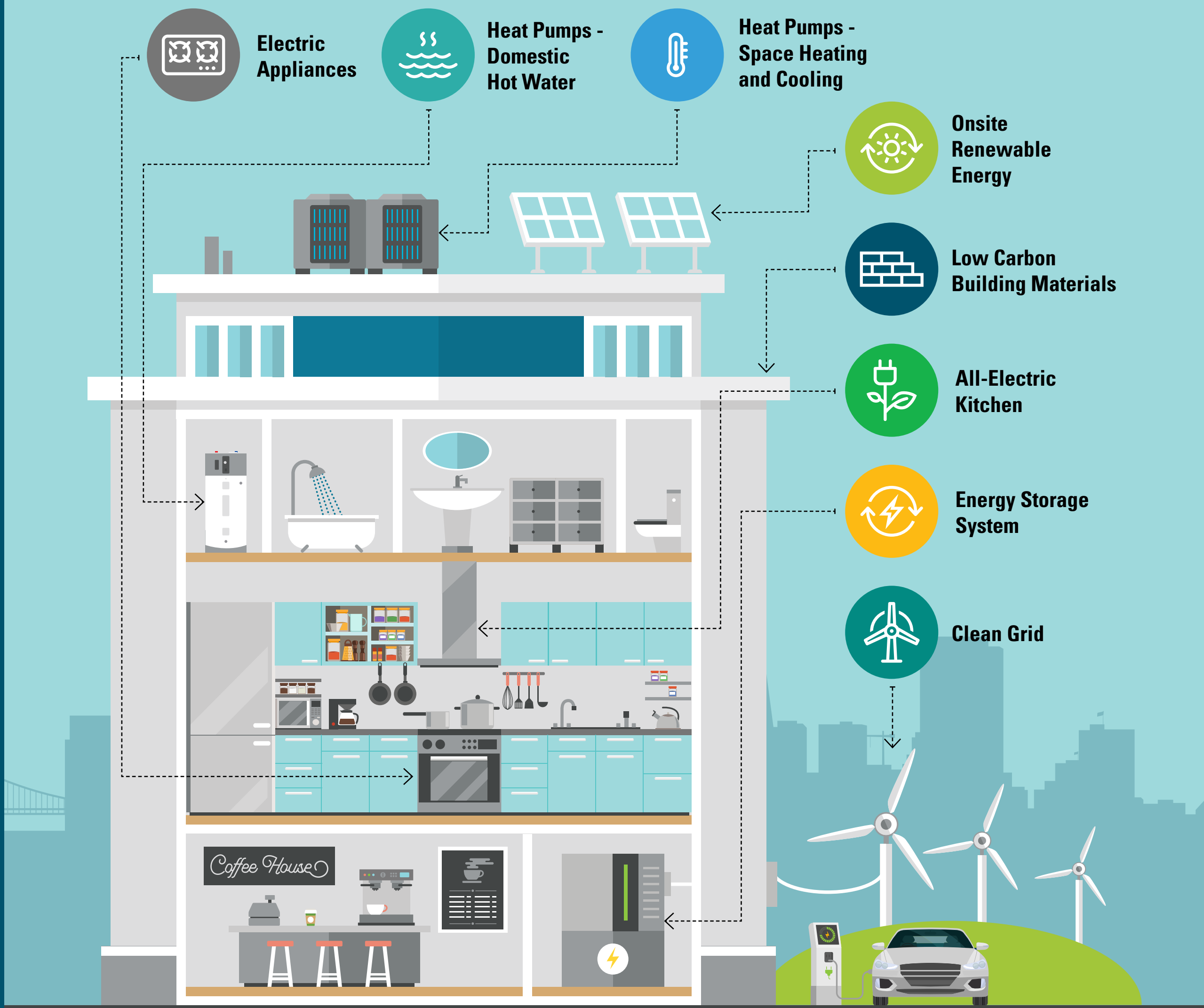

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VOLUME 4

Commercial + Institutional Buildings

4.1_Introduction

The building construction industry changes slowly. Unlike the high-tech world, which is most profitable when nimble and innovative, construction profitability flows from a perfected implementation process. The industry responds by repeating proven, code-compliant strategies and delivery methods. However, the teams behind high performance buildings approach their projects with sustainability in mind and employ strategies that strive to be more energy efficient than "code-minimum." This often involves new technologies and innovative delivery practices. Since the for-profit nature of much of the commercial building construction industry creates disincentives for innovation, high performance buildings have tended to rely on an attractive financial return on investment from reduced operational cost.

In the not-for-profit sector, the perception of limited financial resources creates a competition where the program is often prioritized over performance. This perception, however, ignores the fact that not-for-profits tend to occupy and operate their facilities for the life of the building. Life-cycle cost should thus be a priority, but this is all too often deprioritized due to siloed funding mechanisms.

These emphases on first cost can be even more detrimental to achieving decarbonization goals, as there are currently limited financial incentives — except in rare instances where a price on carbon is enforced[1] — for stakeholders to focus on delivering deep carbon emissions reductions. Therefore, until a national regulatory framework is in place, zero-carbon construction will tend to be localized in places where governments adopt their own climate commitments, such as in Ithaca, New York,[2] or where corporate goals are advanced through carbon neutrality.

Zero-carbon commercial buildings should be created with whole building energy and carbon efficiency in mind. Although discrete actions can reduce carbon emissions (e.g., an LED lighting retrofit, the addition of sensor controlled outlets, or the use of a low-embodied-carbon structural system), a whole building approach to energy and carbon reduction — and the modeling processes to support it — will optimize those reductions. These approaches can either yield maximum carbon emissions reductions or help minimize the investment per pound of carbon emissions avoided. New strategies for modeling a project's decarbonization efforts are discussed in more detail in Volume 2.

Decarbonizing a project involves the use of approaches that draw from a toolbox of technologies and strategies that are not part of conventional design and construction practices. As such, it is good practice to select team members based on their decarbonization expertise (see more discussion of this in Volume 2). Also, these approaches and processes can be delivered most effectively if the design and construction teams are integrated, with the architect, consultants, and contractors working together with the owner starting in early design.

An integrated team of professionals, with expertise in decarbonized technologies and strategies, can ensure that construction costs, product availability, and cost effective methods and practices all inform design decisions. In addition, more highly optimized decision-making in early design can help avoid changes in late design or during construction, which tend to have greater cost and schedule impacts. An integrated team also provides an opportunity for the team members responsible for construction to buy into the proposed solutions, reducing the risk of changes during bidding and/or construction due to contractors' lack of familiarity with the technologies used.

These changes in approaches for achieving maximum decarbonization suggest that commercial building projects will benefit from thinking differently about every facet of project delivery, from conception through construction and beyond.

1 https://openknowledge.worldbank.org/bitstream/handle/10986/35620/9781464817281.pdf

2 https://www.cityofithaca.org/642/Green-New-Deal

4.2_General Considerations for Decarbonization of Commercial Buildings

Commercial buildings encompass a broad and diverse set of project types; nonetheless, the approaches that design teams take to reach decarbonization and electrification goals often follow a similar path. The most common elements, regardless of project type, scale, or end use are covered in Volume 2.

While discussed in detail in Volume 2, section 2.2, incorporating community engagement strategies and social equity considerations into commercial projects (both to improve communities and to educate the public about climate change and the positive impacts provided by all-electric buildings) contribute value to a project that cannot be overstated. Community engagement, when done with honesty and integrity, can enhance community livability and deliver significant improvements in the net quality of life for everyone impacted by a project. Positive impacts on projects and communities that result from these efforts often include:

- Maintaining or developing local connectivity and appreciation for place and nature, as well as local social connectivity and cohesion;
- Locating, designing, and constructing a project in a way that eases traffic congestion, improves mobility and access, and does not promote urban sprawl;
- Facilitating social + economic interconnectivity and cohesion through active civic engagement;
- Facilitating social + economic interconnectivity and cohesion through the built environment by improving existing and/or developing new public spaces, including parks, plazas, and recreational facilities.
- Reinvigorating communities through rehabilitation of important community assets, upgraded and extended access, increased safety, improved environmental quality, and additional infrastructure capacity;
- Elevating community awareness and pride.

Owners and developers can also benefit from community engagement in the following ways:

- Projects that have broad community endorsement can proceed more quickly;
  - When project teams make holistic assessments of community needs, goals, and plans, and incorporate meaningful stakeholder input, barriers to implementation can be identified and addressed.
- Making a net positive contribution to the quality of life of the host and the nearby affected communities can enhance the reputation of the owner/developer;
- Projects can be assured to meet or exceed important identified community needs and long-term requirements for sustainability;
- Adverse impacts can be minimized and can hopefully become accepted as reasonable trade-offs for benefits achieved.

General opportunities to reduce carbon in commercial buildings, from pre-design through end-of-life, include:

- Reducing the embodied carbon in construction materials (see Volume 6);
- Designing for maximum energy efficiency;
- Incorporating Building Performance Modeling early and often throughout the design process (see Volume 2);
- Designing an all-electric building, and maximizing energy recovery within and between building systems;
- Addressing emissions related to the carbon "signature" of the local utility grid through onsite and offsite renewable energy systems;

> "The tagline that I use for my firm is '*working in collaboration with communities to leverage design projects that deliver deep and sustained social benefit.*' The key component of social impact design is that you are working *with* communities as opposed to perhaps some earlier models which focus on doing work for the community. That earlier model tends to be more charity-driven and assumes that experts know better. But social impact design is saying that the community needs to be a stakeholder and a co-owner of whatever it is that is being developed. The idea is to challenge different ways of engagement and models of inclusion by asking: *'what is the actual social benefit beyond what is being created?'* That [extended benefit] is also part of the design project. The idea is also to articulate that the benefit of the project will be some kind of social impact beyond, say, a house or a building."
>
> **— Liz Ogbu, Studio O[3]**

» Incorporating grid-responsive design and control strategies, for example by shifting energy use — via energy storage and/or strategies that shift peak demand — to times when marginal emission rates on the grid are low (see Volume 2, section 2.6.5);

» Proactively managing energy during the operations phase of a project, including ongoing energy use monitoring and monitoring-based commissioning (see Volume 2, section 2.8.1);

» Periodic re-commissioning (see Volume 2, section 2.8.2);

» End-of-life reuse via deconstruction rather than demolition (see Volume 2, section 2.8.3).

4.2.1_WHAT IS UNIQUE TO COMMERCIAL BUILDING PROJECTS?

The distinguishing characteristics germane to the electrification/ decarbonization process in commercial building projects include:

» Private sector financing: timing and cost of delivery tend to be key considerations (a dollar today is worth more than a dollar tomorrow);

» Buildings are often developed and operated as a financial asset, especially if a managed/leased property, and with return on investment in mind;

» Varying tenants' programmatic and functional needs, especially in terms of energy use intensity;

» Multiple tenants and uses, with a range of infrastructure needs and priorities, on a single site;

» Misaligned incentives often arising from the methods used to allocate owner and tenant energy cost responsibilities;

» Diurnal use patterns (when not a facility housing a continuous, 24/7 operation).

3 https://architectureau.com/articles/liz-ogbu-social-impact-design/

» Potential inclusion of large, energy-intensive infrastructure, such as commercial kitchens (see Volume 5) and data services;

» A large variety in the scale of commercial buildings. The diversity of building size, massing, and orientation requires a wide range of technical and non-technical solutions;

» All manner of ownership and development structures, which creates significant variation in owner or client knowledge, familiarity, and comfort with decarbonization topics and goals.

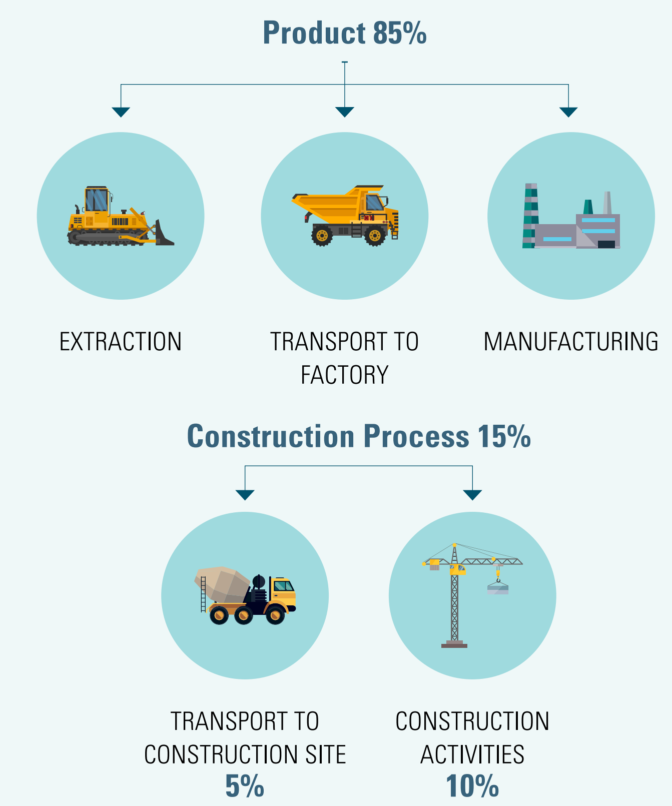
4.2.2_THE PLANNING AND DESIGN PHASES

Building the smallest, most resource-efficient building while still meeting the owner's programmatic and functional needs will minimize embodied and operational carbon. Regardless of whether your project is new construction or adaptive reuse (alternatives to new construction are addressed in Volume 2, section 2.1), the following issues should be considered during the planning and design phases:

Materials selection: Appropriate material selection can reduce embodied carbon and is the best opportunity for reducing greenhouse gas emissions related to pre-occupancy activities. Figure 4.1 shows the proportion of pre-occupancy carbon emissions for each portion of the “Product” stage and “Construction Process” stage. For more detail on the assessment of embodied carbon at various building life cycle stages, and materials selection as it relates to embodied carbon reduction, see Volume 6.

Electrification of HVAC and plumbing systems and systems’ choice: Systems that employ heat recovery, energy storage (thermal and/or electric energy), photovoltaics, and grid harmonization generally produce more cost effective designs and limit the impact of an electrified building on public infrastructure. See Volume 2 for more detailed discussion of these considerations.

FIGURE 4.1: PRE-OCCUPANCY CARBON TOTAL EMISSIONS



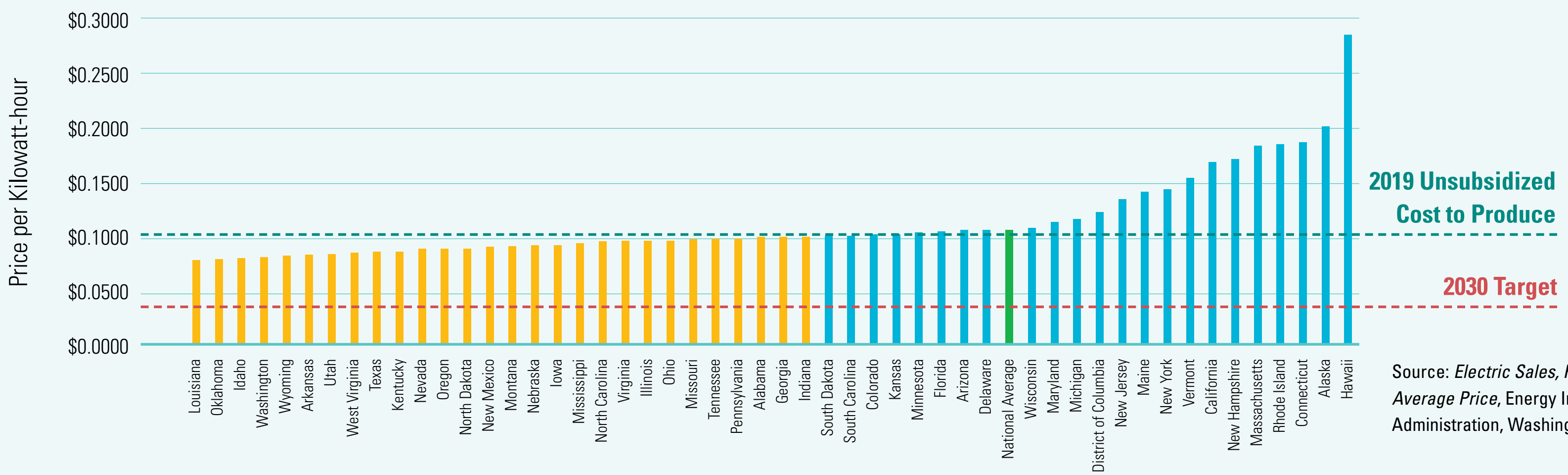
Design for deep energy efficiency: Reducing energy use has a number of project benefits, and deep reductions can sometimes be achieved at lower first cost than conventional design. Energy efficient design can reduce utility infrastructure costs while also reducing the size (and hence cost) of onsite PV and other renewable energy systems. Investment in highly efficient lighting technologies can have extremely attractive life cycle cost benefits. Heat pump technologies for space heating and domestic hot water can be highly energy efficient and are discussed in detail in Volume 2, section 2.6.2. Recovering energy from exhaust air and refrigeration cycles can also be highly effective at reducing the use of utility-supplied energy.

Grid responsive design: Shifting loads to the time of day when the grid has the lowest carbon profile through deliberate load scheduling and the use of onsite energy storage systems (thermal storage, battery energy storage, etc.) can reduce carbon emissions. See further discussion in Volume 2, section 2.6.5.

Plug load management: Plug load management can help normalize an otherwise unpredictable end use. Many Codes require plug load management devices: requirements are included in the 2021 International Energy Conservation Code, the California Energy Code since 2013, the Washington State Energy Code since 2015, and ASHRAE 90.1 since 2010.

Onsite renewables: Investment in self-generation reduces a building's reliance on carbon-emitting grid energy. Energy Storage Systems (e.g., batteries) can also contribute to reductions in grid dependence. When used in conjunction (i.e., a microgrid system), these strategies combine carbon reduction and resiliency benefits. For further discussion on renewable energy systems and resiliency, see Volume 2, sections 2.6.6 and 2.6.7. Electricity from onsite solar photovoltaic systems is already the cheapest form of electricity available in 23 states (see Figure 4.2). Sometime before 2030, it will be the cheapest form of electricity available anywhere in the U.S.

FIGURE 4.2: ANNUAL AVERAGE PRICE PER KILOWATT-HOUR FOR ALL SECTORS BY STATE (2019)



Source: *Electric Sales, Revenue and Average Price*, Energy Information Administration, Washington DC

Commissioning in design and construction: Third party commissioning of the design and installation of energy-using systems reduces the likelihood that choices or mistakes made during design or construction would compromise energy efficiency and carbon reduction strategies. See Volume 2, section 2.3.3 for further discussion.

Operations: Facility Operations staff who have been trained on, and perhaps spent their careers managing, building systems that rely on fossil fuels may be resistant to new all-electric technologies. Therefore, engage staff early in the design process to increase their knowledge of, and comfort with, the operation of fossil-fuel free technologies. Waiting until the end of construction to engage operations personnel is a disservice to owner and operator alike.

4.2.3_CONSIDERATIONS BY OCCUPANCY TYPE

There are compelling reasons to electrify every commercial building type, and the characteristics unique to each building type support specific decarbonization strategies.

4.2.3.1_Office Buildings

» **Multiple tenants and uses on a single site:**

- Central systems can maximize the benefits of heat recovery and thermal storage. These approaches are even more beneficial when tenants' schedules as well as programmatic and functional needs vary in terms of energy use intensity.

» **Diurnal use patterns:**

- Historically, time-of-use energy rates made the generation of thermal energy at night for use during the day a reliable way to reduce energy cost.
- However, in areas with large amounts of renewable energy on the grid during daylight hours, increasing daytime energy use (often to generate thermal energy that can be stored and used later) can be a grid-responsible approach that reduces carbon emissions related to grid-energy use.
- Ensuring that nighttime loads are reduced to the absolute minimum can be very effective at reducing energy costs and carbon emissions related to grid-energy use since nighttime marginal emission rates tend to be high (especially in areas with a lot of renewable energy on the grid).

» **Ubiquitous use of reheat systems:**

- The use of cooling-only, variable air volume systems with zone reheat ("VAV Reheat") is very common in commercial office buildings. There are a number of control strategies to significantly reduce reheat energy use in these types of systems. For example, "dual maximum" control logic (introduced into California Codes in 2008 and ASHRAE 90.1 in 2010) can be easily introduced into existing and new buildings that use direct digital control (DDC) systems.[4]
- Eliminating reheat is entirely possible, but it requires a departure from the use of conventional VAV Reheat systems and transference of cooling and heating capabilities to the zone level. These systems accommodate the types of spaces and buildings where simultaneous cooling and heating needs exist without the use of reheat. Refer to Volume 2, section 2.6.3 for more discussion of these systems.

4 https://tayloreng.egnyte.com/dl/soFjuQ62Ts/ASHRAE_Journal_-_Dual_Maximum_VAV_Box_Control_Logic.pdf_

» **Large amounts of exhaust air:**

- Buildings that require large amounts of outdoor air (e.g., for ventilation requirements due to high occupancies, or for providing make-up air for product-conveying exhaust systems such as in kitchens and light manufacturing facilities) are good candidates for exhaust air energy recovery.

- In these types of facilities, heat recovery from the exhaust air stream can be an effective cold climate strategy. This is discussed further in Volume 4, section 4.2.5.

» **Tendency towards centralized thermal energy systems, especially for larger buildings:**

- Larger office buildings tend to use central thermal energy systems. These present a number of decarbonization opportunities. Most of these strategies are covered in more detail in Volume 2 or herein.

    › Thermal storage,
    › Heat recovery,
    › Heat pump central plants,
    › Advanced control strategies (e.g., ASHRAE Guideline 36).

» **24/7 operations:**

- From a decarbonization perspective, nighttime energy use is what distinguishes these facilities from other commercial buildings. Carbon neutrality will require avoiding grid energy use at night, at least until the marginal emissions profile of energy generated during the night changes significantly. Since solar electricity generation is the fastest growing renewable energy source, interest in the storage of solar energy generated during the day for use at night is accelerating. Combining onsite solar energy production with energy storage and all-electric building operations technologies is currently the fastest available path to carbon neutrality; this is also achievable with other onsite renewable energy generation strategies or even 100% renewable energy purchasing. Combining energy generation and storage technologies into building systems is commonly referred to as a "microgrid": these are discussed in more detail in Volume 2, section 2.6.7.1. Storage technologies that are currently available are discussed in Volume 2, section 2.6.5.1.

4.2.3.2_Retail

» **High lighting loads:**

- Current technology allows for significant reductions in retail lighting energy use, and the related cooling loads. There is no longer any reason to design retail lighting systems around non-LED sources. All of the available light source performance needs can be satisfied with LED light fixtures. Lighting retrofits in existing retail facilities generally provide financially attractive returns on investment: if capital is a barrier to retrofit, this can usually be easily addressed through third-party energy services companies or utility incentive programs.

» **Tolerance for larger variations in comfort conditions:**

- Where a retail environment can accommodate wider variations in comfort conditions, this can be an effective strategy to reduce the demand on air conditioning and heating systems. Using smart controls to change indoor setpoints can both reduce grid energy demand and consumption, and these adjustments can be targeted to avoid energy with high marginal emissions rates.

» **Large, open plan design:**

- Low energy air distribution systems are common in large, open box retail. However, conventional strategies do not deliver the performance equal to the best available technologies: displacement ventilation, underfloor air delivery, and fabric air dispersion systems can provide superior comfort and reduced energy use. While these technologies often come at a higher first cost than conventional approaches, they may be justified on a life cycle cost basis and can be a meaningful contribution towards meeting carbon neutrality goals in an affordable manner.

4.2.3.3_Institutional and Governmental

Institutional and governmental clients have competing characteristics. While they are often mandated to achieve some level of "sustainable" building performance, they can also be organized in ways that make deep sustainability difficult to achieve. Governmental clients tend to have stakeholders that are siloed, making it difficult to trade off first cost increases against operational and maintenance cost savings.

Nevertheless, there are a wide variety of facility types developed by this ownership category, with varied needs as well as unique opportunities for enabling electrification.

4.2.3.3.1_EDUCATIONAL FACILITY CHARACTERISTICS

» **Large amount of outdoor air due to densely occupied spaces:**

- This characteristic means that there are ample opportunities for air-to-air heat recovery. Newer strategies often incorporate dedicated outdoor air systems (DOAS) with unitary heat pumps on a per classroom basis. Where central systems are used, ventilation air can be decoupled from space heating and cooling using a DOAS. Also, demand control ventilation based on CO_2 can be used with a DOAS to reduce ventilation rates.

» **Space occupancy schedules may be inconsistent and/or intermittent:**

- Provide zone level unoccupied setback control to allow unoccupied classrooms to be shut off. This feature needs to be provided in accordance with applicable ventilation Codes and Standards. This can be done in both central and non-central system designs.

- Radiant heating and cooling systems are inherently efficient where internal loads vary significantly and are a large percentage of a zone load. Low-mass radiant systems (e.g., radiant ceiling panel systems) should be used in classrooms — rather than high-mass systems (e.g., radiant floors) — because they have faster reaction times to rapid changes in indoor loads.

» **Noise sensitive spaces:**

- Low energy air distribution systems can eliminate air distribution noise. Both displacement and Underfloor Air Delivery (UFAD) systems tend to have lower air velocities in ducts and at diffusers, which are typical sources of noise from air distribution systems.

» **May have high volume kitchens:**

- Kitchens are very high energy use occupancies. See Section 4.2.3.5 for a discussion of Commercial Kitchens.

4.2.3.3.2_HEALTHCARE FACILITY CHARACTERISTICS

Hospitals are a core example of 24/7 facilities where decarbonization requires a significant departure from business as usual. When combined with the regulatory framework of healthcare construction and an inherent resistance to change in this sector, these factors create barriers to the adoption of systems that promote operational decarbonization. Nevertheless, many of the same strategies discussed above are applicable to hospitals:

» Use of systems that eliminate reheat,
» Heat pump central plants,
» Heat recovery central plants and other heat recovery systems,
» Thermal storage,
» “Smart” control systems.

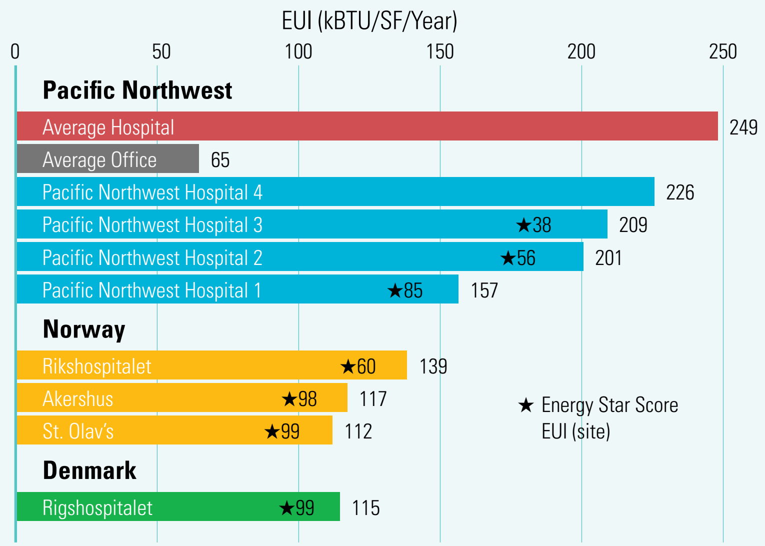
Other characteristics of healthcare facilities include:

» **The highest energy use intensity of any building type other than food service:**[5]

- Along with historically high energy use comes great opportunities for energy use reduction.

5 Based on facilities tracked in the US Energy Administration Information's CBECS database.

FIGURE 4.3: SELECTED HOSPITAL ENERGY USE



Note: Selected site energy use for Pacific Northwest and Scandinavian hospitals. This graph shows site EUI and Energy Star ratings.

Source: Burpee, H., McDade, E., "Comparative Analysis of Hospital Energy Use: Pacific Northwest and Scandinavia," Health Environments Research & Design Journal (HERD), 8(1), 20-44. Fall 2014.

FIGURE 4.4: SWEDISH MEDICAL CENTER IN ISSAQUAH, WASHINGTON

Source: Benjamin Benschneider

- Fig. 4.3, excerpted from a study of hospitals in the Pacific Northwest, contrasts US norms with Scandinavian countries that have a similar climate to the PNW and yet show significantly less energy use intensity. While the average EUI for existing U.S. hospitals nationally is currently around 236 kBTU per square foot per year, it is possible for a new hospital to achieve closer to 100 kBTU per square foot per year.[6] The 2010 publication from the University of Washington's Integrated Design lab — "Targeting 100!"[7] — laid out a roadmap for achieving this goal, and examples of such facilities can be found around the world, including Swedish Issaquah in Washington (Fig. 4.4), Gunderson Health in Wisconsin, Rigshopitalet in Denmark, and St. Olav's in Norway.

6 EUI for existing acute care hospitals taken from the 2012 Commercial Building Energy Consumption Survey.

7 http://t100.be.uw.edu/

» **Healthcare buildings have a lot of simultaneous heating and cooling needs:**

- Any system that can remove energy from a space that requires cooling and transfer that energy to a space that requires heating will be an effective strategy in a healthcare facility.
- Decoupling ventilation systems from space conditioning systems allows each zone to respond to its individual cooling and heating needs. This approach maximizes the benefits of heat pump systems (removing excess heat where needed and moving it to areas where additional heat is needed). It also avoids the energy waste from reheating previously cooled air as a strategy to deal with simultaneous needs for heating and cooling.
- Unchecked solar loads can drive excessive cooling loads in exterior spaces. Reducing direct solar loads reduces peak cooling demand on systems. And, reducing peak cooling demand can reduce costs and increase overall system efficiency.

» **"Smart" control systems can help optimize operations:**

- Control strategies for office buildings that reduce reheat energy use (e.g., ASHRAE Guideline 36) are generally not applicable in hospitals and other licensed healthcare facilities. Nevertheless, many of the current approaches with advanced control systems can improve performance and reduce GHG emissions.
  These include:
  - Controls that are focused on minimizing carbon emissions related to grid-supplied energy use (see also section 4.2.5).
  - Controls that are designed to deliver more reliable performance, and be self-correcting (see also Volume 2, section 2.8.1).

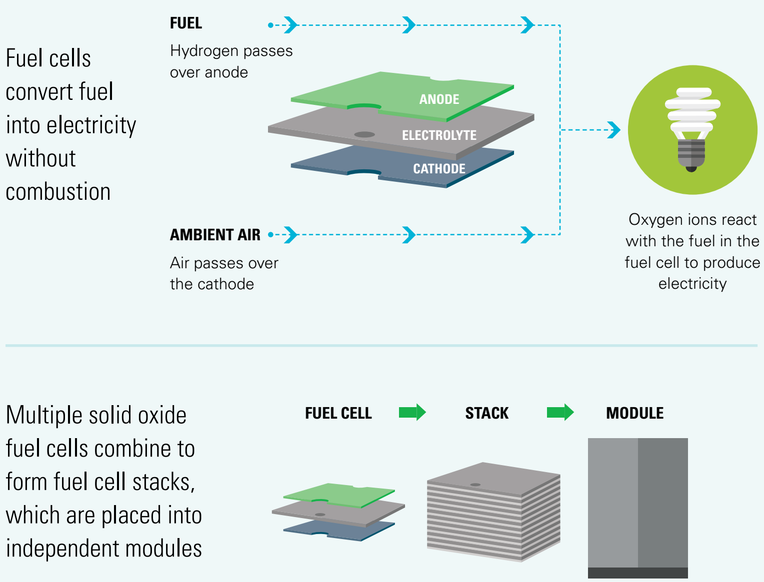
» **High ventilation and air change rates required by Code:**

- These factors generally make air-to-air heat recovery an effective strategy.
- Where peak space loads exceed minimum air change rate requirements, decoupling ventilation systems from space conditioning systems is one of the most important strategies to reduce energy use in healthcare facilities. While not as effective, variable air volume (VAV) systems can be a good first step in reducing the overall energy use.
- There is increasing focus on moving programs that are not required to be located in an "acute care facility" into facilities designed to a lower acuity level. Many of these types of facilities are essentially office buildings, so they can be designed to standards that do not require high air change rates and thus are inherently less energy intensive.

» **Need for reliable back-up power systems:**

- The requirement for emergency power systems comes from an extreme sensitivity to utility service disruptions.
- With the growing recognition that NFPA 110 (Standard for Emergency and Standby Power Systems), NFPA 99 (Health Care Facilities Code), and NFPA 70 (National Electrical Code) all allow continuously operating fuel cells to serve as an emergency power source, all stakeholders are being forced to reevaluate the opportunities and regulations for the ways that reliable power is provided to critical facilities like hospitals.
- Fuel cells powered by green hydrogen offer another carbon-neutral source of electricity (see Figure 4.5).
- Microgrids (onsite energy generation and energy storage combined with grid supplied utilities) are becoming a common consideration for hospitals and other facilities that cannot tolerate utility service disruptions.

FIGURE 4.5: TYPICAL FUEL CELL — POWERED BY GREEN HYDROGEN, FUEL CELLS CAN GENERATE ELECTRICITY WITHOUT CARBON EMISSIONS



Source: Bloom Energy

» **High nighttime energy use:**

- As with the other 24/7 facilities discussed above, carbon neutrality requires avoiding as much grid energy use at night as possible, until grid-supplied power is decarbonized or, where available, 100% renewable energy is purchased for a facility.
- Microgrids can be an effective way to address this issue.
- Another method is to simply turn down or turn off systems, areas, or even rooms that can accommodate lower ventilation rates or wider thermal limits during unoccupied periods. Many Codes specifically address how and when this can be done.

» **Large domestic hot water requirements:**

- The need for large quantities of service hot water can pose challenges for heat pump water heater systems, which require significantly more equipment and space than conventional gas-fired water heaters. Large electric resistance water heaters may actually be a more cost and space efficient solution for hospitals, but this adds significant electrical load to the building, infrastructure and emergency generators.

» **Code-driven facility designs:**

- There is often push-back on hospital projects when systems that do not have a long track record of use are proposed. Moving to all-electric designs for hospitals is driven in large part by the public health benefits of decarbonization, the risk management and future-proofing aspects of carbon emissions reduction, and eliminating natural gas use. These factors are discussed in more detail in Volume 2.

» **Steam use:**

- Steam can be eliminated for most uses in a hospital. The only uses that have few alternatives are humidification and sterilization.
- Humidification can be provided by systems that do not use natural gas. Alternatives include electrode humidifiers, as well as compressed air, ultrasonic and high pressure fog systems.
- Sterilizers can also be provided with integral electric steam generation. To the extent that this option limits chamber size, this may have an impact on the number of sterilizers used and the area required to house them. Designing all-electric Central Sterile Departments for hospitals is an area ripe for innovation.

4.2.3.3.3_DETENTION FACILITY CHARACTERISTICS

Considerations for these types of facilities include many of the same things that are applicable in other types of facilities with similar features:

» 24/7 operations,
» Large domestic hot water requirements,
» Often includes laundry and kitchen loads,
» High ventilation rates,
» Sensitive to utility service disruptions.

4.2.3.4_Laboratories / Life Sciences

» **Many lab spaces have specialized environmental needs:**

- Stringent environmental requirements can be met using all-electric designs.

» **May require large amounts of outdoor air to maintain suitable indoor air quality and to provide make-up air for 100% exhaust systems:**

- Exhaust air energy recovery is an attractive option for this type of facility.

» **High plug and process loads:**

- The actual amount of these loads in lab facilities is often overestimated.[8]

» **Lab buildings have simultaneous heating and cooling needs:**

- Energy use in labs can be significantly decreased by eliminating reheat. To accomplish this, many of the strategies discussed in Volume 2 are applicable to labs.

4.2.3.5_Commercial Kitchens

The unique characteristics and decarbonization opportunities for this type of facility are discussed in great detail in Volume 5, "All-Electric Kitchens — Residential + Commercial", section 5.4. HVAC systems serving commercial kitchens should consider the following characteristics:

» **High exhaust and makeup air requirements:**

- Exhaust air energy recovery is an attractive option for this type of facility.

» **High energy use:**

- Food service is the most energy intensive building type that is listed in the EIA's Commercial Building Energy Consumption Survey.[9] While design of energy efficient commercial kitchens is the subject of Volume 5 of this Practice Guide, many of the energy efficiency strategies discussed in Volume 2 can be utilized for this occupancy type.

» **Large domestic hot water requirements:**

- The need for large quantities of service hot water can pose challenges for heat pump water heater systems, requiring significantly more equipment and space than conventional gas-fired water heaters. Large electric resistance water heaters may be a cost- and space-efficient solution, but this adds a significant electrical load to the building infrastructure.

» **Commercial kitchens have simultaneous hot water needs and refrigeration loads:**

- This provides opportunities for energy recovery to create domestic hot water from refrigeration systems' reject heat.

8 https://sustainable.stanford.edu/sites/default/files/resource-attachments/Plug%20Load%20White%20Paper%20FINAL.pdf

9 https://www.eia.gov/consumption/commercial/data/2012/

4.2.4_THERMAL ENERGY STORAGE

Thermal energy storage (TES) can be thought of like a battery, "charging" the storage container when energy would otherwise be wasted or when excess "clean" energy is available. It can also be used to shift loads to times when clean energy sources are more available ("Load Shifting and Thermal Storage" is discussed in more detail in Volume 2, section 2.6.5.3).

FIGURE 4.6: THERMAL ENERGY STORAGE AT THE UNIVERSITY OF ARIZONA CAMPUS, WITH 23,400 TON-HOURS OF CAPACITY, SERVING 216 BUILDINGS ON A 378 ACRE CAMPUS. INSTALLED IN 2004.

Source: Calmac

Thermal storage can be accomplished in a variety of manners:

1. Storing hot water from processes that would otherwise waste this energy source, such as condenser water from a chiller or other water-cooled refrigeration system;
2. Storing cold water from processes that would otherwise waste this energy source, such as chilled water from a water-cooled heat pump in heating mode. Also, a chiller can produce more chilled water than is needed when powered from a 100% renewable energy source, with excess chilled water stored for later use;
3. Similar to storing chilled water, a chiller can be operated to produce ice. This can generally be stored longer and with a much smaller footprint than chilled water (Fig. 4.6);
4. Heat in a condenser water system, produced by a chiller when cooling, is typically rejected to the atmosphere through a cooling tower. Alternately, this warm water can be collected, stored, and subsequently used by a heat recovery chiller or heat pump to provide hot water for space heating. This approach has been referred to as a "Time Independent Energy Recovery" or TIER Plant concept.[10] This is primarily applicable to large buildings where chiller-based systems are more cost-effective;
5. Thermal mass can also be used to store thermal energy although the timing of the release of this stored energy is generally less controllable. Some thermal mass approaches have similar properties to water and ice storage.

10 https://tayloreng.egnyte.com/dl/WQgmQvAV2J/TIER.pdf

FIGURE 4.7: JESS S. JACKSON SUSTAINABLE WINERY BUILDING AT THE UNIVERSITY OF CALIFORNIA AT DAVIS CAMPUS.

Source: Guttmann & Blaevoet

FIGURE 4.8: A SECTION OF THE 1.4 KILOMETER THERMAL LABYRINTH THAT RUNS BELOW FEDERATION SQUARE IN MELBOURNE, AUSTRALIA.

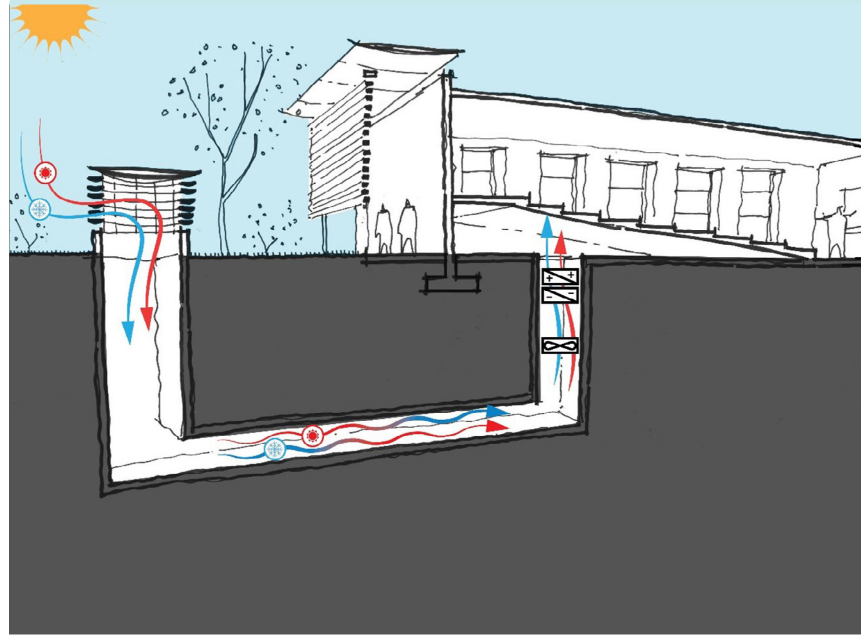
a. **Rock beds:** rock bed thermal storage uses thermal mass in a dedicated "container" that is typically used to directly cool outdoor air. This technology has been around for a long time, and its use has generally been focused on hot and dry climates (which is why most of the research and development work to date has been done in Australia, by the Commonwealth Scientific and Industrial Research Organization — CSIRO — Division of Mechanical Engineering). It has broad application for commercial buildings with large amounts of ventilation air requirements. Information on the history of their use and tools for modern applications can be found in "Optimization of a Rock Bed Cooler for Commercial Building Air Conditioning Systems" (1983).[11] A rock bed system was used at the Jess S. Jackson Sustainable Winery Building at the University of California at Davis campus (see Figure 4.7), a project that was completed in 2013.[12]

b. **Thermal labyrinths:** A thermal labyrinth is typically an underground labyrinth-shaped concrete structure that is part of a building. Through heat exchange with the surrounding soil, a ventilation system that pulls in outdoor air through the labyrinth can pre-cool and pre-heat the outdoor air in the summer and winter seasons, respectively. Federation Square in Melbourne, Australia, completed in 2002, was an early example of this technology (see Figure 4.8).[13] In addition, a new Emergency Department project at Nanaimo General Hospital in British Columbia combined a thermal labyrinth (see Figure 4.9) with displacement ventilation to temper the outside air in their "cool-summer Mediterranean" climate.[14]

11 https://vdocuments.net/optimization-of-a-rock-bed-cooler-volume-1.html
12 https://wineserver.ucdavis.edu/about/facilities/jess-s-jackson-sustainable-winery-building
13 https://www.airah.org.au/Content_Files/EcoLibrium/2013/July13/Eco_July13_4.pdf
14 https://www.cibsejournal.com/technical/ashrae-conference-cooling-seminars/

FIGURE 4.9: THE THERMAL LABYRINTH LOCATED IN THE BASEMENT OF THE NEW NANAIMO HOSPITAL EMERGENCY DEPARTMENT BUILDING. WATER-FILLED CONTAINERS INCREASE THE ACCESSIBLE THERMAL MASS.

FIGURE 4.10: TYPICAL EARTH TUBE CONFIGURATION.



Source: Stantec

c. **Earth tubes:** Less complicated to deploy than thermal labyrinths, "earth tubes" can simply be HDPE ducts (such as BlueDuct® by AQC Industries) and built at relatively low cost. The material is mold and mildew resistant and can be constructed to be waterproof and even more airtight than sheet metal ductwork. With at least six feet of soil cover, in most climates these tubes are exposed to a relatively constant soil temperature, which can provide pre-cooling of air in summer and preheating in winter (see Figure 4.10).

