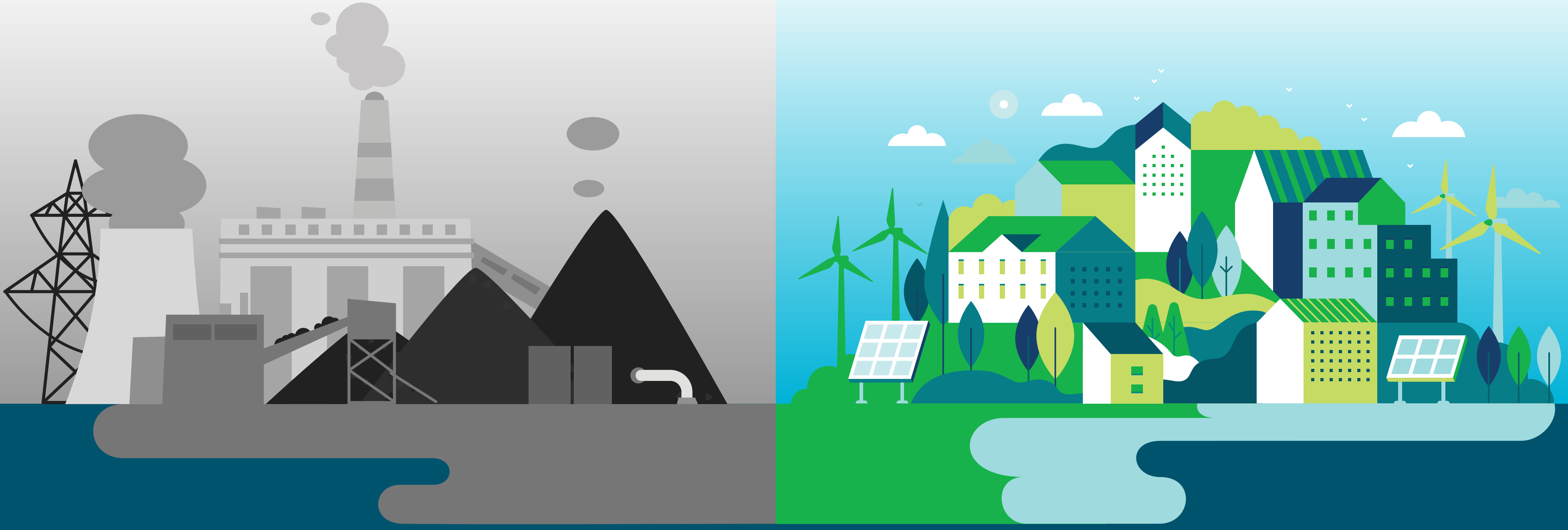

THE BUILDING DECARBONIZATION PRACTICE GUIDE

A Zero Carbon Future for the Built Environment

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VOLUME 4:

