B2E

Building to Electrification Coalition

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BC Commercial Building Electrification Guide

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List of Abbreviations, Acronyms, and Initialisms

AAI	DEFINITION
ADR	Automated demand response
AHJ	Authority having jurisdiction
AMI	Advanced metering infrastructure
ASHP	Air-source heat pump
AWHP	Air-to-water heat pump
B2E	Building to Electrification Coalition
BAS	Building automation system
BCA	Building condition assessment
BESS	Battery energy storage system
BoD	Basis of design
BPS	Building performance standards
CAGBC	The Canada Green Building Council
CC-CT	Closed-circuit cooling tower
CHPWH	Central heat pump water heater
COP	Coefficient of performance
C-Op	Continuous optimization program
CSR	Corporate social responsibility
Cx	Commissioning
DBOM	Design-build-operate-maintain
DCV	Demand controlled ventilation
DDC	Direct digital control
DHRC	Dedicated heat recover chiller
DHW	Domestic hot water
DOE	US Department of Energy
DWHR	Drain water heat recovery
EMIS	Energy management information system
EPA	US Environmental Protection Agency
ERV	Energy recovery ventilation
ESA	Electric service agreement
ESCO	Energy service company
ESG	Environmental, social, and governance
ESPM	Energy star portfolio manager
EUI	Energy use intensity
FDD	Fault detection & diagnostics
GHG	Greenhouse gas
GHGi	Greenhouse gas intensity
GSHP	Ground-source heat pumps
GWP	Global warming potential

AAI	DEFINITION
HFC	Hydrofluorocarbons
HPWH	Heat pump water heater
HRC	Heat recovery chiller
HRV	Heat recovery ventilator
HSPF	Heating seasonal performance factor
HVAC	Heating, ventilation, and air conditioning
HWST	Hot water supply temperature
HWST SP	Hot water supply temperature setpoint
IPD	Integrated project delivery
IPMVP	International Performance Measurement & Verification Protocol
IRR	Internal rate of return
LCCA	Life cycle cost analysis
LCE	Low-carbon electrification
M&V	Measurement and verification
MERV	Minimum efficiency reporting value
NPV	Net present value
NRCAN	Natural Resources Canada
OAD	Outside air damper
OAT	Outside air temperature
OM&M	Operations, maintenance, and monitoring plan
OPR	Owner's project requirements
PDB	Progressive design build
PRV	Pressure reducing valve
PSIG	Pounds per square inch gauge
QC	Quality control
SAP	Supply air pressure
SEER	Seasonal energy efficiency ratio
SOO	Sequence of operations
TAB	Testing, adjusting, and balancing
TCBO	Total cost of building ownership
TER	Total efficiency ratio
TES	Thermal energy storage
TOU	Time of use
TVM	Time value of money
VAV	Variable air volume
VFD	Variable frequency drive
VRF	Variable refrigerant flow
WWHP	Water-to-water heat pump

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Part 1: Introduction

The first Part of the Guide provides an overview of the document, along with the current market drivers of and barriers to LCE retrofits, including:

- **Chapter 1: Overview**
- **Chapter 2: Market Drivers and Barriers**

Its content will be particularly relevant to the following building and project stakeholders:

RELEVANT TO:	
☑	Building Owner
☑	Owner Advisor / Energy Manager
☑	Prime Consultant
	Designer

1. Overview

1.1. CONTEXT

Climate change is a global phenomenon with local impacts. The Province of British Columbia (BC) is already experiencing many of these impacts, including extreme heat events, more powerful storms, and increased frequency and severity of wildfires.

Mitigating climate change will take concerted efforts at all levels and from all sectors. BC has set ambitious climate targets to reduce greenhouse gas (GHG) emissions below 2007 levels by 40% by 2030 and 80% by 2050, including an ambition for the ‘buildings and communities’ sector of a 59%-64% emissions reduction by 2030 (Climate Change Accountability Act, SBC 2007).

It is estimated that 70% of buildings standing today will still be in use by 2050. So, reaching our targets will require a rapid scaling up of decarbonization retrofits for all building types. The Pembina Institute estimates that BC will need to retrofit an average of 4% of its buildings per year, and increase investment from $300 million to $2.8 billion per year, to decarbonize its commercial and residential building stock by 2050 (Kennedy, 2021).

As anyone who has been through one knows, deep energy retrofits of existing buildings are challenging. However, they’re a bit more straightforward in BC than many other jurisdictions, thanks to our plentiful supply of clean electricity, 98% of which is generated from low-carbon and renewable sources. As such, the low-carbon electrification of mechanical systems is “increasingly recognized… as a central strategy to significantly reduce or completely eliminate GHG emissions from the operations of buildings” (Integral Group, 2021).

1.2. OVERVIEW

This first edition of the B2E Commercial Building Electrification Guide was created by practitioners with practical experience with low-carbon electrification (LCE) retrofits, in consultation with leading mechanical, electrical, and structural engineers, as well as building owners and equipment suppliers. It is intended to be a practical guide and resource that enables consultants to plan for, design, and construct successful building electrification projects, avoiding the pitfalls and growing pains often associated with early efforts, and build the sector’s capacity to reach our emissions reduction targets.

The Guide is broken down into 5 Parts:

1. **Introduction** provides an overview of the Guide, and the current market drivers of and barriers to LCE retrofits.
2. **Planning** offers high-level guidance on the recommended steps, principles, and roles for LCE planning.
3. **Implementation** outlines the process for implementing LCE retrofit projects in existing buildings.
4. **Design** digs into the design process and considerations for key systems and technologies.
5. **Appendices** include supplementary information and resources to support the use of the Guide.

A breakdown of the parts and chapters of the book, and the audiences for whom they are intended, can be found in Table 1.

TABLE 1: INTENDED AUDIENCES OF THE GUIDE

			Building Owner	Owner Advisor / Energy Manager	Prime Consultant	Designer
No.	**Part**	**Chapter**	**Primary Audience**			
1	Introduction	1. Overview 2. Market Drivers and Barriers	☑	☑	☑	
2	Planning	3. Electrification Planning Process 4. Decarbonization Principles	☑	☑		
3	Implementation	5. Prime Consultant Role 6. Implementation Considerations		☑	☑	☑
4	Design	7. Heat Pumps 8. Heating, Ventilation, and Air Conditioning Systems 9. Domestic Hot Water Systems 10. Electrical Considerations 11. Structural Considerations 12. Architectural Considerations				☑
5	Appendices	1. Example Pathways 2. Case Studies 3. Technical Appendices 4. References	☑	☑	☑	☑

1.3. THE FUTURE

The field of low-carbon electrification is evolving quickly. We hope to be able to keep expanding and refining this Guide in future iterations. If you have questions or feedback on anything contained herein, or would like to contribute to the next version, please use the feedback form on the Guide's landing page on the B2E website: https://b2electrification.org/b2e-commercial-building-electrification-guide.

2. Market Drivers and Barriers

This chapter will address forces and factors driving low-carbon electrification (LCE) in the current market, along with common barriers.

There are three types of motivating forces driving market demand for building electrification: government policy, economic considerations, and voluntary action. The drivers considered in this chapter can be motivated by more than one force: for example, concerns about climate resilience may be motivated by both the need to meet minimum temperature requirements (policy) and a desire to attract and retain tenants (economic considerations).

2.1. MARKET DRIVERS FOR ELECTRIFICATION

2.1.1. Government Policy and Regulation

Virtually all levels of government in Canada are instituting policies and regulations aimed at incentivizing and facilitating the low-carbon electrification of existing buildings. These range widely in coercive power, from financial incentives and reduced permitting fees and periods; to opt-in pilot programs and voluntary energy-use monitoring and reporting schemes; to mandatory carbon pollution limits, carbon taxes, equipment regulations, and building emissions performance standards (BPS).

2.1.2. Comfort and Safety

As communities face increasingly frequent and severe weather events such as storms, floods, fires, and heat waves, the physical consequences of climate change are becoming more pronounced and harder to ignore. Resilience in the face of extreme heat and poor air quality is becoming an increasingly desirable feature for renters considering their – and their customers' and employees' – comfort, safety, and well-being. This emerging preference is already being codified into law in certain progressive jurisdictions, for example through integration into Occupational Health and Safety Regulations.

Modern building electrification strategies make heating and cooling two sides of the same coin; the rising demand for cooling in the face of extreme heat events offers an opportunity to accelerate and incentivize LCE. Properly implemented, heat pumps offer an opportunity to introduce space cooling that also provides efficient, low-carbon heating. Many non-mechanical efficiency upgrades, such as to a building's envelope, provide passive cooling and reduce heating and cooling loads and, as a result, can bring down the capital costs associated with investing in new HVAC equipment.

2.1.3. Financial Risk

Buildings and portfolios with long-lasting, high GHG-emitting energy systems can face financial risks. These risks could include premature obsolescence and potential depreciation, by being out of step with regulatory regimes, market expectations, or both. They could also take the form of direct financial exposure to regulatory instruments such as carbon taxes, emission charges, or non-compliance fines and penalties.

Early movers are already pricing assets and weighing building emissions and LCE potential to inform their investment, management, and disposition decisions. In a worldwide survey conducted by CBRE in 2022, almost half the investors said they would “seek a discount or walk away from a deal altogether” when considering a building that has high energy consumption and carbon emissions (CBRE Research, 2023).

2.1.4. Environmental, Social, and Governance (ESG)

Many building owners are internalizing regulatory and market indicators, along with other considerations, into their corporate social responsibility (CSR) or environmental, social, and corporate governance (ESG) regimes. This includes small progressive property owners setting their own agenda, and larger real estate companies who manage funds and portfolios on behalf of parent companies and institutional investors with net-zero commitments or mandates.

Incorporating low-carbon electrification into corporate plans and commitments offers building owners an opportunity to differentiate themselves in the market; realize co-benefits; align business departments; and take a planned, proactive, and strategic approach to portfolio decarbonization rather than having to react to outside demands and drivers. External certification programs such as Passive House and the Zero Carbon Building Standard can offer accreditation and recognition, as can participation in market acceleration programs such as the Canada Infrastructure Bank’s Green Infrastructure program, which also offers access to advantageous financing opportunities for early adopters.

2.1.5. Tenant Attraction

Many larger tenants have their own net-zero mandates. These businesses and government agencies are seeking products that align with their operational emission-reduction commitments, and are sending clear signals in the market that are driving electrification, especially of AAA buildings.

2.2. COMMON CONCERNS AND RISKS

While LCE projects are becoming easier, more common, and less expensive, several barriers – real and perceived – remain. Below is a list of some of the most common barriers, along with a brief discussion of the way in and extent to which they have been or are in the process of being addressed.

2.2.1. Cost

The higher upfront costs of high-efficiency electrical equipment relative to gas-fired options are one of the most commonly cited barriers to building electrification. Rebates, subsidies, and other financial incentives offered by governments and utilities can address this barrier. Reducing building loads before proceeding with LCE can also help keep equipment costs down; load reduction is addressed in Chapters 4, 8, and 9.

Higher operational costs represent another financial barrier to LCE. However, several factors, including the improved efficiency of modern electrical heating equipment such as heat pumps, cost premiums associated with “renewable” fossil fuels, and emerging carbon tax and pricing regimes, are narrowing the energy cost gap.

Finally, traditional metrics for evaluating the financial costs and benefits of energy projects, such as simple payback, have not historically supported the case for LCE. Recently, more sophisticated metrics have begun to emerge, which include a broader range of considerations such as incremental costs, net present value, carbon pricing, non-energy benefits, and other costs associated with building ownership, and which can provide more nuanced and accurate bases for financial evaluation. Examples of such metrics, such as life cycle cost analysis (LCCA) and NPV/tonne of GHG emissions reduced are addressed in more detail in Section 3.5.1.

2.2.2. Physical Space Constraints

While like-for-like replacement of gas-fired equipment with electrical equivalents is unlikely to trigger this concern, many LCE configurations – especially those involving heat pumps – can substantially increase system spatial requirements and weights.

Reducing building loads before proceeding with LCE, and carefully considering the need for and scope of supplemental heat requirements, can help minimize spatial requirements by ensuring that new equipment is right-sized.

2.2.3. Scheduling

The low-carbon electrification of a major building mechanical system is often a more complicated undertaking than a like-for-like or -similar replacement. Compatibility issues, equipment availability, a lack of off-the-shelf options, and project unknowns can all contribute to a longer project schedule and a higher probability of delays.

It is anticipated that this gap will decrease as LCE projects become more common and better supported. Some progressive jurisdictions are reviewing their permitting processes to identify opportunities to facilitate projects with energy-saving and emission-reduction outcomes. For now, guides like this one can help consultants plan projects and specify equipment that reduce project durations and the likelihood of delays.

2.2.4. Disruption

Transforming a building's energy systems can require service shutdowns that cause substantial disruptions to occupants. However, as sector experience with such projects increases, and technology and techniques improve, experienced project implementation teams are better able to reduce and mitigate these disruptions.

Open communication with stakeholders and careful scheduling can further attenuate the impacts of service interruptions. The Tower Renewal Partnership's Field Guide to Retrofits in Occupied Buildings (The Tower Renewal Partnership, 2020) is a resource designed to assist property owners, residents, and the construction industry with conducting retrofits efficiently and effectively while tenants are in the building.

2.2.5. Electricity Supply

In order to electrify building heating systems, sufficient electrical supply must be available. Determining the availability of electrical capacity at the building, panel, and even local grid level is one of the first steps in the LCE process. If they are required, building electrical service upgrades can add significant costs to a retrofit project.

Conduct an electrical capacity review during the feasibility stage of a project to determine whether sufficient capacity is available, or whether an electrical service upgrade or change to the energy service agreement with the utility is required. As part of this review, consider load mitigation strategies and how they may be applied to limit or eliminate the need for significant upgrades to the building's electrical service and/or the electrical distribution within the building. For more details on addressing electrical supply considerations, refer to Chapter 0.

2.2.6. Regulation

Even in pro-electrification jurisdictions, municipal building codes and bylaws may not contemplate newer electrical equipment types or configurations. This may require engineers to work closely with or propose alternative solutions to authorities having jurisdiction (AHJs) to avoid being obstructed by prescriptive or restrictive requirements. It may be worth reviewing and referencing municipal climate and energy plans: even in jurisdictions where building electrification and decarbonization policies haven’t been fully operationalized, they can provide soft support for such efforts.

2.2.6.1. Development Charges

Some jurisdictions have bylaws or other mechanisms whereby substantial building retrofits trigger development charges or requirements that existing buildings be upgraded to prescribed levels. Such requirements can impose additional costs and delays on LCE projects. These bylaws often employ simple “threshold” construction values for determining when upgrades are triggered. However, recognizing the benefits of LCE projects and their alignment with community energy and climate policies, some progressive jurisdictions, such as the City of Vancouver, are making exceptions for, among other upgrade types, energy efficiency-focused projects, which can exclude LCE retrofits from these requirements.

2.2.7. Lack of Expertise and Workforce Capacity

The shortage of trained and experienced trades and professionals remains a persistent barrier to building electrification. Broad coalitions such as B2E, Canada’s first building electrification coalition, based in British Columbia, are coming together to identify gaps and develop appropriate strategies to address them – like this Guide. However, as the B2E’s 2022 Building Electrification Scorecard notes, “[a]lthough workforce shortages continue to be cited as one of the biggest barriers by industry participants, increasing recruitment remains the action with the least tangible progress made to date. More concerted effort is needed to address this barrier” (B2E, 2022).

2.2.7.1. Operational Staff Capacity

New LCE equipment and associated controls systems can be unfamiliar to building operators. Employing strategies such as integrated design processes, which include broad stakeholders in the design phase, and ensuring a robust project-handoff phase post-construction, including documentation and training, can ensure building operators are prepared to effectively manage and maintain new LCE systems. More information about these considerations is included in Section 6.6.

2.2.8. Peak Loads

Even among building owners who are on board with LCE, there is hesitation to place the full load on the electrical system at times of peak electrical demand (B2E, 2024). To address this concern, owners often retain gas-fired boilers to provide supplemental heating and meet energy demand during times of extreme temperatures. However, a holistic approach to LCE, like the one outlined in Chapter 4 of this Guide, can reduce building loads to the point that all-electric systems can have lower operational costs than less-optimized buildings relying on gas-fired equipment.

Part 2: Planning

The second part of the Guide offers high-level guidance on the recommended steps, principles, and roles for low-carbon electrification planning, including:

- **Chapter 3: Electrification Planning**
- **Chapter 4: Decarbonization Principles**

Its content will be particularly relevant to the following building and project stakeholders:

RELEVANT TO:	
☑	Building Owner
☑	Owner Advisor / Energy Manager
	Prime Consultant
	Designer

3. Electrification Planning

This chapter seeks to offer high-level guidance on the recommended steps for building electrification planning. Following, or at least accounting for the process outlined here during the initial phases of an LCE project can enhance efficiency, reduce costs, mitigate risks, and significantly increase the likelihood of successfully achieving carbon reduction targets.

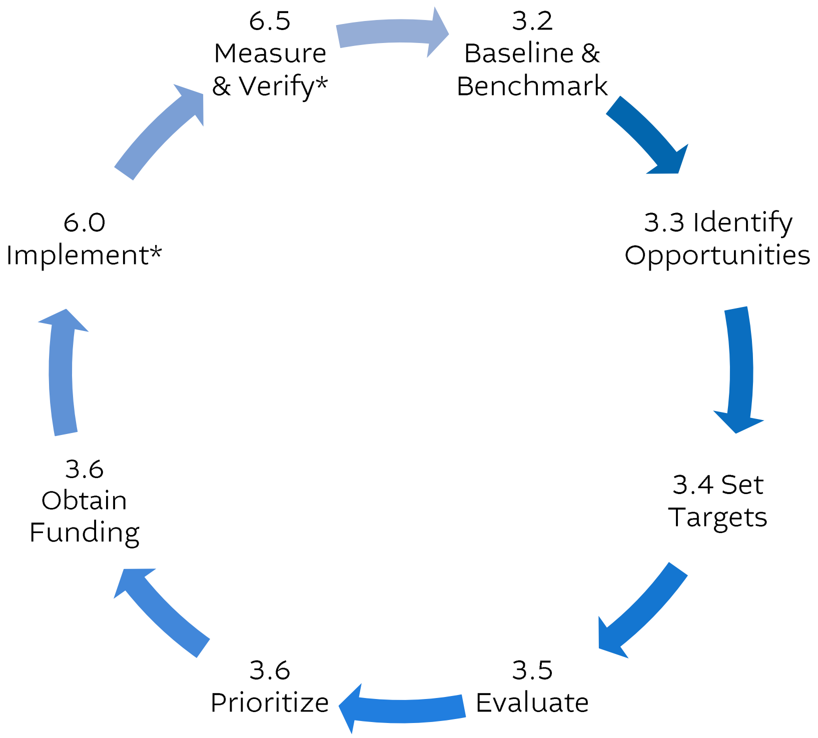
Successful LCE projects require clearly defined roles and responsibilities among the key stakeholders, including building owners, energy managers, consulting teams, operations staff, and procurement. This clarity fosters accountability, encourages project buy-in, and ensures clear and effective communication between stakeholders throughout the process.

Typically, the energy manager within an organization leads LCE projects, working with external consultants and coordinating efforts across departments. In other cases, this responsibility may be assumed by an operations manager, a sustainability lead; or, when internal resources are limited, an external energy consultant brought in to oversee the project. Regardless of who leads the process, designating a single individual to serve as the project champion can serve to maintain focus, drive progress, and ensure that decarbonization targets are achieved.

3.1. THE ELECTRIFICATION PLANNING PROCESS

The recommended electrification planning process is presented in Figure 1 below.

FIGURE 1: ELECTRIFICATION PROCESS MAP



***Implement** and **Measure & Verify** are addressed in greater detail in Chapter 6.

The process is depicted as a circular loop to illustrate that reducing energy and emissions in any building is often an ongoing effort, not a one-time activity. After an LCE measure has been implemented, and the measurement and verification (M&V) process completed to ensure it is performing as intended, continue monitoring the building's emissions and energy use as the next round of the baseline and benchmark step. Ongoing monitoring can ensure that LCE equipment meets long-term emission reduction targets and identify opportunities for further optimization – which can be evaluated and implemented through the same process.

3.2. BASELINE & BENCHMARK

Good energy and system performance measurement is important for energy efficiency projects, but it is particularly key for LCE projects. Energy and performance measurements are useful to understand current performance, inform emissions reduction targets, size low-carbon electric equipment, monitor system performance, confirm savings, and identify issues.

The following are useful sources and means of measuring energy data:

- **Utility data** can be pulled directly from the utility provider, an external energy management information system (EMIS), or the building automation system (BAS).
- **Sub-metering** can offer valuable insights for right-sizing equipment, optimizing performance, and troubleshooting issues. It is particularly useful for systems that are not connected to the BAS, such as domestic hot water (DHW) systems, or for individual buildings within large campuses that lack separate utility billing meters. However, implementing sub-metering – especially at a large scale – can be complex and costly, requiring meticulous maintenance to ensure ongoing accuracy and reliability. More details on using sub-metering for data-driven design are available in the technical chapters of this guide.
- **Virtual metering** uses data from sensors in conjunction with mathematical algorithms to compute and monitor the energy usage of equipment or systems, like boiler plants or heat pump loops. Virtual metering can be a particularly beneficial approach in cases where installing traditional meters or sub-metering is prohibitively expensive or impractical.

3.2.1. Baselining

Once energy consumption has been measured, a baseline can be established. An energy baseline serves as a reference point for measuring future energy consumption and performance improvements: it represents the initial state of energy usage in a building or system against which changes and efficiencies can be evaluated over time; by establishing a baseline, stakeholders can track progress, set targets, and assess the effectiveness of energy-saving initiatives. A baseline is typically established using at least 12 consecutive months of data, normalized for factors such as weather and occupancy.

Baseline energy data can also be leveraged to quantify greenhouse gas emissions, which can provide insights into a building's environmental impact and guide sustainability efforts. The following sources provide emission factors for energy use in BC:

- **Electricity Emission Intensity Factors for Grid-connected Entities:** https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/reporting/quantify/electricity

- **Natural Gas Emission Intensity Factors:** https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/federal-greenhouse-gas-offset-system/emission-factors-reference-values.html

3.2.2. Benchmarking

Benchmarking buildings for energy and greenhouse gas emissions involves comparing their performance against similar buildings to identify whether they represent good opportunities for improvement. Once its baseline of energy use and emissions has been established, a building can be compared to industry standards and peers to determine how it stacks up. At a portfolio level, this can help prioritize investments, inform decision-making, and drive toward environmental goals. At a building level, benchmarking can help stakeholders set goals, track progress, and implement strategies for improved efficiency and sustainability. Some examples of benchmarking databases include:

- **Energy Star Portfolio Manager**: https://www.energystar.gov/buildings/benchmark

- **Building Performance Database**: https://www.energy.gov/eere/buildings/building-performance-database-bpd

Baselining and Benchmarking can be done using a variety of tools, from commonly available desktop spreadsheet tools like Excel; to online tools like those mentioned above; to complex energy management information system (EMIS) or fault detection & diagnostics (FDD) platforms that automatically collect data from multiple sources, streamlining the process of analyzing and comparing energy performance to facilitate the identification of opportunities for improvement.

Some metrics that can be useful for energy and emissions monitoring and benchmarking include:

- **Energy Use Intensity (EUI) or Total Energy Use Intensity (TEUI):** The energy consumption per unit area (typically in kWh/ft^2 or MJ/m^2) allows for a direct comparison between buildings of different sizes and purposes.

- **GHGi:** The intensity of GHG emissions associated with a building's operations, typically expressed in terms of carbon dioxide equivalent (CO_2e) per unit area over a specified period, such as kgCO_2e/m^2 per year. GHGi accounts for emissions from all sources of energy used in a building or process, including electricity, natural gas, and other fuels. It is typically calculated by multiplying the amount of energy consumed by a system by the emissions factor of the fuel or energy source used by the system.

- **Energy Star Score:** A numerical rating, ranging from 1-100, which represents a building's energy efficiency relative to other buildings of similar type and size. A building's Energy Star score is determined when it is set up in Energy Star Portfolio Manager (ESPM), a free online tool developed by the US Environmental Protection Agency (EPA) used for energy benchmarking and performance evaluation in commercial buildings. ESPM is the standard benchmarking tool used across North America, and is administered in Canada by Natural Resources Canada (NRCan).

- **Peak Electrical Demand:** The maximum amount of electricity consumed by a building within a specified period of time, typically 15 minutes. Understanding existing peak demand is critical for LCE planning – see Chapter 0 for more details.

Many certification programs and standards require a building's energy use and emissions to be reported to either internal or external stakeholders. Some of these standards are discussed in Section 3.4.2.

3.3. IDENTIFY OPPORTUNITIES

Once a building's current energy consumption has been measured, the next step toward LCE is to identify emission reduction opportunities. Identifying opportunities comes before target setting because understanding what is possible can inform the development of meaningful and relevant emission reduction targets. However, as discussed below, it is important to have a high-level understanding of project goals before looking at opportunities as they may influence the types of LCE measures considered.

Carbon reduction opportunities can be identified using the following:

- **Reviewing Capital Upgrade Cycles**: LCE is most cost-effective when a system is near the end of its service life. Identifying and planning for these opportunities in advance can ensure swift implementation during equipment failure or replacement cycles, pre-empting like-for-like replacements that can hinder progress toward emission reduction goals.

- **Energy Studies**: Key considerations for energy studies are outlined in Section 0.

- **Discussions with Operations**: Building operators often have the best understanding of a building's systems and can help identify areas that require improvement or equipment that needs to be replaced.

- **High-Level Building (Portfolio) Assessment:** Evaluating heat sources and sinks, renewable energy potential, and system operating temperatures can help identify potential measures for further refinement through energy studies. Include discussions with building operators in this type of assessment, as they will have the best understanding of building systems and operations.

- **Incentive Program Review:** Incentive programs for studies or equipment replacements can guide the identification of carbon reduction opportunities. There are several programs and incentives available in BC to support energy, decarbonization, electrification studies, and project implementation. Due to the dynamic nature of these programs and incentive structures, they are not listed in this Guide. Consultants should be able to assist building owners in leveraging incentives from relevant programs to optimize project support.

3.3.1. Energy Studies

An energy study aims to understand how a building currently uses energy and identify opportunities for improvement. To maximize the utility of the energy study, consider the following:

- **Goals:** While specific targets have not yet been set, it is important to have a high-level understanding of project goals before undertaking a study as they may influence the types of LCE measures that should be considered. Goals could include meeting regulation requirements, achieving net zero emissions, or reducing energy consumption to save costs.
- **Use Case:** Having a clear use case for the energy study can help ensure its scope, depth, and outcomes are appropriately calibrated and aligned. For instance, if the study is intended to inform long-term planning, detailed cost estimates may be unnecessary, as they are all but certain to be out of date before identified measures are implemented.
- **Feasibility:** Assessing the feasibility of proposed measures is essential to ensure practicality and avoid additional costs and delays. Key considerations include:
  - **Placement of equipment**, whether in mechanical rooms, parkades, or on rooftops.
  - **Logistics**, considering how new equipment will be transported and whether it will fit through available openings or require special handling.
  - **Connections**, including planning for ducting and piping tie-ins, along with potential isolation requirements and integration with existing infrastructure.
- **Operability:** Integrate operational considerations into the study or evaluation phase to avoid overly complex designs that can be difficult to maintain. Simplifying designs and equipment where possible can help operators effectively manage and maintain systems to achieve performance goals. Early input from operators during analysis and design stages can enhance the likelihood of successful long-term operation.
- **Risks and Uncertainties:** Identifying risks and uncertainties in an energy study can support future planning – especially in high-level studies, which may lack detailed feasibility information. This is particularly relevant for LCE projects, which tend to involve higher risks and greater complexities than standard low-cost efficiency measures. Considerations may include:
  - Electrical panel or main service upgrades
  - Building permit requirements
  - Structural upgrades

3.4. SET TARGETS

As addressed in Section 2.1, carbon reduction targets can originate from internal corporate mandates, stakeholder pressure, or external policies and regulations such as municipal or regional building performance standards. Whatever their source or impetus, establish and refer to both short-term and long-term targets throughout the electrification journey: commissioning energy studies or implementing LCE measures without first having clear targets can lead to increased study and project costs, delays, missed opportunities, measure misalignment, and equipment lock-in.

3.4.1. Emissions Scope

Define the boundary or scope of emissions to be considered before setting a target for emissions reductions. Most organizations focus on carbon emissions originating from within their operational boundary (Scope 1 and 2), but Scope 3 emissions are increasingly being considered by organizations and standards. Possible scopes include:

- **Scope 1:** Direct emissions from company-owned sources and equipment such as those generated on-site through the combustion of fossil fuels.
- **Scope 2:** Indirect emissions from purchased energy such as those generated by the production of electricity or district energy.
- **Scope 3:** Indirect emissions that occur upstream or downstream of the value chain, from activities such as transportation, shipping products or raw materials, or waste disposal. Embodied carbon would be considered a Scope 3 emission, but it is typically tracked independently.

3.4.2. Existing Standards and Frameworks

A good place to start when setting internal carbon reduction goals is to research and reference existing programs and standards. These will generally have clear goals, along with resources to provide rationale, guidance, and support. There are many programs and standards available, often tied to particular sectors or regions. They may include networks to facilitate sharing and support, have specific performance and reporting requirements, or provide tools and resources to help organizations set their own targets. Some examples include:

- **The Corporate Net-Zero Standard** (SBTi, 2024)**:** Established by the Science Based Targets Initiative, a corporate climate action organization, this standard seeks to provide a common, robust, science-based understanding of net-zero. The standard provides both a cross-sector target-setting methodology and sector-specific guidance to enable companies to develop ambitious and achievable science-based targets aligned with limiting global warming to 1.5°C above pre-industrial levels
- **Zero Carbon Building – Performance Standard** (CAGBC, 2022)**:** Established by the Canada Green Building Council (CAGBC), this performance certification standard for existing buildings considers both operational (Scope 1 and 2 emissions) and embodied (Scope 3 emissions) GHG emissions.
- **Greenhouse Gas Protocol:** An international framework developed by the World Resources Institute (WRI) to measure and manage GHG emissions for both private and public sector operations, value chains, and mitigation actions: https://ghgprotocol.org/

In addition to industry programs and networks, municipal, provincial, and federal policies can provide valuable references for setting internal carbon reduction targets. As various levels of government shift from recommendations to regulations, ensuring that internal targets align with jurisdictional ones can help building owners plan for compliance and avoid penalties.

3.5. EVALUATE

Once LCE opportunities have been identified, a comprehensive evaluation of the options is required to select the most suitable option for implementation. This section outlines the evaluation process, including key considerations, useful metrics, and common challenges.

Note: before proceeding to evaluation, consultants should ensure the identified LCE measures align with the holistic decarbonization principles outlined in Chapter 4. A narrowly focused or piecemeal electrification project that simply replaces gas equipment with like-sized electrical equipment is unlikely to yield a strong business case.

3.5.1. Life Cycle Cost Analysis

While traditional analysis relying on metrics like simple payback can suffice for assessing basic energy efficiency measures, evaluating more complex, ambitious, and impactful LCE measures requires a more comprehensive analysis to reach informed decisions that balance environmental and financial objectives. Life cycle cost analysis (LCCA) is an economic evaluation methodology that integrates both short-term and long-term financial and environmental considerations to provide a holistic evaluation of LCE opportunities.

When conducting an LCCA to assess the financial viability of LCE measures, consider the following key factors:

- **Avoided Cost of Carbon:** The avoided cost of carbon seeks to quantify the financial benefits derived from reducing or eliminating carbon emissions. While accurate costs can be hard to forecast due to evolving regulatory standards and pricing schemes, considering future carbon pricing is critical to developing a comprehensive LCCA that can be used to guide decision-making. Some options for including the avoided cost of carbon into an LCCA are government carbon tax commitments or internal/shadow carbon prices, explored below.

- **Carbon Tax**: Carbon taxes are designed to account for the anticipated social costs of climate change due to increased carbon emissions, including health issues, such as respiratory problems and increased hospitalization; infrastructure damage, such as from forest fires; and ecological disruptions, such as climate refugees. Carbon taxes aim to mitigate these costs by incentivizing LCE investments.

- **Internal/Shadow Carbon Price:** The shadow carbon price can either supplement or replace the federal carbon tax when assessing carbon reduction. Unlike mandated taxes, shadow carbon prices are voluntarily adopted to align with internal sustainability goals. Shadow carbon prices are typically higher than government rates, accounting for transition risks like regulatory changes, market shifts, and investor pressures, as well as prioritizing the social costs of climate change. Once chosen, a shadow carbon price is applied organization-wide to prioritize financially viable carbon reduction measures, allowing selection of the most attractive LCE opportunities.

- **Asset Value:** The carbon intensity of a building can affect its asset value in several ways, including market appeal to occupants and investors, operating and maintenance costs, and compliance – or lack thereof – with environmental policies and regulations. While the effects of LCE retrofits on building asset value can be challenging to estimate accurately, it may be worth considering when evaluating the business case for LCE. More information on the effects of decarbonization on asset value can be found in the BOMA BC Decarbonization Planning Guide for Commercial Buildings.

- **Asset Renewal Cycles:** The most cost-effective time to electrify a piece of equipment is at the end of its service life when it needs to be replaced. For LCE projects that align with end-of-life, the incremental cost of electrification, rather than the total project cost, should be considered in the financial analysis of the LCCA. For equipment not at its end of life, an adjusted incremental cost can be employed, based on the remaining useful life of the original equipment and the future projected costs associated with upkeep and repair.

  - **Incremental cost:** The additional cost incurred by implementing a specific project or initiative compared to the cost of the reference scenario (i.e. the base case cost).

  - **Base case cost:** The cost associated with maintaining the current status or undertaking a business-as-usual approach without any upgrades or improvements.

  - **Total cost:** The overall expense required for capital planning.

- **Incentives and Grants:** Including incentives and grants in the life cycle cost analysis can provide a more accurate and attractive business case for LCE. Explore incentives through FortisBC, BC Hydro, NRCan, and others to determine accurate capital costs. By staying informed about current incentive opportunities, businesses can maximize their potential savings and improve the overall feasibility of LCE projects.

- **Utility Escalation Rate:** The utility escalation rate refers to expected or projected increases in energy costs over time, typically influenced by factors like inflation, demand, and regulatory changes.

- **Discount Rate:** Exploring and integrating low-interest financing opportunities for retrofits into the LCCA can have a significant impact on the attractiveness of LCE measures. The loan interest rate is incorporated into the LCCA via the discount rate: lower discount rates tend to favour high-capital-cost, low-operating-cost measures like heat pumps, while higher discount rates favour low-capital-cost, high-operating-cost options like electrical boilers. Carefully consider the discount rate, as it can significantly influence project viability and attractiveness.

- **Maintenance Costs/Savings:** System maintenance costs can change dramatically following a LCE retrofit. Changes can range from decreases stemming from the replacement of aging equipment with newer, more efficient options; to increases resulting from the introduction of more complex equipment. Considering these shifts and including them in the LCCA can ensure a more comprehensive evaluation.

3.5.1.1. Identifying Uncertainties Through Sensitivity Analysis

While incorporating factors like the utility escalation rate and a carbon price is important for holistic financial analysis, estimating them accurately can be difficult. Conducting a sensitivity analysis as part of an LCCA can explore how uncertainties can impact project outcomes, informing decision-making and risk management. To perform a sensitivity analysis, adjust input variables within plausible ranges and observe their effects on the results to identify influential factors and potential uncertainties.

3.5.1.2. NPV/Tonne: A Carbon-Reduction Efficiency Metric

Once the financial analysis is complete, the financial costs and performance of LCE measures and opportunities can be compared to determine the most financially attractive options. While metrics like net present value (NPV) and internal rate of return (IRR) are effective for such comparisons, NPV/tonne of GHG emissions reduced, a carbon-reduction efficiency metric that evaluates the financial costs or savings relative to GHG reduction, is particularly effective for assessing LCE opportunities, and allows standardized comparisons across opportunities regardless of scale.

Additionally, when comparing measures with the same life span, the metric is independent of the carbon price used in the analysis. NPV/tonne can thereby simplify the evaluation of different LCE options, allowing decision-makers to focus solely on the relative financial costs and benefits per tonne of GHG reduced, without the added uncertainty of carbon pricing projections.

3.5.2. The Evaluation Process

Once an LCCA has been completed for all measures, the calculated financial metrics can guide the comparison and selection of the most attractive LCE measures for implementation. However, a comprehensive comparison of LCE opportunities extends beyond financial considerations alone. To ensure a holistic analysis, consider the following:

- **Owner Priorities:** Consider owner priorities during the evaluation process, such as minimizing tenant disruption or improving comfort, to identify alignments or mitigate potential conflicts.
- **Aligned Non-Financial/Energy Benefits:** These may include enhanced occupant comfort, replacement of aging equipment, improved resiliency with hybrid systems, and attracting or retaining tenants with shared values.
- **Climate Resilience:** This may include the addition of cooling or air filtration to mitigate the impacts of overheating and wildfire smoke events.
- **Risk and Uncertainty:** Depending on the extent of analysis conducted, there may be notable residual risk linked to design costs or system feasibility. Projects exhibiting higher levels of risk or uncertainty may be deprioritized or scrutinized further in the evaluation process.
- **Avoided Future Carbon Risk:** Potential costs related to carbon risk may include stranded assets, reduced asset values, or environmental risks like floods or wildfires. While partially addressed in LCCA, defining this quantitatively can be challenging, so qualitative assessment may also be beneficial in measure evaluation.

3.5.3. Evaluation Challenges

Effectively evaluating LCE measures can help organizations transition to more sustainable practices while optimizing financial outcomes. However, this process presents numerous challenges due to the complexity of the metrics involved, uncertainties regarding future conditions, and trade-offs between objectives. This section explores the major challenges encountered when evaluating LCE measures. By understanding and addressing these challenges, organizations can make informed decisions that promote both environmental and financial sustainability.

3.5.3.1. Uncertainty Regarding Future Conditions

Predicting future energy prices, carbon regulations, technological advancements, and climate-related risks introduces uncertainty into evaluations, affecting long-term projections. Using a sensitivity analysis, as discussed in Section 3.5.1.1, can help ensure the measures selected are optimal under a range of conditions.

3.5.3.2. Measure Costing

Accurately estimating the cost of LCE measures can be challenging due to dynamic equipment costs, inflation, and uncertainties during the design stage of LCE projects. The following strategies can help mitigate these risks:

- **Create Contingencies:** Incorporate substantial contingencies during the preliminary study and design phases.
- **Seek Guidance:** Seek input from diverse engineering disciplines or conduct peer reviews when necessary.
- **Design with Data:** Install metering or trending systems early in the project to collect data to more accurately estimate building loads and size equipment.

3.6. PRIORITIZE

Once the optimal LCE measures have been chosen for implementation using the considerations outlined above, they can be prioritized for implementation. Consider the following when determining the sequence of implementation:

- **Equipment Replacement Cycles:** Prioritize retrofitting failing pieces of equipment or those nearing end-of-life to avoid unplanned or emergency replacements; ideally, an electrical alternative will have been identified through an energy study before failure occurs.
- **Aligned Non-energy Opportunities:** In cases where significant upgrades or renovations are planned, it may be advantageous to implement LCE retrofits simultaneously to minimize occupant disruption and overall costs. This alignment can capitalize on existing resources and planned activities, improving the efficiency and effectiveness of implementation.
- **A Holistic Approach:** Chapter 4 outlines the principles of effective decarbonization which can enable the effective and efficient low-carbon electrification of existing buildings.

3.7. OBTAIN FUNDING

Project funding is a key feasibility consideration for an LCE project, on par with technical, logistical, and practical considerations. Building owners are accustomed to investing in the health and performance of their buildings; however, as discussed in Section 3.5, LCE retrofits don't always lend themselves to simple payback analysis. Just as more comprehensive metrics can help illustrate the full spectrum of project benefits, so too can emerging financing models enable projects that might not otherwise be considered financially viable.

3.7.1. Energy Service Contracts

Energy Service Contracts can enable building owners to implement LCE projects without assuming the upfront cost of the investment. Two popular models are described below; for more information about these models and the key differences between them, refer to the US Department of Energy's fact sheet on Controls Strategies to Reduce the Energy Consumption of Central Domestic Hot Water Systems (US DoE, 2016).

3.7.1.1. Energy as a Service

Through the energy-as-a-service (EaaS) model, building owners can rent or lease heating or cooling equipment from a service provider rather than owning, operating, and maintaining the equipment themselves. Under an EaaS arrangement, the building owner pays for the heating and/or cooling at a fixed rate via a service contract, with the service provider guaranteeing system performance and taking on associated responsibilities and risks.

3.7.1.2. Energy Performance Contracting

Building owners can enter into an energy performance contract (EPC) with an energy service company (ESCO) to implement an LCE retrofit without having to finance it themselves. Under an EPC, the ESCO designs, implements, and finances the retrofit, and is remunerated via the energy savings over the contract period. While EPCs have traditionally been better suited to energy efficiency projects than LCE retrofits, new business models are emerging that are improving alignment, such as the super ESCO, an energy service company with access to purpose-driven, low-interest investment financing.

3.7.2. Green Financing

Purpose-driven financial institutions can offer low- or no-interest green financing opportunities for projects with environmental benefits. In 2022, the Canada Infrastructure Bank established the Building Retrofit Initiative, capitalized with $2B in Federal Government investment. The initiative provides loans at below market rates directly to private and public building owners to finance large – $25M and up – projects that achieve a minimum 30% GHG emissions reduction. It also provides low-interest loans to aggregators – ESCOs, special purpose vehicles, and even commercial banks – that can bring multiple individual projects together into an investment portfolio, thereby providing smaller building owners with access to attractive, purpose-driven financing opportunities.

3.8. IMPLEMENT

The implementation phase of a project covers everything from design to project handoff. Chapter 6 provides a detailed overview of the project implementation process for LCE retrofits and key considerations.

3.8.1. Project Phasing

A phased approach to building electrification offers the best strategy for maximizing LCE opportunities while minimizing the likelihood of triggering electrical capacity or service upgrades. This approach involves determining a building's spare electrical capacity; identifying LCE projects that can be implemented without exceeding that capacity; implementing those projects, along with real-time metering allows the building's post-retrofit electrical capacity to be monitored; and then repeating the process for subsequent rounds of LCE projects using load management systems. Engineering calculations will always be conservative, so there is virtually always more spare capacity using electrical load management after the first round of implementation for a second set of LCE projects.

A phased approach to project implementation offers several additional advantages, including:

- **Simplified Commissioning and Troubleshooting**: Commissioning one system at a time makes the process more manageable, allowing issues to be more easily identified and resolved.
- **Learning and Improvement:** Each phase provides an opportunity to learn from the previous one, enabling adjustments and improvements to be made for subsequent phases based on experience gained and lessons learned.
- **Right-sized Equipment:** Sizing equipment for subsequent phases based on the calculation of reduced load after each phase allows for more accurate determination of equipment needs. This often results in the selection of smaller, less expensive equipment, improving cost-effectiveness.

3.9. MEASURE AND VERIFY

Measurement and verification (M&V) involves assessing the actual performance of, and the energy savings and emissions reductions achieved by, implemented LCE measures. This step is key to ensuring that projects meet their energy efficiency and emission reduction goals, and is covered in detail in Chapter 6.

4. Decarbonization Principles

Many concerns and barriers related to building electrification are rooted in experiences from early efforts to decarbonize buildings that led to expensive projects, increased operational costs, poor system performance, and other less-than-ideal outcomes.

The decarbonization principles outlined below can help mitigate these concerns, if not address them altogether. These principles are part of a holistic approach to electrification that considers all building systems, as opposed to a narrow or piecemeal approach focussed solely on equipment replacements and GHG emissions reductions.

The principles of effective decarbonization include:

- **Start with Load Reduction:** This is the foundation of effective electrification. Implementing load reduction measures early minimizes energy use, reduces waste, improves building efficiency, and optimizes controls systems. This step prepares the building for advanced LCE technologies and allows for the installation of smaller, less expensive equipment, ultimately reducing overall project costs.
    - **Reduce Heating Water Temperatures:** For buildings with hydronic systems, this is a crucial but often overlooked load reduction measure. If the building's hydronic systems require temperatures higher than what standard heat pumps can provide, modifications should be considered to allow for compatibility with low-carbon heating equipment.
- **Heating and Cooling are Two Sides of the Same Coin:** to heat something is to cool something else; efficient and resource-responsible electrification of the built environment requires a unification of heating and cooling systems in order to achieve efficient thermal energy management. Look for opportunities to reuse thermal energy within buildings through passive and active heat recovery and storage, adding or removing heat only as needed to balance the system.
- **When it comes to Design, Evaluate the Most Efficient Electric Technologies First:** Take a sequential approach when considering LCE technologies, starting with the most efficient technologies:
    1. Heat recovery systems (e.g. heat recovery chillers)
    2. Heat pumps
    3. Electric resistance systems
- **Invest in Renewables and Offsets Last:** Renewable energy generated on-site typically comes at a significant cost premium. And carbon offset markets work on the premise of capitalizing projects that will one day reduce or absorb GHGs being emitted today. Neither is a particularly effective means – in terms of cost or impact – of decarbonization; limit both to “yes-and” scenarios, such as addressing residual emissions associated with electricity use, supplemental heating, or embodied carbon emissions from building retrofits that cannot feasibly be eliminated.

Applied in concert – and in the correct order -- these principles can enable the effective and efficient low-carbon electrification of existing buildings.

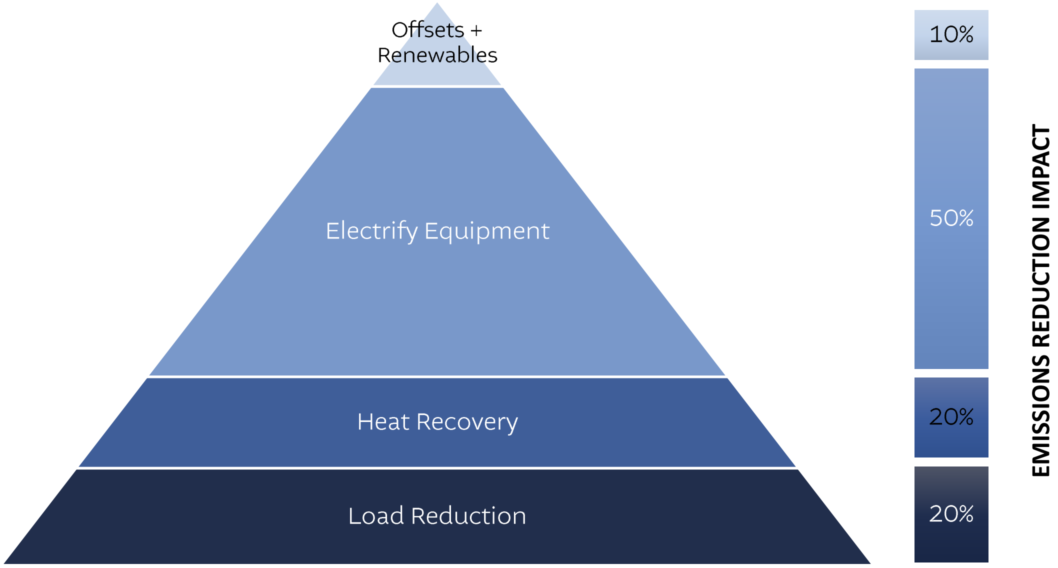


FIGURE 2: THE FOUNDATIONS OF LOW-CARBON ELECTRIFICATION

Applying the principles of effective decarbonization can help building owners and consultants reduce building electrification costs; maximize energy savings and operational resilience; and avoid the pitfalls of isolated upgrades, which can lead to higher costs and suboptimal energy performance.

TABLE 2: EFFECTIVE VS. PIECEMEAL ELECTRIFICATION

EFFECTIVE ELECTRIFICATION	PIECEMEAL ELECTRIFICATION
Increases efficiency, reduces overall energy use and waste.	Focusses only on reducing GHG emissions without addressing total energy use.
Right-sizes equipment based on building performance data.	Replaces existing equipment with like-sized electrical versions.
Involves a holistic analysis across multiple building systems.	Focuses narrowly on electrifying gas-fired equipment.
Can lead to an expensive project, but presents the most attractive business case.	Results in high capital and operational costs and is unlikely to yield a viable business case.

Part 3: Implementation

The third part of the Guide outlines the process for implementing low-carbon electrification retrofit projects in existing buildings, including:

- **Chapter 5: Prime Consultant Role in Retrofit Projects**
- **Chapter 6: Implementation Considerations**

Its content will be particularly relevant to the following building and project stakeholders:

RELEVANT TO:	
	Building Owner
☑	Owner Advisor / Energy Manager
☑	Prime Consultant
☑	Designer

5. Prime Consultant Role in Retrofit Projects

This chapter outlines the role and responsibility of the prime consultant on LCE projects. On new construction or traditional renovation projects, engineering consultants traditionally work as sub-consultants under the direction of an architect. When it comes to LCE retrofits, in many cases the lead engineering consultant – typically the mechanical engineer – takes on the role of prime consultant.

The prime consultant's role on LCE retrofit projects starts before design, and they are involved well after construction is complete. In addition to their technical role, the engineer is placed at the heart of project coordination, acting as a critical link between project stakeholders, including owners, contractors, inspectors, and sub-consultants, with the primary focus of achieving the owner's broader goals within set timelines and budgets.

An overview of the scope of responsibilities of the prime consultant is provided in Table 3.

TABLE 3: RESPONSIBILITIES OF THE PRIME CONSULTANT

PRIME CONSULTANT RESPONSIBILITY	DETAILS
Project Management	• Ensure that the client's vision and goals are understood by all team members • Act as the main point of contact for all stakeholders to obtain feedback, address concerns, and resolve conflicts. • Manage project scope, schedule, budget and risks and provide regular progress updates to clients. • Negotiate and manage contracts with sub-consultants. • Obtain permits and approvals from regulatory authorities.
Technical Oversight	• Determine which registered professionals are required given the project scope, and where sub-consultants will be necessary to fulfill these requirements. • Oversee the design process to ensure that all aspects of the project meet the required standards and regulations, and client specifications. • Coordinate with regulatory authorities to ensure that the project complies with relevant codes and that all inspections, schedules, and letters of assurance are completed.

Quality Assurance	• Coordinate the work of all consultants and contractors to ensure designs and plans from different disciplines are integrated and compatible. • Implement quality control measures to ensure work performed by all parties meets the project's quality standards. • Manage all project documentation, including design documents, contracts, and communication records, and ensure that information is accurate and accessible.

For more details on the role of the prime consultant, and their relationship with the building owner, refer to the following standard contract documents:

- ACEC Contracts: https://www.acec.ca/Publications/acec_contracts.html
- CCDC Standard Contracts: https://www.ccdc.org/document/ccdc31/
- AIBC Board-Approved Contracts: https://aibc.ca/programs-services/contracts/

6. Implementation Considerations

The implementation process for an LCE retrofit typically follows the sequence of steps below:

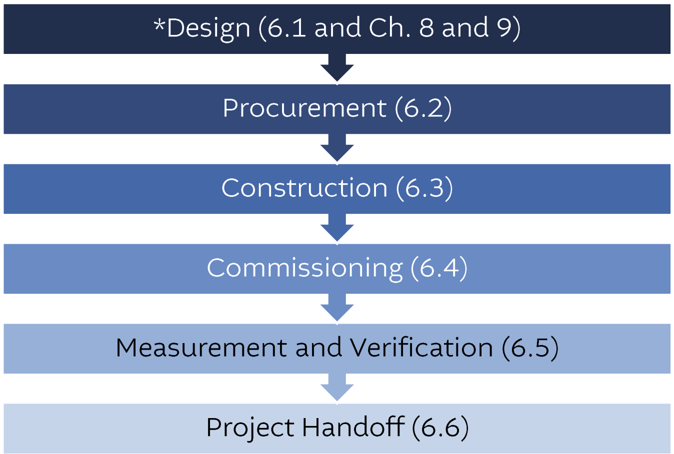


FIGURE 3: THE IMPLEMENTATION PROCESS

This chapter will discuss considerations that are specific to the low-carbon electrification (LCE) implementation process. The chapter has a particular focus on using the integrated project delivery (IPD) method defined below, rather than a traditional project delivery method, as IPD is particularly well suited to implementing LCE projects. More details on the implementation process and considerations for specific pieces of equipment and systems can be found in the technical sections.

***Design** is addressed in greater detail in Part 4: Design

6.1. DESIGN

The design phase involves developing a detailed vision for the LCE project, and specifying the materials, products, and systems. The design phase will include thoroughly evaluating the existing system, selecting new equipment, ensuring system compatibility and regulatory compliance, as well as developing detailed plans for the new systems.

This section covers design considerations relevant to the implementation of a retrofit project. While these considerations are relevant to all retrofits, they are particularly important for LCE retrofits.

6.1.1. Integrated Project Delivery

Traditional project delivery typically uses a design-bid-build approach: the building owner hires a consultant to design the retrofit, and then issues a tender for construction; contractors bid on the project, and the winning firm is hired to construct it. This approach effectively isolates the building owner and operator, the design team, and the construction team from one another, preventing collaboration. While suitable for simple energy efficiency projects or equipment replacements, this traditional method of project delivery does little to facilitate the interdisciplinary collaboration necessary for successful outcomes in large-scale LCE projects, which often involve complex upgrades across multiple building systems.

In contrast, IPD is a nimble, collaborative, and holistic approach to project implementation, commonly applied in new construction projects. In IPD, the building owner selects a combined design-build team based on factors like relationship, qualifications, and their proposed approach to the project. The design-build team then collaborates closely with the owner and key stakeholders through an integrated design process to develop the project scope and design.