Thermal storage can also be deployed at a range of scales: from individual buildings to city districts to regional areas. At the building scale it can be used effectively to reduce the size of central heating and cooling equipment — saving space and first cost — as well as to shift the period when electricity is used to meet loads. In cold climates, load shifting can also avoid the need to operate air-source heat pumps during the coldest part of a day. At the district and regional scale, the increased diversity in heating and cooling needs can create enhanced heat recovery opportunities.

In a decarbonization design paradigm, thermal storage can be used to make the operational cost of all-electric systems more attractive than the alternatives. Figure 4.11 shows a rough estimate of the costs in New York City for different types of energy sources based on 1 million BTUs (293 kWh) delivered. District steam and electric resistance are very expensive methods, especially when compared to the direct combustion of fossil fuels onsite. However, because of the high coefficient of performance (COP) of the heat pump system, when combined with thermal storage the cost of heating is comparable, or possibly even lower, than fossil fuels, while also meeting the goals of electrification of a building.

FIGURE 4.11: COMPARISON OF THE COST OF 1 MILLION BTUs OF HEATING ENERGY IN NEW YORK CITY FROM DIFFERENT ENERGY SOURCES

HEATING ENERGY COSTS[1]

Energy Source	Units[2]	Quantity	Approximate Cost
Natural Gas (Boiler)	Therms ($1.321)	12.5 therms	$16.50
Fuel Oil (Boiler)	Gallons ($3.679)	9.0 gallons	$33.00
District Steam	Pounds ($35.00 per 1,000 Lbs)	833 pounds	$29.00
Electricity (Boiler)	kWh ($0.25 including demand)	293 kWh	$73.00
Electricity (Heat Pump at a COP of 3)	kWh ($0.25 including demand)	98 kWh	$25.00
Electricity (Heat Pump at a COP of 3 with thermal storage)	kWh ($0.25 including demand)"	51 kWh	$13.00

1 Adapted from "Electrification, Heat Pumps and Thermal Energy Storage", Mark M. MacCracken, ASHRAE Journal, July 2020.

2 Prices are approximations from various online sources (bls.gov, Con Edison, NYSERDA) for New York City in 2021.

Facilities that operate 24/7 present good opportunities for using thermal storage systems since daytime generation with renewable energy can effectively offset nighttime energy use when grids are generally "dirtier." TES systems can be deployed to take advantage of the following opportunities:

- Maximize heat recovery when heating and cooling loads are not perfectly simultaneous;
- Shift heating and/or cooling loads to better align with hours of the day with lower marginal emissions factors on the electric grid, resulting in a lower operational carbon footprint;
- Alternatively, shift cooling loads to cooler nighttime hours when traditional cooling equipment (water-cooled and air-cooled chillers and heat pumps) can operate more efficiently;
- Shift wintertime and nighttime heating loads to daytime hours when air-source heat pumps are more efficient and have higher capacity;
- Optimize heat pump sizing and connected electric load to reduce system first cost;
    - By pairing heat pumps with TES, a smaller heat pump with a longer run period is often able to meet the building load at a lower equipment cost and reduced impact on electric switchgear/transformer sizing.
- Maximize electrical demand response flexibility and capacity, enabling improved electric grid interoperability;
- Increase the ability to mitigate local electric grid distribution congestion;
- Provide a more repeatable electric demand hourly profile;
- Provide an opportunity to utilize renewable energy overproduction in mid-day hours, reducing the need for curtailment and maximizing self-consumption.

4.2.5 _MICROGRIDS

Volume 2, section 2.6.7.1 discussed the growing interest in the application of microgrids and their resiliency benefits. Using a building scale microgrid for decarbonization can also reduce the impacts of emissions related to grid energy use. Currently, grid-supplied energy comes with a varying carbon signature that is often poorly aligned with utility rates (see Figure 2.9 in Volume 2). Conventional microgrid control systems — which traditionally optimize for utility cost reduction — can be easily repurposed for carbon emissions reductions by establishing an artificial utility tariff schedule that tracks marginal emission rates on the grid. This can be as simple as multiplying the marginal emission rate assigned to an hour of grid energy (information that is available from real time marginal emissions forecasters such as WattTime[15]) by a "dollar per pound of carbon" multiplier. This allows the control system to establish a cost for a unit of energy during each hour of the day, which can then be used by the microgrid controller's cost optimization algorithms. As stated in Volume 2, section 2.5.1.3.3, "in this approach, minimizing utility costs will be directly correlated with minimizing carbon emissions."

4.2.6_COLD CLIMATE CONSIDERATIONS

One of the destructive myths that is circulating in the midst of the electrification debate is that the technology does not exist to use heat pumps in cold climates. In fact, a number of heat pump system configurations are suitable for cold climates.

1. Refrigerant selection can play a role in the suitability of an air-source heat pump's application in a cold climate. As shown in Figure 3.12 and discussed in Volume 3, section 3.2.3.12, heat pumps that use CO_2 as a refrigerant have inherent performance characteristics that allow them to be used effectively at extremely cold outdoor temperatures.

15 https://www.watttime.org/

2. Using water-source heat pumps can be an effective strategy in cold climates. Such sources can be used to configure an earth-coupled heat pump system, which comes in a variety of configurations, as well as a Sanitary Wastewater Energy Exchange (or SWEE) system and two-stage heat pump systems (see Figure 3.13 in Volume 3). See Volume 2, section 2.6.2.2 for more detailed discussions of these configurations.

While cold climate systems often come at some increase in first cost, many of these configurations will provide a lower life cycle cost when considered over the life of a building.

4.2.7_BENCHMARKING — MEASURING ENERGY VERSUS MEASURING CARBON

Energy Use Intensity (EUI) is a standard building performance metric for evaluating building *energy efficiency*. Both the rationale for and the power of this metric is discussed further below. By itself, EUI is not up to the task of leading the built environment towards a carbon neutral future. As discussed in Volume 2, section 2.5.1.1, energy efficiency (i.e., achieving the lowest EUI that your project can afford) has a number of benefits for all-electric buildings, including reducing the first cost and addressing the Code compliance challenges that still exist for all-electric buildings. So, understanding and evaluating EUI is still important.

EUI — expressed as kBTU per square foot (or kW per square meter) per year — has long been a measure of building energy use. This EUI metric is normally based on site energy use, but occasionally it is expressed as source energy use that includes energy production losses, transmission, and other factors in energy production and delivery. This value is useful as a benchmark for performance due to its ability to compare different occupancy types to their peers without the need to consider project size. For example, by referencing the per square foot metric for multiple office occupancies, you can compare a small office of 10,000 gross SF to an office building of 500,000 gross SF relatively easily. In fact, target EUIs can be developed for whole building energy use, as well as for the energy use of individual building end-use systems (e.g., lighting, cooling, heating, fans, pumps, plug loads, etc.).

EnergyStar Benchmarking[16] has long been the market leader for comparing common building types to the existing national database for existing buildings.[17] This is useful for comparing projects to a national building stock. For more granular data for cities like San Francisco, California that have benchmarking ordinances, more regional comparisons to similar building types are available.[18]

For businesses that have multiple sites, benchmarking their own buildings creates a useful database to inform EUI design targets. A good example of how this can be used in facility planning is the University of California, which has a robust database of their existing building stock. This has been extremely useful for setting EUI targets for new buildings and major retrofits. These targets are outlined in the university's Office of the President's Sustainable Practices Policy.[19]

While EUI is a good metric for performance, it does have limitations. First, it is a fuel agnostic benchmark; it does not distinguish between on-site fossil fuel use and grid electricity use. Second, since it's a yearly target (kBTU/sf/year) it is not useful for evaluating the impact of seasonal conservation strategies, nor does it account for seasonal variations in renewable energy production or storage, grid harmonization strategies, or other approaches that impact seasonal or daily energy use patterns. Finally, it also does not reflect the environmental impacts of fuel choice. The metric will not measure the carbon intensity of the building based on grid region or fuel type, nor does it account for the impacts of utility delivery methods such as electrical transmission losses or methane leakage.

Thus, as discussed in Volume 2, section 2.5.1.3, alternate metrics can be useful in evaluating the performance of all-electric building designs.

16 https://www.energystar.gov/buildings/benchmark

17 https://www.energystar.gov/buildings/benchmark/understand_metrics/how_score_calculated

18 https://sfenvironment.org/energy/san-francisco-existing-buildings-performance-report

19 https://policy.ucop.edu/doc/3100155/SustainablePractices

4.2.8 REGULATORY CHALLENGES

Energy codes continue to compare a proposed all-electric building against a "standard design;" that is, in most cases, a building fueled by a combination of electricity and natural gas. Simulations for annual building energy cost measured against a mixed fuel baseline is the approach used by ASHRAE 90.1, the standard adopted by most State Energy Codes. This approach can mask the beneficial carbon reductions from switching to high-cost/low-carbon fuels (i.e., electricity), which in most states is more expensive per BTU than natural gas. When evaluating the performance of an all-electric building with cost as the metric, the all-electric building design can be penalized in areas with high electricity cost, even though the carbon content of the electricity may be favorable for achieving emissions reduction goals. Thus, as discussed in Volume 2, section 2.5.1.3, establishing appropriate benchmarks at the beginning of a project can ensure that decarbonization efforts are "rewarded."

In California, as of December 2021, there were more than fifty jurisdictions that had adopted local codes or ordinances to achieve natural gas phase-out ahead of new state Energy Code requirements. These jurisdictions recognize that cost alone will not incentivize builders and property owners to shift away from gas and that the regulatory environment needs to take over the task of transitioning away from fossil fuel heating sources (see Figure 4.12). As discussed in Volume 2, section 2.4.2, this approach is expanding to other parts of the country.

Meanwhile, navigating Code compliance can be a tricky proposition while Codes continue to transition away from requirements that inadvertently favor mixed fuel buildings. While ASHRAE is working to update the metrics in Standard 90.1 to address this issue, the fact is that many States still adopt model codes that reference old versions of this standard. The database maintained by the American Council for an Energy-Efficient Economy (ACEEE) shows the Energy Code that each state has adopted. For example, in Texas, commercial and multi-family buildings must comply with the 2015 International Energy Conservation Code (which is based on

FIGURE 4.12: CALIFORNIA JURISDICTIONS WITH ELECTRIFICATION CODES OR ORDINANCES

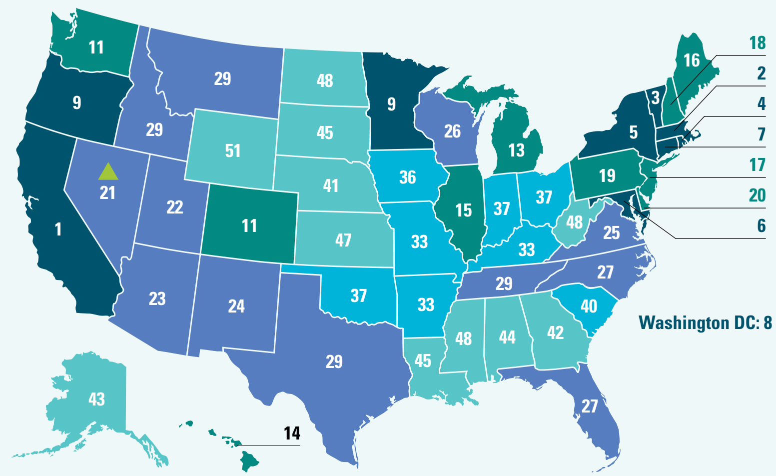
Alameda	Encinitas	Mountain View	San Luis Obispo
Albany	Fairfax	Oakland	San Mateo County
Berkeley	Half Moon Bay	Ojai	Santa Barbara
Brisbane	Hayward	Pacifica	Santa Clara County
Burlingame	Healdsburg	Palo Alto	Santa Cruz
Campbell	Los Altos	Petaluma	Santa Monica
Carlsbad	Los Altos Hills	Piedmont	Santa Rosa
City of San Mateo	Los Gatos	Redwood City	Saratoga
City of Santa Clara	Marin County	Richmond	Solana Beach
Cupertino	Menlo Park	Sacramento	South San Francisco
Daly City	Mill Valley	San Anselmo	Sunnyvale
Davis	Millbrae	San Carlos	Windsor
East Palo Alto	Milpitas	San Francisco	
Emeryville	Morgan Hill	San Jose	

Source: https://www.sierraclub.org/articles/2021/07/californias-cities-lead-way-gas-free-future

the 2013 version of ASHRAE 90.1), and state-funded buildings must meet the 2013 version of the ASHRAE 90.1 standard. This fact, along with other out-of-date policies in areas such as transportation, utility and public benefits programs as well as appliance efficiency standards places Texas at a rank of 29 in ACEEE's 2020 Energy Efficiency Scorecard (see Figure 4.13), tied with Idaho, Montana, and Tennessee.

Thus, it is recommended that teams implementing all-electric designs evaluate code compliance early in the design process. This can help avoid the unfortunate outcome where all-electric building designs struggle to achieve code compliance while meeting the higher aspirations of owners who want to decarbonize their buildings.

FIGURE 4.13: THE 2020 STATE ENERGY EFFICIENCY SCORECARD



Source: https://www.aceee.org/state-policy/scorecard

4.3_Assessing Costs and Value

4.3.1_COST ESTIMATING

Accurately predicting the probable cost of projects is a critical aspect of almost every construction project. In commercial construction, this effort is often led by professional estimating firms, or "Quantity Surveyors."[20] It is also common for general contractors to lead, or assist in leading, cost estimating activities, especially in a design-build delivery process. While both methods have their pros and cons, it is important that cost estimators or contractors who are unfamiliar or inexperienced with the cost of all-electric buildings not introduce "risk pricing" into the process.

"Risk-pricing" often occurs when cost estimators or contractors are asked to estimate the cost of construction for system types with which they have limited experience. In these instances, cost estimators or contractors cannot look back at prior projects for assurance that their costs can be accurately predicted. As contractors and cost estimators become more familiar with new building techniques it is common for costs to come down due to familiarity and competitive bidding.

For general approaches to cost estimating that may improve the success of project cost control, see Volume 2, Section 2.3.2, "Cost Estimating."

4.3.2_LIFE CYCLE COSTS

When selecting alternative design strategies, Life Cycle Costing (LCC) has demonstrated value as an economic analysis tool, giving teams a better sense of the total cost of ownership (costs associated with operational energy use, maintenance, replacement, first cost, etc.). By reviewing initial investment options and identifying the cost of alternatives over the entire building's lifespan (or other time horizon as desired for evaluating investments), design teams can compare alternatives to optimize for the lowest total cost. The LCC of building system alternatives should be analyzed during the earliest stages of a project, since this is the most effective and impactful approach to LCC integration.

When commitments to building electrification are made early in a project, Life Cycle Costing — especially when carbon considerations are factored into these cost models — can help teams keep the multiple stakeholders on track to uphold and deliver on these commitments. See Volume 2, section 2.5.1.3.3 to learn more about how to include carbon metrics in these cost calculations.

In existing buildings, there are several unique cost considerations:

» **How old is the equipment?**
  - Replacement is most cost effective toward the end of the equipment's useful life. However, efficiency often declines as equipment ages, so cost savings may be found before that time.

» **Can existing system components be re-utilized?**
  - For example, can the ductwork in a ducted furnace system be reused by a packaged heat pump unit replacement?
  - Or, must all system components be removed and an entirely different system be installed (such as removal of a ducted system, and replacement with hydronic piping)?

» **Does the reliability, availability, and cost of natural gas factor into the future cost of reliance on systems powered by natural gas?**
  - As building electrification accelerates, and natural gas infrastructure planning responds to a declining customer base, are future changes or costs going to adversely impact the use of natural gas in your building?

20 https://www.rics.org/uk/upholding-professional-standards/sector-standards/construction/

› Is "pruning" of the gas delivery supply branch system by the utility company in the forecast? Would this affect gas supply to the building in the future?

› Are future costs of natural gas going to have a significant effect on the financial returns for electrification?

» **Does a phased approach to electrification make sense?**

- Are there several gas-based systems in the facility (e.g., water heating, space heating, and kitchen) that would warrant a phased approach to minimize disruption, downtime, and current capital requirements?

Analyses can also integrate benefits that are more difficult to monetize or quantify. This is typically done through a "Choosing by Advantages" approach (see Figure 4.14). Such analyses serve to enhance the equity and "community values" components of a project. Benefits that can be incorporated into a quantitative analysis could include:

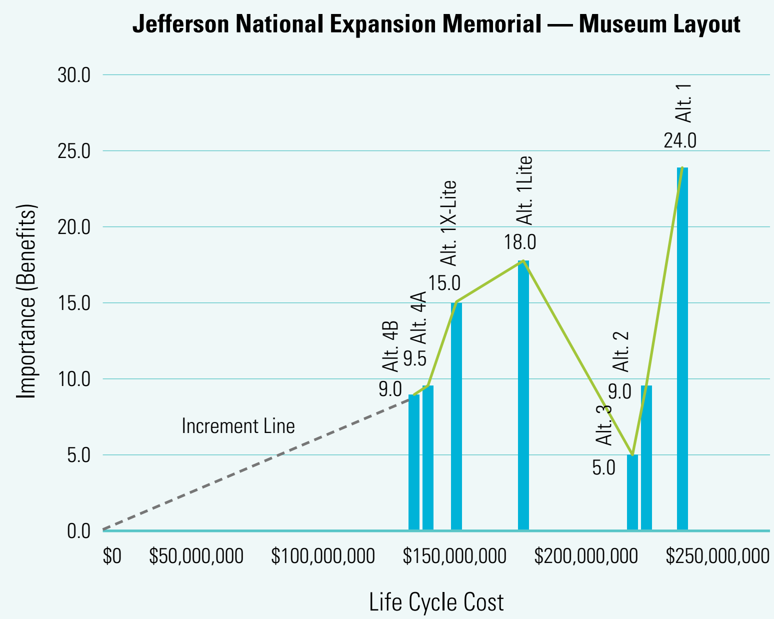
» Sourcing power through a conscientious and equitable provider that can support numerous benefits outside the project walls such as investments in the local economy;

» Creation of healthier environments for neighbors, contributing to lower community healthcare costs;

» Enhancing community resilience, by introducing green technologies alongside workforce development and training.

Instead of economic activities having a negative influence on the environment, sustainable development can meet both current needs as well as create infrastructure for future generations to thrive. Building electrification stands to increase all three pillars of sustainability benefits: environmental, economic, and social.

FIGURE 4.14: CHOOSING BY ADVANTAGES: A METHOD FOR INCORPORATING NON-MONETARY BENEFITS INTO AN ANALYSIS OF ALTERNATIVE PROJECT APPROACHES



Source: "Value Strategies for Success in Business Planning," Stephen J. Kirk, Ph.D. and Stephen E. Garrett, CVS.

4.3.3_COSTS RELATIVE TO BUSINESS AS USUAL

Everyone wants to know if it costs more to build an all-electric building. The answer is both obvious and unsatisfying: it depends. Similar to the discussions about whether a LEED certified building costs more than a non-certified one, or a Platinum certified one more than a Silver certified, the answer depends on many factors, including the location of your project, applicable regulatory and Code requirements, local utility pricing structures and incentives, as well as host of project-specific characteristics. Thus, every project needs to investigate this question based on an entirely unique set of constraints and opportunities.

Furthermore, time of use (TOU) utility rates can often be leveraged to lower the operating costs of an all-electric building. While current TOU tariff schedules generally create conflicts between energy cost savings and the reduction of utility-generated carbon emissions, it is anticipated that tariffs will, over time, become more aligned with carbon-emissions impacts in order to incentivize the use of grid-supplied renewable energy. Meanwhile, the type of systems that enable the alignment of energy use with the characteristics of renewable energy availability on the local grid — grid harmonization — can also enable the shifting of loads to lower both electricity consumption and demand charges. Combinations of the strategies outlined in this Guide can provide the most economic value and future potential when making the case for electrification.

4.3.4_NAVIGATING TENANT/LANDLORD SPLIT INCENTIVES (FIRST COST VERSUS OPERATING COSTS)

Tenant and landlord interests can often be misaligned, and these divergent interests can be a barrier to adopting energy efficiency strategies. In cases where a landlord intends to shield themselves from the utility cost impacts as a result of design choices for a building, the incentives that drive energy efficiency investments may not exist. In these cases, first cost savings usually take priority over operational cost reductions. Strategies exist that can help prevent these "split incentives" from derailing decarbonization efforts. Some of these best practices are discussed in detail in Volume 3, section 3.5.2.3, "Navigating Split Incentives — First Cost vs Operating Costs".

4.3.5_HOW TO NAVIGATE THE COST DEBATES

While Volume 3 is devoted entirely to multi-family residential, hotel/motel, and similar buildings, section 3.5 provides a discussion and framework for navigating cost debates that can be effectively applied to most commercial projects.

Projects designed and built through the investment of public funds can especially benefit from the "Choosing by Advantages" approach discussed in section 4.3.2. This method of analyzing the costs and benefits of public projects can incorporate values such as maintaining the operational functionality of an existing building, or the employment impacts on source fuel stakeholders from a building electrification project. Professionals working on public projects should be mindful of the stakes (economic, social, and environmental) of the community served to ensure support.

4.4_The Design Process

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

There are many elements of the design process that are unique to all-electric building design but that are not necessarily unique to commercial projects (see Figure 4.15). However, this section attempts to identify design phase considerations specific to commercial building projects. It is organized according to specific professional disciplines and specialized building systems.

Many of the items in the design process flowchart are explained in more detail in Volume 2, "Universal Design, Construction, and Operational Phase Considerations." Some items of note from the flowchart include:

Codes: As discussed above in section 4.2.8, the applicable codes in some jurisdictions may make it difficult for all-electric designs to meet basic Energy Code compliance requirements, while other jurisdictions may have ordinances in place to help promote decarbonization of the built environment. This can often require design teams to propose Alternate Compliance Methods or provide extraordinary calculations to demonstrate compliance.

Renewable Portfolio Standards (RPS) for local grids: As discussed in Volume 2, section 2.6.6, the short-term emissions impacts of all-electric buildings is dependent on the current and future "cleanliness" of the local utility grid as well as the amount of onsite renewable energy generation that is incorporated into the project design. The calculations discussed in Volume 2, section 2.5 can help identify the approaches needed to ensure that an all-electric building project provides lifetime emissions reduction benefits.

Study feasibility: For new construction, building performance modeling (e.g., energy, carbon emissions, etc.) should start in the schematic design phase. For existing facilities, decarbonization master planning can provide an effective roadmap for establishing the feasibility and timing of future retrofits.

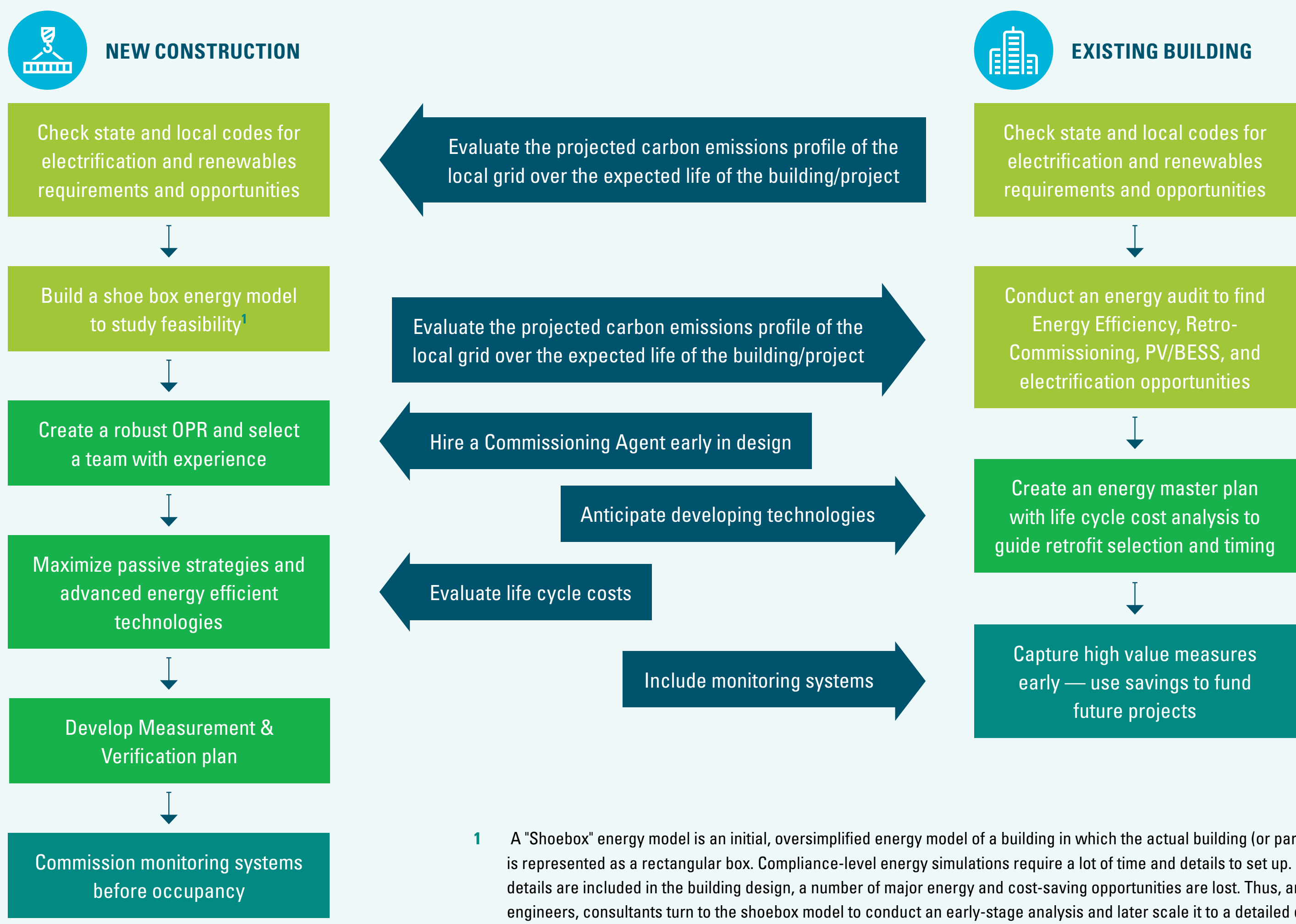
Technologies and strategies: Volume 2, section 2.6 describes many of the technologies and strategies that facilitate a successful all-electric design approach. Since some of these technologies are not yet industry standard, it is helpful to bring knowledgeable practitioners into the process.

4.4.1_ARCHITECTURE + ARCHITECTURAL PROGRAMMING

At the start of design, an architect works with the owner or developer to establish goals and confirm project and programming criteria. This is the moment to ensure that critical considerations are discussed and criteria established so that the broader team can work to create strategies that will meet project specific sustainability and resiliency goals. Decarbonization, and how this contributes to healthier environments and provides better community assets, should be a touchstone during all design phases.

The best designs are a result of continuous and integrated collaboration. Part of an architect's role is to bring together the technical considerations of the broader team, inclusive of, but not limited to, structural, mechanical, acoustical, electrical, landscape, kitchen, and daylighting consultants. This coordination and integration requires an openness about solutions and timely conversations about synergistic approaches to problem solving. Often, integrated design can result in more cost-effective and beautiful designs, while being less resource impactful, but it requires all consultants to think holistically. This approach can also provide information to support a more comprehensive presentation to a client about sustainable strategies as well as cost consequences and benefits, including those tied to decarbonization.

FIGURE 4.15: COMMON ELEMENTS OF ALL-ELECTRIC BUILDING DESIGN PROCESS



1 A "Shoebox" energy model is an initial, oversimplified energy model of a building in which the actual building (or part of the building) is represented as a rectangular box. Compliance-level energy simulations require a lot of time and details to set up. By the time such details are included in the building design, a number of major energy and cost-saving opportunities are lost. Thus, architects, engineers, consultants turn to the shoebox model to conduct an early-stage analysis and later scale it to a detailed developed model.

Designing toward decarbonization requires an architect to recognize the unique program, planning, environmental, and systems opportunities affecting commercial building electrification and to understand how to discuss the wellness, community, and other long-term benefits with clients. Understanding energy intensive processes, shifts from standard layouts, equipment availability, infrastructure requirements, integration of renewable energy generation, and building and site considerations are all part of the puzzle that needs solutions.

4.4.1.1_Facade Consultants

The design, procurement, and construction of the building enclosure has become increasingly important in achieving the goals of decarbonization. All-electric building systems benefit from improving the thermal performance of enclosures. In addition, reducing embodied carbon in facade materials is second only to the focus on structural systems. Volume 2, sections 2.5.1.2 and 2.6.1 discuss various critical aspects of enclosure design, and Volume 6 addresses the embodied carbon of facade materials.

New materials, components, and detailing techniques to improve enclosure performance are constantly changing, and a limited number of professionals have the time to keep up with the latest enclosure systems. Additionally, long lead times for glass and aluminum procurement are driving project schedules. As such architects are being asked to deliver enclosure bid packages earlier and earlier in the design phase, so they are increasingly relying on facade consultants to work alongside them. These consultants can address the technical requirements and coordinate the construction details needed to realize the architect's aesthetic vision without compromising performance. They can also help expedite robust early bid packages that demonstrate compliance with critical performance requirements. The work done by facade consultants to improve the performance of enclosures can provide significant contributions to the cost-effectiveness of other systems needed for an all-electric project. See Volume 2, section 2.5.1.2 for more in-depth discussion.

4.4.2_COMMISSIONING AUTHORITY

All-electric buildings can obtain key benefits from a formal commissioning process conducted by a qualified commissioning provider. Designing all-electric buildings is still a relatively new endeavor for most design teams: a commissioning agent with prior all-electric project experience can assist both designers and builders in delivering practical and effective solutions, as well as ensuring that system designs meet functional requirements.

The value of a robust commissioning process is discussed in more detail throughout Volume 2. Commissioning throughout project implementation will provide the maximum benefit from this quality assurance process.

4.4.3_ELECTRICAL ENGINEERING

With all-electric buildings, much discussion centers around the impacts on utility infrastructure and electrical system capacity. This is requiring electrical engineers to dig deeper into their predictions of peak building demand in order to ensure that oversizing does not become a barrier to an all-electric project. Similar to the need for more accurate predictions of peak domestic hot water demands for right-sizing of water heating systems, the accuracy of electrical load calculations is a critical need for all-electric buildings.

Calculations for peak electrical demand are highly prescribed by relevant National Codes and Standards. Even so, rules can be misinterpreted or various load reduction options ignored, especially when used by engineers to build in larger safety factors. A peer review of the peak electrical demand calculations for all-electric buildings is advisable, at least until all-electric building design becomes established practice. Many commissioning providers have the expertise to include this peer review in their scope of work, as long as they are hired early enough in the design process to provide meaningful input.

All-electric HVAC design does not necessarily increase a building's electrical load since the peak time of use for the heating and cooling equipment are not coincident. Often the required electric power for the cooling equipment is sufficient to operate all-electric heating demand with the same electrical service.

With all-electric building designs, electrical loads from plumbing systems will typically be higher than in conventional building design. This is an area for particular attention by peer reviewers or construction managers, as miscommunication between the plumbing engineer and electrical engineer can result in large errors in calculated loads.

For example, redundancy in water heating system equipment is often desirable. However, designs that allow each piece of equipment to operate simultaneously require that all equipment be included in the calculated demand loads. Back-up configurations that prevent redundant equipment from operating unless there is a failure of the primary piece of equipment may allow for reductions in calculated demand load. These strategies can make use of manual transfer switches or be made automatic with appliance splitters (e.g., the Smart Splitter from Neocharge) or "smart" panels (e.g., EcoStruxure Power from Schneider Electric). Note: be mindful of your local jusriduiction's position on the use of these devices.

High electrical loads can also result from specific equipment choices, which should be closely evaluated to ensure that they provide an acceptable trade-off with higher calculated demand loads. Examples of such equipment include: (1) hybrid water heaters with internal electric resistance booster heaters for higher recovery rates, (2) air-source heat pump water heaters with electric heating coils for low-ambient operation, and (3) air-source heat pump water heaters with electric heating coils for defrost cycles.

Another strategy for reducing the size of a service for an all-electric building is delaying the installation of redundant/backup equipment or other systems that are not "required" as part of the initial project completion. Delay in the installation of equipment allows designers to take advantage of the difference between "calculated demand loads" and "actual demand loads." Actual demand loads are almost always less than calculated demand loads: typically anywhere from 50% to 70% of calculated demand loads. Once a project is in operation and actual demand loads can be measured, future system additions are allowed to use actual demand loads as the basis upon which to calculate future demand loads. Judicious use of this approach can often result in a greater connected load for the same service size than in the case where all loads are part of the initial construction.

4.4.4_HVAC, REFRIGERATION, AND PLUMBING ENGINEERING

HVAC and plumbing are key design disciplines in the execution of all-electric building designs. The HVAC and plumbing services are combined here to avoid repeating information since heat pumps and other all-electric heating systems are the primary approach to both services. The transition from natural gas fired and electric resistance heating equipment to other electric technologies (such as heat pumps or variable refrigerant flow) for the generation of heating and domestic hot water is an essential component in successful all-electric building designs. The application of sophisticated controls and robust monitoring systems are critical with these technologies, especially in circumstances where operations personnel are initially unfamiliar with their maintenance and repair.

4.4.4.1_Heat Pumps

Heat pumps for space heating and domestic water heating are available in a variety of configurations and from a growing number of domestic and international manufacturers. The application of heat pumps for building systems often presents unique challenges to HVAC and plumbing engineers who are unfamiliar with this technology.

» Heat pump water heaters have a lower range of available capacities (i.e., BTU per hour output) compared to gas-fired equipment, and heat pumps of the same capacity as the equivalent gas-fired unit take up much more space.

» Gas-fired equipment is usually located indoors while large central air-cooled heat pump water heaters must be located outdoors or with direct access to the outdoors.

» Increasing domestic hot water storage can facilitate a reduction in the heat pump capacity that is required to meet a defined load. Thus, a typical domestic heat pump water heater system will use more water storage than its equivalent gas-fired system. This often requires more indoor mechanical room space.

Due to the superior energy efficiency of heat pumps, compared to electric resistance heat, the use of heat pump technology is essential to building electrification. Addressing the challenges listed above through proper configuration of heat pump systems is entirely possible (see Volume 2 for many of the applicable strategies), and several approaches are also discussed below.

4.4.4.1.1_SPACE HEATING AND COOLING CONSIDERATIONS

Heat pumps are a readily available and a very energy-efficient technology that works by extracting energy from a "source" and transferring that energy to a "sink." The larger the temperature difference between the extracted and energy source and rejected energy sink, the worse the heat pump efficiency. From an efficiency standpoint (BTU out divided by BTU in), the worst performing heat pump system is always more efficient than the best fossil fuel fired equipment. Nonetheless, it is important to design heat pumps for appropriate heating temperatures. For space heating systems using water-to-water heat pumps in lieu of natural-gas-fired boilers, this is generally in the range of 120 to 130 degrees F in all climates.

4.4.4.1.2_GROUND-UP UNIQUE CONSIDERATIONS

With a storage-centric design, water storage can be integrated into heat pump water heating systems in advantageous ways (see Volume 2 for more detailed discussion of most of the following topics):

» **Schedule heat pump operation for time-of-use rates:**

- Storage systems can be used to allow a system to coast through periods of high utility tariffs, minimizing costs by only operating when utility rates are favorable.

» **Schedule heat pump operation to reduce peak building electrical demand:**

- Storage systems can be used to allow a system to coast through periods of high electrical demand (e.g., peak summer cooling hours), in order to reduce building demand charges that can drive up operating costs.

» **Schedule heat pump operation to avoid grid energy use during periods with high marginal emission rates:**

- From a carbon neutrality perspective, emissions related to grid energy use can be minimized by allowing a system to coast through periods with the highest marginal emissions rates.

» **Schedule heat pump operation to avoid grid energy use during periods of high grid "stress":**

- Often called "grid harmonization," this strategy relieves pressure on utility grids to meet peak demands, which are often concurrent with a rapid drop off in solar energy production in the late afternoon.

» **Reduce installed system maximum heating output:**

- Peak hot water demands are often met by water stored in tanks, and the primary heating equipment is then sized to ensure that hot water in the storage tanks is replaced fast enough to meet subsequent demand. Thus, heating capacity is inversely related to storage capacity; increasing one allows for decreases in the other. Many domestic water system designs use increased amounts of hot water storage as a way of reducing the "recovery rate" of the primary heating equipment. For all-electric systems, this reduction in peak water demand and peak electrical demand can be critical to meeting cost, space, and utility constraints.

4.4.4.1.3_RETROFIT UNIQUE CONSIDERATIONS

Natural-gas-fired boiler systems, which were often originally designed to supply 180°F water, can be retrofitted with heat pumps in a number of different ways.

It is conventional in design that heating loads are overestimated and that excess capacity is also built into equipment. This means that systems can often meet the actual maximum heating demand while losing some capacity at the coils. Thus, an evaluation of the ability of the existing heating coils to meet the required heating loads at reduced supply water temperatures can often be a fruitful exercise in accommodating lower supply water temperatures. If the overall temperature difference between supply and return water in the new design matches the original design, then existing pumps and piping can be reused.

Alternatively, engineers can consider ways of matching the original design water temperature. Heat pumps can generate any water temperature needed, but these systems will require less conventional design approaches:

» Two-stage air-source heat pumps can generate 180°F water at ambient temperatures as low as -30°F (see Volume 2, Figure 2.14).

» Single stage heat pumps can effectively generate 180°F water if the source temperature is around 70 to 80°F. Such sources might include sanitary sewer water (in an application known as Sewer Wastewater Energy Exchange, or SWEE) or condenser water from a water cooled chiller system.

» Use electric resistance type boilers. While operating at a coefficient of performance of 1.0, this is still better than natural gas fired boilers that typically operate at a COP of 0.8, and have a maximum theoretical efficiency of around 0.96. It should be noted that the use of electric resistance boilers may not be a code compliant approach in all jurisdictions. For example, in California's 2022 Energy Code, electric resistance heating is allowed only if one of six conditions apply (e.g., where an electric-resistance heating system supplements a heating system in which at least 60% of the annual energy requirements is supplied by site-solar or recovered energy).

Finally, engineers might consider replacing existing coils with ones selected at the new design parameters. While this may be more costly and disruptive, it can often be accommodated on major renovation projects.

4.4.4.1.4_HEAT RECOVERY CONSIDERATIONS

Heat recovery is covered in detail in Volume 2, section 2.6.2. Some basic concepts are repeated below.

» Air-cooled heat pumps reject cold air as a byproduct of pulling energy out of the air to heat water or indoor air. This cold air, in some applications, can be repurposed to provide useful cooling, such as for electrical and telecom rooms, where cooling loads are typically independent of outdoor air conditions.

» Cooling systems reject heat in order to achieve the energy balance required for continuous operation. This rejected heat can be captured and used to heat water that can be used in building heating or domestic hot water systems. There are a number of system types where this can occur, and engineers continue to identify new opportunities. It is useful to evaluate all opportunities for capturing reject heat:

  - Water-cooled chillers can be purchased with heat recovery condensers that make hot water directly, or condenser water can be diverted from cooling towers to heat exchangers that can be used to transfer heat to hot water systems. The thermal energy in condenser water can also be stored: this thermal storage can enhance overall system performance and reduce installed generation capacity. In addition, condenser water can be fed into the cold side of a water-to-water heat pump, allowing the low grade thermal energy in the condenser water to be boosted to much higher temperatures if needed.

  - Water-cooled heat pumps can be selected and designed for both heating and cooling purposes. When used as changeover devices, they can reduce the first costs of purchasing separate heating and cooling equipment.

- Many manufacturers of variable refrigerant flow systems provide "desuperheaters" that pull heat out of the refrigerant for direct heating of water.

» In hot climates, coils in air handlers can be used to pre-cool the outside air with domestic water, using this heated water as make-up for domestic hot water heat pump systems.

4.4.4.1.5_PIPING AND RECIRCULATION ENERGY LOSS CONSIDERATIONS

Much work has been done on understanding the energy use of space heating and domestic hot water systems, including the use of recirculation piping and pump systems for the maintenance of domestic hot water availability. As much as two-thirds of all energy use in a typical domestic hot water system can be attributed to piping losses (see Figure 4.16).[21] Volume 2 addresses many considerations for improving the efficiency of heat pump systems.

For building space heating systems, higher efficiencies might be achieved by strategies such as:

» Producing as low a temperature of water as can be relied on for space heating. Often, systems can be designed for the use of 120°F water, rather than 180°F water (which became the default design temperature for many heating hot water systems);

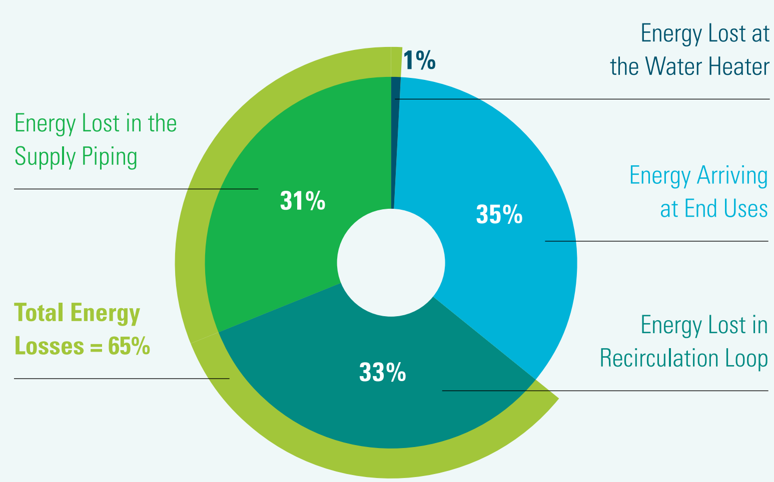
» Sewer water energy recovery for water-source heat pumps is an amazing strategy, especially for cold climates, where this abundant source can be available in all seasons.

The choice between a central and non-central DHW system is influenced by many factors, and each project must weigh these factors (e.g., space, first cost, and maintenance costs) in final system selection. Some non-central system choices — such as point of use systems with no recirculation — can be a reasonable and energy saving option. For central domestic heat pump water heating (HPWH) systems, it has been suggested that the highest efficiencies can be achieved by:

» Handling piping heat losses with a heat source that is separate from the source used to heat the cold water make-up (loop tank heater). Loop tank heaters can be heat pumps themselves or can use electric resistance water heaters;

» Employing advanced recirculation system controls that include strategies that reduce pumping energy during periods of low or no use — such as self-actuating thermostatic balancing valves with VFD-driven recirculation pumps. In combination with HWPHs, these recirculation system controls can be extremely effective at achieving significant reductions in DHW system energy use;

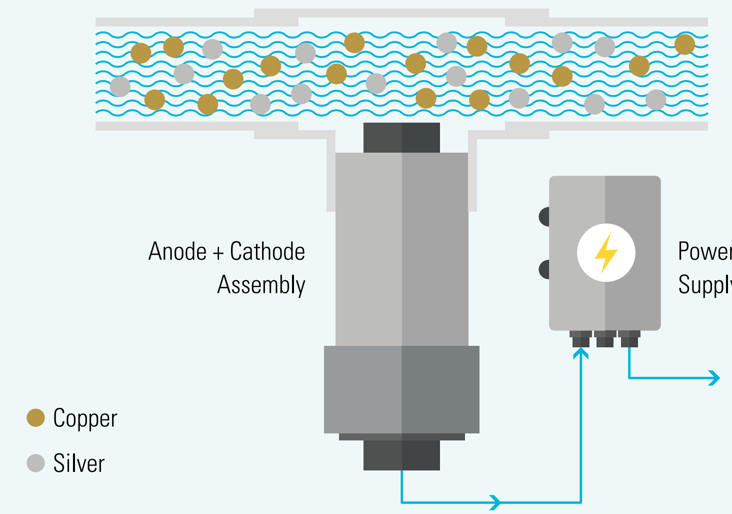
4.16: ENERGY LOSSES IN A TYPICAL DHW SYSTEM WITH RECIRCULATION



21 "Control Strategies to Reduce the Energy Consumption of Central Domestic Hot Water Systems," Dentz et al, June, 2016.