Commercial + Institutional Buildings

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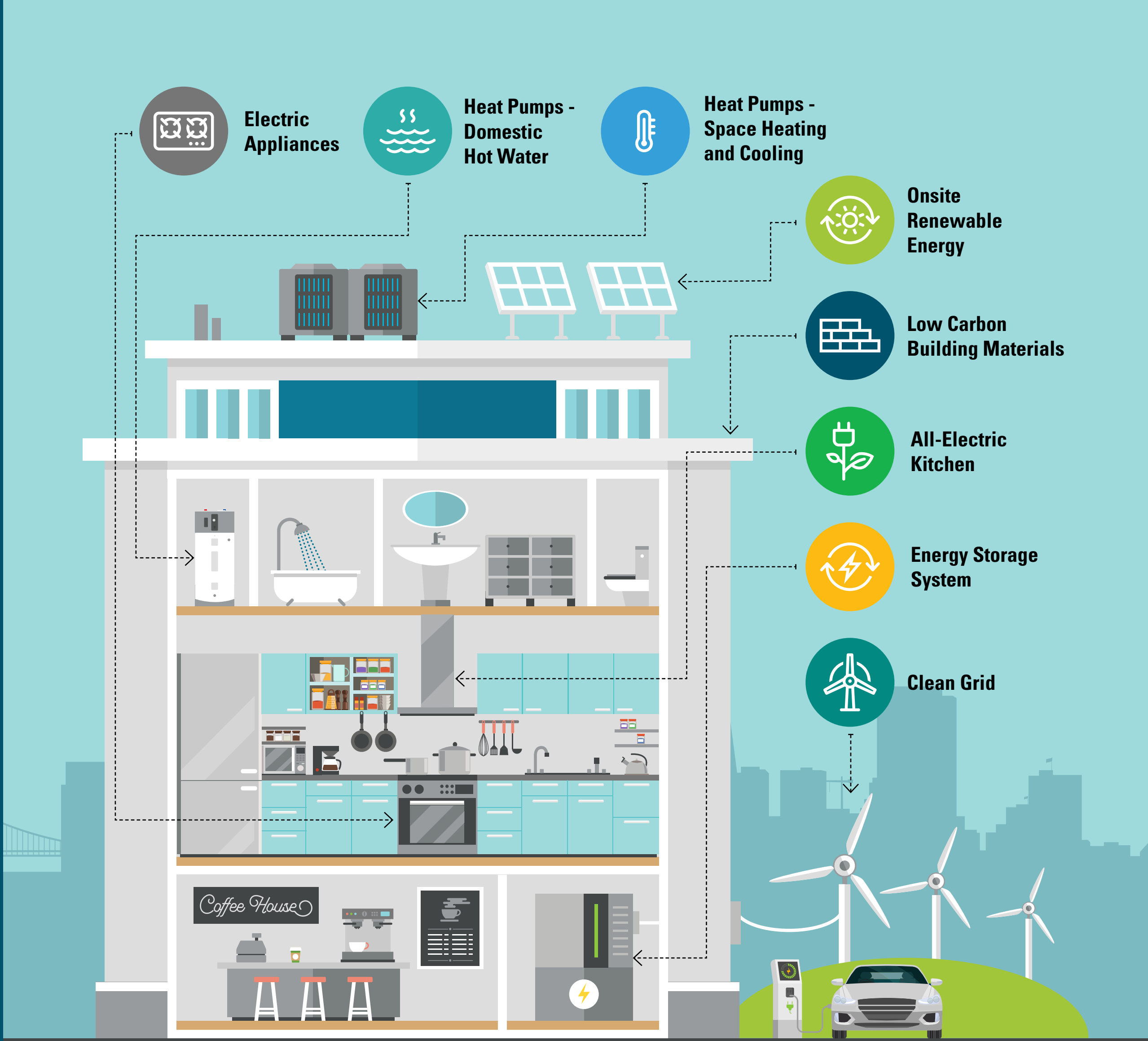

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VOLUME 4: COMMERCIAL + INSTITUTIONAL BUILDINGS

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.

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[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).

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[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.