IPD unites stakeholders from various disciplines, such as architects, engineers, contractors, equipment suppliers, and owners, into a unified team, engaging them early and throughout the implementation of the project. All members of the project team share the risk and reward, are paid for their time spent, and agree to indemnify each other against loss. This fosters collaboration, enhances efficiency, and increases the likelihood of success. This integrated approach is especially effective at addressing the needs of complex, large-scale LCE initiatives. The key differences between IPD and traditional project delivery are outlined in Figure 4.

TRADITIONAL PROJECT DELIVERY	INTEGRATED PROJECT DELIVERY
To Each Their Own: Partners are often selected based on lowest-bid criteria. Individual parties operate under standalone conditions of satisfaction.	**Your Success is Team Success:** Team members are selected based on a holistic assessment of their qualifications. A common definition of success drives the way forward.
Individual Risks/Rewards: Costs and profits are negotiated by each independent entity, which incentivizes self-protection.	**Share Risks/Rewards:** Costs and profits are pooled. Individual performances impact the collective bottom line.
Sequential Implementation of Work: Standalone groups pursue their tasks independently, then “relay” responsibility on to the next group.	**Simultaneous Implementation of Work:** As much as possible, the unified team completes their tasks in parallel and overlapping workstreams, holding regular milestone check-in meetings and engaging in mutual problem-solving.

FIGURE 4: KEY DIFFERENCES BETWEEN TRADITIONAL AND INTEGRATED PROJECT DELIVERY

A key and oft-cited benefit of the traditional approach to project delivery is cost transparency and certainty: contractors submit competitive bids to construct a project, and the winning bid becomes the contract amount. In contrast, under the IPD approach to project implementation, project costs are not known upfront, but are instead determined during the schematic design phase, which typically employs an integrated design process. Integrated design involves collaborative, multidisciplinary input from the entire project team to optimize design, ensure constructability, and increase cost accuracy. Once costs are established, the IPD team commits to maintaining them, barring unforeseen challenges: IPD contracts involve shared savings and loss provisions, so all parties are incentivized to minimize the final cost of the project.

For more information about IPD, refer to the following resources:

- CCDC 30 – 2018 Integrated Project Delivery Contract: https://www.ccdc.org/document/ccdc30/

- BC Housing's Strategies for Collaborative Construction - Integrated Project Delivery Case Studies (BC Housing, 2019).

6.1.1.1. IPD Informed Design

Despite the benefits of IPD, traditional project delivery approaches remain the norm in the retrofit sector due to organizational conventions and public procurement requirements. However, collaboration and innovation can be enhanced in traditionally-procured projects by incorporating elements of IPD such as:

- **Design Charrettes:** Assemble a broad group of subject matter experts for collaborative brainstorming sessions during the design phase to foster innovative solutions and comprehensive project designs.
- **A Collaborative Atmosphere:** Establish a team culture that encourages open communication and cooperation among all project members.
- **Early Contractor and Supplier Engagement**: Involve contractors and equipment suppliers early in the process to provide input on costs, design, and installation in order to generate practical and cost-effective solutions. This can be managed on a time and material (T&M) basis, but be aware that some procurement policies may preclude these contractors from subsequently submitting proposals in a tender or RFP process.
- **Inclusion of Building Operators and Mechanical/Controls Contractors:** Engage building operators and base building mechanical/controls contractors in the design phase to ensure the design is practical and maintainable. However, be mindful that in certain procurement structures, early involvement of contractors can disqualify them from bidding on the project.

6.1.2. Selecting the Right Team

The design phase is typically the phase where the project team is formed. A well-rounded project team brings the necessary technical expertise, can manage budgets and timelines effectively, fosters stakeholder collaboration, mitigates risks, upholds quality standards, embraces innovation, and prioritizes building owner satisfaction.

Engaging key members early in the process is essential for gaining buy-in and setting a strong foundation for success. Establishing clear communication and fostering collaboration from the outset can significantly improve project outcomes by aligning priorities, reducing resistance to change, and ensuring that everyone is working toward the same goals.

Depending on project complexity and scope, the team may include the members outlined in Figure 5.

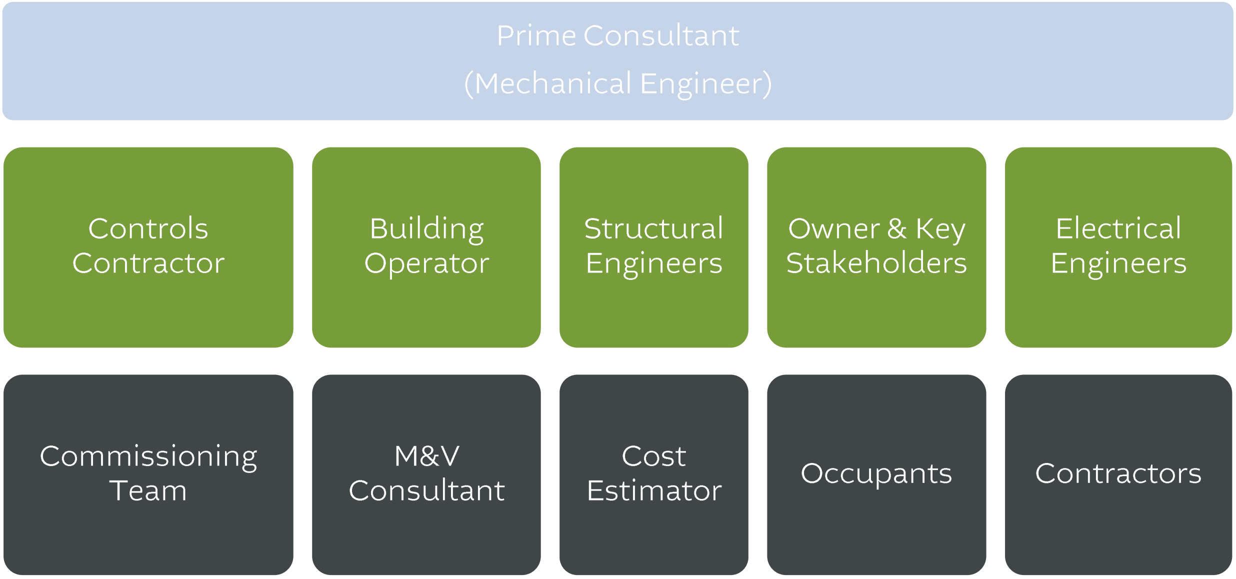


FIGURE 5: POTENTIAL MEMBERS OF THE PROJECT TEAM

Common team member roles and rationales for including them are described in Table 4.

TABLE 4: COMMON TEAM MEMBER ROLES AND RATIONALE FOR INCLUSION

TEAM MEMBER	ROLES + RATIONALE
Mechanical Engineer / Prime Consultant	On LCE projects, the mechanical engineer often takes on the role of prime consultant. For more information about what this role entails see Chapter 5.
Building Operators	Operator engagement, support, and training are key to the success of LCE retrofit projects. Operators often know their buildings and existing systems intimately – including their faults. Involving them early can help identify issues and important considerations, helping to develop optimized solutions that enhance energy savings and occupant comfort. Additionally, engaging operators early can help to ensure they understand the new system and won't just override new equipment or systems when challenges arise.
Owner + Key Stakeholders	Early and consistent engagement of owners and key stakeholders throughout the project significantly enhances the likelihood that the project will align with their requirements and expectations.
Controls Contractor	Engage the building controls contractor in the design process to determine how the new systems will be integrated into the existing building automation (BAS) or direct digital controls (DDC) system.
Structural/ Electrical Engineers	Where electrical or structural limitations could affect the feasibility or costs of a project, it is important to engage these specialties early in the process so their input can be included in the study or planning phase. More information about

	when and why to include structural and electrical engineers in LCE projects can be found in Chapters 0 and 11.
Occupants (Stakeholders)	Unlike energy efficiency projects, which often target specific systems or areas of a building, LCE retrofits can impact all systems in a building, and the disruptions and operational changes they can entail for occupants can be significant. Proactive and frequent engagement with occupants during LCE projects can ensure their concerns are predicted, noticed, and addressed effectively, thereby helping to mitigate their impact.
Commissioning Team	Defining and engaging members of the commissioning team early in the project ensures that equipment or sensors required for the commissioning process can be included in the design documents for construction. For more information about commissioning see Section 6.4.
Cost Estimator	A quantity surveyor or cost consultant is helpful when accurate costing (Class C or better) is required during the pre-design and design phases of a project. However, quantity surveyors are used more often in new construction, and their approach may not be able to account for site unknowns that are common in retrofit work. Where possible, consider using budget estimates provided by an experienced contractor in place of quantity surveyor estimates.
Measurement and Verification (M&V) Consultant	M&V providers are often engaged on retrofit projects where a rigorous post-installation validation of system performance is required by owners, incentive providers, or other stakeholders. For small or straightforward projects, a dedicated M&V consultant may not be necessary, and any required M&V activities could be performed by a qualified Cx team member. However, when needed, M&V Consultants should be engaged early in the project so that meters or sensors required to perform M&V can be included in the design documents to save additional costs and time later. This role can be served by the prime consultant, but may also be performed by an independent mechanical consultant or an energy analyst. See Section 6.5 for more information on M&V.
Contractor	Having a contractor on board early to provide input on constructability, costing, and logistics can reduce construction costs and improve the design. If the project is not using IPD, a fee-based arrangement could be pursued to solicit contractor advice during the design phase. However, exercise caution, as early involvement may disqualify the contractor from bidding later or affect the competitiveness of the procurement, depending on the procurement policies being followed.

6.1.3. Equipment Selection

During design, several logistical considerations should be factored in when selecting equipment to avoid unexpected complications, costs, or delays later in the project.

6.1.3.1. Physical Space Constraints

FIGURE 6: MOVING EQUIPMENT IN CONSTRAINED SPACES

Existing buildings may have limited space available for installing new mechanical equipment or upgrading existing systems. When designing retrofits, consider space constraints and required equipment clearances to determine whether solutions such as compact equipment or reconfiguration of existing spaces are required.

Beyond installation considerations, effective planning and design also consider pathways for moving new equipment to installation locations. Modular equipment may be able to be transported to a rooftop location via a freight elevator, while larger pieces of equipment may need to be lifted by crane or helicopter, potentially adding significant cost and complexity to a project. A site visit can help determine whether a building’s corridors and doorways are wide enough to accommodate the passage of planned new equipment. Where clearances are tight, as illustrated in Figure 6, consultation with contractors and equipment suppliers can help verify exact equipment dimensions and identify a viable pathway. It can also help to consider whether equipment can be partially disassembled, or doorways widened. Identifying these constraints in the design documents can help to avoid additional, unanticipated costs during the construction process.

Space constraints on a project can also impact large pieces of equipment required to complete work, such as drilling rigs required to core routes for new piping or cabling. Consulting with experienced subtrades can help ensure that work can be carried out as planned.

6.1.3.2. Structural Constraints

Equipment associated with LCE systems can be larger and heavier than existing equipment. This can cause issues for a building if the existing structure is not designed to accommodate additional loads. Structural upgrades to a building can be costly, often more than the replacement mechanical equipment, particularly if the upgrade is not planned carefully.

Structural considerations pertinent to LCE retrofits are addressed in detail in Chapter 11.

6.1.3.3. Delivery and Lead Times

Coordinating the delivery and installation of new equipment can be challenging. Since the Covid-19 global pandemic, lead times have increased, and parts shortages have become more common. Checking in with suppliers on lead times for major pieces of equipment early in the design process, especially for pieces of equipment that are not easy to substitute, can help to identify if not avoid long delays. Similar equipment from different manufacturers may have significantly different lead times which may, in turn, play a role in equipment selections.

If major pieces of equipment required for a project have different lead times, it may be necessary for the building owner or contractor to coordinate space and security for storage, either on- or off-site, until all equipment is available. This is particularly true in the case of equipment that may require a crane lift in order to avoid the need for multiple lifts.

The required timing of work, such as the installation of electric heating equipment outside of the heating season, can require creative purchasing solutions – such as having the owner order equipment directly before the completion of tender and the award of the installation contract. Pursue these types of alternative procurement arrangements carefully, as they can resolve immediate issues but can also, in turn, introduce additional complexities that require consideration. In the above example, discussion with manufacturers and prospective contractors is advised to ensure that equipment warranties would still be honoured.

6.1.3.4. Temporary Equipment

Buildings are often occupied during LCE retrofits. Project construction may require temporary shutdowns of certain systems, which can impact occupant comfort and productivity.

Careful planning, scheduling, and communication with building occupants are essential to minimize the impact of disruptions. Additionally, temporary utilities such as heating, cooling, and power may be necessary to maintain occupant comfort and support construction activities. Planning for and installing these temporary utilities requires coordination with contractors and may involve additional costs.

6.1.4. Controls

Effective controls design is key to ensuring LCE systems and equipment are operating efficiently and effectively. The sequence of operations (SOO) included in the design should provide sufficient detail to enable the controls contractor, commissioning team, and building operators to understand how the new equipment and systems are meant to operate, including:

- Details on how system setpoints will be calculated and how the equipment will operate to achieve the setpoints.
- Internal SOO of new equipment as provided by the manufacturer. This is particularly important in the case of heat pump systems that will connect directly to existing building infrastructure. As part of the design process, seek to understand practical equipment limitations and recommended operating envelopes, as these may be different from the absolute limits specified in manuals or submittals.
- Details on how new equipment will interface with the base building automation system (BAS) via BACnet, Modbus, hardwired control points, etc., or whatever standalone controls will be provided. In the controls specifications, clearly indicate where hardwired vs. networked control points are acceptable, according to the operator's preference. Where BACnet or Modbus interfaces are used, indicate in the specifications which available points must be mapped to the BAS. Make the full register of available control points for new equipment available to the commissioning (Cx) team for review.
- Trending requirements, including monitoring and multi-trending, that will be used for performance monitoring and verification.
- Commissioning requirements for new equipment and sequences. Include a Cx plan in the specification package, and clearly communicate commissioning process expectations to the project proponents or bidders. Including the Cx phase in bidding documents as a separate scope with its own price can help ensure that the proponent's level of effort matches the designer's expectations.

In designing the system controls, consider how the system will be maintained and operated by the building operator. Where practical, include operators in the design process to provide their input and feedback on proposed controls. Prioritize simplicity and robustness in controls systems, and beware of sacrificing either in favour of complexity that only offers incremental performance improvements.

6.2. PROCUREMENT

Once the new system has been designed, someone needs to construct it. Finding a contractor with the requisite skills, experience, and approach is key to ensuring that the design is executed correctly and the project achieves its objectives. There are several models of procuring services to construct an LCE retrofit, each of which comes with its own benefits, drawbacks, and considerations, outlined in Table 5.

TABLE 5: PROCUREMENT MODELS AND SUITABILITY

PROCUREMENT MODEL	OVERVIEW AND SUITABILITY CONSIDERATIONS
In-house Implementation	While using internal staff is typically the most cost-effective option for a building owner looking to construct a retrofit, in-house implementation is advisable only if the internal team possesses specific expertise and familiarity with the proposed electrified systems and equipment.
Design-bid-build Contracting	This traditional model involves separate contracts for the design and construction of the retrofit. Compared to design-build contracting, it enables competitive bidding for construction services, and can therefore potentially reduce construction costs; however, having separate design and construction teams can introduce inefficiencies, additional expenses, and delays, and risks introducing tensions between the two teams that can undermine project objectives.
Design-build Contracting	Under a design-build contract, a single firm works with the owner and key stakeholders from project inception to closeout and is responsible for both the design and construction. This model aligns with the IPD approach addressed in Section 6.1.1, with procurement occurring at the outset of implementation.
Progressive Design-build	Progressive design-build (PDB) blends aspects of both IPD and traditional design-bid-build. In PDB, the owner hires a combined design-build team to complete the design of the project collaboratively, like in IPD. At the end of the design process, a target project budget is established, and the owner decides whether to move forward to the next phase with the existing team or take the design to tender.
Energy Performance Contracting	Under this model, the building owner enters into a contract with an energy services company (ESCO). The ESCO handles the design, implementation, and financing of the retrofit, and is remunerated via the energy savings over the contract period. While the model is well suited to energy efficiency projects, energy performance contracting is less well suited to electrification projects, which can increase rather than decrease operational costs.

For more information about the procurement process for LCE projects, refer to the Building Owners and Managers Association of British Columbia's Deep Energy Retrofit Procurement Guide (BOMA, 2022).

6.2.1. IPD Informed Procurement

Even when using traditional procurement models to select contractors, incorporating elements of IPD may still be feasible and beneficial. Examples of such approaches include:

- **Risk Sharing:** Contractors may inflate their bids to account for uncertainties associated with new or complex projects. To address this, define project risks clearly and allocate them appropriately among involved parties. Risks can be shared or mitigated through performance-based contracts to incentivize successful outcomes.

- **Early Contractor Involvement:** Engaging a contractor during the design process, such as through design-assist or as a constructability consultant, can provide valuable insights on matters such as constructability, cost estimates, and feasibility, thereby improving designs and facilitating execution.
- **Objective-Driven Award Criteria:** Establishing award criteria that prioritize experience, expertise, and past performance, rather than simply lowest bid, may increase construction costs but can yield superior outcomes and cost savings throughout the project's lifecycle.

6.3. CONSTRUCTION

The construction phase of an electrification retrofit involves upgrading existing building systems to support new equipment and systems. This phase requires careful integration with existing infrastructure, coordination with trades, compliance with safety standards, and minimizing disruptions to building operations. Quality control, testing, and verification are essential to ensure that all systems perform as expected.

6.3.1. Project Scheduling

Scheduling can be especially complex for LCE retrofits due to the novel and large-scale nature of the work, as well as the uncertainties inherent in upgrading existing buildings. Some key scheduling factors are noted below; considering these early in the construction process can help mitigate challenges and reduce the risk of delays:

- **Equipment Lead Times:** Low-carbon electric equipment may have longer lead times for procurement than more typical gas-fired heating and/or cooling equipment. Early consultation with equipment suppliers can provide lead time estimates that can guide product selection.
- **Specialized Labor Availability:** Finding skilled and experienced labour for electrification projects can be more challenging than for traditional retrofits or system installs. Issuing a request for interest or qualifications to potential contractors early in the design process can help confirm their availability and interest.
- **System Shutdowns**: As electrification projects can affect multiple interconnected parts of a building or system, they can take considerably longer to execute than more traditional retrofit or replacement projects. Careful planning and coordination with the owner and/or property managers around the scheduling of shutdowns is essential to mitigate their impact on occupants.
- **Coordination with Subcontractors**: Coordination of electrification projects can be more challenging than more traditional retrofits as they often involve multiple systems and specialized subcontractors. It is advisable to choose a lead contractor with previous experience on similar projects and reliable subtrades. Where the owner or consultant has longstanding relationships with preferred and

qualified subtrades, it can also be helpful to require their use for certain project aspects, provided this aligns with owner procurement policies.

- **Permitting and Regulatory Approvals**: Large electrification projects will often require building permits or specific approvals. Early consultation with the relevant authorities can ensure that permit requirements and timelines are clearly understood by the design team.
- **Testing and Commissioning**: Commission an LCE project over a full heating and cooling season to ensure and optimize system functionality and performance. Clearly indicate seasonal and deferred commissioning requirements in project specifications so that the necessary members of the commissioning team include sufficient time in their proposals to complete these tasks.
- **Contingency Planning:** Building additional contingency into the schedule to account for unknown risks arising from the inherent complexity of electrification projects.

6.3.2. Quality Control

An essential aspect of any construction project, quality control (QC) is particularly important in LCE projects because of the complexity inherent to retrofitting an existing system and integrating new equipment and processes into existing operations and infrastructure. QC measures of particular relevance to electrification retrofit construction projects, along with considerations for implementation, are outlined in the table below.

MEASURE	IMPLEMENTATION CONSIDERATIONS
Material Inspection	Ensure that the materials being used meet the specified standards and are appropriate for the retrofit project’s objectives.
Installation Verification	Regularly inspect the installation of equipment to ensure it is correctly installed and that any code inspections are done at the appropriate times.
Ventilation System Testing	Verify the performance of ventilation systems to ensure adequate airflow and indoor air quality.
Energy Performance Monitoring	Use monitoring systems such as building automation system (BAS) trends or meter readings to track energy consumption during and after construction, comparing it against predicted performance to identify any discrepancies. Integrate specific performance and testing requirements of relevant incentive or certification programs into the QC plan and process.
Compliance Checks	Ensure that the retrofit adheres to relevant building codes, energy efficiency standards, and any certification requirements.

Documentation and Reporting	Maintain detailed records of inspections, test results, and any corrective actions taken throughout the construction process.

6.4. COMMISSIONING

Commissioning (Cx) is the process of ensuring that all components of a system are tested, operated, and maintained to meet the owner's operational requirements. The commissioning process, including activities both during and after the construction phase, is illustrated in Figure 7.

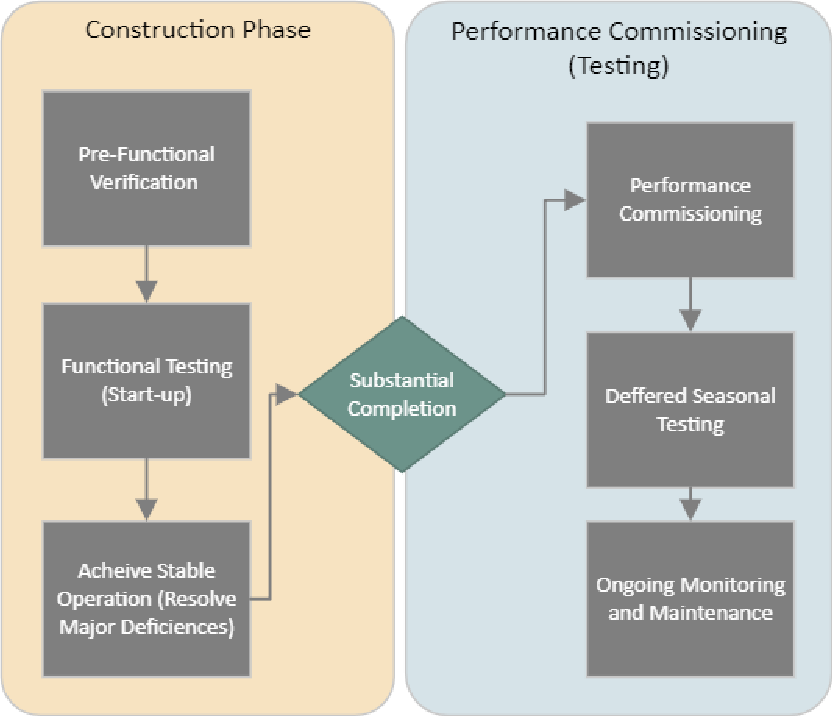


FIGURE 7: THE COMMISSIONING PROCESS

While proper system commissioning is an essential component of any HVAC project, it takes on additional importance in the context of electrification retrofits due to the complexity of the equipment used and project goals: poorly functioning systems perpetuate the belief that low-carbon equipment is ineffective, creating more resistance to decarbonization efforts. Other consequences of deficient commissioning on electrification projects include:

- Failure to achieve emissions reduction targets
- Excessive electricity consumption and/or demand charges
- Unreliable or poor system performance and resulting occupant comfort issues
- Shortened equipment life and premature failure

While the bulk of the effort related to commissioning occurs once the equipment has been installed, considering Cx requirements in every step of the project can ensure the essential elements are in place to allow effective commissioning.

6.4.1. Design Phase

6.4.1.1. Defining the Cx Team

Depending on the size, scope, and complexity of the project, the commissioning (Cx) team can involve some or all the roles defined by CSA Z5000 (CSA Group, 2022), including:

- Consultants
- Contractors
- Project managers
- Manufacturers or equipment suppliers
- Owners or owners' representatives
- Building operators and maintenance personnel
- A commissioning provider
    - Provides oversight, guidance, and validation throughout the commissioning process to ensure systems function as intended and the commissioning process meets standards and objectives.
- A commissioning or testing, adjusting, and balancing (TAB) agent
    - Executes commissioning tasks and works with design and construction teams to ensure systems meet requirements.

Include independent testing specialists in the Cx team as required. For example, specialized equipment may require manufacturer-specific testing by approved specialists. This can include factory-trained and authorized representatives.

In some projects, where deemed appropriate, the same personnel may be responsible for taking on more than one of the roles listed above. For example, the lead consultant may also act as the Cx provider. In other cases, the Cx provider may be an independent third party. The benefit of engaging a third-party commissioning provider is that they are accountable to the building owner, a dedicated expert on Cx, can provide additional technical experience or expertise, and provide an outside perspective; the downside is that third-party providers are often expensive, and may not be familiar with non-standard systems and their operation.

The following criteria are relevant to assembling the Cx team and selecting the Cx provider:

- Demonstrated knowledge in the operation and control of electric building heating and domestic hot water systems.

- Proven expertise in carrying out commissioning work.
- Demonstrated knowledge of and experience commissioning the specific type(s) of electric equipment to be commissioned.
- Experience with BAS system monitoring, troubleshooting, and performance commissioning.
- Experience with and commitment to operator education.

Commissioning is most effective when it is an open, transparent, and collaborative process, with all involved parties working together effectively to uncover and resolve any potential issues. The presence of owners' representatives and building operations personnel during the commissioning process and on the Cx team can help ease the transition into the ongoing operations phase by providing exposure to how the system and components work, as well as introducing troubleshooting and optimization procedures. This can be accomplished by

- Inviting operations personnel to shadow key commissioning activities.
- Including owner's representatives and operators in all Cx team meetings.
- Ensuring an effective handover process at the end of the Cx process that includes all relevant findings and documentation, as well as an overview of any deferred or seasonal testing that may be outstanding.

6.4.1.2. Prepare OPR and BoD

The owner's project requirements (OPR) and basis of design (BoD) are essential project documents that describe the ideas, concepts, and criteria of the electrification project that are important to the owner. While OPRs are common practice in new construction, they are often not prepared as part of retrofit projects, and many owners or managers of existing buildings are not familiar with the information they should contain. As a result, it often falls to the prime consultant to assist the owner in the creation of an OPR document that can be referenced by the project team throughout the implementation process.

In the OPR, cite specific measurable goals for the owner's objectives as clearly and precisely as possible. For electrification projects, goals relevant to the commissioning project might include emission reduction targets, occupant comfort parameters, or operating schedules. The OPR might also reference specific regulations, incentives, financing, or voluntary certification requirements that the owner is seeking or wishes to comply with.

The BoD describes the systems, components, conditions, and methods chosen to meet the OPR. Ensure it includes a description of all components considered necessary to carry out commissioning, such as systems, sensors, and metering equipment.

For a detailed overview of templates, format, and contents for OPR and BoD documents, refer to the following resources:

- ASHRAE Standard 202-2018 – Informative Appendix F: Basis of Design (ASHRAE, 2018).
- Building Commissioning Association's Owner's Project Requirements Template Outline (BCA, 2016).

- Building Commissioning Association's Owner's Project Requirements Template and Sample (BCA, 2016).

6.4.1.3. Commissioning Plan

Develop a commissioning (Cx) plan during the pre-design phase. Typically, Cx plans address items such as team roles and responsibilities, schedule, start-up, and functional performance testing. For LCE projects, extend the Cx plan to include such items as integrated testing requirements to ensure that electrified heating and domestic hot water systems operate as intended and interface successfully with legacy building infrastructure. Additionally, include requirements for ongoing system performance monitoring and post-implementation energy performance verification.

The following resources provide more information about and templates for Cx planning:

- ASHRAE Standard 202-2018 – Informative Appendix E: Commissioning Process Plan (ASHRAE, 2018).
- CSA Z5000-2018 – Section 4.3.3 (CSA Group, 2022).
- The Investor Confidence Project Operational Performance Verification (OPV) Plan Template (ICP, 2015).

During the design phase, complete a thorough review and documentation of controls sequences, and review compliance with the OPR and BoD, to ensure that the intent of these documents is being met. Additionally, have the specification documents reviewed by the Cx team to ensure that the sensors, meters, and other equipment required for commissioning are included in the Cx plan. This includes requirements for both hardware devices and virtual meters. Ensure that the specification documents include requirements that all BAS points important for understanding equipment operation are trended in sufficient resolution and for a sufficient duration. Trends logs are a critical source of information for verifying and troubleshooting the actual operation of the systems.

Where a contractor is involved, have the Cx provider engage them in a constructability review to ensure that the requested Cx-related items are practical to implement. If the contractor has any concerns, they can be given an opportunity to put forward alternative approaches that achieve similar outcomes.

6.4.2. Construction Phase and Beyond

During the construction phase, involve the Cx team in reviewing submittals, particularly those pertaining to hardware or systems required to facilitate the Cx process, such as metering and controls. If alternate equipment to what was specified in the design is installed, ensure that the Cx provider updates the Cx plan and requirements to reflect any operational differences.

6.4.2.1. Pre-Functional Verification

Have the Cx provider review equipment installation to ensure that devices required for commissioning, such as equipment control interfaces, sensors, and meters, have been installed in accordance with submittals and manufacturer requirements.

Accurate data is essential to being able to properly commission electrified heating systems. Contractors performing the startup of sensors and meters, particularly devices measuring energy use, often lack the context to properly validate meter readings. To address this, the CX provider must ensure that all meters and sensors required for commissioning have been properly calibrated during startup, and that measured values fall within expected ranges.

Have the Cx provider communicate with the commissioning and/or TAB agent to ensure that all necessary provisions are in place to successfully complete the TAB process. This may include ensuring access to all balancing valves, and having a pre-testing meeting to ensure there is clarity on all required tests. A pre-testing meeting can also provide a good opportunity to get TAB agent feedback on related controls sequences.

Finally, have the Cx provider, along with the designer and controls contractor, review the SOO to ensure that testing procedures and requirements are clear.

6.4.2.2. *Functional Testing*

During the functional testing phase, ensure the Cx team closely monitors the performance of equipment required for commissioning. This phase has two principal objectives:

- Ensuring that the equipment operates according to the expected performance.
- Ensuring that the SOO works as intended to control the equipment.

For large hydronic heat pump systems, observe input and output water temperatures, equipment staging, and how the equipment responds to commands, in order to determine if the equipment is operating in accordance with the specifications and expected performance. If actual performance differs from what is expected, have the commissioning team review, determine the root cause, and attempt to correct it. This should include a review of all field-configurable limits and settings that may have been set up by factory-authorized technicians during the equipment startup process. The objective is to determine whether there are actual deficiencies with the equipment or, if the equipment is operating normally, there were gaps in the design team’s knowledge regarding equipment operation. Where no actual deficiencies can be found with the equipment, issues can often be the result of commands from the BAS having a different effect on equipment operation than what designers intended or expected.

During functional testing, consult closely with equipment manufacturers and distributors, as they can be essential sources of information. Ensure any equipment performance deficiencies are resolved before proceeding to integrated performance testing and Cx.

If equipment is operating normally, and performance still differs from what is expected, the Cx and design teams may need to review the SOO and update it as required based on the actual performance characteristics of the installed equipment. If comfort issues are encountered, try to resolve the issues through adjustments to the heat pump systems before resorting to increasing the use of supplementary heating or cooling systems in order to avoid unnecessary energy consumption.

6.4.2.3. *Performance Cx (Integrated System Testing)*

Once operational deficiencies have been resolved and the equipment is achieving expected performance, have the Cx team carry out integration testing to ensure that the operation of the new equipment is optimized with respect to the connected building systems. Integration testing may require that the scope of commissioning be increased to cover existing systems such as zone units or ventilation systems.

Consider whether to expand the Cx scope to include integrated systems beyond those installed as part of the project into the Cx plan. If the team assesses that there is a likelihood of this type of expanded testing being required, advise the owner in advance and discuss the possibility of carrying a contingency budget to cover this eventuality.

Have the Cx team review and understand the key parameters of the systems connected to the new equipment. Where applicable, this may include parameters such as the operation of primary and backup or peaking heating and cooling equipment, operating schedules, space temperatures, and building electrical demand. Adjustments to integrated systems can improve overall system performance. For example, adjusting hot water supply temperature reset strategies can lower the required heat pump output temperature; adjusting startup routines to reduce peak heating loads can mitigate or eliminate the need for supplementary gas or electric resistance heating.

When adjusting integrated systems, make changes one at a time to avoid complex interactions that could make troubleshooting difficult. Consider putting in place simplified sequences before introducing more complex optimization strategies. In addition to helping avoid complex troubleshooting, this approach can help gain the trust of building operators by bringing them along during the process. Contrast this approach to starting with fully optimized sequences which may be difficult to understand for operators new to the system and complex to troubleshoot.

Much of the work necessary to optimize integrated systems can be addressed through controls upgrades and energy efficiency investments prior to undertaking equipment upgrades. However, adjustments may still be required following the installation of the electrified equipment.

6.4.2.4. *Deferred Seasonal Testing*

To ensure good performance outcomes, systems must be tested and observed in all seasons in which they are expected to operate. However, the realities of a construction project's schedule could result in new equipment being installed and commissioned during a time of year when it would normally see little use.

Examples of this include the installation of an air-source heat pump in the summer when its heating function is not required and cannot be thoroughly tested, or the installation of a heat recovery chiller during peak heating season when there is no excess heat to be recovered. In cases such as these, interim acceptance following the completion of pre-functional checks and startup can be considered, contingent on completion of full functional testing and integrated system testing during the appropriate seasons.

Ensure that the potential for deferred seasonal testing is clearly identified in the Cx plan and communicated to all involved parties early in the project so that the necessary resources can be allocated and scheduled. If possible, ensure that all deferred testing is done before the expiration of the warranty period so that any identified deficiencies can be dealt with as warranty items. Where this is not possible for contractual reasons, a separate cash allowance can be negotiated, or the testing can be included as an ongoing service contract with the controls contractor.

6.4.3. Hybrid System Considerations

Hybrid systems that use a combination of electrified and fossil fuel-based heating equipment deserve special attention during the commissioning phase to ensure that they meet project objectives. All too often, despite design intent to the contrary, the gas-fired equipment becomes the primary heat source, which in turn significantly reduces the emissions reductions achieved. In many cases, the root cause of this outcome is the relative inexperience of the design, Cx, and/or operations teams with heat pump systems, especially as compared to conventional gas-fired systems.

Heat pump systems, even when designed properly, operate over a smaller range of temperatures, and are typically designed with less safety margin, than gas-fired systems. Troubleshooting heat pump systems can also be more difficult due to the complexity of the equipment or the presence of internal proprietary controls that may not be accessible to anyone other than the equipment representatives.

As a result, it is often faster and simpler for building operators to resolve performance issues of hybrid systems by making greater use of the gas-fired equipment. Following the procedures described in Sections 6.4.1 and 6.4.2 can guard against this outcome. In addition to general best practices for commissioning electric heating systems, there are some specific considerations to achieve optimal performance in hybrid systems.

In order to minimize system-related emissions, hybrid systems should be designed and operated to extract as much energy as possible from the electrified heating sources and minimize use of the fossil fuel-based equipment. To achieve this, ensure that the SOO establishes clear criteria for operation (i.e. start and stop) of gas equipment tied to lack of sufficient capacity in primary electric heating sources. Wide dead bands and adequate time delays can be used in the staging between electric and fossil fuel-based systems to avoid premature operation of the latter. The exact sequences used will depend on the type of equipment and information available on the BAS, but examples of scenarios where use of the fossil fuel equipment would be appropriate include:

- Electric heating equipment is unable to maintain the hot water supply temperature setpoint (HWST SP).
- Electric heating equipment is unable to maintain space temperature setpoints in a certain number of zones.
- Average building space temperature is below target.
- Volume of stored domestic hot water is below target.

When operating gas-fired equipment in a hybrid system, ensure that the gas-fired equipment is disabled again once it is no longer required to meet load requirements and that its operation is not unnecessarily impeding the operation of the electric heating equipment, for example by continuing to maintain heating water temperatures above the operating range of the heat pump. Demand-based sequences can be complemented by other strategies, such as locking out fossil-based equipment above a certain outside air temperature (OAT). This approach provides a backup for when demand-based strategies fail to work appropriately, such as in the case of failed sensors.

Beyond specific considerations in the SOO, the Cx team can use alarms, trend logs, run time totalizers, meters, and utility billing history throughout the commissioning phase and the first year of operation to flag excessive operation of fossil fuel equipment for further investigation. Ensure that the designers are actively participating during this period to determine whether their design intent is being met and provide them with valuable feedback that can be incorporated into future designs.

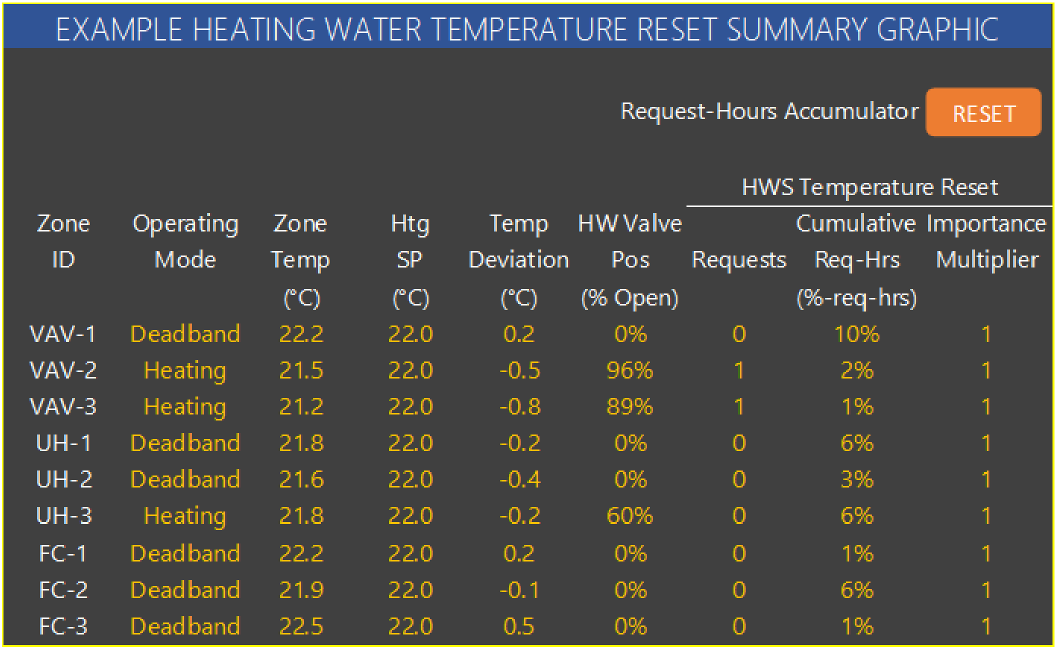
6.4.4. Setting up the BAS to Make Cx Easier

The building automation system (BAS) is an important tool for enabling the proper commissioning of complex mechanical systems. However, not all BAS are created equal. Some essential features can be implemented on most BAS upon request that can make the process of commissioning and troubleshooting systems much easier. These features include:

- Detailed system schematics that accurately represent as-built conditions. A complicated system may have to be spread over many graphics, but the schematic should include an overall graphic of the whole system to ensure it can be understood in its entirety.
- Summary tables that include key points to allow problem areas, such as variable air volume boxes (VAV), to be quickly identified.
- Parameters that can be adjusted during the commissioning process as system variables, ideally from the graphical interface, rather than values hardcoded in programs.
- Robust trending on important system points in the specification. Include both short- and long-term interval trends, as well as multi-trend requirements in the specification document, as these can reveal different information about system operation. When in doubt, err on including additional trends. It is preferable to have trends that are never used than to realize later that certain trends are needed and not have the data available. To minimize network limitations, consider specifying all new controls as BACnet IP. Where other options are not available, BACNet MSTP is acceptable for sub-networks with a very limited number of devices on each subnet; the main network between panels should always be BACnet IP.

To ensure the BAS graphics meet the commissioning requirements, consider:

- Requesting that mockups be included with the controls submittals.
- Providing sample summary graphics. For each instance of sequence, describe the desired graphic and provide an example. All trim and respond logic sequences need a similar graphic that displays relevant variables as software points which can be easily changed for optimization during performance commissioning. Some examples can be seen in Figure 8 and Figure 9.

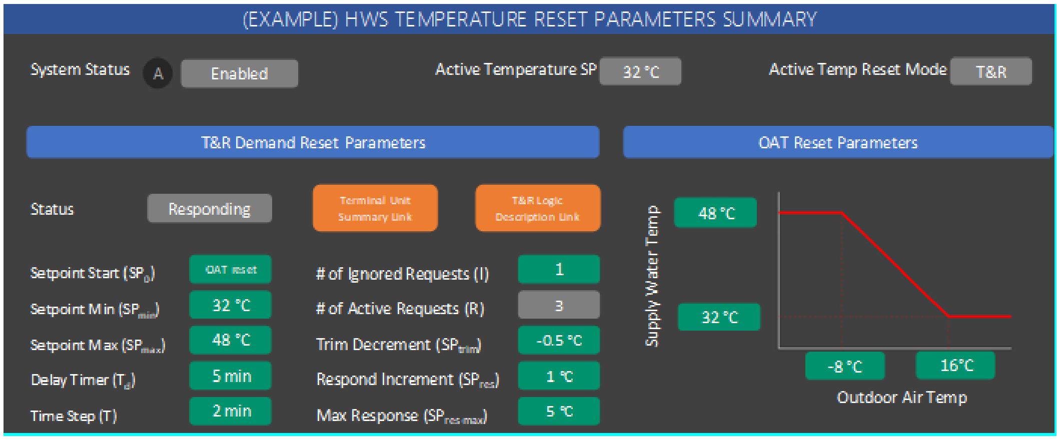


EXAMPLE HEATING WATER TEMPERATURE RESET SUMMARY GRAPHIC

Request-Hours Accumulator

Zone ID	Operating Mode	Zone Temp (°C)	Htg SP (°C)	Temp Deviation (°C)	HW Valve Pos (% Open)	HWS Temperature Reset Requests	HWS Temperature Reset Cumulative Req-Hrs (%-req-hrs)	HWS Temperature Reset Importance Multiplier
VAV-1	Deadband	22.2	22.0	0.2	0%	0	10%	1
VAV-2	Heating	21.5	22.0	-0.5	96%	1	2%	1
VAV-3	Heating	21.2	22.0	-0.8	89%	1	1%	1
UH-1	Deadband	21.8	22.0	-0.2	0%	0	6%	1
UH-2	Deadband	21.6	22.0	-0.4	0%	0	3%	1
UH-3	Heating	21.8	22.0	-0.2	60%	0	6%	1
FC-1	Deadband	22.2	22.0	0.2	0%	0	1%	1
FC-2	Deadband	21.9	22.0	-0.1	0%	0	6%	1
FC-3	Deadband	22.5	22.0	0.5	0%	0	1%	1

FIGURE 8: BAS SUMMARY GRAPHICS SAMPLE 1



(EXAMPLE) HWS TEMPERATURE RESET PARAMETERS SUMMARY

System Status A Enabled

Active Temperature SP 32 °C

Active Temp Reset Mode T&R

T&R Demand Reset Parameters

Status Responding

Setpoint Start (SP_0) OAT reset

Setpoint Min (SP_{min}) 32 °C

Setpoint Max (SP_{max}) 48 °C

Delay Timer (T_d) 5 min

Time Step (T) 2 min

# of Ignored Requests (I) 1

# of Active Requests (R) 3

Trim Decrement (SP_{trim}) -0.5 °C

Respond Increment (SP_{res}) 1 °C

Max Response ($SP_{res\text{-}max}$) 5 °C

OAT Reset Parameters

FIGURE 9: BAS SUMMARY GRAPHICS SAMPLE 2

6.4.5. Additional Resources

The following resources provide more information about the Cx process:

- CSA Z5000, Building Commissioning for Energy Using Systems (CSA Group, 2022).
- CSA Z320 Building Commissioning Standard (CSA Group, 2021).
- ASHRAE Guideline 0, The Commissioning Process (ASHRAE, 2019).
- Investor Confidence Project Operational Performance Verification Plan Template (ICP, 2015).

6.5. MEASUREMENT AND VERIFICATION

The measurement and verification (M&V) process enables the assessment of the actual performance of, and the energy savings and emissions reductions achieved by, implemented electrification measures, and is key to ensuring that projects meet their energy efficiency and emission reduction goals. M&V outcomes can validate investments, enhance the credibility and accountability of electrification projects, and serve as a basis for future improvements and optimization. Engaging an external third party to perform M&V activities can improve impartiality; be especially cautious of M&V results provided “for free” by equipment or technology providers who may be in a conflict of interest.

This section will discuss the M&V process and M&V plan.

6.5.1. M&V Process

M&V requires careful consideration and early planning to be effective, and should be completed by a qualified professional. The scope of M&V can vary significantly depending on the project’s complexity and external requirements: for simpler projects, M&V may involve basic monitoring of building utility bills over time; in more complex cases, often driven by owner or incentive requirements, detailed system-level analysis may be required. Regardless of the complexity, the M&V process generally follows the sequence of steps outlined in Figure 10.

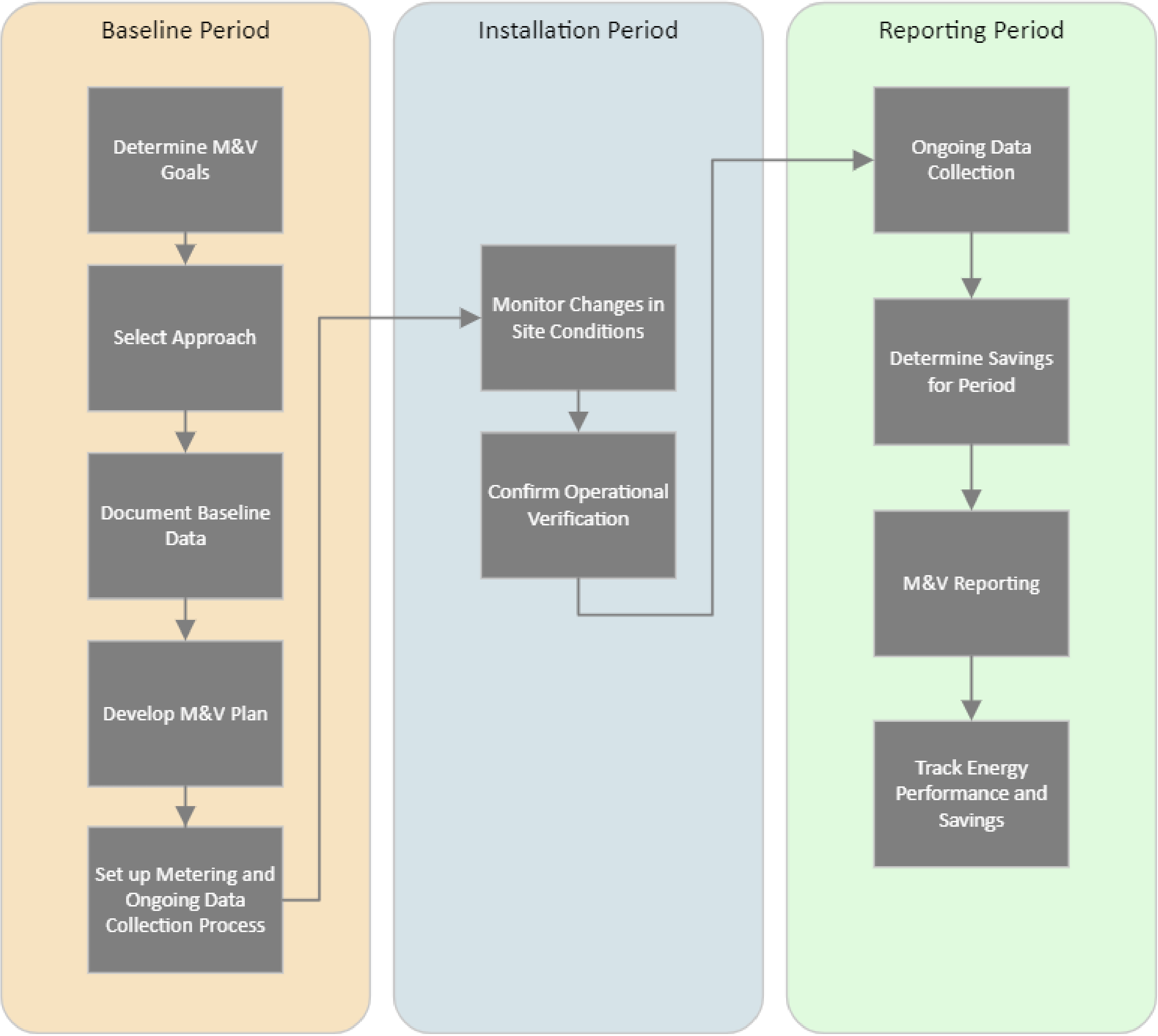


FIGURE 10: THE MEASUREMENT & VERIFICATION PROCESS

This section provides additional details about the steps in the M&V process.

6.5.1.1. Baseline Period

- **Determine M&V Goals:** Consider the goals, accuracy requirements, cost, and data availability for the M&V project.
- **Select Approach:** Choose an approach to M&V based on the type of energy efficiency project, the magnitude of savings sought, and the goals of the M&V project established in Step 1. Determine whether to follow the International Performance Measurement & Verification Protocol (IPMVP) or if a more casual approach is acceptable.
- **Document Baseline Data:** Collect and document relevant baseline energy data, along with data related to any influencing factors that can be used to calculate the actual energy savings and emissions reductions of the electrification project.

- **Develop M&V Plan:** Develop an M&V plan based on the M&V goals, M&V approach, and baseline data. The M&V plan will establish the framework for the rest of the M&V process.
- **Set-up Metering and On-going Data Collection Process:** Set up and install any additional metering devices or trending that have been identified as being required for the baseline period.

6.5.1.2. Installation Period

- **Monitor Changes in Site Conditions:** Monitor changes in the site conditions that occur between the baseline and reporting periods which have the potential to influence the energy savings or emissions reduction performance of the electrification project.
- **Confirm Operational Verification:** Verify that the electrification project has been installed and is operating as intended in the design.

6.5.1.3. Reporting Period

- **Ongoing Data Collection:** Collect data for the reporting period.
- **Determine Savings for Period:** Calculate the energy savings and emissions reductions for the reporting period.
- **M&V Report for Period:** Prepare an M&V report, documenting the energy savings, emissions reductions, and any adjustments made.
- **Track Energy Performance and Savings:** Track energy savings and emissions reductions over time and monitor savings.
- **Update Performance Benchmark:** Once the project is completed and performance has been confirmed, establish a new energy and emissions performance benchmark for the building. This would act as the baseline against which savings from future projects would be compared.

6.5.2. The M&V Plan

An M&V plan is a document that specifies how to measure and verify the outcomes of LCE retrofits. It establishes a baseline for comparison, details data collection methods, and outlines procedures for validating savings, accounting for variables like occupancy and weather. The plan ensures accurate tracking of energy performance, supports quality assurance, and provides stakeholders with verified results, ensuring project credibility and compliance with goals. The M&V plan can be as simple or detailed as the M&V requirements for a particular project require.

Ensure M&V plans are reviewed and agreed upon by all stakeholders prior to implementation, and referenced regularly to ensure data collection and tracking procedures are followed and that all data necessary for project performance verification is captured.

An M&V plan will typically include:

- An overview of the project.

- A description of the energy efficiency or emissions reduction measure(s).
- An overview of the M&V approach, including the selected IPMVP option if applicable.
- Baseline period energy consumption.
- The reporting period.
- The basis for adjustments (if applicable).
- Metering details.
- Monitoring and reporting responsibilities.
- Expectations regarding the accuracy of data.
- Calculation methodology and data analysis procedures.
- Anticipated energy savings, cost savings, and emissions reduction.
- The M&V report format.
- Quality assurance measures.

6.6. PROJECT HAND-OFF

The project hand-off phase involves transitioning a completed project from the construction team to the building operations team. This phase ensures that all necessary documentation, training, and information about the newly implemented systems are provided to the operations team. It also includes final inspections, testing, and commissioning to verify that the project meets performance requirements, and that the operations team is prepared to manage and maintain the new LCE systems effectively.

6.6.1. Operator Training & Support

To maximize the chances of an electrification project achieving its emissions reduction targets, building operators must be equipped, and feel confident, to operate and control complex electric systems and equipment effectively. Achieving this requires involving the operations team throughout the implementation project, and allocating sufficient time and resources for comprehensive training during the project hand-off phase.

Have both the contractor, who understands the equipment, and members of the consulting team, who understand how the overall system is intended to operate, involved in operator training activities. These should include:

- Remote or in-person training to go over new systems, sequences, and controls.
- Documentation aimed at enabling operators to troubleshoot systems that are not performing as intended. This material is typically part of an operations, maintenance, and monitoring (OM&M) plan, but can also be a separate document. Include schematics that show how the system is intended to operate, along with a step-by-step guide for resolving foreseeable issues.

- Follow-up visits by the consultant during the first year to help verify and recommission the system if and as needed. The interval of the visits can be determined based on the complexity of the system, the number of issues being encountered, and the level of support needed. For more complex systems, this can be as often as every 1-2 months; for less complex systems, a single check-in may suffice.

6.6.2. Project Debrief

A project debrief is a meeting or process that is conducted after the completion of a project to review its outcomes, successes, challenges, and lessons learned. The purpose of the debrief is to gather feedback from all project stakeholders and reflect on what worked well, what could be improved, and what insights can be applied to future projects. Project debriefs are particularly important for LCE retrofit projects due to their innovative nature and the potential for significant learning opportunities. A debrief typically includes:

- Reviewing objectives to determine the overall success of the project.
- Identifying successes, including a discussion of the aspects of the project that went well.
- Examining challenges or obstacles encountered during the project, such as technical issues or scheduling conflicts. Analyzing these challenges can help identify opportunities for improvement.
- Capturing lessons learned from the project. This includes insights gained from both successes and challenges, as well as any unexpected outcomes or discoveries. These lessons can inform future projects.
- Sharing feedback on what worked well and what could have been done differently. This feedback can lead to recommendations for process improvements, resource allocation, or changes in project management practices.
- Documenting the findings of the debrief, including key insights, lessons learned, and recommendations. This documentation can serve as a valuable reference for future projects and help in continuous improvement efforts.