- Producing as low a temperature of water as can be relied on for water heating. For service hot water systems, unless high temperatures (i.e., 140°F and higher) are required for "sterilization" purposes, design temperatures can be in the range of 115 to 125°F to improve efficiency.
  - It should be noted that concerns about the control of Legionella bacteria can often be met more effectively by means other than the use of high temperature hot water generation and storage. Evaluation criteria for systems that strive to control Legionella bacteria include (1) a demonstrated efficacy of Legionella eradication in vitro using laboratory assays, (2) anecdotal experiences in preventing legionnaires' disease, (3) passing tests in controlled studies, and (4) validation in confirmatory reports from multiple sites during a prolonged period of time. Copper-silver ionization (see Figure 4.17) was the only disinfection modality to have fulfilled all four evaluation criteria over a 5- to 11-year time frame in one study.[22] There are many advantages of copper and silver ionization:
    - It is precise since ion generation is controlled by the water flow, so it can be adjusted to the required level;
    - It has a residual effect;
    - It penetrates biofilms;
    - It works at a range of water temperatures;
    - Only tiny amounts are needed to achieve Legionella control (20 to 40 ppb silver and 200 to 400 ppb copper);
    - It is more stable, for example, compared to chlorine dioxide; which also off-gasses;
    - It is, most importantly, much safer than chlorine-based chemicals that can explode in situ, during transport, or during disposal of drums with small amounts of the chemical in them.

FIG. 4.17: TYPICAL SILVER/COPPER IONIZATION SYSTEM



4.4.4.1.6_PIPING AND CONTROLS STRATEGY CONSIDERATIONS

With hot water storage systems, high efficiencies may be achieved by:

- Using single pass system designs, where the coldest water enters the heat pumps, allowing heat pumps to operate at their highest COP;
- Using storage tanks piped in series so that stratification of water is not an essential element for proper system operation;
- Ensuring that staging controls — when multiple heat pumps are ganged together — are designed properly and thoroughly commissioned to ensure optimal operation.

22 "Experiences of the first 16 hospitals using copper-silver ionization for Legionella control: implications for the evaluation of other disinfection modalities," Janet E Stout and Victor L Yu, Infection Control & Hospital Epidemiology, August, 2003. | https://pubmed.ncbi.nlm.nih.gov/12940575/

4.4.4.2_Controls

Advanced control system strategies can improve performance and reduce GHG emissions. These include:

» **Controls that are focused on minimizing carbon emissions related to grid-supplied energy use:**

- As discussed in section 4.2.5, using a standard Application Programming Interface (or "API"), control systems can access real-time, forecasted, and historical marginal emissions data for electric grids around the world. When combined with solar PV production forecasting, load forecasting, energy storage systems, and load management strategies, this data can be used to control building systems to minimize GHG emissions related to grid energy use.

» **Controls that are designed deliver more reliable performance and are self-correcting** (see also Volume 2, section 2.8.1):

- ASHRAE Guideline 36, "High-Performance Sequences of Operation for HVAC Systems," was created to standardize many common HVAC controls sequences of operation to relieve the issue of each project design creating new and unique HVAC controls sequences of operation. Creating new sequences for every project leads to wasted time, wasted cost and increased complexity. Using industry standard HVAC control sequences of operation allows for better quality control, easier commissioning, and more successful project implementation;

- Reduced energy consumption and reduced system down-time may also be a byproduct of implementing Guideline 36 by including diagnostic software to detect and diagnose system faults and make operators aware of them before they cause performance problems.

» **Controls that are properly commissioned and tuned and that are verified to deliver predicted performance:**

- Predictive energy models have been improving over the past 20 years, as the industry has continued to promote more robust modeling practices. These predictive models can be used to develop performance criteria that, when properly applied, can help design and construction teams validate the actual performance of buildings without the effort required for more traditional measurement and verification processes;

- Combining standardized advanced sequences of operation with automated fault detection and diagnostics provides a significant set of resources for ensuring that buildings meet projected performance targets. When buildings deviate from established targets, these tools also provide methodologies for driving actual performance toward the desired goals.

4.4.4.3_Refrigerants

Many refrigerants are potent greenhouse gas (GHG) contributors when released into the atmosphere. Selecting refrigerants with a low Global Warming Potential (GWP), limiting onsite refrigerant quantity, and reducing refrigerant emissions will reduce a building's carbon footprint.

The GWP of refrigerants is an important factor that should be addressed as we continue to electrify buildings. Common refrigerants in use today have GWPs in excess of 1,000, which means they are over one-thousand times more powerful a greenhouse gas than CO_2, which has a GWP of 1.0. See Volume 2, Figure 2.7 for a listing of the GWP of common refrigerants.

As the HVAC industry has evolved, there has been an ongoing transition to using lower GWP refrigerants (low examples being CO_2, propane, and ammonia). Manufacturers are introducing new refrigerants every year, particularly Hydrofluoro-Olefin (HFO) refrigerants and HFO blends, that provide reduced climate change impacts and in some cases can directly replace existing high-GWP refrigerants with minor adjustments to equipment parts, performance, and capacity.

Equipment type may also increase the amount of refrigerant in a system, which can result in greater GHG emissions impacts. Central chillers, for instance, have a fairly low refrigerant charge per ton of cooling. Variable Refrigerant Flow (VRF) — also referred to as Variable Refrigerant Volume (VRV) — systems have central compressors that send refrigerant throughout a building to zonal fan coil units to transfer energy. These systems, by design, have a much larger GWP because of the increased amount of refrigerant and the extensive pipe distribution system throughout a building. For this reason most VRF/VRV systems do not meet the threshold for earning the LEED v4 Enhanced Refrigerant Management Credit.

Volume 2, Section 2.5.1.3.2 provides a discussion of the role refrigerants play in assessing the carbon emissions impacts of design alternatives. For example, VRF/VRV systems have become increasingly popular due to claims about improved energy efficiency compared to more traditional alternatives (e.g., VAV systems with heat recovery). However, evaluations of the carbon metrics of VRF/VRV designs often show that any emissions reductions from their efficiency are undermined by the lifetime release of refrigerant (assuming a 2% leakage rate and 10% end of life leakage). Thus, the contribution of refrigerant releases must be included in system evaluations to fully assess alternatives and identify the options with low CO_2e emissions.

4.5_Construction Phase

For a discussion of the role construction practices play in decarbonization efforts, see Volume 2, section 2.7.

4.6_Operations Phase

The accuracy of the predicted energy performance of new buildings and major renovations has been much discussed over the past 20 years as green building certifications have brought new focus to the use of energy modeling as a design tool. The fact is that no predictive model, by itself, can guarantee actual performance. It is essential for the building industry to recognize and support the unique role of designers, builders, and owners/operators in helping to make the potential efficiency of each building a reality.

We have discussed in this Practice Guide how architects, engineers, and contractors can help make sure that the promised efficiency is actually delivered, but we feel it is also important to address some additional key considerations in assisting owners/operators to operate buildings as efficiently as possible: training, fault detection and diagnostics (FDD), and measurement and verification.

4.6.1_PROJECT DELIVERY AND TURNOVER

At the end of construction, there are standard steps taken by contractors to turn over a project: delivery of as-builts, Operations and Maintenance (O&M) manuals, warranties, training, etc. Yet, it is still commonplace to find that, within a couple of years of turnover, equipment is no longer operated in automatic mode under control of a building management system, setpoints for various system operational parameters have often been significantly altered, and initial operational efficiencies have degraded. Retro-commissioning activities have given us insight into the alterations that occur relatively soon after projects are turned over to an owner's operations staff. Thus, it is important to look for ways to improve the hand-over from the construction to the operations phase of a project in order to help operators maintain optimal operation of buildings. Improvements might include:

» **Training**

- Training of O&M staff is customary for commercial building projects; however, this training is usually delegated to the construction team, and historically, it has been focused on maintenance of individual system components. Unfortunately, this training almost never includes "systems" training, which should be focused on how components within the facility are intended to operate as a system, what "normal" operation should look like, and the methods available for troubleshooting off-normal operations. This training should be delivered by team members with the best "systems" understanding, which will typically be the engineers-of-record or the commissioning agent. Recording these "systems" training sessions on video will provide an extremely valuable resource for O&M staff to refresh their understanding as well as orient new members for proper integration onto the operations team.

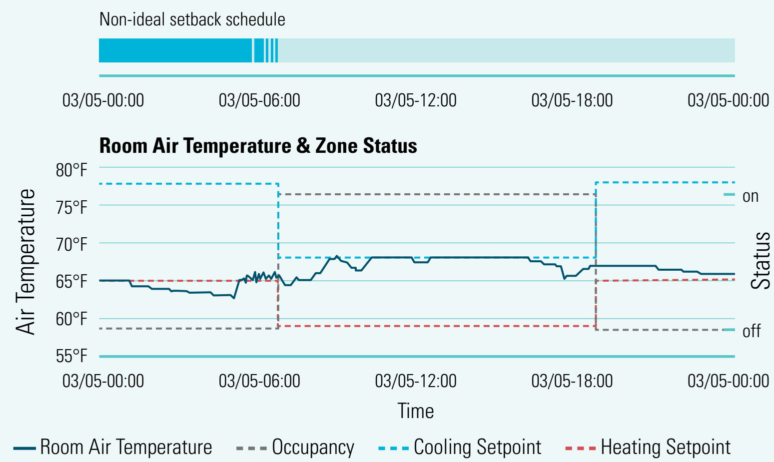
» **Fault Detection and Diagnostics (FDD) tools, integrated with facility management, service, and maintenance management systems**

- One of the most exciting developments supporting efforts to maintain optimal building performance over time is the advent of software platforms that detect system performance issues and that strive to help identify potential solutions to correct them;

- Fault detection and diagnostics tools collect data from central HVAC control systems in real-time (temperatures, flows, pressures, actuator control signals, etc.) and then apply a set of rules to identify anomalies (see Figure 4.18). These platforms have continued to develop in sophistication, and some will estimate the energy cost consequences once an issue is identified. Some provide methods for connecting observations and recommended corrections to maintenance management systems that assign and track corrective actions;

- In 2022, PG&E's Pacific Energy Center hosted a series of one hour presentations from FDD platform vendors as a follow-up to an all-day workshop on FDD in winter 2021,[23] and over fifteen vendors signed up to present their tools!

FIG. 4.18: SAMPLE OF ONE FDD PLATFORM'S IDENTIFICATION OF AN ANOMALY AND ITS POSSIBLE CAUSES.



PROBLEM: ABNORMAL ROOM AIR TEMPERATURE SETPOINT SETBACK SCHEDULE

Although a setback schedule was identified, the heating temperature setpoint increased during the setback period(s), which was unexpected.

Possible Causes:

– Zone or AHU controls or scheduling error
– Zone thermostat manual overide

Faults and opportunities investigated by this diagnostic:

Damper cycling check. Heating and cooling deadband check. Max room air temp check. Night setback check. Non-ideal setback schedule check. Room air temp setpoint tracking. Sensor checks. Setpoint error check. Slow air temp response check. Zone on while unoccupied check.

23 PG&E's all-day FDD workshop is available for free through their on-demand training platform https://pge.docebosaas.com/learn/course/internal/view/elearning/1183/new-developments-in-fault-detection-and-diagnostics-previously-recorded

4.6.2_POST-CONSTRUCTION PRACTICES

Volume 2 of this Practice Guide addresses a number of critical post-construction practices: monitoring-based commissioning, retro- and re-commissioning, and deconstruction. Existing building commissioning projects have consistently shown that it requires effort to ensure that a building operates optimally over the long term, and that the cost of these efforts are some of the most cost effective investments in energy efficiency available to building owners.[24]

For commercial buildings, many features are commonly incorporated that help owners and operators track building performance. When utilized, these features can be effective tools for ensuring that any building performs to its original design intent and meets the energy efficiency requirements built into the design.

4.6.2.1_Measuring, Monitoring, and Reporting Operational Energy & Water Consumption

Early buy-in from operations staff, coupled with robust training, can inspire proactive energy management through energy monitoring and ongoing commissioning. Real time energy and system monitoring, once a project is built, can uncover energy waste from sources such as equipment and control device failure, human error, and functional drift. Once identified, corrections can be made.

One of the best ways to ensure that buildings are operating as "intended" by the design team after being turned over to an owner is to validate the system performance through a formal Measurement and Verification (M&V) process.

M&V of a building's performance can be as simple as comparing utility bills to a performance prediction, which is materially different from an energy use estimate prepared for Energy Code compliance.[25] Deviations from predicted performance can be complicated to analyze and require careful evaluation in order to identify potential causes that can be acted upon. However, there can be a significant positive return on M&V investments. No one would think twice about asking a car dealer to explain why the actual gas mileage of your new car was only 50% of the EPA-rated mileage. Similarly, operation and management teams should use M&V to ensure their building is performing as predicted.

> "Ongoing Commissioning (OCx) is defined as the means and process to optimize and sustain building performance on an ongoing basis through investigation, analysis, and monitoring the operating conditions of building systems."
>
> **— Building Commissioning Association OCx Subcommittee, 2019**

An M&V process can use the power of a computerized building management system to gather performance data. Such systems are ubiquitous in commercial construction projects. Green building ratings systems typically encourage the use of submetering systems for tracking energy and water use in a manner that supports facility performance optimization. LEED has "Advanced Energy Metering'' and "Water Metering" credits for just this purpose, and BREEAM ("Building Research Establishment Environmental Assessment Method") offers credits for sub-metering of major energy-consuming systems and of high energy load and tenancy areas.[26] Building Energy Codes are also moving towards requiring more submetering in order to help facilitate a future where all buildings perform to their design targets.

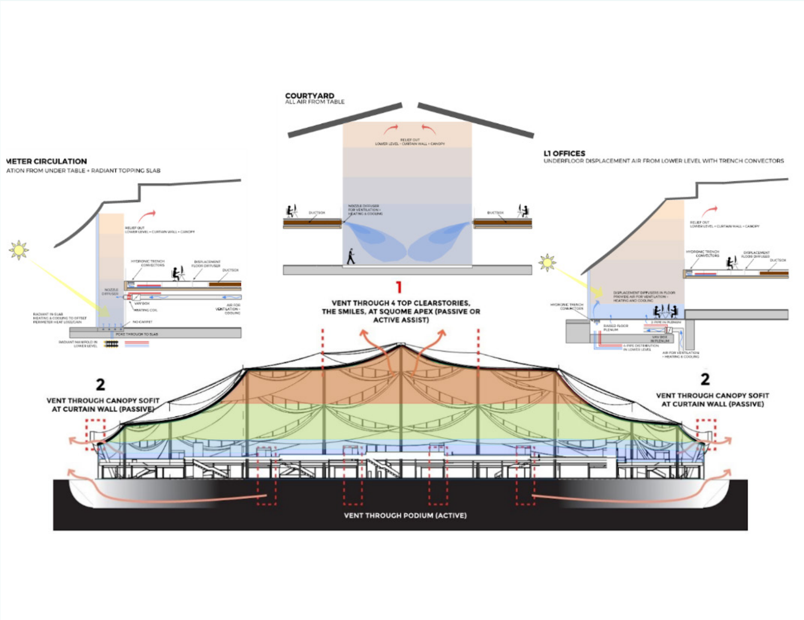
24 "Building Commissioning Costs and Savings Across Three Decades and 1,500 North American Buildings," Eliot Crowe et al, Lawrence Berkeley National Laboratory, Energy Technologies Area, November, 2020

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

26 https://www.breeam.com/BREEAMInt2016SchemeDocument/#06_energy/ene02.htm?

4.7_Case Studies

4.7.1_GOOGLE BAY VIEW



Project Location: Mountain View, California

Completion Year: 2021

Project Size: 1.1 million square feet

What:

Designed by architects Heatherwick Studios and Bjarke Ingels Group (BIG), the Google Bay View campus is a 1.1 million square foot office project on the northern edge of Moffett Field. The project uses a multi-tiered canopy system interspersed with clerestories for daylight and views. The canopy roof captures rainwater for reuse and is covered by 3.5 megawatts of solar panels.

The project uses heat recovery chillers coupled with an "Energy Pile" geo-exchange system fully integrated into the building foundation to exchange heat with the ground. Traditionally, structural piles have a single purpose, but Bay View's integrated design approach utilizes them to activate the thermal mass of the ground underneath and enable all-electric heating and cooling.

Out of roughly 4,500 structural piles, about 2,300 are thermally activated, making this the largest Energy Pile installation in North America. This system provides 100% of annual heating and 95% of annual cooling, cutting carbon emissions by half and energy use by 36% compared to a code-compliant building.

Many large HVAC systems use cooling towers for high efficiency cooling at the expense of large volumes of water use. Most all-electric HVAC systems retain this approach and then add electric heat pumps or electric boilers for heating. Consequently, this increases costs while continuing to rely on increased water consumption for cooling. By integrating the heating and cooling into a single system, costs are reduced because a single set of equipment (the heat recovery chillers) are providing both heating and cooling. Additionally, by storing heat in the ground, this innovative system also saves 90% of water that would have been used to reject heat in a cooling tower.

The central heating and cooling plant is so efficient that it allowed the designers to absorb the energy penalty associated with using a 100% outdoor air air-handling system. This approach improved the indoor air quality and also eliminated the need for return air shafts, unlocking additional usable floor area.

Finally, the project implemented all-electric kitchens, completely eliminating natural gas use from the site.

How:

HVAC	- Heat recovery chillers with geo-exchange energy piles - 100% dedicated outdoor air system - Heat recovery on exhaust air - Stratified displacement ventilation - Targeted radiant heating and cooling in perimeter spaces
Domestic Hot Water	Heat pumps connected to the ground-source heat exchanger
Cooking	Induction and electric resistance
Building Envelope	Continuous exterior insulation; Canopy structure which shades facade glass; high volume to skin ratio
Electric Load Offset	3.5 MW Building Integrated PV Array
Actual EUI	55 kBTU per SF per year (modeled); 84 (code baseline)
Developer / Client	Google
Architect	Heatherwick Studios and Bjarke Ingels Group (BIG)
MEP Engineer	KPFF Engineers

Trade-offs or Challenges:

- Google encouraged the design team to approach the project holistically. Any design element with a single-purpose is a missed opportunity to capture value. This strategic thinking led to combining the geo-exchange elements into the piles.
- Risk mitigation of the geo-exchange system was critical, including visiting construction sites in other geographic regions, performing numerous test piles, stringent QA/QC process during construction, and validation testing at each stage of construction.

Lessons Learned:

- Construction planning must integrate mechanical trades into the structural foundation work schedule to thoroughly coordinate work and avoid construction schedule extensions.
- Contrary to popular myths, electrical service size was not impacted by the all-electric design; however, more panels and feeders for kitchens were required (offsetting the savings from eliminating gas piping).
- Waste heat recovery from kitchen exhaust is possible, but it is maintenance intensive and reliant on active grease monitoring (with fail-safes).

4.7.2_MICROSOFT CAMPUS MODERNIZATION PROJECT

Project Location: Redmond, WA

Completion Year: Estimated 2023

Project Size: 3,000,000 square feet

What:

Microsoft's East Campus Modernization Project is a major update that will replace the company's original 14 office buildings with 17 new buildings, featuring 3 million square feet of office and amenity space across a 72 acre site. The new office buildings are designed and clustered into four distinct areas that are blended together to create a unified campus. The entire site is designed for pedestrians and cyclists, with no surface driving. All parking is contained below grade in a garage that connects and supports the areas above.

How:

Campus	Fully electric, zero carbon campus
Thermal Energy Center	All-electric thermal energy center, which uses ground-source heat loops, reduces energy consumption by over 50% compared to typical utility plants
Cooking	All-electric cooking, with induction for 75% of griddles and ranges
Embodied Carbon	30% reduction in A1 to A3 embodied carbon compared to 2019 baselines[27]
Electric Load Offset	60 kW PV Rooftop System will generate 58,000+ kWh of energy annually
Energy Procurement	Procurement of carbon-free renewable energy for 100% of the campus
Developer	Microsoft
Construction Managers	CBRE, OAC Services, JLL
Sustainability Consultant	Atelier Ten
Culinary Sustainability Consultant	Chef Chris Galarza (Forward Dining Solutions LLC.)
Architects	LMN, NBBJ, ZGF, WRNS, DS+R, Heliotrope, Gensler, Berger/Olin
Energy Modelers	Morrison Hershfield, Stantec, Integral Group, BuroHappold, Interface Engineering, PAE

General Contractors	Skanska Balfour Beatty, GLY, Sellen
MEP Engineers	AEI Affiliated Engineers, Metrix Engineers, McKinstry, MacDonald-Miller, PAE, Apollo Mechanical, Hermanson, Auburn Mechanical, Stantec, Coffman, Gerber Engineering, Cochran Electric

Trade-offs or Challenges:

» **Commitment to a combustion-free campus.** Microsoft committed early on to reducing greehouse gas emissions in the Campus Modernization Project. The first step was to ensure that the new campus didn't emit CO_2 onsite during daily operations. Microsoft required only electric building energy systems; the campus will not include natural gas infrastructure.

» **Acknowledgment that high-performance all-electric systems come at a cost.** The Campus Modernization is served by a Thermal Energy Center (TEC), including 875 geowells and over 222 miles of piping that comprise a ground source heat loop system, which saves energy year-round by providing cooling in the summer and heating in the winter. Though this system comes at a cost compared to some code-compliant alternatives, the TEC is expected to reduce energy consumption by over 50 percent compared to a typical utility plant. As a long-term owner, Microsoft will benefit from the reduced utility costs over the project's life.

27 Cradle-to-gate (A1 to A3): this refers to the time frame from when a component's life starts to when it leaves the manufacturing facility ("gate"), before it is transported to the project site. This is often referred to as the "Product Stage". For further discussion, see Volume 6, Embodied Carbon.

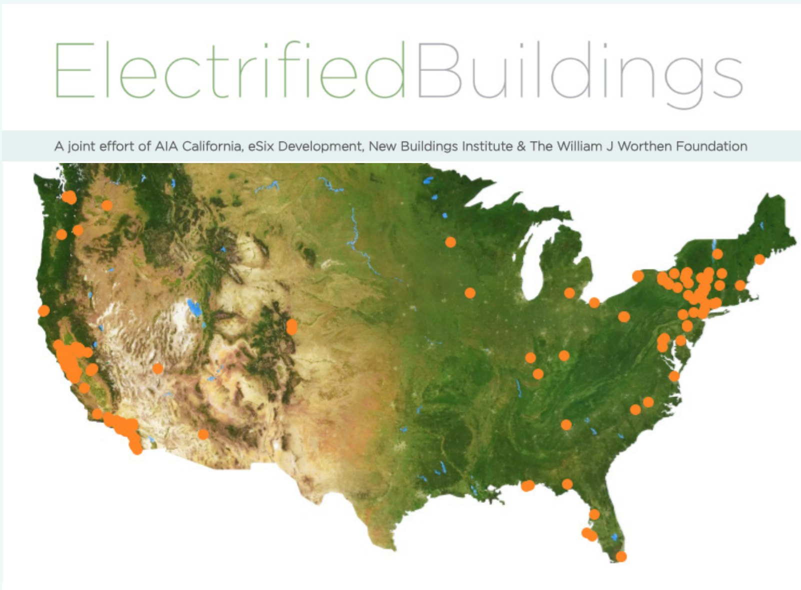
- **Limitation of energy consumed.** In addition to the TEC's efficient heating and cooling equipment, each project on campus was required to limit its energy use. Microsoft set energy budgets for different major space types on the campus, such as work spaces, food service, retail, wellness, and the garage. Early-phase energy analysis identified reasonable energy use intensity (EUI) targets for these different program types, and the owner and team committed to hit the low end of these ranges. The Campus Modernization projects were also required to reduce whole-building EUI by 25% below the baseline (ASHRAE 90.1-2010).
- **Desire to eliminate all natural gas use.** Natural gas is still status-quo for some process uses, such as food service. The Campus Modernization includes food service facilities designed to serve 10,000 – 12,000 meals per day. Many chefs and cooks are trained on gas equipment, which is familiar and highly effective. Eliminating gas from the campus meant eliminating gas from the kitchens too. Initial conversations with the dining teams centered around throughput concerns, the ability to cook a variety of foods, particularly with respect to authenticity of global cuisines, and reduced potential to attract popular restaurants if requiring them to change their cooking methods. The project prioritized the zero combustion decision and worked through numerous challenges, including the selection of induction equipment. Electric-resistance radiant equipment was initially proposed. Energy modeling and cost estimation informed the owner that induction cooktops are more energy efficient than radiant but have an upfront cost premium. In alignment with low energy campus goals, the client selected induction equipment for the majority of the cooktops, leading to a reduction of over 500,000 kWh of energy annually.
- **Investment in onsite and offsite renewable energy.** The Campus Modernization includes a PV array on the roof of the TEC. The density of the Campus Modernization made it infeasible to generate enough energy onsite for the campus to be truly net-zero. However, the scale of the project made offsite renewable energy generation viable. Currently, the campus is powered by 100% carbon free electricity. Upon opening, Microsoft will contract for the output from a new wind or solar resource in the state to power the campus through a power purchase agreement (PPA).
- **Reduction of embodied carbon.** Microsoft was the first large corporate user of the Embodied Carbon in Construction Calculator (EC3) tool, which is used to identify lower-carbon options for building materials. EC3 use starts early in design when structural options are evaluated, and the pace picks up as the project moves into procurement. Specifications must require environmental product declarations (EPDs) for key material categories, such as concrete, steel, and gypsum wall board. The Campus Modernization project team committed to reducing embodied carbon by at least 30 percent compared to 2019 baselines established by the Carbon Leadership Forum (CLF).
- **Reduction in onsite-generated greenhouse gas emissions during construction.** The project's general contractors collaborated to identify best practices that reduce carbon emitted on the construction site. They agreed to track fossil fuel use of: off-road vehicles, equipment, and tools used within the jobsite; delivery vehicles for building materials; and crew transport provided by the general contractor. In addition to an anti-idling requirement, best practices include equipment electrification, prioritizing of Tier 4 final equipment (i.e., for large equipment used for earthwork or paving), retrofitting older large equipment, and use of biofuel blends.

- **Use of benchmarking systems to help uphold sustainability goals.** The Campus Modernization is pursuing a LEED v4 Platinum rating and International Living Future Institute (ILFI) Zero Carbon certification. These rating systems reinforce Microsoft's values for the project and keep the project team focused on an achievable outcome: certification. Their structure provides a framework under which project team members can build off of knowledge shared from other projects that pursued similar goals. While the Campus Modernization might have pursued many of the same sustainability goals without these benchmarking systems, they have proven invaluable in guiding the teams toward the verified completion of these goals.

Lessons Learned:

- **Strong partnerships drive industry advancement**. Focus groups were convened from experts in various topics (energy, materials, water, daylight, etc.) identified within the team. These groups met regularly and collaborated to establish goals alongside Microsoft's building teams. By involving the team members responsible for meeting sustainability goals during this initial goal setting stage, sustainability ambitions were higher and more achievable than if they had been imposed from the top down.
- **Establish energy goals early on in the project, including percent reduction targets and EUI budgets**. The EUI budget prompted a close look at equipment loads, which represent an increasing percentage of building energy use. Teams need to take the time to accurately understand building equipment operation and work within the budget by developing innovative strategies to reduce these loads.
- **Define assumptions and processes for energy modeling.** To ensure success on a complex project with multiple design teams, defining modeling assumptions allows for energy budgets to be accurately tracked and ambitious goals to be met.
- **Incorporate modeling milestones and deliverables into the project schedule.** Energy modeling should be used to inform design approaches, rather than simply predicting outcomes. On a complex project, agreeing to milestones and deliverables early is even more important since modeling must be completed to inform design on a different schedule than modeling for Code or LEED compliance documentation.
- **In a commercial kitchen, induction equipment saves a lot of energy**. For example, the project teams found that induction ranges and griddles can save over 500,000 kWh of energy annually compared to radiant equipment.
- **Choose a metric and a target for embodied carbon reduction goals.** The project used the 2019 baselines and set a reduction target of 30% for materials included in those baselines. Large reductions have been found in ceiling tiles, carpet, concrete, and steel.
- **Track construction activity carbon emissions.** Transport and construction carbon emissions can be tracked and reduced. Construction practices are not static, and new innovations can reduce carbon emissions.
- **Set goals and associated requirements during the pre-design phase of the project.** Make sure that requirements and strategies are included in both project scope and contract documents.
- **Commit to sustainability certifications early on in the project.** Evaluate certification options and identify synergies between them to streamline scope and efforts. Define roles and responsibilities and integrate milestones into the project schedule.
- **Include EPD requirements in specifications.** Collect product-specific Environmental Product Declarations (EPD) and track reduction targets against embodied carbon goals.

4.7.3_OTHER CASE STUDIES



An ongoing effort to develop the largest and most diverse data set of all-electric and decarbonized buildings in the United States was started in 2020. This database — https://electrifiedbuildings.org/ — is a project of e6 Development (https://www.esixdevelopment.com/) in collaboration with a handful of other organizations and provides access to case study information on many projects. This website also provides an opportunity for all decarbonization practitioners to contribute all-electric building case studies of their own.

ACKNOWLEDGMENTS

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WRNS STUDIO

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CONNECTING POLICY AND PRACTICE WITH DESIGN URBAN FABRICK

WILLIAM J WORTHEN FOUNDATION

Contributors

Building Decarbonization Practice Guide Content Leadership

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

Project Management

» **Brett Rosenberg,** LEED AP, Treeline Strategy, LLC
» **Steven Guttmann,** PE, BCxP, LEED Fellow, Guttmann & Blaevoet, Principal Investigator

Graphic Design

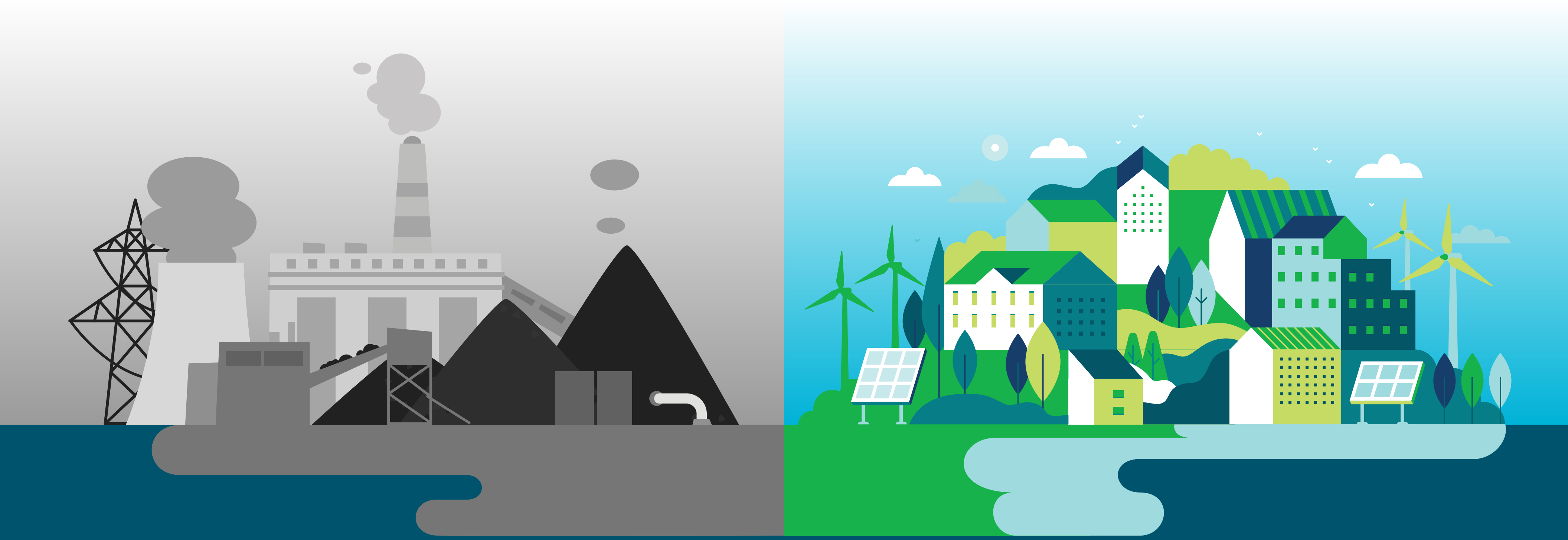
» **Stoller Design Group**

Copy Editor

» **Geoff Martin,** Wheelhouse Writing Services

Working Group Members and Content Contributors

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



THE BUILDING DECARBONIZATION PRACTICE GUIDE

A Zero Carbon Future for the Built Environment

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VOLUME 5:

All-Electric Kitchens: Residential + Commercial

VOLUME 5 CONTENT LEADERSHIP

- **Rachelle Boucher,** Kitchens to Life
- **Chef Christopher Galarza,** Forward Dining Solutions, LLC
- **Steve Guttmann,** Guttmann & Blaevoet
- **Teresa Jan,** Gould Evans
- **Pauline Souza,** WRNS Studio

VOLUME 5 ADVISORS

- **Steve Gross**
- **David Kaneda**
- **Chef Tu David Phu**
- **Brett Rosenberg**

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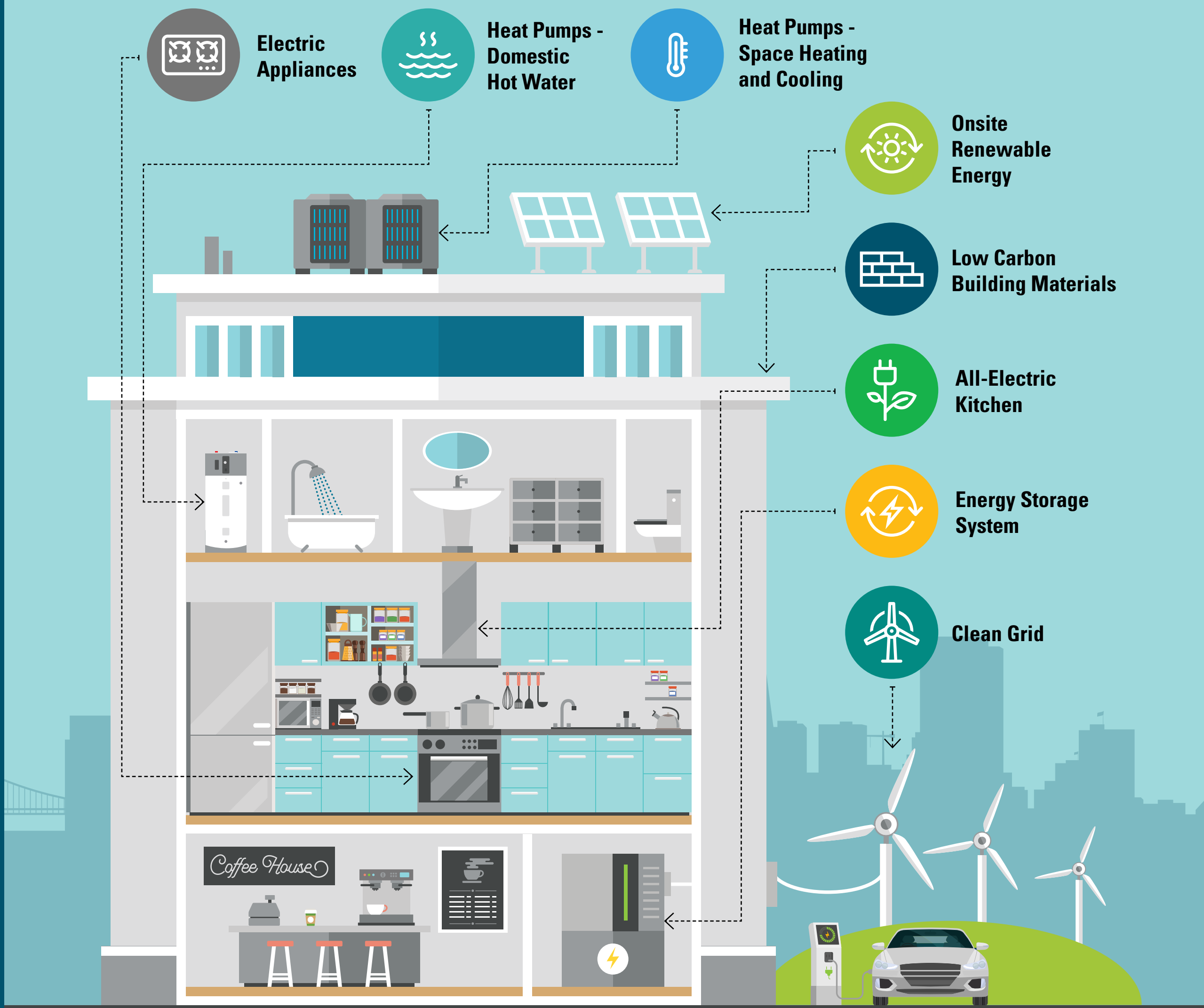

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VOLUME 5

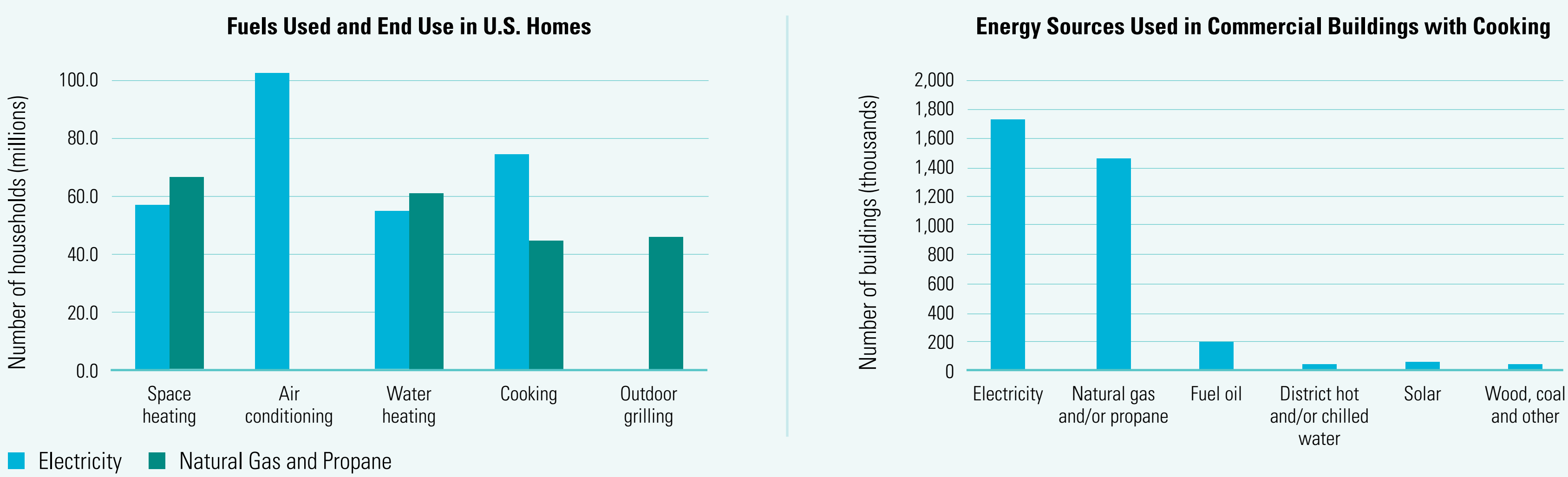
All-Electric Kitchens: Residential + Commercial

5.0_All-Electric Kitchens: Residential + Commercial

A traditional 20th century kitchen typically contains a combination of natural gas and electric appliances. This is true of kitchens at restaurants, in multifamily residential buildings and in large commercial operations. But an all-electric kitchen — one that reflects the goals of decarbonization — is one with no natural gas or other fossil fuel-based energy source. Kitchens are the last place that the post WWII myth of "better living through gas" has been hard to overcome; this Volume explains why this is a myth and how to design a better kitchen — both residential and commercial — in an all-electric paradigm.

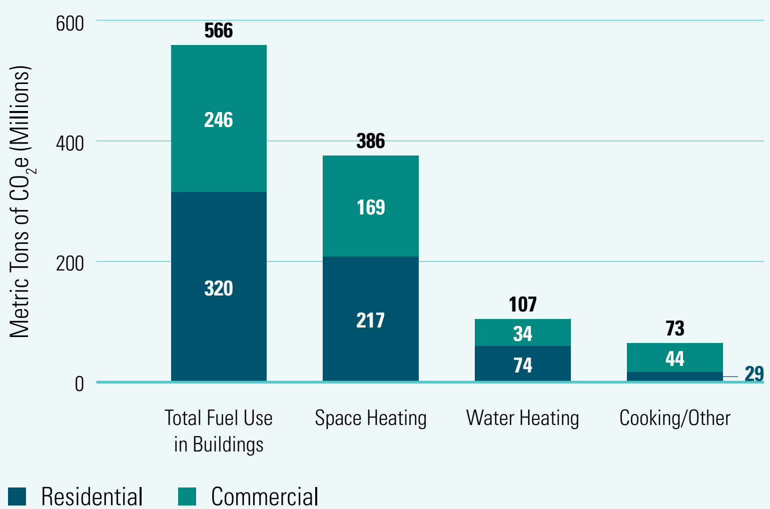
This Volume focuses strictly on kitchens, which is still a source of natural gas use within a significant number of residential and commercial buildings (See Figure 5.1A), and is responsible for perhaps as much as 13% of total US greenhouse gas emissions from buildings (see Figure 5.1B). Kitchens present superb opportunities for decarbonization since electric cooking technology has advanced considerably in the past ten years and costs are becoming more competitive due to increased market penetration.

FIGURE 5.1A: PREVALENCE OF NATURAL GAS AND PROPANE USE IN RESIDENTIAL BUILDINGS, AND IN COMMERCIAL BUILDINGS WITH COOKING



Source: 2015 Residential Energy Consumption Survey Data, U.S. Energy Information Administration (https://www.eia.gov/consumption/residential/data/2015/index.php?view=characteristics) and 2018 CBECS Survey Data (https://www.eia.gov/consumption/commercial/data/2018/index.php?view=characteristics#b22-b33)

FIGURE 5.1B: CARBON EMISSIONS OF FOSSIL FUEL END USES IN U.S. BUILIDINGS (2015)



Source: The Economics of Electrifying Buildings, RMI 2018

The challenges, however, include overcoming the inertia of the construction industry as well as dealing with the impacts on the dwindling number of natural gas users from having to carry an ever greater burden of the cost of stranded gas assets.[1] Perhaps most challenging, however, is overcoming cultural preferences for gas cooking as well as educating the public about modern induction and other high efficient electric cooking sources.

In an effort to synthesize information and help designers, architects, and engineers make more enlightened building decisions, this Volume presents both the pros and cons of electric kitchen technologies. It looks at questions of performance, health benefits, and greenhouse gas reductions, and it presents design considerations for all-electric kitchens in multifamily residential and commercial projects. Throughout, cost considerations are woven into the discussion.