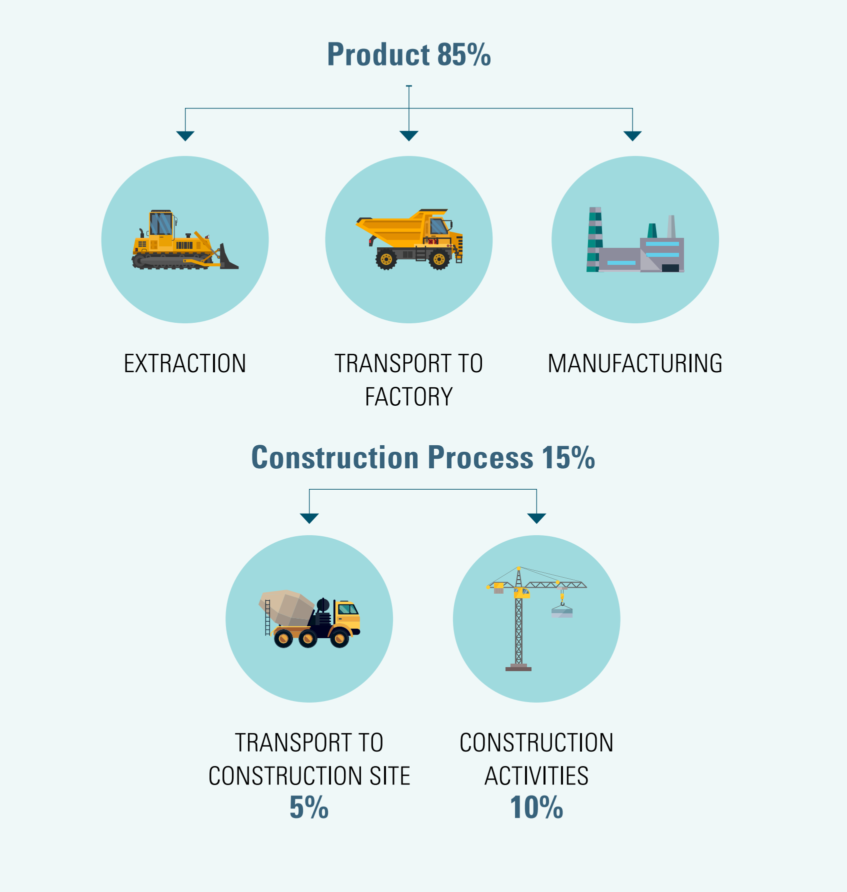
4.2.2_THE PLANNING AND DESIGN PHASES

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



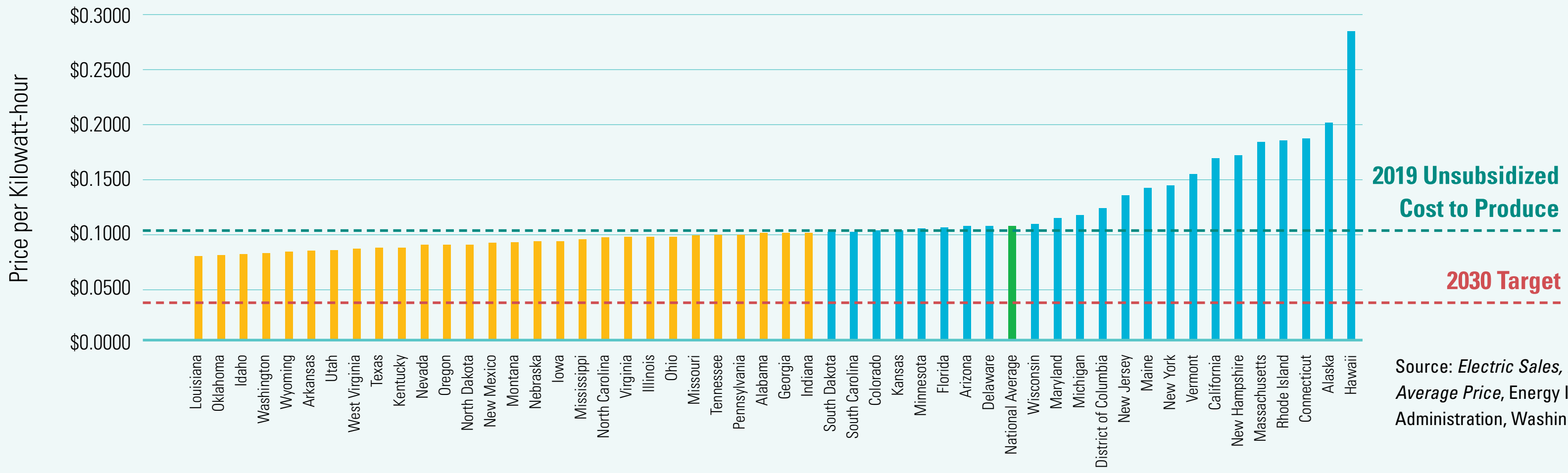
Design for deep energy efficiency: Reducing energy use has a number of project benefits, and deep reductions can sometimes be achieved at lower first cost than conventional design. Energy efficient design can reduce utility infrastructure costs while also reducing the size (and hence cost) of onsite 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.

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[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.

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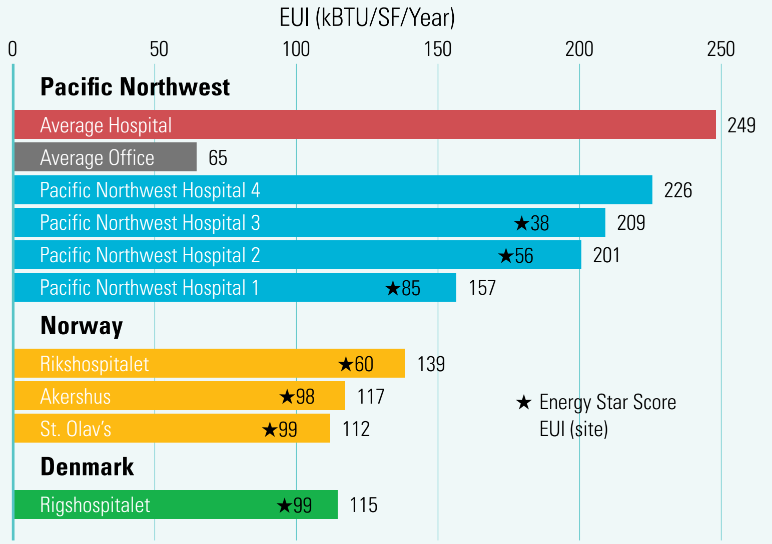
[5] Based on facilities tracked in the US Energy Administration Information's CBECS database.