Part 4: Design

The fourth part of the Guide digs into the design process and considerations for key systems and technologies, including:

- **Chapter 7: Heat Pumps**
- **Chapter 8: Heating, Ventilation, and Air Conditioning Systems**
- **Chapter 9: Domestic Hot Water Systems**
- **Chapter 10: Electrical Considerations**
- **Chapter 11: Structural Considerations**
- **Chapter 12: Architectural Considerations**

Its content will be particularly relevant to the following building and project stakeholders:

RELEVANT TO:	
	Building Owner
	Owner Advisor / Energy Manager
	Prime Consultant
☑	Designer

7. Heat Pumps

7.1. INTRODUCTION

This chapter covers heat pump system design and selection, and identifies common pitfalls to avoid when retrofitting heat pumps into existing building systems.

Heat pumps are an essential technology for decarbonization and future climate resilience in BC and across Canada. The main benefits of heat pumps include:

- **Efficiency and Cost Savings**: Unlike traditional heating systems, heat pumps transfer heat rather than generate it by burning fuel, making them up to three times more efficient than a standard boiler. This high efficiency often results in lower operating costs, even when accounting for the higher electricity costs compared to natural gas.
- **Carbon Emissions Reduction**: In British Columbia, the emissions reduction potential of heat pumps is further enhanced by the province's clean electricity grid, which is predominantly powered by hydroelectricity. The combination of high efficiency and clean electricity significantly reduces greenhouse gas emissions compared to conventional heating systems that rely on fossil fuels.
- **Climate Resilience**: Heat pumps provide the dual benefit of heating and cooling, which is increasingly essential for climate resilience. As global temperatures rise and heatwaves become more frequent, the ability of heat pumps to cool homes and buildings helps protect public health and maintain comfort, making them an indispensable technology for mitigating and adapting to climate change.

The main drawback to heat pump technology is its high cost. As Figure 11 illustrates, the cost of heat pump equipment is significantly higher than equivalently sized gas-fired equipment and rises significantly as capacity increases. Therefore, appropriate sizing of these systems is critical (see Section 8.3.4).

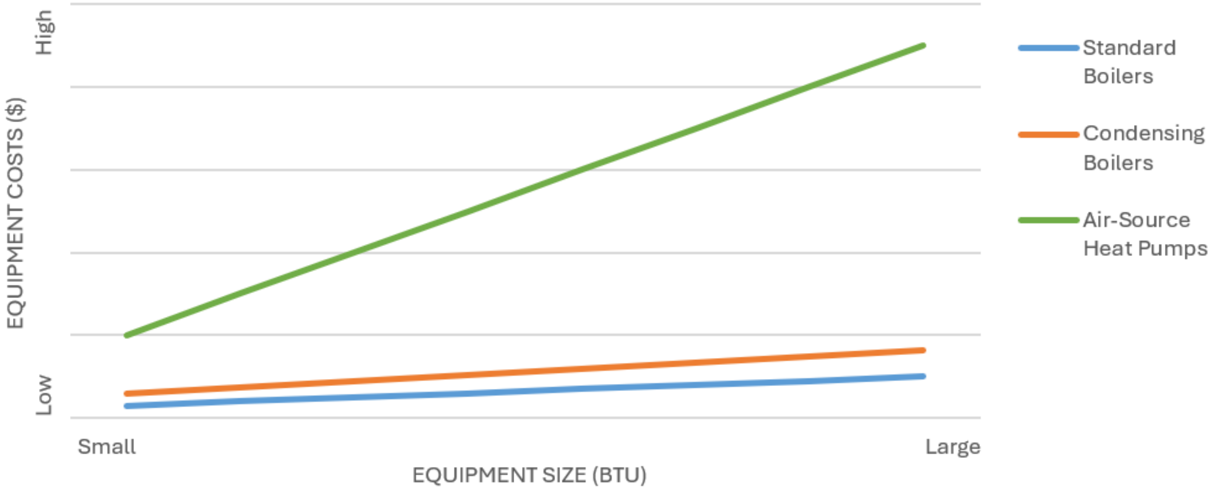


FIGURE 11: MECHANICAL EQUIPMENT COSTS VS. BTU

7.2. HEAT PUMP RETROFIT BASICS

Heat pumps operate fundamentally differently and on different principles than conventional gas-fired and electric-resistance heating systems. Understanding these differences and how heat pumps work is vital to successfully designing and implementing systems around them.

7.2.1. Heat Pump Configurations

Heat pumps are available in many configurations to suit diverse buildings' size and configuration needs. When designing heat pump systems, it is important to maintain a balance between simplicity and functionality. Several factors underscore the importance of this balance, including:

- **Operability**: Simpler systems are typically more user-friendly to operate. This can reduce errors, enable easier training and increase the chances that the system is used to full capacity.
- **Maintenance**: Simple systems usually comprise fewer components, making it easier to diagnose and resolve issues when they arise.
- **Reliability:** Simpler systems tend to have fewer potential points of failure and be more reliable.
- **Energy Performance:** Overly complex systems often encounter commissioning and operational challenges, potentially negating predicted efficiency gains resulting from optimized designs.
- **Adaptability and Flexibility:** Simple systems are typically easier to modify in response to the evolving needs of the building.

7.2.2. Heat Pumps are Not Boilers

Approaching a heat pump retrofit in the same way as one would a boiler retrofit can cause issues in operation. Some of the key operating differences between heat pumps and boilers are outlined in Table 6. These will be discussed in more detail throughout this chapter.

TABLE 6: KEY OPERATING DIFFERENCES BETWEEN HEAT PUMPS AND BOILERS

CHARACTERISTIC	BOILERS	HEAT PUMPS
Service(s) provided	Boilers only provide heating.	Heat pumps can provide heating and cooling simultaneously.
Operating temperature range	Operate over a wide temperature range with little impact on capacity.	The operating temperature range is limited by compressor technology and refrigerant type.
Factors that determine efficiency and capacity	Efficiency is mainly dependent on return water temperature. Capacity is minimally affected by operating temperatures.	Both source and load temperatures impact capacity and efficiency.
Sizing considerations	Some oversizing can be accommodated as boiler costs do not change drastically based on capacity.	Right-sizing is required on both the source and load sides. Oversizing is expensive and can lead to short cycling of equipment.
Modulation capacity	Modulating capacity control is common with turndowns exceeding 5:1.	Typically, the capacity is stepped by starting/stopping compressors. Modulating control is becoming more common.
Controls	Simple and well-understood controls.	Controls are more complex and typically require more ongoing monitoring and optimization.
Reaction times	Boilers can typically react quickly to load changes to meet building demand.	Heat pumps can take time to respond to setpoint changes. Sufficient thermal storage is required to achieve system response without short-cycling compressors.

7.2.3. Temperature Drives Efficiency

System temperature, specifically temperature lift (Delta T), is a primary driver of heat pump efficiency. Figure 12 offers a normalized comparison of heat pump efficiency based on lift.

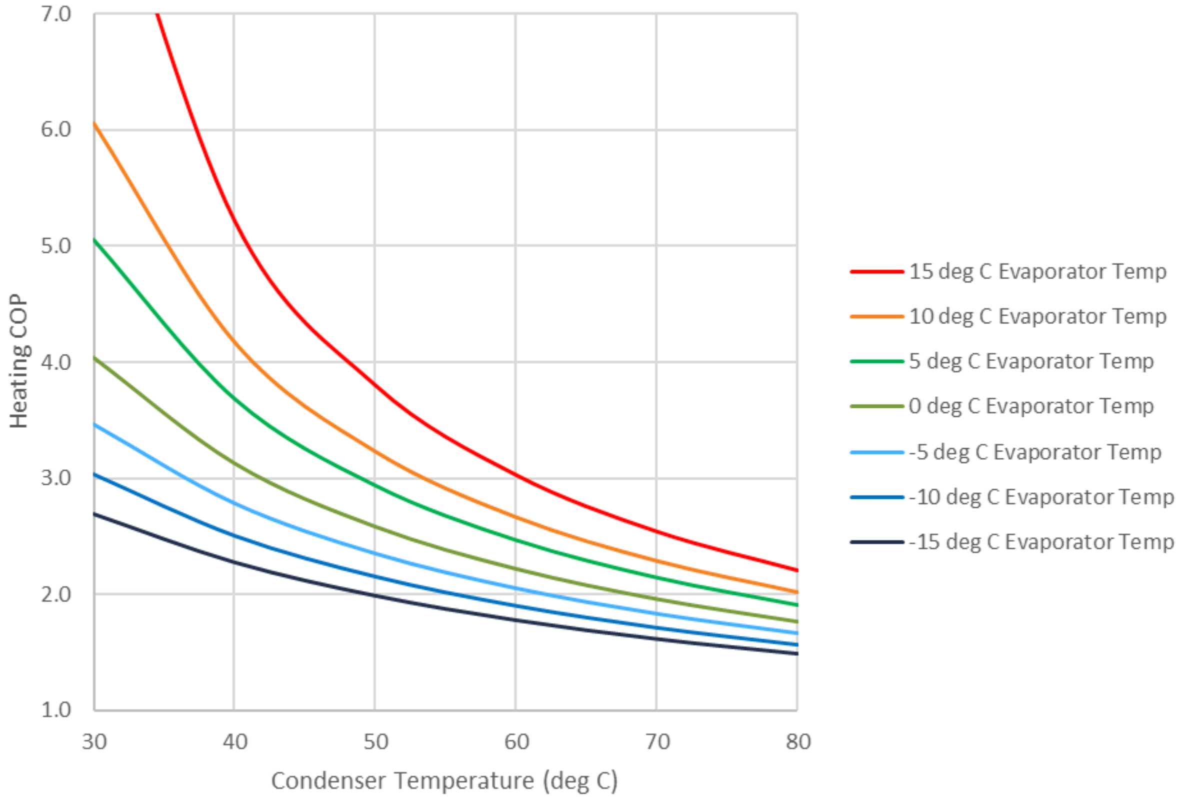


FIGURE 12: TEMPERATURE IMPACT OF HEAT PUMP EFFICIENCY

While other factors such as the percent of full load, compressor selection, evaporator and condenser designs, and compressor part-load control capabilities influence heat pump performance, temperature remains the most important factor in driving performance.

The design engineer and building operator greatly influence system operating temperature through initial design and operating decisions. For retrofit applications, design engineers must explore and implement strategies to lower heating water temperatures to facilitate compatibility with heat pumps. Even for buildings already operating within acceptable operating limits of heat pumps, further reduction in operating temperature can improve operating efficiency. Refer to Section 8.4 for strategies to reduce heating water temperature through testing or retrofit.

7.3. HEAT SOURCES AND SINKS

Heat pumps move thermal energy rather than generate it directly. This distinction underscores the importance of selecting appropriate and reliable sources and sinks of heat for effective operation. Table 7 outlines the key heating system characteristics to evaluate when choosing a heat source/sink:

TABLE 7: HEATING SYSTEM CHARACTERISTICS

QUALITY	QUANTITY	AVAILABILITY
• What is the source temperature? • What is the source temperature range (i.e. consistent or variable)? • Is the temperature within an acceptable range of available heat pump technology?	• How much heat is available? • Do any external factors limit the heat quantity?	• Is the heat source available as required or only periodically? • Do times of availability align with heating needs?

A thorough understanding of these evaluation considerations can greatly aid designers in identifying suitable sources and sinks for heat pump design.

Traditional sources and sinks include ambient air, geo-exchange (ground-source), and water sources such as lakes. However, understanding that the building is itself a thermal energy resource can expand possibilities for additional heat sources and sinks, some of which are covered in Table 8.

TABLE 8: HEAT SOURCES AND SINKS OF BUILDINGS AS THERMAL ENERGY RESOURCES

SOURCE	OPPORTUNITY
Building Exhaust Air	This involves capturing heat from exhaust or relief air and internal cooling loads within the building.
Wastewater	In buildings with consistent and substantial domestic water usage, wastewater can be a heat source.
Building Cooling Loads	Anything that needs to be cooled can serve as a heat source, including heat generated from cooling loops, server rooms, or process refrigeration plants.
Thermal Energy Storage Systems	Thermal energy storage (TES) is an effective heat source or sink, particularly when the availability of sources does not align with a building's heating requirements. For more information, refer to Section 7.5.1.10
Renewable Energy Sources	Solar thermal and other renewable sources can complement other heat sources and are typically most effective when coupled with thermal energy storage.

Table 8 presents a summary comparison of various heat sources and sinks, providing insights to assist designers in assessing the most suitable sources and sinks based on specific project characteristics. This section addresses additional considerations for several of these sources and sinks.

7.3.1. Ambient Air

Ambient air's abundant availability and flexibility as a heat source and sink make it a popular choice for residential and commercial settings, particularly in moderate to warm climates. While standard air-source heat pumps (ASHPs) are mainly used in mild to moderately cold climates, advances like vapour injection technology have enabled cold-climate heat pumps to function efficiently in colder conditions, expanding their use geographically.

7.3.1.1. ASHP Capacity Considerations

During the heating season, as ambient temperatures fall, ASHP capacity is reduced when it is needed most (see Figure 13). Conversely, ASHP heating capacity increases at milder ambient conditions, when heating loads are reduced. This phenomenon aggravates control stability during low part-load conditions, becoming more pronounced for systems sized to meet peak heating requirements. Analyze heat pump quantity, control capabilities, and system turn-down limitations against expected load curves to provide stable and reliable operation at part-load conditions.

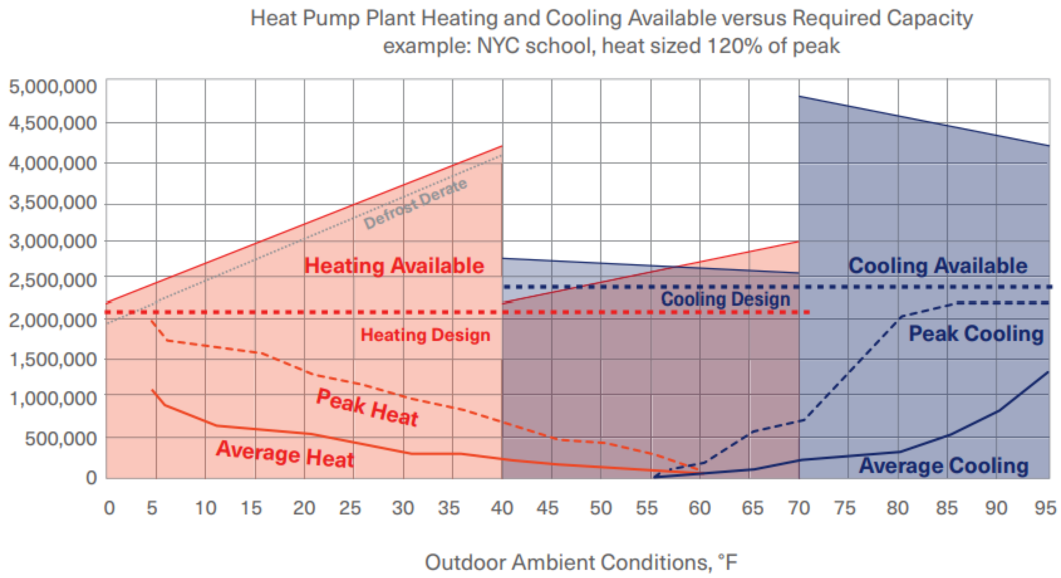


Chart of available capacity
Assumes 40°F cooling lock out
Assumes 70°F heating lock out

FIGURE 13: ASHP CAPACITY AS A FUNCTION OF OUTDOOR AIR TEMPERATURE

7.3.1.2. ASHP Defrost Considerations

In addition to operating less efficiently during colder weather, ASHPs are further challenged by frost accumulation on the outdoor coils at low ambient temperatures and high humidities, typically a concern at outdoor air temperatures between 4°C and -8°C. Defrost cycles are essential to maintaining performance, but disrupt the heating cycle. In wet climates, frost formation can exceed psychrometric predictions, requiring more frequent defrost cycles. The requirement for defrost diminishes as air temperatures and humidity drop and is typically not a concern below humidity ratios of 0.001 to 0.002 kgw/kga.

Utilizing multiple modules can minimize the impact of defrost cycles, as most controllers can coordinate defrost cycles of individual ASHP modules to limit the number of units in defrost at any given time, typically limiting the number of modules in defrost to between 30% and 50%. For systems without backup, a higher number of units or an N+1 configuration can ensure full capacity during defrost, offering both redundancy and reduced reliance on backup heating systems.

Published performance data for ASHPs typically does not include the effects of defrost on capacity and efficiency. However, in operation, defrost cycles can lead to noticeable capacity degradation. Table 9 can be used for order-of-magnitude estimates of the negative impacts of defrost.

TABLE 9: TYPICAL DEFROST CAPACITY DERATE FACTORS

OUTDOOR AIR TEMPERATURE	CAPACITY DERATE FACTOR
> 8.3°C (47°F)	1 (no derate)
1.7 to 8.3°C (35 to 47°F)	0.95 to 0.98
-6.7 to 1.7°C (20 to 35°F)	0.90 to 0.95
-15 to -6.7°C (5 to 20°F)	0.85 to 0.90
-17.8 to -15°C (0 to 5°)	0.80 to 0.85

Additional application considerations for ambient air-source systems include:

- **Cost-Effectiveness:** ASHPs are generally more cost-effective in mild climates than systems that rely on other external sources/sinks, such as ground and wastewater.
- **Variable Efficiency:** ASHPs have more variable efficiency and capacity than systems that use more temperature-stable heat sources. These challenges can be mitigated by locating air-source equipment in interior spaces, such as underground parkades, which provide a more moderate and consistent ambient environment.

- **Space Requirements and Location:** ASHPs often require outdoor space for installation, such as on rooftops or ground level. Locating equipment can be challenging for high-rises with very little roof space. Consider utilizing buffer spaces like parkades to temper outdoor air temperature or ducted configurations where roof space does not allow installation. As an example, with proper planning, ASHPs can be integrated into parkade exhaust systems.

- **Noise:** ASHPs use high-volume fans to exchange heat with ambient air. Consider the noise levels generated by these fans, especially in larger heat pump systems, as the fans run in both heating and cooling seasons. Local noise bylaws can limit the location of units. Noise can be mitigated using acoustic enclosures and variable speed fans, which limit start-up noise.

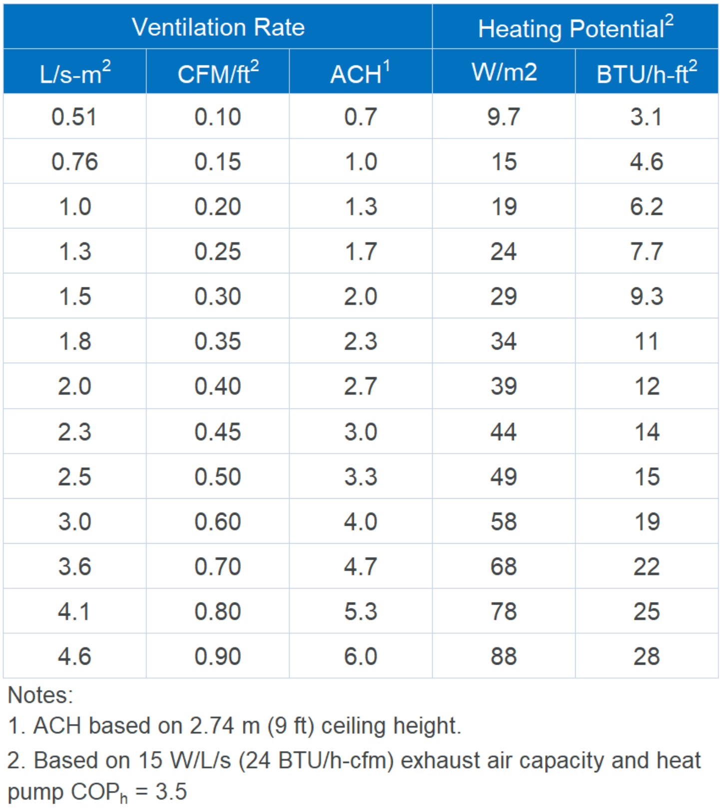
7.3.2. Exhaust Air

Building exhaust air can be a valuable heat source, and sometimes a sink, for heat pump systems, offering consistent and moderate temperatures ideal for efficient heat reclaim using standard chilled water temperatures. Additionally, the predictable operation schedule of exhaust systems can provide a reliable heat source throughout the year.

However, exhaust air alone cannot meet peak heating requirements. It is most effective when combined with other heat sources to create a robust and efficient system for hydronic heat pumps. The suitability of exhaust air as a heat source largely depends on the configuration of the existing air systems; systems with central exhaust fans or building relief are particularly well-suited to this application.

The extent to which exhaust air can meet a building's heating needs will also vary based on the building's ventilation rate and operating schedule. For preliminary design considerations, Table 10 can serve as a helpful reference.

TABLE 10: POTENTIAL EXHAUST RECOVERY CAPACITY BASED ON VENTILATION RATE



Ventilation Rate			Heating Potential[2]	
L/s-m^2	CFM/ft^2	ACH[1]	W/m2	BTU/h-ft^2
0.51	0.10	0.7	9.7	3.1
0.76	0.15	1.0	15	4.6
1.0	0.20	1.3	19	6.2
1.3	0.25	1.7	24	7.7
1.5	0.30	2.0	29	9.3
1.8	0.35	2.3	34	11
2.0	0.40	2.7	39	12
2.3	0.45	3.0	44	14
2.5	0.50	3.3	49	15
3.0	0.60	4.0	58	19
3.6	0.70	4.7	68	22
4.1	0.80	5.3	78	25
4.6	0.90	6.0	88	28

Notes:

1. ACH based on 2.74 m (9 ft) ceiling height.
2. Based on 15 W/L/s (24 BTU/h-cfm) exhaust air capacity and heat pump $COP_h = 3.5$

Sizing exhaust heat recovery coils involves considerations similar to those involved in sizing cooling coils but with specific nuances, including:

- **Entering Air Conditions:** The return air humidity significantly impacts the total heat reclaim potential. Low humidity levels during peak heating conditions can reduce coil capacity by upwards of 30% compared to selection conditions; therefore, in buildings without active humidity control, take care not to overestimate the heat recovery potential in system modelling.

- **Leaving Air Conditions:** To maximize heat recovery, consider sizing coils with lower leaving air temperatures than those in typical air conditioning applications. Consider temperatures as low as 10°C (50°F).

- **Air Velocity:** Given the specific entering and leaving air conditions, exhaust heat recovery coils tend to be larger than those used in standard air conditioning applications, often requiring up to 8 to 10 rows with tight fin spacing to achieve desired capacities, leading to significant air pressure drops. Where space permits, it is advisable to size coils for low air velocities of a maximum of 2 m/s (400 fpm).

For retrofit applications, the capacity of the exhaust fans needs to be assessed to ensure the system can accommodate the added pressure drop of the exhaust coils. Adding an exhaust coil can require upgrading the fan motor or replacing the fan itself to maintain the original airflow rates under increased pressure drops. Previous balancing reports and shop drawings, including fan curves, are helpful when conducting a desktop assessment of fan capacity.

To reduce fan energy, consider incorporating a bypass damper around the for when it is not being used for heat reclaim. It is essential to size the bypass damper and associated ductwork for a low-pressure drop to reduce the required fan pressure in bypass mode. For air handler applications, this needs to be communicated to the manufacturer providing selections to prevent the bypass damper from being sized for control purposes only.

7.3.3. Building Cooling Loads

Building cooling loads offer efficient heat sources for heat pump-based systems, particularly in commercial and industrial settings with year-round cooling requirements. High efficiencies can be achieved when using a heat pump to simultaneously meet both heating and cooling loads.

In this application, heat pumps can be configured to meet cooling loads directly by supplying chilled water or configured in a cascaded setup with existing cooling systems. The decision of which configuration to pursue is often driven by the required temperature lift or the remaining service life of the existing chillers. Efficiency considerations between single lift and cascaded systems are discussed further in Section 7.5.1.9.

Process cooling loads, such as refrigerant plants in arenas or supermarkets, tenant condenser loops, and data centre cooling systems, can provide consistent year-round heat sources at stable operating temperatures. When utilizing these sources, it is crucial to integrate them with the cooling systems without compromising their operational reliability – this can often require hydraulic separation using heat exchangers and making connections upstream of existing heat rejection equipment so unused heat can be rejected.

The use of air and water-side economizing within a building signals an opportunity to use building cooling as a heat source when a building needs heating. In such scenarios, minimize economizing efforts and use mechanical cooling systems as heat sources instead (see Figure 14).

While building cooling loads can act as a heat source, they can rarely be used for more than a base heating source. Additional heat sources are usually necessary to meet peak demands. Nevertheless, utilizing building cooling loads is often a cost-effective first step toward LCE. Integrating thermal energy storage can allow asynchronous heat recovery of building cooling loads, further enhancing system performance.

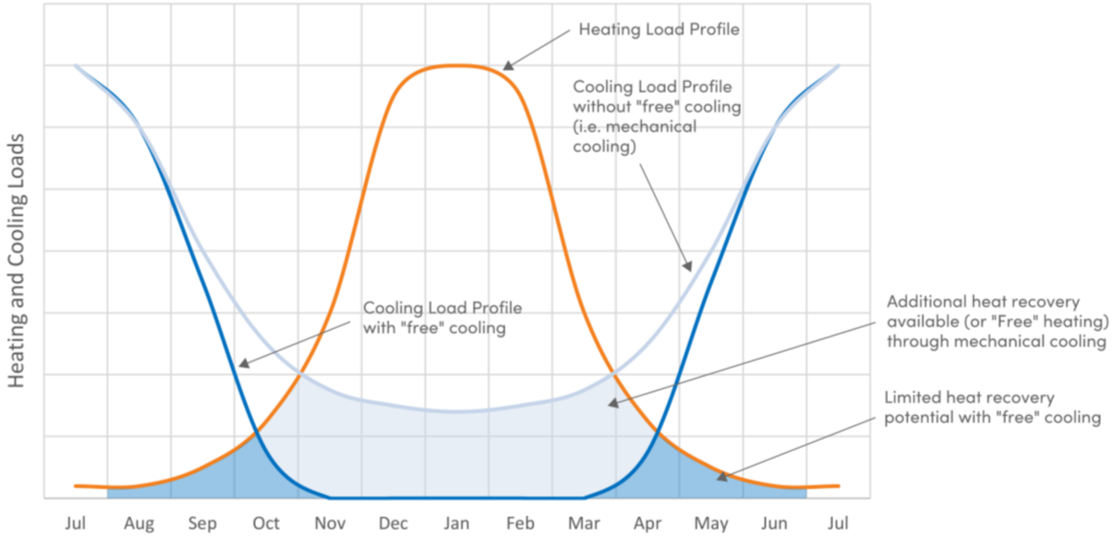


FIGURE 14: AIR-SIDE "FREE-COOLING" VS. MECHANICAL COOLING

7.3.4. Ground-Source

Compared with other sources and sinks, ground-source heat pumps (GSHPs) have notable advantages, but also significant challenges, in retrofit applications. As both heat sources and sinks, GSHPs harness the consistent temperature of the earth, enabling a more stable temperature exchange than air-source methods. This consistency makes them an efficient choice, particularly in colder climates where they perform exceptionally well. However, within the context of retrofits, several considerations must be addressed:

- **Upfront Capital Cost:** The initial expense of retrofitting existing buildings with GSHPs tends to be higher than for new construction applications due primarily to the complexity of installing underground loop systems within existing buildings and sites.

- **Site Feasibility and Constraints:** The effectiveness and capacity of GSHP systems are greatly influenced by local geological and groundwater conditions; a thorough site assessment is essential to determine the feasibility and design constraints for the particular application. Vertical boreholes are usually more practical than horizontal loops in urban sites with limited outdoor space. However, drilling vertical boreholes within an existing building's footprint demands meticulous planning and the potential use of specialized low-head-height drilling equipment to avoid underground utilities and building foundations.

- **Rightsizing & Capacity:** Proper sizing is crucial for the long-term success and efficiency of GSHP systems. It is essential to account for both instantaneous peak loads and annual load profiles to determine the system's capacity and the predicted temperatures that influence efficiency. Unlike air-source heat pumps ASHPs, where the size of the heat pump itself often limits capacity, ground loop size is typically the constraining factor for GSHPs. Additionally, operators must understand these capacity constraints to prevent issues such as sub-cooling or the saturation of the ground loop.

- **Seasonal Energy Storage:** In areas with little groundwater impact, GSHPs can be utilized as borehole thermal energy storage systems. By using the ground as a thermal battery, GSHPs in retrofit projects can store surplus heat in the summer, which can then be retrieved during the heating season. This capability can significantly boost a system's overall efficiency and save energy.

7.3.5. Sewage and Wastewater

Wastewater, an often overlooked resource, offers an efficient heat source and sink for heat pumps due to stable temperatures, typically 10 to 18°C. The use of wastewater is particularly effective in urban settings with high development density and consistent volumes of wastewater.

For high water-use facilities like recreation centres, large residential buildings, and healthcare facilities, wastewater can provide a consistent heat source or sink year-round. Evaluating local sewer flow rates and identifying suitable connection locations are important for successful design.

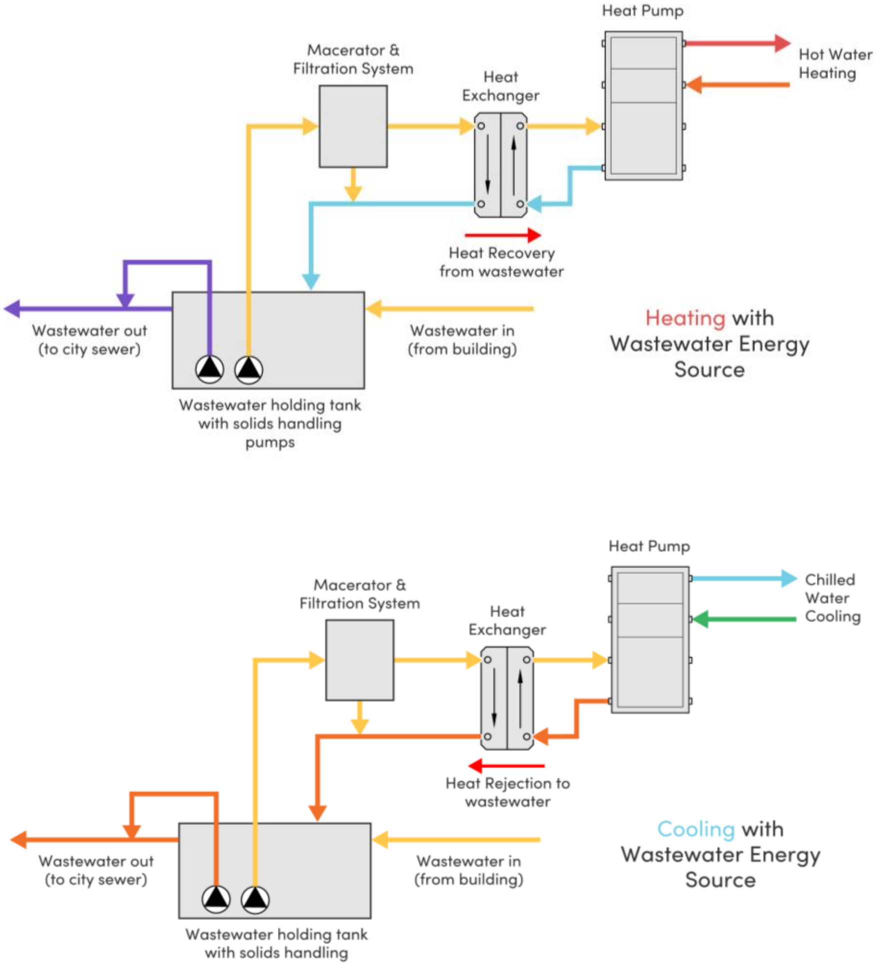


FIGURE 15: SEWAGE SOURCE HEAT PUMP

Application considerations for heat recovery systems include:

- **Energy Efficiency:** Wastewater heat recovery is often more efficient and cost-effective than geo-exchange, leading to significant energy savings and a reduced environmental footprint.
- **Public Perception:** Initial skepticism about using wastewater for heating may arise due to misconceptions regarding its cleanliness and safety.
- **Installation Complexity and Cost:** The complexity and high initial investment required to integrate wastewater into a system, particularly on a smaller scale, can be challenging.
- **Legal and Planning Hurdles:** Securing permissions to connect to municipal sewer lines can involve a complex and lengthy process.
- **Maintenance Requirements:** Ensuring system efficiency and longevity demands diligent maintenance, including regularly cleaning filters and heat exchangers.

7.3.6. Transitional Heat Sources

Hybrid systems utilizing existing gas-fired heating sources or other non-electrified process loads can be heat sources for heat pump systems. When considering these options, evaluate their cost-effectiveness compared to more permanent heat sources, considering their anticipated operational duration. A key advantage of these systems is their ability to provide heat during peak demand periods when other heat sources might be inadequate. Options include:

- **Boiler Flue Gas Economizers:** In hybrid systems that incorporate existing non-condensing gas-fired boilers, flue gas economizers can be employed to recover heat from the boiler flue gases. As the flue gas passes through the economizer, the water cools the gas, extracting residual sensible and latent heat from the combustion process.
- **Steam Condensate Cooling:** Systems that depend on steam for supplemental heating in scenarios where the steam condensate is not recirculated back to the heating plant – a common situation in many downtown Vancouver buildings – can benefit from reclaiming heat from existing steam condensate cooling tanks using chilled water.

7.4. HEAT PUMP SELECTION CONSIDERATIONS

7.4.1. Compressor Selection

HVAC compressors generally fall into one of two main categories, as illustrated in Figure 16. Matching the compressor to the application is important for successful operation, reliability, and performance.

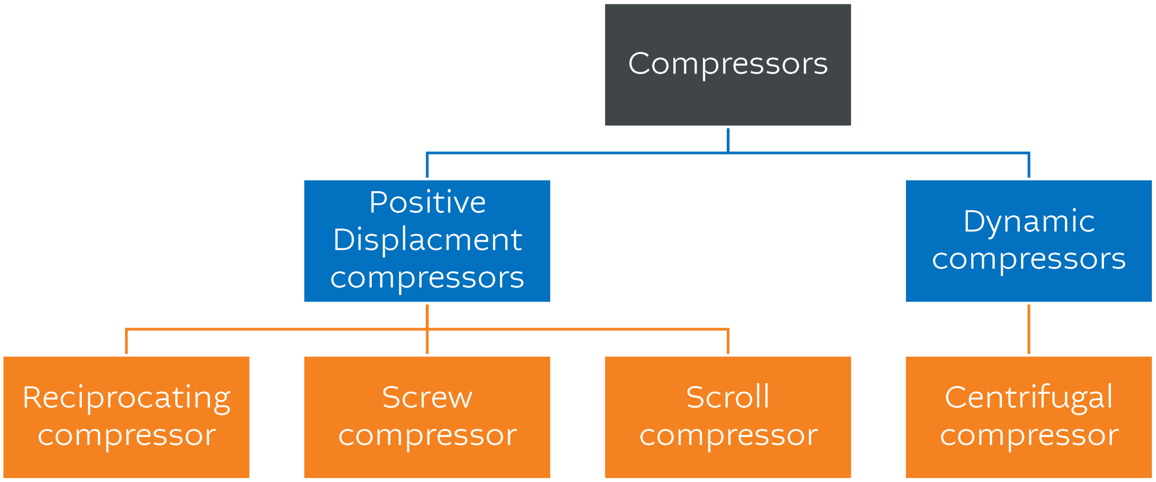


FIGURE 16: CLASSIFICATION OF COMMON HVAC COMPRESSOR TYPES

7.4.1.1. Compressor Selection Considerations

Choosing the right type of compressor involves considering several factors:

- **Capacity Requirements:** Smaller systems may use reciprocating or rotary compressors, while larger applications typically require centrifugal or screw compressors.
- **Operating Conditions:** The temperature and pressure requirements of the application can drive compressor selection. Some compressors perform better under low-lift conditions, while others are suitable for high-lift applications.
- **Capacity Control and Operational Tolerance:** In tandem with operating conditions, system turn-down requirements often direct compressor selection. Applications with variable capacity requirements are seldom suitable for centrifugal compressors, and typically require positive displacement compressors to achieve reliable operation.
- **Redundancy:** Heat pumps utilizing several small scroll compressors are frequently chosen for their modularity and redundancy.
- **Physical Size:** Physical size and access constraints can limit the type of compressors suitable for an application. Modular refrigerant systems using scroll compressors can often fit more capacity within a smaller footprint and accommodate moving equipment using elevators and standard door sizes.
- **Noise Level:** This can be a significant concern in residential and commercial settings, particularly for air-source heat pumps. Rotary and scroll compressors are often favoured for their quiet operation. Variable-speed outdoor fans and compressors can also help alleviate the noise associated with starting and stopping. Many compressors include a quiet or night control mode that reduces fan speed to limit noise.

- **Maintenance Requirements:** Maintenance requirements vary drastically by compressor type. Understanding and communicating these requirements to operating staff can ensure a system's long-term reliability. Smaller hermetic scroll compressors are replaced with a new compressor upon failure. Large centrifugal or reciprocating compressors have long service lives but require routine breakdown and rebuilding to maintain longevity.
- **Cost:** The initial cost of compressors varies based on type; consider life-cycle costing when investigating potential compressor types for a given application.

7.4.2. Refrigerant Selection

While heat pumps offer significant environmental benefits, their refrigerants are not without their impacts. Many common refrigerants used in heat pumps have high global warming potential (GWP), meaning that even small leaks can have disproportionately large climate impacts. Additionally, these substances can be hazardous to human health and safety, posing risks such as toxicity or flammability if released.

The Kigali Amendment to the Montreal Protocol addresses the need to phase out high global warming potential (GWP) refrigerants. As of January 2025, it will no longer be possible to import chillers or heat pumps that contain refrigerant with a GWP exceeding 750 into Canada, directly affecting systems that rely on common refrigerants such as R134a and R410a.

7.4.2.1. Next-Generation Refrigerants

ASHRAE Standard 34 categorizes refrigerants into eight categories based on their toxicity and flammability (ASHRAE, 2019), which helps guide safe handling and application. Currently, the most commonly used refrigerants fall under the A1 classification, and are considered the safest in terms of toxicity and flammability. Many of the next-generation low-GWP refrigerants are classified as A2L. These A2L refrigerants are slightly more flammable and have different safety requirements than A1 refrigerants, requiring updated safety protocols and system designs.

Ultra-low GWP refrigerants are currently available for low-pressure applications such as large centrifugal chillers, and are anticipated to be the long-term solution. Newer “low” GWP refrigerants being adopted by manufacturers for medium and high-pressure applications typical for heat pumps still have GWPs hundreds of times higher than CO_2 and will likely be phased out in the late 2020s or early 2030s in favour of ultra-low GWP solutions.

This ongoing evolution of refrigerants highlights the importance of balancing environmental benefits with safety considerations. As newer refrigerants are adopted, ensuring that they meet both low-GWP standards and safety requirements will be essential for their successful implementation in heat pump systems.

TABLE 11: COMMON REFRIGERANTS AND LOWER GWP ALTERNATIVES

Refrigerant	ASHRAE Class	OEL	GWP	Atmospheric Life	COP	Capacity Change
LOW PRESSURE APPLICATIONS (e.g., larger centrifugal compressors)						
R-123	B1	50	77	1.3 years	8.95	baseline
R-514A	B1	320	1.7	22 days	8.91	~5% loss
R-1233zd(E)	A1	800	1	26 days	8.87	~35% gain
MEDIUM PRESSURE APPLICATIONS (e.g., screw compressors and smaller centrifugal compressors)						
R-134A	A1	1000	1430	13.4 years	8.47	baseline
R-513A	A1	650	630	5.9 years	8.27	similar
R-515B	A1	810	298	3.1 years	8.32	~25% loss
R-1234yf	A2L	500	6	11 days	8.17	~5% loss
R-1234ze(E)	A2L	800	4	18 days	8.45	~25% loss
HIGH PRESSURE APPLICATIONS (e.g., scroll compressors, unitary and packaged equipment)						
R-410A	A1	1000	2088	17 years	7.99	baseline
R-454B	A2L	850	467	3.6 years	8.16	~3% loss
R-32	A2L	1000	675	5.2 years	8.22	~8% gain
R-717 (HN4)	B2L		0			
R-744 (CO2)	A1		1			
R-290	A3		3			

Transitional	Lower GWP	Ultra-Low GWP

7.4.2.2. Refrigerant Code Updates

Currently, adopted refrigeration codes do not incorporate refrigerant classifications A2L and B2L. The most recent Canadian Refrigeration Code update, CSA B52-2023, includes classification and application requirements for these new classes of refrigerants (CSA Group, 2023). The adoption of CSA B52:2023 in British Columbia is anticipated in late 2024 or early 2025, allowing the use of provisions tailored explicitly to A2L refrigerants. Under the current regulations, A2L refrigerants are classified as A2 refrigerants, severely restricting their use without the use of project-by-project alternate solutions.

7.4.3. Sizing Based on Actual Conditions

Sizing and selecting a heat pump based on actual capacity, specific to the expected operating conditions, rather than nominal capacity, can ensure operation matches expectations. Sections 8.3 and 9.3 provide guidance on using data-driven design to right-size equipment. Capacity and efficiency of heat pumps are more variable than those of boilers and chillers, necessitating equipment selection based on realistic operating conditions rather than idealized or standardized operating conditions that define nominal equipment capacities.

Nominal capacity, commonly listed in manufacturers' literature, is typically determined under ordinary conditions defined by industry standards like AHRI-550/590 (AHRI (Air Conditioning, Heating, and Refrigeration Institute), 2023). However, the reported capacities do not always reflect the specific environmental and operational conditions a heat pump will encounter in real-life operations. The difference between nominal and actual capacities is more pronounced in heat pumps and heat recovery equipment than in cooling-only chillers or boilers. Relying solely on nominal values can lead to incorrectly sized equipment and can result in misleading estimates of energy performance or emissions reduction.

Verify that the equipment can perform under actual design conditions, particularly when those conditions are near the upper limits of a heat pump's operating range. Specifications or restrictions on heat pump operation that aren’t considered during the selection process can lead to inefficiencies or failure to achieve the expected performance levels. Press equipment suppliers on these details, as they are sometimes not clearly stated.

7.4.4. Modular Heat Pumps

Modular heat pumps are popular in retrofit applications for both water-to-water and air-to-water heat pump applications, due to their space-saving design and flexibility for phased capacity increases. In addition, their compact size makes transport and installation easier, and reduces craning and lifting costs. Additional benefits include:

- **Flexibility and Scalability:** Modular heat pumps allow for precise sizing for both current and future loads, as additional modules can easily be added if capacity requirements change. This scalability makes them ideal for retrofits, where space and load requirements can vary.
- **Improved Redundancy:** With multiple modules, if one unit fails or enters a defrost cycle, others can continue to operate, ensuring continuous cooling and heating. This redundancy is beneficial in applications where heating and cooling are essential operations.
- **Lower Noise Levels:** Modular units can be quieter than larger heat pumps, an important consideration in urban or residential areas.
- **Compliance with Refrigeration Codes:** Modular heat pumps can drastically reduce machinery room ventilation requirements due to their small refrigerant charge per module—a refrigerant leak in one module will result in substantially less refrigerant loss than a leak in a large, packaged heat pump.

7.4.4.1. Modular Heat Pumps are Multiple Heat Pumps

From a design and hydronic perspective, modular chillers and heat pumps are effectively multiple chillers or heat pumps piped in parallel rather than a single machine because each module has a separate evaporator and condenser. This has implications for both heat pump selection and system piping design, to ensure the system can efficiently deliver design heating water temperatures at varying load conditions while avoiding nuisance trips to protect the heat pump from low and high-pressure safeties.

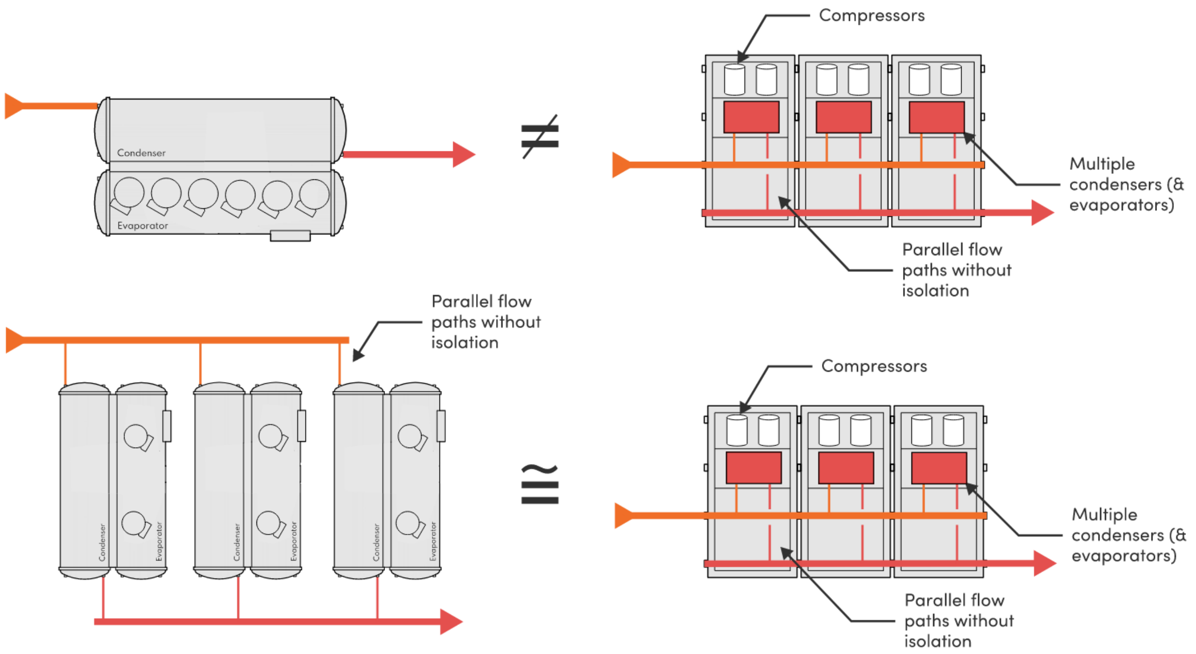


FIGURE 17: MODULAR CHILLERS ARE MULTIPLE CHILLERS IN PARALLEL

Without internal motorized isolation valves, each module always sees a proportion of the system flow, even when inactive. At part-load, this results in degradation of the leaving water temperature due to the mixing of water flowing through inactive modules. This condition lowers heat pump efficiency, as the operating modules must create warmer water to achieve the desired leaving water setpoint, as shown in Figure 18. The adverse effects of this condition increase with increasing temperature differentials.

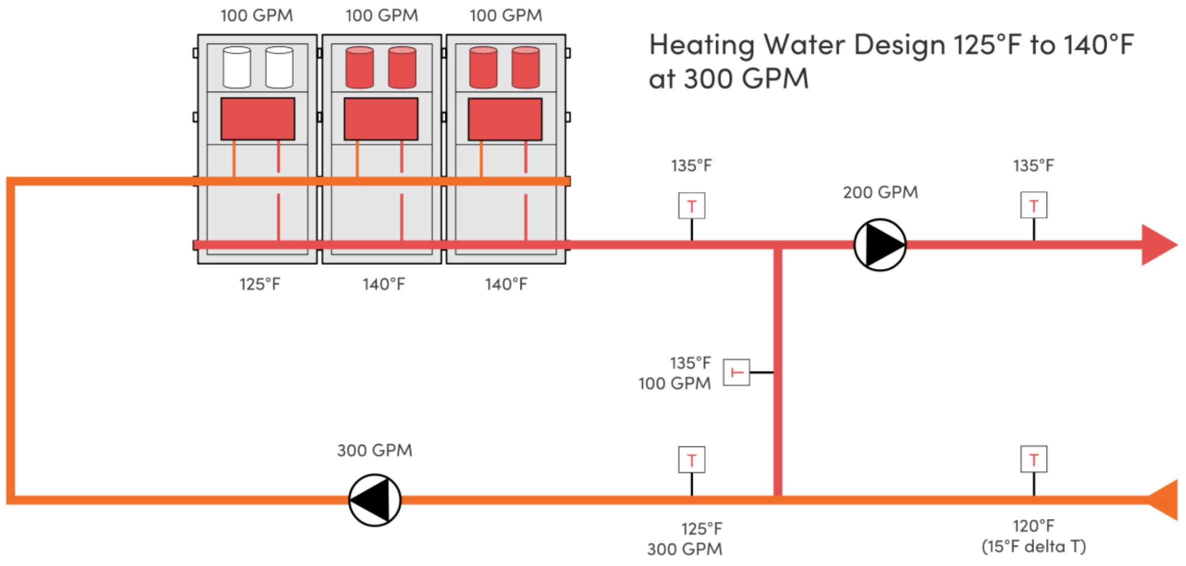


FIGURE 18: IMPACT OF MODULE MIXING DURING PART LOAD (CONSTANT FLOW SYSTEM)

This condition is worsened when system conditions require the heat pumps to operate close to or beyond the top of their operating limits at part-load conditions, as shown in Figure 19. This condition can result in reoccurring nuisance trips at part-load conditions.

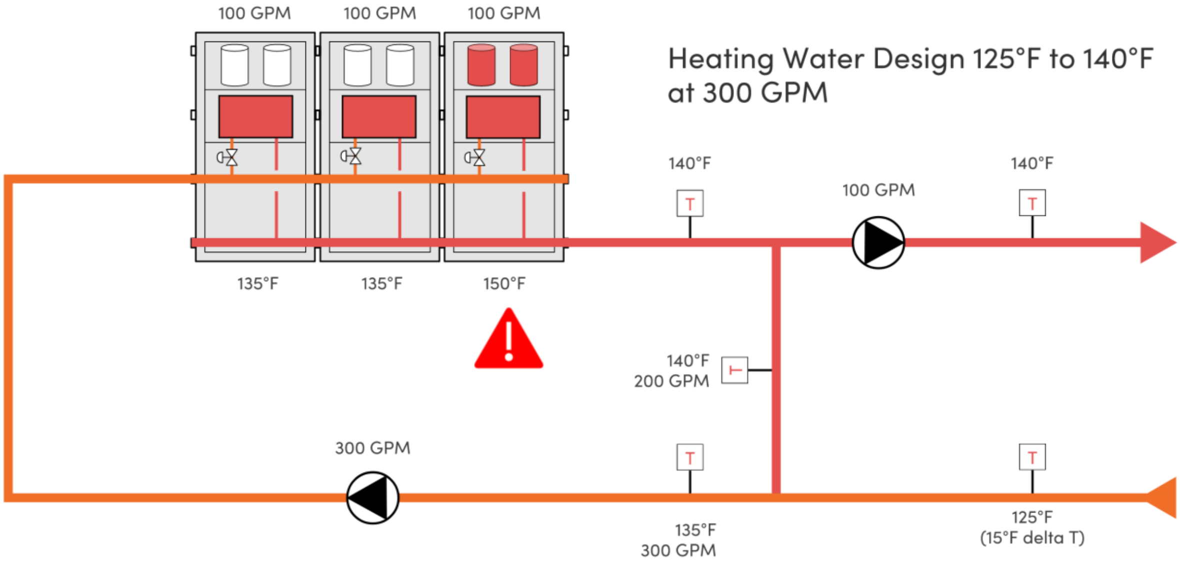


FIGURE 19: CONSTANT FLOW PUMPING RESULTING IN HEAT PUMP TRIPS

This configuration may not be an issue for systems operating near-constant high part-load ratios, lower heating water temperatures, or systems where hot water temperature reset tracks with heat pump load – although efficiency is reduced anytime water bypasses through a non-operating module. This configuration is also less of an issue with constant flow distribution systems (i.e., 3-way valves). However, it is an issue for systems serving variable flow secondary systems, especially for variable load systems that require a high-temperature setpoint to be maintained at partial loads.

This operating challenge can be resolved by providing motorized isolation valves for each heat pump module, equivalent to installing isolation valves on each packaged chiller or heat pump in a system. In this configuration, inactive heat pumps are isolated from the system and mixing is avoided, allowing the operating heat pump modules to maintain the hot water supply temperature setpoint at a lower lift.

In this configuration, in addition to control valves at each module, the following system components are required:

- VFDs on circulating pumps.
- A high-quality differential pressure sensor or flow meter across the modular heat pump bank to maintain minimum flow rates as individual modules stage on and off.
- A heat pump flow bypass, or the ability to keep one module's control valve open whenever the system is operating, prevents deadheading of the system pumps. Base the size of the bypass on the turn-down capabilities of the system pumps.

- A minimum flow bypass with a remote differential pressure sensor to maintain flow through the heat pump bank as loads stage off. Size the bypass for at least 1.5 times the design flow of the largest module. The valve actuator needs to be quick-acting; hardwire control of this valve to the plant controller to avoid operational issues with network lag or disruptions.

7.4.4.2. Temperature Control

For modular heat pump systems with fixed compressor staging, temperature control precision is determined by the design system temperature differential and the number of compressor steps available. Increased precision in temperature control is achieved with more compressor steps (i.e. system turn-down) and smaller design temperature differentials. Because heating systems typically operate at larger temperature differentials than chilled water systems, temperature cannot be controlled as precisely without additional considerations.