> "What Winston Churchill once said of architecture — *'First we shape our buildings, and then they shape us'* — might also be said of cooking. First we cooked our food, and then our food cooked us."
>
> Source: Michael Pollan, *Cooked: A Natural History of Transformation*

5.1_Electric Kitchen Technology

Cooking over an open flame is perhaps the oldest means of preparing edible food. Watch any house hunting or celebrity chef program on TV, and it's easy to assume that the luxury gas ranges/cooktops will continue indefinitely. Unfortunately, cooking over a flame, whether indoors or outdoors, often means cooking with gas. Electric coil cooktops and electric resistive cooktops are slow to heat up, respond poorly to temperature adjustments, and continue to be seen as inferior for serious chefs. Given some of these perceptions, this electric cooking technology hasn't accelerated the all-electric kitchen approach, and gas appliances remain the top choice for performance, quality, and luxury. Fortunately, induction cooking and other recent technology advances in modern electrical cooking appliances have expanded the range of options and the effectiveness for all-electric residential and commercial kitchens. As many multifamily

1 https://www.edf.org/sites/default/files/documents/Managing%20the%20Transition_1.pdf

residential developments and well-respected restaurants — including Michelin starred establishments — install induction cooking equipment to prepare fabulous and innovative meals, the paradigm that cooking with gas is the best option is undergoing a significant shift.

All-electric kitchens, especially when outfitted with induction equipment, do in fact allow for precision-temperature cooking for authentic cuisine. Additionally, they result in a healthier environment for the people who cook in commercial and residential kitchens.According to the US EPA, Americans spend an average of 90% of their time indoors and that indoor air quality is often considerably worse than outdoor air quality.[2] Given this reality, indoor air quality should be a significant public health concern especially given how vulnerable so many people are to respiratory disease and chronic respiratory problems.

A COMMON LANGUAGE

For clarity when researching residential cooking appliance options, it is helpful to know a few terms. While the term "stove" or "stove top" is still used, it is outdated and not very specific.

Cooktop: a drop-in gas, electric or induction unit without an attached oven

Oven: a cooking chamber with no attached cooktop.

Convection oven: ovens with built-in fans to circulate heat.

Range: a cooktop and oven combination. Can be gas, electric or dual fuel and can be a built-in or a slide-in style.

Rangetop: similar to cooktops, but they are often more powerful (higher BTU) and wrap around the front of the counter with controls on the front.

2 https://www.epa.gov/report-environment/indoor-air-quality

5.1.1_DO ELECTRIC KITCHENS PROVIDE COST SAVINGS?

The transition to modern all-electric kitchens is still in its infancy. While the cost of certain appliances still exceeds more conventional kitchen equipment, one can be certain that the cost of appliances will continue to fall as this transition accelerates and market share increases. Moreover, there is ample evidence that the new generation of all-electric kitchens can be built at a no- or low-cost premium. This is due to many of the savings discussed below.

Gas Infrastructure Savings
All-electric kitchens save a significant amount of money in new construction projects by eliminating the need for gas utility connections and indoor gas plumbing systems. For retrofits, some cost will be associated with capping off the existing gas main, but future costs for gas infrastructure maintenance will be avoided. In all-electric multi-family residential projects, significant space and cost savings can also be realized from eliminating the multiple gas meters that would otherwise be required.

Energy and Utility Savings
Electric kitchens are cooler because of reduced heat loss to the environment. This is particularly beneficial in hot climates where air conditioning use may be reduced, saving on overall energy costs. Furthermore, as discussed in Volume 2, section 2.5.1.3.3, the future cost of gas may further tilt the scale in favor of reduced operating costs for all-electric kitchens.

Labor Savings
In commercial kitchens, induction cooking increases productivity and allows for a faster throughput. Furthermore, less time is required for scrubbing and clean-up of cooking appliances, pots and pans, hoods and ventilation. This offers the added benefit of increasing the revenue-per-labor-hour ratio in commercial kitchens, or simply reduced cleaning time in residential kitchens.

Longer Life of Cookware
The violent nature of fire tends to alter the structure of pans, degrading and warping the metal over time. Induction, however, works within the molecular structure of cookware to more efficiently introduce a large amount of heat energy without adverse impacts.

5.1.2_ALTERNATIVES TO ALL-ELECTRIC KITCHENS: ELECTRIC-READY KITCHENS

Many municipalities that have adopted all-electric ordinances have exceptions that allow the use of gas appliances in exchange for designing an electric-ready kitchen. Thus, the decision to maintain the use of gas appliances is often made due to a reluctance to let go of well-established practices. Until perceptions change and costs come into alignment, future-proofing a building for both gas and electric-ready will likely cost more in the short term.

While not strictly aligned with the ideals of full decarbonization, when a project cannot justify an all-electric kitchen, electric-ready kitchen designs can at least set a project on the path to decarbonization.

An electric-ready kitchen may run on gas at first but is designed and wired so that gas equipment could be easily replaced with electric appliances, and gas infrastructure can be easily dismantled and removed sometime after the original kitchen installation. This helps mitigate the long-term effects of a costly future retrofit.

There are at least two important considerations when planning an electric-ready kitchen:

» Try to incorporate electric kitchen equipment to replace any and all gas equipment that would have an open flame. Equipment that uses open flame is the greatest contributor to poor indoor air quality and has the biggest risk of causing kitchen fires. Open flame equipment also contributes to the degradation of the cookware that regularly sits on the flame.

» For commercial kitchens, identify the equipment with the largest gas usage and replace it with an electric/induction counterpart.

5.2_Induction Technology and Other Electric Equipment

Of all the electric cooking options, induction cooktops are often the most discussed but perhaps the least understood. Relatively new in American kitchens, modern induction cooktops have significant benefits over electric coil, electric ceramic, and gas cooktops (see Figure 5.2). They also offer superior culinary performance, energy efficiency, and labor efficiency, as well as improved safety. Though there has been much advancement with induction cooking technologies, a lingering misperception persists that induction cooktops are either the same as or will perform just like traditional electric coil or electric resistive ceramic cooktops. Given this misunderstanding, a brief overview of cooktop technologies is in order.

FIGURE 5.2: COOKTOP HEAT SOURCES: THREE WAYS OF PROVIDING A HEAT SOURCE ON A COOKTOP: ELECTRIC COIL, GAS, AND INDUCTION

Source: https://factorybuilderstores.com/compare-electric-gas-induction-cooktops/

5.2.1_TRADITIONAL COOKTOPS VERSUS INDUCTION HOBS

A gas burner heats food by creating a flame that is controlled by the mix of oxygen and natural gas applied to the outside of a pot. This is heating the food via convection. However, much of the heat wicks off the pot and thus ends up in the exhaust hood or throughout the kitchen. This results in unhealthy air quality, an uncomfortable thermal environment, and a great deal of lost energy.

Electric coil cooktops are constructed of spiral steel tubing that houses a heating element powered by electricity. Heat is thus transferred by conduction from the coils to the pot. The temperature is adjustable, but the temperature will rise and fall with a significant time lag. Coils also radiate heat downward and to the sides, reducing their efficiency.

Electric ceramic cooktops appear similar to induction cooktops but function quite differently. The coiled metal elements under tempered ceramic glass are electrically heated to the desired temperature. The coil transfers heat to the pot via a combination of convection/conduction (from the coil, to the air under the glass, to the glass, to the pot) and radiation (from the coil to the bottom of the pot). Due to the unit having to convert the electrical energy into heat, electric ceramic cooktops are slower and less energy efficient than induction, and heat spreads over the entire ceramic top. One quick way to differentiate a ceramic cooktop from induction is that the coil heating elements can be seen glowing under the ceramic glass plate when in use. Currently, electric ceramic is cheaper than induction, but it does not perform as precisely and efficiently.

An induction hob contains a coil of copper wire underneath a tempered ceramic glass plate. An alternating electric current is passed through it, resulting in a magnetic field. When ferrous cookware is placed in the magnetic field, it produces an eddy current. The resistance to the eddy current flowing through the metal creates heat in the pot. To visualize this, we need to understand two things:

1. How metal is structured: metal has a linear molecular structure that makes it a great conductor of heat and electricity.
2. How a microwave works: a microwave works by using the aforementioned "microwaves" to excite the water molecules in the food to oscillate at such a high rate of speed that the friction on a molecular level creates the heat that cooks/heats the food from inside out.

Both of these physical phenomena are used in induction cooking. As the magnetic current generated in the coils of the induction unit is created, that current is excited and oscillates the magnetic molecules in the metal of the pan exactly the same way the water is excited in the microwave. Due to the linear structure of the metallic molecules, this allows for the easy flow of energy into the pan and thus creates the heat. Figure 5.3 presents how induction works.

In an induction hob, unlike the other cooktops, the energy is transferred directly from the coil into the pot — and only the pot. Therefore, the cooking surface and surrounding area remain relatively cool, safe, and user friendly. Only the surface directly under the pot becomes hot, from heat transferred back out of the pot to the ceramic glass. This means that more of energy is transferred directly into the food, thus speeding up cook times and creating a kitchen with much cleaner air and a more comfortable thermal environment.

Similarly, induction cooktops are more efficient than gas, transferring heat to the food with an 80% efficiency rate, vs 30–35% heat transfer efficiency for gas. Furthermore, induction cooktops are among the top rated by Consumer Reports and have received many positive reviews by professional chefs.[3]

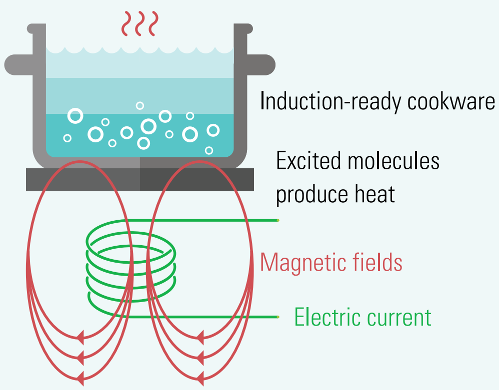
> "Once you get the hang of them, they're far easier than cooking on gas or electric."
>
> **— Celebrity Chef James Ramsden**

3 https://www.consumerreports.org/electric-cooktops/the-best-induction-cooktops/

HOW DO I KNOW IF MY EXISTING POTS WILL WORK ON AN INDUCTION COOKTOP?

To tell if a pot or pan is compatible with your induction stove, hold a magnet to the bottom. If the magnet clings to the underside, the cookware will work on an induction cooktop. If the magnet grabs the pan softly, you may not have good success with it on your cooktop.

FIGURE 5.3: HOW ELECTRIC INDUCTION COOKING WORKS



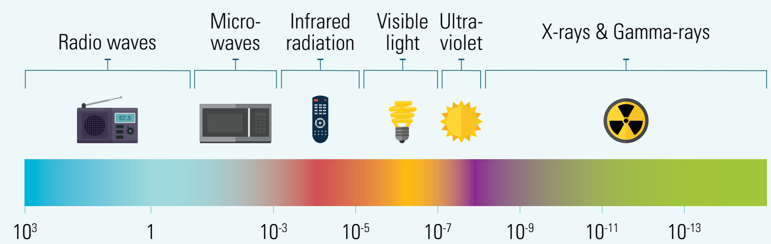
- » An electrically charged copper coil underneath the hot top surface creates a electromagnetic field.
- » When ferrous metal cookware (magnetic) is placed in this field an electric current is induced, causing the cookware to heat.
- » The cookware becomes the heat generator, making the appliance very energy efficient.
- » Without cookware in the electrmagnetic field, no energy is consumed and no heat produced.

Source: Image from Richard Young, Mark Duesler, Hot New Induction Technologies for Cooler Kitchens

5.2.2_INDUCTION COOKING AND ELECTROMAGNETIC FIELDS

All electronic equipment (such as cell phones, electric wiring in buildings, baby monitors and WiFi systems) create electromagnetic fields (See Figure 5.4). Like with the arrival of microwave ovens, each new technology has faced consumer concerns about whether electromagnetic fields (EMFs) can cause bodily harm. The same is true now for induction cooktops.

FIGURE 5.4: THE ELECTROMAGNETIC SPECTRUM



There are many reasons that these concerns are overstated in relation to induction cooking. Induction cooktops work by creating a fairly powerful but low frequency (24 kHz) magnetic field. While high frequency electromagnetic radiation (such as ultraviolet or gamma rays) is known to cause cellular damage, potentially resulting in cancer, lower frequency radiation such as radio signals and the earth's magnetic field are pervasive and not harmful. The magnetic field that emanates from an induction hob is equally harmless, and the strength of the field falls within inches of the hob, which is why pots need to be touching the cooktop surface to heat up.[4]

4 https://academic.oup.com/europace/article/8/5/377/460579

Granted, a small measure of uncertainty still exists about the low frequency non-ionizing radiation generated by many common devices, like computers, WiFi hotspots, and LED lights. The EMF from an induction stove is classified as a class 2b carcinogen, alongside coffee and pickles: "it is possibly carcinogenic to humans — but no conclusive evidence has yet been found."[5] The National Cancer Institute notes that "No mechanism by which ELF-EMFs[6] or radiofrequency radiation could cause cancer has been identified."[7]

One final area where some caution is warranted concerns people with implanted pacemakers and defibrillators, which can be sensitive to EMFs. Like any other equipment, induction cooking carries an inherent — albeit minimal — risk to human health and safety, and misuse can exacerbate such risk. While the odds are extremely low that the pacemaker may malfunction if placed within a couple of inches of an operating induction hob, the risk is greater than if that same pacemaker was inches away from an open flame on a gas cooktop. As we will see in the next section, the benefits of induction technology far outweigh these concerns.

> "I have had elderly staff members and pregnant staff members, and after working with and learning about electric kitchen appliances I am more concerned about the harmful effects of the carcinogenic byproducts of burning natural gas than I am with any potential ELF and ELM that could come off of an induction unit."
>
> **— Chef Chris Galarza, Forward Dining Solutions LLC**

5 https://therationalkitchen.com/induction-cooking-safe/

6 Extremely Low Frequency Electro-Magnetic Frequencies (ELF-EMFs).

7 https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/electromagnetic-fields-fact-sheet

5.2.3_HEALTH AND SAFETY BENEFITS OF AN ALL-ELECTRIC KITCHEN

Non-combustible: All-electric kitchens with no open flames and no gas lines minimize ignition sources and mitigate the risk of gas leaks and gas-induced fires. The lack of open flames also eliminates the risk of grease fires and the burning of cloth and other combustible and flammable materials.

More thermally comfortable: Since there is almost no waste heat transferred into the kitchen, an all-electric kitchen is much cooler than its gas-powered equivalent. Commercial kitchens in particular — which are characterized by high occupancy and a great deal of moving about in tight spaces as well as long hours of use — stand to benefit most from a more comfortable ambient temperature. Cutting out gas powered equipment also reduces the demand on ventilation hoods and cooling equipment (saving cost and energy use). Most modern commercial kitchen hoods are specifically controlled by heat and smoke sensors that directly save energy in an all electric kitchen

Fewer accidents: Specific to induction cooktops, it is almost impossible to lean against a control knob and inadvertently turn on the hob since it requires both the selected hob to be turned on and a vessel placed on the unit before a connection can be made. Induction appliances have additional cooking and safety features such as cooking timers, alarms, and automatic shut off if a pot boils over or boils dry. Furthermore, fewer burns and other injuries occur with induction cooking. Unlike all other types of cooktops, the handles on pots and pans do not heat up considerably — only the surfaces contacting the induction hob are heated. The heated portions of induction equipment are more confined and efficient than other electric equipment, and there are no open flames as with gas cooking appliances; consequently, the risks of injuries occurring are minimal.

Healthier indoor air quality: all-electric kitchens using induction can offer better air quality due to the lack of combustion. Natural gas cooking appliances, which are currently used by a third of U.S. households, can contribute to poor indoor air quality, especially when used without an exhaust hood.

5.2.3.1_Combustion and Air Quality

Cooking with gas emits nitrogen dioxide (NO_2), carbon monoxide (CO), formaldehyde, carbon dioxide (CO_2), particulate matter (PM), and volatile organic compounds (VOCs), each of which can cause or exacerbate various respiratory and other ailments.[8] For people experiencing diminished lung capacity (including some survivors of COVID-19), it's now more important than ever to improve indoor air quality to ensure a better quality of life while at work and at home. Figure 5.5 describes the potential health impacts of several indoor air pollutants.

Gas burners are estimated to add 25–33% to the week-averaged indoor NO_2 concentrations during summer and 35–39% in winter. The variability between seasons likely reflects the fact that windows are closed and natural air ventilation is lower in winter.[9] Numerous studies have shown that elevated indoor NO_2 levels have been associated with chest tightness, shortness of breath, increased asthma attack incidences, and daily deaths.[10 11 12] At higher concentrations, NO_2 has been associated with increased sensitivity to allergens in patients with asthma.[13]

Exposure to carbon monoxide is most serious for those who suffer from cardiovascular disease, as it can enter the bloodstream and reduce oxygen delivery to the body's organs and tissues. Elevated indoor CO levels have been associated with increased incidences of chronic obstructive pulmonary disease, asthma symptoms, and lower respiratory system infections.[14]

FIGURE 5.5: OVERVIEW OF HEALTH EFFECTS OF MAIN POLLUTANTS FROM GAS STOVETOPS AND OVENS

Pollutant	Acute Health Effects	Chronic Health Effects
Nitrogen oxides (NOx)	Decreased lung function, asthma exacerbation, respiratory infection, stroke	Premature mortality, lung and breast cancer, cough, shortness of breath, asthma, wheezing, respiratory illness in children
Carbon monoxide (CO)	Death, brain damage, seizures, memory loss, dementia, headaches dizziness, nausea	Brain and heart toxicity, heart failure and cardiovascular disease, low birth weight
Fine particulate matter ($PM_{2.5}$)	Stroke, increased blood pressure	Premature mortality, bronchitis, asthma onset and exacerbation, low birth weight and preterm birth
Ultrafine particles (UFP)	Increased blood pressure	Cardiovascular disease, neurological disorders
Formaldehyde	Respiratory/eye/skin irritation, sneezing, coughing, nasal congestion, drowsiness, chest tightness, shortness of breath, asthma exacerbation, death (higher doses)	Cancer, asthma and bronchitis in children, damage to respiratory system, headaches, sleep disorders, memory loss, birth defects, low birth weight, spontaneous abortion

Source: Dr. Yifang Zhu, Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California, April, 2020, Table 2-8. https://coeh.ph.ucla.edu/effects-of-residential-gas-appliances-on-indoor-and-outdoor-air-quality-and-public-health-in-california/

8 https://ehp.niehs.nih.gov/doi/10.1289/ehp.122-A27

9 https://ehp.niehs.nih.gov/doi/10.1289/ehp.122-A27

10 Touloumi G, Katsouyanni K, Zmirou D, Schwartz J, Spix C, Ponce de Leon A, et al. Short-term effects of ambient oxidant exposure on mortality: a combined analysis within the APHEA project. Am J Epidemiol. 1997.

11 Jarvis D, Chinn S, Luczynska C, Burney P. The association of respiratory symptoms and lung function with the use of gas for cooking. Eur Respir J. 1998.

12 Hajat S, Haines A, Goubet SA, Atkinson RW, Anderson HR. Association of air pollution with daily GP consultations for asthma and other lower respiratory conditions in London. Thorax. 1999.

13 Tunnicliffe WS, Burge PS, Ayres JG. Effects of domestic concentrations of NO2 on airway responses to inhaled allergen in asthmatic patients. Lancet. 1994.

14 https://buildingevidence.forhealth.org/research-summary/cooking-emissions/

The indoor pollutant that scientists believe may be most harmful to human health is particulate matter (PM), including fine particulates (less than 2.5 micrometers in diameter) and ultrafine particulates (smaller than 1 micrometer). These are produced by both gas and electric burners and by cooking. They are potentially very harmful because they can enter the lungs and even the bloodstream or other tissues.[15] As Figure 5.6 demonstrates, the health benefits of electrictrification and clean air, vis-a-vis particulate matter, also provide economic benefits. Figure 5.7 suggests that while cooking in general emits particles of concern, these and many other pollutants are associated with cooking on gas stoves.

FIGURE 5.6: ESTIMATED ANNUAL MONETIZATION OF HEALTH BENEFITS FROM RESIDENTIAL BUILDING ELECTRIFICATION FOR FIVE CALIFORNIA AIR BASINS

Air Basin	All $PM_{2.5}$ Mortality Valuation (Annual)	Acute Bronchitis Valuation (Annual)	Chronic Bronchitis Valuation (Annual)
San Francisco Bay Area	$1.2 billion	$100,000	$58 million
South Coast	$1.0 billion	$97,000	$46 million
Mojave Desert	$0.6 billion	$57,000	$26 million
Sacramento Valley	$0.2 billion	$16,000	$7 million
San Joaquin Valley	$0.2 billion	$18,000	$6 million

Source: Dr. Yifang Zhu, Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California, April, 2020, Table 3-2. https://coeh.ph.ucla.edu/effects-of-residential-gas-appliances-on-indoor-and-outdoor-air-quality-and-public-health-in-california/

Much research shows that indoor air pollution is a health concern for residential kitchen occupants in particular, where ventilation is less strictly regulated than commercial kitchens.This is especially true for children and other vulnerable populations; refer to additional research provided in Section 5.3.3. Although commercial kitchens tend to provide good ventilation systems, a chef standing over a gas stove cannot help but regularly inhale the various harmful emissions produced by burning natural gas.

Contribution to Better Outdoor Air Quality: Research has shown that the combustion byproducts of indoor gas appliances generally get transported outside, via windows, doors, and ventilation systems such as the hoods over cooktops. The harm from CO, NOx and PM that can occur to building occupants can, in turn, harm those outside as well, as Figure 5.8 indicates (using California regions as examples).[17]

Finally, a recent study[16] determined that gas cooktops and stoves leak natural gas and other harmful pollutants, even when not in use. In fact, the study indicated that more than three quarters of gas appliances' emissions occur when in "steady-state off." According to the study, "Using a 20-year timeframe for methane, annual methane emissions from all gas stoves in U.S. homes have a climate impact comparable to the annual carbon dioxide emissions of 500,000 cars."

15 https://newscenter.lbl.gov/2013/07/23/kitchens-can-produce-hazardous-levels-of-indoor-pollutants/

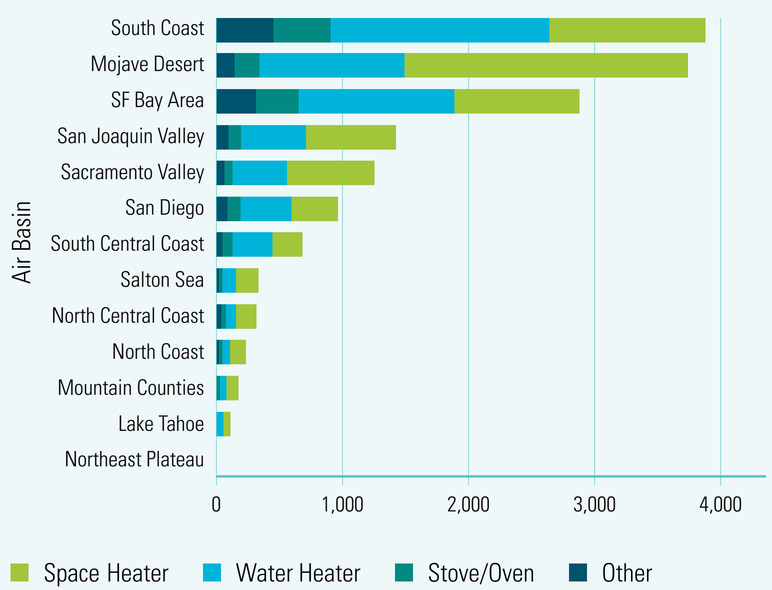
16 Eric D. Lebel, D.; Finnegan, C.; Ouyang, Z.; Jackson, R. Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. 2022. *Environ. Sci. Technol.*

17 Dr. Yifang Zhu, Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California, April, 2020, Table 2-8. https://coeh.ph.ucla.edu/effects-of-residential-gas-appliances-on-indoor-and-outdoor-air-quality-and-public-health-in-california/

FIGURE 5.7: DIFFERENTIATING POLLUTANTS FROM COOKING FOOD VS. GAS FUEL

Pollutants Generated from Cooking Food (regardless of stove type)	Pollutants Associated with Gas Stoves
Particulate Matter (PM_{10}) Small particles with a diameter less than 10 micrometers. Commonly measured in cooking activities like frying or broiling with the highest emissions levels.	**Ultrafine Particles (UFP)** These tiny particles are less than 100 nanometers (nm) in diameter and are hazardous to health. Cooking is the main source of UFP in homes, particularly those with gas stoves. Gas stoves and electric coil resistance stoves emit high quantities of UFP, particularly smaller than 10 nm in diameter.
Particulate Matter ($PM_{2.5}$) Small particles with a diameter less than 2.5 micrometers. $PM_{2.5}$ can penetrate deep into the lungs and even enter the bloodstream. Stove tests show emissions are dependent on a number of factors such as the type of food cooked, cooking temperature, type of oil used, and type of fuel/stove used.	**Nitrogen Oxides (NOx)** When nitrogen and oxygen react to each other, especially at high temperatures, they produce several toxic gases. NO_2 and NO are the principal gases associated with combustion sources (collectively known as NOx). * A 2001 laboratory study showed no rise in NOx when using an electric stove. * A study published in 2016 showed that after subtracting outdoor contribution, all-electric homes had NOx levels close to zero.
Other Emissions from cooking also include various volatile organic compounds (VOCs) such as benzene and acrolein as well as polycyclic aromatic hydrocarbons (PAHs).	**Nitrogen Dioxide (NO_2)** Nitric Oxide (NO) is oxidized in the air to form NO_2. More data exists on NO_2 than NO. NO_2 is regulated by the EPA and thus is the component most studied and considered by the EPA in terms of health effects.
	Nitric Oxide (NO) A primary gas associated with combustion; NO is also a precursor to NO_2. * A 2001 major study found NO concentrations on electric stoves were insignificant compared to gas stoves.
	Carbon Monoxide (CO) An odorless, colorless gas. A 2011–2013 study found that gas stoves can substantially increase the risk of elevated CO in the home.
	Formaldehyde (CH_2O or HCHO) A known human carcinogen. Exposures at levels that occur in homes have been associated with human health impacts such as lower respiratory infections. A new test of one gas stove shows that simmering on low heat for multiple hours can produce significant exposure levels if ventilation is not used.
	Other Emissions from cooking also include various volatile organic compounds (VOCs) such as benzene and acrolein as well as polycyclic aromatic hydrocarbons (PAHs).

FIGURE 5.8: NOx EMISSIONS IN TONS/YEAR



Source: Dr. Yifang Zhu, Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California, April, 2020, Figure 3-2. https://coeh.ph.ucla.edu/effects-of-residential-gas-appliances-on-indoor-and-outdoor-air-quality-and-public-health-in-california/

5.2.3.2_Residential Indoor Air Quality Issues and Health benefits

Natural gas use in residential kitchens poses unique health risks to occupants, especially children.

» Prior to the recent pandemic's shelter-in-place requirements, people spent an average of 90% of their time indoors, exposed to all the various substances permeating the indoor environment, including those that result from cooking. Since the onset of COVID-19, more people have spent even more time inside and are cooking and baking at home more than before. Therefore, residential indoor air quality should be a top public health concern, especially as scientific studies continue to reveal the vulnerability of the population with respiratory conditions to the ill effects of air pollution, both indoor and outdoor.

» Due to the noisy nature of many ventilation hoods, residents often do not use their range hoods while cooking. Some research estimated that, during a typical winter week, 1.7 million Californians could be exposed to carbon monoxide (CO) levels that exceed standards for ambient air quality, and 12 million could be exposed to excessive nitrogen oxide (NO_2) levels, if they do not use venting range hoods during home cooking.[18]

» Research shows that in kitchens without proper ventilation, cooking for one hour with a gas stove and oven, NO_2 levels are so high they exceed both state and national outdoor acute air quality standards in more than 90% of the homes modeled (see Figure 5.9).[19]

» Gas stoves emit many pollutants that are respiratory irritants. Children under age six who live in homes where gas stoves are used for cooking or even heating the room have an increased risk of asthma, wheezing, and reduced lung function. More research is needed to help understand the correlation of good ventilation to decreased respiratory illnesses, but there are enough studies to encourage taking precautions. Figure 5.10 demonstrates how NO_2 can impact children.

18 https://ehp.niehs.nih.gov/doi/10.1289/ehp.122-A27

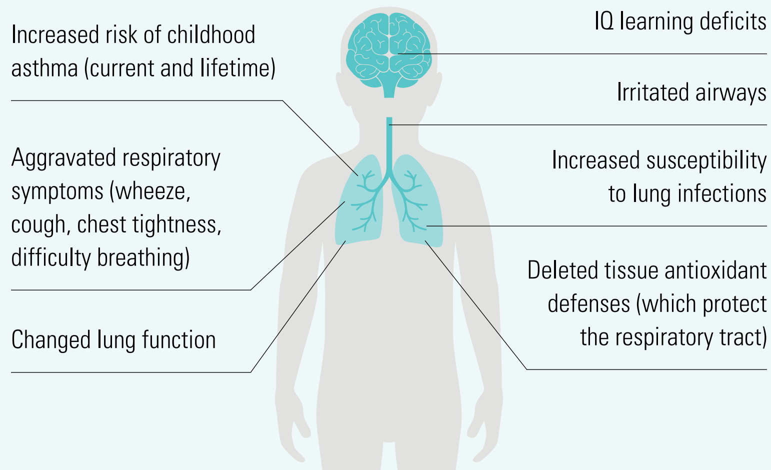
19 https://rmi.org/insight/gas-stoves-pollution-health/

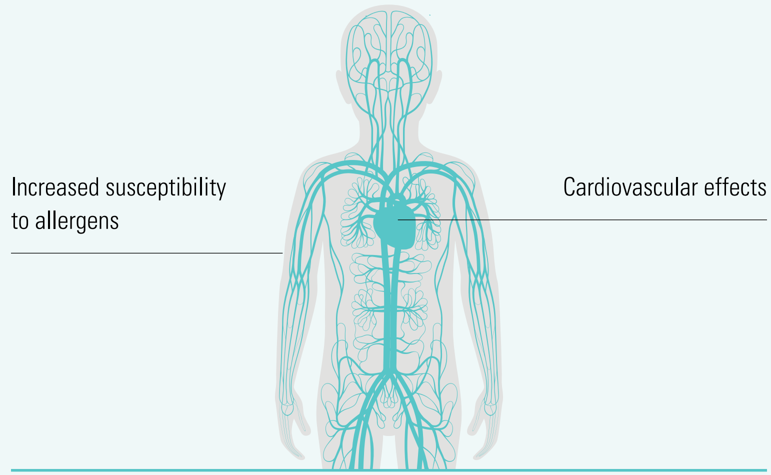
FIGURE 5.9: INDOOR EMISSIONS FROM GAS STOVES OFTEN EXCEED OUTDOOR STANDARDS

Outdoor Standards for NO_2	1-hr average (ppb)
US National Standard (EPA)	100
Canadian National Standard	60
California State Standard	180
Indoor Guidelines for NO_2	**1-hr average (ppb)**
Canada	90
World Health Organization	106
Measured NO_2 Emissions from Gas Stoves	**Peak (ppb)**
Baking cake in oven	230
Roasting meat in oven	296
Frying bacon	104
Boiling water	184
Gas cooktop (no food)	82–300
Gas oven (no food)	130–546

Source: https://rmi.org/insight/gas-stoves-pollution-health/

FIGURE 5.10: HEALTH EFFECTS OF NO_2 IN CHILDREN





Source: https://rmi.org/insight/gas-stoves-pollution-health

» Asthma is the number one chronic disease in children. More than 1 in 7 children in California have an asthma diagnosis. In some California Counties, 1 in 4 kids have asthma. A recent study concluded that replacing all residential gas appliances with clean electric alternatives would cut particulate matter pollution (Figure 5.11 shows the anticipated reductions in $PM_{2.5}$ concentrations that would be achieved). The study estimates that these reductions would be enough to result in approximately 350 fewer deaths, 900 fewer cases of bronchitis, and $3.5 billion in health savings each year in California.[20]

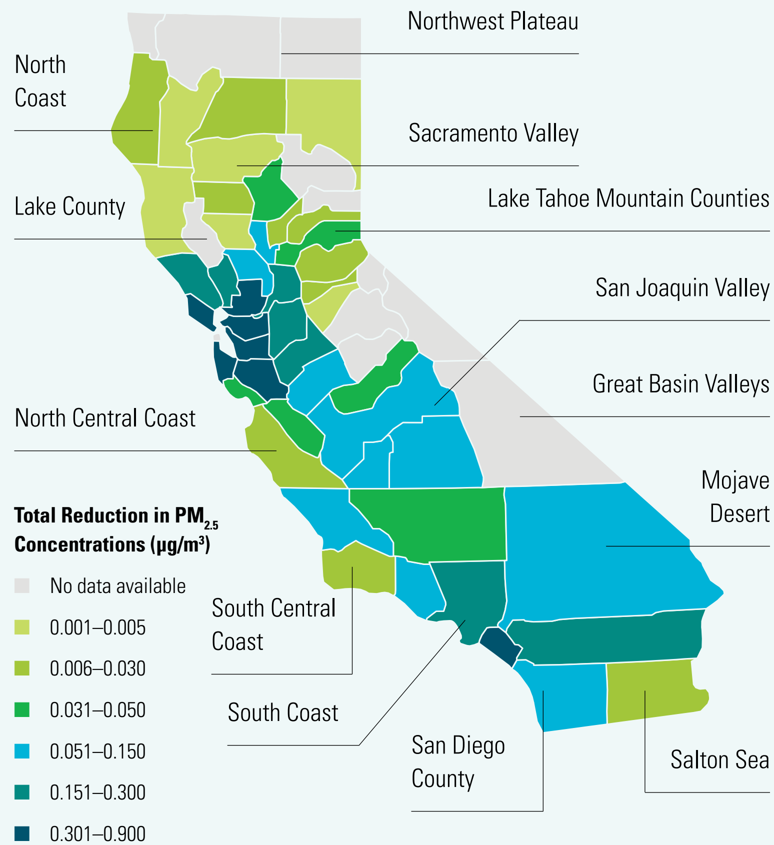
5.2.4_INDUCTION IMPROVES CULINARY PERFORMANCE

Cooking with electric appliances in general, and induction equipment in particular, has the potential to make the experience in the kitchen better for any cook.

Thermal Comfort: Given that gas cooktops are only 30–35% efficient, about 70% of the energy is lost to the ambient environment rather than used to cook the meal. Open gas flames, especially in busy commercial kitchens, tend to unduly and inefficiently warm the room. Reducing the ambient heat in commercial kitchens can improve people's working conditions and make cooking a more enjoyable experience.

Temperature Responsiveness: Induction equipment provides unparalleled precise temperature control. Pan temperatures react to user adjustments much quicker than other types of electric or gas equipment. When the hob is turned down or off, the heat stops immediately so there is no need to remove the pan from the cooking surface. Contrast this with grates and gas burners that can stay hot for a significant amount of time after cooking, which can lead to overcooking and make it harder to clean the pans.

FIGURE 5.11: TOTAL REDUCTION IN AMBIENT $PM_{2.5}$ CONCENTRATIONS IN CALIFORNIA FROM ELIMINATION OF GAS APPLIANCES BY COUNTY IN 2018



Source: Dr. Yifang Zhu, Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California, April, 2020, Figure 3-3. https://coeh.ph.ucla.edu/effects-of-residential-gas-appliances-on-indoor-and-outdoor-air-quality-and-public-health-in-california/

20 Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California. Dr. Yifang Zhu, April 2020.

Speed/High Food Production Capacity: Induction hobs boil water in half the time of gas burners. The production capacity of induction (for the three manufacturers listed in Figure 5.12) averages 70.9 lb/hour, a substantial improvement over electrical resistance (average of 43.5 lb/hour for the two manufacturers listed) and gas (38.6 lb/hour for the Samsung unit).[21]

FIGURE 5.12: COOKTOP HEAT-UP TIME RESULTS

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance Ceramic (Whirlpool)	Resistance Coil (Frigidaire)	Gas Burner (Samsung)
Medium Hob Input Rate	2.8 kW	2.5 kW	2.3 kW	1.2 kW	1.5 kW	9.5 kBTU/hr
Equivalent kBTU/hr	9.6	8.5	7.8	4.1	5.1	9.5
5-lb water heat up time (min)**	5.3	5.8	6.4	18.8	11.5	14.1
Efficiency	86.2%	86.8%	85.3%	70.3%	72.3%	30.6%
Large Hob Input Rate	3.6 kW	3.7 kW	3.3 kW	2.5 kW	2.4 kW	17 kBTU/hr
Equivalent kBTU/hr	12.3	12.6	11.3	8.5	8.2	17.0
12-lb water heat up time (min)**	9.8	9.3	11.6	17.8	15.5	18.6
Efficiency	85.2%	86.1%	83.0%	75.5%	79.3%	31.9%
Production* Capacity (lb/hr)	73.5	77.2	62.2	40.4	46.5	38.6

*calculated based on a single high-input element or burner heating 12 lb of water from 70 to 200°F in an 8 qt pot

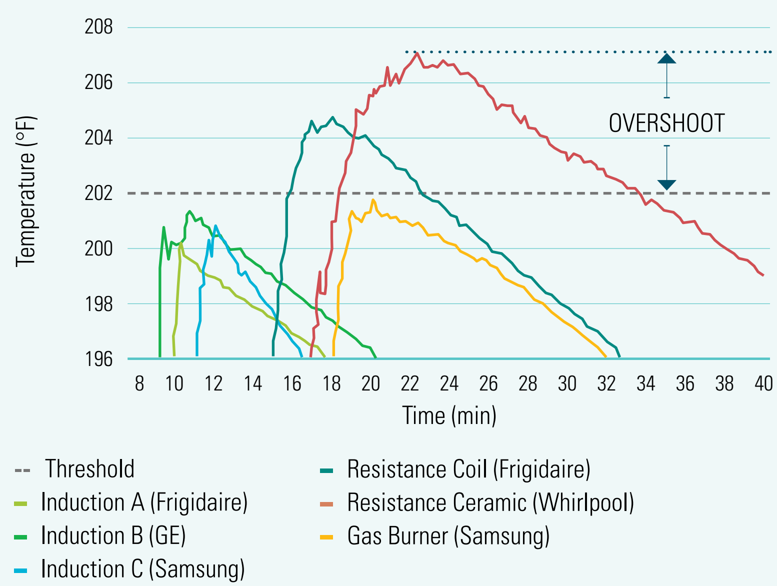
** water heated from 70°F to 200°F.

Source: *Residential Cooktop Performance and Energy Comparison Study*, Frontier Energy, Report # 501318071-R0, July 2019.

21 Denis Livchack, Russel Hedrick, Richard Young, Mark Finck, Todd Bell, Michael Karsz. Frontier Energy. "Residential Cooktop Performance and Energy Comparison Study," July 2019, Report #501318071-R0. Report prepared for SMUD, Sacramento Municipal Utility District. Table 1 and Figure 7 (https://cao-94612.s3.amazonaws.com/documents/Induction-Range-Final-Report-July-2019.pdf)

Precision control: Digital displays often indicate exact cooking temperature on induction appliances, and heat adjustments are so instantaneous that cooks no longer need to rely on visual clues from the fire or the ambiguous range of high/low dial controls for gas or electrical resistant cooktops. Figure 5.13 shows the speed and accuracy of control that is possible with an induction cooktop versus electric resistance and gas.

5.13: TEMPERATURE OVERSHOOT RESULTS FOR 12-LB OF WATER



*calculated based on a single high-input element or burner heating 12 lb of water from 70°F to 200°F in an 8 qt pot, and then turning off the element/hob or burner and leaving the pots of water in place. Water temperature was measured for 40 minutes after turning off the hob or burner to see how much residual heat was transferred to the water above the 200°F end of test (defined as overshoot), and how fast the water cooled down to 190°F.

Source: *Residential Cooktop Performance and Energy Comparison Study*, Frontier Energy, Report # 501318071-R0, July 2019.

Consistency: Instead of continuously turning heat up and down and constantly checking the temperature of the meat, such as when frying chicken, it is easy to find the exact power level that maintains the precise temperature required. In fact, the low temperatures are so precise that a double boiler is not needed for melting or low simmering.

More working surface area: Induction cooktops provide a flat area which is very safe to work on. This results in an increase in available working surface area in a kitchen. It is safe to place a cutting board, recipe or cooking tools on the cooktop as long as they are not magnetic and do not cover the controls.

Easy to clean: The hob itself isn't directly heated, so there's little chance of burnt-on food. A simple wipe is all that is generally necessary to clean an induction cooktop, which reduces overall clean up time and cost of cleaning chemicals. Less need of using harsh chemicals also improves indoor air quality.

5.2.5_BARRIERS TO ACCEPTING ELECTRIC INDUCTION KITCHENS

This Volume aims to provide alternatives to traditional, inefficient — and possibly harmful — food preparation equipment. Induction technology is among the most promising of these alternatives. As a relatively new option, it faces some important barriers to widespread use; however, these issues, several of which are listed below, are not insurmountable.

Unfamiliarity: Chefs tend to be very process-oriented and often develop personal relationships with their tools and equipment. Taking them out of their comfort zone (i.e., using gas equipment), especially without providing ample reason and training, can create a strong reaction and pushback to the idea of induction cooking.

Upfront costs: Financiers of culinary endeavors tend to dwell on the upfront costs rather than the long term implications of their investments. Induction equipment may have a higher cost than equivalent gas equipment, but will more than pay for itself over the life of the unit through energy efficiency and increased throughput, which is much faster than their gas counterparts. Furthermore, it is not always true that an all-electric kitchen will cost more to build than a conventional kitchen.

Maintenance availability: Those who are responsible for maintenance often worry about the ability to get induction kitchen equipment serviced due to its relatively recent entry to the American marketplace. Although this is a valid concern when sourcing equipment, reputable appliance vendors always have options for certified service representatives who are able to take care of the equipment during its lifetime. Oftentimes companies won't even begin selling their equipment in a territory until there is a reliable certified maintenance source in the area that can take care of their equipment. It's incumbent on the company to give its equipment the best possible chance to have a long and effective life.

5.3_Residential Kitchens + Case Studies

In order to successfully design a multifamily residential project with all-electric kitchens, planners must clearly communicate the costs, benefits, and functionality of different kitchen options based on client specifications. Moreover, as *Volume 3 (Multifamily Residential, Hotels/Motels, and Similar Buildings)* describes, healthy indoor air quality is a key aspect of meeting social equity responsibilities: Given pervasive respiratory diseases (like COVID-19) and increasing climate disruptions, which keep us indoors more, it is important that we improve our indoor air quality. Electrification is a huge step in that direction, and designing and properly installing energy efficient, cost-effective electric cooking appliances is a key contribution to these goals.

5.3.1_START THE CONVERSATION ON DAY ONE

Unlike other building systems, cooking equipment is something that many decision makers personally and directly use every day. Simply suggesting that people adopt a new cooking technique and technology is like asking them to stop a relationship with an old friend — the cooking equipment they are familiar with can evoke a more emotional response than just about any design decision. Many reach codes in California cities and counties demand all-electric building systems, but have exceptions for cooking appliances for this reason. Accordingly, it's crucial to dedicate time early during a project goal-setting session to consider the health, environmental, and cost benefits of all-electric kitchens.

Consumer Reports is a reliable indicator of current market trends, and a growing number of top-rated ranges are electric and induction. In other words, the market and end users continue to embrace induction technology and products. For stakeholders who aren't familiar with induction technology, however, it is important to use demos or show induction cooking videos to engage in fun conversations and spark people's curiosity and commitment to change. It is important for home chefs to directly experience how electric kitchens — especially induction — work and feel assured that it would be a great choice for how they cook.