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.

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[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:**

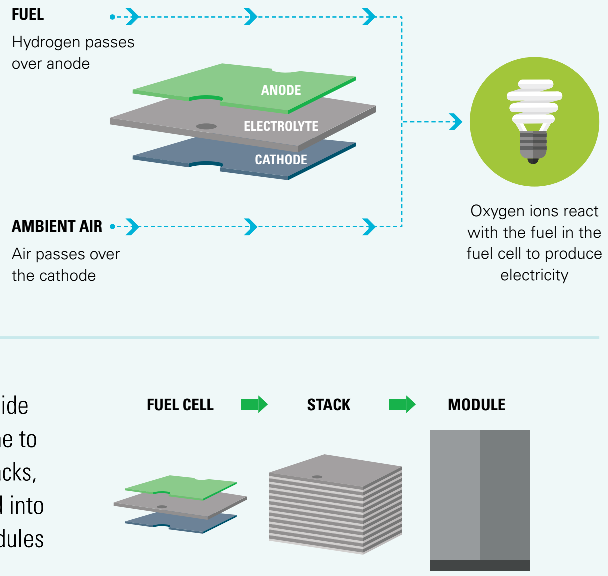
- These factors generally make air-to-air heat recovery an effective strategy.
- Where peak space loads exceed minimum air change rate requirements, decoupling ventilation systems from space conditioning systems is one of the most important strategies to reduce energy use in healthcare facilities. While 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

Fuel cells convert fuel into electricity without combustion



Multiple solid oxide fuel cells combine to form fuel cell stacks, which are placed into independent modules

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.

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[8] https://www.semanticscholar.org/paper/Inventorying-Plug-Load-Equipment-and-Assessing-Plug-Hafer/da86271f0f754eecbf12d1d7678e5b38c3237b40

[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.

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[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]

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[11] https://vdocuments.net/optimization-of-a-rock-bed-cooler-volume-1.html

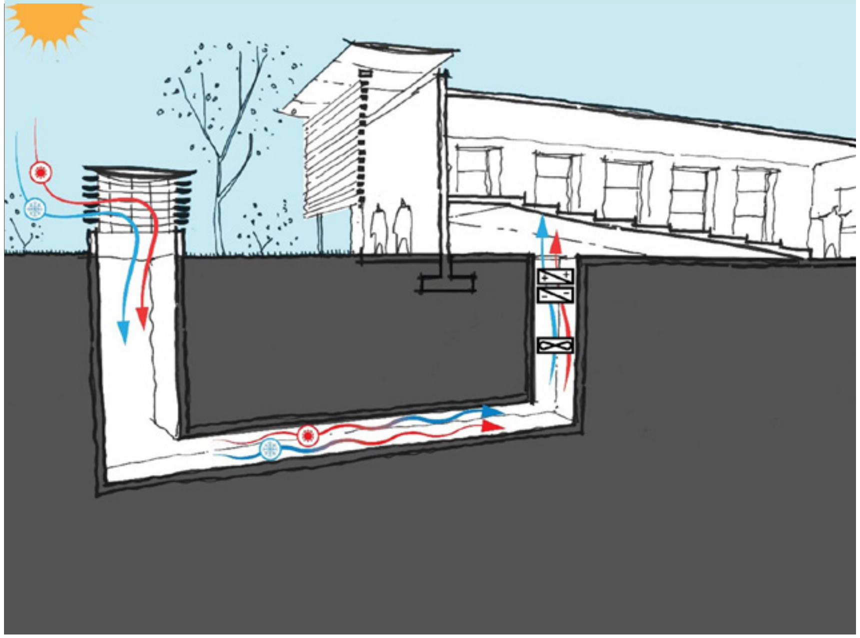
[12] https://wineserver.ucdavis.edu/about/facilities/jess-s-jackson-sustainable-winery-building

[13] https://www.airah100.org.au/faces-42.html and https://www.youtube.com/watch?v=vBWYe99ERqM

[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.
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

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[15] https://www.watttime.org/

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.