Hydronic heating systems seldom require tight control of heating water temperature to maintain thermal comfort. However, when operating heat pumps near the top of their temperature capabilities, tighter control is required to avoid nuisance trips for fixed-stage heat pumps. Strategies to improve temperature control include:

- Installing a greater number of smaller modules to increase turndown capability.
- Adding mixing valves downstream of the heat pump to control load temperature to setpoint and let the heat pump run at higher deadbands.
- Adding system storage volume to mitigate temperature swings.
- Adding variable-frequency drives (VFDs) to one or two modules, thereby allowing heat pumps to more closely match output with loads.

7.4.4.3. Flow Control

Flow control is critical for all heat pumps, particularly for modular heat pumps, due to the fixed-capacity compressors and small internal water volume of the evaporators and condensers. Any time there is a change in flow, there is a corresponding change in temperature differential across the heat pump. Sudden changes in flow can lead to temperature alarms, especially when a machine is operating close to its high limit.

7.5. HEAT PUMP TYPE CONSIDERATIONS

7.5.1. Centralized Heat Pump Considerations

The considerations discussed in this section pertain to large, centralized hydronic heat pumps where the heat pump system (typically air-to-water or water-to-water) is integrated into a hydronic heating system. This heating system distributes the heat generated by the heat pump via a heating water loop to terminal units such as AHU coils, fan coil units, and VAV boxes with reheat.

7.5.1.1. Physical Space and Access Constraints

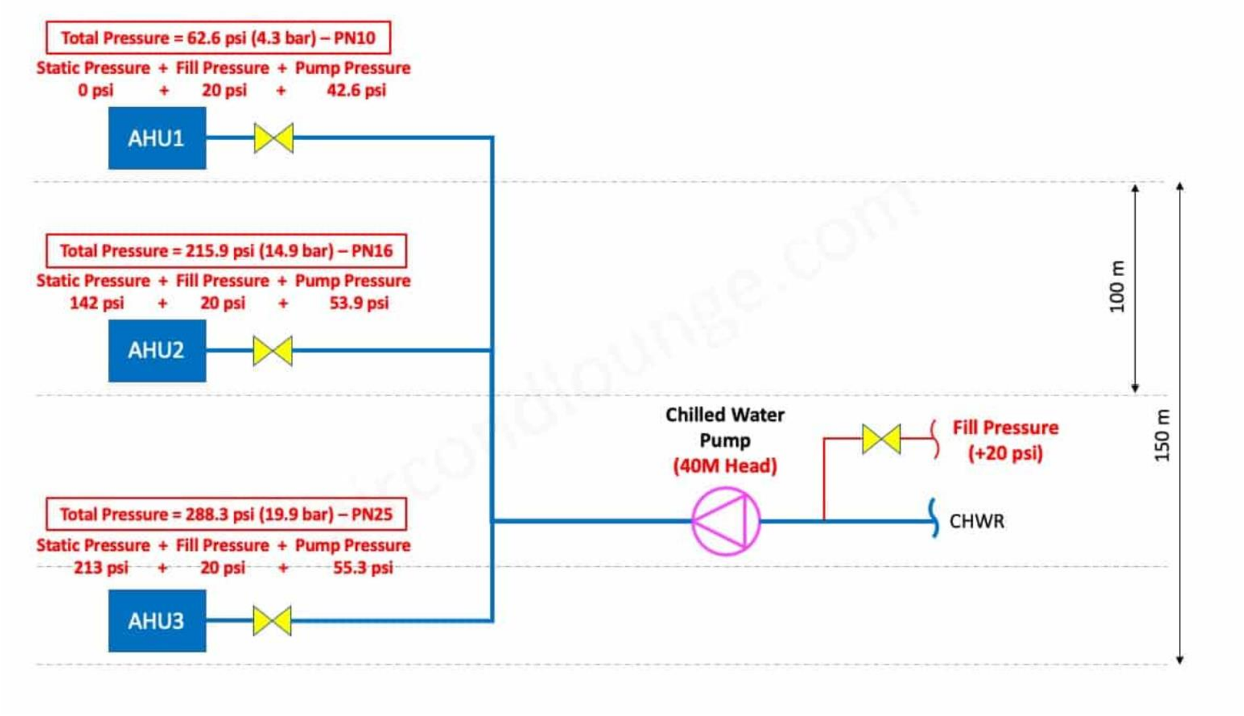
Evaluating physical space and access constraints is crucial for replacing and retrofitting HVAC equipment. Assess the accessibility of different areas for installation and maintenance; the availability of indoor and outdoor space for new equipment; and any restrictions on equipment transport, such as tight corridors. Vertical access, including the availability and size of elevators and stairs, can impact the transportation of large equipment. For rooftop installations, consider whether cranes or helicopter lifts are needed and if there is an existing gantry crane on the roof.

The following options provide solutions to common access challenges**:**

- **Modular Chillers:** These are designed to be disassembled and transported in manageable pieces, making them ideal for buildings with access limitations.
- **Smaller Units:** Instead of one large chiller, multiple small chillers may be used. This approach can ease transportation and installation challenges, and increase redundancy.
- **Pre-Planning with Building Management:** Coordinate with building management to identify the best times for transportation and installation to minimize disruption.
- **Custom Solutions:** In some cases, custom-designed equipment or systems may be necessary to fit the unique constraints of a building.

7.5.1.2. System Working Pressures

In high-rise buildings, hydrostatic pressure, driven by building height, impacts piping and equipment. When combined with dynamic pressures from pumps and system residual pressure at the top of the building, hydrostatic pressure can greatly affect the working pressure of the system. During the design phase, confirm the working pressures of the system and ensure that all equipment is available at the required pressure rating. Explicitly state these specifications in the design documents to ensure proper equipment selection and compliance. If equipment with the necessary pressure rating is unavailable, pressure-break heat exchangers are needed to protect the equipment. Consider the system impacts of these heat exchangers, including a reduction in system volume, which can affect control stability, and reduced efficiency due to the temperature approach across the exchanger.



CHWS Total Pressure Calculation

FIGURE 20: SYSTEM WORKING PRESSURE

7.5.1.3. Refrigeration Safety

Technical Safety BC (TSBC) and the Mechanical Refrigeration Code (the Code; CSA Group, 2023) govern requirements for refrigeration system installations in BC, including unitary systems above specific capacities, chilled water systems, and heat pump plants. Compliance with their standards is a regulatory requirement. It is essential to determine provisions required for compliance as part of the design process in order to ensure the safety of building operators and tenants. Some common requirements include:

- **Machinery Room Requirements:** Machinery rooms must enclose indoor refrigeration equipment when required by the Code. Machine room requirements can include refrigerant detection, adequate ventilation, and specific architectural features like well-sealed doors. A commonly missed detail in retrofits of existing buildings is the need for a vestibule when the room opens onto a public corridor. Typically, modular chillers and heat pumps do not trigger these requirements.

- **Refrigerant Relief Valves:** Refrigerant relief valves must be piped outside the building per the Code. Small units like modular chillers that lack relief valves and are certified by UL or CSA are generally exempt.

- **Plant Supervision Requirements:** The necessity for plant supervision depends on the refrigeration equipment's capacity. Typically, plants with prime mover nameplates exceeding 200 kW require a risk assessment or supervision when operating, incurring additional costs for the building owner. A refrigeration circuit constitutes a refrigerant plant within the Code; hence, supervision is mandated by the rating of the largest circuit, not the aggregate capacity of all equipment in the room.

7.5.1.4. Operating Limits

Avoid running heat pumps near their operational temperature limits whenever possible. Operating limits stated by manufacturers are often achieved during ideal operating tests; reported values in literature may not have sufficient operating margins for actual operating conditions and should be discussed with the supplier.

Potential issues of operating equipment near its limits include:

- **Staging Instability:** When compressors stage on, they may overshoot temperature setpoints, triggering high pressure or temperature alarms. This can result in inefficient and frequent cycling, as subsequent compressors stage on in a similar fashion to compensate.
- **Reduced Operational Reliability:** Resulting from nuisance high- or low-pressure trips, which can significantly undermine the system's reliability and create frustration for building operators. Heat pumps that operate in this fashion will often be manually shut down and bypassed by operators, negating the energy-saving or GHG-reduction benefits they were intended to provide.
- **Equipment Wear and Tear:** Regularly operating compressors near their limits accelerates wear and tear, reducing compressor life and increasing maintenance costs.

Reducing hot water temperature requirements as much as possible through demand-based reset strategies or installing low-temperature coils and terminal units can mitigate these issues (see Section 8.4). For systems required to work consistently under high-lift conditions, the capacity control capabilities of the heat pumps become crucial. Cascading heat pumps may be necessary to ensure more stable and reliable operation (see Section 7.5.1.9).

7.5.1.5. Fouling

Water treatment and filtration are essential to maintain heat exchangers' efficiency and longevity. This is particularly true in the case of shell and tube and brazed plate heat exchangers, both common components of heat pumps and chillers. Adhere to the specific water quality requirements set by equipment manufacturers to maintain the warranty of heat exchangers. Requirements vary; ensure that they are documented in the design drawings and system specifications. In cases where brazed plate evaporators and condensers are used, manufacturers often specify strainer mesh sizes ranging from 30 to 60 mesh, which is much finer than commonly provided on inline strainer and pump suction diffusers.

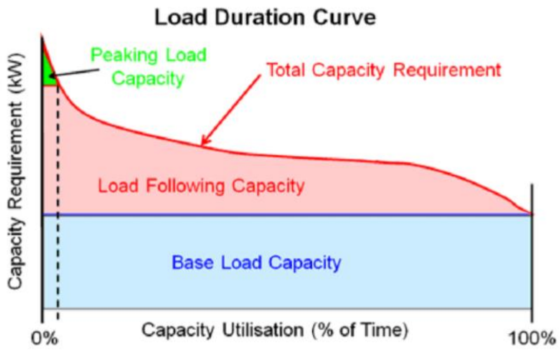
7.5.1.6. Turn-down Capability

Sizing and selecting a heat pump configuration without understanding part-load conditions can lead to operational issues. Insufficient turn-down capacity can create problems that affect both the efficiency and lifespan of the system. These problems include:

- Frequent cycling heat pumps to meet the load requirements. Constant cycling increases wear and tear on system components, reducing reliability and service life.
- Reduced efficiency because the heat pumps spend more time operating in less efficient start-up and shut-down transients than steady-state operation.

- Comfort issues due to poor temperature control of heating water or air temperatures, leading to noticeable temperature swings which can be uncomfortable.

An understanding of peak loads and annual load profiles is required to inform decisions on the number of stages and type of capacity control required to meet system load requirements over the entire operating season (see Sections 8.3 and 9.3). Load duration curves and part-load ratio bin tables are valuable tools for understanding the turn-down requirements of a system. Analysis of stable operation at part loads should also include considerations on system volume (see Section 7.5.1.7).



PLR Bin	Hours	% of Operating
System Off	3076	-
10 - 20%	428	8%
21 - 30%	1569	28%
31 - 40%	1578	28%
41 - 50%	1141	20%
51 - 60%	433	8%
61 - 70%	308	5%
71 - 80%	116	2%
81 - 90%	66	1%
91 - 100%	46	1%

FIGURE 21: EXAMPLES OF LOAD DURATION CURVE AND PART-LOAD BIN TABLE

7.5.1.7. System Volume

Adequate system volume is essential to ensure system operating stability as heating and cooling loads vary. Inadequate system volume can lead to compressor short-cycling, which significantly shortens compressor lifespan, reduces equipment efficiency through excessive start/stop cycles, and destabilizes the system's temperature control. For air-to-water heat pumps (AWHPs), the defrost cycle is an additional consideration that requires even higher system volumes to mitigate the adverse effects on the building loops and provide an adequate heat source during defrost cycles.

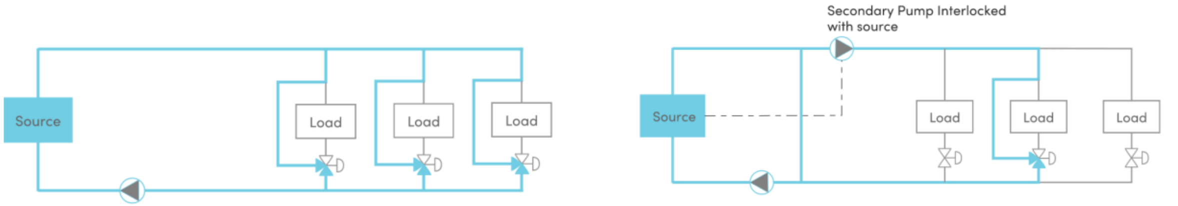
7.5.1.7.1. Minimum Effective System Volume

Follow manufacturers' guidelines when determining the minimum system volume required for a given application. For detailed design, rely on the manufacturers’ recommendations and first principles that account for the actual system operating limits and configuration.

The "effective" or "accessible" system volume is the volume available to the heat pump during low load periods.

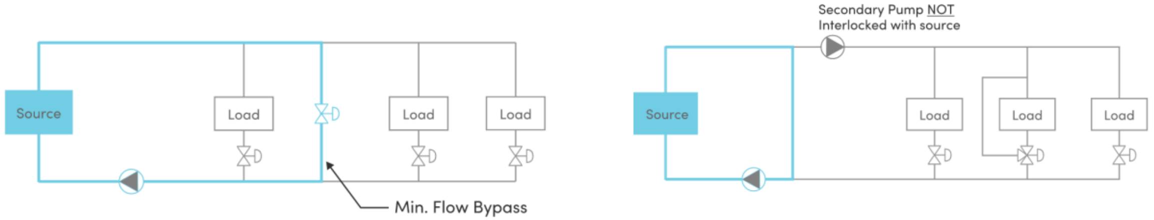
In constant-flow systems with three-way bypass valves around the loads, the effective system volume includes the entire distribution system, extending up to and including the bypass piping around the loads. In contrast, in variable flow systems that use two-way valves, the effective system volume is limited to the distribution system up to the location of the minimum flow bypass valve. In scenarios where the minimum flow bypass valve is situated in the mechanical room, buffer tanks may need to be sized to accommodate the required effective system volume.

For primary-secondary systems, the operation of secondary pumps is critical in determining effective system volume. When the secondary pumps might not operate concurrently with the primary pumps or have a minimum flow bypass, size the primary side of the system to meet the required effective system volume.



Constant Flow System with 3-way valves

Primary-Secondary: Secondary pump interlocked with source operation



Variable Flow Primary System with bypass

Primary-Secondary: Secondary pump not interlocked with source operation

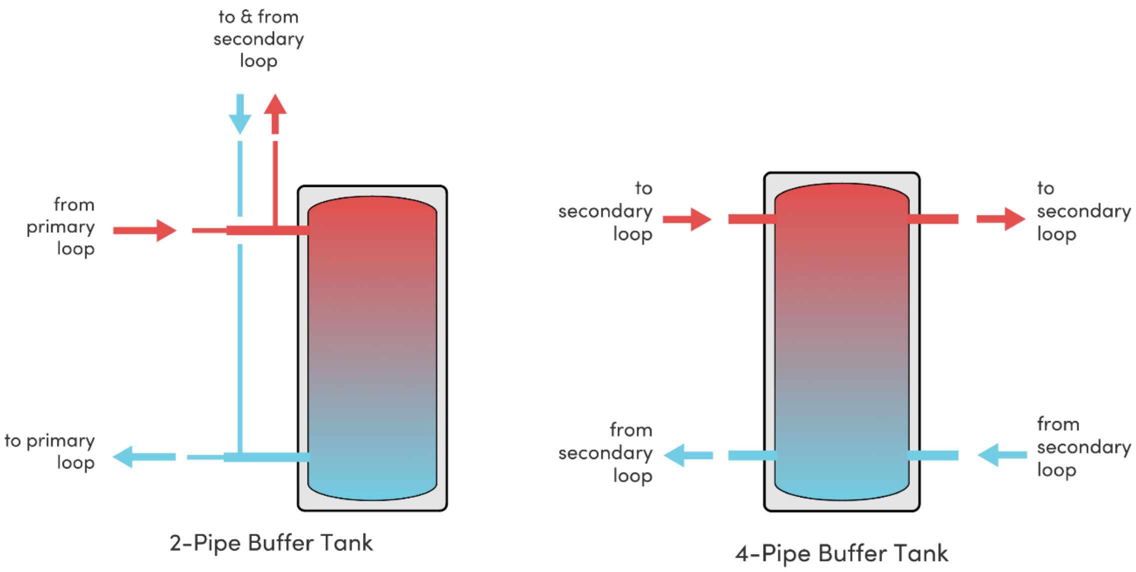
FIGURE 22: EFFECTIVE SYSTEM VOLUME

7.5.1.7.2. Buffer Tanks

Buffer tanks, often essential for meeting system volume requirements, are available in 2-pipe and 4-pipe configurations, as shown in Figure 23. These configurations are adaptable to various applications. In primary-secondary systems, buffer tanks commonly serve as hydraulic decouplers between the primary (heat pump) and the secondary loop(s).

The 4-pipe configuration connects the tank to the primary loop on one side and the load on the other. In this configuration, heated water from the primary loop flows through the tank's upper portion to the secondary loop, with cooler return water moving through the bottom connections.

On the other hand, the 2-pipe configuration joins the primary and secondary supply loops at the upper tank connection and the returns at the lower one. Here, only the differential flow between the loops passes through the tank. The 2-pipe configuration, due to its piping arrangement, facilitates quicker load response and better stratification, as it only handles the flow difference and allows direct primary to secondary system energy transfer without engaging the buffer tank's thermal mass. Large connections are crucial to minimize flow velocity and pressure drop; positioning the primary-secondary tees near the tank connections is advisable.

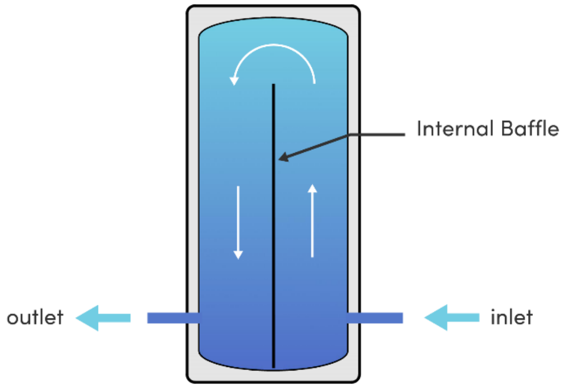


2-Pipe Buffer Tank

4-Pipe Buffer Tank

FIGURE 23: BUFFER TANK AS HYDRAULIC SEPARATOR CONFIGURATIONS

Inline tanks are used in primary-only systems to increase system volumes but are less effective than decoupled 4-pipe and 2-pipe systems due to reduced stratification. Buffer tanks in this configuration should include an internal baffle to prevent inlet flow from bypassing the tank volume directly to the outlet.



Inline Buffer Tank

FIGURE 24: IN-LINE BUFFER TANK

Bi-modal configurations are often necessary for heat pumps serving heating/cooling switchover loops. In heating-dominant applications, pipe the system to promote stratification in heating mode. For balanced heating and cooling needs, consider tanks piped to allow for flow reversal to encourage stratification in both modes of operation. This setup complicates the piping arrangement and often requires additional control valves. Inline buffer tanks with internal baffles can be effective in these scenarios.

General recommendations for all configurations include:

- Prefer vertical tanks to promote stratification. Consider multiple tanks piped in series if height, space, or structural constraints limit tank size.
- Ensure generously sized tank connections to reduce fluid velocity and preserve temperature stratification by avoiding fluid jets within the tank.
- Avoid vertical connections to maintain stratification. If unavoidable, ensure tanks are equipped with internal flow diffusers.
- Insulate tanks with a minimum RSI-2.1 (R-12) and preferably R-3.2 (R-18) or more for systems operating above 60°C (140°F). In cases with multiple smaller tanks, consider higher insulation values to offset the increased surface area-to-volume ratio.

7.5.1.7.3. Expansion Tanks

Where substantial system volume is added to the existing piping system, check the capacity of the existing expansion tank capacity to avoid pressure fluctuations and nuisance relief valve discharges caused by undersized expansion volume.

7.5.1.8. Condenser or Evaporator Circulators

Condenser and evaporator flow rates are often determined based on a selected temperature differential across the heat pump evaporator or condenser. Choose the design temperature differential based on the system operating temperature differentials instead of relying on rules of thumb. When heat pumps are sized for total heating capacity, the design temperature differential is based on the system's peak load and flow rate. Wherever possible, use actual data for retrofit applications.

For applications where the heat pump is not sized for total heating capacity, base the temperature differential and corresponding flow rate on the system temperature differential encountered when the heat pump fully loads, not the system design temperature differential. Sizing based on the system design temperature differential will result in an undersized pump, which will reduce the efficiency of the heat pump through almost the entire system operating range and, at worst, limit the heat pump output as it hits the upper limit of its supply temperature limits, even when the system requires temperature well below these upper limits. An example best illustrates this condition (see Figure 25).

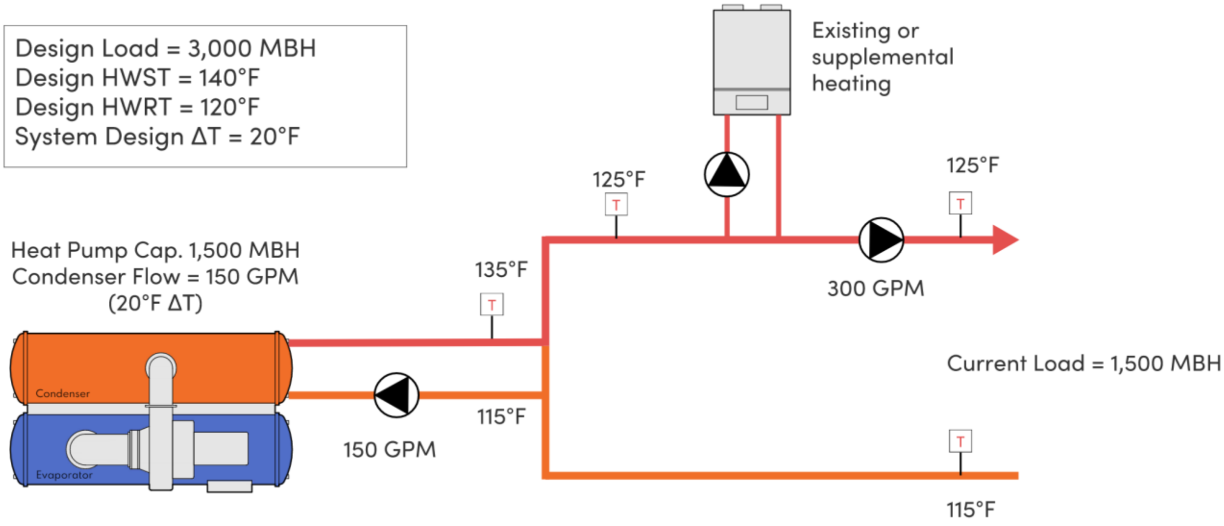


FIGURE 25: HEAT PUMP SIZED AT SYSTEM DESIGN TEMPERATURE DIFFERENTIAL

In the example illustrated in Figure 25, a heat pump has been retrofitted into an existing heating water system. The heat pump has been sized at 50% of the design heating load, which is anticipated to represent 80% of the annual heating energy requirements. The condenser pump has been sized on the system design temperature differential of 20°F, resulting in a condenser water pump size of 150 GPM, or half of the system design flow rate; however, the existing heating water system operates at constant flow. Consequently, the system operates at temperature differentials far below the design temperature differential of 20°F. Because of the undersized pump, the heat pump must deliver a supply water temperature above the system setpoint to meet the supply system temperature requirements.

Potential solutions to this issue include:

- Converting the existing heating water system to a variable flow system to maintain high-temperature differentials at part load by reducing the system flow rate.
- Sizing the heat pump circulator to match the system flow (while being careful not to exceed the maximum rated flow rate of the heat pump) to ensure the heat pump can fully load without generating excessively high water temperatures to maintain the system heating water supply temperature.

7.5.1.9. Single-Lift vs. Cascade Lift

In single-lift applications, a single heat pump generates useful heating and chilled water to serve both loads directly. In this configuration, the COP can be maximized since both sides of the refrigeration process are useful for meeting building loads.

On the other hand, a cascaded system relies on a combination of two refrigeration cycles to achieve the full lift. The first refrigeration machine is typically an existing cooling-only chiller or process cooling system. The heat pump evaporator is piped to the condenser side of the chiller to reclaim heat that would otherwise be rejected to the atmosphere.

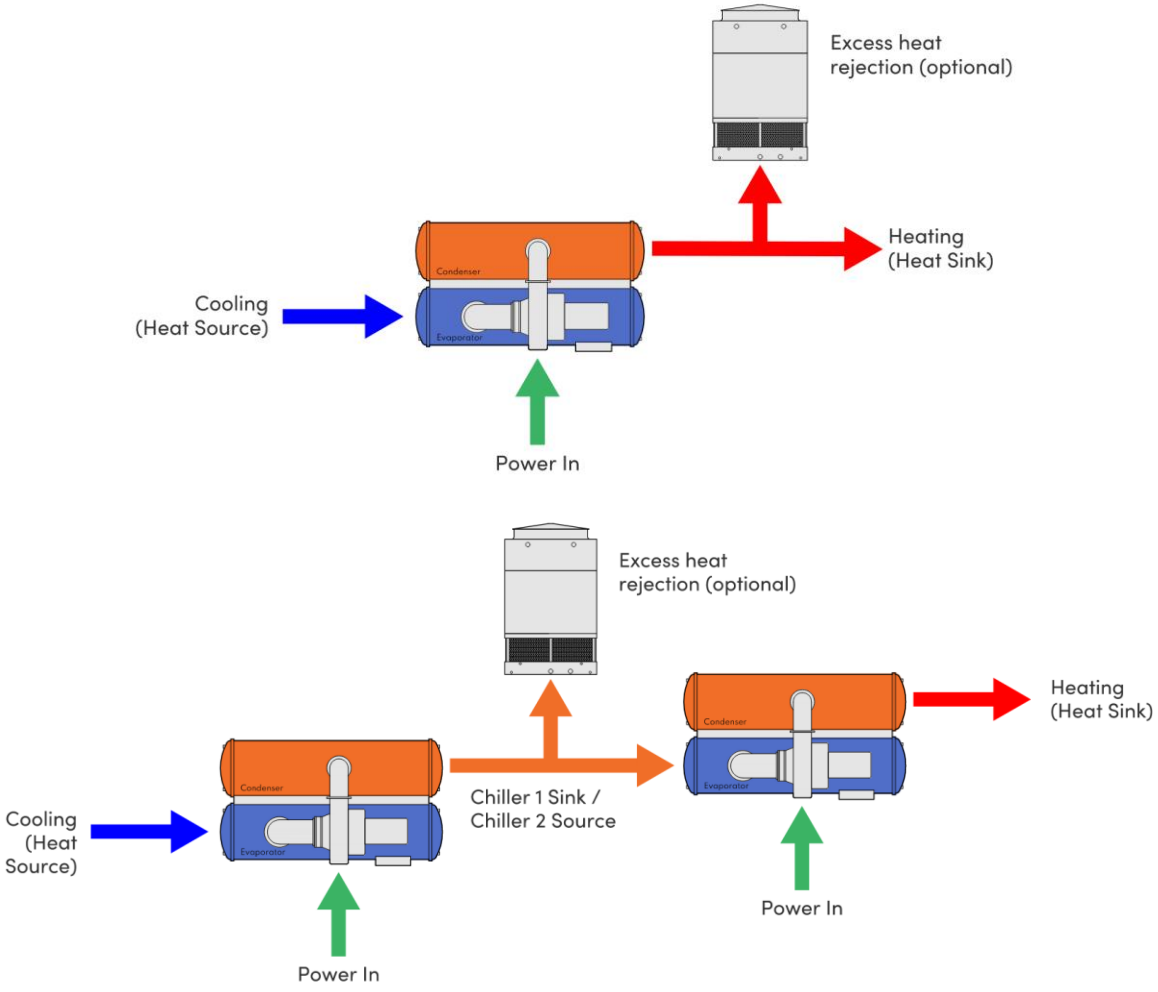


FIGURE 26: SINGLE VS. CASCADED LIFT CONFIGURATIONS

The efficiency of a cascaded configuration can be calculated using the formula in Figure 27. The COP of the cascaded system will always be less than the COP of the least efficient machine in the cascade, as illustrated in Figure 28.

$$\mathrm{COPh}_{\mathrm{cascade}} = \left(\frac{1}{\mathrm{COPh}_{\mathrm{stage\ 2}}} + \frac{1 - \frac{1}{\mathrm{COPh}_{\mathrm{stage2}}}}{\mathrm{COPh}_{\mathrm{stage1}}} \right)^{-1}$$

FIGURE 27: EFFICIENCY OF A CASCADED CONFIGURATION

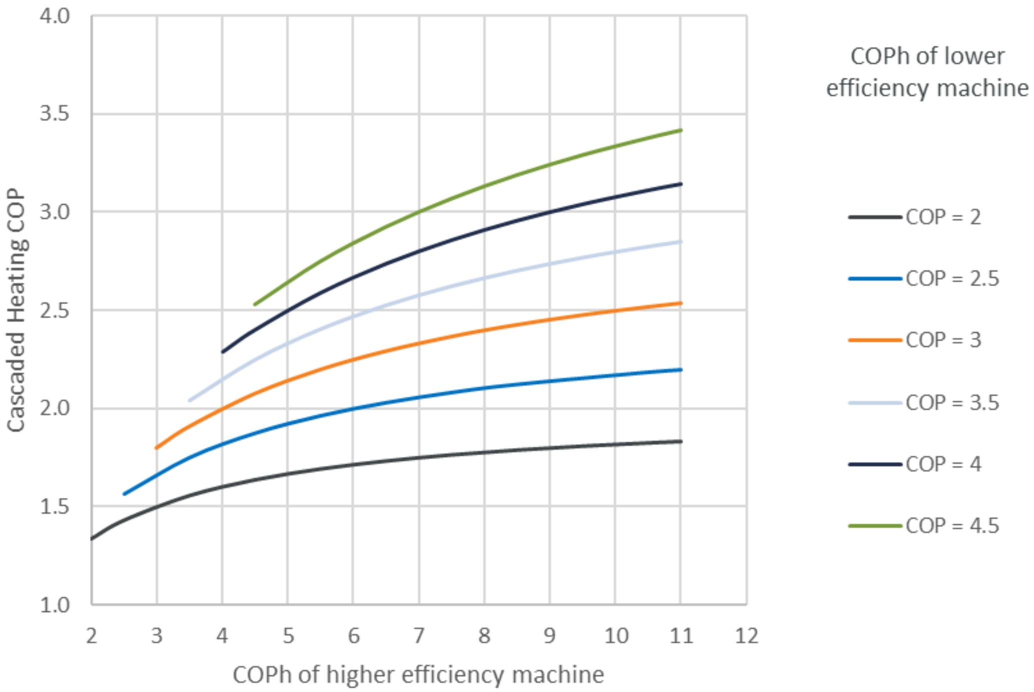


FIGURE 28: HEATING COP OF CASCADED HEAT PUMPS

Comparing the operating efficiency of single-lift and cascaded systems at a single operating condition can be misleading. Factor efficiency comparisons in expected early operating conditions to provide a helpful comparison.

For example, a cascaded system can allow tailoring of compressor types to specific lift conditions: more efficient centrifugal compressors can be used for the first stage, which can sometimes improve overall efficiency over a single lift application. Or, where cooling loads regularly exceed heating requirements, a cascaded system can allow waste heat to be rejected at lower temperatures than a single-lift configuration, improving overall system efficiency.

Consider a cascaded configuration:

- For high-lift applications where a single chiller cannot provide suitable temperatures.
- Where cooling-only chillers are not at end of life.
- Where cooling loads regularly exceed heating loads.
- Where a condenser loop serves smaller distributed water-cooled equipment rather than a single chiller, e.g. tenant cooling loops.
- For process applications that require lower condenser temperatures to operate effectively (e.g. arena refrigeration plants or cold storage facilities).

7.5.1.10. Thermal Energy Storage (TES)

Incorporating building-level thermal energy storage (TES) alongside heat pumps is a key technology for the decarbonization of new and existing buildings. TES can reduce energy use and costs, while also enhancing resilience during extreme weather and emergencies. Most practical TES systems rely on water as a storage medium, typically hot water, chilled water, or warm condenser water. Other storage media, such as phase change materials or sand, are under development but not yet widely available at a reasonable cost.

Table 12 outlines the many benefits associated with TES.

TABLE 12: THE BENEFITS OF THERMAL ENERGY STORAGE

BENEFIT CATEGORY	SPECIFIC BENEFITS
Cost Savings Potential	• Reduces energy costs through load shifting. • Allows for smaller backup/peaking generation. • Potential to downsize electrical and HVAC plant capacity. • Potential to avoid or mitigate electrical service upgrades.
System Efficiency	• Allows for effective reclaim of waste heat, asynchronous with load requirements.
Reliability	• +40-year service life • No storage degradation. • Reduces equipment short-cycling, reducing wear and tear on mechanical equipment. • Enhances building resilience
Flexibility	• Enables load flexibility and grid responsiveness. • Enables demand response without sacrificing comfort.

HVAC, refrigeration, and water heating account for approximately 50% of building energy consumption, and are the primary drivers of peak demand during summer and winter. Shifting these specific loads is more manageable compared with other internal building loads. By strategically shifting these thermal loads, it becomes possible to reduce peak demand.

Consider integration of TES for projects where any of the following are applicable:

- The maximum heating load is significantly higher than the average, valid for most "scheduled" buildings that are not occupied 24/7. Approach the application of TES with optimal start and temperature set-back analysis to reduce peak loads.
- Electric utility rate structures that include time-of-day demand rates, or incentives for peak demand management, are in place or anticipated to be brought into place within the service life of the mechanical equipment.
- Limited spare electrical capacity is available. In this case, weigh the cost of TES against the cost of service upgrades.

7.5.1.10.1. TES Sizing Considerations

Using actual building hourly heating and cooling load profiles over estimated loads is preferred when sizing TES for a specific application. Measure these profiles at or near design conditions, over several days to weeks. Measured load data can then be used to develop a calibrated sizing model of the building's design heating load profile.

When investigating TES sizing options, consider the following:

- **Peak Shifting:** For a typical 3-4 hour peak period, size the TES to handle a fraction or all of the heating capacity throughout the peak period. The optimal fraction of load met requires a cost-benefit approach based on potential demand savings.
- **Value Limitation:** At a certain size, increasing the TES further won't provide additional value since it won't reduce the heating source size, as the daily heating requirements remain unchanged.
- **Stress Testing:** Stress test the sizing for extreme conditions and Monday morning warm-up scenarios when downsizing heating plant equipment.

To validate TES sizing:

- Ensure the plant size is not less than the average daily load, as this is the smallest the heating plant can be to meet the heating load regardless of TES capacity.
- Consider that the higher the ratio of peak load to average load, the more potential there is for reducing the size of heating equipment.

7.5.1.11. Controls Sequences

The controls strategy for heat pump systems must be considered and understood as part of the design process, not left to the end of the design. A clear and well-communicated controls strategy is essential for the successful operation of any heat pump system. Retrofits can provide particular challenges, such as integrating existing backup heating sources and legacy controls systems.

At a minimum, consider and document the following items as part of the design:

- A list of the points that can be provided through heat pump network connections and the points that should be hardwired for stable and reliable system control.
- A clear understanding of how the manufacturer's heat pump controller operates. Each manufacturer has a different way of controlling their heat pump. Pay particular attention to how simultaneous heating/cooling is controlled for heat recovery chillers and how defrost cycles are coordinated for ASHP applications. It is important to understand upper and lower safety limits and document them clearly.
- A clear delineation between packaged equipment controls and the BAS.
- Clear controls strategies for sequencing heat pumps with backup or supplemental heating. This is essential to maximize the benefits of heat pumps. Ill-defined and unclear controls strategies can lead to operators manually bypassing heat pumps and limiting the extent to which they contribute to the heating supply.
- Details on how the induced cooling loads, such as exhaust reclaim or economizer operation, will be coordinated.

See Section 6.4 for additional considerations.

7.5.1.11.1. Demand Reset Strategies & Compressor Stage Changes.

Demand-based temperature reset strategies can help maximize the usefulness of a heat pump in retrofit applications by ensuring the hot water systems operate at the lowest temperature required to meet loads. ASHRAE Guideline 36 recommends utilizing trim & respond for temperature-based resets (ASHRAE, 2021). While these strategies are helpful, they do require tuning for successful operation. Additionally, it is essential that controls programming temporarily pauses temperature or pressure (i.e. flow) based demand resets during and after compressor staging to avoid short cycling or tripping compressors. This requirement includes pausing resets when individual compressors of modular heat pumps stage on or off.

Refer to Section 8.4.1.4 for more information on the implementation of demand-based resets.

7.5.2. Unitary ASHPs

Packaged rooftop air-source heat pumps (ASHPs) can provide heating, cooling, and ventilation like traditional rooftop units. Their rooftop location provides space efficiency, ease of installation, and reduced indoor noise, making them well-suited for small and medium-sized commercial buildings.

The benefits and challenges of unitary ASHPs are outlined in Table 13.

TABLE 13: THE BENEFITS AND CHALLENGES OF UNITARY ASHPS

BENEFITS	CHALLENGES
• Packaged rooftop ASHPs are efficient at providing both heating and cooling. • Single, pre-assembled, packaged unit makes installations simple and reduces the need for complex ductwork.	• In previously heating-only systems, existing ductwork networks may be insufficient to meet design cooling loads. • Packaged rooftop ASHPs are heavier than gas-fired models; structural upgrades can be costly if required. • Packaged units offer less customization and flexibility than split systems, which could be challenging if specific performance requirements or configurations are necessary. • ASHP efficiency decreases in cold climates and supplementary heating may be required.

7.5.3. Terminal Water-Source Heat Pumps

Terminal water-source heat pumps (WSHPs) are popular for medium-sized office and retail buildings in British Columbia due to their cost-effectiveness, high efficiency, and flexibility. WSHPs use a shared water piping loop as a heat source and sink, generally operating with a temperature range of 10°C (50°F) to 32°C (90°F). The mild operating temperatures of WSHP water loops are conducive to integrating various heat sources, including air-source, ground-source, sewer-source, or even solar thermal. Because of this, modern applications often use a low-carbon heating source as the primary source of heating and heat rejection, with boilers and cooling towers providing additional heating and cooling capacity as needed for peak loads, depending on the climate.

In existing buildings with hydronic loops and terminal WSHPs, electrification of the primary heat source is relatively straightforward as a retrofit, assuming sufficient space and electrical capacity are available. Individual heat pumps are typically installed in ceiling spaces, each serving a specific thermal zone or tenant.

7.5.4. Variable Refrigerant Flow (VRF) Systems

A Variable Refrigerant Flow (VRF) system is characterized by a single outdoor condensing unit connected to multiple indoor units, which can include wall-mounted or ceiling cassette fan coil units, air handling units (AHUs), or furnaces equipped with direct expansion (DX) coils. The defining characteristic of VRF systems is their ability to modulate the amount of refrigerant sent to each indoor unit, thereby precisely matching the specific heating or cooling demands of each space. This ability to efficiently control refrigerant can enhance energy savings and ensure optimal comfort.

VRF units can be configured as:

- **2-pipe systems**: This configuration requires all indoor units to be in the same mode – either heating or cooling – and is simpler and less expensive to install.
- **3-pipe systems**: This configuration enables the VRF to provide both heating and cooling simultaneously through different terminal units by allowing refrigerant to flow through three separate lines: one for heating, one for cooling, and one for return. This configuration also supports heat recovery between zones, improving energy efficiency and offering greater flexibility in temperature control.
- **Hybrid VRFs:** Hybrid VRF systems combine the efficiency of traditional VRF technology with the comfort and flexibility of hydronic systems. In this setup, refrigerant from the outdoor condensing unit is used to heat or cool water, which is then circulated to indoor units, typically fan coil units, via hydronic piping. The use of water instead of refrigerant improves safety while also reducing overall refrigerant volume, making it an environmentally friendly option. However, hybrid VRF systems require larger diameter hydronic piping than is typically found in existing buildings, and an additional module to transfer heat between the refrigerant and hydronic loops, which can increase installation and equipment costs.

FIGURE 29: VRF SYSTEM SCHEMATIC

The benefits and challenges of VRF systems are outlined in Table 14.

TABLE 14: THE BENEFITS AND CHALLENGES OF VRF SYSTEMS

BENEFITS	CHALLENGES
• Improved energy efficiency and zone temperature control as a result of the variable refrigerant control. • VRF systems are highly versatile and suitable for a range of building types and sizes. • 3-pipe VRF systems can provide simultaneous heating and cooling to different zones within a building.	• The initial installation cost of a VRF system can be higher than that of traditional systems. • While VRF systems are generally reliable, maintenance and repairs can be complex and costly. • Large VRF systems include substantial refrigerant volumes, posing a risk if there is a leak in the system. Utilize low GWP refrigerants to mitigate emissions associated with system leaks. • The performance of VRF systems declines in cold conditions, and may have limitations in extreme climates. This can require auxiliary heating sources or alternative placement of outdoor units.

Additional application considerations for VRF systems include:

- **System Compatibility and Integration:** Ensure the VRF system can be integrated into existing building infrastructure such as controls, sensors, and building automation systems to optimize overall HVAC performance.
- **Refrigerant Piping and Indoor Unit Placement:** Evaluate the feasibility of installing refrigerant piping and determine the optimal location for indoor units. Consider spatial constraints, architectural features that may affect the placement of indoor units and the routing of pipes. The ability to effectively distribute conditioned air to different zones is crucial for maximizing the benefits of a VRF system.

8. Heating, Ventilation, and Air Conditioning Systems

This chapter provides a framework for electrifying HVAC systems, including key design principles and strategies to successfully ready existing systems to integrate low-carbon heating technologies, with a focus on heat pumps. It aims to provide mechanical consultants who may not be familiar with existing building retrofits with guidance on key considerations for the electrification of HVAC systems in existing buildings.

This chapter is intended to guide consulting engineers when electrifying HVAC systems in existing buildings. The sections of this chapter are illustrated in Figure 30 in a loosely linear order; revisit and reconsider earlier assumptions or steps as required to optimize system design.

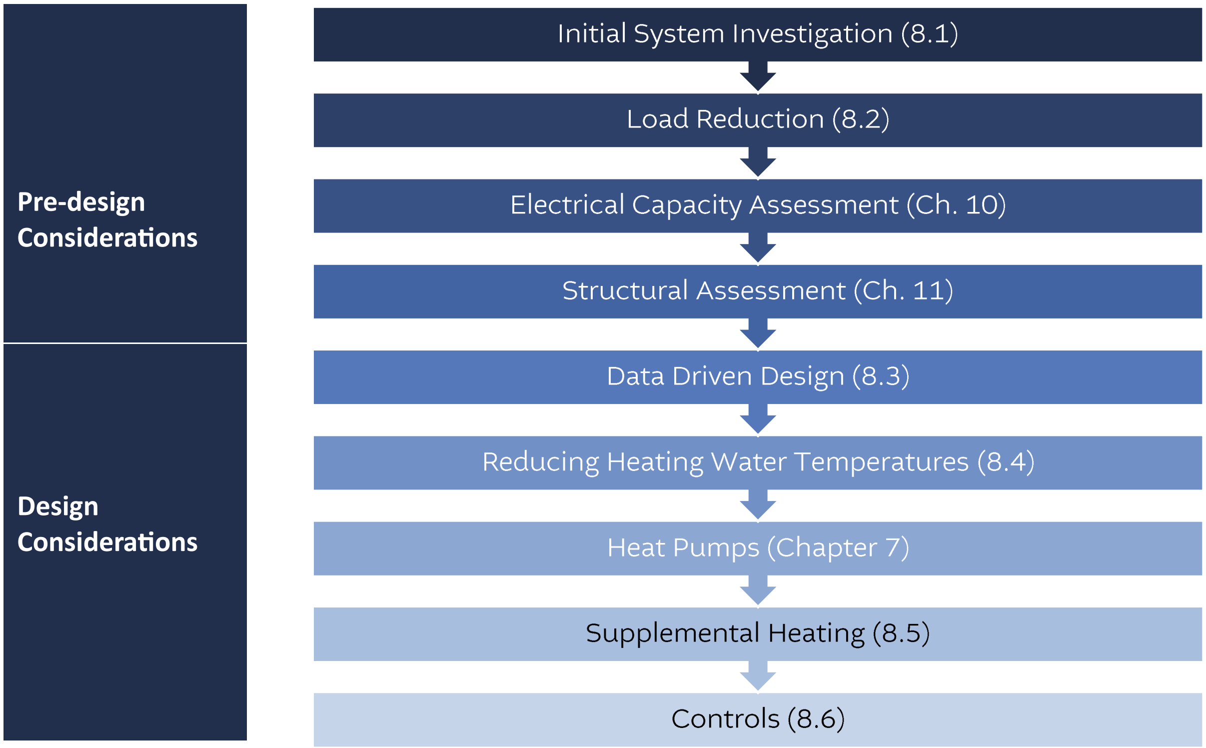


FIGURE 30: HVAC ELECTRIFICATION DESIGN PROCESS

Appendix 4: Example Pathways provides design trees for the electrification of common HVAC system types that follow the process outlined above. A list of resources that provide further guidance on the topics covered is included at the end of this chapter.

8.1. INITIAL SYSTEM INVESTIGATION

When approaching an electrification retrofit for an existing HVAC system, it is crucial to first understand its current configuration and operating condition. Conduct a comprehensive site assessment to collect necessary data and answer key questions. This section outlines the primary considerations for such an assessment, broken out by different types of building systems; a detailed checklist to guide the assessment can be found in

Appendix 3.1: Existing Ventilation System Assessment Checklist.

The first step in assessing an existing HVAC system is data collection, which includes determining what data is available to confirm current system operating characteristics. Building automation system (BAS) trend logs are beneficial for assessing energy performance and are further discussed in Section 8.3. Historical energy data is essential to understand natural gas and electricity consumption patterns.

8.1.1. Heating System

Consider the following factors when assessing the heating system: System configuration (central vs. distributed); equipment type; and the central equipment's fuel source, capacity, and efficiency. Evaluate the age and condition of the system and equipment, and any issues related to uneven heating or cold spots. Review maintenance history, efficiency upgrades, and modifications. Assess the system's ability to meet the building's heating load, especially during peak demand periods. Consider compliance with current building codes and level of integration with other HVAC components.

8.1.2. Cooling System

Identify the current type of cooling system, such as central air conditioning, split system, or ductless mini-split. Determine the age, condition, and primary equipment type for cooling. Assess how well the cooling system meets the building's cooling load, especially during peak periods. Consider energy efficiency ratings, maintenance history, recent repairs, compliance with building codes, and level of integration with other HVAC components.

8.1.3. Ventilation Systems

The following steps can be used as a guide for assessing existing ventilation systems:

1. Check code-required minimum ventilation rates.
2. Check existing ventilation rates.
3. Verify the condition of outside air dampers.
4. Check air filter integrity and level of filtration.
5. Confirm the accuracy of sensors.
6. Verify ventilation control systems.
7. Assess building pressure control
8. Review the effectiveness of existing energy recovery systems

For more information on each of these steps please refer to

Appendix 3.1: Existing Ventilation System Assessment Checklist. Appendix K of ASHRAE Standard 62.1 (ASHRAE, 2022) provides a comprehensive list of compliance suggestions which can be adapted as a field review checklist for pre-design investigation to review ventilation systems down to the zone level.

8.1.4. Distribution Systems and Terminal Units

Identify the type and condition of distribution systems, and consider whether replacement is necessary. The piping system configuration (2-pipe vs. 4-pipe) can impact what retrofit options are viable. Understanding system flow control can help identify potential upgrades to pumping that can improve system temperature differentials.

Identify the type of terminal units, such as fan coil units, VAV systems, or radiant panels. Evaluate the terminal units' age, condition, and type of controls system, and their integration with the overall HVAC system. Assess the condition of ductwork or piping connected to the terminal units.

8.1.5. Building Automation Systems

Assess the type, age, and components of the building automation system (BAS), including sensors, actuators, controllers, and user interfaces. Evaluate sensor accuracy, recent modifications, and BAS integration with HVAC systems. Consider controls strategies, energy monitoring capabilities, user interface, historical data storage, trend analysis tools, and vendor support. Older BAS systems may need to be upgraded to accommodate the sophisticated controls strategies, data trending, and storage capabilities required to operate some heat pump systems. Older pneumatic or analog controls may need to be replaced with direct digital controls integrated into the BAS in order to allow the sensor feedback that is required for demand-based reset strategies.

8.1.6. Operations & Occupant Concerns

Assessing occupant satisfaction involves understanding occupancy density and patterns, occupant comfort levels, and indoor air quality. Evaluate occupant satisfaction with the current heating and cooling system's performance and the availability of controls for temperature and airflow. Appendix L to ASHRAE Standard 55 provides guidance for assessing thermal comfort in existing buildings, including conducting occupant surveys (ASHRAE, 2017).

Include discussions with building operators in the initial system investigation to identify comfort concerns and understand operational and maintenance concerns and pain points.

8.2. LOAD REDUCTION

When considering the transition from gas-fired systems to electric alternatives, first look for opportunities to reduce building loads. These measures maximize efficiency, improve controls systems, and minimize energy waste in buildings, preparing them for electrification by optimizing operations and reducing electrical and heating load. They also allow buildings to operate at lower temperatures, enhancing their suitability for heat pump systems and allowing for smaller, more affordable equipment.

A summary of the load reduction strategies tied to relevant objectives is outlined in Table 15. More detailed information on specific measures is provided in the following sections.

TABLE 15: SUMMARY OF LOAD REDUCTION STRATEGIES

OBJECTIVE	INCREASE ELECTRICAL CAPACITY	IMPROVE CONTROLS SYSTEMS	REDUCE HEATING LOAD
Strategies	• Demand response. • Load management. • Advanced controls strategies.	• Add trending, sensors that can be used for low-carbon equipment design, installation, and commissioning. • Upgrade controllers.	• Advanced controls strategies. • Reduce waste (control based on demand). • Improve building envelope. • Heat recovery.

Beyond readying a building for low-carbon electric equipment, reducing building load can result in significant energy and cost savings. Load reduction measures can also provide the following benefits:

- **Operator Buy-In for Future Electrification:** Starting with these measures before delving into more intricate capital upgrade projects can serve as an effective way to obtain operator buy-in and support.
- **Enhances Building Comfort and Value:** Energy-efficiency upgrades frequently result in enhanced indoor comfort, air quality, and overall building performance. These improvements can boost worker productivity and enhance the appeal of the building to potential tenants or buyers. Moreover, high-performing buildings are more likely to receive proper maintenance over time, thereby ensuring that the energy savings are sustained.
- **Demonstrates Progress:** Improving energy efficiency can be a tangible and measurable step toward electrification. When combined with baselining and benchmarking efforts, it allows building owners, communities, and governments to see immediate, and often substantial, reductions in energy use and GHG emissions, providing proof of progress in the broader electrification effort.

Incentives for conducting energy studies on low- and no-cost measures can be accessed through programs like the BC Hydro/FortisBC Continuous Optimization Program (C-Op).

8.2.1. Load Reduction Opportunity Assessment

The relative priority and level of effort warranted for load reduction measures in a building can be determined based on considerations such as:

- **Existing Building Performance:** High-performing buildings often have less room for improvement than buildings that have higher energy use intensity (EUI).

- **Ratio of Peak to Average Heating Demand:** Analyze daily heating demand patterns to determine whether heating demand remains relatively constant throughout the day, or if there are shorter periods of higher demand. Buildings with higher ratios of peak demand to average demand have more potential for reducing peak heating loads through controls optimization.
- **Available Spare Electrical Service Capacity:** Comparing existing peak electrical demand to service capacity and preliminary estimates for sizing of electrified heating equipment can help determine whether load reduction opportunities are likely to have an impact on whether or not an electric service upgrade is likely to be required. Note that even if the service size is adequate, upgrades to the building's electrical distribution may still be required to accommodate new equipment.
- **Existing Hot Water Supply Temperatures in the Building:** If these are already relatively low, less optimization or modification may be required for a heat pump to work effectively.
- **Presence (or Absence) of Comprehensive BAS Controls**: If there is no controls system, there may be less optimization opportunity; however, there will likely be a stronger case for the installation of a controls system as part of the load reduction step.

8.2.2. BAS Strategies for Load Reduction

Building automation systems are fundamental to modern HVAC systems. Proper design and operation of the BAS are critical for ensuring reliable and efficient HVAC system performance and maintaining acceptable indoor environmental quality. A well-implemented BAS can optimize energy use, enhance occupant comfort, and provide real-time monitoring. Conversely, a poorly designed or implemented BAS can lead to excessive energy consumption, increased operational costs, and poor indoor conditions. Review the following BAS strategies and, if applicable, implement them as part of load reduction:

- Scheduling and optimal start.
- Dual maximum VAV.
- Demand-based resets.
- Demand controlled ventilation.
- High performance sequences.
- Demand response/load shedding.

For more detailed information on each of these strategies, please see Appendix 3.2: BAS Strategies for Load Reduction.

8.2.3. Load Reduction Through Heat Recovery

Recovering and re-using heat in a building can reduce overall heat and energy demand. Ideally, low-carbon systems should use a combination of passive- and active-heat recovery: passive-heat recovery to minimize peak heating and cooling loads, and active-heat recovery in larger buildings to offset hydronic heating loads throughout the year and maximize GHG emissions reductions.

8.2.3.1. Passive Heat Recovery

Passive air-to-air heat recovery systems, including fixed-plate heat exchangers and enthalpy wheels, can significantly reduce peak ventilation heating loads. They are highly effective during cold outdoor air temperatures, and can lead to notable decreases in peak electrical demand during winter when there is no need for compressor operation to reclaim heat. Total energy recovery devices can also effectively reduce peak cooling loads during summer.