When advocating for all-electric kitchens, it is important to bring empathy to the conversation and listen carefully for cues that may indicate sources of a user's resistance. This kind of empathic listening makes it easier to align the end-user's concerns with the technology's benefits, such as energy and overall construction cost savings, induction cooking's selling points, and better indoor air quality. For instance, induction is highly recommended for housing for seniors, for families with young children, and for people with respiratory and immuno-compromising diseases.

Bringing a clear understanding of the benefits of all-electric kitchens to early and ongoing conversations, alongside a deep insight into your clients' and end users' needs, can help to craft a roadmap for success.

5.3.2_SELLING INDUCTION: PROVIDE A HANDS-ON EXPERIENCE

The design phase is an ideal time to reshape the perception of owners and potential residents. In addition to sharing a detailed overview of operational considerations and benefits, it may prove helpful to have potential residents experience the benefits of induction cooking first hand. This could assuage concerns over food quality and safety, and counter a preconceived bias for gas. It can also help dispel other myths about induction cooking.

Many residential appliance showrooms have "try before you buy" sessions, where you can schedule a demonstration or try out appliances with assistance of their staff. Local clean power organizations sometimes have an induction hob loaner program available. While portable induction hobs are an inexpensive introduction to the technology, they often aren't as powerful as a standard induction cooktop; it's also worth noting that some portable products could be louder and less steady than the permanent higher grade induction appliances.

5.3.3_ENVIRONMENTALLY RESPONSIBLE COOKING IS ALSO SOCIALLY AND CULTURALLY RESPONSIBLE

Cooking and sharing food is about bringing family and friends together. It is also an act of sharing cultural traditions and knowledge. Today's electric cooking technology, such as induction cooktops and appliances like Instant Pot™, offer a new conduit to pass along culture while also creating a safe, healthy, and sustainable environment for the next generation. In fact, many home cooks and professional chefs have been sharing their successes and joyful transitions from cooking on gas to cooking with electrical appliances. Using all-electric equipment offers the opportunity for shorter cook times, safer and healthier indoor environments, and an atmosphere more conducive to togetherness and learning.

CHEFS' THOUGHTS...

" As a corporate chef in the appliance industry, I have had the pleasure of cooking side-by-side with people of all walks of life for many years as we explored both induction cooking and other electric cooking options. I have cooked with little kids and aging-in-place couples, Chinese grandmothers, multi-generational families from India, famous chefs, groups of architects, designers, and more. From making naan, to wok cooking to whipping up a perfect caramel in half the time, these rewarding adventures made me into the induction and electric kitchen super-fan that I am today."

— Chef Rachelle Boucher

" I've cut my culinary teeth in the kitchens of some of the nation's top restaurants; across a wide range of cooking cultures — from the American culinary greats to classical European traditions; to my grassroots, Vietnamese origins; and Top Chef. Coincidentally, I've always found that electric kitchen appliances and electrified kitchens seemed to offer an advantage in precision cooking. Thanks to innovative electric cooking technologies (I.e., combi-oven, induction, etc.) the variables around heat can be precisely controlled. And in my book, that's what cooking is all about. I love that I can cook better and be aligned with my ethos to implement green practices. And that's why I support the full electrification of all commercial and residential kitchens. Electric kitchens for a sustainable future."

— Tu David Phu, Celebrity Chef and Top Chef Alumnus

5.3.4_EQUIPMENT IN RESIDENTIAL ALL-ELECTRIC KITCHENS

Residential electric kitchen equipment comes in numerous configurations to meet a variety of culinary needs. Many manufacturers provide residential induction ranges that come with an electric oven, which bake foods more evenly and have many more features than gas ovens (such as convection cooking, microwave-assisted speed cooking, steam cooking, built-in air fry technology, and more). Some new cooktops have fully functional, built-in ventilation systems, which eliminate the need for overhead hoods. For modern and minimalist kitchens, a single surface countertop with the induction elements hidden below the surface is available. With this technology, the kitchen island (Figure 5.14) could truly become multi-functional, offering space not just for cooking and dining but for doing homework, gathering as a family, or playing games.

FIGURE 5.14: A SINGLE SURFACE COUNTERTOP WITH THE INDUCTION ELEMENTS HIDDEN BELOW THE SURFACE

5.3.4.1_The Benefits of Residential Induction Hobs

Induction offers a number of benefits when compared to equivalent gas and electric appliances. These include:

» **Cooking Performance**

- The low settings are so precise that a double boiler is not needed for melting or low simmering.
- Induction appliances can have additional cooking and safety features such as timers, alarms, timed cooking and automatic shut off if a pot boils over or boils dry.

» **Safety**

- Reports show that gas and electric coil ranges and cooktops were involved in 62% of reported home cooking fires, 89% of cooking fire deaths and 79% of cooking fire injuries. Unattended burners were the leading cause of cooking fires and related casualties. While clothing was the item first ignited in less than 1% of these fires, clothing ignitions led to 8% of the home cooking fire deaths, especially during holiday times.[22]
- Modern appliances that enable the reduction of the total cooking time, or have a timer that would automatically shut off would help prevent such accidents.
- Induction hobs are responsible for a substantial reduction in accidental burns. Only the surfaces contacting the induction hob are directly heated.
- The lack of open flame, extremely hot surfaces, and generally better air quality create a safer environment, particularly for children, people with disabilities, and the elderly.

» **Reduced Maintenance**

- Cleaning the induction hob is quick and easy. The hob itself isn't directly heated, so there's little chance of burnt-on food. In fact, it's possible to place a thin medium such as cloth, newspaper or paper towel between the pan and induction surface; heat will still transfer to the vessel and food efficiently, and cleaning will be even easier. Reduced need for cleaning chemicals also prevents more indoor air quality pollutants and saves money.

» **Other Benefits**

- Depending on your location there may be incentives and rebates for investing in induction and other electric residential kitchen equipment. Check with the local government or utility.
- Induction cooktops provide a flat surface, effectively increasing counter space in small residential kitchens.

5.3.4.2_Residential Induction Woks

The art of cooking with woks is undergoing significant changes due to induction technology. Concave induction wok hobs, for example, are now available for residential use (see Figures 5.15 and 5.16). The concave sides of the hob heat up the sides of the wok, producing greater responsiveness than heating surfaces found in traditional wok pans, which require high BTU gas burners to achieve the same result.

Alternatively, flat bottom woks generate a larger surface area of heat when placed on standard induction hobs (see Figure 5.17).

22 https://www.nfpa.org/News-and-Research/Data-research-and-tools/US-Fire-Problem/Home-Cooking-Fires

FIGURE 5.15: CONCAVE INDUCTION COOKTOP IN A HOME KITCHEN

Source: David Kaneda

FIGURE 5.16: PORTABLE CONCAVE INDUCTION WOK HOB

Source: https://www.nuwavenow.com/shop/mosaic

5.17: FLAT BOTTOM WOK FOR INDUCTION

Source: https://foodsguy.com/best-woks-induction-cooktop/

5.3.4.3_Residential Convection Ovens

Convection electric ovens preheat and cook faster and more evenly than gas ovens and require no rotation of the pans because continuously operating fans move heated air within the oven. When it comes to roasting, convection also results in crisper and more pleasingly browned dishes because the exhaust also pulls moisture out of the oven. Finally, convection is more energy-efficient and allows home chefs to cook multiple dishes at once. Since flavors do not transfer, there's no need to worry about cooking savory and sweet dishes in the same oven at the same time.

5.3.4.4_Residential Combi and Steam Ovens

Combi steam ovens are electric and combine three distinct cooking methods: convection (as defined above), steam, and convection/steam combination. Convection allows for baking, roasting and, in some models, broiling. Steam is used to prepare rice and vegetables, pasta or delicately poached fish to the perfect temperature and texture. Finally, the combination method uses both convection and steam simultaneously, which produces foods that are moist and flavorful. It also reduces the potential of overly dry food. Roasted meats and vegetables, baked breads, pastries, and casseroles all benefit from this technique. Combi steam ovens are exceptional for reheating food; although they take longer to reheat than microwaves, they yield a superior result. Residential Combi Steam ovens do not, however, have a self-clean function.

Speed ovens combine three cooking methods as well: convection, microwave, and a convection/microwave combination. They can be used as a small, efficient oven or to quickly heat and cook foods like a stand-alone microwave oven. It can also combine the technologies to cook food faster than in a standard oven and to a better quality finish than in a microwave alone. Some versions can also broil foods.

5.3.4.5_All-Electric Residential Outdoor Cooking Equipment

All-electrical cooking is not limited to the indoors. Outdoor portable induction carts and electric grills are also worthy of consideration (see Figure 5.18). No gas hook-up is needed; it needs only an outdoor electrical outlet. Many of the products can also be stored easily. Most importantly, there is no charcoal smoke to sting your eyes or harmful CO, methane, or NOx emissions.

5.18: INDUCTION HOB AND TEPPANYAKI TROLLY

Source: https://www.architonic.com/en/product/indu-cooking-plates-400-one-zone/1332480#&gid=1&pid=6

5.3.4.6_Residential Hood Selection

Selecting the appropriately sized hood for all-electric residential kitchens is still important to ensure fumes and grease are captured for better indoor air quality. Fortunately, induction cooktops and other electric appliances do not need ventilation hoods that require as much space or power as with gas appliances. Larger capacity hoods are bulkier and louder and require more make-up air. When hoods are smaller and quieter, they are often used more frequently. In fact, some induction tops are directly connected to ventilation, turning on and off as needed.

Current residential Codes and Standards generally do not recognize any difference between gas, electric resistance, and electric induction appliances. However, good design practices generally end up with a hood that exceeds the minimum exhaust air requirements in Code for residential kitchen hoods. Thus, in situations where a designer is guided by good practice rather than minimum Code compliance, there are opportunities to take advantage of the decreased need for ventilation with induction appliances. Commercial kitchen codes provide guidance on how to size any exhaust hood, and these rules can be used to establish the reduction in hood exhaust capacity based on hood configuration and appliance type. Codes are likely to change in the near future as they continue to encourage all-electric options for buildings and recognize some of the benefits of certain electric technologies such as induction cooktops.

5.3.5_COSTS AND FINANCIAL INCENTIVES FOR RESIDENTIAL KITCHENS

Currently, induction cooktops and ranges cost slightly more than their gas-based counterparts. Fortunately, many local regulatory agencies, utilities, and non-profit organizations offer rebates for purchasing induction — often over $300 — for homeowners who replace a gas range with an induction range. As the technology matures and supplies increase, costs will likely continue to become more competitive.

For new residential construction projects, a cost-benefit analysis of induction versus gas cooking should be performed. It should include expected increases in equipment cost as well as potential offsetting reductions in infrastructure cost. Rental unit developers and owners should also include operating cost reductions from reduced air-conditioning loads in all-electric kitchens.

As noted in the previous section, induction cooktops and ranges can accommodate lower exhaust air rates, even though the required minimum exhaust rate does not differentiate by cooktop type in current Codes. When good design practice governs a kitchen hood design, using induction equipment can result in a reduced cost for meeting desired exhaust and make-up air requirements. Additional space savings can be achieved with all-electric kitchen designs, potentially reducing the size of kitchens and hence the total cost.

Many local municipalities, particularly in California, mandate that all new residential projects be all-electric, and they aim to require the same for future retrofit projects. The decision to build all-electric, multi-family housing infrastructure from the start can offset the potentially expensive retrofit and electric infrastructure upgrades that may be coming in the near future.

Marketing an all-electric project, with an emphasis on how induction and other electric kitchen equipment provides a clean, healthy, and family-friendly indoor environment, can help set the building apart in a crowded marketplace.

5.3.6_GROUND-UP DESIGN CONSIDERATIONS

Design teams should start a dialogue with owners, developers and utility suppliers early to understand utility power infrastructure requirements and availability and outline steps necessary for installation during construction. *Volume 3 (Multifamily Residential, Hotels/Motels, and Similar Buildings)* delves into other electric appliance considerations, including hot water heat pump power requirements.

Conceptually, residential kitchen gas and electric appliances can be swapped one-to-one, except that some appliances are more energy efficient and offer more versatility, such as induction cooktops, combi ovens, or convection ovens with air fry features, etc.

Induction ranges come in 30-inch and 36-inch widths, with a few 48-inch wide luxury options. 30-inch induction ranges come in a variety of brand features, are widely available, and often cost the same as their gas counterpart. However, the price range of 36-inch induction ranges vary significantly and are only made by a few manufacturers.

An alternative option to ranges is to provide a cooktop on the counter and a separate oven or ovens. For example, for micro-units, a 24-inch induction cooktop and a countertop toaster oven or a seperate oven under the counter would be more efficient for space planning, since there is no 24-inch induction range yet. Not all induction range ovens come with the latest features; providing a separate cooktop and oven can allow for the flexibility to modernize the oven or change the oven type in the future.

5.3.7_RETROFIT DESIGN CONSIDERATIONS

Assessing the feasibility of upgrading electrical infrastructure capacity is a crucial step in a retrofit project that includes eliminating gas or changing electric equipment and appliances. If upsizing electric panels and transformers is cost prohibitive or not supported by the utility infrastructure, then the user can opt for induction countertop hobs (single or double units) as well as a countertop electrical convection oven/microwave or multicooker (e.g., Instant Pot™), which simply require 120 volt wall outlets, not dedicated electrical circuits. In small apartments, these portable appliances also provide the flexibility of storing them, freeing up counter space. Unlike other countertop cooking appliances, however, it is important to locate even countertop induction hobs under new or existing exhaust hoods.

Residential units with central domestic hot water systems and central laundry facilities often have an existing small 30 to 50 amp panel for each apartment. There are "smart" panel systems that can manage electrical loads, such as electrical vehicle charging, a hot water heater, or induction cooktop. For example, condominiums can use a load sensing EV charger controller (e.g., the DCC-9 from DCC Electric) that is designed to allow the connection of an EV charger to the main feeder of the unit's electrical panel without affecting the load calculation. Similarly, hard-wired load switching devices (e.g. the simpleSwitch by B&B Technology Solutions) can be connected as a load management device that shares the power between two appliances.

5.3.8_RESIDENTIAL KITCHEN CASE STUDIES

5.3.8.1_Belfield Townhomes

Source: Sam Oberter

Project Location: Philadelphia, PA

Completion Year: 2012

Project Size: 5,760 square feet

Source: Tim Griffith

What:

The project involved the development, design, and construction of three row homes for the Raise of Hope (ROH) organization, a local Community Development Corporation in Philadelphia. The townhomes, designed to provide affordable housing for very low-income residents, contain four bedrooms and three full bathrooms, one of which is accessible on the ground floor. Parking is provided onsite and accessed from the rear. This project is intended to be a model of affordable and sustainable housing for the City of Philadelphia. The homes are designed as high performance buildings utilizing Passive House™ standards, and they approach zero-energy status.

An all-electric eat-in kitchen with induction cooktop and convection oven offers a pleasant and healthy place for families to spend time together. All energy consumption from electric cooking appliances can be directly offset by onsite renewable energy, which is an attractive saving for affordable housing residents.

This project is the recipient of 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).

How:

HVAC	Ultimate Aire ERV with a GE PTAC
DHW	50 gallon GE heat pump water heater
Cooking	Induction cooktop and convection oven
Building Envelope	Airtight envelope and triple glazed windows
Predicted EUI	22 kBTU/SF/year
Client	Philadelphia Redevelopment Authority, Raise of Hope
Architect / Developer	Onion Flats / Plumbob
General Contractor	JIG Inc.

5.3.8.2 Manzanita Square

Source: Bruce Damonte

Source: Tim Griffith

Project Location: San Francisco State University, San Francisco, CA

Completion Year: 2020

Project Size: 239,000 square feet

What:

Manzanita Square is a student residential and mixed-use complex that creates a new campus gateway, mediating space between the University's southern edge, the Parkmerced residential neighborhood, and the larger community.

The eight-story mixed-use residential complex creates a uniquely urban student living experience. Its 169 apartments with two staff units are organized around a landscaped public courtyard with retail space. At ground level, the building interior is planned as a centralized hub of community space — a vibrant urban retreat encompassing a social lounge directly adjacent to the main building entry, game room, coffee/kombucha bar, the Academic Success Center, and a podium with lease spaces for retail or food services

The design team capitalized on the microclimate of the site to employ a super-insulated building envelope design that dramatically reduced heating loads and eliminated the need for active cooling systems. This created the opportunity for "all-electric" residences, which allowed for individual metering and the opportunity to empower each resident with complete energy consumption information.

How:

HVAC	Common Areas: VRF systems with MERV-8 and MERV-13; Residential Units: ERVs with MERV-13 and electric resistance baseboard radiators
DHW	Central Heat Pump Water Heating System with recirculating loop
Cooking	Electric Resistance, Energy Star for residences; Induction Warmers at individual tables at ground floor restaurant (retail tenant)
Building Envelope	Rain Screen system over 6" mineral-wool blanket insulation outboard of structural framing; R-20+ walls and R-30+ roof; Thermally-broken Aluminum Frame dual-pane, argon-filled low-E glazing
Electrical Load Offset	200 kW roof-mounted PV system designed, not installed
Predicted EUI	22 kBtu/SF/year
Building Code	2016 California Building Code
Developer	American Campus Communities
Architect	Gould Evans
General Contractor	Build Group
Mechanical Design-Build Contractor	ICOM Engineers
Electrical Design-Build Contractor	Helix Electrical
Plumbing Design-Build Contractor	J.W. McClenahan Co.

Structural Engineer	Nishkian Menninger / IMEG
Energy Consulting	Point Energy Innovations

Trade-offs and Challenges:

» Electric resistance appliances were installed, due to lower first cost, even though induction is much more energy efficient and would save operational cost. There was also concern, in 2017 when induction was still an unfamiliar technology, that the students might not have induction-ready pots and pans.

Lesson Learned:

» With robust all-electric-ready infrastructure, and the strong support of SFSU (client) and ACC (developer) for implementing an all-electric building, the retail tenant of the ground floor restaurant fitted out an all-electric back of house kitchen and induction warmers at individual dining tables in 2021. This case study shows that an understanding and availability of all-electric kitchen technology has improved over time.

» Reduced infrastructure (no gas line!) and reduced infrastructure coordination (simpler joint trench) allowed the project to be delivered ahead of schedule, even after a rainy construction season that was also impacted by the COVID-19 pandemic.

5.4_Commercial Kitchens + Case Studies

Commercial kitchens can use up to five times the amount of energy than other building programs. It stands to reason that if you want to make a big impact in building decarbonization, the commercial kitchen and its culinary program should be a top priority.

"Microsoft is committed to being carbon negative by 2030 — which means tackling every aspect of our business and reevaluating practices to drive out carbon emissions. On our headquarters redevelopment project in Redmond, Washington, we are building 17 new buildings with 3 million square feet of office and amenity space.

These buildings will serve over 12,000+ meals a day in involves 77,000 square feet of all electric kitchens and food amenities of kitchen space — all solely powered by electricity. **We will be introducing new radiant + induction cooking styles at a scale that's never been done before.** As we embarked on this journey to deliver all-electric dining facilities at this scale over 3 years ago our teams worked diligently to overcome barriers such as equipment availability, throughput considerations and station design. We have leaned into this as an opportunity to consider different approaches to menus and training. **We have seen a positive response from the industry in these few short years enabling this transition for us,** and hope to see this trend continue."

— Katie Ross, Global Real Estate & Facilities Sustainability Lead at Microsoft

Microsoft Redmond Campus Case Study

A comprehensive case study of this groundbreaking achievement can be found in the Commercial Buildings volume.

Replacing gas appliances in existing commercial kitchens or installing all-electric equipment in new projects may be the easy part of the decarbonization process. Convincing owners, chefs, culinary design consultants and foodservice providers to adopt new cooking equipment and techniques may present the biggest challenge.

This is why it is critical for the design team to set the stage for early and continual dialogue regarding expectations, perceived challenges, and positive outcomes with anyone who has a stake in a project's sustained success. A holistic discussion around food offerings, cooking staff retention, and operational savings can ensure a better design. Underlying these conversations: all electric kitchens produce food quality for all cuisines that are at least as good, if not better, than their gas-based counterparts. This winning recipe also includes the benefits of improved air quality, enhanced comfort, better staff morale, long-term cost savings, and reduced greenhouse gas emissions.

5.4.1_TALKING ABOUT THE QUALITY OF FOOD ON DAY ONE

While this guide discusses the many positive attributes of an all-electric kitchen, what people care about most is good, authentic food. Often, when proposing an all-electric kitchen to a commercial project client, it is helpful to start with a conversation about delivering quality food more efficiently, in a more comfortable environment, and reducing overall operational costs. It is also important to acknowledge that producing ideal results may require adapting new techniques and skills.

In reality, the quality of food is based on the quality of the equipment, team, and chef — less so on the actual heat source. Where induction cooking excels is in offering teams far superior pieces of equipment that allow more control over their craft by being able to cook with greater precision, speed, and consistency.

> "I have had the pleasure of cooking for Legislators, University Presidents, a World Certified Master Chef, and everyone in between. When my guests tasted our food and learned that it was prepared in an All-Electric Kitchen they were blown away that we were able to provide such exceptional quality food without the use of gas equipment. It is always a pleasure to see the moment when people realize that there is nothing tethering them to the antiquated shackles of gas cooking."
>
> **— Chef Chris Galarza, Forward Dining Solutions LLC**

5.4.1.1_Supporting Effective Techniques

There are very few techniques in the pantheon of cooking that are not achievable with induction. At its absolute core, cooking comes down to using heat to take an ingredient from its raw state to a desired state of doneness. As such, it doesn't matter to the food where the heat source comes from — it simply needs to be provided. And, the difference between gas and electric cooking equipment is in the increased power, control, and speed that induction technology provides.

The notion that the techniques developed over the course of culinary history will be fundamentally upended and subverted by induction technology is a manifestation of the unwillingness to let go of a bygone era, one that holds our environment, our health, and our planet hostage.

Chefs have always pushed the boundaries of culinary art through new developments in technology and understanding. It's how Albert Adria was able to develop a sponge cake recipe using a microwave. It's how Alex Stupak was able to develop a Creme Brulee that needed no baking, which led Aki Kamozawa and H. Alexander Talbot to develop a key lime pie custard that could be tied into a knot. With the embrace of induction cooking we can now continue our pursuit of culinary knowledge with clean air, increased control, and a clear conscience.

Source: Troisgros Grande Maison in Roanne, France - cooking with induction in a Michelin 3 star restaurant. (photo: Rick Theis) | http://troisgros.fr/page_3-maisons

5.4.1.2_Commercial Kitchen Equipment

Full kitchen electrification is a reality. In fact, most of the equipment in a typical conventional kitchen is already electric. Deli meat slicers, buffalo choppers, blenders, food processors, steam jacketed kettles, and steamers all run on electricity.

There are just a select few appliances that still rely on gas, but these too can be switched to an electric counterpart (often that is built to be identical in footprint, so there would be no design impacts).

COMMON GAS-FIRED COMMERCIAL COOKING EQUIPMENT

- **Range**
- **Ovens (convection, deck, combination)**
- **Flat top griddle**
- **Fryers**
- **Tilt skillet**
- **Food warmers (drop-in/flat)**
- **Broiler/salamander**
- **Wok Range**

Currently, every piece of commercial gas-fired food preparation equipment has a modern, electric counterpart designed to be more efficient, safer to use, and capable of outperforming its gas version. These pieces of electric equipment have the added benefit of providing more control over cooking and operation, increasing overall throughput, and decreasing overhead costs in the process.

> " No other cooking technology that we've tested is faster than the fastest induction elements — we're talking 2-4 minutes speedier than the competition to bring 6 quarts of water to a near boil."
>
> — ***Consumer Reports***[23]

5.4.1.2.1_OVENS

For commercial kitchens, there are three distinct options: Convection oven, Combination oven, and Deck oven (which are all more insulated than their gas counterparts). Increased insulation improves their energy efficiency and puts less heat into the ambient kitchen space. Figure 5.19 includes many of these items common in an all-electric commercial kitchen.

FIGURE 5.19: A HIGH TECH ALL-ELECTRIC KITCHEN LINEUP WITH COMBI OVEN, INDUCTION COOKTOP, FLEXIBLE BRAISING PAN, BLAST CHILLER, HOT AIR FRYER, AND HEAT RECOVERY DISHMACHINE

Source: Picture courtesy of the Frontier Energy Induction Technology Center | fishnick.com/ITC/

23 "Pros and Cons of Induction Cooktops and Ranges: What to know before buying an induction range or cooktop." *Consumer Reports*. December 3, 2019. | https://www.consumerreports.org/electric-induction-ranges/pros-and-cons-of-induction-cooktops-and-ranges/

Convection Oven

Convection electric ovens preheat and cook faster and more evenly than their gas counterparts, and they require no rotation of the pan because continuously operating fans move heated air within the oven. In a gas oven, temperatures are hotter at the top of the oven, so baking requires rotation and placement farther from the heat source. When it comes to roasting, convection also results in crisper, browner dishes (because the exhaust pulls moisture out of the oven), is more energy efficient, and allows chefs to cook multiple dishes at once as flavors do not transfer (there's no need to worry about mixing savory and sweet dishes in the same oven).

Combination Oven

Combination electric ovens use a mix of three distinct cooking methods: Convection, Steam, and Convection/Steam Combination. Convection Steam allows the chef to prepare rice and vegetables, or even delicately poach fish to the perfect temperature and texture. The final cooking method uses a combination of convection and steam simultaneously. The benefits of these two methods working together produce results that are moist, flavorful and have minimal shrinkage, thus reducing the potential for dry food. Most combination ovens come with a self-clean function, cutting down on labor and chemical use: it quickly cleans itself and flushes away any excess water, leaving the oven ready for the next day, with minimal interaction.

Deck Oven

An electric deck oven offers unparalleled control over the precise temperature of the top and bottom elements. It also offers the ability to manage a "heat barrier," which allows for greater control over baking. This allows greater control over baking. For instance, with pizza there is the ability to set the bottom elements higher, allowing you to set a crispy crust while you delicately melt the cheese on top. The "heat barrier" allows you to work in the oven with the door open without the fear of losing precious heat; therefore, the unit does not have to work as hard to replenish that heat and thus saves money and energy over time. They also have the ability to inject steam into each individual deck or compartment allowing you to easily set crusts on breads such as baguettes and the like.

Source: An electric Tandoori oven by Golden Tandoors
http://www.goldentandoors.com/professional_tandoor_electric.php

5.4.1.2.2_COMMERCIAL INDUCTION WOK

Cooking food made on high heat with a wok — as typically used for many Asian recipes — has been one of the lingering justifications for commercial kitchens to keep gas cooktops. However, since 2013, there have been significant and recognized advances for induction wok cooking in hotel facilities in China. Full-size induction woks were introduced to the U.S. market at the 2019 National Restaurant Association conference (see Figures 5.20 and 5.21).

FIGURE 5.20: EXAMPLES OF COMMERCIAL INDUCTION WOKS

Source: Picture courtesy of The Frontier Energy Induction Technology Center | fishnick.com/ITC/

FIGURE 5.21: CHEF MARK DUESLER, COOKING ON A COUNTERTOP INDUCTION WOK

Source: Picture courtesy of The Frontier Energy Induction Technology Center | fishnick.com/ITC/

5.4.1.2.3_ELECTRIC WARMING OPTIONS

Flat Induction Warmers

Induction warmers work exactly the same as their induction range counterparts except that they have built-in restrictions. Typically the temperatures are adjustable from 120°F - 210°F, allowing for unparalleled control over the food you are warming.

Note that it may be necessary to use heat lamps above the food since the warmers only heat the bottom of the serving vessel, not the sides or top.

Induction Wells

Induction wells offer customizable capabilities that were previously unheard of in the world of food warming. Most wells work with either 2" or 4" deep hotel pans, and with two induction units in each well, they are further customizable by having one half raised to accommodate a 2" pan and the other lowered to accommodate a 4" pan (see Figure 5.22). This offers great flexibility to the production line and reduces overall deeper pan usage and cleaning time and costs. Since no plumbing hook-up is needed, induction wells also save on first cost and water consumption.

Some induction well units come with a low/medium/high setting. It is recommended to find induction wells that offer the full range of temperature control that are offered with the flat induction warmers.

FIGURE 5.22: INDUCTION WELL

Source: https://www.webstaurantstore.com/vollrath-fc-6ih-02120-two-well-modular-induction-drop-in-hot-food-well-120v-1590w/9226IH02120.html

5.4.1.2.4_COMMERCIAL KITCHEN HOODS

Similar to residential codes, current commercial Codes and Standards generally do not recognize any difference between gas, electric resistance, and electric induction appliances. Thus, all-electric commercial settings will require the same sized hoods as their gas counterparts. However, modern control systems for hood exhaust can provide exceptional savings. Some of the most advanced systems available use optic and temperature sensors to monitor the level of cooking activity, continually adjusting based on the need at the time. The simple payback on these systems is often very attractive (i.e., less than 3 years). Coupled with heat recovery (if your state allows it), the potential exists for considerable operational savings.

With increasing use of induction appliances, codes are likely to change in the near future as they continue on their course to encourage all-electric options for buildings and better recognize the specific performance characteristics of induction technology.

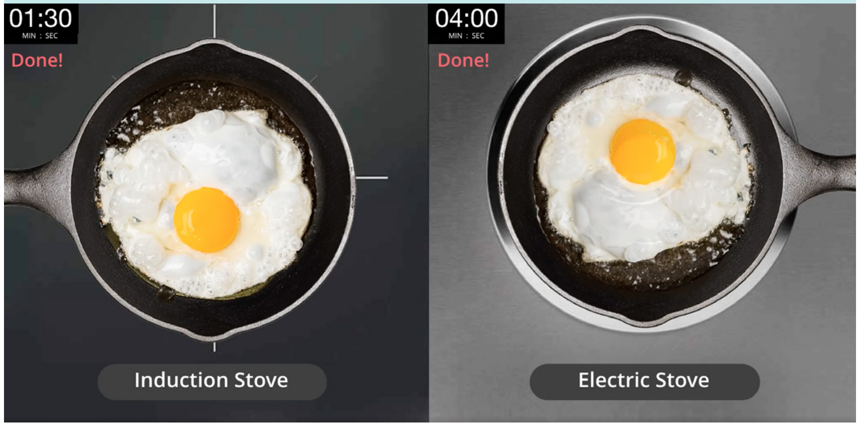
5.4.1.3_Throughput

> "We've noticed an increase in our throughput. Due to the equipment's incredible response time and immediate heating we are able to cook more food in a shorter amount of time. This has created an environment where we are able to put out a high quality product in a shorter time span. We have been virtually limitless in what we can create with our induction equipment and have seen no reduction in quality or variety."
>
> **— Chef Chris Galarza, Forward Dining Solutions LLC**

Chefs tend to judge the efficiency and success of their kitchens by the concept of throughput: how much high quality food can their kitchen process and serve as quickly as possible.

Induction technology is important in this conversation because by harnessing its speed and efficiency, cooking time can decrease dramatically (see Figure 5.23). Whether it's saute pans getting hotter faster or a pot of water coming to a boil in half the time of the gas counterpart, induction speeds up the process, allowing chefs to get more food cooked and served.

FIGURE 5.23: THE DIFFERENCE IN TIME SPENT TO COOK AN EGG



Source: http://sponsored.bostonglobe.com/frigidaire/induction/. Similar time lapse videos can be viewed on Hot Induction Technology for Cooler Kitchens at https://www.youtube.com/watch?v=yG8hn4vyWf0.

With more true back-of-house induction hobs coming from manufacturers, operators are beginning to see the benefits of induction for production in the kitchen. Power and durability make these commercial units highly compatible with the rigors of production cooking. While typical light-duty countertop induction hobs generate up to about 1,800W of power, hobs designed for the back-of-house can generate 2,500W or more. Most can generate 3,500W, equivalent to a typical 31,000 BTU gas burner. They're also engineered to withstand the heat and grease in a production kitchen that might cause lighter duty hobs to fail.

Precision and Control

Induction technology generates an incredibly precise amount of localized heat. It has the instant on/off characteristic of gas-flame cooking that chefs like, but it is even more precise. Many of today's induction hobs allow the cook to either adjust power from 0%–100% in increments of 1% or to choose a specific set point temperature, from about 70°F to 500°F and accurate to within 1°F. Cooks cannot do this on a gas burner. Built-in programmability is also available on some units, which reduces the training required for cooking to specific recipe specs.

How exact an induction hob should be depends on your application. If you're using induction hobs simply for sauteing you probably don't need much in the way of settings or bells and whistles. However, if you're searing proteins for sous vide, making pastry creme, or tempering chocolate — techniques that require precise temperatures — or if you want employees to strictly follow a multi-stage cooking process, you should carefully consider what tools to equip your chefs with.

Speed and Efficiency

Since most of the energy in an induction hob goes directly into the pan, it heats much faster than on a gas flame, which heats and cooks food faster. Induction hobs are typically about 84%–93% efficient while gas burners, in contrast, are only about 30%–44% efficient. In other words, if a gas burner puts out 35,000 BTU per hour and is 35% efficient, only about a third of the energy or heat is going into the pan.

Meanwhile, 22,750 BTU per hour is dissipated into the air. Thus, the need for powerful hoods to capture and remove the byproducts of combustion, heat and moisture, which in turn means your HVAC has to work harder to keep the kitchen cool. With induction, kitchen employees stay more comfortable.

> "Chefs are all about control. Once you talk about how much control you have, it piques their interest. With induction, you can set the temperature to the degree you want. You can fine tune the settings for the food you are going to poach or sear. It gives unparalleled control. Instant temperatures. Pans get hot immediately."
>
> **— Chef Chris Galarza, Forward Dining Solutions LLC**

Safety and Human Error

Even with the strictest precautions in place, accidents can still happen in the kitchen, including extinguishing pilot lights by overboiling pots, leaving a towel too close to burners, and getting burned when grabbing a pot without a towel. When these accidents happen, they usually cost the establishment money. Induction ranges have the added benefit of lessening the consequences of common mistakes by a considerable degree. According to the CDC an average burn to an extremity such as hands, arms, or legs can cost an average of $6,226 in terms of medical costs and work loss. That cost, based on 2010 figures, does not take into account the cost of increased insurance premiums experienced by the employer.[24] Reducing the risk of injury, of course, has its own benefits.

Source: At Marlow & Sons in Brooklyn, all the cooking is done on five induction units in the basement.
https://www.nytimes.com/2010/04/07/dining/07induction.html

5.4.1.4 _Training

When planning an all-electric commercial kitchen, simply informing the kitchen staff of all the benefits described in this guide and expecting their complete buy-in is likely overly optimistic. There needs to be a plan in place for educating the staff on how electrification will help them in their day-to-day tasks. We recommend a two-pronged approach to help educate and ease any anxiety:

First exhibit the ease of operating the new equipment and demonstrate its practical applications to the kitchen staff's existing work. Showing them the ease, versatility, and speed of the equipment may be enough to get them onboard.

24 Calculations done on June 22, 2021 via US Centers for Disease Control and Prevention's "Data & Statistics (WISQARS™): Cost of Injury Reports" | https://wisqars.cdc.gov:8443/costT/

Secondly, educate and earn the support of the managing chefs in advance of the transition. A chef is the most influential person in the culinary hierarchy and their excitement about induction technology can be highly influential with the rest of their staff.

The Transition is Easy

The beauty of induction cooking is that a cook does not have to change their understanding of how to cook since the principles are the same as a gas range. You turn the knob, your pan gets hot, you cook — it's as simple as that. Once you understand the basic nature of the unit you start to unpack the benefits of its ease of use as well as its speed, efficiency, thermal comfort and every other benefit that this document has outlined.

How Much Time Will It Take to Train?

Depending on staffing size, training on induction equipment should take a minimum of two days although three days is ideal. This should always be done by a trained chef who has experience using the equipment and experience teaching others on this technology. This is important to be able to troubleshoot and prevent mistakes.

Source: Cooking with induction at Pineapple and Pearls in Washington, DC, a Michelin star restaurant. (photo: Rick Theis)

SAMPLE TRAINING SCHEDULE

Day 1: Chef & Culinary Leadership (Mandatory)

Day 2: Other Staff (Mandatory)

Day 3: (Optional/Recommended)

An optional third day is beneficial for when a kitchen comes online for the first time. Learning something new is always easier during a relaxed setting than when the kitchen is "live." Having an experienced Chef Consultant in the kitchen for the first day of prep and cooking is beneficial to ensure that the information given was properly conveyed. Being able to correct behaviors and mistakes in real time will go a long way to establishing good habits that will keep the equipment safe and in good working order for years to come.

NOTE: It is imperative that a trained chef experienced in operating a high-level electric kitchen educate and train the team on proper usage and maintenance to ensure long-term success.

" I have been training folks in all manner of skill sets, age groups, and experience for many years now. You name it, I've encountered it. I'm always impressed by how quickly everyone takes to the new equipment. To them the concept is simple… turn the dial and start cooking, but of course it's so much more than that."

— Chef Chris Galarza, Forward Dining Solutions LLC

5.4.2_INDOOR ENVIRONMENTAL QUALITY

An all-electric kitchen has a number of health and safety benefits as discussed in section 5.2.3. Figure 5.7 suggests that while cooking in general emits particles of concern, these and many other pollutants are associated with cooking on gas stoves.

An increasing number of investigations support the health benefits to be gained from eliminating indoor cooking using natural gas. In an effort to understand the public health impacts over the past decade, a study was initiated by the Center for Climate, Health, and the Global Environment at the Harvard T.H. Chan School of Public Health in Boston, MA. This study was recently published in *Environmental Research Letters*.[25] The authors used three different public health modeling tools to estimate the health impacts from specific emissions sources, including commercial cooking activities. Results indicated that, in 2008, somewhere between 4,800 and 8,200 mortality cases in the U.S. were due to commercial cooking. This increased to between 7,100 and 13,000 mortality cases in 2017. The study further estimated that cooking with gas had the highest estimated health burden due to $PM_{2.5}$ in 9 states: WA, NV, FL, MA, CT, NY, NJ, MD, and DE.[26]

Good indoor air quality translates to more comfortable and healthier working conditions, and all-electric kitchens are quieter, cooler, and safer. Happier and safer cooking teams yield higher quality output and lower staff turnover.

25 A decade of the U.S. energy mix transitioning away from coal: historical reconstruction of the reductions in the public health burden of energy, by Jonathan J Buonocore, Parichehr Salimifard, Drew R Michanowicz and Joseph G Allen. Table 1. Published May 5, 2021. https://iopscience.iop.org/article/10.1088/1748-9326/abe74c

26 Ibid. See Figure 9.

5.4.2.1_Comfort

> "Since we've adopted induction technology and committed to the overall electrification model of our kitchen systems, we've noticed a significant improvement in my employees' moods and overall comfort at work. In turn we've seen an **overall improvement of guest-facing interactions.** We have seen less conflict and a more relaxed working environment."
>
> **— Chef Chris Galarza, Forward Dining Solutions LLC**

While comfort is a relative term, there are some parameters that can be applied to commercial kitchen spaces. Ideally, a comfortable working environment is one in which the ambient temperature is never excessively hot, where fresh air circulates regularly, and where staff interactions are more relaxed and amiable. Such conditions are vital for creating an environment in which people can thrive.

"Thermal comfort" is a complicated topic and has been written about endlessly by engineers and scientists. There are six primary factors that directly influence a person's thermal comfort, and these can be grouped in two categories. First, personal factors, which are characteristics of the occupant, are affected by metabolic rate and clothing level. Environmental factors, on the other hand, are conditions of the thermal environment, and these are affected by air temperature, mean radiant temperature, air speed, and humidity.

It is generally hot in a commercial kitchen, a fact that has been largely accepted by designers and kitchen staff. There is growing recognition, however, of the adverse effects of heat stress on workers. In February 2016, the National Institute for Occupational Safety and Health (NIOSH) published the Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments, a technical resource on heat stress and heat-related illness signs and symptoms. In 2017, OSHA updated the chapter in their Technical Manual on heat stress.[27] For an active commercial kitchen, the recommended temperature Threshold Limit Value (the temperature above which a worker will experience heat stress) is around 81.5°F (27.5°C), assuming the worker is exposed to the hot kitchen environment 50% to 75% of the work day. Recent Federal action is likely to result in new regulations that will set maximum indoor temperature standards for commercial kitchens at 80°F.

BIDEN ADMINISTRATION MOBILIZES TO PROTECT WORKERS AND COMMUNITIES FROM EXTREME HEAT

New Initiatives at OSHA and Across Agencies Will Enhance Workplace Safety, Build Local Resilience, and Address Disproportionate Heat Impacts

On September 20th, 2021 President Joe Biden issued an order to create new initiatives at OSHA and other agencies to enhance workplace safety, build local resilience, and address disproportionate heat impacts. This coordinated, interagency effort to respond to extreme heat in the workplace is leading to new regulations that will set indoor temperature standards to 80°F. This will make it more difficult for any commercial kitchen using gas as a primary heating source to comply with these stricter regulations due to the inefficiency of gas equipment and the excessive heat it produces.[28]

ASHRAE has developed a comfort standard — Standard 55 — based on models that evaluate satisfaction with the thermal environment against an "operative" temperature, which is a metric derived from air temperature, mean radiant temperature, and air velocity (see Figure 5.24). In practice, however, these comfort models are rarely applied to commercial kitchens. Given all the hot surfaces in a working kitchen, the air temperature required to offset the radiant energy from all the hot surfaces would be quite cool (often 66°F or less). Further, increasing the air velocity in a kitchen to help achieve an appropriate operative temperature can have detrimental effects on the performance of exhaust hoods and can inadvertently cool plated food before it is served. The best way to achieve "comfort" conditions in a commercial kitchen is by reducing the radiant heat emanating from the equipment (i.e. the temperature and area of hot surfaces).

The reduced cooling loads from induction cooking equipment come, at least partially, from a reduction in radiant energy. Thus, an all-electric kitchen can help make comfortable thermal environments in commercial kitchens an affordable and practical reality. This isn't to say that induction cooking will solve every social problem on a team, but since establishing all-electric kitchens, many workplaces have experienced noticeable improvement in staff demeanor and interactions, which have created a more welcoming environment for guests. Anecdotal evidence from chefs who manage commercial kitchens suggests that when people are not overheated and uncomfortable they tend to be happier and more relaxed at work, which in turn reduces overall tension and gives people more patience with each other.

The switch to electric also solves the problem that most high-end kitchens have with providing an enjoyable experience at the Chef's Table (a table typically in the kitchen in which the guests are witness to the action and receive personalized service from the chef). Many kitchens have problems with guests being uncomfortably hot at the Chef's Table, and thus lose out on consistent bookings at the most expensive table in the house. Eliminating gas equipment can lead to a much more satisfying guest experience, which may help keep Chef's Tables fully booked.

27 https://www.osha.gov/otm/section-3-health-hazards/chapter-4

28 https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/20/fact-sheet-biden-administration-mobilizes-to-protect-workers-and-communities-from-extreme-heat/

FIGURE 5.24: "COMFORT" RANGE FOR THE ACTIVITY LEVEL (METABOLIC RATE) AND CLOTHING ASSUMED TO BE TYPICAL IN A COMMERCIAL KITCHEN

The range highlighted in green shows the "comfort" range for the activity level (metabolic rate) and clothing assumed to be typical in a commercial kitchen, and is based on relatively still air (20 feet per minute). At 60% relative humidity, the operative temperature comfort range is from approximately 59°F to 69°F.