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

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[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

FIGURE 4.12: CALIFORNIA JURISDICTIONS WITH ELECTRIFICATION CODES OR ORDINANCES

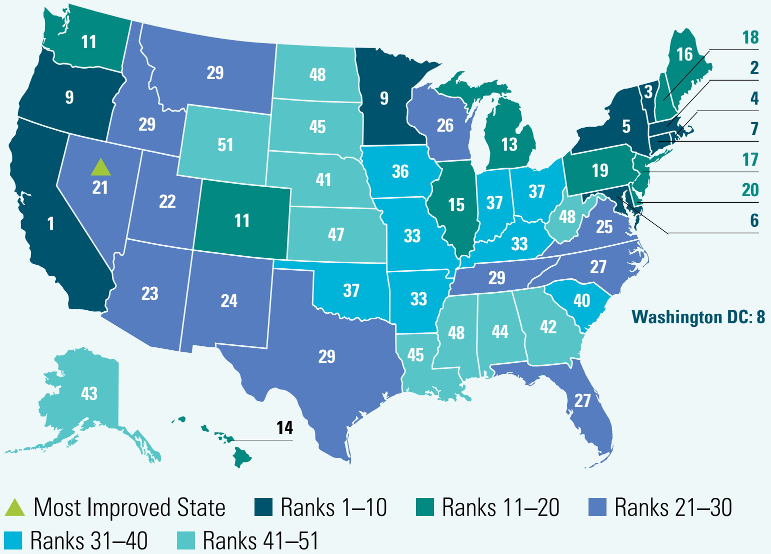
- Alameda
- Albany
- Berkeley
- Brisbane
- Burlingame
- Campbell
- Carlsbad
- City of San Mateo
- City of Santa Clara
- Cupertino
- Daly City
- Davis
- East Palo Alto
- Emeryville
- Encinitas
- Fairfax
- Half Moon Bay
- Hayward
- Healdsburg
- Los Altos
- Los Altos Hills
- Los Gatos
- Marin County
- Menlo Park
- Mill Valley
- Millbrae
- Milpitas
- Morgan Hill
- Mountain View
- Oakland
- Ojai
- Pacifica
- Palo Alto
- Petaluma
- Piedmont
- Redwood City
- Richmond
- Sacramento
- San Anselmo
- San Carlos
- San Francisco
- San Jose
- San Luis Obispo
- San Mateo County
- Santa Barbara
- Santa Clara County
- Santa Cruz
- Santa Monica
- Santa Rosa
- Saratoga
- Solana Beach
- South San Francisco
- Sunnyvale
- Windsor

Source: https://localenergycodes.com/content/adopted-ordinances

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?

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[20] https://www.rics.org/surveyor-careers/surveying/what-surveyors-do/what-is-a-quantity-surveyor

    - 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?

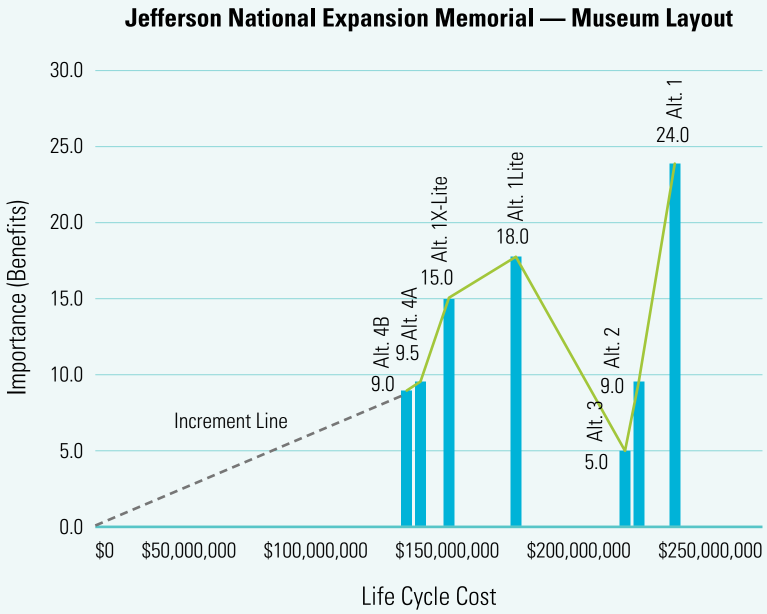
- **Does a phased approach to electrification make sense?**
  - Are there several gas-based systems in the facility (e.g., water heating, space heating, and kitchen) that would warrant a phased approach to minimize disruption, downtime, and current capital requirements?