Compared with active-heat recovery, the primary limitations of passive-heat recovery are lack of flexibility and dependence on outdoor temperature. Because passive-heat recovery depends on the direct energy transfer between two air streams, recovered heat cannot be readily used for other heating loads within a building. Additionally, because the amount of heat transfer is driven by the temperature differential between the air streams, the outdoor air temperature significantly impacts the amount of heat that can be recovered.

8.2.3.2. Active Heat Recovery

Unlike passive-heat recovery, active-heat recovery does not reduce peak heating loads, as compressor-based heating systems are required to extract heat from the exhaust air using chilled water. However, active-heat recovery has the potential to provide more heat than passive-heat recovery since the amount of heat reclaimed is not dependent on the temperature of outdoor air. Additionally, heat reclaimed through active recovery can be moved to other loads in the building such as perimeter heating, reheat coils, or domestic hot water.

Where active exhaust heat recovery is not feasible, load-shedding economizers can be used to induce mechanical cooling loads when heating is required within the building. Refer to Section 7.3 for more information on active-heat recovery as a heat source for heat pump systems.

8.2.4. Envelope Improvements

Improving a building’s enclosure can substantially reduce space heating demand while ensuring comfortable indoor air temperatures and can be an ideal complement to low-carbon electrification efforts – under certain conditions.

The positive impact of envelope improvements on heating water temperature requirements can be estimated using the formula in Figure 31. While this estimate does not replace detailed design calculations, it can help inform initial consideration of the potential impact of envelope improvement on the heating system.

$$HWST_{new} = T_{indoor} + \frac{Q_{new}}{Q_{old}}(HWST_{old} - T_{indoor})$$

FIGURE 31: IMPACT OF ENVELOPE IMPROVEMENTS ON HW TEMPERATURE REQUIREMENTS

While envelope improvements alone may not reduce heating water temperatures at design load conditions to ranges suitable for heat pumps, they may translate to reductions at part load that can allow most heating loads to be met with heat pumps during part-load conditions. Table 16 summarizes potential hot water supply temperature (HWST) reduction based on improvement in the building envelope for various starting HWSTs.

TABLE 16: HWS TEMPERATURE REDUCTION OPPORTUNITIES

Heat Loss (Q_{new} / Q_{old})	Required HWS Temperature, °C (°F)				
100%	82 (180)	77 (170)	71 (160)	66 (150)	60 (140)
95%	79 (175)	74 (165)	69 (156)	64 (146)	58 (137)
90%	76 (169)	71 (160)	66 (151)	62 (142)	56 (133)
85%	73 (164)	69 (155)	64 (147)	59 (138)	54 (130)
80%	70 (158)	66 (150)	61 (142)	57 (134)	52 (126)

More information on specific building envelope upgrades and considerations can be found in Chapter 12.

8.3. DATA DRIVEN DESIGN

Retrofit projects offer an opportunity to make design decisions based on real building performance data, rather than relying solely on load calculations and energy models. This process is called data-driven design.

Relying on general standards, rules of thumb, or direct replacement of existing system sizes can lead to oversized equipment. This is especially important to avoid with respect to high-efficiency electrification technologies, as their costs increase significantly with capacity (see Figure 35).

A data-driven approach to designing electrification retrofits minimizes guesswork, reduces risks, and maximizes return on investment through right-sizing. It ensures that retrofit measures are tailored to the specific needs of the existing building. Leveraging existing building data facilitates:

- **Identifying System Sizing Issues:** Load profiles can help identify whether HVAC systems are oversized or undersized. This knowledge can prevent inefficient operation, ensure systems are appropriately scaled to meet demand, and help select equipment with sufficient turn-down to provide stable operation during part-load conditions. When full load coverage by heat pumps is not feasible due to site or project constraints, load profiles can provide the data necessary to make informed decisions on heat pump sizing, maximizing GHG emissions reduction impact within project budget or technical constraints.

- **Calibration of Design Calculations:** By including load calculations and energy models, designers can improve predictions on potential energy, operating cost, and GHG emissions of proposed system upgrades.

- **Detecting Operational Deficiencies:** Analyzing load profiles can facilitate the identification of deficiencies in the operation of HVAC systems, leading to more efficient troubleshooting and maintenance practices.
- **Identifying Opportunities for Load Reduction and Heat Reclaim:** Load profiles can highlight simultaneous heating and cooling loads within a building, presenting opportunities to reclaim heat. They can also help identify suitable load-reduction strategies. This includes potential opportunities to improve building efficiency through BAS controls logic modifications (see Section 8.2.2).
- **Leveraging Thermal Storage**: Understanding daily load profiles can enable the strategic use of thermal storage to mitigate peak loads, which can be particularly beneficial in managing energy costs and improving system performance during high-demand periods.

8.3.1. Sources of Data

Data sources that can be used for data-driven design include:

- **Utility Data:** Utility data can provide historical energy consumption and peak demand information, clearly showing a building's energy use patterns. Analyzing this data can help to identify inefficiencies, seasonal variations, and potential areas for improvement. This information is also helpful for early benchmarking of a building's energy use, operating costs, and GHG emissions.
- **BAS Data:** Data from the BAS can provide real-time insights into the operation of specific HVAC systems and components, helping to pinpoint underperforming systems, diagnose operational issues, understand system interactions, and identify the root cause of inefficiencies noted in utility data analysis. BAS data can also be used to create “virtual” meters to determine heating and cooling loads where sub-metering is absent, such as by using supply and return water temperature sensors together with pump flow rates from balancing reports.
- **Sub-metering:** where utility and BAS data do not provide sufficient information or detail, temporary or permanent sub-meters can be useful for providing granular information on specific systems.

8.3.2. Collecting Data

Identify the data needs of the project as early as possible. Ideally, collect and analyze a year's worth of data to understand the HVAC system's operation throughout different seasons. If this is not possible, gather data during the peak heating season, to ensure the most relevant and valuable information is collected for equipment sizing and selection.

Gathering long-term trending of specific data points often requires collaboration with the existing controls service contractor to set up long-term trending or add additional sensors. To avoid data loss, ensure operators understand the importance of these long-term trends. Periodically downloading trend data can help maintain its availability. Where permanent sensors are not available and installing them is not feasible, it may be necessary to install temporary sensors and data loggers to monitor key parameters.

8.3.3. Understanding Load Profiles

Heating and cooling load profiles are essential for understanding the operating characteristics of existing HVAC systems. They offer valuable insights that can inform critical aspects of building management and system optimization, including:

- **Identifying System Sizing Issues:** Load profiles can help identify whether HVAC systems are oversized or undersized. This knowledge can prevent inefficient operation and ensure systems are appropriately scaled to meet demand.
- **Detecting Operational Deficiencies:** Analyzing load profiles can facilitate the identification of deficiencies in the operation of HVAC systems, leading to more efficient troubleshooting and maintenance practices.
- **Identifying Opportunities for Heat Reclaim:** Load profiles can highlight simultaneous heating and cooling loads within a building, presenting opportunities to reclaim heat.
- **Leveraging Thermal Storage**: Understanding daily load profiles can enable the strategic use of thermal storage to mitigate peak loads, which can be particularly beneficial in managing energy costs and improving system performance during high-demand periods.
- **Informing Heat Pump Sizing:** When full load coverage by heat pumps is not feasible due to site or project constraints, load profiles can provide the data necessary to make informed decisions on heat pump sizing, maximizing GHG emissions reduction impact within project budget or technical constraints.

Each type of load profile serves different purposes, making it crucial to understand their usefulness in various contexts.

8.3.3.1. Peak Heating and Cooling Loads

Building equipment is typically designed for peak heating or cooling loads, which may only occur infrequently. For existing buildings, peak loads can be measured through BAS trend data. Ideally, this data is collected at or near peak ambient conditions. Compare measured heating and cooling loads against those determined through traditional sizing calculations to ensure the accuracy of the results. Significant deviations between estimated and actual loads could indicate operational issues or a lack of capacity, which can result in wasted energy use or occupant comfort issues.

8.3.3.2. Daily Load Profiles

Daily load profiles can help identify opportunities and measures to reduce peak loads, such as pre-cooling or pre-heating strategies, and assist in determining the effectiveness of thermal energy storage in reducing peak demands. As demand on the grid increases, it is expected that building owners will face time-of-day demand billing during heating or cooling seasons within the next decade. An understanding of how peak daily loads align with grid capacity can inform decisions on system configuration and operational flexibility to reduce operating costs.

Design day load profiles are constructed based on design day ambient conditions for heating and cooling, which are often derived from historical weather data or ASHRAE climatic data. These profiles simulate how the building load varies on the hottest or coldest days of the year. In existing buildings, this simulation can often be validated with real data from days that are close to design conditions. Considering design day load profiles during equipment sizing can help to ensure that a heat pump system can handle extreme conditions without oversizing it for most of the year when the load is significantly lower.

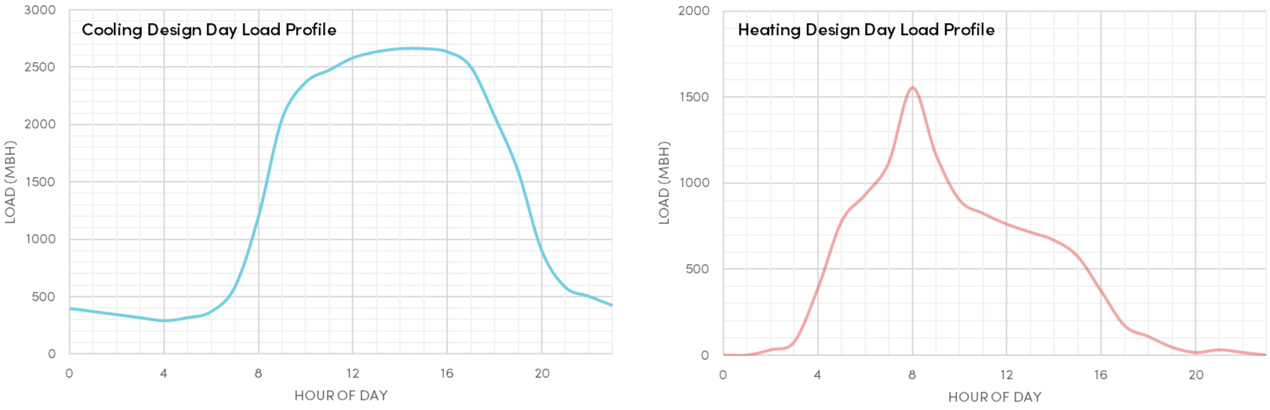


FIGURE 32: EXAMPLE DESIGN DAY LOAD PROFILES

8.3.3.3. Annual Load Profiles

Annual load profiles capture the heating and cooling demands of a building over the course of a year. These profiles illustrate how loads fluctuate due to seasonal changes, daily temperature variations, and other factors such as seasonal occupancy trends.

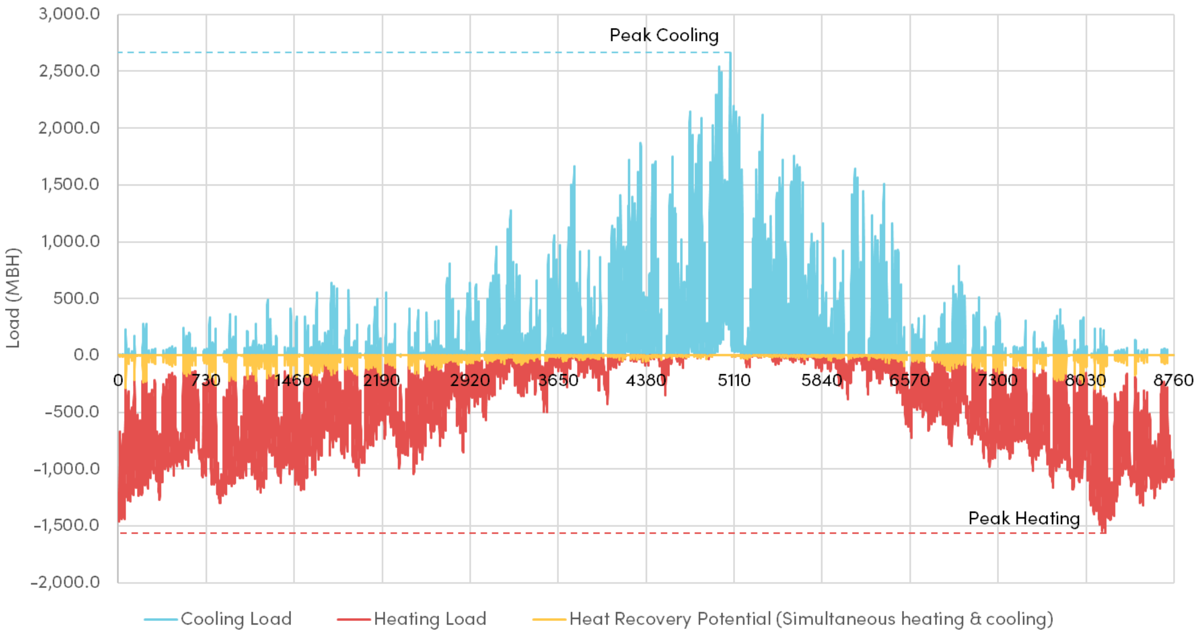


FIGURE 33: EXAMPLE ANNUAL HEATING AND COOLING LOAD PROFILE

A load duration curve is a graphical representation of an annual load profile that shows the relationship between the magnitude of a load and the percentage of time that load is equalled or exceeded over a specific period. Load duration curves are extremely useful for equipment sizing because they provide insights into how often different levels of demand occur. Additionally, load duration curves can assist with:

- **Identifying Part Load Conditions:** The curve indicates periods when the load is lower than the peak demand. Most of the year, systems operate under partial load conditions. Understanding the common part-load conditions can help specify equipment configurations and capacity control requirements that ensure reliable operation with minimal short-cycling of equipment.
- **Determining Backup or Supplemental Heating Needs:** For systems where the peak demand occurs infrequently, it is often more cost-effective to use a heat pump system sized at less than peak load and rely on a supplemental heating system to augment or fully cover the peak heating load. Refer to Chapter 7 for more information.
- **Energy Efficiency and Cost Analysis:** The area under the curve represents the annual heating or cooling energy that must be supplied or removed from the building. Load duration curves can be used to quickly assess the potential energy- and carbon-savings and associated operating costs of different system configurations.

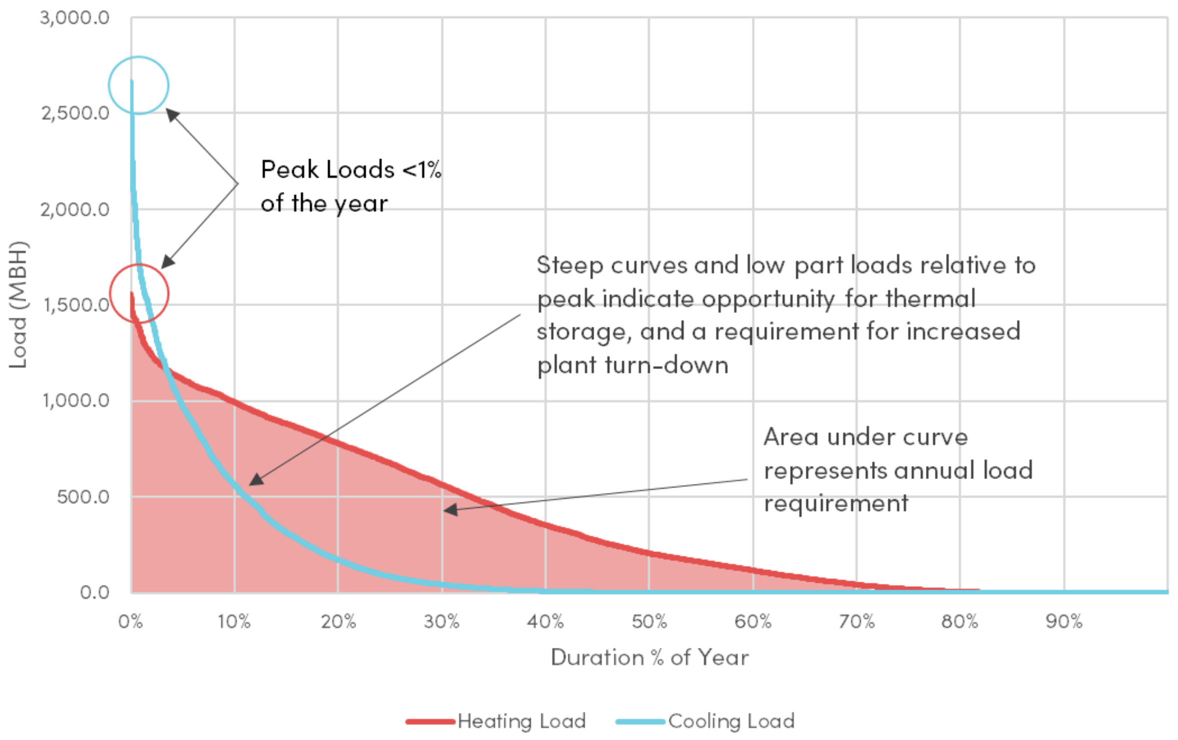


FIGURE 34: EXAMPLE LOAD DURATION CURVE

8.3.4. Right Sizing

Past engineering practices often led to the significant oversizing of heating systems. Recent studies have found that, on average, hot water plants in commercial buildings are oversized by a factor of two, even after accounting for intentional redundancy (Raftery, 2024). This oversizing can be attributed to several factors:

- **Conservative Heating Load Calculations:** Conventional heating load calculations often use steady-state calculations that ignore the thermal mass effects of buildings. These calculations assume design ventilation rates at the outdoor air heating design condition with no internal loads. However, peak heating conditions frequently occur during night setback periods when ventilation systems are not operating or during occupied periods when internal gains are present.
- **Oversizing Factors:** Applying an oversizing factor of 25% is typical for morning warmup periods. In some cases, designers have applied oversizing factors of 50% or more.
- **Discrete Equipment Sizes**: Heating equipment is available in discrete sizes, and designers often round up to the next larger equipment size because the incremental cost of larger boilers is relatively low.

While the traditional approach of oversizing might have been considered acceptable due to the relatively low cost of larger boilers, this practice can significantly impact the feasibility and cost of heat pump retrofit projects. Heat pumps typically require much more physical space per unit of heating capacity than boilers, and their equipment costs can be 4-6 times higher for comparable capacities. This relationship is illustrated in Figure 35.

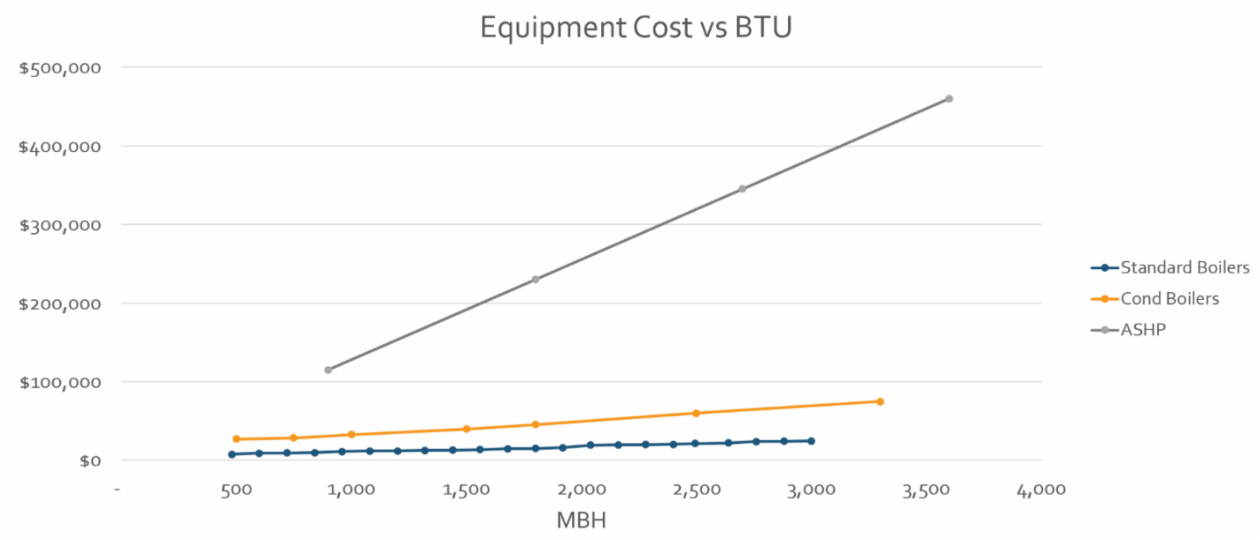


FIGURE 35: EQUIPMENT COST GRAPH

Moreover, needless oversizing of heat pump systems can result in operational issues such as short-cycling, which reduces equipment longevity and creates operational instability as compressors cycle on and off frequently. Oversizing also increases equipment impact on building structural capacity and electrical infrastructure, and may trigger otherwise unnecessary upgrades.

Considering these factors, rightsizing for heat pump applications is critical. Using data from existing operations provides the designer with information that can be relied on to make informed decisions on system sizing. Consider the following when utilizing existing data to size equipment:

- **Use Measured Data:** For accurate load predictions, turn off nighttime setback during monitoring to separate the effects of morning warmup. Morning warmup increases peak heating loads as the system quickly attempts to recover from night setbacks. These loads tend to reflect the installed capacity of the heating equipment rather than the actual heating load. Heat pump system design should consider the planned night setback and warmup strategy.
- **Develop Load Regressions:** If measured data for peak conditions is not available, off-peak data can be used, with caution, to develop a load regression based on outdoor air temperature to estimate peak loads.
- **Time-Average Data:** Apply time-averaging to trended data. Instantaneous values recorded by trended points may reflect transient spikes that are not representative of peak heating demand. Consider averaging values over 30 to 60 minutes to evaluate the peak heating load accurately.

Refer to Chapter 7 for additional considerations on heat pump sizing and selection.

8.3.5. Future Proofing

When designing and selecting technologies for LCE projects, consider the current building requirements, based on building performance data, and building requirements dictated by the external environment. This includes factors like future cooling and air filtration needs, building owner plans and agendas, and compliance with updated codes or performance standards.

8.3.5.1. Climate Change

As global temperatures rise due to climate change, buildings will face increased cooling demands. Higher outdoor temperatures and humidity levels will put additional strain on these systems, leading to greater energy needs for cooling and dehumidification. Consider these heightened cooling requirements during the planning phase of electrification projects to ensure that the chosen systems can meet the building's needs throughout their operational life. Strategies to address these challenges might include passive energy recovery for dehumidification or increasing the size of cooling plants.

8.3.5.2. Building Owner Plans

Consider any plans for building expansions or renovations that might impact the HVAC system requirements, including planned changes to occupancy or building use. Identify these plans early so they can be considered and accounted for in the design process.

8.3.5.3. Code Considerations

Electrifying HVAC systems offers an opportunity to comply with current or anticipated codes and standards. Key considerations include energy efficiency or GHG intensity requirements, ventilation standards (see Section 8.1.3), refrigerant management, exhaust system standards, and fire and safety regulations. If the existing system fails to meet any codes or requirements, consider including updates in the electrification design to ensure the new system is code-compliant; inspectors often have discretion to withhold approval until system-adjacent deficiencies are addressed, even if these items were not within the direct scope of the project.

8.4. REDUCE HEATING WATER TEMPERATURES

For hot-water-based heating systems, required heating water temperatures can often be the most significant impediment to efficiently electrifying a building's heating system. In buildings built before the turn of the century, it is common to have designed hot water heating temperatures in the range of 82°C to 93°C (180°F to 200°F).

Since heating load calculations do not account for internal gains from people, equipment, and lighting, most of these systems typically operate at lower peak heating water temperatures of around 70°C to 85°C (158°F to 185°F) and lower during off-peak conditions. However, even these lower temperatures can limit the application of heat pump technology in existing buildings.

This section covers strategies and considerations for reducing heating water temperatures.

8.4.1. Cold Temperature Thermal Stress Test

An essential first step in the hot water temperature reduction process is to conduct a cold temperature thermal stress test to evaluate the existing heating system's potential compatibility with lower heating water temperatures and the integration of heat pumps.

Testing should ideally be completed during the peak heating seasons and last between two weeks and a month. The test involves periodic reductions in hot water supply water temperatures accompanied by monitoring to assess the impact on the building. Two stress test methods are presented below: one is an automated test for buildings with a BAS; the other is a manual test method that can be applied to any hot water system, irrespective of controls infrastructure.

8.4.1.1. Pre-Test Readiness

Before starting the test, complete a review of the heating systems to verify proper operation and identify any existing issues that may hinder the test. This step aims to identify any operational concerns in the heating system that could invalidate the testing results.

Turn off unoccupied setbacks during the test to provide an accurate representation of the peak heating loads for the building. Morning warmup can impart a false peak load as existing heating equipment ramps up to its maximum capacity to bring the building back to temperature as quickly as possible; this heating rate depends more on the existing equipment's installed capacity than the building heating loads. Refer to Appendix 3.2: BAS Strategies for Load Reduction for more about nighttime setbacks and electrified heating systems' optimal start considerations.

8.4.1.2. System Monitoring Requirements

For both test methods, ensure the following system monitoring is in place, either through permanent sensors and controls systems or through temporary data loggers:

- **Outdoor Air Temperature**: Monitoring outdoor air temperature at regular intervals during the test can help with understanding the building's temperature dependence. These readings can also be used to develop a heating curve regression should the testing period not coincide with peak heating conditions.

- **Zone Temperature Sensors:** Monitor space temperature to determine if lowered heating water temperatures can maintain adequate thermal comfort within occupied spaces. Data loggers may be required within key spaces when the building lacks a BAS. Consult building operators and tenants to identify spaces often perceived as cold during the heating season, crucial candidates for temperature logging.

- **Hot Water Supply Temperature:** Correlate hot water supply temperature (HWST) trends with outdoor air temperature and zone temperatures. Again, use a data logger if this information is unavailable through a BAS system or boiler controller.

In addition to the data above, enable zone temperature alarms for buildings with a BAS.

8.4.1.3. Manual Testing Method

Manual testing involves resetting the hot water supply temperature to the terminal devices incrementally and monitoring the building to determine the results of the lower heating water temperatures. Where buildings do not have networked temperature sensors capable of trend logging, let occupants know the test is being conducted so they can flag temperature issues in their space during the test. In systems with conventional boilers, where reductions in HWST results in the hot water return temperature (HWRT) dropping below the threshold where condensation of water vapour in the flue gasses can occur (~55°C), take care to avoid prolonged periods of condensation which could damage equipment. Figure 36 outlines the testing process.

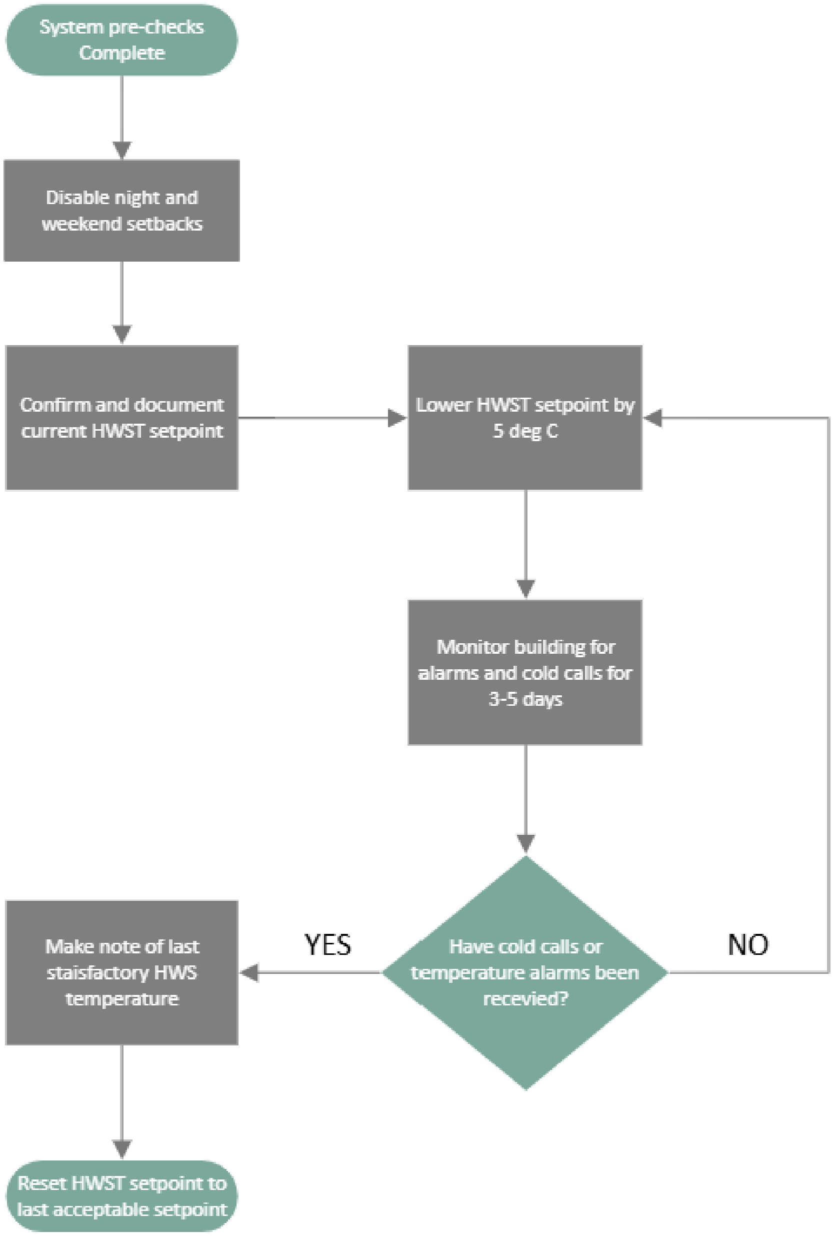


FIGURE 36: TEMPERATURE STRESS TEST - MANUAL APPROACH

8.4.1.4. Automated Test Method – Demand-Based Reset

The automated approach implements a demand-based temperature reset of the heating systems based on zone requirements. There are numerous ways to accomplish this; the method outlined below is based on the trim & respond (T&R) demand-based reset strategy sequence of operation (SOO) included in ASHRAE Guideline 36 (ASHRAE, 2021). Note that a BAS with zone-level control is a prerequisite for this test method.

This modified method of T&R reset includes upper and lower temperature limits that are reset based on outdoor air temperature. The purpose of this is twofold:

- It limits the upper heating water setpoint to the existing system operation.
- It provides a suitable starting point for the heating system's initial heating water temperature setpoint on startup of the system.

Starting the system with a fixed-design heating setpoint can drive the heating plant to overshoot and cycle during low-load conditions. Conversely, setting the initial setpoint at a low setpoint can result in long system response times, which can result in erroneous temperature alarms. Figure 37 illustrates the reset logic.

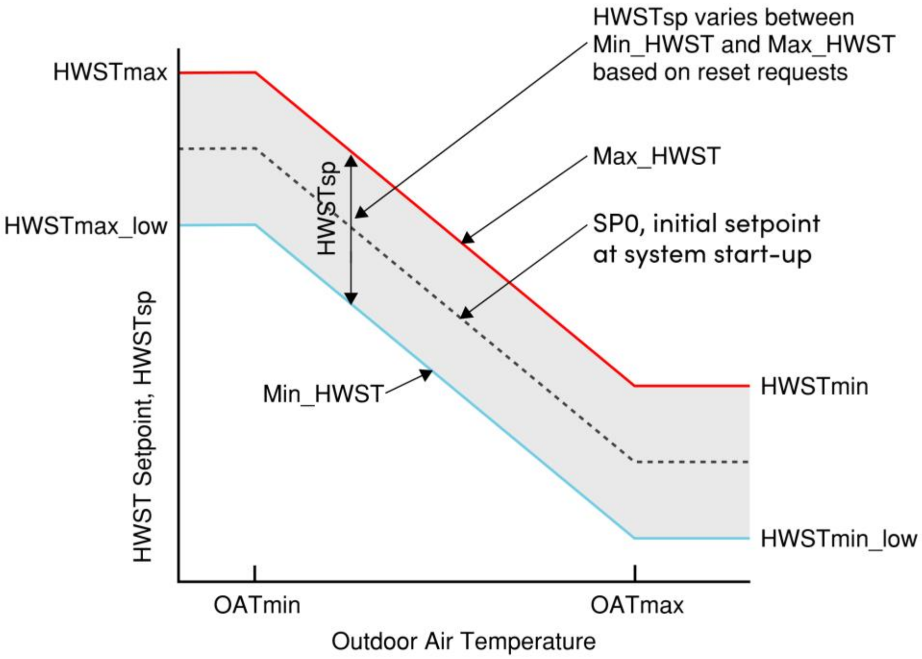


FIGURE 37: GRAPHIC REPRESENTATION OF T&R HEATING WATER RESET STRATEGY

This testing method minimizes thermal comfort complaints because the system automatically adapts to zone requests for heat. This method can provide a clear picture of daily and weekly hot water temperature requirements as influenced by changes in outdoor air temperature, solar gains, and building occupancy. Another benefit of this approach is that zones driving the temperature reset can be identified through the BAS. This information helps inform a targeted approach to terminal unit retrofits.

The main drawback of this method is the upfront effort required to implement it. However, once successfully implemented, this strategy can be left in place as a permanent SOO with energy-saving benefits. Accordingly, it is often best accomplished along with other controls modifications identified to reduce heating demand and energy use. Refer to Section 8.2.2 for more information about this method.

8.4.2. Modify Morning Warmup Routine

Commercial buildings commonly utilize nighttime setback temperatures to reduce heating loads during non-occupied hours. Recovery from night setback temperatures, commonly referred to as "morning warmup", is the period after setback during which the heating system operates to recover space temperatures from setback temperatures.

Optimal start control algorithms are often used to manage morning warmup, typically waiting as long as possible before starting the HVAC systems and recovering space temperatures as quickly as possible before scheduled occupancy. While the conventional wisdom is that short warmup periods maximize energy savings, recovering zone temperatures as quickly as possible creates large peak heating loads, often more representative of the installed heating capacity versus the actual steady-state heating needs of the building. For all-electric heating plants, these large peak loads drive up utility demand charges. They can also encourage the oversizing of replacement equipment when designers use these measured peaks for sizing. For hybrid plants, short warmup periods can increase energy use and GHG emissions as large peak loads during morning warmup cause gas-fired systems to operate, even during mild conditions.

Preliminary research suggests that conventional warmup routines may not be appropriate for electrified heating systems (Cheng H. R., 2024). A long warmup period of up to 3 hours, with ramped zone setpoint reset and optimal start tuning, can significantly reduce peak heating loads while achieving similar energy performance to shorter warmup periods. It is recommended to test this strategy on existing buildings pre-retrofit.

FIGURE 1 Morning warm-up strategies.

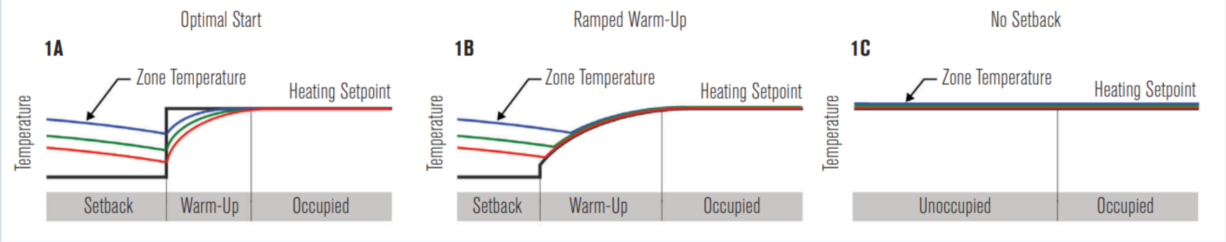


FIGURE 2 Associated heating loads.

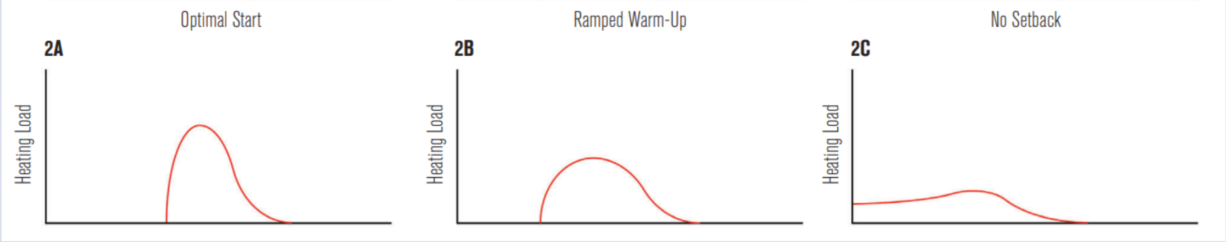


FIGURE 38: ILLUSTRATIONS OF WARMUP STRATEGIES

Morning warmup routine modification recommendations include:

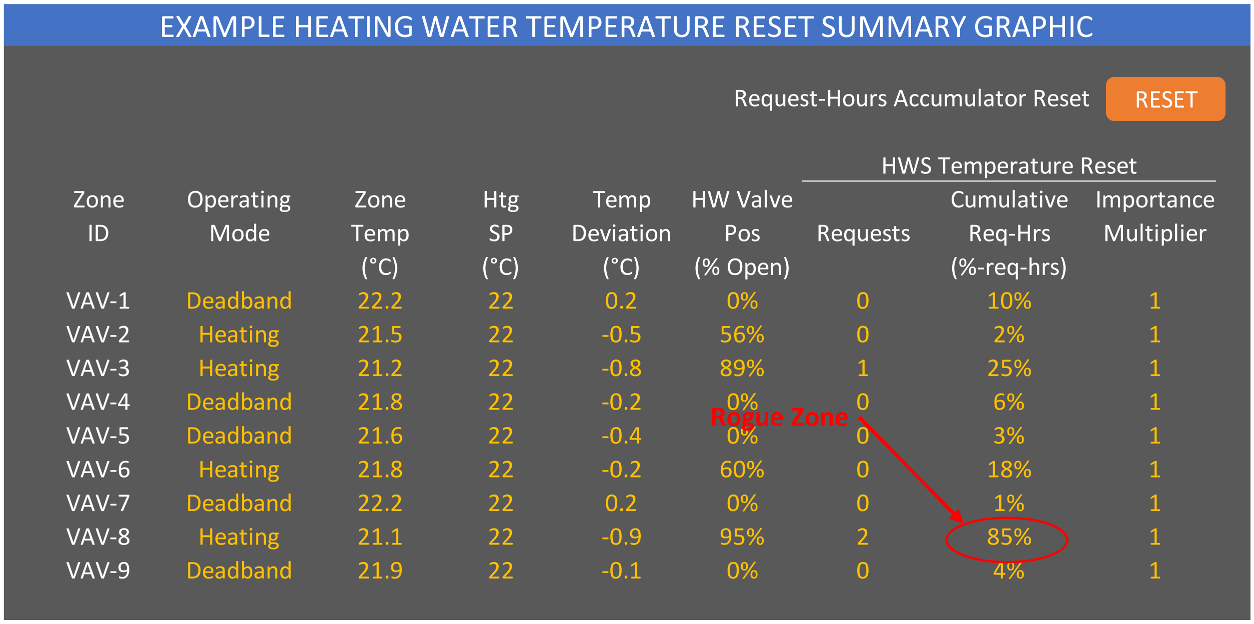
- Implementing a dedicated "warm up" mode for all air handling systems, ensuring that ventilation remains off during warmup periods (except where required).
- Implementing a ramped zone temperature setpoint reset from the start of morning warmup until occupancy. A decaying exponential rise in setpoint is recommended as a starting point.

- Extending the optimal start time to 3 hours and adjusting the optimal start tuning for the full warmup period.

Consider testing a no-setback approach on the coldest days of the year. Although no setback results in increased energy use, it may effectively maintain zone temperatures at reduced heating water temperatures, which can allow for system electrification without requiring terminal unit and distribution system replacements.

8.4.3. Targeted Retrofit of Terminal Heating Systems

Implementing a demand-based temperature reset strategy, as described in Section 8.4.1.4, allows trending and automated identification of zones driving the reset logic. For example, when using ASHRAE Guideline 36 trim & respond reset logic (ASHRAE, 2021), request-hours for each zone are accumulated to identify zones most often requesting higher heating water temperatures (see Figure 39 for an example summary graphic). This provides a list of zones to be prioritized for retrofit, and a plan can be developed to target retrofits of terminal heating systems that makes the best use of a project budget to achieve the most significant impacts on heating water temperature reduction.



EXAMPLE HEATING WATER TEMPERATURE RESET SUMMARY GRAPHIC

Request-Hours Accumulator Reset

						HWS Temperature Reset		
Zone ID	Operating Mode	Zone Temp (°C)	Htg SP (°C)	Temp Deviation (°C)	HW Valve Pos (% Open)	Requests	Cumulative Req-Hrs (%-req-hrs)	Importance Multiplier
VAV-1	Deadband	22.2	22	0.2	0%	0	10%	1
VAV-2	Heating	21.5	22	-0.5	56%	0	2%	1
VAV-3	Heating	21.2	22	-0.8	89%	1	25%	1
VAV-4	Deadband	21.8	22	-0.2	0%	0	6%	1
VAV-5	Deadband	21.6	22	-0.4	0%	0	3%	1
VAV-6	Heating	21.8	22	-0.2	60%	0	18%	1
VAV-7	Deadband	22.2	22	0.2	0%	0	1%	1
VAV-8	Heating	21.1	22	-0.9	95%	2	85%	1
VAV-9	Deadband	21.9	22	-0.1	0%	0	4%	1

Rogue Zone

FIGURE 39: EXAMPLE TEMPERATURE RESET SUMMARY

8.4.4. Hot Water System Distribution System Considerations

8.4.4.1. Pipe Sizing

Existing pipe sizing often limits the potential for reducing heating water temperatures, particularly in systems designed for a high-temperature differential between supply and return water. Boiler-based systems are typically designed around temperature differentials of 20°F to 40°F, while modern heat pump systems are usually limited to 10°F to 30°F.

Understanding the existing pipe sizing, system flow rates, and condition of the piping is important to determine how flow rates can be adjusted to accommodate lower heating water temperatures. Strategic replacement of terminal units can sometimes negate the need to upsize existing piping by enabling terminal units to operate with high-temperature differences at reduced heating water temperatures (see Section 8.4.5).

For buildings that don’t need year-round cooling of interior zones, converting chilled water piping systems to switchover systems can be beneficial. These systems can operate in parallel with existing heating water systems to provide low-temperature heating throughout terminal unit cooling coils.

8.4.4.2. Flow Control

Many older systems operate at constant flow, where unneeded hot water supplied to terminal units or AHU heating coils is bypassed to the return water piping. This operation results in small temperature differentials, particularly at part-load conditions, and increases return water temperatures.

Converting constant flow systems to variable flow systems can ensure the coolest heating return water temperature is achieved throughout system operation and maximize the effectiveness of heat pumps integrated into the system. Any bypass of hot water flow required to maintain minimum boiler flow rates should occur downstream of heat pumps to ensure heat pumps see the coolest return water temperature.

8.4.5. Terminal Units Considerations

Terminal units are often the system's most limiting factor when lowering heating water temperatures, and the highest-cost components to replace. Unlike air handling units, coil options for terminal units are typically much more limited. Additionally, the distributed nature of terminal units means that projects to retrofit fit them cost have higher costs and are more disruptive to occupants compared to retrofits of central systems.

Several strategies are available to maintain heating capacity at lower heating water temperatures. In many cases, some combination of strategies is necessary. Effective strategies include:

- **Reducing Perimeter Heat Loss:** As described in Section 8.2.4, improvements made to the building envelope can reduce perimeter heat loss, which in turn reduces the required capacity of thermal units and allows a corresponding reduction in heat and water temperatures.

- **Reducing Indoor Air Temperature Setpoint:** Lowering the indoor air temperature setpoint during peak heating conditions can marginally decrease heat losses by reducing the temperature differential across the building envelope. The reduction in indoor air temperature also has a marginally positive impact on terminal heating capacity by increasing the temperature difference between the heating water temperature and the entering air temperature.

- **Increasing Supply Air Temperature to VAV Boxes:** Increasing the supply air temperature to the inlet of VAV boxes through demand-based supply air temperature (SAT) reset can noticeably improve the heating capacity of reheat coils at lower heating water temperatures (see Section 8.4.5.2). However, this needs to be balanced with the cooling needs of internal zones to avoid overheating.

- **Increasing Heat Transfer Surface Area:** Increasing the surface area of a heat emitter or heating coil significantly impacts improving heating capacity at reduced heating water temperatures. However, this often requires replacement of existing terminal units or supplementing with additional units.

The following sections provide specific strategies for maintaining heating capacity at reduced heating water temperatures for several common terminal unit types, including fan coils, VAV reheat coils, finned-tube baseboard convectors, radiant heating, and induction units.

8.4.5.1. 4-Pipe Fan Coils

The heating capacity of a fan coil is approximately proportional to the temperature difference between the entering air and entering water temperatures. This relationship can help estimate how entering water temperature changes affect the fan coil's heating capacity.

$$Q_{New}=\frac{E.W.T._{new}-E.A.T._{new}}{E.W.T._{old}-E.A.T._{old}}\times Q_{Old}$$

FIGURE 40: FORMULA TO ESTIMATE HOW ENTERING WATER TEMPERATURE CHANGES AFFECT THE FAN COIL'S HEATING CAPACITY

Increasing the surface area of the is the best way to accommodate lower heating water temperature. 4-pipe fan coils typically include separate heating and cooling coils. The heating coil is traditionally a single-row coil, while the cooling coil usually consists of 2-4 rows, depending on cooling requirements. One strategy to improve heating efficiency and accommodate lower heating water temperatures is to reconfigure existing 4-pipe fan coils to use the cooling coil for heating and cooling. Where a common drain pan is provided under both coils, the existing heating and cooling coils can be piped together to provide one larger coil. This modification requires piping re-work at each fan coil to accommodate additional or new control valves to facilitate heating/cooling switchover, but it saves the cost of replacing fan coils. The Table 17 compares the heating performance of a fan coil converted from a standard configuration to a switchover coil arrangement.

TABLE 17: COMPARISON OF FAN-COIL PERFORMANCE WITH SWITCHOVER ARRANGEMENT

COIL ROWS	1-ROW (HOT WATER)	2-ROW (HOT WATER)	3-ROW (CHANGEOVER)	4-ROW (CHANGEOVER)
HWS / HWR Temperatures (°F)	180 / 150	140 / 115	130 / 95	120 / 92
Heating Capacity (MBH)	42,000	40	40	40

EAT / LAT (°F)	60 / 96.9	60 / 95	60 / 9	60 / 95
Fluid Flow Rate (GPM)	2.9	4	2.3	2.9
Fluid Pressure Drop (ft H_2O)	2.8	1.8	4.7	1.6
Airside Pressure Drop (in. H_2O)	0.15	0.22	0.33	0.41

The same approach can be used on other types of terminal units and air handling units (Taylor, 2017). A common piping arrangement for small terminal units is illustrated in Figure 41.

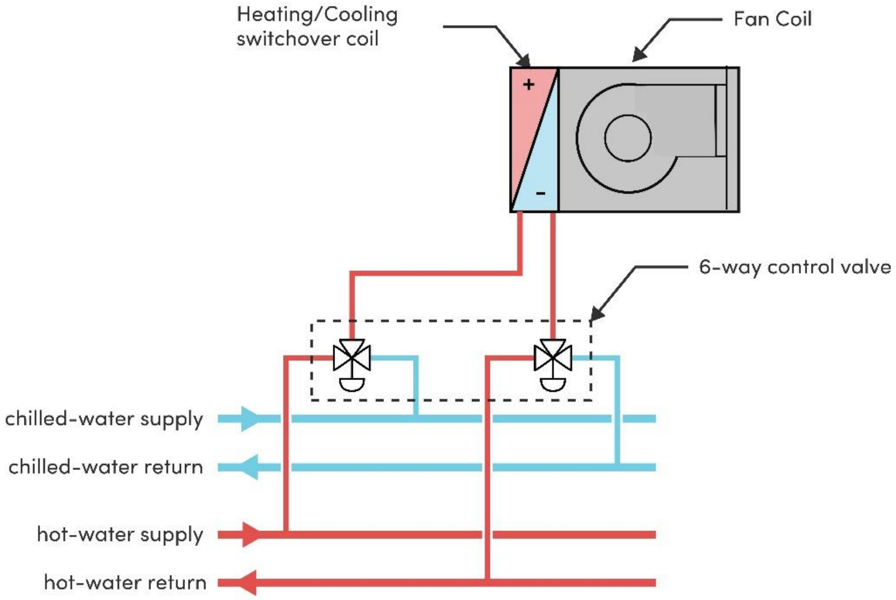


FIGURE 41: SWITCHOVER COIL PIPING CONFIGURATIONS

Two-pipe switchover fan coil systems, sometimes encountered in existing buildings, are often already capable of utilizing lower heating water temperatures due to the larger coil surface area required for cooling. In these applications, maintaining the switchover configuration is beneficial for facilitating the low-temperature conversion of the heating system.

Two-pipe heating-only fan coils are challenging for low-temperature conversion, and complete replacement or supplementing with another heating source may be the only option to reduce heating water temperatures meaningfully.

8.4.5.2. VAV Reheat

The same heat transfer principles described for fan coils hold for VAV reheat coils. For systems designed with 180°F to 200°F HWST, single-row coils were often sufficient for the required heating output. However, these coils present challenges when operating with lower heating water temperatures.

Reheat coils were often selected based on a fixed entering air temperature, typically around 55°F, providing an opportunity to reduce heating water temperatures while maintaining zone heating capacity by utilizing supply air temperature reset at the air handling unit. Figure 42 illustrates how raising the reheat coil entering air temperature impacts zone heating capacity. As the entering air temperature increases, overall coil capacity decreases, but the leaving air temperature rises, providing additional heating capacity to the zone. This reduction in coil capacity signifies a reduced reheat load, contributing to a lower overall heating load for the plant.

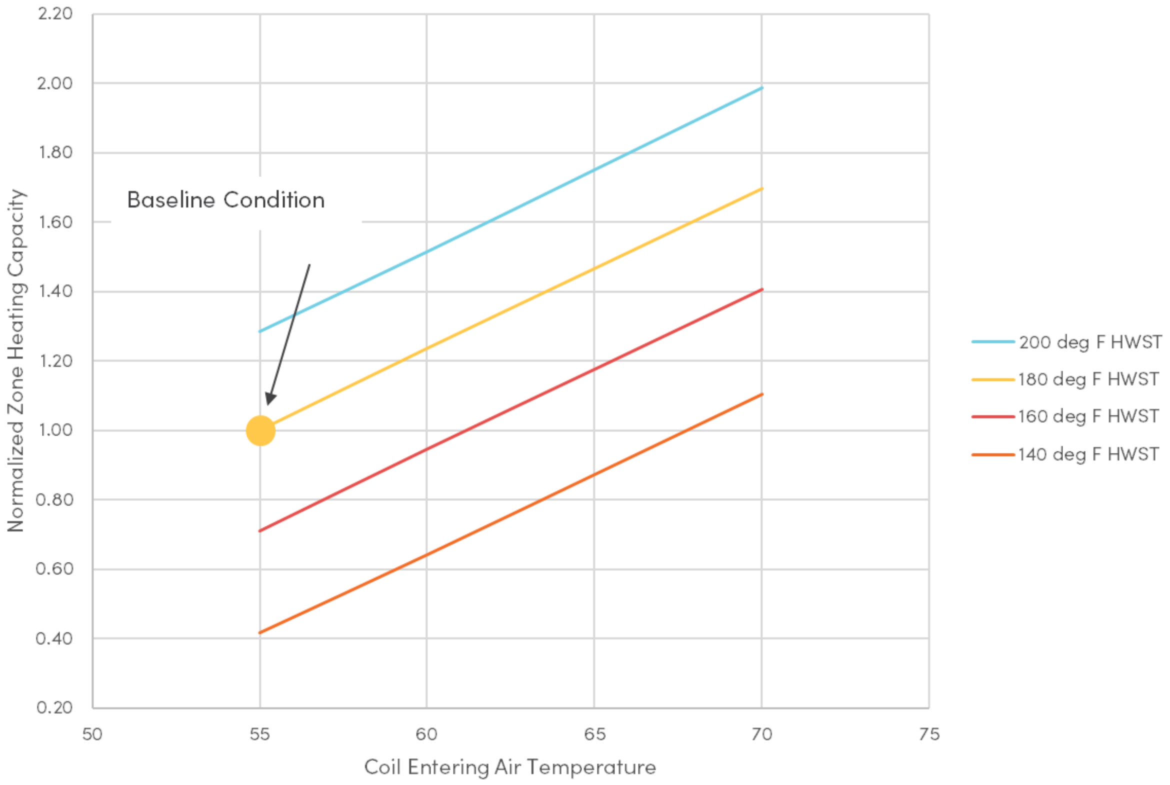
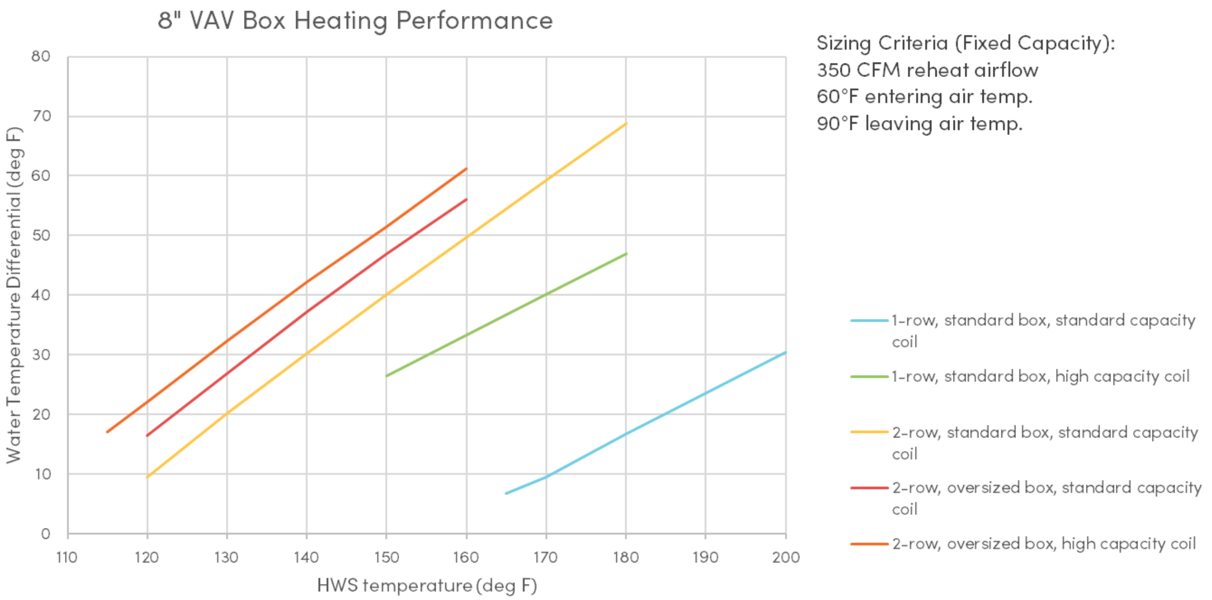


FIGURE 42: ZONE HEATING CAPACITY AS A FUNCTION OF ENTERING AIR TEMPERATURE

While effective, this strategy risks overheating interior zones if the SAT is insufficient for adequate cooling. Implementing a demand-based SAT reset before plant retrofits can confirm this strategy's potential to reduce heating water temperature. Where feasible, increasing the maximum cooling airflows of interior VAV boxes during shoulder and heating seasons can maximize the benefit of this strategy.