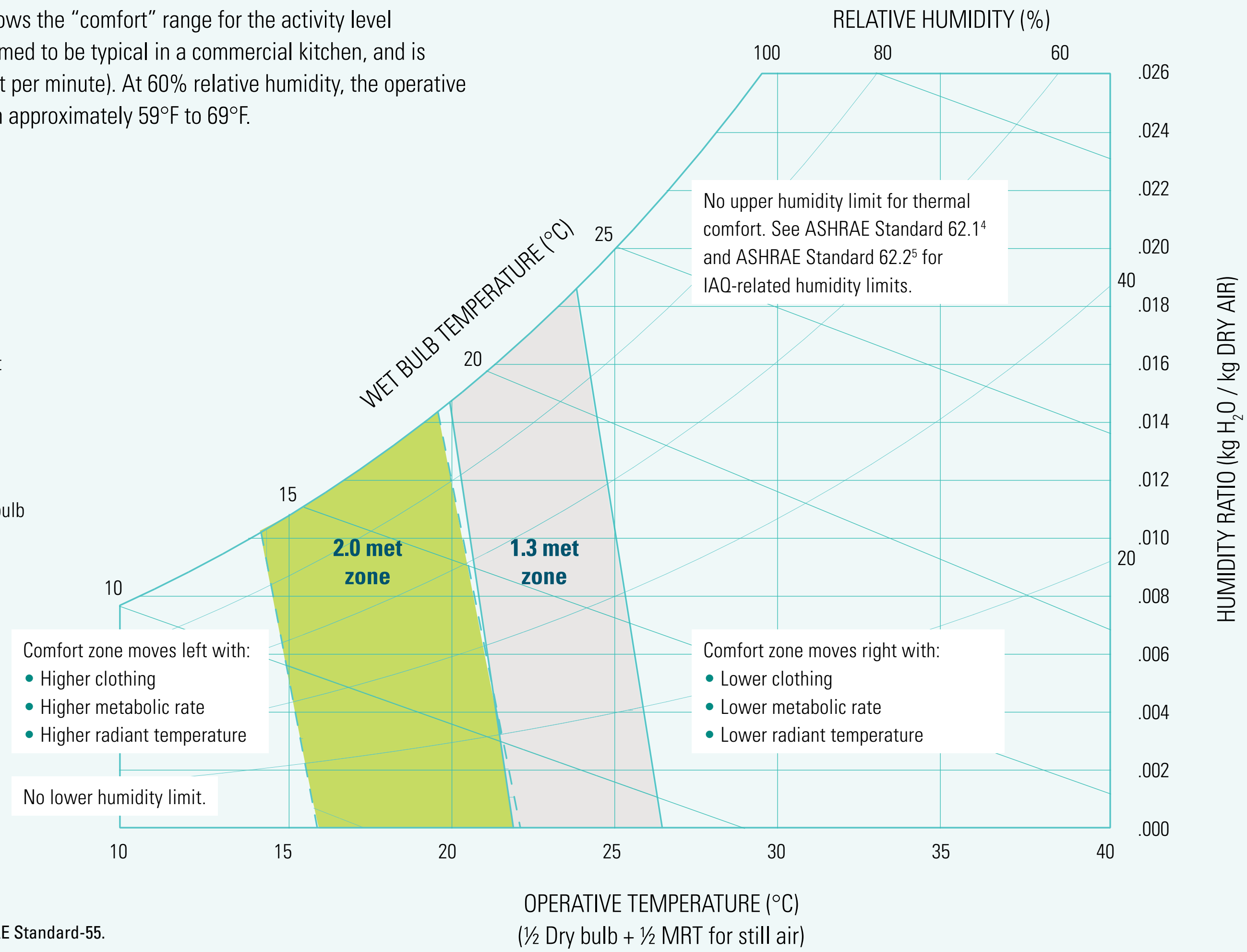
This graph is only applicable for the following conditions:

Metabolic Rate: 1.3 met or 2.0 met as indicated on graph (interpolation of met values not allowed)

Clothing Level: 0.65 clo

Average air speed: 20 fpm

Graph cannot be applied based on dry bulb temperature alone.



5.4.2.2_Safety

A commercial kitchen without open flames and very hot surfaces is a safer place to cook for several reasons:

Reduction in Fires

The lack of open flames greatly reduces the chances of accidental fires (see Figure 5.25). The risk of personal injury or damage stemming from aprons and towels catching on fire from contact with pilot lights and gas hobs is also greatly reduced, as are grease fires and other fire-related incidents.

FIGURE 5.25: AT SONOMA ACADEMY IN SANTA ROSA, CALIFORNIA, TEACHING KITCHENS WITH INDUCTION BURNERS CREATE LESS CHANCE FOR ACCIDENTAL FIRES AND ARE EASIER TO CLEAN FOR NEW STUDENTS AND FACULTY

Source: Celso Rojas

Reduction in Burns

Similarly, induction technology can greatly reduce hot surface areas, thus reducing the chance of employees burning themselves on the cooking surfaces or cookware handles.

Significant Reduction in Air Pollutants

The omission of combustible gas means no more air pollutants such as carbon dioxide, carbon monoxide, and nitrous oxide. This results in a kitchen that is safer for those with breathing difficulties, such as those suffering from asthma or bronchitis or experiencing diminished lung capacity, including those who have survived COVID-19.

Reduced Need for Caustic Cleaning Chemicals

Because there are no heat sources in an induction range, anything that spills onto the surface does not burn on and can thus be cleaned with just soapy water. As discussed in 5.4.3.1 below, this allows for a significantly easier cleaning process. For staff in a commercial kitchen, not only does induction technology make end-of-shift cleaning easier, it reduces their exposure to harsh cleaning chemicals and related burns and noxious vapors.

5.4.3_KEEPING IT WORKING: MAINTENANCE

Responsible commercial kitchen ownership and operation requires regular maintenance and cleaning of the equipment. It's the simplest way to ensure a long lasting and well-functioning kitchen. It’s also among the least popular or desirable kitchen tasks but is arguably the most critical. An all-electric kitchen can drastically reduce the time and effort required for maintenance and cleaning, relative to a traditional gas-powered kitchen. Embracing the electric kitchen means spending more time cooking and less time scrubbing.

> "Our induction equipment has cut down on our overall cleaning budget by largely eliminating the harsh chemicals needed to clean traditional equipment as well as the time needed by the staff to clean said equipment. Now we only use hot soapy water and a clean towel to clean everything from our ranges to our flat tops. This makes for a much **more enjoyable cleanup and saves us money.**"
>
> **— Chef Chris Galarza, Forward Dining Solutions LLC**

5.4.3.1_Easy Cleaning

Traditional gas equipment generally needs to be taken apart and scrubbed daily, often with harsh chemicals. The foil in the drip trays need daily cleaning and relining, their foil liners discarded and replaced, cleaned, and relined. The closing chef also needs to ensure that the pilot lights are re-lit and the burners properly in place. In short, cleaning a traditional gas line is expensive, in terms of both time and money, and is often seen simply as a "cost of doing business."

These costs, however, can be reduced significantly while also increasing overall productivity. Since the induction hobs are housed under the work surface, there are fewer places for food to burn onto. Additionally, induction griddles no longer require degreaser and grill bricks to clean. Simply using hot soapy water and a gentle scrub pad lifts all of the food debris and leaves the surfaces with a mirror finish. This not only cuts down on time but also chemical/cleaning costs as well. Gone are the days for grill bricks, harsh degreasers and other heavy duty cleaners, as well as long end-of-shift cleaning processes.

Due to the simplicity and efficiency of the clean-up, kitchen staff can spend less time cleaning and more time cooking. A switch to induction can lead to far fewer disruptions, such as forgetting to relight the pilot lights, or accidents, such as mistakenly turning on the burners, which can create gas leaks and potential health and safety dangers. Induction significantly reduces the risk of chemical burns and eliminates burns from touching a hot burner. The staff of an all-electric kitchen are now safer and more productive, which in turn saves the operator money and increases revenue in the long run.

5.4.3.2_The Tools: Pots and Pans

As noted above, not all cookware is compatible with induction equipment. The cost of pan replacement depends on whether the pots and pans currently on hand are induction-ready. In reality, though, it is recommended to replace all of your pans when switching from gas to induction. While this may sound exorbitant, expensive, and unnecessary, it's essential to maximize the efficiency and power of a kitchen using induction technology. Regardless of their magnetic qualities, pans that have been used on gas ranges have been damaged to some degree by the flame. The extreme nature of gas cooking degrades and warps the metal which means that, over time, a pot will sag in the middle or not sit flat (see Figure 5.26). When this happens, pans tend to sway and won't sit still on a burner. This is dangerous and can cause major injury if not replaced. Establishments should be replacing their cookware every other year anyway, or whenever they show signs of warping.

On an induction surface it's imperative to have a flat bottomed cooking surface to ensure a good connection with the induction unit. Without this flat bottom you could have hot spots, inconsistent temperatures, and — in extreme cases — an improper connection, which won't heat the pan at all. Poor connections between the induction unit and the cookware risks damaging the unit.

While the new cookware recommendation may sound contrary to the touted cost savings of induction, over time the investment will pay for itself. On average, restaurants replace their cookware every 3 to 5 years, depending on business levels. Fortunately, pans that are used exclusively on an induction unit boast much longer than average life spans. While Chef Chris Galarza was at the helm of Chatham University's Eden Hall Campus, he was using the same pans for over five years with no signs of warping or degradation.[29] The savings in kitchenware replacement should be included in any financial assessment, reducing the life cycle cost of maintenance for all-electric versus conventional kitchens.

FIGURE 5.26: WARPED AND BURNT PANS ARE EXTREMELY COMMON IN CONVENTIONAL COMMERCIAL KITCHENS

5.4.3.2_The Tools: Equipment

See "Maintenance Availability" in section 5.2.5 for a discussion of the equipment maintenance considerations.

5.4.4_FINANCIAL CONSIDERATIONS AND INCENTIVES

When shopping for electrified kitchen equipment, it is imperative that proper due diligence and research be done. The initial cost of the equipment, for example, is only one among many cost considerations that should be assessed. Listed below are a number of cost considerations, and this can help stakeholders determine what equipment is best suited for their operation. Prior to purchasing, it is recommended that an expert be consulted to help choose the right equipment for the right operation. Cutting corners at this stage may compromise the efficacy of the operation down the line, as the old adage goes: "you get what you pay for."
With proper choices and care, an operation can enjoy an all electric-kitchen for many years.

Cost Considerations

1. First cost and construction time savings (one less utility)
2. Availability of tax incentives and credits
3. Overall reduction in utility costs
4. Increased production efficiency and throughput
5. Rebate and other cost offset programs available from local utilities and governmental entities
6. Reduction in pot and pan replacements (increase in lifespan by several years)
7. Reduced life cycle costs and increased ROI potential

29 Interview with Chef Chris Galarza, June 24, 2021.

5.4.4.1_Energy Efficiency

Commercial food service equipment consumes over $10 billion of energy per year in the U.S., with as much as 80% of that energy wasted — transformed into heat and noise by inefficient equipment.[30] According to the most current Commercial Building Energy Consumption Survey from the US DOE (2012),[31] food service is the most energy intensive occupancy type in this database with over 3.5 times more energy use per square foot than office buildings (see Figure 5.27). This is likely due, in large part, to the long work-days (often 14 hours per day or more) as well as the inefficiency of gas cooking: when you cook with gas, as much as 50 to 80 percent of the energy used goes into the atmosphere, heating your kitchen, but not your food (see Figure 5.28).

FIGURE 5.27: ENERGY USE INTENSITY BY PRINCIPAL BUILDING ACTIVITY

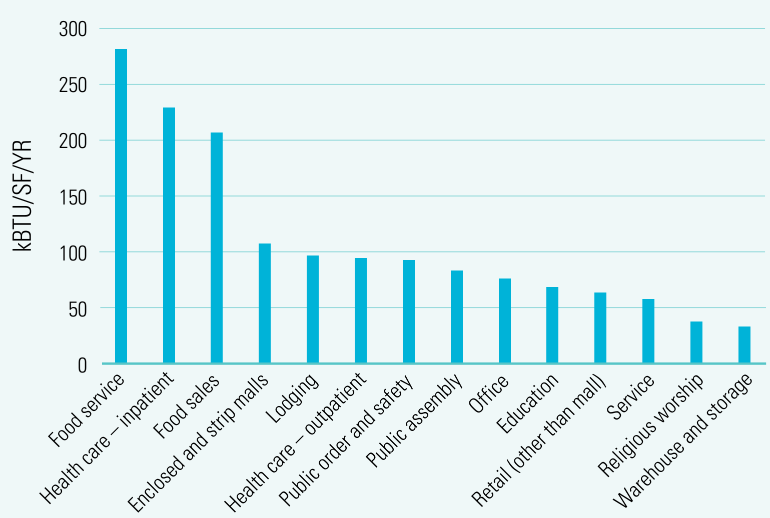
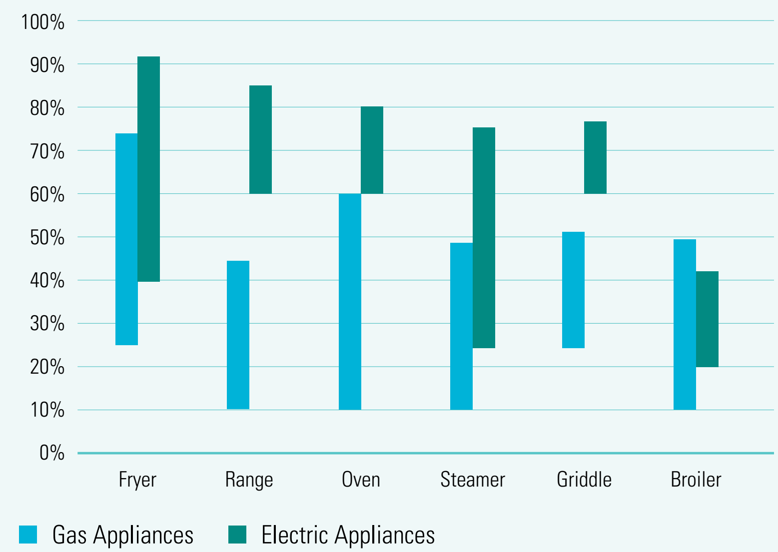


FIGURE 5.28: EFFICIENCY DIFFERENCE — GAS VS. ELECTRIC EQUIPMENT



Source:
https://fishnick.com/handouts/06232016/RYoung-Sustainability_Beyond_the_Plate-06232016.pdf

30 https://www.buildinggreen.com/feature/commercial-kitchens-cooking-green-opportunities

31 https://www.eia.gov/consumption/commercial/data/2012/index.php?view=consumption

According to research by Brent Ehrlich:[32]

> *The food service industry has lagged behind many others where energy and water efficiency are concerned. Old, inefficient kitchen equipment was made to last for decades and is often kept as a matter of tradition, passed from chef to chef as restaurants change hands. New restaurant owners trying to save on start-up costs — particularly if they are renting the building space — may look for bargains in used kitchen equipment, weighing first costs against restaurant failure rates that approach 60% in the first three years of operation, according to a study by researchers at Ohio State University.*
>
> *Focusing only on lower first costs can be a poor business decision, however, even considering the chances of failure.* ***Large utility bills month after month cut into profits, while new energy-efficient equipment can often pay for itself in as little as a year.*** *Faced with a future likely to include higher utility costs and a challenging business climate, commercial kitchen owners and renters alike are beginning to view energy and water efficiency as both an environmental and business necessity.*

5.4.4.2_First Cost, Operating Cost, and Carbon Emissions Reduction

This practice guide is unapologetic in its advocacy for all-electric equipment in kitchens and elsewhere. The environmental, equity, and public health benefits are too strong to do otherwise.

However, there are currently tradeoffs between first costs and long-term savings, GHG emissions reductions, maintenance costs (where significant reductions can be realized in an all-electric kitchen as discussed in section 5.4.3), and other considerations. Thus, it is always beneficial to evaluate the choice between an all-electric kitchen and other design approaches from the standpoint of life cycle cost.

Until market demand lowers the cost of induction equipment, the first cost of most electric commercial kitchen equipment is still likely to be more than their gas counterparts. In addition, electricity is often more expensive than gas. These two factors often present financial challenges for projects seeking to replace traditional kitchens with all-electrical kitchens. Smart design strategies, rebates and other incentives from utilities and local governments, onsite renewable energy systems, a focus on life cycle cost instead of first cost, and support from policy makers can help alleviate these barriers, real or perceived.

Irrespective of rebates and other incentives, there are several ways to assess the costs and trade-offs inherent in your initial kitchen design and planned operations. To understand these tradeoffs, one can look to a study performed by a leading California-based food services consulting firm, which used PG&E utility rates and average carbon emissions from the California electricity grid. The study was developed in order to evaluate the potential first cost, operating cost, and carbon emissions reductions from three kitchen design scenarios: A) a Base Efficiency Cookline, B) an energy efficient Hybrid Cookline, and C) an All-Electric Cookline (see Figure 5.29).[33]

Commercial food services equipment does not get updated frequently, so the Base Efficiency Cookline is modeled from equipment that has largely gone unchanged since World War II. By replacing this old equipment with more energy efficient equipment, including an induction cooktop and a rapid cook oven, the Hybrid Cookline would save roughly $4,000 in fuel cost and 24.3 tons of carbon emissions annually when compared to the Base Efficiency Cookline. The upfront investment in new equipment can be easily paid back from fuel cost savings.

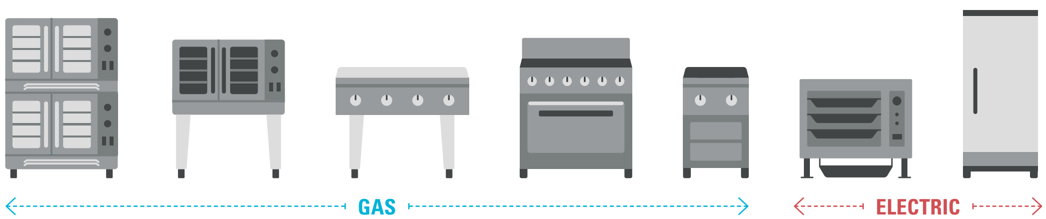
Replacing all kitchen appliances with all-electric models (the All-Electric Cookline) would save $2,456 in annual fuel costs and approximately 32.1 tons of carbon emissions, compared to the Base Efficiency Cookline. The All-Electric Cookline's higher annual fuel costs versus the Hybrid Cookline is due to the higher electricity costs, which can be reduced or eliminated by investments in onsite renewable electricity generation.

32 https://www.buildinggreen.com/author/brent-ehrlich

33 Decarbonizing the Commercial Kitchen with Energy Efficient Equipment, FISHNICK, April 30th, 2020.

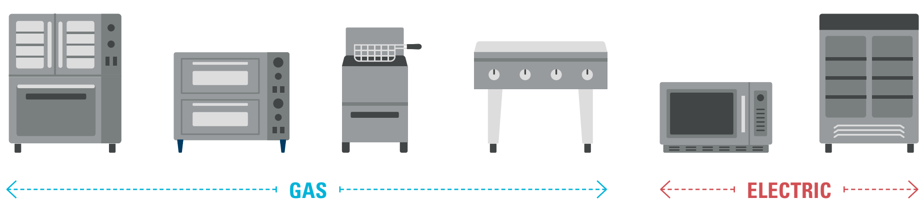
FIGURE 5.29: COMPARISON OF A TRADITIONAL ("BASE EFFICIENCY") COOKLINE, A HYBRID COOKLINE (MIXED FUEL), AND AN ALL-ELECTRIC COOKLINE

BASE EFFICIENCY COOKLINE



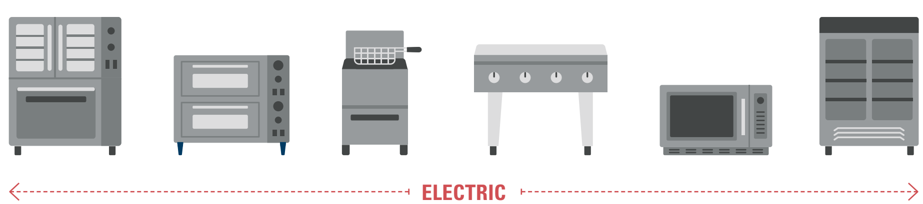
CO_2 = 37.3 metric tons / year
Fuel Cost = $11,812 / year

HYBRID KITCHEN COOKLINE



CO_2 = 13 metric tons / year
Fuel Cost = $4,079 / year
Savings vs Base = 24.3 tons and $7,733

ALL-ELECTRIC KITCHEN COOKLINE



CO_2 = 5.2 metric tons / year
Fuel Cost = $9,356 / year
Savings vs Base = 32.1 tons and $2,456

Source: Decarbonizing the Commercial Kitchen with Energy Efficient Equipment, FISHNICK, April 30th, 2020.

This study points out other savings from the all-electric kitchen that may not be included in the financial modeling and that are also worthwhile for designers and owners to examine:

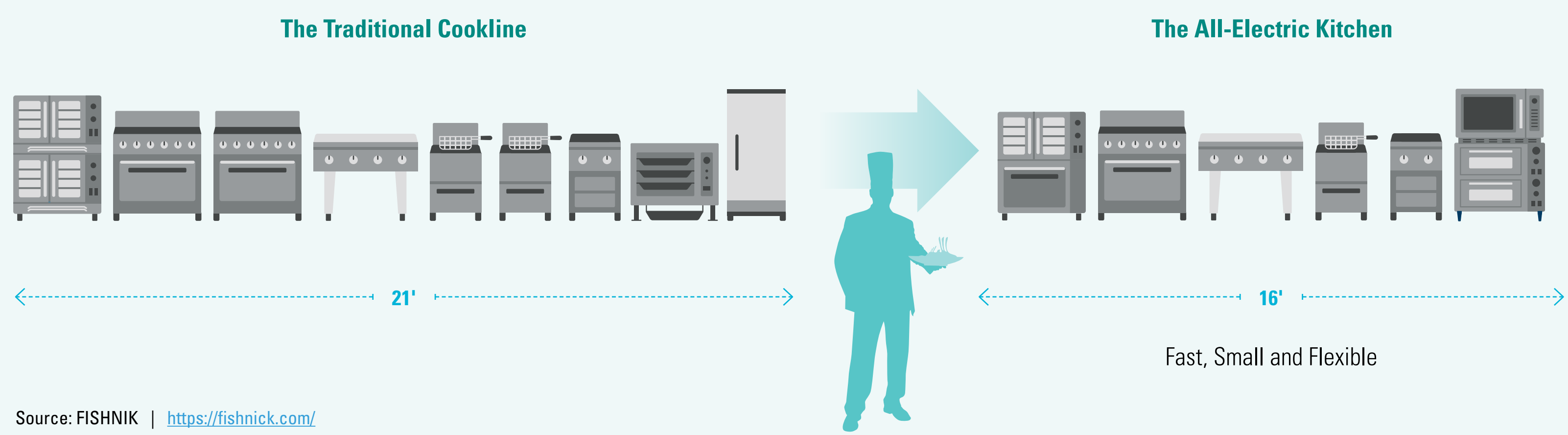
» The savings on labor and staff
  - The newer cooking equipment could produce more food in a shorter amount of time due to the efficiency and precision of the equipment.

» More flexible use of all-electric equipment
  - Modern, all-electric equipment can help a kitchen be more versatile provide more consistent quality, elevating the culinary performance in ways that can enhance an operation's revenue.

» The space savings of an all-electric cookline
  - The space savings could result in a smaller kitchen area (see Figure 5.30). An all-electric cookline requires a smaller footprint than a traditional cookline for equal or improved throughput. The freed up space could lead to lower rent or provide additional dining area, which can help generate more revenue.

» The first cost and operational costs savings from kitchen exhaust hood systems
  - The reduced size of controlled kitchen ventilation systems could cut energy cost by as much as 50 percent.

FIGURE 5.30: AN ALL-ELECTRIC COOKLINE REQUIRES A SMALLER FOOTPRINT THAN A TRADITIONAL COOKLINE FOR EQUAL OR IMPROVED THROUGHPUT



Source: FISHNIK | https://fishnick.com/

5.4.5_THE IMPORTANCE OF COMMUNICATION AND EXPERTISE

Designing, building, and operating an all-electric kitchen usually involves a diverse set of professionals, including architects, engineers, chefs, and various appliance manufacturers and vendors. Communication is key: many chefs don't speak "Climate Change," and many architects don't speak "Food Preparation." As such, translating between professionals is key to the success of any project.

5.4.5.1_Consult with an Experienced Chef

When considering the buildout of an electric kitchen, it can be critical for the success of the project to seek the expertise of a chef who has experience working in an all-electric space and can speak from an authentic point of view. Chefs or other qualified consultants can offer a unique perspective to a project that architects and engineers often can't bridge. When clients defer to their trusted in-house chefs, it's imperative that the chef is on board with the project at its onset. A well-respected chef/consultant can often assuage any concerns and can be instrumental in getting more hesitant chefs on board.

Culinary teams are often put off by the introduction of new technology, and instead argue for the inefficient but well known gas equipment. Having a consultant who can "speak their language" on a peer-to-peer basis can help lessen or eliminate the push back. Even better, it may generate excitement for the change. A chef who can speak to the efficacy of the equipment that will be inhabiting the space can be extremely effective at changing hearts and minds.

The earlier a chef or consultant can be introduced into the conversation the better.

5.4.5.2_Recommended Stakeholder Engagement

The various stakeholders in the design process can bring useful attributes and skills to the conversation:

The Owner

Every owner has a vision that extends past just getting a kitchen or project completed; there are often long-term investment and business concerns as well. Understanding the Owner's perspective is essential to framing the opportunity and approach to all-electric kitchen design. Cost, risk, attractive leasing, market competition, and employee satisfaction are common considerations. Speaking from a point of employee retention and wellness continues to be of much interest. Understanding market forces and code pressures will help them understand and value current investments against future proofing strategies. Framing the opportunity around leadership, employee health, and overall energy savings helps to flesh out the conversation so that it is not just about the decision between gas or electricity.

The Chef/Culinary Consultant

Having a colleague who has gone through the transition and understands the world the culinary team inhabits is a powerful tool to use to help quell any resistance. It is also important to provide kitchen design consultation to assist chefs and small restaurant owners with the task of figuring out long-term financial planning based on an ROI analysis (and one that includes all life cycle costs). Furthermore, the fact that healthy food is often the least energy intensive, while things like deep fried foods are very energy intensive, should be considered in ROI evaluations.

The Operations Staff

Operations staff are at the crux of the whole undertaking. As the primary users, it is important that they make their vision clear and be in constant communication with the rest of the team to ensure that the vision is being met. It is also important that they serve as the point of contact for the design team and act as a liaison to make sure that the needs of the culinary team and the design team are met.

The Architect

The role of the architect is to start the conversation on day one of the design process. They should urge the client to get the food services team involved early, especially the end users, and allow time for open dialogue and hands-on experience selecting the right kitchen equipment for the right menu. This gives time for the culinary team to creatively think how to prepare certain dishes in a new, safe and more precise way with all-electric kitchen equipment. It is also crucial to compare the space savings and more robust and versatile food output of all-electric kitchens compared to traditional gas kitchens. It is worth noting during the early design process that an all-electric kitchen can provide the same throughput as a larger gas-fired kitchen, which can free up space for revenue-generating activities or other programmatic features.

The Engineers

It is useful to have an engineering team that includes members who are experienced in providing complete evaluations of the costs and benefits of all-electric kitchens (including detailed life cycle cost analyses). The engineers should be able to highlight potential energy use reductions available from a design that uses all-electric kitchen equipment. In most cases, engineers will be able to demonstrate that the energy cost savings provide a reasonable payback period for investments in induction equipment and advanced exhaust hood controls. They might also highlight the increased likelihood of delivering good thermal comfort in the kitchen, as well as the benefits of improved indoor air quality. Furthermore, all-electric, single fuel kitchens are generally easier for the engineering team to design since there are fewer utilities to coordinate and many of the safety issues that need to be addressed with the installation of natural gas systems do not exist in an all-electric kitchen.

Hands-on Engagment

Each stakeholder should consider the value of visiting an educational center that provides hands-on experience with all-electric kitchen equipment. For example, for more than 30 years the Food Service Technology Center (FSTC)[34] in Northern California has offered consultation for energy and water efficiency design and provides current rebate program information. Their "Try Before You Buy" program gives chefs and restaurant owners hands-on experience to test recipes and all-electric products before making a financial commitment. The experiential knowledge gained in this kind of a setting can feed back in crucial ways into the design phase.

34 https://fishnick.com/fstc/

5.4.7_COMMERCIAL KITCHEN CASE STUDIES

5.4.7.1_Eden Hall Campus, Chatham University

Source: Sam Oberter

Source: Mithun

Project Location: Pittsburgh, Pennsylvania

Completion Year: 2016

Project Size: 48,250 square feet[35]

35 985 SF Cafe/Kitchen building, 3,535 SF Field Lab, 20,500 SF dormitory building, and 23,500 SF Common building (which includes dining and banquet facilities, and classroom spaces).

What:

The Eden Hall Campus of Chatham University, a private university in Pittsburgh, Pennsylvania was created to be the world's first fully self-sustained and ZNE university campus. It boasts 46 geothermal wells, an on campus water treatment site, and a 40 acre farm. The campus' Commons Building houses an all-electric kitchen that consists of induction ranges, induction flat tops, induction warmers, convection ovens, an electric triple deck oven with two built in proofers, an induction tilt skillet, an electric fryer, and an electric steamer. The kitchen is equipped with hood vents that have a heat recovery system built in and that works in conjunction with the geothermal systems.

Given the energy-intensive nature of a campus dining program, an extensive energy analysis focusing on the commercial kitchen equipment and HVAC systems was conducted during the design phase. Through this process, induction equipment was shown to reduce kitchen energy consumption by over 50%, in comparison to a traditional kitchen using natural gas. Further, the demand-based exhaust hoods with integrated heat recovery, the geo-exchange heat pump, and the radiant heating and cooling systems dramatically reduced HVAC energy for the dining program. The facility is predicted to operate at an EUI of 121 kBtu/ft2-yr, which is almost 60% below a typical full-service restaurant.

The Commons Building was designed with an onsite PV system that was expected to offset approximately 50% of the building's electrical energy use, with the other half almost entirely satisfied by a small cogeneration system that also provides recovered thermal energy for space heating and domestic water heating.

How:

HVAC	VAV hood vents with geothermal compatible heat recovery
DHW	All-electric (details not available)
Cooking	Induction range, Induction tilt skillet, Steamers, Electric convection ovens, Electric deck ovens w/proof boxes, Recessed induction warmers, Electric fryer, Induction flat top griddles, Recessed counter top induction hobs
Owner	Chatham University
Architect	Mithun
General Contractor	SOTA Construction
Mechanical Engineering	Interface Engineering
Electrical Engineering	Interface Engineering
Structural Engineer	KPFF Engineers
Kitchen Consultant	The Marshall Group / Chef Chris Galarza

Source: Chris Galarza

5.4.7.2 _McAteer High School Culinary Center Renovation

Source: Tim Mena

Source: Tim Mena

Project Location: San Francisco, CA

Completion Year: 2019

Project Size: 9,000 square feet

What:

McAteer Culinary Center Renovation was the first all-electric kitchen for the San Francisco Unified School District (SFUSD). This renovation project served as a prototype kitchen for five future "central kitchens" that will deliver fresh meals instead of prepackaged foods to Early Education Development programs across the SFUSD. For the health of staff, students and community members, SFUSD's Sustainability Department strongly advocated for electrification and the removal of natural gas for this project. The electrification of the project included the installation of state-of-the-art, energy-efficient commercial kitchen equipment such as electrical combi ovens, an industrial electrical kettle, and an electrical tilting skillet. The kitchen also connects to a welcoming servery and cafeteria for McAteer high school students and staff to dine in.

How:

HVAC	All Electric High Efficiency Indoor Fan Coils and Outdoor Condensing Units with SEER values up to 14
DHW	Existing natural-gas fired domestic hot water heater
Cooking	Combi Oven, Portable Induction cooktop, Electrical and convection oven
Owner	SFUSD
Architect	Gould Evans
General Contractor	Build Group
Mechanical Engineering	Capital Engineering Consultants, Inc.
Electrical Engineering	Helix Electrical
Structural Engineer	Murphy Burr Curry, Inc.
Kitchen Consultant	The Marshall Associates, Inc.

Electrification features:

Energy efficient commercial kitchen equipment such as electrical combi ovens, an industrial electric kettle, and an electric tilting skillet were incorporated for batch cooking of bulk food. A 1 kW portable induction hob is used at a separate workstation dedicated for small numbers of meals to suit special dietary needs, such as gluten-free meals.

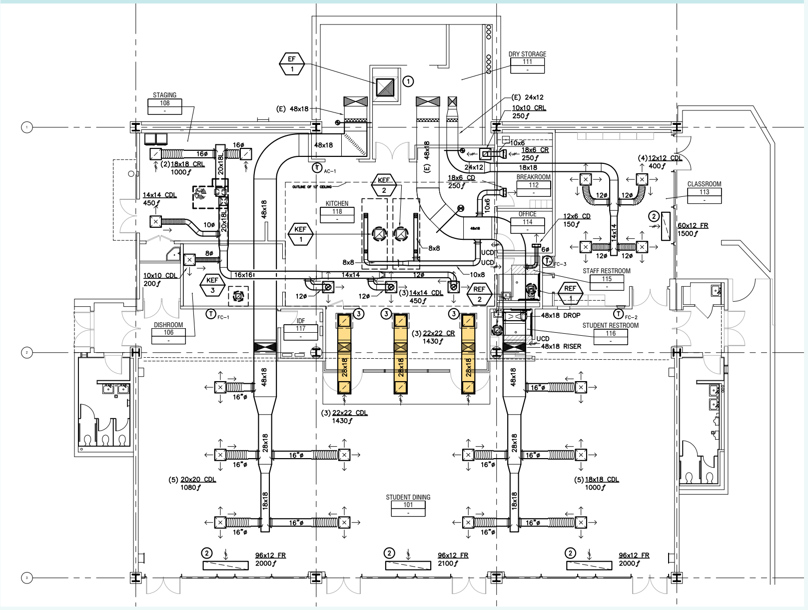
A demand controlled kitchen ventilation strategy saves energy by adjusting the quantity of kitchen hood exhaust and incoming outdoor air to reflect the amount of cooking taking place under the hood. The system maintains full capture and containment of smoke and combustion byproducts in response to appliance operation.

Demand controlled kitchen ventilation systems reduce fan power consumption and produce HVAC savings proportional to the reduction in airflow of approximately 10% to 50%.

Additionally, the McAteer kitchen space is directly adjacent to the dining room. An additional energy saving strategy incorporated transfer air from the dining area (which has large OSA ventilation loads) into the kitchen (highlighted in yellow in Figure 5.31) to serve as make-up air during kitchen hood operation. Transferring this pre-conditioned air allowed for the downsizing of the heat pump that serves the kitchen area proper.

Split heat pumps (indoor fan coil unit and outdoor heat pump unit) provided all heating and cooling. A BMS system was installed to optimize energy use. A new 24-inch ventless heat pump dryer was also installed along with an on-site washer for all kitchen-related laundry.

FIGURE 5.31: TRANSFER DUCTS (HIGHLIGHTED IN YELLOW) ALLOW FOR THE USE OF DINING AREA VENTILATION AS MAKE-UP AIR TO THE KITCHEN HOOD EXHAUST SYSTEMS



Lesson Learned:

A challenge for electrification was getting the operation and maintenance team on board for switching the existing gas domestic hot water heater to electric heat pump water heaters. More outreach and training with the O&M team leading up to future kitchen projects would be beneficial.

Testimony from Joshua Davidson, chef from SFUSD Student Nutrition Services:

Compared to our most recent experience with a gas-powered kitchen, the space here is much more comfortable. Not having to fiddle with matches or crawl on the floor to relight pilots is a welcome change of pace and safety.

All of the electrical appliances perform better than their gas counterparts, but the real stars of the show here are the Combi oven and the new kettles. The gas kettle we used previously was much slower to warm. The Combi oven is leaps and bounds faster than any other oven we've used, with warm-up times sometimes under a minute and never more than 5 minutes. One combi oven can output the same amount of food as four regular ovens.

The new tilt skillet and kettles give us much more even and reliable temperature control. The combi oven gives us capabilities we didn't have before, like low temperature steaming for perfectly textured hard-cooked eggs. As things return to normal after the pandemic, we have growth plans and the new equipment is a big part of that. Catering programs for school districts, the city, or school events are all in progress due to the excellent output of the kitchen.

One of the best things about the new ovens is they can be unplugged and rolled away to thoroughly clean the workspace. Even surface heating means the tilt skillet does not develop burn spots that accumulate carbon over time. Induction burners never cover the pots and pans in carbon, so there is a whole world of cleaning we don't even have to think about anymore.

Significantly, since the new all-electric kitchen provides such a versatile food menu, teachers and staff have started purchasing meals at the cafeteria, which was unprecedented in the past.

5.4.7.3_Janet Durgin Guild and Commons, Sonoma Academy

Source: Michael David Rose

Source: Celso Rojas

Project Location: Santa Rosa, CA

Completion Year: 2018

Project Size: 22,494 square feet

What:

Sonoma Academy, a private high school in Santa Rosa, California, has an all-electric kitchen with induction equipment that serves the students, staff and faculty. Located at the base of Taylor Mountain, the project includes 29 geoexchange wells, and enough photovoltaics to ensure the project is net positive. Early work with the school included an energy balance matrix that helped outline options for storing, preparing and cooking the desired diversity of food options the school wanted to provide its community. Equipment selection was vetted through the priorities of sustainability, quality, variety, and education, resulting in induction ranges, induction flat tops, convection ovens, and induction warmers.

The very tight kitchen and back-of-house area generated discussions on how to maximize the space for efficiency and use. Benchmark systems like LEED, WELL and the Living Building Challenge (LBC) provided the lenses through which marketplace offerings were matched with all team members' needs (including the school dining vendors that would eventually operate the facility). All materials and systems, including the cooking and warming components were vetted through the LBC's Materials Petal. The project was awarded the LBC Petal for Material, Health and Happiness and Equity along with Zero Carbon. The project is an AIA Top Ten COTE winner.

How:

HVAC	Ground Source Heat Pump (GSHP), FCUs and energy recovery
DHW	Electric water heater, preheated through GSHP
Cooking	Ovens, Combi ovens, Induction ranges, Tilt kettle
Owner	Sonoma Academy
Architect	WRNS Studio
General Contractor	XL Construction
Mechanical Engineering	Interface Engineering
Electrical Engineering	Integral
Structural Engineer	Mar Structural Engineering
Foodservice / Kitchen	Consultant Flik/Vision Builders

Good indoor air quality is critical to learning environments. Connection to nature, daylight and natural ventilation dictated the building's design — 80% of the project is naturally lit. South-facing exterior blinds tune for exposure and wind - managing sunlight and heat for the teaching kitchen, the main kitchen and the dining room.

Active and passive mechanical design strategies are incorporated, taking advantage of the mild Bay Area's climate. Natural ventilation and ceiling fans are used throughout the shoulder season, providing user control, passive cooling, and a high degree of user adjustability.

Radiant heat and cooling is used during the more extreme months, which is provided by geo-exchange ground source heat pumps. The geo-exchange system provides groundwater directly to the radiant manifolds when the groundwater is at an appropriate temperature — expected to provide 10-15% of the annual cooling demand. The mechanical system captures waste heat from the ventilation air and refrigeration system in the commercial kitchen — used for space heating and domestic hot water production. The central heat pump is also used for domestic hot water heating — one of the largest demands due to food service.

As food service facilities often have an EUI above 400, a significant challenge included working with the food service provider and the school to tune choices and detail use schedules, resulting in aggressive load reductions in the maker and food service equipment in order to get to ZNE. The food service EUI is 98 while the classrooms and office total an EUI of 17. In total the project has tracked an EUI of 38.

The kitchen facility is 100% electric, including electric warmers and induction cooktops, which reduce or eliminate energy consumption by eliminating idling. The reduced byproducts and particulates contribute to a healthier work environment for the kitchen staff, and due to the open kitchen plan, a healthier dining experience for the students and community.

5.5_Resources

5.5.1_THE INDUCTION MISCONCEPTION LIBRARY

As a relatively new but proven and promising technology, induction is subject to many misconceptions about its impact and effectiveness. Figure 5.32 (Parts 1 and 2) outlines the misconceptions and realities of induction equipment.

FIGURE 5.32:_THE INDUCTION MISCONCEPTION LIBRARY, PART 1

Misconception	Reality
Cooking with induction is difficult	While there is a learning curve, getting used to the power and control of induction is quite easy and very rewarding. The additional features (that are not even available in gas appliances) may take more time to master.
Induction cooking is overrated and benefits are overstated. Gas cooking is the gold standard for a reason.	Induction is in fact considerably underrated and its benefits understated: • Induction cooking provides precise temperature adjustments that gas cannot. • There is no idling of equipment with induction, unlike the gas counterpart. • There is no combustion and therefore no carbon monoxide and other harmful combustion byproducts. • There is much cleaner air quality in the work environment. • Induction heats up significantly quicker than gas.
Cooking with gas gives you more control.	Induction cooking offers more control over gas. Most units come with built-in temperature displays that help fine tune your cooking by individual degrees. It responds far quicker to the temperature changes because it works with the molecular structure of the pan to more effectively control temperature and speed response time. The result is faster and more precise control.
Induction cooktops and ranges don't cook as well as gas, and because of this quality suffers.	Food served on cruise lines is fully prepared on all-electric kitchen equipment since no gas is allowed on these vessels. The popularity of meals on cruises suggests food quality is on a par with land-based kitchens.
The radiation waves from induction are harmful.	There are many reasons that these concerns are overstated in relation to induction cooking. The EMF from an induction stove is classified as a class 2b carcinogen, alongside coffee and pickles. The National Cancer Institute notes that "No mechanism by which Extremely Low Frequency Electro-Magnetic Frequencies (ELF-EMFs) or radiofrequency radiation could cause cancer has been identified." For further discussion of these considerations, see section 5.2.2.
Chefs or home cooks can't preheat their pans and therefore can't sauté properly.	With induction there is no longer a need to warm your pans prior to sauteing. Chefs developed that technique to assist in the heating of their pans due to the woefully inefficient method of gas cooking. Also removing the pan from the induction unit doesn't render the pan or the heat in the pan useless. It's no different than removing a pan from the fire. The pan still retains its heat for a period of time.