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.

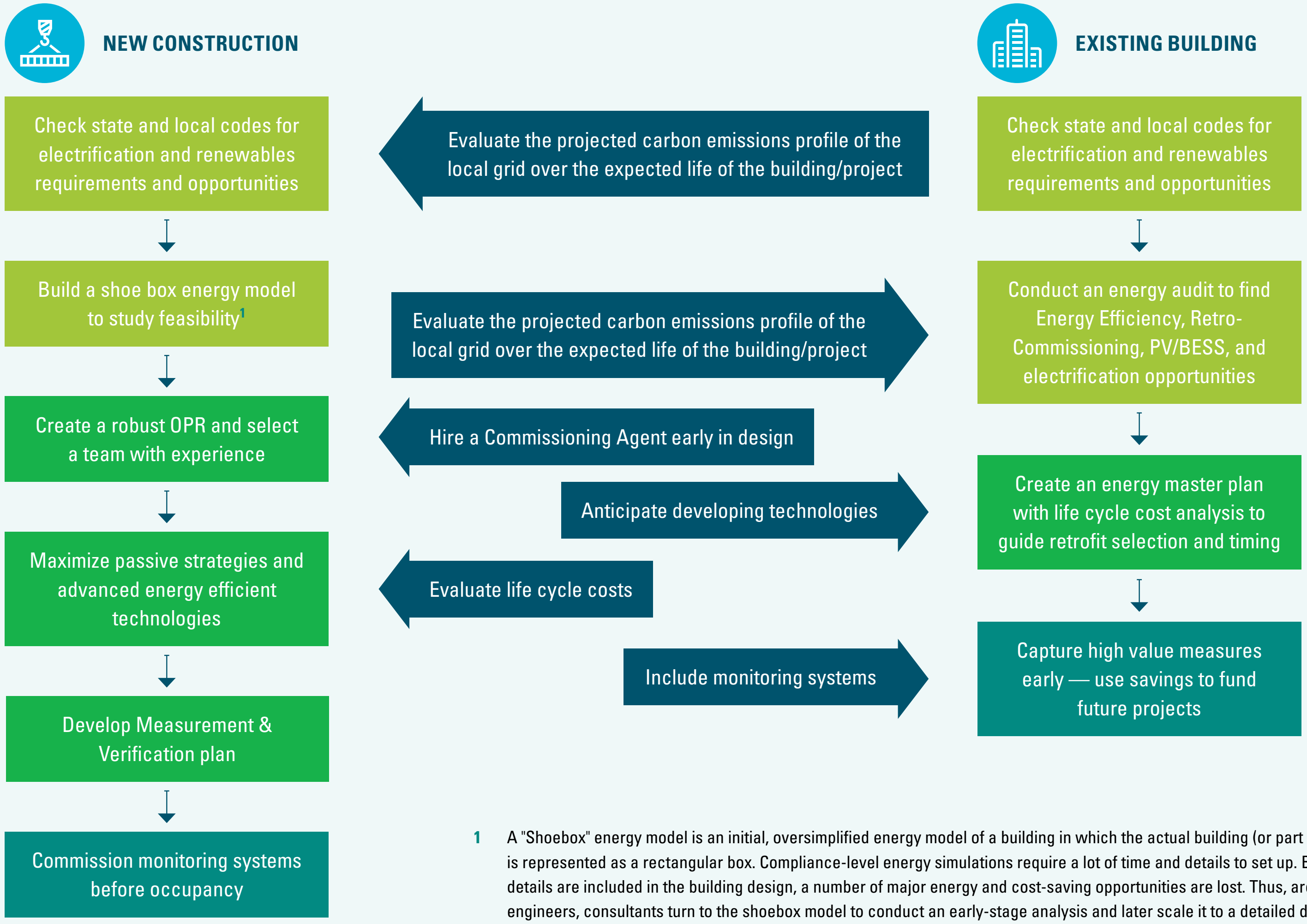
Technologies and strategies: Volume 2, section 2.6 describes many of the technologies and strategies that facilitate a successful all-electric design approach. Since some of these technologies are not yet industry standard, it is helpful to bring knowledgeable practitioners into the process.