Most manufacturers offer multiple coil and casing options for modern VAV boxes. When replacement is necessary, consider VAV boxes with oversized casing options, which use the next larger box and coil size. This option, often requiring a special order but typically priced similar to the larger box size, enhances waterside performance, supporting lower heating water temperatures while minimizing multi-row coils' airside pressure drop effects. High-capacity coils are another option to improve heating performance at the expense of increased air pressure drop.

Figure 43 compares several VAV box configuration options (casing size and coil rows) that achieve the same heating output at various supply water temperatures. Selecting a box with a similar temperature differential to the existing box allows “plug-and-play” replacement without increasing pipe size. With any box replacement, verifying the fan system's static pressure capability is essential to ensure the system can support the new VAV boxes.

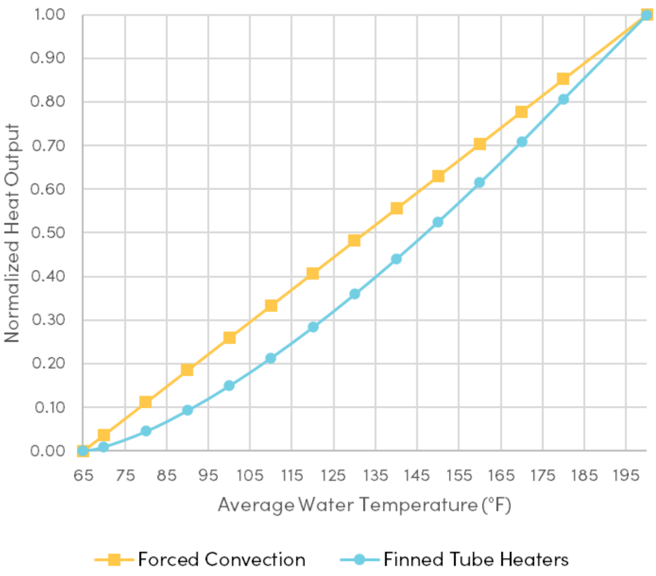


Sizing Criteria (Fixed Capacity):
350 CFM reheat airflow
60°F entering air temp.
90°F leaving air temp.

FIGURE 43: VAV BOX CONFIGURATIONS PROVIDING THE SAME HEATING OUTPUT

8.4.5.3. Finned-Tube Baseboard Heaters

Finned-tube baseboard heaters rely on natural convection to drive heat output. The temperature difference between the water and the entering air temperature drives the magnitude of natural convection. The height of the heater also aids in enhancing natural convection. Figure 44 summarizes the heat output of finned-tube heaters as a function of average water temperature. These curves are normalized and can be used for various convectors if the rated condition is known. Compared to forced convection, natural convection output derates more rapidly with reduced heating water temperatures, making low-temperature conversion of finned-tube heaters particularly challenging.



AWT (deg F)	Heat Output Correction Factor	
	Natural Convection (i.e. finned tube)	Forced Convection (i.e. fan coil)
200	1.00	1.00
180	0.81	0.85
170	0.71	0.78
160	0.62	0.70
150	0.53	0.63
140	0.44	0.56
130	0.36	0.48
120	0.28	0.41
110	0.21	0.33
100	0.15	0.26
90	0.09	0.19
80	0.04	0.11
70	0.01	0.04
65	0.00	0.00

FIGURE 44: HEAT OUTPUT OF NATURAL CONVECTION & FORCED CONVECTION HEATERS AS A FUNCTION OF WATER TEMPERATURE

Many manufacturers add a 15% "heating effect factor" to the tested heating capacity. This factor originated decades ago when finned-tube heaters were compared to cast-iron radiators. However, this factor is not based on test data and should be discounted when sizing and comparing units (Seigenthaler, 2023).

When aiming to lower heating water temperatures to finned-tube heaters, several strategies can be considered:

- **Piping Series Heaters in Parallel:** Piping heaters in parallel vs. series can increase the output of finned-tube heaters by ensuring each heater sees a higher average water temperature. Floor-level piping modifications and re-balancing are typically required when converting to parallel piping.
- **Replacing Heaters with Low-Temperature Options:** To achieve meaningful reductions in hot water temperature, it is often necessary to replace existing finned-tube heaters with low-temperature finned-tube heaters or fan-assisted finned-tube heaters. Figure 45 compares the heat output of a standard commercial finned-tube heater with comparable low-temperature finned-tube and fan-assist options. Replacing heaters means that existing piping infrastructure can remain largely undisturbed.
- **Add Supplemental Overhead Heating:** Supplementing or outright replacing finned-tube heaters is often preferable to free up perimeter floor space for buildings in mild climates where overhead heating may be sufficient to maintain thermal comfort. For colder climates, assess thermal comfort to ensure that removing perimeter heaters will not negatively affect occupants. In addition, consider setback heating operations. Perimeter radiation allows heating without the need to operate air handling systems. Consider fan-powered VAV boxes or fan coils when replacing perimeter heating systems where setback operation is desired.

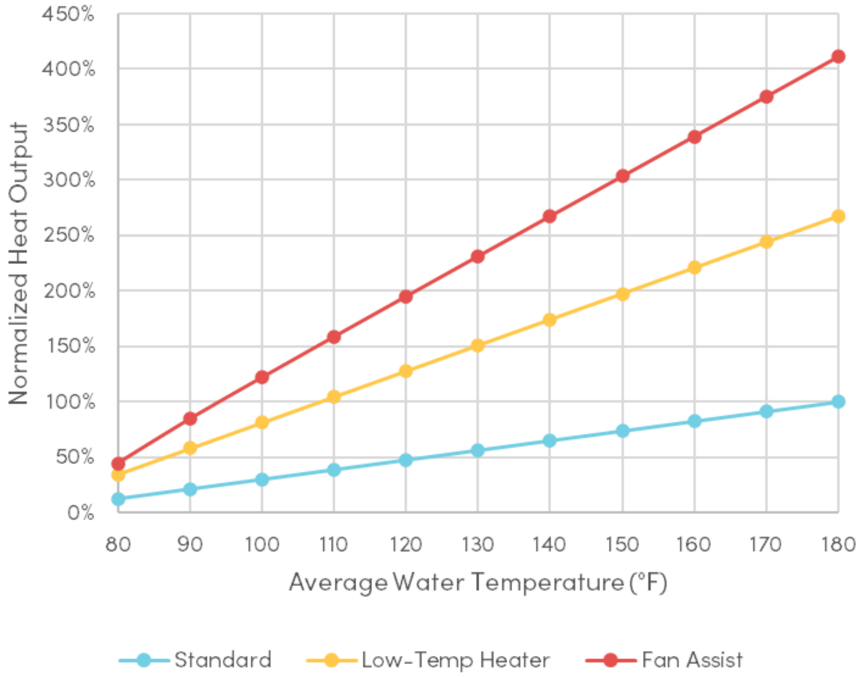


FIGURE 45: EXAMPLE COMPARISON OF STANDARD FINNED-TUBE HEATERS VS. LOW-TEMPERATURE AND FAN-ASSIST TUBE HEATERS

8.4.5.4. Induction Units

Floor-mounted induction units are terminal devices common in 1970s vintage commercial office buildings. Typically used for perimeter zones, they operate using the same induction principles as chilled beams. Primary air, often conditioned outside air, is supplied at high velocity through nozzles to an induction chamber, creating a low-pressure zone that induces room air into the unit. The induced air passes over the heating or cooling coil and is conditioned and mixed with the primary air discharged into the space.

FIGURE 46: INDUCTION UNIT

Compared to induction units of the 1970s era, modern units have higher induction ratios, lower primary air requirements, and lower noise levels. Often, modern units can reduce fan static pressure requirements by 125 to 250 Pa (0.5 to 1.0-inch w.g.) compared to older units, and higher induction ratios mean that modern units can provide the same capacities with less primary air.

Induction units' secondary coil(s) can provide heating and sensible cooling. However, they are commonly used only for sensible cooling, with heating supplied by the primary air. Consider the following strategies when aiming to reduce heating water temperature requirements and energy consumption for induction unit systems:

- **Use Demand-based Temperature Reset to Reduce Supply Air Temperatures Whenever Possible:** Resetting primary supply air temperature based on demand, rather than outdoor air conditions, maximizes the potential to lower supply water temperatures. This approach is a low-cost first step for systems utilizing zone-level BAS controls; it is not feasible for existing pneumatic systems without some investment in zone-level temperature sensors.
- **Investigate the Conversion of an Air Handler Cooling Coil into a Switchover Coil to Achieve Supply Air Temperatures at Lower Water Temperatures:** Primary air systems are typically equipped with both heating and cooling coils. The deeper row cooling coil can be repurposed during heating to reduce water temperatures required to deliver the required supply air temperature.
- **Investigate Using the Induction Unit Chilled Water Loop as a Heating/Cooling Switchover Loop:** Sometimes, the original design intent of older systems included an interface with the heating systems to accommodate seasonal switchover of the induction unit loop from heating to cooling. Consider reinstating this mode of operation after careful consideration and investigation of the integrity of the existing piping. Caution is warranted, as converting a system used purely for cooling for decades can cause damage at joints when used for heating.
- **Consider Adding Zone-level Heating Coils to the Induction Unit’s Primary Air Supply if Induction Unit Heating is not Feasible:** Where heating through the induction unit loop is not feasible, consider retrofitting primary air heating coils to allow supply air temperature reset at a zonal or exposure level to reduce heating and re-cool energy. This approach can also lower the heating water temperature required by splitting the heating load between the air handler and zone-level reheat coils. Take care to ensure the existing air handling systems can accommodate the added static pressure of zone-level heating coils.
- **Consider Adding VAV Boxes to the Primary Air Supply**: Retrofitting VAV boxes, or floor-level isolation valves, to the primary air system can minimize underventilation and overventilation throughout the building. It can also ensure that induction units receive sufficient primary air for induction and primary heating. Unoccupied floors or zones can be isolated to reduce the heating, cooling, and fan energy associated with these systems when used with floor-level schedules or occupancy sensors.
- **Consider Replacing Floor-level Induction Units with Ceiling-mounted Units Capable of Providing Low-temperature Heating:** Outright replacement of induction units is often an attractive measure for building owners and leasing agents, as converting to an overhead system frees up valuable floor

space at the perimeter of the building. Thermal comfort and maintenance requirements are also often improved because system air inlets and outlets are less likely to be blocked by furniture.

8.4.5.5. Terminal Water-Source Heat Pumps

Terminal water-source heat pump (WSHP) systems are great candidates for electrification because they typically do not require zone-level or piping distribution system upgrades. WSHP distribution loops operate at low temperatures, typically between 10°C and 35°C, making them readily compatible with low-temperature heating sources such as air-to-water heat pumps, geo-exchange systems, or sewer heat reclaim. Refer to Chapter 7 for additional considerations and recommendations on integrating heat pumps into WSHP systems.

8.5. SUPPLEMENTAL HEATING

While full electrification via heat pumps represents the ideal means of reducing GHG emissions, it may not be financially viable or practical for every site. In some cases, LCE retrofits can become more financially attractive if supplemental heating sources are integrated into designs.

The decision as to whether to provide supplemental heating depends on the local climate conditions, technical considerations, and financial constraints. It often involves finding an optimal design solution that meets both the building owner's GHG reduction targets and economic constraints.

Figure 47 illustrates an example annual load profile for a medium-sized existing building. As shown in the figure, 80% of the annual heat energy demand occurs when the heating load is less than 25% of the design load, indicating that most GHG emission reductions can be achieved with a heat pump sized well below the design heating load. In this example, sizing beyond 35-40% of the design load has diminishing returns. A smaller heat pump can often provide most of the GHG emission reductions, while a lower-cost backup heating system supplements the heat pump during high-load conditions.

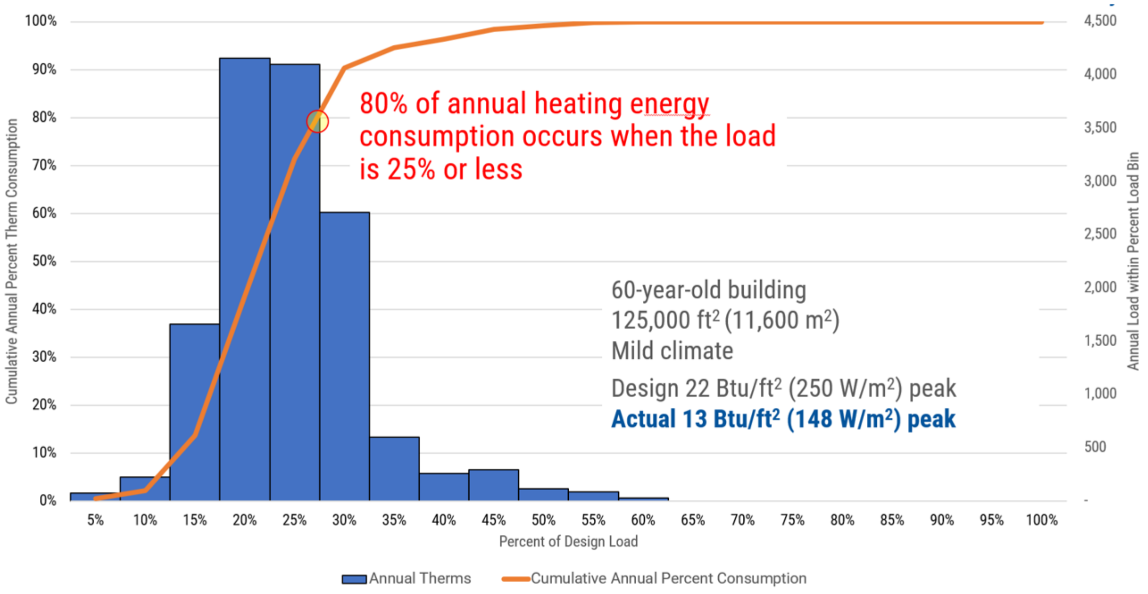


FIGURE 47: BUILDING ANNUAL HEATING LOAD PROFILE

As illustrated in Figure 48, the thermal balance point of the heat pump occurs at the intersection between the heat pump capacity curve and the building heating load. At outdoor air temperatures above this point, the heat pump will be able to meet the entire heating load. At outdoor air temperatures below the balance point, supplemental heating will be required to meet the building heating loads; within this region, the heat pump(s) and supplemental heating should be capable of working in tandem to maximize energy efficiency and GHG emission reductions.

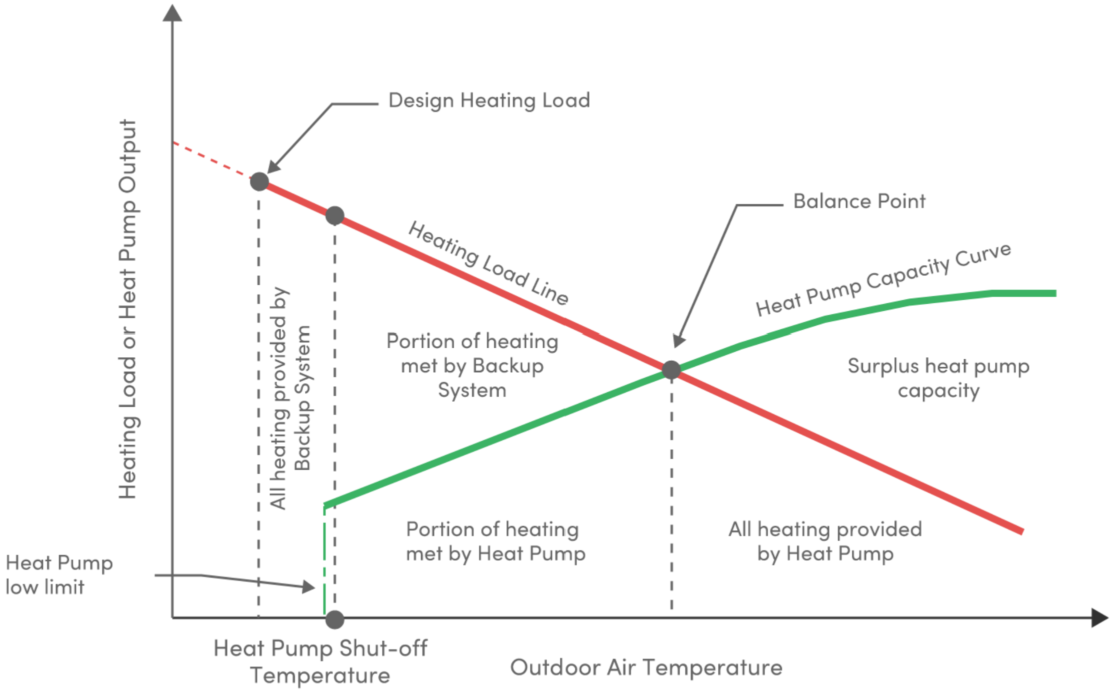


FIGURE 48: THERMAL BALANCE POINT BETWEEN HEATING LOAD AND HEAT PUMP CAPACITY

Selecting an appropriate supplemental heating system involves weighing several factors. However, retaining the existing heating system is typically the most economical choice for existing buildings, provided the heat pumps can operate simultaneously with the supplemental heating system. Wherever possible, it is recommended to avoid full-capacity backup systems by selecting heat pumps with a sufficiently low cut-off temperature, and ensuring system controls are well coordinated and commissioned to allow for simultaneous operation of the heat pump systems and supplemental systems. Figure 49 illustrates a decision-making process for identifying an appropriate supplemental heating option.

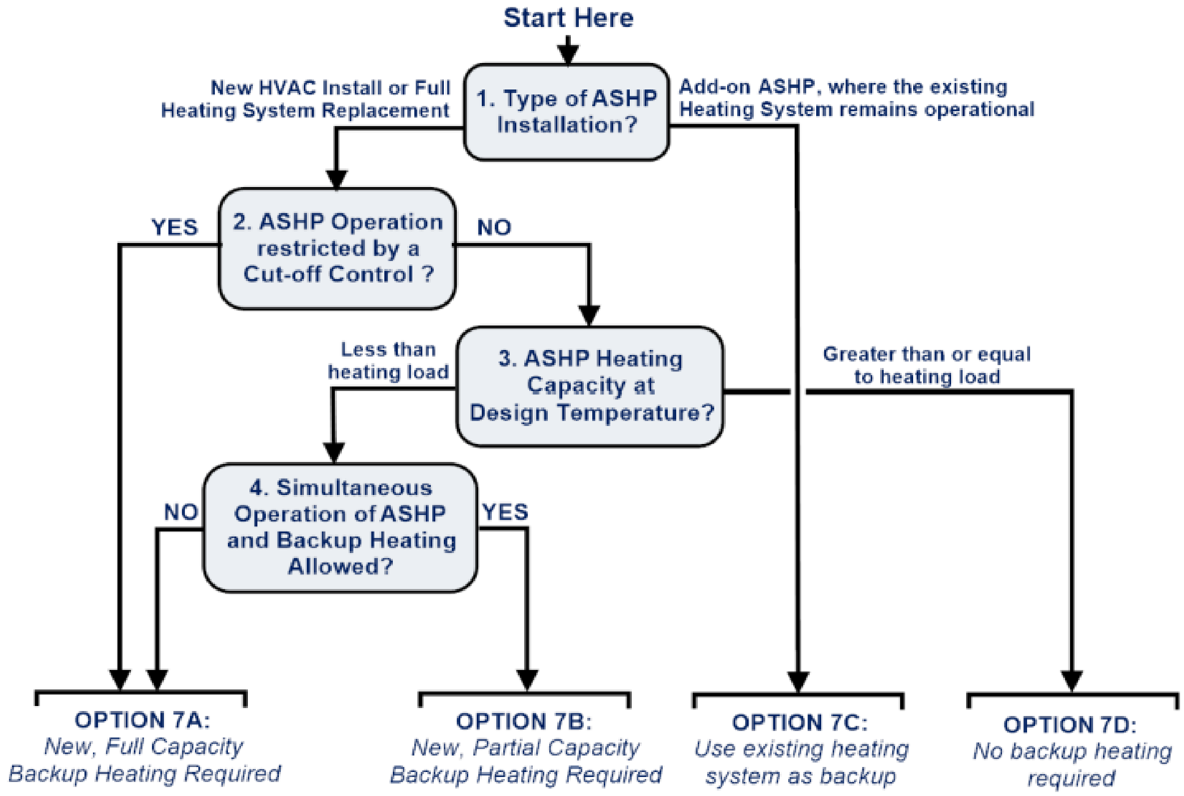


FIGURE 49: DECISION TREE TO DETERMINE SUPPLEMENTAL HEATING REQUIREMENTS

8.6. CONTROLS

Controls requirements are highly dependent on system type.

Standalone unitary or packaged equipment may require little to no controls integration as these systems are simple and operate off integrated factory controls.

Conversely, central heat pump-based and hybrid systems comprise multiple components and equipment that must work in a coordinated fashion to perform efficiently. Central systems should be integrated with the BAS, and include trending and alarming. The designer must convey the required sequence of operations, trending, and monitoring requirements within the contract documents rather than leaving guesswork for the contractor regarding the intended mode of operation. For hybrid systems having supplemental gas or electric heat sources combined with heat pumps, controls sequences must be clear on the staging of primary and backup heating systems to prevent backup systems from operating prematurely or in a manner that degrades heat pump performance.

Confirm control and monitoring expectations with the building operators to ensure that the system can provide real-time information that is useful and actionable while avoiding nuisance alarms that erode operator confidence.

For further discussion of commissioning heat pump systems, see Section 6.4.

8.7. ADDITIONAL RESOURCES

The following resources can provide additional information about the electrification of HVAC Systems:

- ASHRAE Guideline 36 (ASHRAE, 2021).
- Advanced Building Automation Systems – Best Practice Guide (Cheng H. E., 2022).
- ASHRAE Grid-Interactive Buildings for Decarbonization: Design and Operation Resource Guide (ASHRAE, 2023).

9. Domestic Hot Water Systems

This chapter is intended to guide consulting engineers in designing electrification retrofits of domestic hot water (DHW) systems in existing buildings. Two common technologies are available for DHW electrification: electric resistance heating and heat pumps. Additional technologies, such as solar thermal systems and gas-fired heat pumps, can also be implemented to reduce carbon emissions but are beyond the scope of this Guide.

Specifically, this chapter covers:

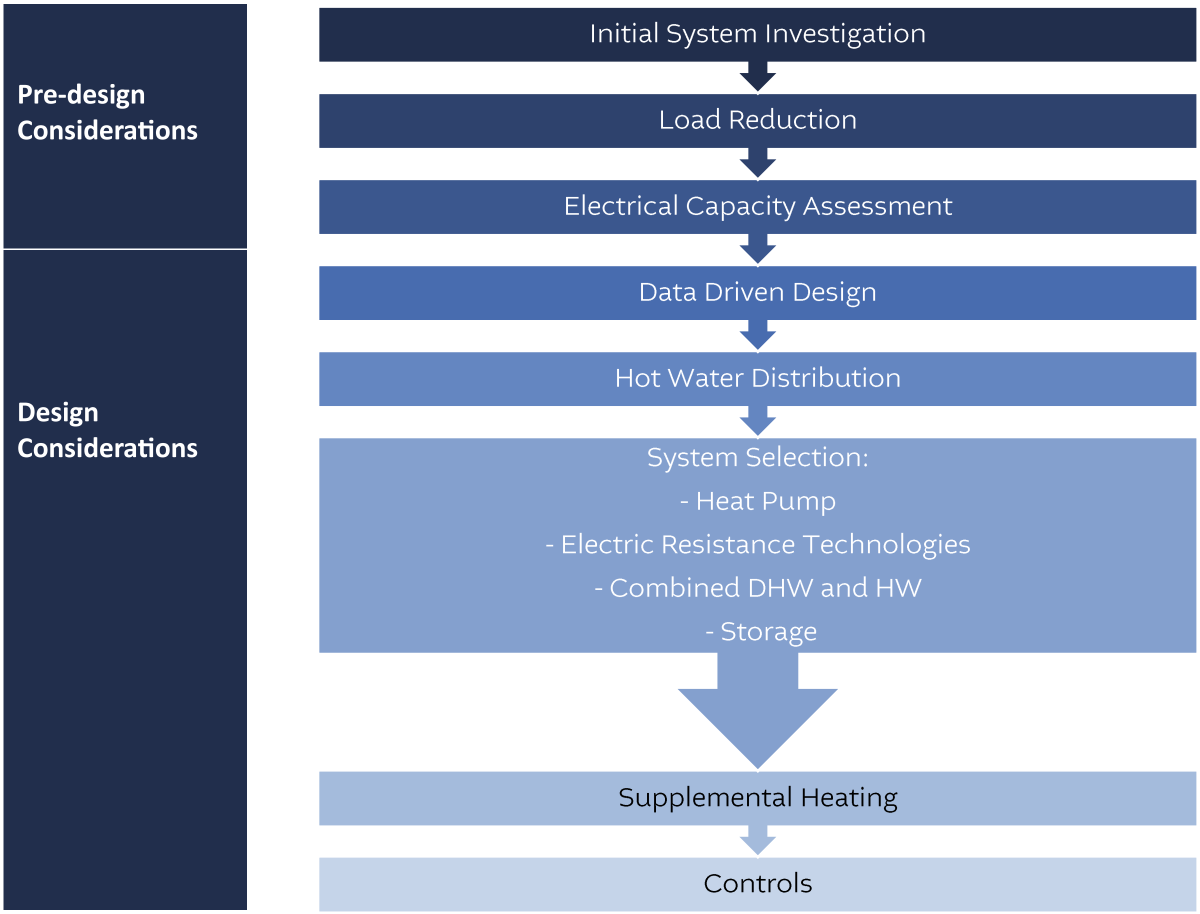


FIGURE 50: DHW ELECTRIFICATION DESIGN PROCESS

The sections of this chapter are arranged in Figure 50 in a loosely linear order; revisit and reconsider earlier assumptions or steps as required to optimize system design. Appendix 4: Example Pathways provides design trees for the electrification of common DHW system types that follow the process outlined above. A list of resources that provide further guidance on the topics covered is included at this chapter's end.

9.1. INITIAL SYSTEM INVESTIGATION

Understanding the configuration and operating condition of the existing DHW system is essential to identify opportunities and constraints when determining feasible retrofit measures. Conduct an initial site assessment of the existing DHW system to gather information on:

- Historical DHW consumption amounts and patterns.
- Configuration and components of the existing DHW system including heating capacity and storage volume.
- Equipment location and incoming water pressure.
- Layout and zoning of distribution and recirculation systems, including pressure zoning (for more information on system pressure considerations refer to Appendix 3.5: Additional Considerations for DHW System Pressures).
- Condition of existing system including distribution piping.
- DHW end uses.
- Identification of any existing deficiencies with respect to compliance with current building or plumbing codes (for more information on code considerations refer to Appendix 3.5: Additional Considerations for DHW System Pressures).

A detailed checklist for assessing existing DHW systems for electrification is provided in Appendix 3.4: Existing DHW System Assessment Checklist.

9.1.1. Determining Existing DHW Water and Energy Consumption

Several methods can be used to establish baseline energy performance, GHG emissions, and water consumption. This is an essential step in the electrification process as DHW consumption plays a key role in the proper sizing and selection of equipment. This section includes some sample methods that can be applied, depending on available information.

Energy consumption of DHW systems can be divided into three main categories:

- **DHW generation** (i.e. hot water used at fixtures).
- **DHW recirculation losses** (i.e. pumping energy and heat loss due to distribution).
- **DHW standby losses** (i.e. heat loss due to storing hot water).

Understanding each category's proportion to the overall energy consumption can help determine which retrofit measure can offer the most significant impact.

9.1.1.1. Method #1: Preliminary Energy Performance from Utility Bills

As will be discussed in Section 9.3, understanding energy performance through data is essential in the electrification retrofit process. Utility bills contain consumption and cost data, which can be used to conduct a preliminary assessment of the building's energy performance and end uses. Although DHW consumption can vary month to month based on occupancy and municipal water temperature fluctuations, it is generally considered weather-independent. For gas-fired DHW systems, estimates of DHW energy consumption can be made through utility bill analysis that includes energy regression models and quantification of energy consumption in the summer months (i.e. the non-heating season). If necessary, a DCW incoming temperature model can also be included to refine the DHW energy consumption model. Although a utility analysis does not provide accurate information for design and sizing, understanding DHW energy consumption early in the process can assist in decision-making and assessing the business case of retrofit options.

9.1.1.2. Method #2: Sub-Metering

If sub-metering of the DHW consumption is available, this method is preferred compared to using utility bills and BAS trend data as it provides a more comprehensive indication of water use. For this method, it is recommended to have a minimum of one month of DHW consumption data at a minimum of 1-hour intervals. The water meter should be installed on the domestic cold-water makeup line supplying the DHW system, before it mixes with the DHW recirculation line, to avoid erroneous readings caused by recirculation flow. When selecting a meter, consider the additional pressure drop and water meter accuracy level.

If available, it is preferable to use DHW gallon-per-minute and gallon-per-hour data to identify any instantaneous peaks within the system. Understanding DHW consumption peak and average patterns in gallon per minute, gallon per hour, and gallon per day can allow the designer to utilize more current sizing methodologies that reduce the risk of oversizing. This information allows the designer to evaluate trade-offs between storage and system-recovery rates and the corresponding effect on electrical demand for storage-based systems. For distributed and point-of-use systems, this data can be used to estimate peak electrical demand vs. installed capacity to assist with making decisions on electrical upgrades.

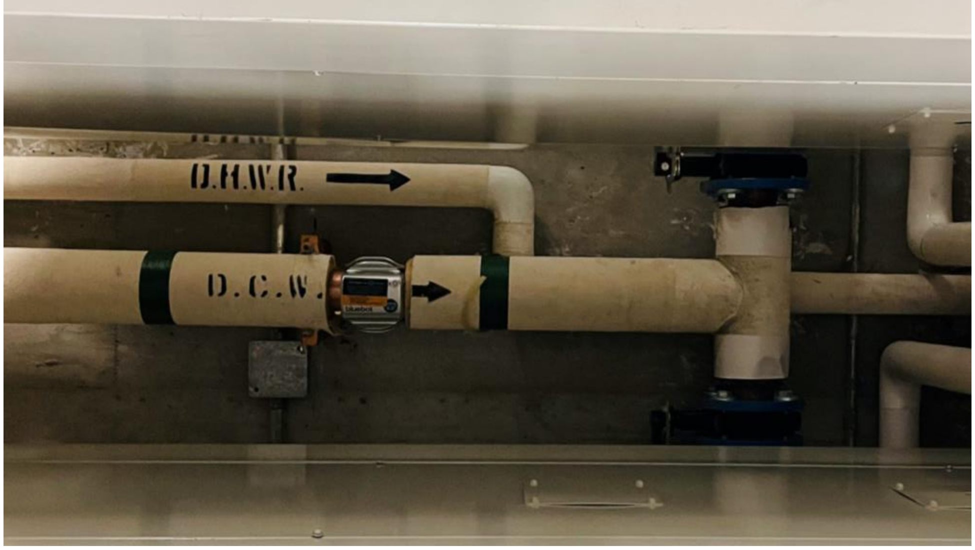


FIGURE 51: EXAMPLE OF SUB-METER INSTALLED ON COLD-WATER MAKEUP TO DHW SYSTEM

9.1.1.3. Method #3: Using Utility Bills and BAS Trend Data:

This method can be used when sub-metering data of DHW consumption is unavailable. It involves the following steps:

1. **Determine Total DHW Monthly Energy Consumption:** Determined based on gas input from utility bills. Recirculation power can be estimated using the pump runtime schedule and motor size.

2. **Estimate Recirculation Energy Consumption:** If available, this can be estimated using the recirculation pump flow rate and trended supply & return temperature from the BAS. If BAS info is unavailable, recirculation losses can be estimated based on pipe length and heat loss based on pipe diameter and insulation value.

3. **Estimate Standby Losses**: Estimated based on storage tank configuration, storage temperatures, and tank insulation.

4. **Estimate Domestic Hot Water Usage**: Estimate DHW usage using the remaining load after accounting for recirculation losses and standby losses. Confirm these results by metering or checking ASHRAE or other resources for expected usage per person. Domestic hot water usage can be compared against the total water consumption of the building from the water utility bills, or a model can be developed to estimate use per fixture. When utilizing water utility bills to verify DHW consumption, consider other water end uses such as cooling towers, irrigation, and steam condensate cooling water use. Comparing shoulder season (i.e. early spring/fall) water use can be the best period to represent typical water consumption.

9.2. LOAD REDUCTION

As discussed in Chapter 4, load reduction and energy efficiency strategies are essential to consider before the electrification of building systems. Several relatively low-cost strategies can be implemented to reduce both peak DHW demand and annual energy requirements effectively.

9.2.1. Low-Flow Fixture Retrofit

As illustrated in Figure 52, low-flow retrofit of fixtures requiring DHW can significantly reduce both peak demand and energy consumption associated with DHW heating. These retrofits focus on replacing DHW fixtures – typically sink faucets and shower heads. These retrofits can be low cost, as flow reduction can be achieved by replacing sink aerators and shower heads. Depending on the building owner's resources, the building operations staff can complete these retrofits to reduce implementation costs further.

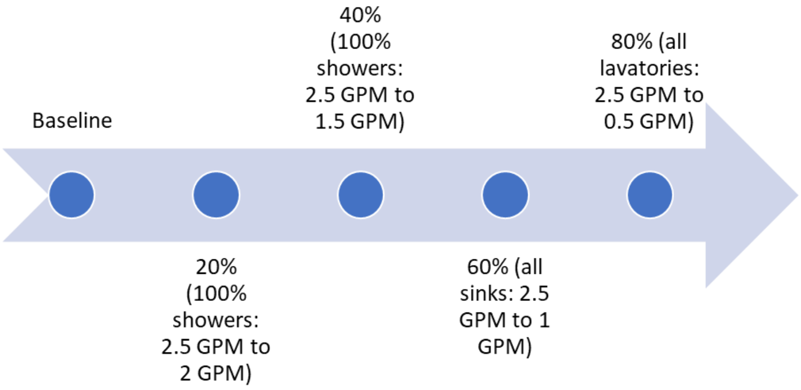


FIGURE 52: ENERGY IMPACT OF LOW-FLOW FIXTURES

Although low-flow retrofits are relatively simple compared to other strategies, the following considerations can ensure a successful outcome and persistence in savings:

- **User Education and Buy-in:** Users can often have initial adverse reactions to reduced flow rates, particularly from shower heads and general increases in wait times for DHW at the fixture. Developing an occupant awareness and engagement strategy to support implementing these changes is essential. Communication strategies, incentives, and commitments can be employed to promote the message and shift users' expectations.
- **Pressure Control:** Significant reductions in flow rates can cause challenges with existing pressure-reducing valves if they are already oversized. This further reduction in flow can cause wire draw, reducing the life expectancy of pressure-reducing valves (PRV). In these situations, consider retrofitting a smaller PRV in parallel with existing larger PRVs to provide a higher turn-down on the PRV station.
- **Sub-metering:** If DHW submetering is available, metering results can be incorporated into user education and buy-in strategies to provide positive reinforcement as water use is reduced.
- **Testing**: Piloting a few low-flow fixture options may be necessary to determine which fixtures perform best before a full-scale retrofit. This is less of a concern with commercial buildings but is very important for residential applications, as residents use these fixtures daily and are more likely to notice and be affected by flow rate changes.

9.2.2. Insulation Retrofit

Insulate all domestic hot water systems, including equipment (e.g. storage tanks) and DCW, DHW, and DHW recirculation pipes, to reduce heat loss and energy waste.

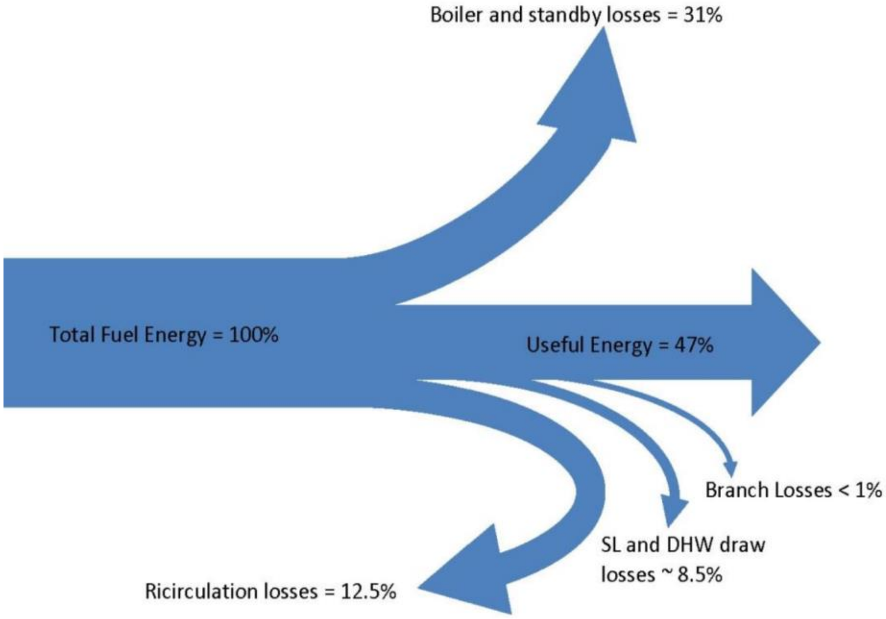


FIGURE 53: TYPICAL ENERGY DISTRIBUTION WITH CONTINUOUS HEAT PUMP OPERATION

Insulating DHW storage components is also essential to minimize standby losses. Larger tanks will perform better than smaller tanks with less insulation due to lower surface-area-to-volume ratios. Other benefits of tank insulation are reduced cycling of DHW heating equipment during low hot water use periods and increased passive survivability during power outage events. Figure 54 illustrates the impact tank insulation has on temperature stability. For heat pump water heaters (HPWH), a minimum tank insulation value of RSI-3.2 (R-18) is recommended to eliminate heat pump cycling during low-to-no hot water usage periods (Ecotope, 2022).

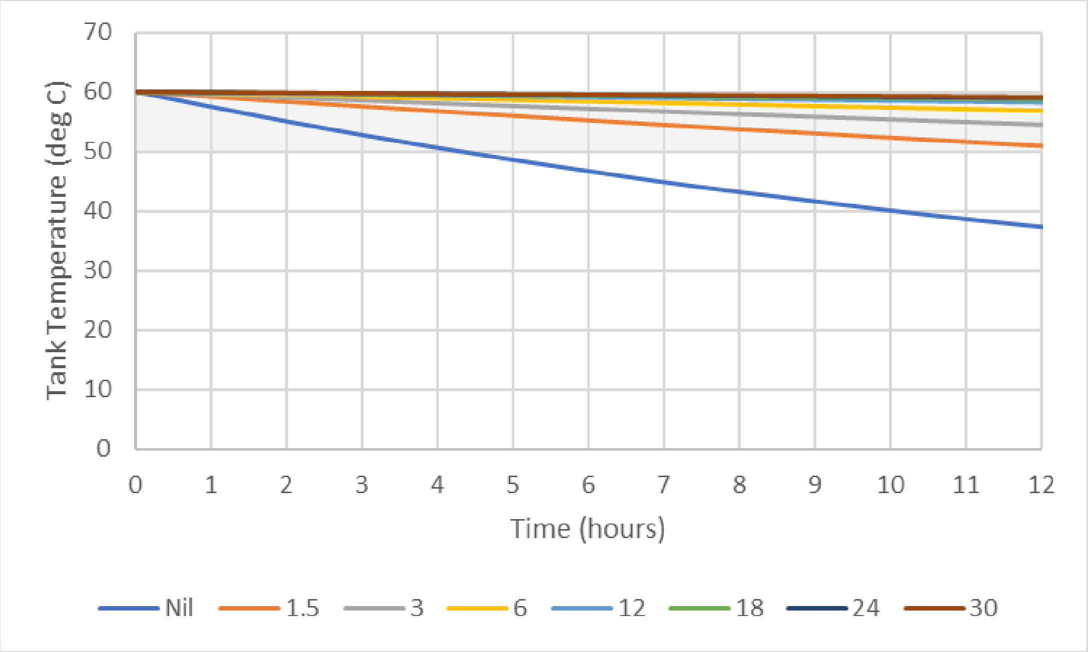


FIGURE 54: STORAGE TANK TEMPERATURE DROP OVER TIME BY INSULATION PERFORMANCE

9.2.3. Temperature Maintenance System Control

Constant operation of DHW recirculation systems in the absence of hot water demand increases energy consumption by subjecting the supply and return distribution piping to ongoing heat loss. Consequently, for scheduled buildings with intermittent hot water use, energy losses through recirculation make up a high percentage of total system energy use.

Four common strategies to reduce recirculation losses through pump control are presented below:

- **Temperature Control:** Uses a temperature sensor in the recirculation return line. When the temperature falls below the setpoint, the pump is activated until the temperature exceeds the setpoint plus a temperature differential.
- **Scheduled Control:** A standalone time clock or BAS operating schedule operates the recirculation pump and shuts the pump off during unoccupied periods.
- **Demand Control Operation:** Recirculation pump starts and stops based on flow as measured on the DHW system cold-water makeup piping and a temperature sensor installed in the recirculation

piping. A typical controls sequence starts the pump only if there is a call for hot water, as detected by the makeup flow meter, and if the recirculation temperature falls below the setpoint. In addition, if the pump has been idle for over a predetermined period, the pump can be enabled until the recirculation water temperature exceeds the set point.

- **Demand Control with Temperature Modulation:** Temperature modulation control resets the DHW supply setpoint temperature based on expected demand. The temperature setpoint is reduced when hot water demand is expected to be low, such as when the building is unoccupied, and raised before expected periods of peak demand. This strategy lowers the average temperature within the distribution piping, which reduces distribution heat loss. A US DOE study of this control measure concluded that this measure is most effective when implemented along with demand control operation (US DoE, 2016).

In addition to reducing distribution losses and achieving minor pump energy savings, an added benefit of reduced recirculation pump runtime is better stratification in domestic hot water storage tanks. This, in turn, can improve combustion efficiency for gas-fired heating systems and COP for single-pass heat pumps, and increase the usable heat output of the DHW tank. In applying strategies to the DHW temperature maintenance system, take care to follow local code requirements for controlling Legionella growth. Employ temperature monitoring and control strategies, such as minimum off times, to mitigate Legionella risk.

9.2.4. Recirculation Balancing and Flow Rate Reduction

Balancing systems can reduce overall flow rates while ensuring each area has sufficient recirculation flow to avoid long wait times at fixtures. Recirculation systems are often oversized, and flow rate reductions can frequently be achieved without negatively impacting hot water delivery wait times. Existing systems are often unbalanced, which can starve fixtures of hot water while overdelivering to other areas of the system. Consider reviewing the recirculation flow rates and balancing as part of any DHW electrification project to assist with rightsizing the system.

9.2.5. DHW Preheat

Excess heat loads available for heat reclaim in a building can be used to preheat the DHW supply. Increasing the cold supply water temperature decreases the energy required to heat DHW, thereby reducing energy use and GHG emissions. Note that installing DHW preheat requires a double wall heat exchanger to prevent cross-contamination. Give consideration to controlling Legionella growth, as preheated water may be stored at temperatures where Legionella growth can occur, particularly if preheated water is stagnant at these temperatures for more extended periods. Additional details about heat reclaim strategies and sources in commercial buildings are discussed in Chapters 7 and 8.

9.2.6. Drain Water Heat Recovery

Drain water heat recovery (DWHR) can be utilized on various configurations of DHW heating systems. These systems capture and can store heat from hot water after use. Heat recovery systems can be integrated with a storage tank to offset the difference in time of use or can directly preheat incoming cold water to a fixture as warm water flows down the drain, reducing water heating requirements and improving the DHW system's energy efficiency. Again, steps may be required to control Legionella growth if preheated water is stored at temperatures where bacterial growth can occur.

Retrofit opportunities for DWHR systems can be limited in commercial settings. Performance can be limited by the orientation of the recovery coils, with a vertical installation being preferred as the water in a vertical pipe tends to travel as a film along the inside surface of the pipe, increasing the thermal interface between the wastewater and the heat exchanger. Avoid installing heat recovery on kitchen wastewater due to the risk of grease buildup. The ideal wastewater heat source would be on a sanitary drain serving showers, for example, in a fitness centre or locker room.

9.2.7. Comparison of Load Reduction Strategies

Table 18 provides cost comparisons of load reduction strategies discussed above. Consider low-flow fixture retrofits and controls upgrades for all DHW electrification projects, as they tend to deliver the highest cost-effectiveness across building types. Consider insulation retrofits, recirculation balancing, and flow reduction as further steps for large facilities with extensive DHW recirculation systems. Application of DHW preheat and DWHR are highly dependent on specific system configuration and sources of available heat; complete project-specific assessment before considering implementation of these measures.

TABLE 18: RELATIVE COST-EFFECTIVENESS OF LOAD REDUCTION STRATEGIES

LOAD REDUCTION MEASURE	COST
Low-Flow Fixture Retrofit	$$
Insulation Retrofit	$$
Temperature Maintenance Controls Upgrades	$
Recirculation Balancing and Flow Rate Reduction	$$
DHW Preheat	$$$
Drain Water Heat Recovery	$$$

9.3. DATA DRIVEN DESIGN

DHW heating systems are often oversized. And the implementation of load reduction measures effectively results in further oversizing. Replacing existing gas-fired equipment with like-for-like capacities often results in oversized equipment, which can have significant drawbacks for electrified systems, including:

- High power requirements and increased peak demand charges.
- Increased wear and tear on heating equipment through excessive cycling.
- High equipment costs reduce the cost-effectiveness of DHW electrification measures.
- Reduced available space in equipment rooms due to unnecessary oversized equipment.

As such, electrified DHW systems provide an opportunity to "right-size" for the actual peak loads and usage patterns of the building. Within existing buildings, rightsizing is best accomplished through metering and data analytics. The sizing methodology depends on the retrofit system type; considerations are outlined in the sections below.

9.3.1. Metering & Load Profiles

Metering of post-load reduction DHW usage is recommended for all DHW electrification projects. Refer to Section 8.2.1 for a detailed discussion of metering considerations.

9.3.2. Recirculation and Standby Losses

Reassess recirculation and standby losses after implementing load reduction measures; refer to Section 9.1.1 for methodology. Understanding the resulting recirculation and standby losses is essential for deciding on potential system retrofit options, including conversion from central to distributed or point-of-use hot water systems.

9.3.3. Sizing Methodology for Storage-Based Systems

Central heat pump water heater (CHPWH) and electric resistance systems are typically sized using a higher storage-volume-to-recovery ratio than gas-fired systems. High storage volumes provide several benefits, including:

- Allowing for smaller heat pump sizes, making the system more economical and reducing power requirements.
- Reducing potential short cycling of HPWHs, thereby extending operating life and reliability.
- Facilitating load shifting and demand response to reduce peak electrical consumption.
- Increasing passive survivability during power outages by having more hot water available through storage.

Traditional industry sizing methodologies relying on fixture counts or Hunter's curve tend to be conservative and can substantially overestimate the required system capacity. Modern sizing methodologies using daily load profiles based on occupancy type can provide more accurate sizing results and generate a hot water sizing curve of the type illustrated in Figure 55. This curve represents the combination of storage volume and recovery rate that will satisfy the hot water demand of a building. This sizing exercise is best accomplished using a spreadsheet based on the cumulative volume versus time interval method outlined in the ASHRAE Handbook – HVAC Applications, Chapter 51 (ASHRAE, 2023), or using software such as Ecosizer.

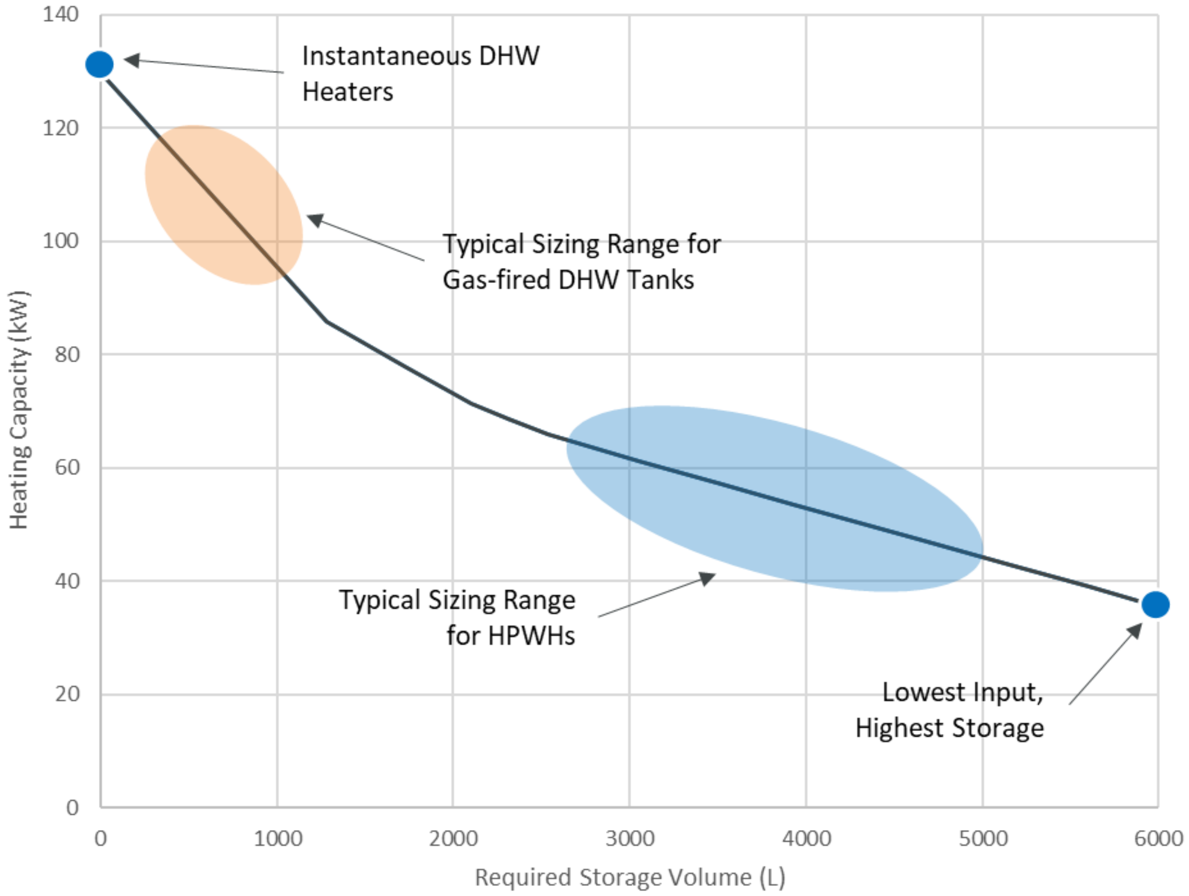


FIGURE 55: EXAMPLE DHW SIZING CURVE

ASHRAE Handbook – HVAC Applications, Chapter 51 (ASHRAE, 2023) provides load shapes for various occupancy types. These can be normalized to be scaled with actual peak demand. However, the best source of information is site-specific demand profiles obtained from pre-design monitoring of DHW usage.

9.3.4. Sizing Methodology for Point-of-use Systems

The methodology for sizing point-of-use (POU) systems differs from storage-based systems. Size POU systems with sufficient input capacity to provide desired water temperatures at the plumbing fixtures; heaters should be sized for hot water delivery temperatures no lower than 40°C (105°F) for sinks and no lower than 43-45°C (110 to 113°F) for showers.

9.4. ELECTRICAL CAPACITY ASSESSMENT

Sufficient electrical capacity is required at the building, floor, and panel levels to accommodate additional electrical equipment; where it is unavailable, electrical upgrades can add significant costs to a retrofit project. Electric-resistance heaters can significantly increase electrical demand; heat pumps require less electrical demand than similar electric-resistance units and can be a viable solution when electrical capacity is limited. Have an electrical engineer conduct an electrical capacity review before installation to ensure sufficient capacity and inform equipment selection and design. Electrical capacity considerations are discussed in further detail in Chapter.