FIGURE 5.32:_THE INDUCTION MISCONCEPTION LIBRARY, PART 2

Misconception	Reality
The glass surface of the induction equipment will crack/warp because it's not able to withstand a professional kitchen setting.	Induction units do not use tempered glass and are instead installed with tempered ceramic glass. This is an important distinction. While tempered glass withstands constant temperatures up to 470°F, tempered ceramic glass can withstand temperatures surpassing 1,200°F. This means the surface of induction equipment will not crack and warp.
The glass surface of induction isn't conducive to home cooking practices.	Tempered ceramic glass on induction units can handle intense activity with ease and there is no reason why it shouldn't be conducive to home cooking practices. The same glass is used in commercial kitchen induction equipment.
Induction costs too much and isn't worth the price in the long run.	The induction unit itself does currently cost more than a traditional gas range. However, numerous federal/state/local authorities offer rebates that offset the higher cost. It's also important to account for the fact that induction cooking is 80%–90% efficient compared to its gas counterpart, at 30%–40%. Induction technology saves money in the long term.
Induction cooking technology does not accommodate wok cooking.	Induction cooking has evolved to accommodate induction wok cooking. This new equipment is created for the wok to sit comfortably in the unit. This also has the added benefit of creating contact with all surfaces of the wok, making wok hei achievable using induction. Induction wok cooking also has the added benefit of saving the average Asian food restaurant hundreds of thousands of gallons of water per year. (https://p2infohouse.org/ref/50/49033.pdf) Also see 5.3.4.2 "Residential Induction Woks."
The nature of induction requires you to replace all of your pots and pans because most stainless steel isn't magnetic. For this reason alone induction is too expensive and not worth it.	While much commercial cookware may need to be replaced, most residential cookware works perfectly. Exceptions are old style anodized aluminum, copper, and glass cookware. Most of today's cookware works, such as triple ply cookware, cast iron, enameled cast iron and many others. Remember this: if a magnet sticks, it works. And, don't forget that pans that are used exclusively on an induction unit boast much longer than average life spans (especially in commercial settings).
There isn't enough electric equipment to justify the change.	Nearly every piece of cooking/warming equipment in any home or commercial kitchen is already electric. There are only a few that still use gas. Below is a list of equipment that can be replaced with all-electric equipment: Gas cooktops, ovens, and ranges; convection, combination, rapid cook, rack, and deck ovens; flat top griddles; fryers; woks, tilt skillets, soup wells; well warmers, delivery bags.

5.5.2_OTHER RESOURCES

Residential Kitchen Data Hub

(https://www.buildingdecarb.org/kitchen-electrification-group-resource-directory.html)

Rebate Programs

» Sacremento Municipal Utility District (SMUD) induction rebates

- SMUD Multifamily Retrofit (https://www.smud.org/en/Business-Solutions-and-Rebates/Business-Rebates/Multi-Family-go-electric-incentives)
- SMUD All-Electric Smart Homes (New) (https://www.smud.org/en/Going-Green/Smart-Homes)
- SMUD Appliance Rebates (https://www.smud.org/en/Rebates-and-Savings-Tips/Rebates-for-My-Home/Home-Appliances-and-Electronics-Rebates)

» BayRen induction rebates (https://bayrenresidential.org/get-rebates)

» Silicon Valley Clean Energy Rebates (https://content.govdelivery.com/accounts/CAORGSVCE/bulletins/2fd0aeb#induction)

Residential Kitchen Hands-on Experiences

Culinary and maker spaces dedicated to sharing the excitement of electric kitchens with online events, chef experiences, videos and content:

» The Electric Kitchen Workshop, Monark Premium Appliance, San Francisco, CA (https://monarkhome.com/).

- Other Monark Premium Appliance locations:
  - › Santa Clara, San Rafael, Concord, and Rancho Cordova, CA
  - › Reno, NV
  - › Miami, Bonita Springs, Palm Beach, and Pompano, FL

» Yale Appliance Dorchester, Framingham and Hanover MA (www.yaleappliance.com)

» Miele USA Experience Centers

- San Francisco and Beverly Hills, CA
- Boca Raton and Coral Gables, FL
- Chicago, IL
- Manhattan, NY
- Princeton, NJ
- Scottsdale, AZ
- Seattle, WA
- Tyson's Corner, VA

» Pirch Appliances (www.pirch.com)

- Costa Mesa, Glendale, Palm Springs, La Jolla, and Solana Beach, CA

- BSH Appliances Experience and Design Center (https://www.bosch-home.com/us/kitchen-planning-resources/showrooms)
    - Irvine, CA
    - Chicago, IL
    - New York, NY
- Monogram Design Centers (www.monogram.com)
    - Chicago, IL
    - Denver, CO
    - Philadelphia, PA
    - Norwalk, CT
- Fisher & Paykel Experience Center (https://www.fisherpaykel.com/ca/inspiration/experience-centres)
    - Costa Mesa, CA and New York, NY
- Hestan Cue Smart Cooking (www.hestancue.com)
    - Vallejo, CA
- Purcell-Murray (www.purcellmurray.com)
    - San Francisco, CA
- Riggs Distributing, Burlingame, CA (https://www.riggsdistributing.com/events/)
- Portable Induction Loaner Programs (https://www.acterra.org/induction)
- Advanced Energy Center, Sonoma Clean Power, Santa Rosa, CA (https://scpadvancedenergycenter.org/education-hub)

Residential Kitchen Videos for Conversation Starter

- *Nourishing Our Net-zero Future:* Induction vs Gas Cook-off, by Gould Evans (https://vimeo.com/gouldevans/netzero)
- Spotlight on Electric Induction Cooking! (https://www.youtube.com/watch?v=eOeauIma3xM)

Commercial Kitchens

- Food Service Technology Center offers consultation for energy and water efficiency design and provides current rebate program information; "Try Before You Buy" program offers hands-on experience with food services equipment before financial commitment. (https://fishnick.com/fstc/)
    - The Induction Technology Center (ITC) is a technical and educational resource dedicated to sharing accurate and unbiased energy and performance information about induction cooktops, woks, and hot food holding. Based at the Food Service Technology Center (FSTC), the ITC was created to help demystify induction cooking and holding and assist in the promotion and adoption of this efficient technology. (www.fishnick.com/itc)
- SMUD Rebates for Commercial Kitchens (https://www.smud.org/en/Rebates-and-Savings-Tips/Go-Electric/Business-Go-Electric)
- Induction for Commercial Kitchens, on-demand webinar from Sonoma Clean Power's Advanced Energy Center (https://scpadvancedenergycenter.org/news/induction-for-commercial-kitchens-webinar-recording-1)

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Project Sponsors

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At Google, sustainability is at the core of everything we do. We tackle environmental sustainability projects because they reduce our company's environmental impact, and also because they help our bottom line. But mostly we do it because it needs to be done and it's the right thing to do. And we're not just saying that. Google has been carbon neutral since 2007. We believe this Building Decarbonization Practice Guide is a great tool that will help enable design and engineering teams everywhere to deliver water innovation for residential and office-space projects of all scales.

Microsoft

At Microsoft, we believe sustainability is critical for meeting the economic, societal, and environmental needs of today and of future generations. We also believe sustainability is good for business.

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Energy Foundation supports education and analysis to promote non-partisan policy solutions that advance renewable energy and energy efficiency while opening doors to greater innovation and productivity — growing the economy with dramatically less pollution. For nearly 30 years, Energy Foundation has supported grantees to help educate policymakers and the general public about the benefits of a clean energy economy. Our grantees include business, health, environmental, labor, equity, community, faith, and consumer groups, as well as policy experts, think tanks, universities, and more.

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BUILDING DECARBONIZATION COALITION

The Building Decarbonization Coalition unites building industry stakeholders with energy providers, environmental organizations and local governments to help electrify California's homes and work spaces with clean energy. Through research, policy development, and consumer inspiration, the BDC is pursuing fast, fair action to accelerate the development of zero-emission homes and buildings that will help California cut one of its largest sources of climate pollution, while creating safe, healthy and affordable communities. The Project Team gives special thanks to the BDC for its leadership in this endeavor and for the generous support of its Membership.

WRNS STUDIO

Guttmann & Blaevoet CONSULTING ENGINEERS

CONNECTING POLICY AND PRACTICE WITH DESIGN URBAN FABRICK

WILLIAM J WORTHEN FOUNDATION

Contributors

Building Decarbonization Practice Guide Content Leadership

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

Project Management

- **Brett Rosenberg,** LEED AP, Treeline Strategy, LLC
- **Steven Guttmann,** PE, BCxP, LEED Fellow, Guttmann & Blaevoet, Principal Investigator

Graphic Design

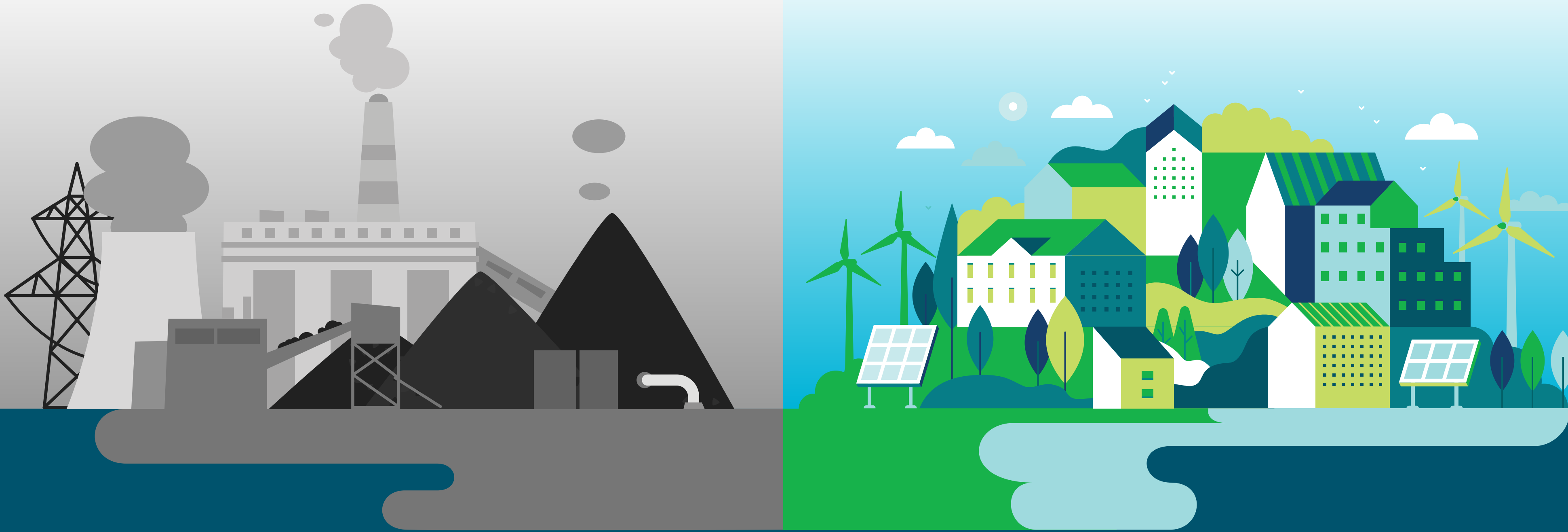
- **Stoller Design Group**

Copy Editor

- **Geoff Martin,** Wheelhouse Writing Services

Working Group Members and Content Contributors

- **Katie Ackerly,** AIA, David Baker Architects
- **Sean Armstrong,** Redwood Energy
- **Don Davies,** PE, SE MKA
- **Pierre Delforge,** Natural Resources Defense Council
- **Susan Freed,** County of San Diego
- **Andreas Gyr,** Google
- **Ryan Hamilton,** Nyle Systems
- **Barry Hooper,** SF Environment
- **Josh Jacobs,** LEED AP+ BD&C, UL
- **Dirk Kestner,** PE, LEED AP BD+C, ENV SP, Walter P Moore
- **Bruce King,** Ecological Building Network
- **Meghan Lewis,** Carbon Leadership Forum
- **Maurya McClintock,** McClintock Facades Consulting, LLC
- **Hilary Noll,** AIA, LEED AP BD+C, Mithun
- **Kelsey Rose Price,** PE, MKA
- **Cole Roberts,** PE, LEED AP, WELL AP, Arup
- **Stacy Smedley,** Skanska
- **Patrick Doss-Smith,** HGA
- **Henry Siegel,** FAIA, LEED AP, Siegel & Strain Architects
- **Larry Strain,** FAIA, LEED AP, Siegel & Strain Architects
- **Mark Webster,** PE, LEED AP BD+C, Simpson Gumpertz & Heger
- **Wolfgang Werner,** AIA, LEED AP BD+C, CPHD, Urban Fabrick, Inc.
- **Breana Wheeler,** BRE (BREEAM USA)
- **Tamim Younos,** Green Water-Infrastructure Academy



THE BUILDING DECARBONIZATION PRACTICE GUIDE

A Zero Carbon Future for the Built Environment

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VOLUME 6:

Embodied Carbon

VOLUME 6 CONTENT LEADERSHIP

- Don Davies
- Dirk Kestner
- Kelsey Rose Price
- Mark Webster

VOLUME 6 ADVISORS

- Patrick Doss-Smith
- Glenn Friedman
- Steve Guttmann
- Andreas Gyr
- Timonie Hood
- Josh Jacobs
- Meghan Lewis
- Lisa Matthiessen
- Brett Rosenberg
- Henry Siegel
- Larry Strain

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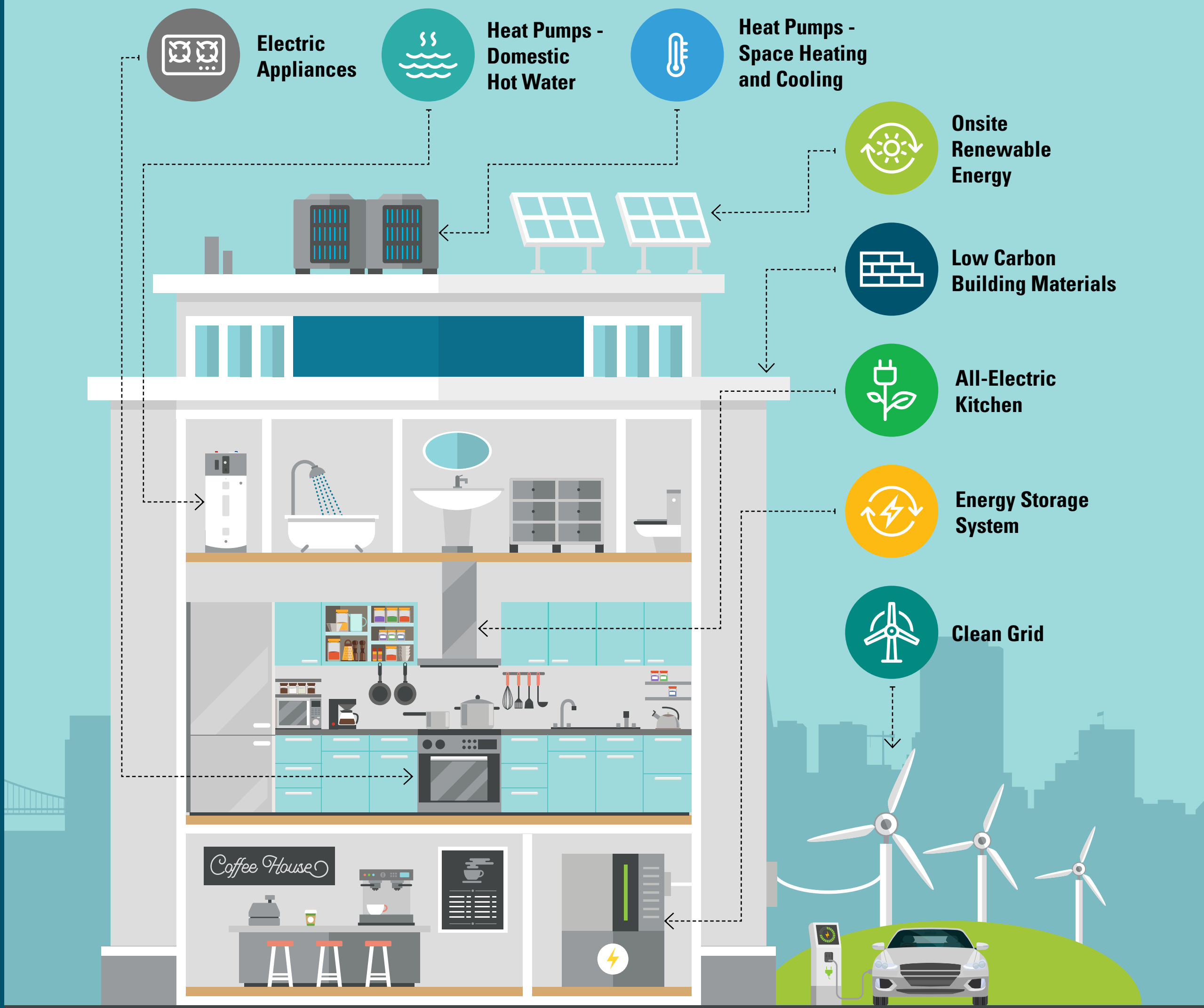

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VOLUME 6

Embodied Carbon

6.1_Introducing Embodied Carbon

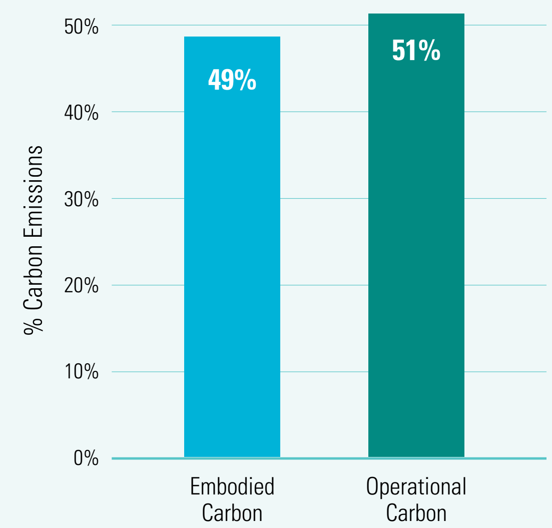
When trying to reduce a building's carbon footprint, the building industry has historically focused on operational carbon — the greenhouse gas emissions (expressed in terms of an equivalent amount of carbon dioxide) that result from the building's operations. However, the true impact of a building includes many carbon emissions that occur during other points in the project's life-cycle and that occur outside the immediate project boundary.

The term "Embodied Carbon" refers to the sum of all the greenhouse gas emissions across a building or product's lifecycle, which includes those associated with the mining, harvesting, processing, and manufacturing of materials as well as transportation, installation, maintenance and replacement, and disposal. Embodied carbon includes emissions of all greenhouse gasses, many of which have a more potent warming effect than carbon dioxide despite often being emitted in smaller quantities.

As buildings are increasingly designed to consume less energy, and that energy is, itself, less carbon intensive, neglecting lifecycle carbon emissions becomes increasingly problematic. Considering both embodied and operational carbon offers a much more complete understanding of a project's total carbon emissions and, importantly, helps identify areas where carbon reductions may be achievable.

While operational carbon is emitted over the life of a building, the majority of embodied carbon emissions occur during manufacturing and construction — prior to building occupancy. A much smaller proportion of the emissions is associated with maintenance activities during the life of the project and end-of-life deconstruction/disposal. Therefore, reducing embodied carbon becomes a way to drastically cut carbon emissions in the near term, which is also essential to a successful — and rapid — response to climate change. Figure 6.1 demonstrates the opportunity that embodied carbon represents globally (almost the same amount of carbon emissions between 2020 and 2050 as from operational energy use). In fact, as operational carbon emissions continue to decline, embodied carbon represents almost 75% of all construction-related emissions over the next ten years (see Volume 1, Figure 1.5).

FIGURE 6.1: TOTAL CARBON EMISSIONS OF GLOBAL NEW CONSTRUCTION FROM 2020-2050 (Business as Usual Projection)



Source: UN Environment Global Status Report 2017; EIA International Energy Outlook 2017

When addressing the problem of embodied carbon, it's important to make an initial assessment to identify what materials in a given project make the largest contribution to its embodied carbon content. This will vary based on project-specific details, but it is generally agreed that the majority of embodied carbon occurs in the structural systems of the building while the second largest percentage occurs in the facade. As with operational energy, which was initially addressed through efficiency improvements, we can think of the core and shell of a building as the low hanging fruit of embodied carbon. As we learn more about the embodied carbon associated with mechanical, electrical, and plumbing (MEP) systems, as well as periodic tenant improvements, we see that these are also large sources of embodied carbon that add up over the life of a building.

Embodied carbon should be addressed throughout project design, with continuous refinement throughout the design phases. During the conceptual phase, designers can start evaluating the embodied carbon of design choices utilizing industry average data with a focus on high level schematic comparisons. Site selection and design decisions (e.g., whether to reuse buildings or materials, building massing, and which structural and envelope system to choose) are made early in design and have a large impact on a project's total embodied carbon. Early comparisons can be refined as the selected design approach is optimized.

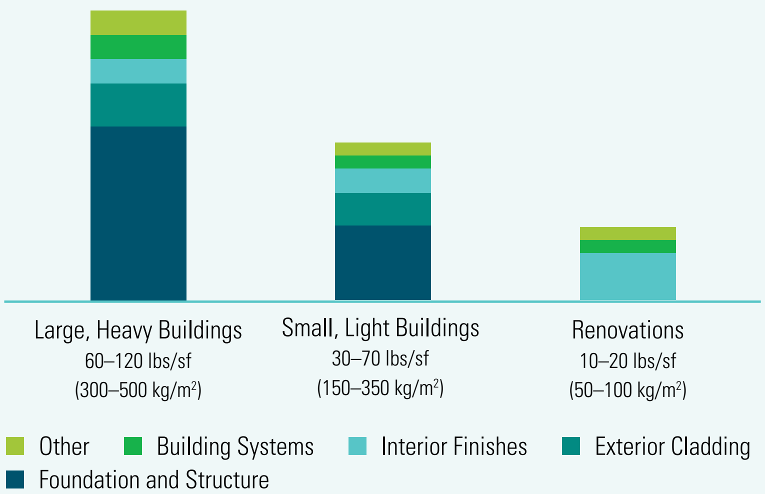
During the procurement phase, designers and builders should work together to source materials and products from suppliers that are manufacturing products with low carbon impacts. Suppliers may achieve reductions by using product ingredients with low carbon content, increasing production efficiencies, using clean energy sources, and manufacturing the product(s) in closer proximity to the project site, among other approaches. While it is possible to achieve reductions in embodied carbon through focusing efforts on procurement only, it is recommended that teams begin with a design focus to first achieve the optimal system and then use procurement as a means to reduce the embodied carbon even further.

6.1.1_WHERE IS A PROJECT'S EMBODIED CARBON?

When assessing the embodied carbon of a given project, it is important to clearly establish what assemblies and other aspects of the project, and what life-cycle stages (e.g., use and end-of-life), are included in the assessment. As the AEC community's awareness of the importance of embodied carbon grows, the scope and rigor of such assessments are developing in tandem. When making any comparisons, it is important to ensure that the assemblies, systems, and life-cycle stages meet the same functional requirements. This functional equivalence across the system must include trade-offs between embodied and operational carbon; when comparing assemblies with different performance characteristics (such as windows), one must ensure that embodied carbon reductions are not more than offset by operational carbon increases. For example, when comparing enclosure assemblies, the enclosure must either provide the same performance (U-factor, Solar Heat Gain Factor, etc.) or the operational carbon changes must be considered in combination with the assessment of embodied carbon.

Many available studies of carbon emissions are limited to structural and envelope materials, and these materials were among the first to have widely available industry-wide carbon impact data. They are now some of the first to have supply-chain-specific carbon data as well. This is a result of both the desire to focus on the materials that make up a significant portion of the initial emissions associated with creating a building (see Figure 6.2) and the fact that data for these assemblies is more accessible since they include a comparatively small number of materials.

FIGURE 6.2: CARBON EMISSIONS BY TYPE OF BUILDING STRUCTURE AND BUILDING ELEMENT



Source: "Time Value of Carbon", Carbon Leadership Forum, 2017

There are many other assemblies and life-cycle phases, however, that contribute to the embodied carbon of a project, such as site materials, emissions from construction equipment on site, interior materials, HVAC systems, and refrigerants. All of these elements are increasingly included in embodied carbon assessments. As the various assemblies, including their refreshment and refurbishment cycles are better understood, the full picture of their impact over the building's life-cycle is becoming clearer. As such, it is essential to understand the data gaps in past embodied carbon assessments and the new data needed to broaden the scope of future assessments.

As part of these more granular evaluations, it is important to consider the life-span and post-use pathways for materials such as interior finishes that may be highly impacted by renovations and maintenance.

6.2_Estimating Embodied Carbon

6.2.1 _OVERVIEW

There are various methods and procedures that can be used to measure embodied carbon. The method chosen for a particular project may depend on which life-cycle stages are being considered. Figure 6.3 illustrates and classifies the different stages, from product stage to end-of-life stage.

To measure the carbon impact of a project or product, a life-cycle assessment (LCA) can be performed.[1] This process aims to take stock of all carbon emissions of that material or product through its full life-cycle. The most common methods to measure embodied carbon either consider the entire life-cycle of the building or project (i.e. cradle-to-grave) or focus only on the Product Stage (i.e. cradle-to-gate). Figure 6.3 also illustrates how several aspects of a project life cycle can impact operational and embodied carbon emissions.

When an LCA is performed at the building or project scale, a whole-building life-cycle assessment (WBLCA) is done. This combines the individual LCAs of the different components that make up a project and provides an overall sum of carbon impacts for that project. The methodology for the WBLCA has been standardized through British Standard EN 15978:2011.

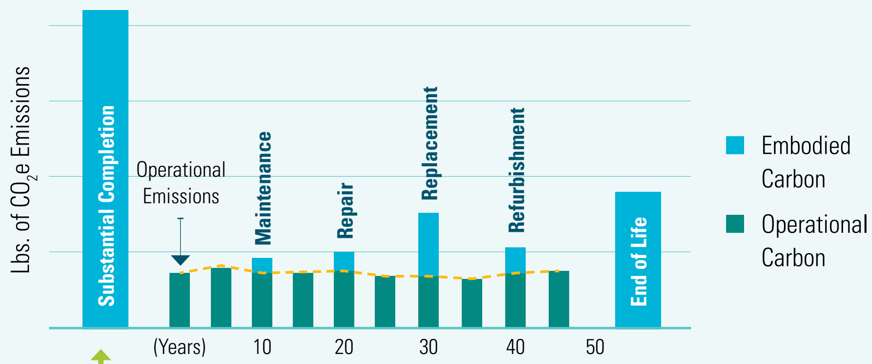
1 Reference ISO 14040, "Environmental management — Life cycle assessment — Principles and framework" and ISO 14044, "Environmental management — Life cycle assessment — Requirements and guidelines".

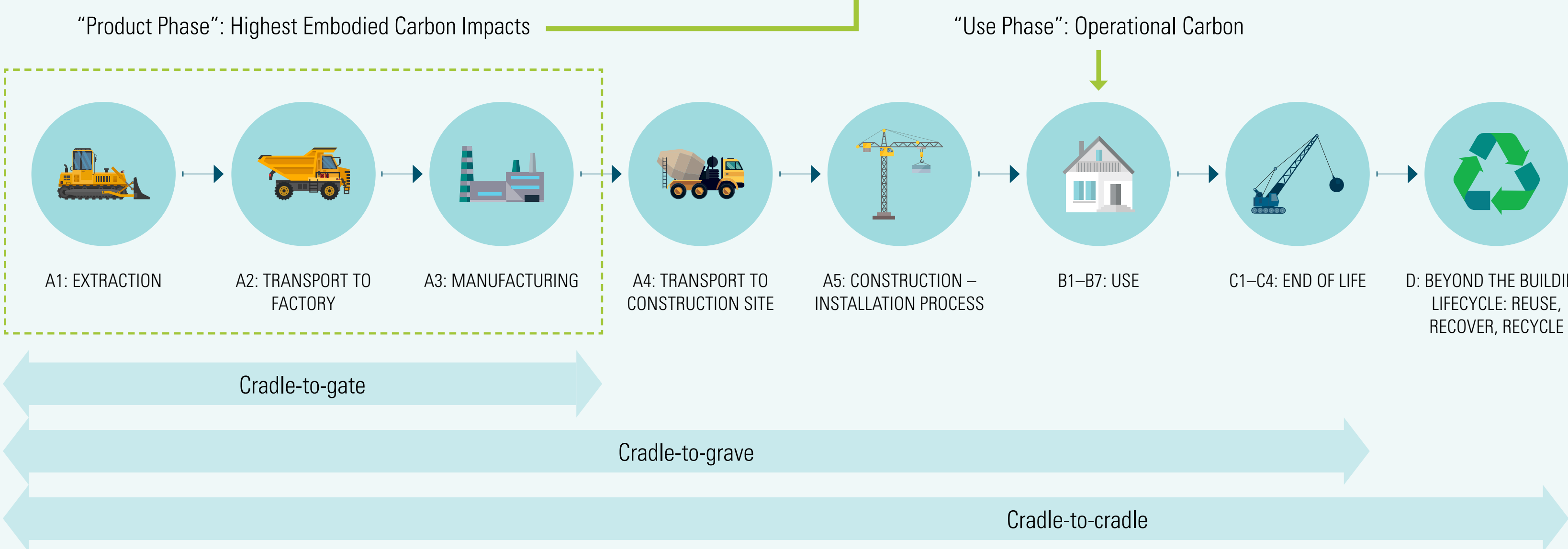
FIGURE 6.3: BUILDING LIFE-CYCLE ASSESSMENT (LCA)

Cradle-to-gate (A1 to A3): refers to the time frame from when a component's life starts to when it leaves the manufacturing facility ("gate"), before it is transported to the project site. This includes the entire "Product Stage."

Cradle-to-grave (A1 to C4): refers to the time frame from when a component's life starts ("cradle") to when it ends ("grave"). It includes all stages from "Product Stage" to "End-of-Life Stage."

Cradle-to-cradle (A1 to D): refers to the time frame from when a component's life starts to when it starts again. This includes all stages from the "Product Stage" to the "Benefits & Loads Beyond the System Boundary."





Source: Adapted from https://www.leti.london/ecp

6.2.3_ENVIRONMENTAL PRODUCT DECLARATIONS (EPDs)

Many manufacturers have chosen to quantify and disclose the embodied carbon of their products through an Environmental Product Declaration (EPD). An EPD is a report that discloses the environmental impacts of a material or product. It is created by performing an LCA at the component level, taking stock of materials that make up the item and the processes used to assemble it. Currently, EPDs are primarily based on a cradle-to-gate LCA, covering the early stages of a product's life from extraction through manufacturing.

EPDs are analogous to a nutrition label for food, which reports a food item's nutritional content, along with the ingredients that make it up. In a similar way, an EPD report tells the life cycle story of a product in a single, comprehensive report. The EPD provides information about a product's impact upon the environment, such as global warming potential, smog creation, ozone depletion, and water pollution. In the same way that a person might focus on the calories reported by a nutrition label, designers often focus on the Global Warming Potential (GWP) reported by an EPD.

EPDs are generally categorized as industry-average or product-specific. Industry-average EPDs are typically created by a trade organization, such as the National Ready Mixed Concrete Association (NRMCA) for concrete, and are not specific to a certain manufacturer. Conversely, a single manufacturer would produce a product-specific EPD.

Of the various types of EPDs, the most desirable is a product-specific Type III EPD (see Figure 6.4). This type follows a set of rigorous processes, which makes it the most relevant and reliable data for the project in which it is used. The Type III label also indicates that it has gone through third-party audit and verification.

FIGURE 6.4: THE THREE TYPES OF ENVIRONMENTAL PRODUCT DECLARATIONS (EPDs)

	PCR* is third-party reviewed?	EPD is third-party reviewed?	Specific to a single product from a single supplier	Standard followed
Product-Specific Declaration (Self-Declared)	–	–	✓	ISO 14044
Product-Specific TYpe III (Preferred)	✓	✓	✓	ISO 14025 ISO 14040 ISO 14044 ISO 21930/EN 15804
Industry-Wide	✓	✓	–	ISO 14025 ISO 14040 ISO 14044 ISO 21930/EN 15804

* Product Category Rule. A PCR enables different practitioners using the PCR to generate consistent results when assessing products of the same product category.

6.2.4_TOOLS TO ESTIMATE EMBODIED CARBON

Measuring embodied carbon can be a simple or complex process depending on the scope and methodology used. To aid designers, consultants, and contractors, a variety of tools are currently available to quantify embodied carbon. These tools offer quick, early estimates or deeper dives. There are also ever-expanding databases of EPDs that contain product-specific and industry-average product data. A brief overview of these tools follows.

6.2.4.1_Early Design Tools

The purpose of early design tools is to give project members a starting point for embodied carbon estimation. These are meant to be approachable to users of all experience levels, from the interested owner to the experienced design consultant, and they do not typically require in-depth project-specific inputs.

These tools offer only a rough estimate and should not be considered highly accurate. They are best used at the earliest stages of a project to give teams a sense of what project components contribute the largest carbon impact in relative terms. These initial estimates should be confirmed in later design phases by other, more accurate tools.

Early Design Tools:[2]

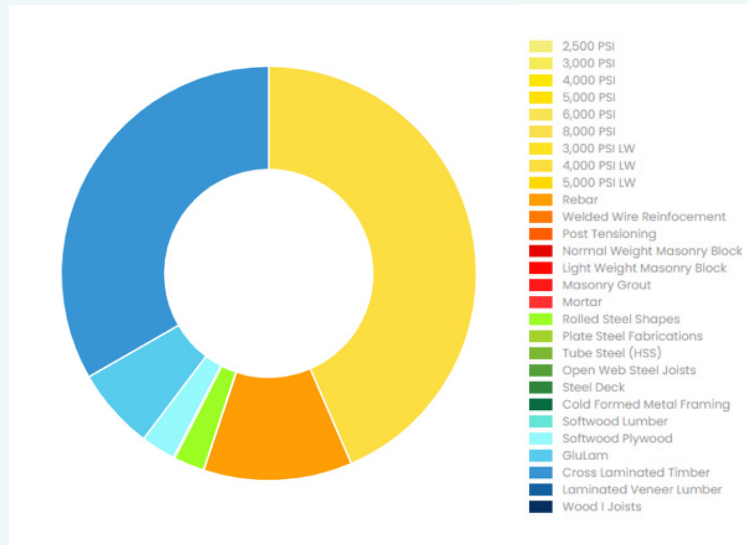
- ECOM, by SE2050 (See Figure 6.5 for a sample of the output)
- EcoCalculator, by ASMI

6.2.4.2 _Life-Cycle Assessment Tools & Datasets

LCA tools and datasets allow project members to delve deeper into embodied carbon accounting. Although many are user-friendly, they are best suited for more experienced users, such as sustainability consultants, architects, and engineers. Users should have a robust knowledge of project inputs to increase the accuracy of a given tool's results.

These tools and datasets can be used from early design through to final design. Since they are typically used to identify embodied carbon reduction targets, they are most useful during the design phase, when design decisions are still being made. Once in construction, it is less likely that an impactful design reduction strategy can be implemented.

FIGURE 6.5: EXAMPLE OF OUTPUT FROM ECOM



Source: https://se2050.org/ecom-tool/

2 For additional tools, see https://carbonleadershipforum.org/clf-architect-toolkit/

WBLCA Tools:

- » Tally*, by KT Innovations, thinkstep, Autodesk
  (See Figure 6.6 for example output)
- » Athena Impact Estimator*, by ASMI
- » One Click LCA*, by Bionova Ltd.
- » Carbon Planning Tool, by the Environment Agency
- » eTool

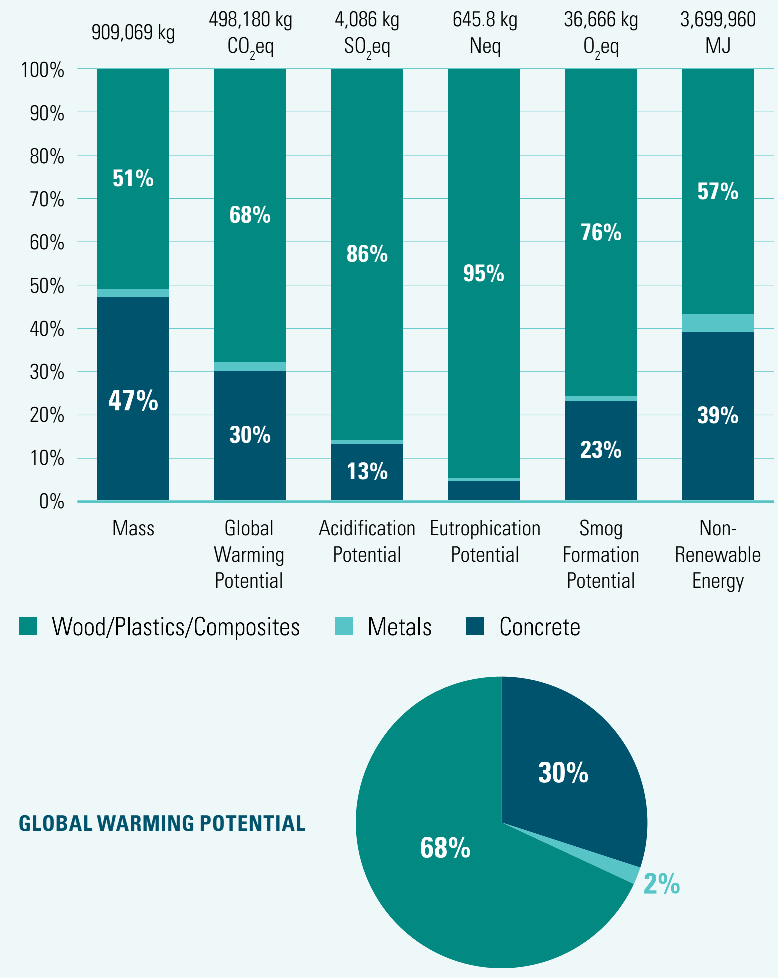
* Denotes tools widely used in the U.S. market

LCA / Embodied Carbon Tools and Datasets:

- » openLCA, by GreenDelta
- » ICE Database, by Circular Ecology
- » GaBi Database, by sphera
- » ecoinvent Database

For additional tools, see the tools listed in the AIA-CLF Embodied Carbon Toolkit for Architects, Part II, Measuring Embodied Carbon (see section 6.5).

FIGURE 6.6: EXAMPLE OUTPUT FROM TALLY (EXCLUDING BIOGENIC CARBON)



6.2.4.3_EPD Databases

Since EPDs are currently the best source of Product Stage data, EPD databases are an important tool for project participants. Different from LCA tools, the goal of these databases is to provide users with direct access to Product Stage data from a single source. These databases can be queried for industry-average or product-specific EPDs, often by region or manufacturer.

Because EPD data is product-specific, these databases are best used in the later stages of design and when component procurement strategies are formulated. Designers may use these databases to determine more accurate embodied carbon estimates for their materials during design or to choose which products to specify. Once material take-offs are available, the design team or contractor may use these databases to compare carbon information from two prospective suppliers.

EPD Databases:

» EC3, by BuildingTransparency (See Figure 6.7 for sample output)

» International EPD System, by EPD International AB

6.2.4.4_Comparability of Estimation Tools

The various tools available to estimate embodied carbon may derive results from different embodied carbon or LCA datasets. Because the underlying data is not the same, results from various tools should not be compared to each other. Instead, the same tool should be used when results are compared at different phases of design.

6.3_Reducing Embodied Carbon

Reducing embodied carbon takes an entire team, and every member can have an impact. Figure 6.8 includes high-impact reduction strategies and the parties — policy maker, owner, design professional, contractor — best positioned to influence their implementation. This is, however, only a partial list of available strategies; others may be found in the references. Recent studies present strong arguments that reducing embodied carbon emissions by 20% to 30% is feasible now, using readily available materials and current technologies.[3]

Policy makers are among the most important drivers of change. Many project teams would not address embodied carbon reductions without policy-driven incentives and mandates. More information about the growing embodied carbon policy landscape may be found at the Carbon Leadership Forum's website.[4]

Of course, reducing the embodied carbon through the strategies discussed below should always be done in consideration of possible trade-offs in environmental impacts (e.g., water use and operational carbon impacts that may offset embodied carbon reduction benefits).

Each of the nine strategies listed in Figure 6.8 are elaborated on below.

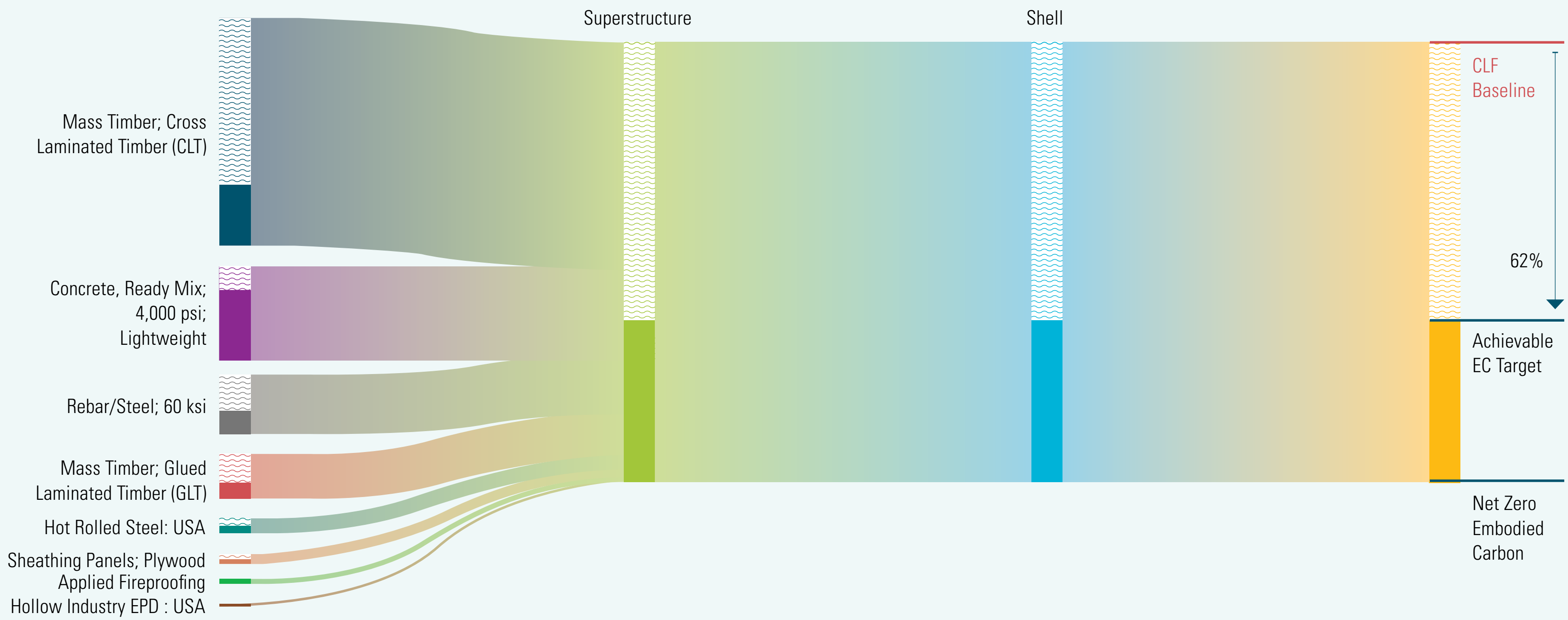
6.3.1_REUSE BUILDINGS

Always consider reuse and retrofit before designing a new building. Reuse and renovation with system upgrades typically generates 50% to 75% less embodied carbon emissions than new construction. For this reason, reuse is almost always the most effective strategy to reduce embodied carbon.

3 For example, see the London Energy Transformation Initiative's Embodied Carbon Primer, January 2020 edition, or the Embodied Carbon Stewardship Report, published by Walter P. Moore

4 https://carbonleadershipforum.org/clf-policy-toolkit/

FIGURE 6.7: EXAMPLE OUTPUT FROM EC3



Note: This graphic shows a project, evaluated in May of 2021, that has achieved a 62% embodied carbon reduction compared to the CLF Baseline and how reductions in each superstructure and shell component contribute to this reduction.