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



NEW CONSTRUCTION

- Check state and local codes for electrification and renewables requirements and opportunities
- Build a shoe box energy model to study feasibility[1]
- Create a robust OPR and select a team with experience
- Maximize passive strategies and advanced energy efficient technologies
- Develop Measurement & Verification plan
- Commission monitoring systems before occupancy

EXISTING BUILDING

- Check state and local codes for electrification and renewables requirements and opportunities
- Conduct an energy audit to find Energy Efficiency, Retro-Commissioning, PV/BESS, and electrification opportunities
- Create an energy master plan with life cycle cost analysis to guide retrofit selection and timing
- Capture high value measures early — use savings to fund future projects

Evaluate the projected carbon emissions profile of the local grid over the expected life of the building/project

Evaluate the projected carbon emissions profile of the local grid over the expected life of the building/project

Hire a Commissioning Agent early in design

Anticipate developing technologies

Evaluate life cycle costs

Include monitoring systems

[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.

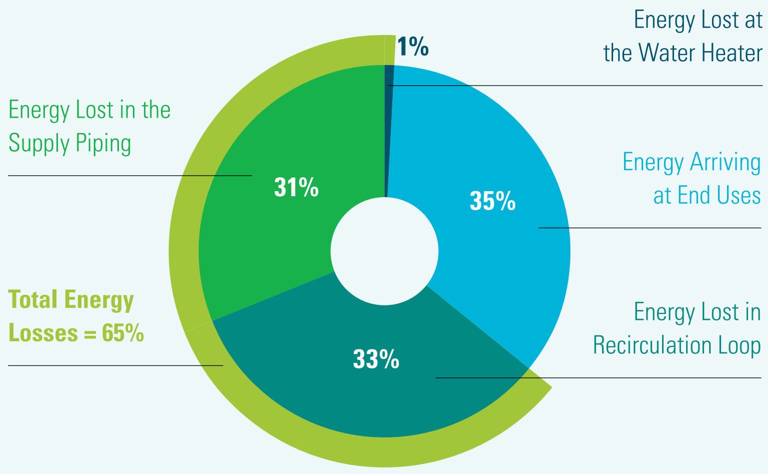
For building space heating systems, higher efficiencies might be achieved by strategies such as:

- 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



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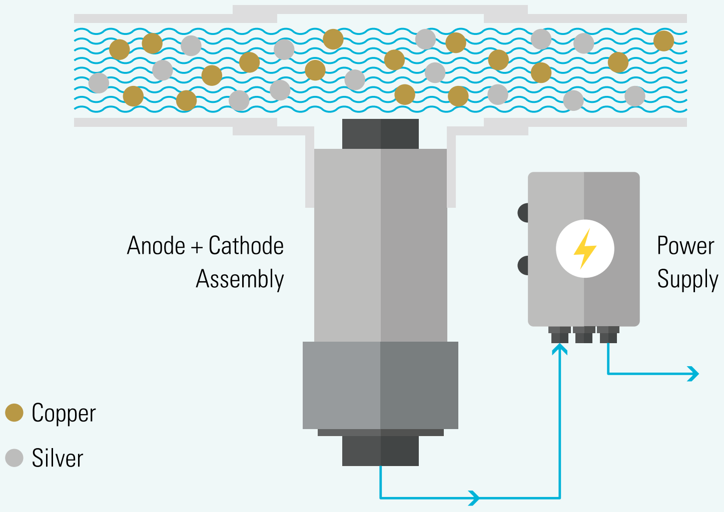
[21] "Control Strategies to Reduce the Energy Consumption of Central Domestic Hot Water Systems," Dentz et al, June, 2016.

- 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.

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[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.