9.4.1. Considerations for Storage-Based DHW Systems

Storage-based DHW systems have the advantage of flexibility associated with trade-offs between recovery rate and storage volume (see Section 9.3.3). Available electrical capacity can determine the suitable combination of storage-volume-to-recovery-rate and should be considered as part of the sizing exercise to avoid unnecessary electrical upgrades.

9.4.2. Considerations for Distributed and Point-of-Use DHW Systems

Distributed and POU systems are less flexible than storage-based systems, as storage volumes are low or non-existent, and electrical upgrades are often required throughout a building to accommodate distributed heaters. Early involvement of an electrical consultant is crucial to understanding these cost implications.

Current research suggests that diversified electrical demand for distributed systems with multiple POU heaters is not significantly different from tank-type systems, as only a few POU heaters are generally active at any given time (ASHRAE, 2023). This should be considered before electrical service upgrades are made on-site. Estimating diversified electrical demand can be done using metered water-use data at the building level or by applying relevant modified Hunter's curves based on occupancy type, as these curves can account for diversity in flow demand. Furthermore, specifying modulating output heaters can also effectively reduce peak demand and provide more accurate temperature control to fixtures.

9.5. HOT WATER DISTRIBUTION

9.5.1. Central and Decentralized Configurations

The configuration of a hot water distribution system can have a significant impact on the electrification approach for the DHW system. During a DHW system retrofit, a decision will need to be made on whether the system should be centralized or decentralized; considerations related to each configuration are outlined in Table 19.

TABLE 19: COMPARISON OF CENTRAL AND DECENTRALIZED DHW SYSTEMS

CONFIGURATION	CENTRALIZED	DECENTRALIZED
Benefits	· Less equipment to maintain · Less installation labour is required	· Eliminates recirculation losses
Challenges	· Recirculation losses	· Quantity of equipment · Reliability/maintenance

9.5.2. Hot Water Temperature Maintenance

Domestic hot water temperature maintenance (HWTM) systems are necessary for central DHW systems where end uses are located remotely from the generation source. HWTM systems aim to ensure timely and convenient hot water delivery to end users and for Legionella control within distribution systems.

However, these systems do not play nicely with single-pass HPWHs, which require the lowest possible entering water temperature to operate efficiently and provide their design recovery rate; returning recirculated hot water to the storage tanks destroys thermal stratification and increases entering water temperature to the heat pumps. Consequently, it is essential to separate the temperature maintenance function from the primary heating and storage. This section discusses two popular configurations.

9.5.2.1. Parallel Tank Configuration

Parallel tank configurations are best applied for facilities that experience large distribution losses compared to the DHW consumption, including applications such as office buildings. This configuration maximizes efficiency when a dedicated multi-pass heat pump offsets distribution losses.

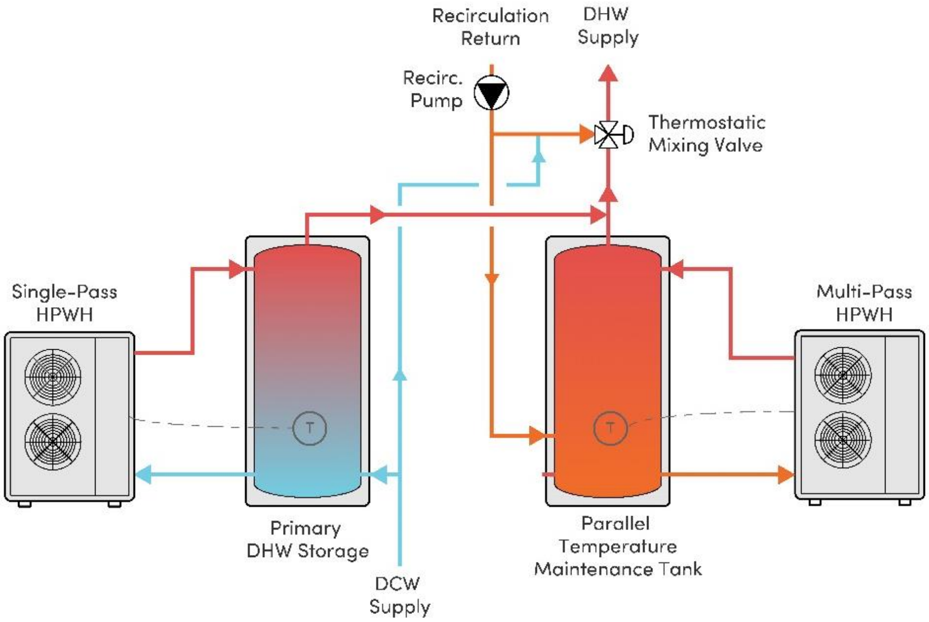


FIGURE 56: DHW PARALLEL TANK CONFIGURATION

9.5.2.2. Swing Tank Configuration

Swing tank configurations typically have a lower first cost than parallel configurations. However, operating costs can be higher for systems with low-use but high distribution losses since the electric resistance heater in the swing tank is required to maintain distribution temperatures during low to no DHW use.

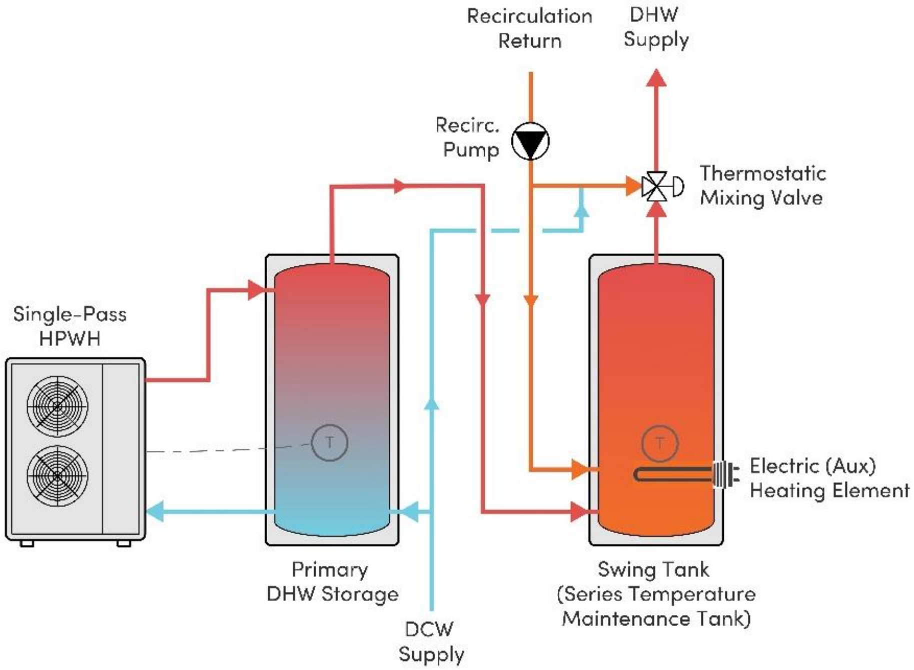


FIGURE 57: DHW SWING TANK CONFIGURATION

The swing tank configuration is conducive to hybrid heating systems because the swing tank "sees" the total domestic hot water flow rate. Backup heating is readily incorporated into the swing tank, whereas a parallel tank configuration cannot provide this backup functionality without installing backup heating in the primary storage tank. The existing fossil-fuel or electric resistance DHW tank can often be retained as the swing tank for existing systems.

9.6. HEAT PUMP TECHNOLOGIES

Air-source heat pumps (ASHP), water-source heat pumps (WSHP), and heat recovery chillers are options to provide DHW heating for a building. These systems are most appropriate for buildings with consistent or large DHW loads. The primary benefit of using heat pumps for DHW heating is reducing energy use due to higher efficiencies than electrical resistance heating. Seasonal efficiencies of DHW heat pumps can be 3 to 4 times higher than similar electric-resistance units. Another significant benefit is the reduction in peak electrical demand. However, heat pump performance and efficiency are heavily affected by the heat source; not all heat pumps can function under all climate conditions. Backup heating systems can be required for colder climates. In addition, heat pump systems may require additional storage tanks to prevent short cycling and increase the usable DHW volume during peak demand.

Applying heat pump technology for DHW systems with low consumption profiles can result in long payback periods due to high implementation costs and low operational savings.

Finally, local water quality can have a significant impact on the longevity of DHW heat pump systems, though this can be addressed through the use of water treatment systems. Within Metro Vancouver, low-conductivity water from the municipal water supply is generally favourable for equipment longevity and does not require additional treatment.

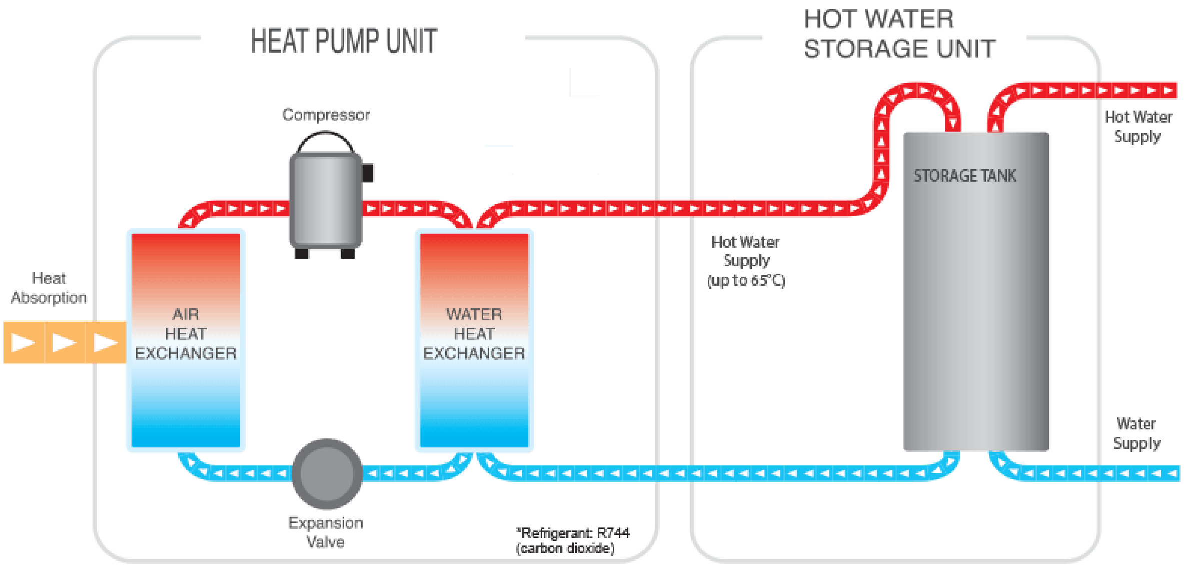


FIGURE 58: HEAT PUMP WATER HEATER CONCEPT

9.6.1. Heating Source

Evaluate the feasibility of employing various heat sources for electrified DHW projects. It is recommended to choose the heat source with the highest available temperature to maximize efficiency, provided it can adequately meet the load requirements and is practically accessible.

Consider siting equipment in locations that can improve source temperature for air-source systems. Examples include:

- Parking garages and sheltered outdoor areas can serve as buffering spaces to moderate source temperature.
- Warm mechanical rooms, electrical rooms, or IT/server spaces, where transferring air can provide beneficial cooling while improving heat pump efficiency.
- Providing access to multiple sources based on seasonal loads. For example, in summer, a heat pump could be used to pre-cool outdoor air entering a building, while in winter, it could source air from an exhaust plenum to use waste heat from the building – provided exhaust air quality is suitable.

Remember that air-source systems require a large airflow when operating, and consider adequate air supply and exhaust paths to achieve rated capacities.

For water-source systems, first consider heat recovery from year-round cooling loads such as tenant cooling loops or condenser water systems. Reclaim from sewer discharge is often viable for facilities with large water use patterns. For buildings with low-temperature heat pump-based hot water heating systems, consider cascading off this system as a heat source for HPWHs. Geo-exchange is another option, but it is typically more costly.

9.6.2. Refrigerant Selection

Refrigerant selection is an important consideration, as the refrigerant type can determine the type of heat pump cycle available (see Section 9.6.3) and the emission impact associated with a refrigerant leak. Currently, R-410A is a common refrigerant for multi-pass heat pumps, R-134A is common for both single- and multi-pass heat pumps, and R744 (CO_2) is becoming a popular low global warming potential (GWP) option for single-pass heat pumps. However, R-410A and R-134A will be phased out soon due to their high GWP. Refer to Section 7.4.2 for additional considerations when choosing a refrigerant.

9.6.3. Heat Pump Heating Cycles

HPWHs can be classified as single-pass or multi-pass heating based on their heating control cycle. The selected configuration drives the design configuration of associated hot water storage and temperature maintenance systems. As such, it is important to understand the benefits and constraints of each type.

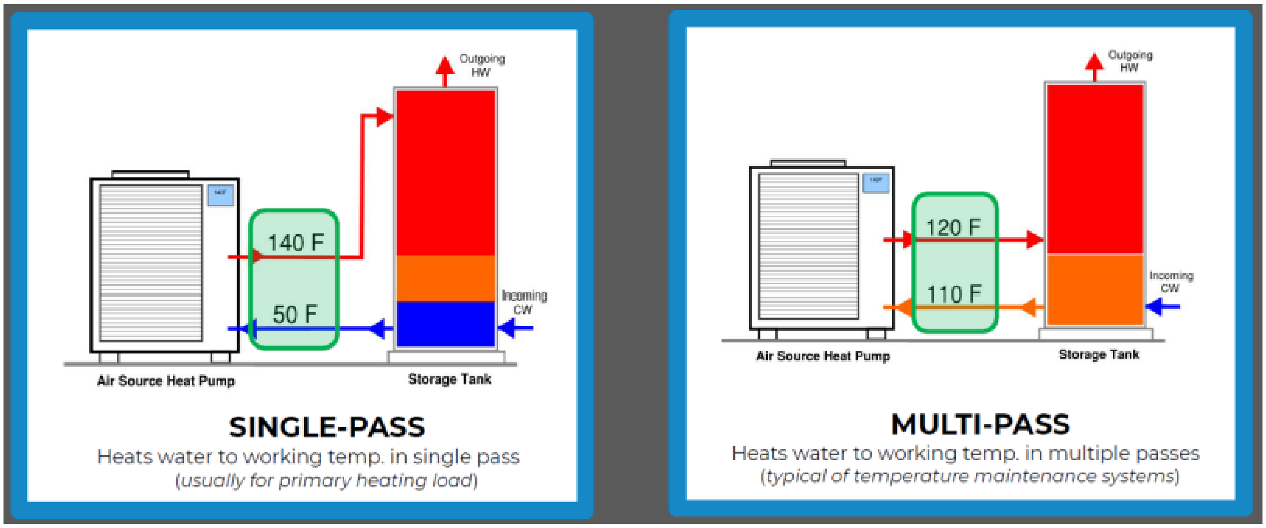


FIGURE 59: HPWH HEATING CYCLES: SINGLE-PASS AND MULTI-PASS

9.6.3.1. Single-Pass Heat Pumps

Single-pass heat pumps operate using a variable flow rate to maintain a constant outlet temperature at or above the required storage temperature, heating water in a single pass through the heat pump. Single-pass heat pumps are typically more efficient than multi-pass and can provide hot water to the system even if the storage is depleted. These systems are very sensitive to entering water temperature and require a low entering temperature to achieve rated capacities and efficiencies. This is best achieved through stratification of the stored hot water and managing hot water temperature maintenance with a separate system. R-134a and R-744 (CO_2) are common refrigerants for single-pass systems.

9.6.3.2. Multi-Pass Heat Pumps

Multi-pass heat pumps operate at higher flow rates than single-pass units: water is heated over multiple passes through the heat pump, with each pass generating a relatively small temperature lift compared to the final storage temperature setpoint. Multi-pass heat pumps can operate efficiently even when incoming water temperatures exceed 45°C (113°F). This type of heating cycle typically relies on the reverse-Rankine cycle using synthetic refrigerants; R-410A and R-134a are very common. Multi-pass heat pumps are typically less efficient than single-pass. Still, their efficiency is less sensitive to entering water temperature, making them a good choice for handling hot water temperature maintenance loads, or small systems with insufficient space to provide separate hot water temperature maintenance systems.

9.6.4. Central Heat Pump Water Heaters

Central heat pump water heater (CHPWH) systems consist of one or more heat pump water heaters, a central hot water storage system, and a hot water temperature maintenance system, as illustrated in Figure 60.

Air-source heat pumps are a very common heat source for CHPWH systems. However, water-to-water heat pumps should also be considered an option for buildings with excess cooling loads or large domestic water use where sewer heat reclaim is feasible. Considering how hot water temperature maintenance heating is accomplished is critical to maximizing the efficiency of heat pumps, and it is essential to consider how Legionella risk can be appropriately managed in all storage tanks.

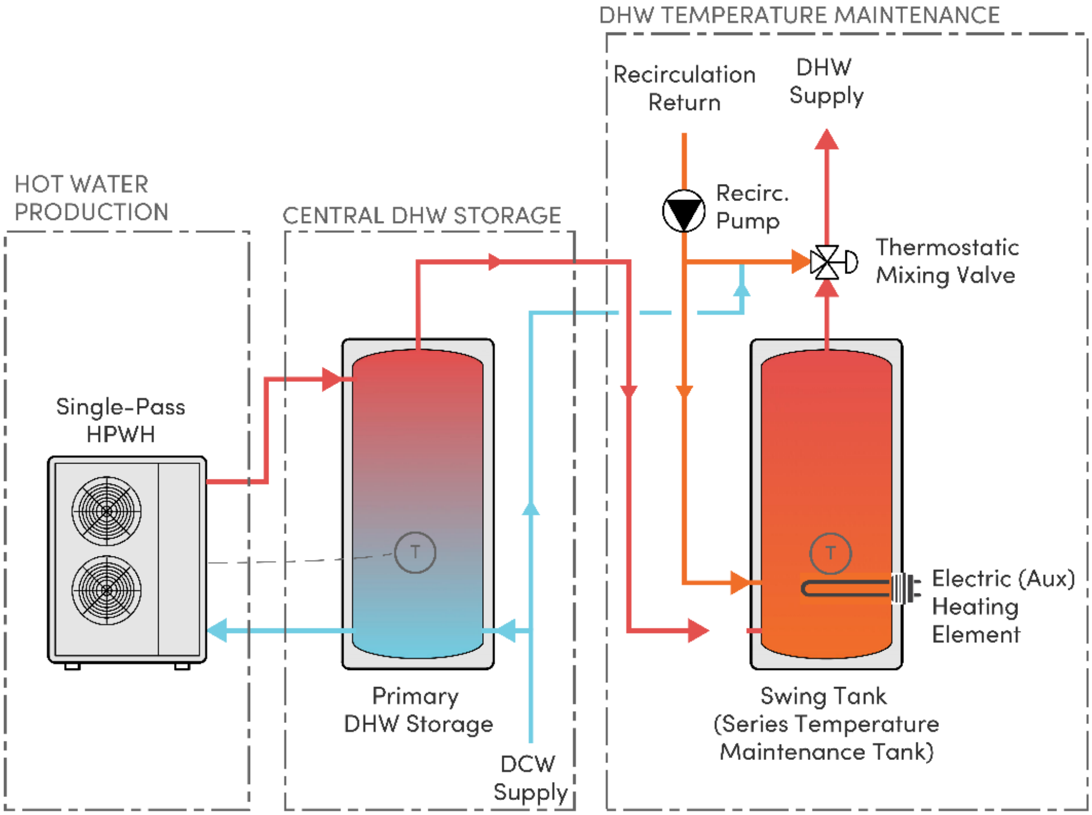


FIGURE 60: CENTRAL HEAT PUMP WATER HEATER SYSTEM

9.6.4.1. Space and Location Considerations

CHPWH systems require more space than gas-fired systems due to higher storage volumes. Locate the heat pumps as close to the storage tanks as possible to limit piping costs.

Heat pump evaporators produce condensate during operation; provide and pipe drains following applicable plumbing codes to handle the condensate produced. Condensate pumps may be required for areas in existing buildings that are not served by gravity drainage. For exterior-mounted applications, consider freeze protection for condensate drainage.

If new heat pumps are planned to be located indoors, check the Refrigeration Code (CSA Group, 2023) as it may ask for refrigerant detection and additional ventilation systems for life safety depending on the type of system, amount of refrigerant, and room size.

9.6.5. Distributed Heat Pump Water Heaters

Distributed HPWH systems consist of multiple packaged (unitary) heat pump water heaters throughout a building to meet domestic hot needs.

The primary advantage of distributed DHW systems over centralized systems is the potential reduction or elimination of hot water distribution losses. Distributed system configurations may come at a higher initial cost than central systems due to increased labour expenses. However, such configurations can be cost-effective alternatives to central systems when riser replacements are necessary. The decentralized nature of these configurations can result in additional maintenance requirements due to the increased amount of equipment compared to centralized options.

This configuration eliminates the requirement for a central DHW distribution system and associated hot water temperature maintenance system. Local hot water temperature maintenance can also be eliminated if water heaters are strategically located to reduce pipe lengths, and system piping design is configured in a headered home-run arrangement with rightsized piping to reduce wait times at fixtures.

9.6.5.1. Efficiency Considerations

Distributed HPWH systems rely on packaged unitary HPWHs, which are often equipped with one or more auxiliary electric-resistance heating elements to provide supplemental heat during periods of high demand. These units consist of a storage tank with a top-mounted air-to-water heat pump assembly, as illustrated in Figure 61.

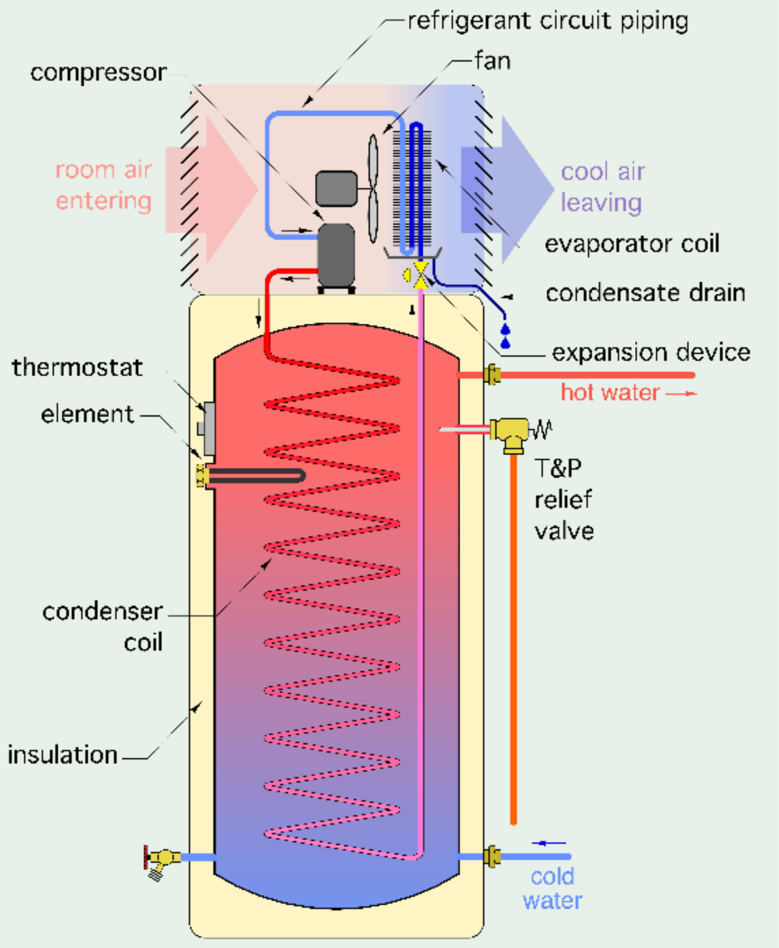


FIGURE 61: TYPICAL UNITARY HPWH

In the field, unitary HPWHs can expect to achieve COPs in the range of 3. However, to achieve these efficiencies, these tanks should not be applied in configurations requiring DHW recirculation: while the heat pump section can achieve COPs of between 3 and 5 depending on the ambient air, frequent operation of the electric resistance section can drastically decrease the overall efficiency of the system; applications including recirculation have often resulted in very low COPs in the range of 1.5 due to excess usage of the auxiliary heating elements to meet recirculation loads. Instead, it is recommended that tanks be sourced without auxiliary heat or externally controlled auxiliary heat to avoid COP degradation.

Recently, limited capacity 120V unitary HPWHs have become available; these can be applied for low-demand applications such as lavatories and eliminate the need for electrical upgrades.

9.6.5.2. Space and Location Considerations

A distributed/unitary HPWH typically relies on indoor space within the building as a source of heat, effectively cascading off the building heating system during the heating season and directly conditioning the space in the cooling season.

Install distributed heat pumps as close to hot water fixtures as possible to eliminate the need for recirculation and minimize hot water wait times at fixtures. Adequate airflow is an essential consideration for achieving rated capacities and efficiencies. These heat pumps can often be placed in a closet with a louvred door. For acoustic-sensitive areas, acoustically lined ducting can be used; however, newer models have low-sound power ratings, mitigating noise concerns even in areas such as lunchrooms and washrooms.

Like all heat pumps, these units generate condensate, which must be piped to drain. A drain pan can be installed with a condensate pump and leak detector for locations without a drain.

9.7. ELECTRIC RESISTANCE HEATING TECHNOLOGIES

In buildings with low hot water consumption, electric resistance DHW systems can often be a more cost-effective decarbonization solution than HPWH systems. Several configuration options are available when using electric resistance DHW heating systems. The three commonly employed options for commercial facilities are central storage-based systems, distributed storage-based systems, and point-of-use heaters. Assess the electrical load for all three options to evaluate if the existing electrical system can accommodate the significant electrical load increase that the electric resistance heating upgrade would generate.

9.7.1. Central Electric Resistance Water Heaters

This configuration incorporates one or more electric resistance water heaters and storage tanks to supply DHW to an entire building.

One of the primary advantages of opting for centralized electric resistance DHW is its compatibility with existing space requirements and installation procedures when replacing a conventional gas-fired centralized system. In many cases, these new systems can be conveniently situated in place of the existing gas-fired systems, streamlining the transition to electrified DHW without significant equipment room modifications.

Another advantage is that electric resistance heating has lower maintenance costs than gas-fired or heat pump-based DHW systems.

9.7.2. Distributed Electric Resistance Water Heaters

A distributed electric resistance DHW system includes multiple integrated DHW storage heaters that serve specific zones or floor areas within a building. Considerations for a decentralized DHW design are discussed in Section 9.6.5.

9.7.3. Point-of-use Electric Resistance Water Heaters

Electric POU water heaters are a direct alternative to central DHW systems, delivering hot water without storage tanks and an extensive hot water distribution system. Eliminating energy losses associated with storing and distributing hot water is a notable advantage of POU water heaters over centralized systems, as water is only heated when and where required. POU water heaters are particularly effective for office buildings and other facilities with low DHW demand, and where storage tanks tend to experience longer standby periods during unoccupied hours.

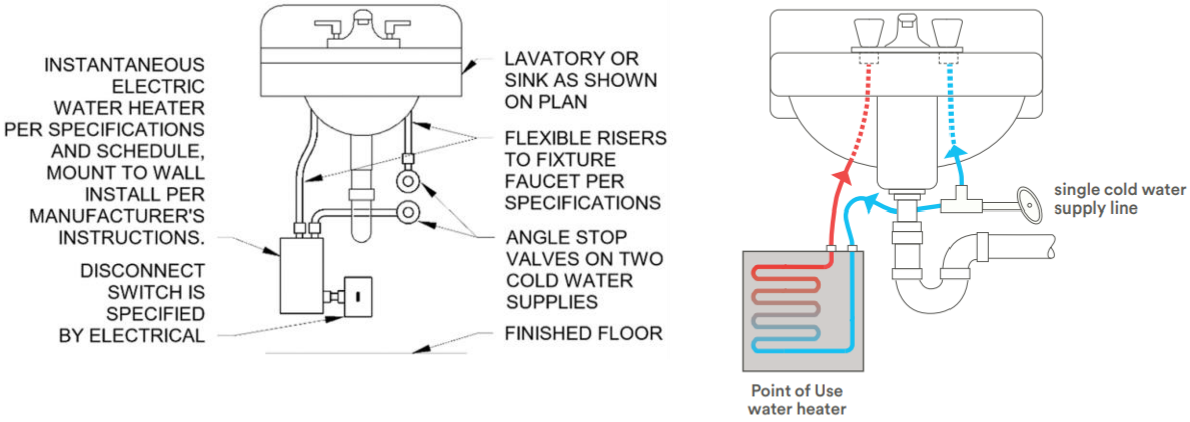


FIGURE 62: TYPICAL UNDER-SINK POU WATER HEATER

POU heaters typically have a longer service life and lower operating and maintenance costs than centralized or decentralized systems. Most POU water heaters have an expected service life of more than 20 years compared with tank-type water heaters, which typically last only 10-15 years (Energy Saver, 2021). Electric resistance POU water heaters require minimal maintenance. Additionally, the replacement of POU heaters is much simpler than the replacement of storage tanks. They can typically be replaced by a building owner's operations staff, rather than requiring the engagement of a contractor. POU heaters can significantly reduce hot water waiting times for buildings with poor-performing hot water temperature maintenance systems.

When considering POU, consider the avoided costs of domestic water piping riser replacements for systems where distribution systems are near the end of life. Avoiding riser replacements can often offset any added cost of POU systems.

For example, POU DHW units can be installed in phases, floor-by-floor or room-by-room. The existing centralized DHW system can continue to provide service to the rest of the building throughout the installation and can be disconnected once complete. This approach can minimize disruption to existing DHW service. The existing piping can be abandoned but must be drained to avoid future Legionella or other bacterial growth. Consider multiple POU heaters in parallel or decentralized electric DHW tanks for high-use areas such as end-of-trip facilities.

9.8. COMBINED DHW AND HW SYSTEMS

DHW generation can be integrated with building heating systems; the primary HVAC heating system typically provides DHW heat through double-walled heat exchangers.

Combined systems can be attractive because they reduce the required equipment and can be suitable for buildings with high domestic hot water loads or year-round space heating requirements.

However, combined systems can present several challenges:

- They are prone to being oversized, which can reduce system efficiency and equipment service life through short cycling, especially during summer months.
- The DHW system can drive system operating temperatures for low-temperature heating systems, reducing efficiency.
- The heating system is required to operate year-round, which can result in significant standby losses, particularly in buildings with low DHW demand, such as office buildings.

During any electrification project, consider decoupling combined systems and installing dedicated DHW heating equipment to avoid these issues.

9.9. DHW STORAGE TECHNOLOGY

Rightsizing DHW storage is important to ensure the system operates efficiently and effectively. For storage-based systems, the combination of storage volume and recovery rate must be sufficient to meet the hot water needs of the building effectively. Needlessly oversized tanks can lead to unnecessary standby losses, while undersized tanks can result in insufficient hot water. Space availability also influences equipment selection for retrofit applications.

9.9.1. Determining Total Storage Volume

The sizing methodology for storage-based DHW systems is covered in Section 9.3.3. This sizing methodology determines the useable volume of DHW storage required to meet DHW requirements. However, the total storage volume provided must also consider DHW heater cycling volume and unusable volume, as illustrated in Figure 63.

The cycling volume is the volume of water between the controlling temperature sensor and the cold-water connection. Sufficient volume is required to prevent the heater from short cycling. For HPWHs, it is recommended that this volume be enough to allow the smallest compressor stage to operate for at least 15 minutes.

The unusable volume is the volume of water below the cold-water inlet. This volume is essentially dead space and is not useful for meeting DHW storage needs or providing sufficient volume for heat pump cycling.

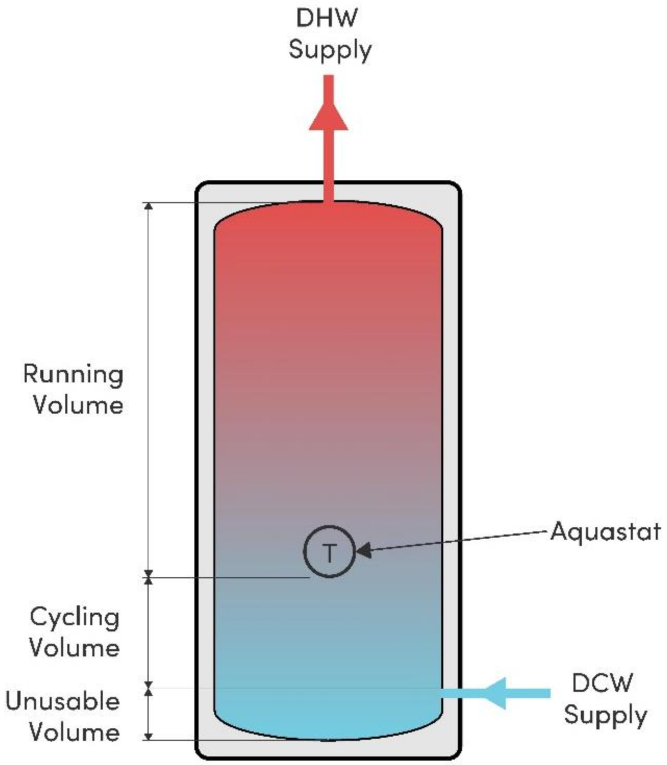


FIGURE 63: COMPONENT VOLUMES OF TOTAL STORAGE VOLUME REQUIREMENTS

9.9.2. Single Tanks vs. Tank Arrays

The total system volume can be achieved using one or more large storage tanks or an array of smaller tanks. Space and access requirements often limit layout options and can drive the need for an array of smaller tanks. Table 20 summarizes selection considerations to assist with deciding on tank configurations.

TABLE 20: COMPARISON OF LARGE STORAGE TANKS VS. TANK ARRAYS

	LARGE STORAGE TANKS	STORAGE TANK ARRAYS
Benefits	Lower standby losses due to low-surface-area-to-volume ratio. Require less floor space per unit volume. Pipe connection sizes and locations can be customized to suit the application. Less site piping reduces the potential for piping errors. More options with tank material and warranties.	More flexibility for installation and replacement access. More flexibility for laying out systems in existing mechanical spaces. Lower cost tanks. Tank sizes below 120 Gallons do not require an ASME rating. Existing tanks can sometimes be repurposed for use within the tank array.
Challenges and Considerations	Consider installation and replacement carefully. Higher weight per unit area, which may exceed structural allowances. ASME rating required; increased first cost.	Higher standby losses due to high surface-area-to-volume ratio. Consider adding additional insulation in the field to reduce standby losses. Requires more floor space per unit volume. Less flexibility with pipe connection sizes and locations, which can be a challenge for series piped tanks. Some manufacturers provide smaller tanks with large pipe sizes to accommodate this.

9.9.3. Insulation Requirements

The National Energy Code for Buildings requires a minimum insulation value of RSI-2.2 (R-12.5) for unfired tanks (NRCC, 2020). Consider increasing insulation values above this, especially for tanks installed in unheated or semi-heated spaces. As a rule, a minimum tank insulation value of RSI-3.2 (R-18) is recommended for heat pump applications.

9.9.4. Tank Piping Configuration

Tank piping configuration is dependent on the type of heating source provided. Electric resistance heating and multi-pass heat pumps operate at higher water flows and low, variable temperature differentials, and tanks can be piped in a parallel configuration.

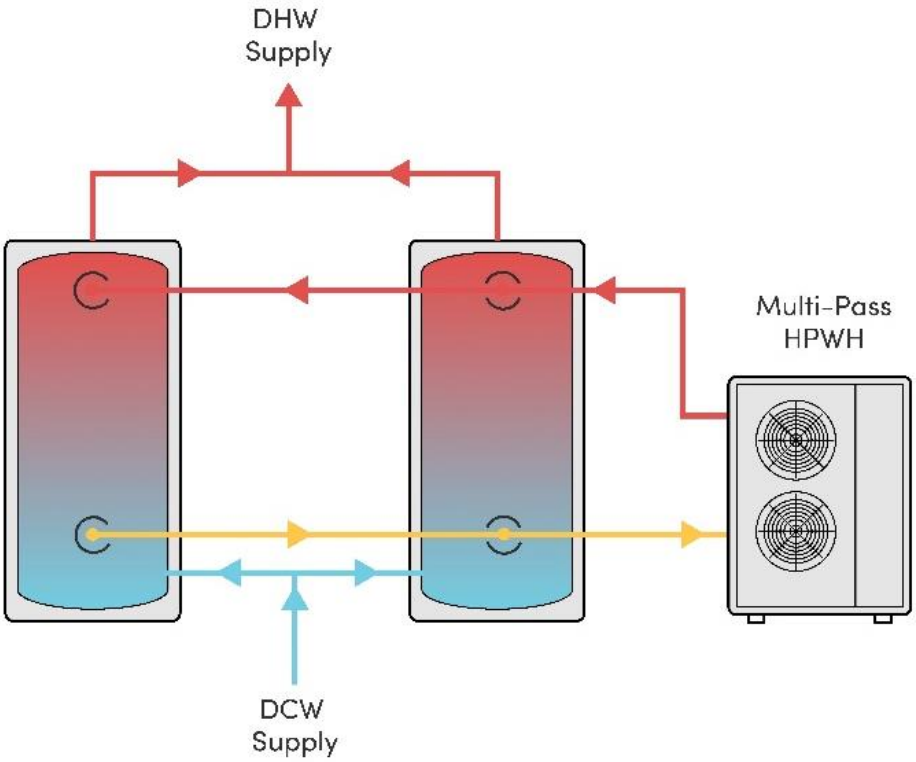


FIGURE 64: PARALLEL TANK CONFIGURATION FOR MULTI-PASS HEAT PUMPS

Single-pass heat pumps require low entering water temperature to be effective (see Section 9.6.3). Temperature stratification is vital to ensure the lowest temperature water enters the heat pump(s); in multi-tank arrays, piping tanks in series promotes stratification. Pay attention to tank connection sizes because each tank experiences the peak system flow; undersized connection sizes increase pressure drop and disrupt stratification by creating internal flow jets. Some manufacturers provide tanks specifically designed for series piping, and designers should consult with manufacturers to ensure proper tank selection for the application. The piping arrangement should also consider auxiliary valves to permit a tank to be removed from service without affecting the operation of the remaining tanks.

Consider series tank arrangements for DHW systems using heat recovery as preheat or gas-fired or electric resistance for peaking capacity. Refer to Section 9.10 for information about integrating supplemental heating systems into swing tanks.

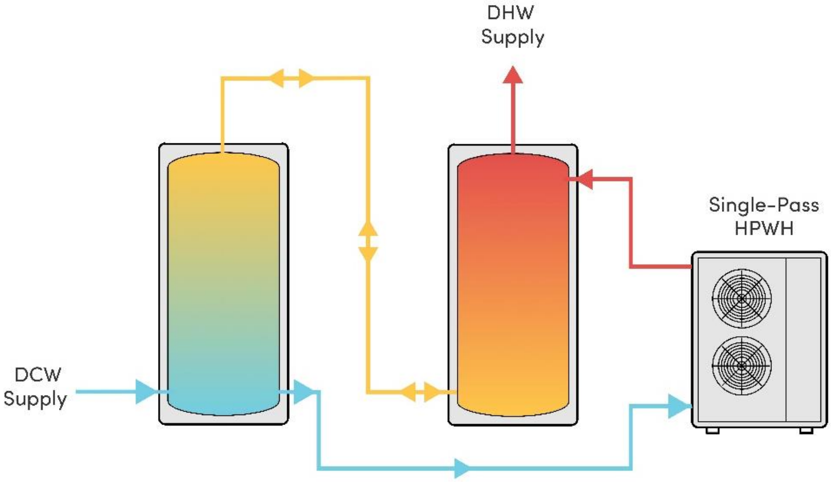


FIGURE 65: SERIES TANK PIPING CONFIGURATION

9.9.5. Location of Sensor Wells

Locate the aquastat or controlling temperature sensor to provide enough system volume below the sensor to prevent short cycling of the HPWH. Additional temperature sensors are useful for monitoring large tanks or tanks piped in series. For parallel tank systems, consider adding a sensor in each tank.

9.9.6. Secondary Heat Exchangers

Provincial building codes require separating non-potable water systems from potable water systems using double-walled heat exchangers with positive leak detection. Separate heat pump water heaters from the storage system using a secondary heat exchanger unless the manufacturer offers a heat pump with an integrated double-wall refrigerant-to-water heat exchanger. This can, in turn, require additional piping, pumps, and controls to achieve separation. When heat exchangers are needed, expect a reduction in temperature between the heat pump heating loop and the DHW loop. To maintain the same DHW loop temperature, a heat pump heating loop must deliver a higher temperature to the heat exchanger.

9.9.7. Thermal Expansion

Consider thermal expansion for all storage-type DHW systems. When assessing thermal expansion requirements, consider the additional storage volume and potentially higher storage temperatures. Flow-through expansion tanks are recommended to minimize the potential for Legionella contamination.

9.9.8. Thermostatic Mixing Valves

A master thermostatic mixing valve (or master mixing valve) thermostatically blends hot and cold water to ensure a safe hot water distribution system temperature. Provide a master mixing valve at the outlet of all hot water storage systems; this is particularly crucial for heat pump water heater systems, which may experience more significant temperature fluctuations than gas-fired or electric-resistance systems. Opt for digital thermostatic mixing valves that can quickly respond to temperature changes instead of wax-motor-type valves with slower response times; digital thermostatic mixing valves offer the advantages of accommodating thermal disinfection cycles, supporting recirculation pump operation, and integrating with the BAS.

9.10. SUPPLEMENTAL HEATING

In retrofit applications, limited electrical capacity and budget constraints can often preclude the complete electrification of a DHW system within one project. In colder climates, providing full heating using heat pumps may not be feasible. In these cases, existing or newly installed electric resistance or gas-fired DHW heating systems can be configured to provide supplemental heating during peak load events. Take care in configuring the system controls to ensure that the heat pump remains the primary source of heat, and that the operation of the supplemental heat source does not compromise or degrade the operation of the heat pump. Heat pump retrofits can be staged for projects with available electrical capacity and budget limitations while relying on lower-cost gas-fired or electric resistance heat to meet peak requirements.

It is important to consider full electrification even within the scope of partial electrification projects and ensure that design and implementation do not impede further system electrification and optimization.

9.11. CONTROLS

Controls requirements are highly dependent on the type of system chosen for retrofit. POU and distributed electric resistance heating systems require little to no controls integration as these systems are simple and operate off packaged controls.

Conversely, central heat pump-based and hybrid systems comprise multiple components that must work in a coordinated fashion to perform efficiently. Central systems should be integrated with the BAS, and include trending and alarming. Convey the required sequence of operations, trending, and monitoring requirements within the contract documents rather than leaving guesswork regarding the intended mode of operation for the contractor. Consider Legionella risk management as part of the controls sequence; storage tanks in which water temperatures are not always above 60°C may require a sterilization sequence. For hybrid systems, controls sequences must be clear on the staging of primary and supplemental heating systems to prevent supplemental systems from operating prematurely or in a manner that degrades heat pump performance.

It is also important to confirm control and monitoring expectations with the building operators to ensure that the system can provide real-time information that is useful and actionable while avoiding nuisance alarms that erode operator confidence.

For further discussion of commissioning heat pump systems, see Section 6.4.

9.12. ADDITIONAL RESOURCES

The following resources provide more information about electrified DHW systems:

- EnergyTrust of Oregon's Central Heat Pump Water Heater Design Guide (Ecotope, 2023).
- BC Housing’s Design Guide for Domestic Hot Water Heat Pumps in New Multi-Unit Residential Buildings (BC Housing, 2019).

- Northwest Energy Efficiency Alliance's Advanced Water Heating Specification Version 8.0 (NEEA, 2024).
- ASHRAE Handbook—HVAC Applications, Chapter 51 (ASHRAE, 2023).
- Ecotope's memo on Improving Thermal Storage to Reduce Installation Costs for Heat Pump Water Heating Systems (Banks, 2022).
- JMP Study Hall blog post Domestic Hot Water Recirculation Part 4: Pump Sizing Example (JMP, 2014).
- Ecotope's manual for the Ecosizer Central Heat Pump Water Heating Sizing Tool (Kintner, 2020).

10. Electrical Considerations

This chapter provides an overview of the electrical considerations critical to planning low-carbon electrification (LCE) retrofit projects, with a focus on making the best use of existing electrical service(s) in order to avoid or minimize the need for upgrades.

LCE projects invariably add additional electrical loads to buildings: even though LCE projects typically reduce the overall energy use of a building, they lead to increased electrical energy consumption (kWh) and load (kW) as previously gas-fired systems are electrified. Electrical engineers play a key role in LCE projects, identifying electrical capacity constraints and solutions to inform the feasibility of electrification options.

Early involvement of electrical engineers in an LCE project – starting at the feasibility stage – is critical to understanding the impact of proposed upgrades on the building’s electrical infrastructure. This engagement allows the team to explore options for reducing and shifting loads; evaluate associated opportunities and costs; and ensure decisions are fully informed by electrical considerations that can significantly affect the project’s cost, feasibility, and chances of success. Early involvement also allows the team to proactively evaluate and address potential challenges, such as long lead times for electrical equipment, and coordination with local utilities if a service upgrade is required.

10.1. ELECTRICAL CAPACITY ASSESSMENTS

To evaluate the feasibility of accommodating new LCE loads, have an electrical engineer conduct an electrical capacity review during the project's feasibility phase to determine whether adequate capacity exists at the building service, distribution, and branch circuit levels, or if an electrical service upgrade is necessary to accommodate the new load. These upgrades can add significant costs and potentially affect the project schedule.

The following section describes key steps and considerations in electrical capacity assessments as they relate to LCE projects.

10.1.1. Site & Drawing Review

Review site conditions and existing electrical drawings, where they exist, to develop an understanding of the existing electrical service and power distribution system, including layout and locations, and any necessary space adjustments required to meet current codes, standards, and utility requirements. Where service upgrades are required, existing electrical equipment must meet current utility requirements; this can necessitate upgrades to existing equipment and access to the electrical room.

10.1.2. Total Capacity

To establish a baseline for available electrical capacity, determine the existing utility service capacity by assessing the relevant parameters. This assessment can be performed through a desktop review of available electrical drawings, but should be verified on-site to ensure all data is correct. Contact the local electrical utility to determine the capacity of essential components such as utility transformers to confirm that these elements will not become limiting factors when implementing LCE upgrades.

10.1.3. Peak Power Demand

Power data analysis is crucial to understanding the peak power demand of a building, the timing of these peaks, historical demand trends, and seasonal variations. This information can help determine the spare capacity available for accommodating new electrified systems for space heating, space cooling, or water heating. For example, a building that has a cooling system will typically experience peak electrical demand during the summer. However, if the planned LCE loads, such as from electric heat pump systems, are added during the winter, the peak electrical demand may shift or create dual seasonal peaks, thereby impacting capacity requirements.

Existing peak power demand and its timing can often be derived from historical utility bills. Depending on the service account type, energy consumption (kWh) data may be available in 5-minute or 60-minute intervals from the building’s online utility account. If a building does not have a master meter, the aggregated consumption may be available from the electrical utility upon request. Additional details and more granular data can be obtained from main or distributed sub-meters if the building has them. Note that some buildings may have recently installed electrical loads, such as EV charging infrastructure, which have not been fully utilized, or seasonal systems, such as heating systems installed last summer or cooling systems installed last winter, which may not have shown their peak loads in the current metering data. It is important to account for the designed peak loads of such systems in the calculations to ensure that they are accurate.

When utility data is not available or insufficient – for example, from municipal utilities that don’t have digital smart meters, or in off-grid regions – temporary metering can be used to gather accurate information about the building's current electrical load. If historical data is inadequate, the existing electrical load requirements can be estimated based on connected loads. This can be done by analyzing the electrical drawings, or by conducting a comprehensive inventory of all building systems, including fire pumps, elevators, lighting, HVAC systems, appliances, and any specialized equipment. It is critical to estimate loads accurately to identify potential electrical deficiencies before proceeding with any LCE retrofit.

10.1.4. Determining Spare Capacity

Conducting an electrical spare capacity screening can help determine if a building’s main electrical feed can handle the current load. This involves comparing the peak power demand over the past 12 months to the rated capacity of the main electrical service in accordance with the Canadian Electrical Code (CSA Group, 2021). The peak power demand should remain within the limits of the main electrical feed: any difference between these values indicates the available spare capacity. Overloading the electrical feed can cause overcurrent protection devices to trip and significantly increase fire hazards.

10.1.5. Allowable Electrical Load Increases by Utility

During the feasibility study phase, evaluate whether and how the expected load increase can be accommodated by the electrical utility. Load increases are generally governed by an electricity tariff. In BC, Section 7.1 of the BC Hydro Electric Tariff limits load increases to “15 kW or 20% [above existing peak demand], whichever is greater, or such that the aggregate load exceeds 80% of the rated capacity of the Customer’s main switch, except to the extent that BC Hydro may otherwise approve in advance” (BCUC, 2017). Similar requirements can be found in Section 9.3 of the FortisBC Electric Tariff, although it is less prescriptive (BCUC, 2019). For new buildings in their first few years of operation which are supplied at primary voltage (typically, 12.5kV or 25kV in BC), an Electric Service Agreement (ESA) will stipulate the maximum allowable demand.

As part of planning for electrification, review the applicable electrical tariff or agreement governing the electrical load that the utility is obligated to provide to the building, as it may be less than the nameplate rating of the main service. If the anticipated load increase exceeds the limits specified in the tariff or agreement, consult with the utility to ensure that the required load increase can be accommodated.

Where a building shares a utility transformer with neighbouring buildings, consult with the utility in cases where the anticipated load increase will exceed the available capacity on the utility transformer and/or feeder. In such cases, if the utility determines that there is sufficient available capacity, the building owner can submit a service request and deposit to “reserve” the spare capacity and prevent neighbouring buildings from using it. If such coordination has not been performed, there is a risk of overloading the utility transformer beyond its operating limits and creating a fire hazard.

10.1.6. Voltage Requirements

Electrical services to buildings vary in voltage and phase systems depending on several factors including calculated load, availability of phases in the service area, designated voltage areas, and sharing of utility transformers. Consider the existing voltage level of the building’s electrical system to determine equipment compatibility; as more technologies are being imported from abroad, it is not uncommon to come across voltage systems that are atypical in Canadian commercial buildings, such as 230V L-N. Coordinate equipment selection between the electrical engineer, mechanical engineer, and equipment supplier to ensure compatibility with the voltages available at the building, and/or installation of transformers.

10.1.7. Emergency Power Systems

If the proposed LCE systems are considered to be provided with backup power during power outages, determine the existing capacity of onsite emergency and standby power systems, such as those serviced by generators. Quantify the total loads connected to the generator to determine the available electrical capacity of the generator. Note that increasing a building’s electrical load can reduce the amount of time the generator can support emergency loads, as defined by building codes, in the event of an emergency. Review the relevant sections of the BC Building Code carefully when deciding whether the LCE loads qualify as emergency loads or not.

10.2. NEW LOADS AND PROJECTED LOAD CALCULATIONS

Beyond the new loads that will be incurred by an LCE retrofit, consider anticipated electrical needs, such as EV charging, building expansions, and changes in tenant types, to ensure that your project will not have unanticipated future consequences. Preparation of a load calculation of such potential load increases and their impact on the building’s electrical infrastructure by an electrical engineer can support executive decisions on LCE retrofit options.

10.2.1. EV Charging

Electric vehicle supply equipment (EVSE) has the potential to significantly increase a building's peak electrical demand. A typical level 2 charger draws 32A, 240V, or 7.68 kW per vehicle, but can draw as much as 80A, 240V, or 19.2 kW per vehicle. As more commercial buildings provide EV charging as an amenity and/or as required by local bylaws, this can introduce considerable loads. DC fast chargers will typically draw significantly more power, in the range of 50kW to 350kW per charging port, but are typically fewer in number than a level 2 EVSE. An electric vehicle energy management system (EVEMS) can manage the power delivered to each vehicle so as not to exceed the designed capacity of the EV charging system.

10.3. ELECTRICAL SERVICE UPGRADES

Where a building's existing spare electrical capacity is insufficient to accommodate the proposed LCE loads, an electrical service upgrade can be considered. Such upgrades are typically the costliest electrical scope of work: they may involve installation of new equipment such as a new utility pad-mounted transformer (PMT), a customer-owned unit-substation, and Vista switches; and require on and off-site civil work, and structural and architectural modifications.

If a service upgrade is required, it is recommended to plan for additional electrical loads, such as EV chargers, that may be desired or required in the future to avoid subsequent service upgrades.

10.4. ELECTRICAL INFRASTRUCTURE UPGRADES

Similar to electrical service upgrades, the power distribution systems within a building may require upgrades to service new LCE loads. Such upgrades typically include new distribution boards, step-down and/or step-up transformers, and associated feeders and circuit breakers or fuses. Such upgrades are typically less contingent on service level capacity, but will nonetheless require careful consideration, especially when working with older equipment, as compatible parts are becoming less available.

10.5. LOAD MANAGEMENT

At a building level, effective load management can help to minimize service upgrade requirements in cases where there is limited spare electrical capacity. Load management strategies are techniques and practices that can be employed to balance and optimize the distribution of electrical load for the grid and buildings. Examples include modulation of cooling capacity or switching from heat pump to supplemental gas-fired heating when the service observes a higher load. Load management systems are currently being pioneered, and require close collaboration between electrical and mechanical designers, building stakeholders, and authorities having jurisdiction.

The following section discusses some common building-level load management strategies that can be considered as a first step to reduce peak loads and improve overall energy efficiency.