FIGURE 6.8: EMBODIED CARBON REDUCTION STRATEGIES AND DECISION INFLUENCERS

	Influencers			
Strategy	**Policy Maker**	**Owner**	**Design Professional**	**Contractor**
Reuse Buildings	X	X	X	
Reuse Materials	X		X	X
Measure and Identify Project "Hot Spots"			X	
Focus on High-GWP Materials and Systems	X	X	X	X
Use Less Portland Cement	X		X	X
"Right-Size" the Project		X	X	
Use Biobased and Other Carbon-Storing Materials in Place of High-Embodied Carbon Materials	X	X	X	
Optimize Use of Materials			X	X
Source from Lower-GWP Manufacturers			X	X

In some cases, the project team may choose to perform an LCA to measure the carbon impacts of design options (reuse, retrofit, or build new), accounting for both embodied and operational carbon emissions. Project teams should also consider including energy performance upgrades to reduce emissions from operations when renovating existing buildings. Even if the energy efficiency of the upgraded building is not as good as the new building option, the lower overall carbon solution is often the upgraded option due to the high embodied carbon content of new construction and the short term benefits of embodied carbon reduction. We recommend evaluation time frames that align with the goal to achieve carbon neutrality in the building sector by 2050.

When reusing existing buildings, project teams should evaluate the potential for converting existing mixed-fuel buildings into all-electric buildings. Deep energy upgrades and electrification are effective ways for projects to reduce total emissions from the built environment. When full electrification cannot be accomplished, an all-electric ready approach should be the goal; this will prepare renovated buildings for a true carbon neutral future as utility grids become powered by 100% renewable energy.

6.3.2_REUSE MATERIALS

Salvaged materials have a much lower embodied carbon footprint than newly manufactured materials because the extraction and manufacturing life-cycle stages are eliminated. As such, wherever possible, we recommend reusing materials such as brick, metals, broken concrete, wood, furniture, casework, and doors. The environmental impacts of reuse are due solely to extraction from the previous building, transportation (generally from the previous building to a storage facility then to the current building), and refabrication, if needed. Reuse also reduces embodied carbon more than recycling by avoiding the emissions from processing, manufacturing, and transporting recyclables. In addition, reuse keeps wood out of landfills where it decays and releases methane, a powerful greenhouse gas.

The U.S. General Services Administration's Green Building Advisory Committee made this recommendation on quantifying the embodied carbon benefits of reuse for federal buildings:

"Where possible, product reuse (salvaged products) is highly encouraged, as these products do not create new emissions (low/zero additional Global Warming Potential) and can be considered zero embodied carbon for this analysis. This does not include new materials with recycled content. EPDs are not required for salvaged or reused materials/products…"[5]

Most code officials will permit the use of salvaged structural materials if approved by the structural engineer under the "alternative materials" provisions of building codes (e.g. the International Building Code, section 104.11). Timber and steel framing are the best candidates for reuse. Structural engineers can evaluate the properties of existing timber and steel structural members using assorted tools, including tests and inspections. If needed, wood specialists can recommend species and grades of structural members. If the age of steel is known, engineers can make an educated assumption as to its strength based on the specifications in use at that time. Steel samples can also be removed for strength testing and to evaluate weldability.

Concrete framing is not usually salvageable for many reasons. Cast-in-place concrete members, for example, often rely on continuity with other members, which is lost if the pieces are separated. They are also heavy and the reinforcement is hidden; this makes it harder to determine its strength. Even precast concrete members are often interconnected with each other using toppings, grouted joints, and welded embedments. Recycled aggregate for concrete, however, can be made by crushing demolished concrete elements.

Source: U.S. Army Corps of Engineers Headquarters building utilizing 300,000 board feet of structural and non-structural lumber from an adjacent warehouse deconstruction. | https://www.gsa.gov/cdnstatic/GSA_FCS_Press_Book_email.pdf

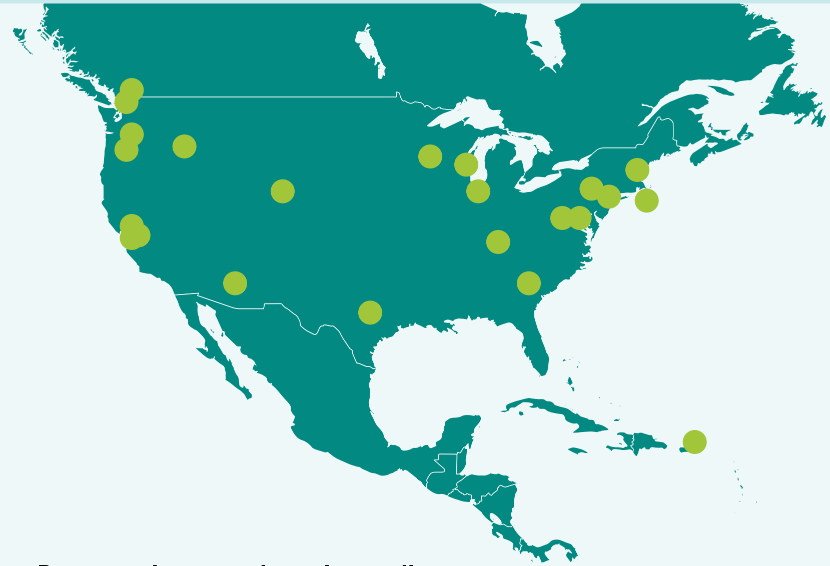
5 U.S. GSA, Green Building Advisory Committee Advice Letter: Policy Recommendations for Procurement of Low Embodied Energy and Carbon Materials by Federal Agencies, Feb. 2021 https://www.gsa.gov/cdnstatic/GSA%20GBAC%20Low%20EC%20Procurement%20Policy%20Advice%20Letter-2-17-21.pdf

Embodied carbon can also be dramatically reduced through design for disassembly or reversible building design and deconstruction. Oregon and Washington have adopted state building codes that allow the use of reclaimed lumber for structural purposes without regrading,[6] and Portland, Oregon, and Palo Alto, California have adopted mandatory deconstruction ordinances.[7] As the City of Portland's construction waste specialist, Sean Wood, reported at the January 2021 Urban Land Institute's Resilience Summit, Portland's ordinance over the previous five years resulted in the recovery of an average of five tons of material, primarily clean lumber, from the deconstruction of a typical single-family home. A deconstruction case study, from New Orleans, can be found in section 6.4.4.

6.3.3 _MEASURE AND IDENTIFY PROJECT "HOT SPOTS"

Measurement is fundamental to any budgeting or optimization exercise, and it is no different with embodied carbon. Prescriptive guidance — such as requiring a minimum percentage of cement replacement in concrete or excluding steel without an EPD (steel is discussed in more detail in Section 6.3.9) — can provide general approaches to reducing embodied carbon. However, it is still beneficial to develop project-specific estimates of a building's embodied carbon, even if it contains some level of uncertainty. Appropriate LCA or other tools can help project teams identify "hot spots" — those assemblies or phases responsible for the largest contribution to the overall embodied carbon. It is often most efficient to make changes to those few materials responsible for the biggest impacts instead of smaller reductions across many assemblies. As a project progresses, users may choose to increase the sophistication of their tools to get a better handle on the carbon-intensive "hot spots" and to confirm that they are being

FIGURE 6.9: EXAMPLES OF DECONSTRUCTION POLICIES ACROSS THE U.S. AND CANADA



Decontruction executive orders, ordinances, incentives, plans, or Deconstruction Advisory Groups

Atlanta, GA	Nantucket, MA	San Francisco, CA
Baltimore, MD	Nashville, TN	San Mateo County, CA
Boise, ID	Oakland, CA	Seattle/King County, WA
Chicago/Cook County, IL	Palo Alto, CA	Somerville, MA
Connecticut (State of)	Phoenix, AZ	Vancouver, BC
Denver, CO	Pittsburgh, PA	Victoria, BC
Ithaca/Cornell, NY	Puerto Rico	
Milwaukee, WI	San Antonio, TX	

Source: Shawn Wood, Construction Waste Specialist, City of Portland, OR, as presented at the ULI Resilience Summit, January 26, 2021.

6 Oregon Residential Specialty Code, Chapter 1, Section R104.9.1, 2017, https://codes.iccsafe.org/content/ORRSC2017; Washington Administrative Code, R602.1.1.1 Used sawn lumber, 2018, https://apps.leg.wa.gov/wac/default.aspx?cite=51-51-0602

7 Portland Deconstruction Mandatory Residential Requirements, 2016, https://www.portland.gov/bps/climate-action/decon; Palo Alto Deconstruction and Construction Materials Management Residential and Commercial Building Requirements, 2020, https://www.cityofpaloalto.org/Departments/Public-Works/Zero-Waste/Zero-Waste-Requirements-Guidelines/Deconstruction-Construction-Materials-Management

addressed. Remember that all embodied carbon evaluations are estimates, even those from more sophisticated tools, so we recommend focusing on the big contributors to avoid getting bogged down in the small ones.

6.3.4_FOCUS ON MATERIALS AND SYSTEMS WITH THE LOWEST AMOUNTS OF EMBODIED CARBON

Generally, the structural system has the highest proportion of embodied carbon, followed by the building enclosure. Interior and MEP systems, especially if subject to high churn rates, can also have high embodied carbon. Look to these systems for embodied carbon reduction opportunities.

Materials such as aluminum, certain types of foam insulation, and products with a high cement content can pack a lot of embodied carbon into a small quantity of materials. Be familiar with such materials and on the lookout when selecting and specifying products. Sometimes materials with high carbon content are incorporated into products such as facade components, which may not be obvious at first glance. Ask manufacturers for EPDs and, if they do not have one, inquire about the materials that are used in their products (e.g., the type of insulation in a facade component).

6.3.4.1_Tenant Improvements

How often spaces are remodeled can have a large impact on the lifetime embodied carbon of a building. A Carbon Leadership Forum study found that the embodied carbon of the tenant improvements in five case study buildings ranged from 45 to 135 kg CO_2e/m^2.[8] If these impacts occur every 10 to 20 years over the life of a building, total life-cycle tenant improvement impacts could range from 130 to 810 kg CO_2e/m^2, which is comparable to the total initial construction carbon impacts. High impact items from the study included cubicles, furniture, doors, carpet, glazing, acoustical and metal ceiling panels, ceiling panel suspension systems, and partition walls.

8 "Life Cycle Assessment of Tenant Improvements in Commercial Office Buildings", Carbon Leadership Forum, April, 2019, https://carbonleadershipforum.org/lca-of-mep-systems-and-tenant-improvements/.

9 https://www.buildingproductecosystems.org/closed-loop-wallboard

HIGH CARBON INTENSITY MATERIAL ANALYSIS: GYPSUM WALLBOARD AS AN EXAMPLE FOR DEVELOPING STRATEGIES TO REDUCE EMBODIED CARBON

Gypsum board (aka Sheetrock, drywall, wallboard, etc.) presents unique challenges due to the amount of product that ends up in the waste stream. The following discussion focuses on this one aspect of tenant improvements.

» Gypsum board is a challenge because once it is painted it is nearly impossible to recycle, or at least it isn't cost effective to recycle. One alternative is to use modular partition systems that can be disassembled and reused. However, they typically have high embodied carbon content.

» 10% of new gypsum board typically ends up as scrap on the job site.[9] While new, unpainted gypsum board is the easiest to recycle, most scrap ends up in a landfill. Although high recycled content is generally available, there are also limits to how much recycled content gypsum panels can contain due to issues with fire ratings. Clean, unpainted gypsum board can also be ground up and used as a soil amendment.

» Gypsum board sheets typically come in 4' x 8' and 4' x 10' sizes. To minimize waste, wall studs should be designed to a 2' framing module. Alternatively, for light duty construction, joints can "float" between framing with the gypsum board screwed to a backing that bridges the joint.

» **Lower Carbon Alternatives:**

- Lightweight gypsum board can reduce embodied carbon by up to 25%.
- An industrial waste product — sulfur dioxide from power plant emissions (flue gas desulfurization, or FGD) — can be used to produce synthetic gypsum. While it is also a lower carbon alternative, some concerns have been raised about the potential presence of heavy metals, including mercury.

» **Very Low Carbon Alternatives:**

- Where fire rating is not a concern, eliminate gypsum board altogether and use biobased alternatives, such as salvaged and FSC-certified wood or straw-based MDF and HDF panels. These products sequester as much, if not more, carbon as it takes to produce them.

6.3.5 _USE LESS PORTLAND CEMENT

Concrete accounts for more carbon emissions than any other building material and is often the largest single source of embodied carbon in a building project. Portland cement is the primary source of embodied carbon in concrete, and it accounts for somewhere in the range of 5 to 8 percent of total global carbon emissions from the built environment. A majority of projects use concrete, if not in the structural frames and envelopes then in the foundations and floor slabs.

Increasingly, there are other options. Cement may be replaced with supplementary cementitious materials (SCMs) such as fly ash, slag, ground post-consumer glass, and other pozzolans. The replacement rate depends upon the project requirements, the type of SCM, and the concrete application. SCMs can slow the rate of strength gain, which can limit the replacement rates for concrete elements that require higher early strength, such as post-tensioned elements and suspended slabs where the formwork must be removed at a rapid pace. However, in many applications, such as footings, foundation walls, and insulated concrete forms (ICFs), the rate of strength gain may not be as critical. In such cases, higher replacement rates should be considered. SCMs improve many properties of concrete, including density and durability, so they can offer additional benefits beyond embodied carbon reduction.

Blended cements, which include a mix of portland cement and fly ash, slag, or ground limestone, are also becoming more readily available. Blended cements provide similar performance to unblended portland cement but deliver a smaller carbon footprint.

Other strategies to consider are using larger aggregate sizes or better blended aggregates. Both these approaches reduce the paste volume, which is the cementitious matrix that fills the spaces between the aggregates and holds the concrete together. Larger aggregates displace more of the paste volume, and with well-graded aggregates, the smaller stones fill more of the voids between the larger ones.

An easy solution to reducing embodied carbon is to simply use less concrete. This strategy works as long as the concrete is not replaced with other materials, like structural steel, that have a similar amount of embodied carbon (an LCA can help the team evaluate such options). Ways to reduce concrete quantity include:

» Casting concrete with voids either hidden within slabs (such as BubbleDeck) or with joists or waffle slabs in place of flat slabs;

» Eliminating basements and below-grade spaces if they are not required;

» Using frost-protected shallow foundations instead of deeper footings in cold climates;

» Using light structural systems that can reduce the size of foundations.

We recommend working with the project's structural engineer to implement these strategies where feasible.

6.3.6_RIGHT-SIZE THE PROJECT

When focusing on embodied carbon, constructing a building that is larger than absolutely necessary is counterproductive. Once the project scope and program are known, it is essential to avoid over-sizing the project.

In general, making rooms smaller is not the most effective way to accomplish “right sizing.” The best way to “right size” is to design spaces that can be adaptable and do double, if not triple, duty. Flexible and expandable rooms, which can accommodate multiple uses, will keep the overall project footprint smaller. Adding systems to facilitate the scheduling of space use and providing adequate storage space are key to making this strategy work. Project teams should design efficient circulation paths, and, above all, avoid superfluous spaces. Careful planning and layout will reduce both material consumption and heating and cooling demands.

In residential construction, LEED has created incentives for reducing the size as well as increasing the density of single-family and multi-family buildings in order to promote the benefits of “right-sizing.”

6.3.7_BIO-BASED AND OTHER CARBON-STORING MATERIALS

The term "bio-based materials" typically refers to products that mainly consist of a substance (or substances) derived from living matter (biomass) and either occur naturally or are synthesized. It may also refer to products made by processes that use biomass. New options for bio-based materials that compete with conventional materials are becoming more ubiquitous. The great thing about carbon storing/capturing materials is that the more you use the more carbon you store.

Wherever possible, use bio-based and other carbon-storing materials in place of high embodied carbon materials. For both structure and finishes, wood structural systems (as opposed to steel and concrete) and wood siding (rather than vinyl) offer lower embodied carbon alternatives. For products of the same material — carpet for example — compare the EPDs of different suppliers prior to selection.

Bio-based materials are perceived as potentially "greener" alternatives than their counterparts; however, this claim should always be scrutinized closely. For example, wood is often a lower carbon choice than steel or concrete, but its carbon footprint is determined by forestry practices at its source, as well as harvesting and manufacturing methods. Be mindful of industry claims concerning wood; use wood that is certified by a third-party certification organization such as the Forest Stewardship Council (FSC) where possible. One study by Ecotrust showed that FSC certified forests sequestered 20% to 60% more carbon than traditionally managed forests.[10] This study is representative of a particular region (the Pacific Northwest) and did not compare the FSC forests to those certified under other programs such as the Sustainable Forestry Initiative (SFI) or Program for the Endorsement of Forest Certification (PEFC), which are also preferable to uncertified forests since they assure a baseline of good forestry practices.

The impact of forestry management practices on embodied carbon is complex and continues to be studied. For designers seeking guidance on the sourcing of "climate friendly" wood products, the whitepaper "Forestry Embodied Carbon Methodology" offers some helpful guidance.[11]

Cross laminated timber (CLT) can be a viable alternative to concrete and steel for taller buildings. Because the floors and often the walls are solid wood, designers will need to rethink insulation and MEP systems. CLT buildings can use up to five times as much wood as a light frame building, so it is even more important to choose sustainably-sourced wood from well-managed sources that actually store carbon.

For smaller-scale, low-rise projects and single family homes, there are an increasing array of bio-based materials. There is still considerable uncertainty in the data on embodied carbon in many of these materials, and investigating embodied carbon reduction claims — as with most materials used in construction — should be thoroughly evaluated. Also, their structural and other performance characteristics need to be considered carefully. In addition, there are limitations on the use of many bio-based products where fire-resistive construction is a requirement.

Where appropriate, the use of alternate agricultural products, like straw, hemp, cork, bamboo, and cellulose, as well as traditional building materials, like rammed earth and cob construction, can be considered. Short-cycle agricultural crops can sequester carbon more effectively than forests.

» Hemp stalks are used in hemp-based thermal insulation and hempcrete. Straw, the non-edible stock of cereal grains, is used in straw bale construction, insulation panels and fiberboard products. Stacked straw bales, plastered in lime are a great carbon storing material. Strawbale walls can be load bearing but typically rely on posts and beams to support the roof. The bales are pinned or tied together between reinforcing bars and then plastered. They perform well seismically and thermally, and they offer excellent fire resistance.[12] People are also experimenting with prefabricated straw bale wall panels that can be used as infill in CLT structures. Water needs to be kept away from straw bale walls; effective strategies include deep overhangs and raised footings.

10 https://ecotrust.org/wp-content/uploads/Forests_Tradeoffs-in-Timber-Carbon-Cash-Flow_2018-2.pdf

11 https://www.arup.com/perspectives/publications/research/section/forestry-embodied-carbon-methodology

12 See https://www.architecturaldigest.com/story/strawbale-construction and https://www.researchgate.net/publication/316463900_Fire_Resistance_of_the_Straw_Bale_Walls

- Using earth as a structural, load bearing system can be a low carbon alternative, but only if the earth doesn't require a lot of cement or asphalt as a binder/stabilizer. Some rammed earth applications call for the addition of up to 3% to 8% cement content.[13] Traditional, non-stabilized adobe blocks reinforced with straw and rammed earth can work well in dry climates in low seismic zones. There are also compressed, low-cement content blocks available. Look to local sources for what is appropriate and understood by local builders as well as what is code-compliant.

Finally, be on the look-out for new carbon-storing technology. This industry is expanding rapidly and new technologies are emerging at varying levels of availability. Look for new materials that are under development, including concrete aggregates. One such product entering production, a lightweight aggregate for use in concrete, can potentially compensate for all the emissions associated with the cement in the concrete mix.

6.3.8_OPTIMIZE THE USE OF MATERIALS

In any given project, use the most efficient structural solutions that local building codes allow and which save on the quantities of materials used. Optimization works best when started early in the design process. The flexibility to re-think structural layout and design diminishes as a design progresses. Since many of the larger embodied carbon elements are in the structure of the building, optimization of these elements must happen at the beginning of the project, and poor decisions made early are difficult to remediate. The following layout tips are recommended for efficient material use:

- Use moderate spans (longer spans usually require more material).
  - In flat slab concrete construction, the longest bay can sometimes dictate the thickness of the full floor system due to formwork construction.
- Avoid load transfers at floor levels where columns above and below the floor level do not align.
  - Where possible, run columns and walls down to the foundation without offsets.
- Minimize story heights while balancing other project objectives such as daylighting and natural ventilation.

Source: Camp Arroyo, Livermore, CA. Dining Hall. Straw bale construction. Photos courtesy of Siegel & Strain Architects and JD Peterson.

Source: Camp Arroyo, Livermore, CA. Bath House. Stabilized earth construction. Photos courtesy of Siegel & Strain Architects and JD Peterson.

13 "Materials for Sustainable Sites: A Complete Guide to the Evaluation, Selection, and Use of Sustainable Construction Materials", Meg Calkins, October 2008.

It is also important to eliminate unnecessary materials. Where possible, use structural materials as finishes, and eliminate the other finish materials (for example, use exposed concrete floors and ceilings, or exposed wood structures).

Finally, design in standard modules to minimize waste, taking advantage of standard size sheets for common materials such as 4x8 plywood and gypsum board. Another option is to use prefabricated modular construction since shop-built components generally have less waste, and shops often do a better job recycling/reusing waste. Keep in mind that sometimes transportation and lifting requirements can add materials and carbon emissions; these impacts can be mitigated by using onsite factories for prefabrication.

6.3.9_SOURCE FROM MANUFACTURERS THAT HAVE REDUCED THEIR GHG EMISSIONS

Wherever possible, source materials from manufacturers that use low-carbon energy sources and have efficient practices that reduce their products' embodied carbon compared to their competitors. When comparing products, use product-specific EPDs that have been evaluated using the same Product Category Rules, and compare product-specific EPDs to industry-average EPDs when available.

Usually, recycled-content materials have a lower embodied carbon than equivalent virgin materials, but not always. Processes required for recovery and recycling, as well as transportation and energy-source impacts, will influence this comparison. Review product-specific EPDs where available to confirm climate performance.

GHG impacts from the fabrication of **architectural aluminum** can vary greatly, and emissions from virgin ore can be more than six times higher than recycled aluminum. However, it can be difficult to find high recycled content material for architectural grade aluminum. As a result, either consider using aluminum sparingly and efficiently, or help move the market towards better recycled content material by demanding transparency from suppliers so that appropriate decisions on alternatives can be made.

Steel products such as structural steel, rebar, and cold-formed steel can be sourced from electric arc furnaces (EAFs) or basic oxygen furnaces (BOFs). As discussed in Volume 2, section 2.5.2, EAF steel has a higher recycled content and generally lower embodied carbon, especially if the electricity is from renewable sources. Most of the steel consumed in the U.S. is produced domestically, but significant quantities are also imported.[14] Whereas nearly all domestically produced structural rolled shapes and rebar are produced in EAFs, many foreign producers rely more heavily on BOFs. Therefore imported sources are more likely to have a higher embodied carbon, especially with the added transportation impacts. Specifying domestically-produced steel can be a good strategy, especially if producer-specific EPDs are available that show good climate performance. As manufacturing practices are always evolving, it is good practice to evaluate foreign products when EPDs are available.

Plastics and foam insulation have a high carbon footprint compared to the alternatives, and spray foams currently use expanding agents with very high global warming potential. Use these materials sparingly and only when there are no alternatives. Many foam insulation materials (e.g., polystyrene and polyisocyanurate) are petroleum-based products that require significant energy to manufacture, resulting in a high-embodied carbon footprint. For thermal insulation, consider alternatives such as cellulose-based products (primarily made from recycled newspaper) and even sheep's wool and cork. As always, transparency from manufacturers helps facilitate the analysis of alternatives.

14 According to a White Paper produced by the American Institute of Steel Construction in August of 2018, production of hot-rolled structural shapes in the United States in 2017 exceeded 6.1 million tons, of which 8% was exported. Also in 2017, 14% of the structural steel erected in the United States was fabricated outside the U.S.

6.4 Embodied Carbon Case Studies

Source: Dror Baldinger©

6.4.1_HOUSTON ADVANCED RESEARCH CENTER

Project Location: The Woodlands, TX

Completion Year: 2017

Project Size: 20,000 SF

What:

The Houston Advanced Research Center (HARC) is an ILFI Certified NZE research facility that successfully implemented a whole-building life-cycle assessment to reduce embodied emissions and push toward a "zero-carbon" building.[15] As an organization, HARC is a "not-for-profit research hub providing independent analysis on energy, air, and water issues."[16] In 2014, HARC's original campus no longer supported its mission, and they sought to build a new headquarters that directly reflected its mission and served as a living example for regionally appropriate sustainable design in the Gulf Coast region. It was also essential that the design respect the financial realities of a not-for-profit research institution.

15 https://dashboard.harcresearch.org/ and https://www.aisc.org/globalassets/modern-steel/archives/2018/11/redefiningnetzero.pdf

16 https://harcresearch.org/about/building/

How:

The project took a holistic approach to carbon, considering both operational and embodied carbon. Both operational and embodied carbon were considered as measures of performance from the early programming charrettes, and the full design team was engaged in the early meetings. This led to the inclusion of Whole Building LCA early in the process to inform the structural system as well as the bay spacing. Multiple schemes were considered, as were the interaction and total embodied carbon of the structure and enclosure. The WBLCA determined that a steel-framed system, and not the more common exterior concrete bearing wall, resulted in the lowest embodied carbon. This system, which also included continuity of the exterior cold form wall framing, allowed for reductions in both the embodied carbon of the super structure and the volume of concrete required in the foundation. In 2016 concrete suppliers in Houston did not have mix-specific EPDs; however, the team required that the supplier have participated in the NRMCA Industry Average EPD and also used cement content as a proxy for the GWP of the concrete mixes.

Structural System	Steel framed with concentrically braced frames
Embodied Carbon Reduction from Business as Usual	Approximately 20%
Owner	Houston Advanced Research Center (HARC)
Architect	Gensler
General Contractor	Brookstone
Structural Engineer	Walter P Moore

6.4.2._LCA OF THE CATALYST BUILDING

Project Location: Spokane, WA

Completion Year: 2020

Project Size: 168,800 SF

Source: Benjamin Benschneider

What:

During the design phase of this five-story office building, Katerra commissioned the Carbon Leadership Forum (CLF) and Center for International Trade in Forest Products (CINTRAFOR) at the University of Washington to analyze the environmental impacts of its Cross Laminated Timber (CLT) as a structural and design element. The Catalyst Building's life-cycle assessment offers a better understanding of the life-cycle environmental impacts of mass timber buildings and identifies opportunities to optimize the environmental performance of mid-rise CLT structures.[17]

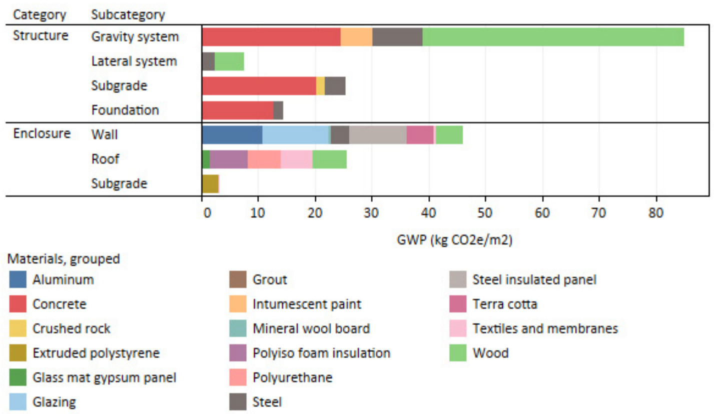
The life-cycle assessment of the core and shell estimated the building's upfront embodied carbon to be 207 kg CO_2e/m^2 (see Figure 6.10). This result is similar to other mass timber buildings and is lower than most other office buildings per unit of floor area, according to the Carbon Leadership Forum's Embodied Carbon Benchmark Study.[18] Additionally, the Catalyst Building stores approximately 204 kg CO_2/m^2 of biogenic carbon, which nearly offsets its upfront embodied carbon. However, a more comprehensive analysis, including end-of-life considerations, should have been performed in order to draw more definitive conclusions about the total carbon footprint of the building.

How:

Structural System	Gravity System: Glu-lam beams and columns, CLT slabs Lateral System: Buckling-Restrained Braces (BRB) and CLT shear walls
Embodied Carbon Reduction from Business as Usual	No business-as-usual case presented in this case study.

Owner	South Landing Investors, LCC
Architects	MGA/Michael Green Architecture, Katerra
General Contractor	Katerra
Structural Engineer	KPFF

FIGURE 6.10: GLOBAL WARMING POTENTIAL RESULTS (EMBODIED CARBON) FOR LIFE-CYCLE STAGE A (CRADLE-TO-GATE)



Source: "Life Cycle Assessment of Katerra's Cross-Laminated Timber (CLT) and Catalyst Building: Final Report", Carbon Leadership Forum and University of Washington Center for International Trade in Forest Products, November, 2019.

17 Note: this description is adapted from the case study write-up on the Carbon Leadership Forum's website: https://carbonleadershipforum.org/katerra/

18 https://carbonleadershipforum.org/embodied-carbon-benchmark-study-1/

6.4.3_OPENHOME WHOLE BUILDING LCA[19]

Project Location: Prototype (one completed project in New Hampshire, and currently under construction at sites in Colorado and New York)

Completion Year: N/A

Project Size: 3,653 SF

OpenHome is a system for constructing customizable prefab homes created in collaboration with Bensonwood, a builder of timber-frame houses and high-performance architectural components. The project is KieranTimberlake's first to identify a pathway to net-zero embodied carbon. The system also meets the requirements of the Passive House Standard, making it low- to zero operational carbon. The baseline prototype includes three bedrooms, three and a half bathrooms, a home studio space, kitchen, media room, living room, and dining room. KieranTimberlake's OpenHome system can be customized according to the climate, landscape of the site, and preferences of the owner.

The scope of the WBLCA model includes the substructure, superstructure, enclosure, and interior partitions and finishes. Without the purchase of carbon offsets, the final embodied carbon intensity of the buildings is 84 kg CO_2/m^2 (as shown in Figure 6.11) — a remarkable improvement over the baseline for single-family residential buildings of 315 kg CO_2/m^2 (developed based on the database in the Carbon Leadership Forum's 2017 benchmark study).[18]

Key steps in this optimization included:

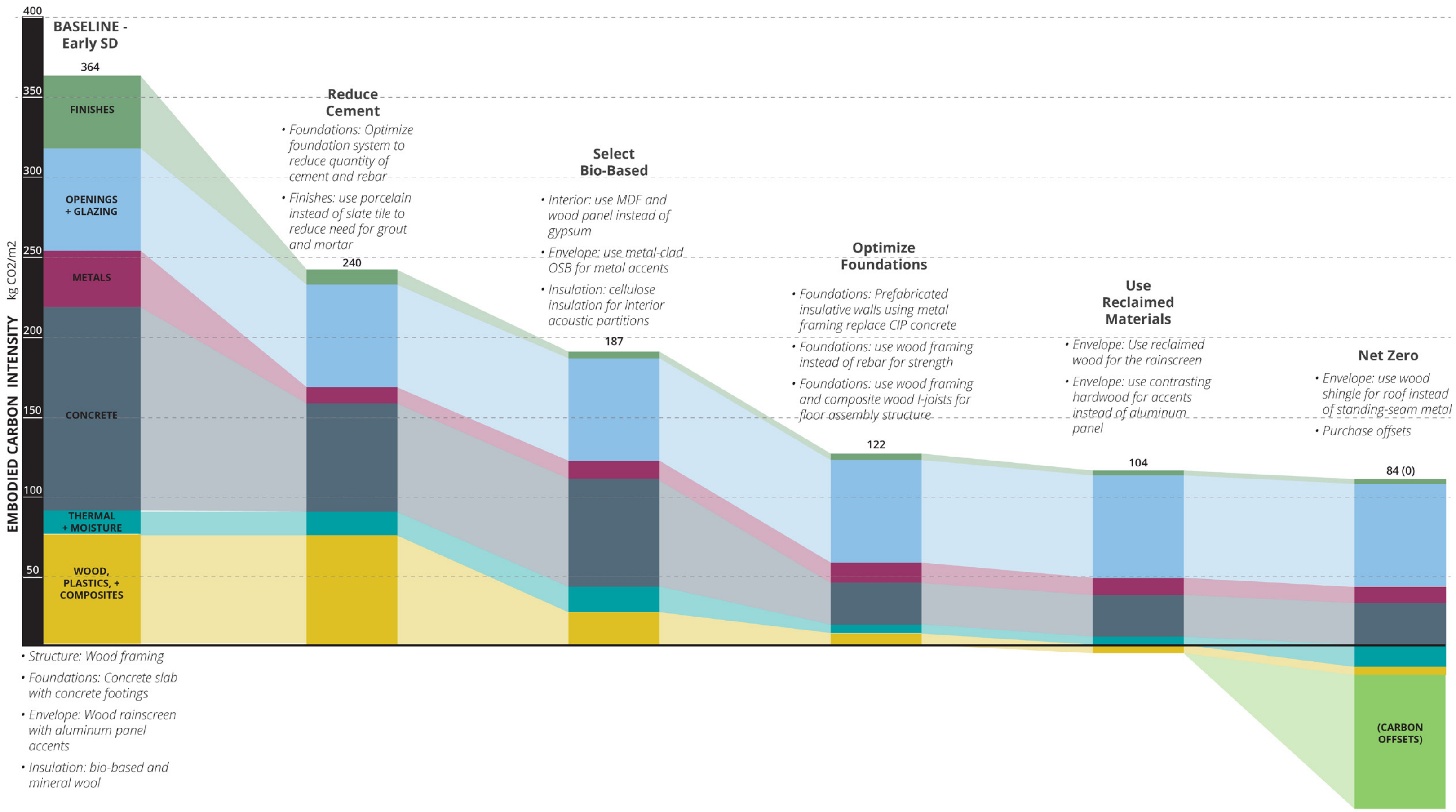
» reducing cement content, including in the concrete for the foundations (removal of footings and modifications to foundation walls) and in the mortar for the interior tiled areas;

» adding more bio-based materials to act as "carbon sinks" to sequester carbon; and

» using reclaimed materials when possible for any wood that is not carbon-negative over its lifecycle.

19 Simonen, K., Rodriguez, B., Barrera, S., Huang, M., "Embodied Carbon Benchmark Study, LCA for Low Carbon Construction, Part One", available at http://hdl.handle.net/1773/38017.

FIG. 6.11: ““OPEN HOME” WHOLE BUILDING LIFE CYCLE ASSESSMENT



Source: Case Study, KieranTimberlake, February, 2021.

6.4.4 DECONSTRUCTION AND REBUILDING PILOT AFTER HURRICANE KATRINA

Project Location: New Orleans, LA

Post-Katrina Mercy Corps deconstruction projects involved a range of materials and home types, from historic to contemporary. Photos: Brad Guy

What:

Within weeks of the 2005 hurricanes, Katrina and Rita, which hit the Gulf region of the United States, the non-profit Mercy Corps implemented a deconstruction program to reclaim building material from 60 of the approximately 275,000 destroyed and abandoned homes. In contrast to machine demolition, where entire buildings are crushed into waste and directed into landfills, deconstruction diverts materials away from landfills by redirecting them into reuse or recycling.

A detailed study was conducted on four homes deconstructed by Mercy Corps.[20] A total of 44 tons of material was redirected back into the local building material stream — enough to build three new homes out of the four that were deconstructed.

Architect and building materials reuse expert, Brad Guy, who worked on the New Orleans deconstruction, estimated that as many as 30,000 homes were demolished. If just 2,000 of those homes had been deconstructed, they would have yielded 6 million to 10 million feet of high-quality lumber and other usable materials. Meanwhile demolishing them generated landfill debris *equivalent to a 10-story building covering an entire Manhattan block.*

20 Hazel Denhart, "Deconstructing disaster: Economic and environmental impacts of deconstruction in post-Katrina New Orleans," January 2010 https://www.sciencedirect.com/science/article/abs/pii/S0921344909001712

How:

Organization	Mercy Corps (four home study findings)
Tons of Material Recovered	44 (11 tons/home average)
Wood Recovered	32,342 board feet of lumber
Salvage Rate	38-75% of the buildings by weight
Value of Building Material Recovered	$60,000
Cost	Deconstruction: $3.80 net cost to $1.53 net profit/square foot Demolition: $5.50 net cost/square foot

Images of an undamaged 1970s Florida floodplain buyout home being deconstructed. The lumber was used, under existing building codes, to rebuild HUD Section 8 Affordable Housing inland. Photos: Brad Guy

Trade-offs and Challenges:

Homeowners whose buildings were damaged beyond 51% of the fair market value received free demolition through federal funding provided by FEMA, but no funding was provided for deconstruction.

Deconstruction significantly reduces hazardous dust and associated pollution and health impacts. Lead-based paint dust from demolition projects has been shown to travel 400-600 feet — further than a block, or about twenty houses, from the site of the demolition. The lead dust contaminates more than just the soil; it can also enter windows of other homes in the area, and it directly impacts the health of demolition and debris transportation crew members.[21] When disaster debris waste is improperly disposed of, often in unlined construction and demolition or emergency landfills, it can generate methane and cause further community contamination.

Lessons Learned:

In addition to embodied carbon savings and other environmental benefits, deconstruction can provide meaningful local jobs and job training opportunities to help those impacted by disasters recover economically and socially.[22]

While not all disaster-damaged buildings can be safely deconstructed and reused, many more buildings can be, with large quantities of clean lumber, brick, and other building materials safely recovered for use.

21 Oregon Health Authority, Best Practices for the Demolition of Residences with Lead-Based Paint, 2018
https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/HEALTHYNEIGHBORHOODS/LEADPOISONING/Documents/Best-Practices-Demolition-of-Residences.pdf

22 Hazel Denhart, "Deconstructing disaster: Psycho-social impact of building deconstruction in Post-Katrina New Orleans," Cities, August 2009 | https://www.sciencedirect.com/science/article/pii/S0264275109000572

6.5_Embodied Carbon References & Resources

Websites

- AIA-CLF Embodied Carbon Toolkit for Architects: https://www.aia.org/resources/6445061-aia-clf-embodied-carbon-toolkit-for-archit
- Carbon Leadership Forum: https://carbonleadershipforum.org/
- Structural Engineering Institute's SE 2050 Commitment: https://se2050.org/
- Architecture 2030, Actions for Zero Carbon Buildings, Embodied Carbon: https://architecture2030.org/embodied-carbon-actions/
- All for Reuse (Commercial Building Reuse): https://www.allforreuse.org/
- Buildings as Material Banks: https://www.bamb2020.eu/

Books

- *Structural Materials and Global Climate: A Primer on Carbon Emissions for Structural Engineers*, ASCE (Structural Engineering Institute Sustainability Committee), 2017: https://ascelibrary.org/doi/book/10.1061/9780784414934
- *The New Carbon Architecture*, Bruce King, Nov. 2017: https://ecobuildnetwork.org/projects/new-carbon-architecture
- *C40 Implementation Guide, How to Start Deconstructing and Stop Demolishing Your City's Buildings*: https://www.c40knowledgehub.org/s/article/How-to-start-deconstructing-and-stop-demolishing-your-citys-buildings?language=en_US

Articles / Papers

- "Reducing Embodied Carbon in Buildings Low-Cost, High-Value Opportunities," RMI, July, 2021
- "A Brief Guide to Calculating Embodied Carbon," John Orr, Orlando Gibbons and Will Arnold, The Institution of Structural Engineers, July 2020: https://www.istructe.org/journal/volumes/volume-98-(2020)/issue-7/a-brief-guide-to-calculating-embodied-carbon/
- "Embodied Carbon Primer," London Energy Transformation Initiative, January 2020: https://www.leti.london/ecp#:~:text=Embodied%20Carbon%20Primer,embodied%20carbon%20in%20more%20detail.&text=This%20document%20represent%20LETI%27s%20understanding,climate%20change%20targets%20in%202020
- "What Can We Do about Embodied Carbon?", Jennifer O'Connor, *Canadian Architect*, February 2020: https://www.canadianarchitect.com/1003753921-2/
- "Bringing Embodied Carbon Upfront," World Green Building Council, September 2019: https://www.worldgbc.org/news-media/bringing-embodied-carbon-upfront
- "Embodied Carbon in Building Materials for Real Estate," Urban Land Institute: https://americas.uli.org/research/centers-initiatives/greenprint-center/greenprint-resources-2/best-practices-in-sustainable-real-estate/embodied-carbon-in-building-materials-for-real-estate/
- "Structural Design and Embodied Carbon," Christopher Horiuchi, *Structure Magazine*, March 2019: https://www.structuremag.org/?p=14262#:~:text=Embodied%20carbon%20of%20structural%20systems,material%2C%20product%2C%20or%20system

» "The Urgency of Embodied Carbon and What You Can Do about It," Paula Melton, BuildingGreen Vol. 27, Issue 9, September 2018: https://www.buildinggreen.com/feature/urgency-embodied-carbon-and-what-you-can-do-about-it

» Royal Institute of British Architects (RIBA), 2030 Climate Challenge: https://www.architecture.com/-/media/files/Climate-action/RIBA-2030-Climate-Challenge.pdf

Webinars

» "Embodied Carbon 101," Boston Society of Architects: https://www.architects.org/embodied-carbon-101

» "Embodied Carbon in the Built Environment," Annual Webinar Series, Carbon Leadership Forum: https://carbonleadershipforum.org/news-and-events/webinars/

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The Building Decarbonization Coalition unites building industry stakeholders with energy providers, environmental organizations and local governments to help electrify California's homes and work spaces with clean energy. Through research, policy development, and consumer inspiration, the BDC is pursuing fast, fair action to accelerate the development of zero-emission homes and buildings that will help California cut one of its largest sources of climate pollution, while creating safe, healthy and affordable communities. The Project Team gives special thanks to the BDC for its leadership in this endeavor and for the generous support of its Membership.

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Contributors

Building Decarbonization Practice Guide Content Leadership

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

Project Management

- **Brett Rosenberg,** LEED AP, Treeline Strategy, LLC
- **Steven Guttmann,** PE, BCxP, LEED Fellow, Guttmann & Blaevoet, Principal Investigator

Graphic Design

- **Stoller Design Group**

Copy Editor

- **Geoff Martin,** Wheelhouse Writing Services

Working Group Members and Content Contributors

- **Katie Ackerly,** AIA, David Baker Architects
- **Sean Armstrong,** Redwood Energy
- **Don Davies,** PE, SE MKA
- **Pierre Delforge,** Natural Resources Defense Council
- **Susan Freed,** County of San Diego
- **Andreas Gyr,** Google
- **Ryan Hamilton,** Nyle Systems
- **Timonie Hood,** U.S. EPA Region 9
- **Barry Hooper,** SF Environment
- **Josh Jacobs,** LEED AP+ BD&C, UL
- **Dirk Kestner,** PE, LEED AP BD+C, ENV SP, Walter P Moore
- **Bruce King,** Ecological Building Network
- **Meghan Lewis,** Carbon Leadership Forum
- **Lisa Matthiessen,** Amazon
- **Maurya McClintock,** McClintock Facades Consulting, LLC
- **Hilary Noll,** AIA, LEED AP BD+C, Mithun
- **Kelsey Rose Price,** PE, MKA
- **Cole Roberts,** PE, LEED AP, WELL AP, Arup
- **Stacy Smedley,** Skanska
- **Patrick Doss-Smith,** HGA
- **Henry Siegel,** FAIA, LEED AP, Siegel & Strain Architects
- **Larry Strain,** FAIA, LEED AP, Siegel & Strain Architects
- **Mark Webster,** PE, LEED AP BD+C, Simpson Gumpertz & Heger
- **Wolfgang Werner,** AIA, LEED AP BD+C, CPHD, Urban Fabrick, Inc.
- **Breana Wheeler,** BRE (BREEAM USA)
- **Tamim Younos,** Green Water-Infrastructure Academy