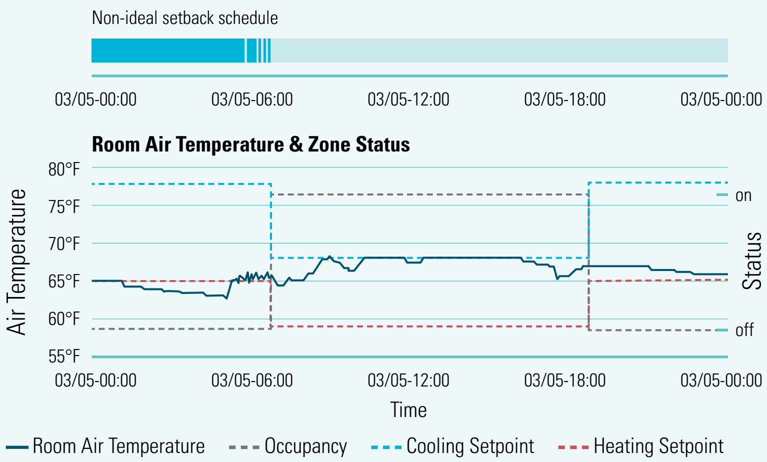
» **Fault Detection and Diagnostics (FDD) tools, integrated with facility management, service, and maintenance management systems**

- 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.

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[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.

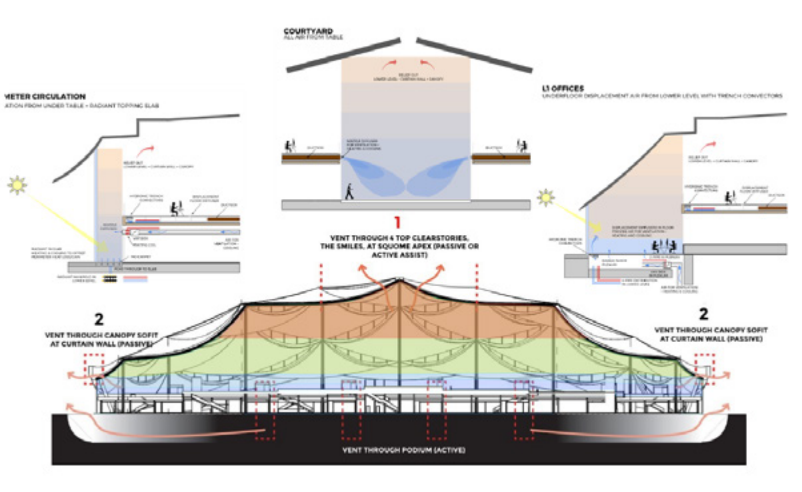
[24] “Building Commissioning Costs and Savings Across Three Decades and 1,500 North American Buildings,” Eliot Crowe et al, Lawrence Berkeley National Laboratory, Energy Technologies Area, November, 2020

[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.

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[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.

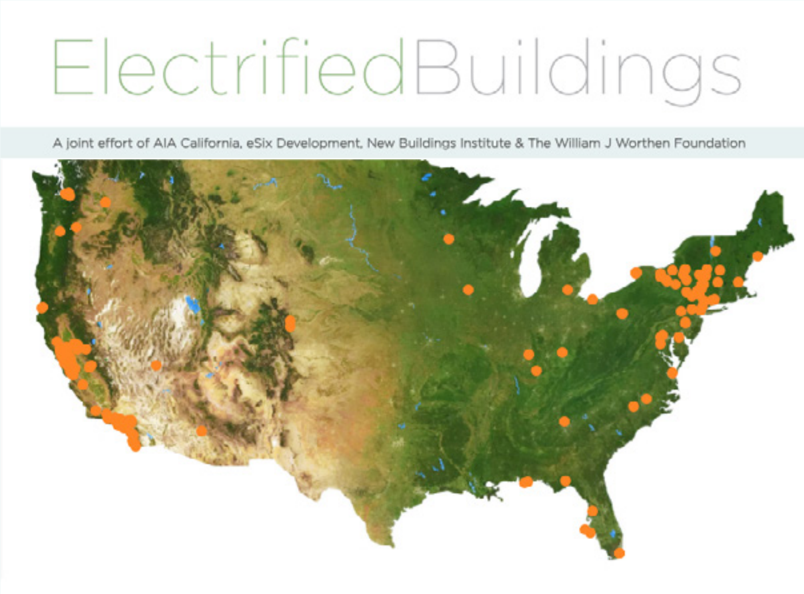
- **Track construction activity carbon emissions.** Transport and construction carbon emissions can be tracked and reduced. Construction practices are not static, and new innovations can reduce carbon emissions.

- **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.

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