10.5.1. Energy Efficiency

The role of energy efficiency in system electrification is addressed in each of the technical chapters. At a building level, energy efficiency can improve the energy usage of systems and help manage electrical load, increasing spare electrical capacity and minimizing the need for costly service upgrades.

10.5.1.1. Lighting Upgrades

Upgrading a building to LED lighting and adding automatic controls to optimize energy usage is an effective means of reducing power loads and energy consumption at a building level. Lighting upgrades typically have promising payback periods and can increase spare electrical capacity, making them excellent complements to LCE projects. Canada is phasing out the manufacturing and import of fluorescent lamps, making like-for-like lighting replacements more difficult to source and further supporting the case for upgrading.

10.5.1.2. Plug Load Reduction Strategies

Plug load electricity consumption – the energy used by equipment that is plugged into outlets – can be minimized through energy-efficient technologies and practices such as:

- Smart power strips and smart plugs, which turn devices off when not in use or during specific times of the day, and provide user feedback on consumption.
- Power management software, which automatically puts computers or other devices into low-power mode when not in use.
- Time controls, which control the operation of electronic devices, turning them off when not intended or anticipated to be in use.
- Remote monitoring and controls, which can be connected to a building's building automation system (BAS) so that electronics can be turned off during non-working hours when they are not in use. Some BAS manufacturers offer smart plugs or inline circuit controllers that can monitor and control electrical plug loads for individual devices or circuits.

10.5.1.3. Power Quality

Poor power quality can significantly reduce the efficiency of power distribution systems in a building, hindering the effective use of available capacity to meet energy needs. Common power quality issues include:

- Low power factor, often caused by inductive loads like motors, which results in the system drawing more current than necessary to perform the same amount of work.
- System harmonics, introduced by non-linear loads such as variable frequency drives (VFDs) and LED lighting, which degrade power quality by distorting voltage and current waveforms.
- Voltage imbalances, often due to uneven load distribution across phases, which can shorten equipment lifespan and increase energy losses.
- Transient disturbances, such as voltage spikes or surges, which can damage sensitive equipment.
- Flicker, caused by rapid load changes, which can lead to equipment malfunctions and occupant discomfort.
- Voltage sags (temporary drops in voltage) and swells (temporary increases in voltage), which can disrupt equipment operation and cause premature equipment failure.

These issues limit a building's effective power capacity and place extra strain on the utility, reducing its efficiency in supplying energy. Power quality considerations are especially important in LCE projects, where additional electrical loads are added to an existing electrical system which may have been operational for decades and could be approaching the end of its expected design life. Existing loads may not be as resilient as newer equipment to new power quality issues, making it essential to address these concerns to ensure reliable operation.

When addressing power quality, reference relevant codes and standards, such as those from the Institute of Electrical and Electronics Engineers and the Canadian Electrical Code (CEC), to ensure compliance and adherence to best practices.

10.5.2. Dynamic Load Management

In order to plan and optimize their resources, utilities use predictive analytics, such as load forecasting, to predict future electricity demand. This can include smart grid technologies and advanced metering infrastructure (AMI) which enable two-way communication between utilities and consumers, facilitating real-time monitoring and control of electricity usage. Utilities use these technologies, along with demand response programs, to manage loads during peak periods and ensure that supply is available to meet demand.

Two common strategies utilities use to manage demand are:

- Peak shaving programs for commercial rates, which encourage consumers to reduce their electricity usage during peak demand periods to reduce their demand charge, thereby helping to avoid strain on the grid.
- Time-of-use (TOU) pricing for residential rates, which incentivizes consumers to shift their electricity usage to off-peak hours when rates are lower.

Refer to the ASHRAE Grid-Interactive Buildings for Decarbonization: Design and Operation Resource Guide (ASHRAE, 2023) for additional information on dynamic load management systems.

10.5.3. Load Shifting & Shedding

Flexible load scheduling and shifting involve moving energy-intensive activities to off-peak hours in order to manage electricity demand efficiently. Some industries can adjust production schedules to align with periods of lower electricity usage, thereby reducing strain on the grid. For example, data centers can delay non-urgent computing tasks, like data backups, to off-peak periods.

In commercial buildings, building automation systems (BAS) can be used to limit demand by adjusting space temperature setpoints during peak power consumption times. For instance, BAS in office buildings can slightly raise cooling setpoints during peak hours to reduce HVAC loads. Additionally, pre-conditioning spaces during early morning hours and using thermal energy storage systems can help shift or shed thermal energy loads.

Other load shifting and shedding systems include:

- **Demand Response Programs**: Utilities use incentives to encourages businesses to reduce their electricity use during peak periods, such as through temporary reductions in non-essential services or by adjusting HVAC and lighting systems.
- **Electric Vehicle Energy Management System (EVEMS)**: EV charging stations can be scheduled to operate during off-peak hours to reduce strain on the grid during peak periods. Smart charging systems can manage aggregate charging power by monitoring the electrical service.
- **Hot Water Load Control**: Heating water can be a significant energy load. By controlling when electric water heaters operate, such as during off-peak hours, facilities can shift energy usage and help shed peak loads.
- **Smart Appliances**: Using smart appliances that can be programmed to operate during off-peak times can also be an effective means of load shifting. For example, dishwashers, laundry machines, and industrial equipment with programmable controls can help distribute energy use more evenly throughout the day.

10.5.4. Energy Storage

Energy storage systems can play a critical role in modern energy management, and contribute to reliable and resilient energy infrastructure. The work by storing excess energy generated during low-demand periods and making it available for use during high-demand periods. These systems have a number of benefits, including:

- Balancing and smoothing out fluctuations in energy demand.
- Allowing more loads to be connected to the electrical system.
- Reducing utility demand charges.
- Improving reliability.
- Facilitating integration of renewable energy resources.
- Maintaining power quality.
- Giving consumers more control over their energy use and costs.

As technology improves, these systems will continue to evolve, offering more efficient, cost-effective, and environmentally friendly options for managing energy in commercial settings. This section addresses the two most common methods for storing energy: battery storage and thermal energy storage.

10.5.4.1. Battery Energy Storage

Battery energy storage systems (BESS) offer a versatile solution for shifting electrical loads from peak hours to off-peak times, optimizing energy use while improving overall efficiency. They are particularly beneficial when used alongside distributed energy generation systems, such as solar photovoltaic (PV) panels, to store electricity generated during periods of low demand for use during high-demand times.

For instance, a commercial building equipped with solar panels can store excess energy produced during sunny hours and use it to power operations in the evening when grid energy costs are higher. Battery storage can also serve as a backup power source during outages, enhancing energy resilience.

Evaluate the initial capital investment and ongoing maintenance costs of on-site battery carefully against service upgrade costs or other energy management alternatives. Advances in battery technologies, such as lithium-ion, flow batteries, and solid-state batteries, continue to enhance energy density, efficiency, and cost-effectiveness, making battery storage an increasingly attractive solution for many applications. Electrical utilities may offer rebates to incentivize the installation of BESS in buildings which will participate in demand response programs.

10.5.4.2. Thermal Storage

Thermal energy storage (TES) systems which shift heating and cooling related thermal loads from peak hours to off-peak periods are an effective and efficient means of managing building climate controls. In addition to HVAC applications, thermal storage can be used in industrial processes requiring temperature control, contributing to greater flexibility and energy cost savings.

Common thermal storage mediums include water, ice, or phase-change materials, each of which offers unique benefits depending on the application. For example, ice storage systems produce ice overnight when electricity rates are lower. The stored ice is used for cooling purposes during the day, thereby reducing the HVAC load during peak periods and minimizing utility costs.

Thermal storage can both support peak demand reduction and improve overall energy efficiency in buildings. Specific HVAC applications of thermal energy storage are discussed in detail in Chapter 8.

10.6. ADDITIONAL RESOURCES

The following resources provide more information about electrical considerations for the low-carbon electrification of existing mechanical systems:

- EGBC Practice Advisory: Electrical Considerations for Decarbonizing Existing Part 3 Building (EGBC, 2022).
- ASHRAE Grid-Interactive Buildings for Decarbonization Design & Resource Guide (ASHRAE, 2023).

11. Structural Considerations

This chapter includes an overview of structural considerations for LCE retrofits. Equipment associated with LCE systems can be larger and heavier than existing, gas-fired equipment. This can cause issues for a building if the existing structure is not designed to accommodate additional loads. Structural upgrades to a building can be costly, often more than the replacement mechanical equipment, particularly if the upgrade is not planned carefully.

Involve qualified and experienced structural engineers in the design and implementation process for LCE projects to ensure that the upgraded building meets structural safety standards, and obtain the necessary permits and approvals from local authorities to ensure compliance with regulations. Involving a structural engineer and completing a structural assessment early in the feasibility and design process can reduce overall project costs by identifying the best locations and orientation of equipment in order to minimize the structural impacts on the project. Ideally, a structural engineer is actively involved in suggesting the best locations for equipment to minimize structural impacts, rather than just providing a yes/no response to initial locations proposed by a mechanical engineer. A small increase in mechanical/electrical costs associated with a structurally beneficial location can result in substantial project savings by mitigating or eliminating structural upgrade requirements.

11.1. STRUCTURAL CONSULTANTS: WHEN ARE THEY REQUIRED?

Include structural consultants early in the design process if the electrification project intends to add new equipment or replace existing equipment with larger or heavier equipment, or if building services (piping, ducts, conduits) need to penetrate load-bearing walls or floor/ceiling slabs. Structural consultant feedback can identify potential risks before the retrofit design is finalized, mitigating costly mistakes and additional soft costs.

11.2. STRUCTURAL ASSESSMENTS

11.2.1. Site and Drawing Review

Have a structural engineer review the site, existing structural and architectural drawings, and any modifications or repairs to understand the building’s layout the structural integrity, the materials used in its construction, and its condition. A site review should include a visual review of structural elements, such as columns, beams, slabs, walls, and connections, for signs of damage, deterioration, or inadequate design.

Depending on the extent of the LCE project, review potential shaft locations, floor and wall penetrations, and equipment locations with a structural engineer to identify design constraints.

11.2.2. Load Analysis

A structural load analysis can determine the load-carrying capacity of the structure, and provide an understanding of the loads that the building can support or has the potential to support in the future. Understanding whether there are areas that cannot accommodate additional loads from new equipment early on in an LCE retrofit project can allow the project team to together to identify alternative solutions to avoid costly structural upgrades. Load analysis requirements can vary depending on the location and structural elements within the building, and should consider unique characteristics.

11.2.2.1. Equipment Weight Considerations

Verify that the existing structure can handle the loads imposed by the proposed LCE retrofit equipment. Types of loads and relevant considerations to each are listed in Table 21.

TABLE 21: TYPES OF EQUIPMENT STRUCTURAL LOADS

TYPES OF LOADS	SPECIFIC CONSIDERATIONS
Equipment Operating Weights	Include the weight of any fluids within the equipment such as water or refrigerant in equipment weights given to the structural consultant. In some cases, the weight of the fluid can exceed the weight of the equipment itself (e.g., larger storage tanks). Where unclear, confirm with the equipment manufacturer that the weight provided is the operating weight.
Seismic Forces	Seismic forces are those imposed by the equipment on the primary structure. Although a structural consultant is not typically retained to design seismic restraints, the forces transferred to the primary structure must be accounted for in their analysis.
Thermal Expansion Forces	High-temperature piping systems can impose large point loads at riser supports or pipe anchor locations which must be considered in the load analysis.

Equipment cut-sheets with dimensional data and weights can help the structural engineer understand how the load will be applied to the structure, for example as a point load or distributed load. For larger equipment, details on the centre of gravity and points loads are essential, particularly when the equipment is installed on lighter structural systems such as open web steel joints. The size and weight of the existing equipment that will be removed as a part of the LCE retrofit are required to determine the incremental change in load and impact on the structure.

For phased LCE projects, it is important to identify the planned equipment weights and locations early in the design process to ensure that all planned retrofit options can be accommodated.

11.2.2.2. Roof Load Capacity Considerations

If the proposed LCE retrofit equipment is intended to be installed on the roof, assess its load-bearing capacity to ensure it can support the weight of the equipment, especially in regions with snow or seismic considerations.

Depending on the age of the roof, re-roofing the areas below and around the proposed new LCE equipment may be required.

In addition to equipment loading, ensure requirements for acoustic and visual screens are considered from a structural perspective. In particular, acoustic screening and solid screening systems can impact high-point loads on existing roof structures.

11.2.2.3. Roof Penetrations & Openings Considerations

Coordinate required roof openings and penetrations for ducts, pipes, or other equipment with structural engineers to ensure that they do not compromise the structural integrity of the building. Depending on the location of the penetrations, reinforcement may be needed.

Air-source heat pump technologies have defrost cycles to manage frost buildup during cold climate conditions. It is important to coordinate the management of condensate, a byproduct of the defrost cycle: condensate buildup on the roof can result in clogged drains, freeze/thaw cycles, and/or penetration of vulnerable roofing membranes leading to leaks in occupied spaces below. Engage a structural engineer if dedicated penetrations are required for condensate collection.

11.2.2.4. Snow Load Considerations

Snow load refers to the weight of snow that accumulates on rooftops and other structures during a snowfall. LCE equipment with different dimensions than those of the existing equipment can impact snow load allowances; have a structural engineer perform load calculations to verify that the structure can handle the additional snow load. Snowdrift and potential areas where snow accumulation may be higher also need to be identified, and mitigation strategies should be developed to eliminate any potential safety concerns. The BC Building Code currently carries an exemption for snow load for roof-mounted equipment where the largest horizontal (plan) dimension is less than 3m in length. This can be useful when assessing potential mechanical equipment options on light roofs or areas with limited load-carrying capacity.

Improvements to the envelope of a building, such as installing additional roof insulation to improve thermal performance, are often considered during LCE retrofits. Thermal performance improvement measures can also increase snow loads and require additional consideration during a structural assessment.

11.2.2.5. Seismic Considerations

In regions prone to seismic events, assess buildings' resistance to seismic forces. Often, a third-party structural consultant is engaged by the mechanical contractor to design the seismic restraint systems for equipment and piping. However, the structural consultant also needs to determine whether the primary structure complies with seismic design codes and standards, and whether it is capable of supporting the connected seismic loads.

11.2.2.6. Vibration Isolation

Implement measures to control vibrations generated by HVAC equipment to prevent interference with the building structure and to ensure occupant comfort. This may include the use of vibration isolators and flexible connections.

11.2.2.7. Earthworks

Where below-grade work such as excavation or shoring is required, or additional support in the form of piles, footings, and pads is needed, engage a geotechnical consultant to provide pertinent soil and loading characteristics to the structural consultant. Wastewater heat recovery retrofits, which are becoming more popular, can require new sump pits; a parkade mechanical slab may need additional support to accommodate a new heat recovery chiller. In some cases, shoring or underpinning may be required to facilitate the installation of new load-bearing elements.

11.2.3. Penetration and Shaft Planning

A critical component of many LCE retrofit projects is planning for new service shafts and penetrations. Engage a structural engineer to identify feasible shaft and penetration locations early in the design process, since load bearing capacity and penetration size are often limited.

Permissible shaft locations are affected by several factors including, but not limited to, the type of structural system, the weight and size of pipes, pipe or duct insulation thickness, riser expansion compensation design, whether access into the shaft is required, and pressure breaks. Penetrations through the floor may require additional structural reinforcement or be limited by proximity to transfer slabs, embedded reinforcing elements, columns, beams, or existing openings.

Identify and coordinate preferred penetration locations to ensure that structural considerations and measures are incorporated into designs. Penetrations through walls can require additional fire ratings, whether in the form of fire wrap, fire and/or smoke dampers, or firestopping. Load-bearing walls have limitations on the size of the penetrations that can be made before their capacity is compromised.

11.2.4. Equipment Installation

Getting equipment into or out of existing spaces can be problematic. When considering LCE retrofit options, review existing access pathways and assess whether new temporary openings need to be created. Review existing hoisting and craning infrastructure, such as freight elevators, hoists, winches, or derricks, and determine if third-party craneage is required. Craning costs can be prohibitive; an LCE design including modular or smaller pieces of equipment may be more feasible where installation logistics pose substantial challenges. Also, consider having the structural engineer review the floor load-bearing capacity and the equipment transportation route to determine whether reinforcement is required to facilitate installation.

11.2.5. Deficiencies & Recommendations

Throughout the design process, a structural engineer can identify and document any structural issues, deficiencies, or potential risks that could compromise the safety or stability of the building. They can also provide recommendations for remediation or repair based on the findings in the assessment. This can include repairs, reinforcement, or modifications to address the issues that have been identified.

Ensure that the structural engineer’s findings are compiled and summarized in a structural assessment report, along with any recommendations, and any necessary engineering calculations. This report is essential for communication with project stakeholders, including building owners, architects, and regulatory authorities. Ensure that the report is signed and sealed by a structural engineer with expertise in the specific type of construction and local building codes. Use the findings and recommendations from the assessment to guide decision-making processes related to maintenance, renovation, or potential structural modifications required for the LCE retrofit.

11.3. CODE COMPLIANCE

Adhere to local and national building codes and regulations to ensure the safety and legality of new equipment installation. Compliance helps prevent electrical hazards and ensures that the system meets standard specifications.

The following building codes and standards are applicable in British Columbia:

- BC Building Code.
- Canadian Standards Association.
- Vancouver Building By-Law.

11.4. STRUCTURAL COORDINATION AND CONSIDERATIONS CHECKLIST

The following is a list of key structural considerations to bear in mind and opportunities for coordination with a structural engineer when evaluating LCE retrofit options.

- Give equipment locations, sizes, and operating weights to the structural engineer. For phased projects, identify locations of future equipment along with estimated size and weight.
- Identify new shaft locations early in the process.
- Carefully coordinate new pipe risers with the structural engineer to ensure adequate space is provided for expansion compensation and anchor locations and associated forces can be accommodated.
- Coordinate equipment housekeeping pad locations and sizes.
- Coordinate all new floors, roofs, and wall openings. Review fire ratings with the architect, code consultant, or AHJ.
- Advise the structural engineer where flexibility in mechanical system layout can accommodate structural constraints.
- Understand equipment access routes and any structural implications for installing and decommissioning equipment during the construction phase.

12. Architectural Considerations

12.1. ENVELOPE IMPROVEMENTS

The building envelope, also known as the building shell or thermal envelope, includes the exterior elements that separate the interior conditioned space from the exterior environment.

Building envelope upgrades can improve energy efficiency and comfort, and reduce heating loads. Envelope upgrades are complementary to electrification retrofits of a building: by reducing heating loads, they allow mechanical system sizes to be decreased, and can thereby mitigate the increase in electrical demand.

Envelope upgrades can be costly, and it can be challenging to gain stakeholder buy-in based on the energy benefits alone. On the other hand, buildings with façade elements at end-of-life are prime candidates for electrification: because they can substantially decrease building heating and cooling loads, envelope upgrades can enable a significant reduction in the size and cost of mechanical equipment selected for the retrofit.

12.1.1. Insulation

Insulation can be upgraded as an envelope improvement in walls, roofs, and floors to reduce heat transfer and improve thermal performance. Insulation thickness will determine the energy benefit, which can be evaluated against the cost to provide an optimal selection for the building. Have a building science consultant consider the addition of inboard or outboard insulation to mitigate interstitial condensation development due to vapour and wind pressure. Condensation is a particularly important consideration when insulating a building, as it can lead to mould and an expensive remediation project if not done correctly.

12.1.2. Windows and Doors

Windows and doors can be upgraded to energy-efficient models that have low U-values and high energy performance ratings to reduce heat loss. This can include double or triple glazing in thermally broken framing. Although window replacements can provide substantial thermal load reductions, implementation is costly and often only makes sense at end-of-life. The solar heat gain coefficient of windows can be used as a lever to increase or decrease solar gain, depending on whether the building is heating or cooling dominant.

12.1.3. Air Sealing

Air leakage through the building envelope can be identified through air tightness testing, and buildings can be sealed to prevent and reduce infiltration of outside air and the loss of conditioned air. This can be done by using weatherstripping, caulking, and sealants to seal gaps and cracks in walls, windows, and doors. Consider vestibules to reduce outdoor air infiltration. Air sealing can be implemented as a low-cost measure to improve building performance and reduce heat load.

Tall buildings usually have stratification of air within stair and elevator shafts due to the pressure differential at the lower and upper heights, more commonly known as stack effect. Doors connecting to common corridors from above-grade shafts can increase the thermal load at that location. Proper sealing around stair and elevator doors at upper levels will reduce the unwanted thermal gains into treated corridors. Entrance vestibules or revolving doors will also help to reduce the stack effect in high-rise towers.

12.1.4. Roofing Materials

Roof materials with low emissivity can be used to reduce heat absorption and lower cooling loads for a building. Several options, including white roofs, reflective roofs, or green roofing options can improve energy efficiency and reduce solar heat gains. Roofing materials can be considered when the roof is at end-of-life and requires replacement. Bifacial solar PV panels can utilize reflected heat from white or reflective roof surfaces, further reducing the electrical demand increase for electrification retrofits.

12.1.5. Façade Design & Materials

Innovative designs can be considered in a façade replacement that incorporates aesthetic and energy performance improvements. Advanced materials and technologies can be used, such as dynamic or responsive façades. Consider the thermal mass of the materials used in the replacement, as they can absorb and store heat, moderating temperature fluctuations within a building. Explore opportunities to reduce thermal bridging.

Envelope upgrades can be considered when the façade is at end-of-life and requires replacement. If the existing façade is in fair condition, a double-skin façade retrofit can be considered, as this will reduce demolition requirements as compared with a full replacement. However, as previously noted, the addition of new outboard insulating material can result in a new dew point within the envelope assembly. Engage a building science consultant to complete the design and verify constructability, and a structural engineer to review the added load on the exterior walls.

12.1.6. Solar Shading & Control

Shading elements such as overhangs, awnings, or blinds can be used to control sunlight, and reduce solar heat gain and overheating. Optimize the design of the retrofit for natural daylight while minimizing glare and solar heat gain. Low-emissivity films can be used for windows and are a low-cost measure that can improve thermal performance and reduce solar heat gain. Solar shading can be considered in combination with larger façade upgrade strategies or as a standalone measure for targeted improvements.

12.2. THERMAL COMFORT

Implementing envelope upgrades can significantly improve occupant thermal comfort. Improving insulation, air sealing, upgrading windows and doors, and controlling solar gains can reduce temperature fluctuations and air stratification in occupied spaces.

12.3. WEATHER & FUTURE CLIMATE CONSIDERATIONS

Understanding historical weather data and future climate change projections can help identify typical weather patterns and how those patterns may shift over time. When upgrading building envelope components, considerations need to be made for variations in temperature extremes, humidity levels, and precipitation. Use historical weather data and climate change projections to inform decisions regarding insulation levels, solar control measures, and ventilation requirements, as well as anticipate potential future challenges with envelope upgrades, to ensure that the building is resilient and adaptable to future climate conditions.

12.4. LOAD REDUCTION & EQUIPMENT SIZING

Envelope upgrades can be worth considering if the building's existing façade elements are at end-of-life: when aligned with mechanical equipment replacement, they can allow for a significant reduction in the size of mechanical equipment selected for the retrofit due to their ability to substantially decrease heating and cooling loads. This can reduce capital costs for the mechanical equipment.

12.5. ARCHITECTURAL ENCLOSURES

New rooftop mechanical equipment can require architectural enclosures for sound attenuation or aesthetic purposes. Development permit revisions may be required depending on the location of the project and the owner's requirements.

Part 5: Appendices

The fifth part of the guide features supplementary information and resources to support the use of the Guide, including:

- **Appendix 1: Case Studies**
- **Appendix 2: References**
- **Appendix 3: Technical Appendices**
- **Appendix 4: Example Pathways**

Its contents will be relevant to all building and project stakeholders, including:

RELEVANT TO:	
☑	Building Owner
☑	Owner Advisor / Energy Manager
☑	Prime Consultant
☑	Designer

Appendix 1: Case Studies

ASHP CASE STUDY

FIGURE 66: THE NEW ASHP AT THE ATRIUM

Project Summary

The Atrium Building, a 7-storey office building owned by Jawl Properties and located in Victoria, British Columbia, was built with a modular air-source heat pump (ASHP) – one of the first implemented at this scale in British Columbia. As the system neared the end of its life, Jawl's operation team identified an opportunity to learn from their experience with the original unit to inform the project to replace it. The original system had functioned reasonably well during the heating season but struggled to provide adequate cooling capacity during the summer. Jawl wanted to ensure the new system would be reliable and trouble-free, and improve tenant comfort year-round.

Jawl initiated the project by talking to their primary HVAC provider, who was familiar with the system and the building, to identify specific aspects of system performance that needed to be improved. Next, they brought in a consultant to lead a collaborative process to design the new system.

An initial feasibility study identified some issues with the flow rates between the ASHP and the primary mechanical plant, and some capacity challenges stemming from load requirements and space usages that changed from the original design of the building. The study identified several options, including heat recovery and a dedicated high-efficiency chiller for summer cooling, for consideration; its findings justified the inclusion of both items in the new system, with incentives from BC Hydro.

TABLE 22: ANNUAL SAVINGS OF THE ATRIUM'S NEW HEATING SYSTEM

			Annual Savings			
Description	**Incremental Cost**	**Payback**	**$**	**kW**	**kWh**	**GHG**
Dedicated High Eff. Chiller	$50,000	5.4	$9,200	347	65,800	2.6
ASHP Heat Recovery	$90,600	7.1	$12,700	68	174,300	7.0
Total Mechanical	**$140,600**	**6.4**	**$21,900**	**415**	**240,100**	**9.6**

Several years of building and performance data helped inform the design of the new system.

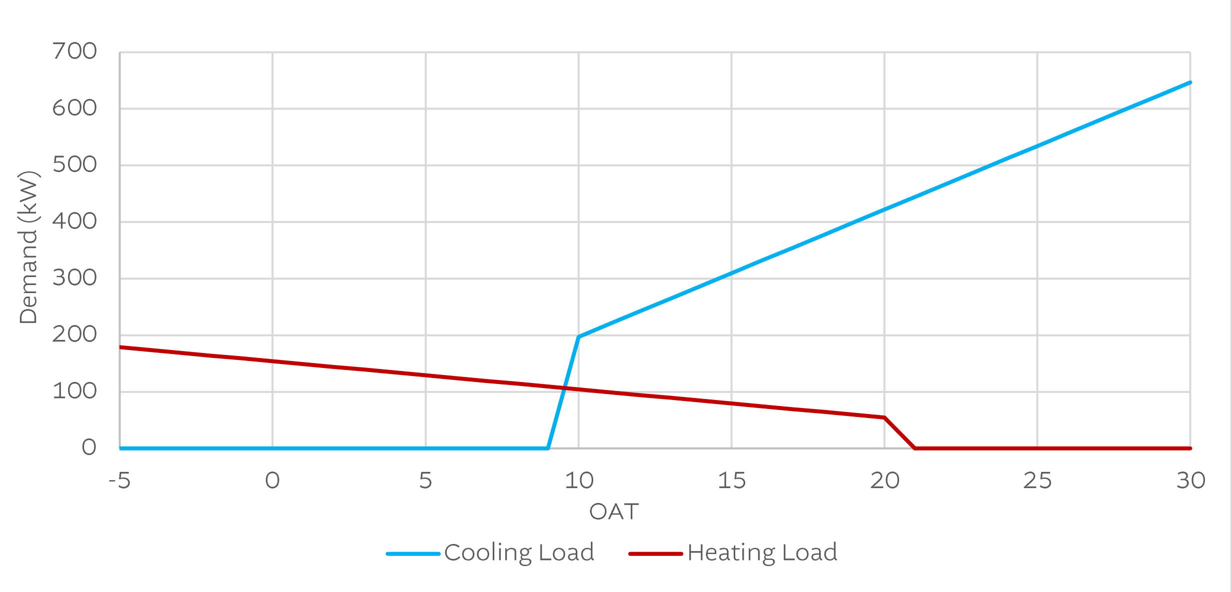


FIGURE 67: ATRIUM HEATING AND COOLING ENERGY DEMAND

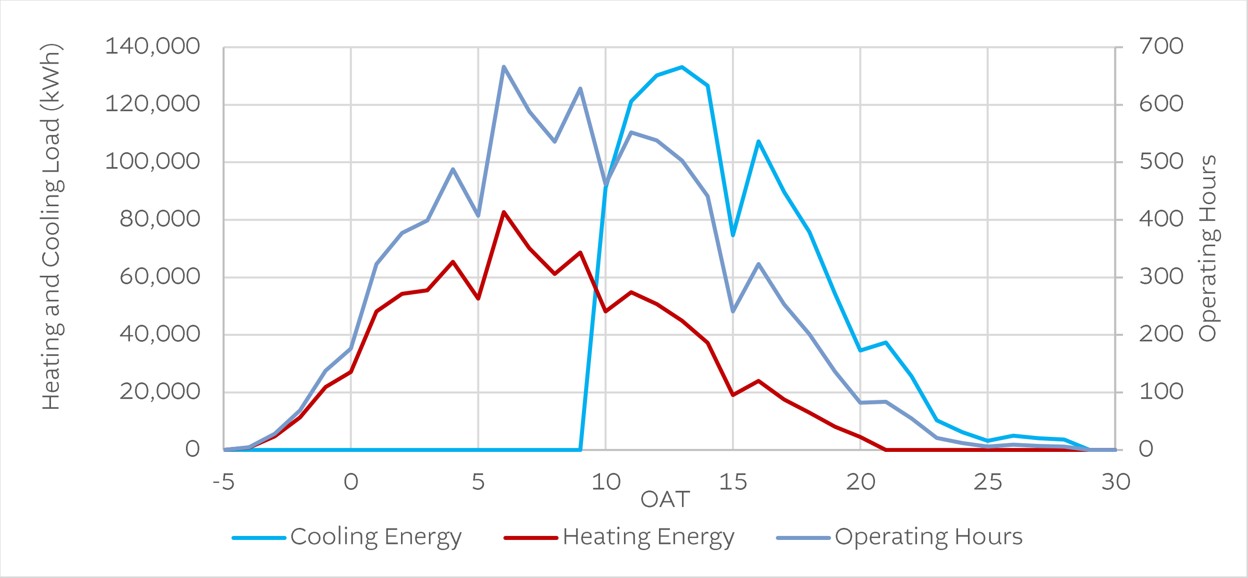


FIGURE 68: ATRIUM HEATING AND COOLING ENERGY CONSUMPTION

In addition to replacing the mechanical equipment, implementing the new system required replacing a fair amount of the piping and the primary pumps in the building, and the addition of new heating and chilled water buffer tanks.

Project Outcomes

The new system began operating in the Spring of 2023 and functioned well in cooling mode from the start – according to building staff, that summer was the first time since the building opened that the system didn't have to run 24/7 to maintain a comfortable temperature. Ongoing commissioning identified and resolved several issues over the next several months.

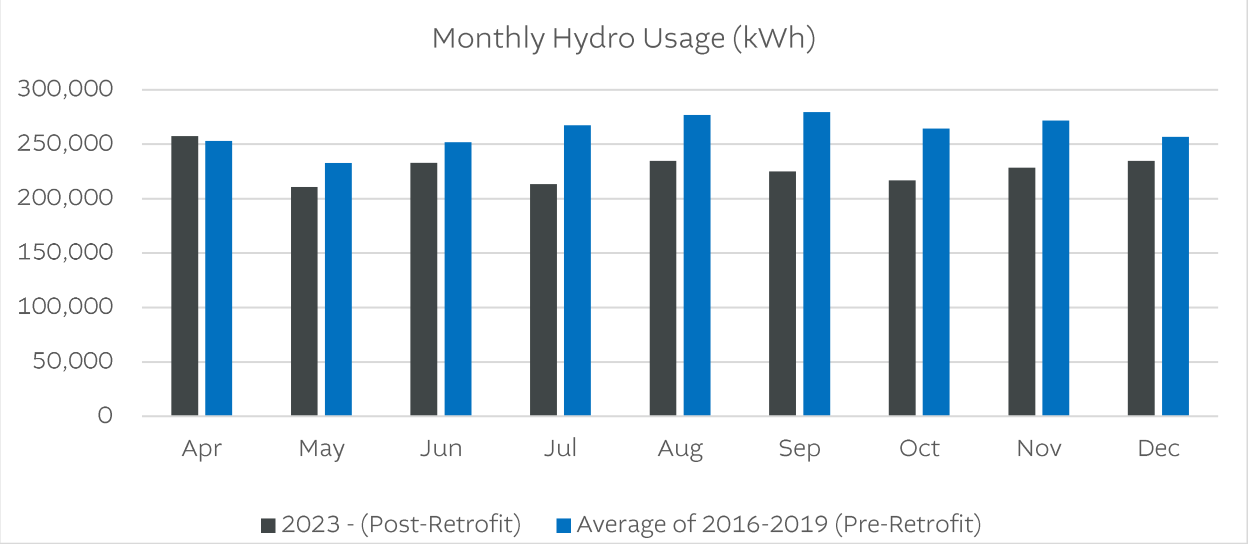


FIGURE 69: ATRIUM MONTHLY ENERGY CONSUMPTION

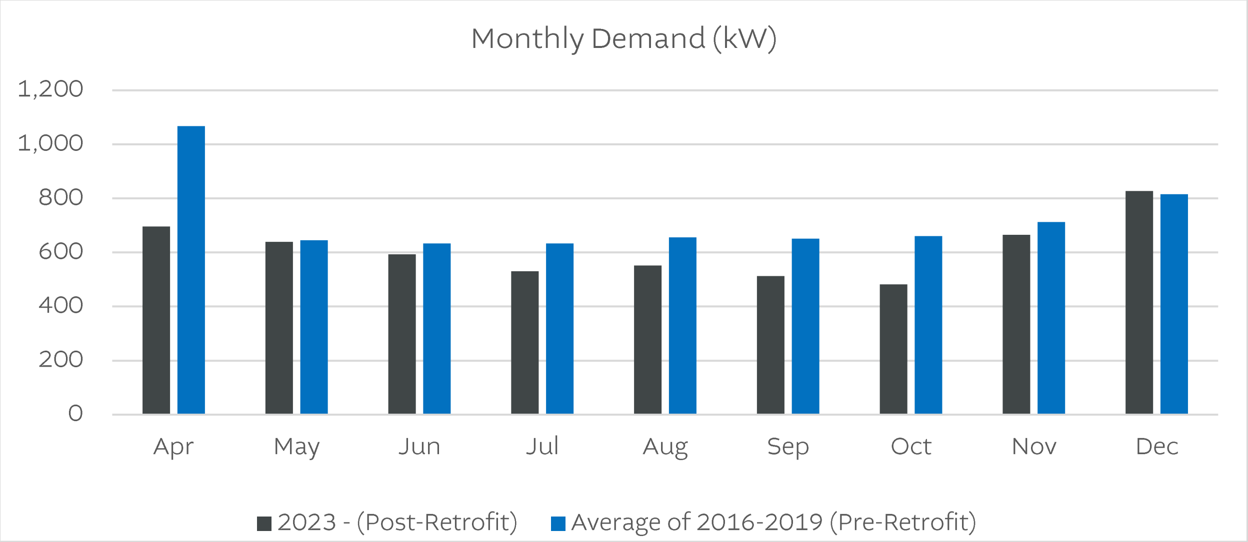


FIGURE 70: ATRIUM MONTHLY ENERGY DEMAND

Challenges and Key Learnings

During equipment startup, it became apparent that there was a considerable gap, with regards to heating water temperatures produced by the ASHP, between the stated performance capability of the equipment and the "recommended" performance limits to avoid excessive wear and tear. To address this, a controls strategy was developed that limited the amount of time the ASHP operated at higher temperature outputs while still allowing it to deliver as much of the load as possible. Where required, the supplementary electric boilers "topped up" the system temperature, ensuring that it could be maintained even on the coldest days without overtaxing the ASHP.

Other issues identified:

- The original design had anticipated less frictional loss in the pipes, leading to a greater-than-expected pressure drop on startup. However, the original design had also recognized the critical importance of ensuring adequate flow, so pumps had been oversized (and equipped with VSDs) out of an abundance of caution. This approach allowed the system to deliver the required flow despite the greater-than-anticipated friction without requiring changes to the equipment.
- In the first few months of operation, lockouts on heating mode were found to be too aggressive, resulting in comfort complaints from occupants in some areas of the building. This was resolved by allowing the heat pump to operate over a greater range of conditions before switching over to the chiller. During colder weather, the response time of the electric boiler was improved to allow the heating loop to reach target temperatures more quickly.
- Troubleshooting cold zones identified numerous VAV boxes with faults. These faults, along with other issues with the overall building HVAC system, will be addressed in the future through the BC Hydro Continuous Optimization Program.

FIGURE 71: THE NEW DHW SYSTEM AT ARTHUR ERICKSON PLACE

Project Summary:

Arthur Erickson Place is an iconic 26-storey office building co-owned by KingSett Capital, Crestpoint Real Estate Investments Ltd. (in joint venture with Vestcor Inc.), and Reliance Properties Ltd., located in downtown Vancouver.

Prior to the project to retrofit its domestic hot water (DHW) system, hot water in the building was generated by different gas-fired boilers depending on the season. In the heating season, two large 3,077 MW (10,500 MBtu/hr) gas-fired boilers, dating from the original construction, were used for DHW production and also provided hot water for hydronic space heating. These large boilers were turned off during the cooling season and three smaller gas-fired boilers, ranging from 88 MW (300 MBtu/hr) to 147 MW (500 MBtu/hr), were used instead. One of these three smaller boilers provided DHW for the tower while the other two were dedicated to the fitness centre change rooms. The DHW was stored in two large 1,325 L (350 US gallon) storage tanks, both original to the building.

The copper risers, running vertically through two mechanical shafts beside the elevator shaft, were also original to the building and had begun to leak on occasion. This signalled to Colliers that the risers were approaching the end of their long service life and required replacement.

Each year, KingSett Capital, one of the building owners, holds an Innovation in Sustainability competition for projects at their managed properties. For the 2020 competition, Kingsett indicated that they were particularly interested in seeing submissions focused on innovative technologies that had not yet scaled up to mass adoption or were new to the Canadian or North American market. The award prize was a $50,000 contribution towards the winning project.

For its submission to the competition, Colliers proposed to combine the planned replacement of the aging risers with the electrification of the tower's DHW system to significantly reduce the building's GHG emissions. The electrification project would include decoupling the large boilers from the DHW systems, replacing the boiler serving the tower with two sets of all-electric, CO_2-based heat pumps for year-round DHW generation, and installing new DHW storage tanks. Electrification of the DHW system for the change rooms was not part of the proposal because the two boilers for this system were less than ten years old.

The project won the internal competition and was approved for some additional funding from the CleanBC Better Buildings Program, and Colliers was tasked with implementing it.

Project Outcomes

The new system was commissioned in 2021 and has been operating successfully to provide the building with DHW without issue. Since implementation, this project has reduced the building's energy consumption by an average of 640 GJ annually, and reduced its GHG emissions by approximately 32 tCO_2e/year (at full occupancy). In addition to reducing the building's operational emissions, the CO_2 refrigerant used in the system also reduced the emissions impact of a potential refrigerant leak.

Assuming full occupancy, an increase in electrical consumption of approximately 60 MWh/yr, and a carbon tax escalation of $170/$tCO_2e$ by 2030, Colliers estimates the payback period of the retrofit to be 15 years. The project cost $146 per tonne of CO_2e savings considering the incentives received but not factoring in any anticipated reductions in maintenance costs.

Based on an average run time and indoor installation (protected from precipitation and high humidity), the heat pumps are expected to have a service life of 15 to 20 years with annual or semi-annual maintenance. After the expected service lifespan, it may be possible to replace worn-out components rather than replace the entire heat pump.

Colliers has recently begun to monitor the energy consumption of the new domestic hot water systems with dedicated submeters. In addition to providing specific energy consumption data for the DHW systems, the submetering should provide a means of detecting operational issues as they occur. This will allow Colliers to maintain and repair the systems in a timely manner and should maximize the service life of the heat pumps.

Based on the success of this project, Colliers and the project team are now working with the building owners to design and implement a net-zero carbon retrofit plan to electrify all of the building's remaining gas equipment.

Challenges and Key Learnings

The original DHW system was assessed by the project team to ensure proper sizing of the new equipment. Concerned that simply following American Society of Plumbing Engineers (ASPE) guidelines could lead to oversizing of equipment, the designer refined the sizing calculations with a third-party-reviewed, manual calculation which took into account the building's low-flow fixtures and time-of-day usage patterns for certain fixtures. This ensured that the replacement equipment would be appropriately sized for the specific hot water heating demands of the building.

Since the tower's DHW system is divided into two loops – one serving the upper sixteen floors of the building and one serving the floors below – two separate right-sizing exercises had to be undertaken. The designer determined that six heat pumps and four 450 L (119 US gallon) storage tanks would be required for the upper system, and four heat pumps and three 450 L storage tanks would be required for the lower system. Because the original boilers were retained to continue providing space heating for the building, the new all-electric DHW heating plants required new homes. Non-tenanted spaces on the top floor and parkade level were converted to secondary mechanical rooms to accommodate the new equipment.

An important consideration for many electrification projects is the electrical service to the building, in particular the difference between the peak demand and the maximum capacity. In this case, the typical peak demand was approximately 1,500 kW, representing less than 40% of the available service. The project team determined that there was more than enough spare capacity for the DHW electrification project, which would add no more than 100 kW to the building's electrical demand. The panelboards to which the heat pumps would connect also had spare capacity and therefore did not have to be replaced.

As is often the case in older office towers, there was enough room in the mechanical chase to install a new riser while the adjacent existing riser was in use. This allowed the contractor to install the new equipment in the new secondary mechanical rooms and connect it to the new riser without disrupting the water supply to the building. Once the new system was tested and commissioned, it was tied into the existing branch piping outside of regular office hours because this part of the work involved shutting off the water supply to the building or several floors at a time. The switchover was completed at the end of April 2021.

Because CO_2-based heat pump water heaters require low supply water temperatures to maximize efficiency, the temperature of the hot water recirculation loops is maintained using one electric swing tank for each system instead of the heat pumps. The swing tanks, installed in the secondary mechanical rooms, are equipped with electric resistance coils to keep the temperature in the recirculation loop at 55℃ (131℉).

According to the contractor, a big advantage of the model of heat pump water heaters chosen for the project is that, because the CO_2 refrigerant they use is sealed entirely within the heat pump units, they can be installed by plumbers rather than requiring specialized refrigeration technicians. This reduced the installation cost of the system compared to systems where refrigerant lines are installed in the building.

HEAT RECOVERY CHILLER CASE STUDY

FIGURE 72: COQUITLAM CENTRE MALL

Project Summary:

Coquitlam Centre is a shopping mall owned by Morguard Property Management located in the City of Coquitlam that houses 200 stores, a food court, and administrative offices. Constructed in 1979, the north section of the mall was expanded 17 years ago and new chillers, gas boilers, and controls were installed. The two-level shopping centre stretches over 1 million sq ft and an average of 34,000 people visit the mall each day. In the mall, heating is only supplied to the common areas, such as the corridors and hallways; shops are heated by their lights and residual heat from the common areas. Exterior shops that don't benefit from the building's residual heat have their own rooftop gas heaters that tenants control and pay for themselves. A hot water loop runs through seven rooftop air handling units (AHUs) which also supply cooling to the common areas.

In 2014, given the facility's substantial cooling load, Morguard's property management team was looking to save energy costs and improve operations. Because of the heat produced by lighting and occupant load in the shops, the facility requires both year-round space cooling and heating for ventilation systems. The contractor and consultant worked together to propose a heat recovery chiller (HRC) that would reject waste energy into the facility's existing water heating systems instead of its cooling towers.

The mall's original plant had a constant volume hot water tank fed by two 6 million BTU gas boilers. This hot water was supplied at 40°C (104°F) and 60°C (140°F) to the two heating systems that operate in the old and new sections of the mall, respectively. Since the old mall runs at 40°C, it previously ran on a heat exchanger to keep the temperatures lower. The new HRC project re-piped the heating supply system to run in series: 60°C water goes to the loads of the new mall first, and cooler return water is then mixed as needed and supplied at 40°C to the old mall.

This piping redesign allowed the existing heat exchanger to be removed. All distribution pumps were switched from constant flow to variable flow to pump only the water that is needed. The HRC intercepts the return water from the mall and reheats it before it enters the boiler. Post-retrofit, the entire mall can be heated solely by the heat recovery chiller down to 2°C outside temperature, after which the boilers turn on to top-up the heat in the system. The scope of the project also included replacing leaking AHU coil valves, as well as the addition of speed drives on major heat pumps.

Project Outcomes:

The total project cost was $470,000. An incentive of $237,000 was provided by FortisBC, which put the total project cost to the owner at $232,700 with a project payback of 2.1 years. The project had the following outcomes:

- 70% reduction in annual gas consumption.
- 4% reduction in annual electricity consumption.
- 35% decrease in annual GHG emissions.
- $110,000 decrease in annual operating costs.

Challenges and Key Learnings:

The project team attributed the success of the project to careful consideration of the design of the new system and ensuring that the right parties were involved from the beginning of the project.

Despite the Trane chiller's relatively small size, the biggest obstacle was finding space for the new equipment as well as for the necessary re-piping. This was overcome by relocating the existing air compressor system to a different part of the room, removing the air separator that was not needed, and reusing existing piping from the old heat exchanger system to make room for the new chiller. The HRC's single- and dual-point power electrical connection options allowed the reuse of existing electrical wiring. In February 2016 the new system was installed. The HRC was lifted over the food court and into the door of the mechanical room. There were no disruptions to the center's operation. The system was commissioned for a full year after installation to ensure correct operation.

The cascade configuration of the HRC, which piped the evaporator into the chiller plant's condenser water supply line, enabled the system to capture waste heat, use it in the building, and reduce cooling tower water consumption. The schematic design and modelling were critical to proving the benefits of a cascade configuration of the HRC over a parallel configuration. Since the existing chillers with their speed drives were already so efficient, and neither were end-of-life, it made sense to add the new HRC and recover heat off the condenser water from the existing chillers. This staged configuration allows the HRC to operate at a much higher COP, produce hotter heating water, and use simplified controls.

The final key learning for this project was the value of doing a thorough and detailed review of the existing system's controls before initiating a mechanical retrofit project. In this case, the controls review revealed that the AHU coil heating valves were leaking significantly, which was creating a false load on the chiller plant. Resolving this prior to system design ensured the new system was right-sized for the actual building loads.

ASHP MUA CASE STUDY

Project Summary

SES Consulting was commissioned to investigate the performance of two recently installed make-up air (MUA) units at two separate social housing complexes in Vancouver, BC. For the purposes of this study, we will call them Building A and Building B.

The MUA units provide heating and ventilating the corridors and amenity spaces, while in-suite space heating was provided by hydronic radiators and gas boilers. Neither building has a building automation system (BAS). Terminal zone setpoints are controlled via analog thermostats and the MUA supply air temperature setpoint (SAT SP) is set locally at the onboard controllers.

In September 2020, the old gas-fired MUA units were replaced with new hybrid air-source heat pump (ASHP) models, which included gas-fired backup. These upgrades were expected to cut gas consumption in the ventilation system by about 85%. However, contrary to expectations, Building A experienced a mere 10% reduction in gas usage, while Building B saw an unexpected 11% increase.

SES performed a site visit to investigate why the installations were not meeting savings expectations and installed data loggers on both MUAs to verify unit controls and identify issues. Using this data, SES developed strategies to adjust controls and recommend repairs to improve operation on the units.

Project Outcomes

<u>Building A</u>

SES found that the MUA fan speed had been manually set to 25% of its nominal capacity. This meant that not only was the unit not meeting the building's minimum ventilation requirements, but it was also not meeting the minimum flow requirements across the heat pump coil, which was causing the heat pump compressor to trip off on internal safety alarms. The team increased the fan speed to 90% temporarily and encouraged the building owner to reengage the original design engineer to determine the correct design airflow level.

SES also found that the MUA controller setpoints had not been set correctly during commissioning, preventing the heat pump compressor from operating as the first stage of heating when outdoor air temperature (OAT) was above the heat pump lockout temperature. The MUA local controller compressor lockout setpoints were adjusted based on input from equipment representatives. After the setpoints had been adjusted and the unit restarted, the compressors energized and acted as the first stage of heating. No alarms were active on the local controller.

Once the heat pump was operating, it was noted that the gas burner was cycling often to meet the required discharge temperature due to the proximity of the SAT duct sensor to the burner and the lack of thermal mass to allow for adequate runtime. To avoid excess gas use and reduce cycling of the burner, the manufacturer recommended control of the SAT with feedback from a space temperature sensor rather than discharge air.

Finally, the manufacturer representative recommended that the building owner obtain a preventative maintenance contractor with a trained service contract to ensure optimal operation of the MUA unit moving forward.

<u>Building B:</u>

In reviewing the MUA in Building B, it was noted that the unit had been shut off at the unit disconnect switch. In addition, the parkade vestibule supply air grilles, believed to have been initially designed for pressurization, were completely shut, meaning no airflow was being supplied at these locations. SES is currently working with the building owner, the equipment contractor, and the installer to address these issues and develop a preventative maintenance contract with the service contractor. The unit was also noted to be collecting water in the condensate drain pan, which was slightly sloped away from the drain point.

The manufacturer representative recommended that the building owner obtain a preventative maintenance contractor with a trained service contract to ensure optimal operation of the MUA unit moving forward, including regular filter changes, compressor testing, and constant airflow above the minimum flow requirements of the unit. In addition, SES recommended a review and update of heat pump switchover temperatures – and that this step be completed in consultation with the equipment manufacturer to avoid excessive defrost cycle operation and potential damage to the equipment. Finally, SES recommended that the unit be adjusted so that condensate drains effectively to prevent water pooling inside the unit.

Challenges and Key Learnings

- The final installed cost of the project significantly exceeded the initial estimate from the study. This was mainly because a structural upgrade was determined to be necessary during the design process. Although this need was recognized early in the design phase, it had not been identified during the study phase, which had served as the basis for the cost estimate and funding request to the Clean BC Social Housing Incentive Program. To avoid this issue, funding requests should only be made after a detailed Level 3 study has been completed, including electrical, structural, and building envelope consultants where appropriate. Additionally, contingencies of 10-30% (depending on the level of uncertainty) should be included in cost estimates and funding requests when there are outstanding feasibility questions about a project.

- When the heat pump in Building A was initially activated, the compressor caused the wooden structure to vibrate, causing a significant disruption to the occupants. The occupants had to endure this vibration for six months to a year before an isolation pad was installed to mitigate the vibration. Typically, it is recommended that vibration isolation measures – such as sleepers, curbs, or housekeeping pads depending on the size and type of heat pump – be installed with roof-mounted heat pumps, and that vibration isolators, such as neoprene pads or spring isolators, be used to mitigate vibrations.

- While ASHP MUAs are relatively straightforward to design and install, most of the issues encountered on these projects were due to incomplete or improper commissioning. It is recommended that building owners include performance commissioning requirements in RFQs for these types of retrofits to ensure that the engineer and the contractor include sufficient budget and time to effectively commission the system and ensure it is performing as intended.

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Appendix 3: Technical Appendices

APPENDIX 3.1: EXISTING VENTILATION SYSTEM ASSESSMENT CHECKLIST

1. **Check Code-Required Minimum Ventilation Rates:** Calculate building-level ventilation rates needed based on occupancy type, local codes, and standards. For British Columbia, building codes currently reference ASHRAE Standard 62.1 (ASHRAE, 2022) for commercial buildings and CSA Standard Z317.2:19 (CSA Group, 2019).

2. **Check Existing Ventilation Rates:** With the outdoor air damper (OAD) set to minimum position, verify the total air quantity of outdoor air delivered by the air handling systems. Ventilation rates should be within ±10% of calculated requirements.

   For systems with calibrated airflow sensors, airflow readings through the BAS and temperature sensors can be used to estimate outdoor air volume. Retain a testing and balancing agent to complete measurements where system airflows are not monitored.

   For systems where total airflow is known, the outdoor air volume can be estimated using return air, outside air, and mixed air temperature sensors with the outdoor air damper set to the minimum position. Complete these measurements during winter conditions when the temperature difference between the return air and outdoor air is at least 14°C (25°F) or more to minimize error due to temperature sensor accuracy.

$$\text{Airflow}_{OA}=\text{Airflow}_{SA}\times\frac{T_{RA}-T_{MA}}{T_{RA}-T_{OA}}$$

3. **Verify the Condition of Outside Air Dampers:** Verify that the outdoor air and mixed air dampers are not warped, and that the seals are not dried out or cracked. Confirm dampers seat tightly in their closed position and stroke fully open.

4. **Check Air Filter Integrity and Level of Filtration:** Verify that the air filters fit tightly and that the housing seal integrity is intact without air bypass. This is also a good time to confirm the level of air filtration provided for the building and consider increasing air filtration values if they are below MERV 13.

5. **Confirm the Accuracy of Sensors:** Verify the accuracy of permanent sensors for outdoor air delivery monitoring, outdoor air delivery, or dynamic minimum outdoor air control. Check sensors essential for controlling minimum outdoor air at least once every five years.

6. **Verify Ventilation Controls Systems:** Verify that automatic controls function as intended and provide dynamic control of outdoor air over all modes of operation (heating, economizing, and mechanical cooling).

7. **Assess Building Pressure Control:** Verify building pressure control is functioning as intended and identify areas with building pressure control issues with the building operators. This is particularly

important for high-rise applications where excess pressure is often experienced during shoulder seasons where systems are equipped with airside economizers.

8. **Review the Effectiveness of Existing Energy Recovery Systems:** Review the condition of existing air-to-air energy recovery systems. For systems relying on heat wheels, confirm the integrity of motors, sheaves, and pulleys. For systems with bypass dampers, verify the operating condition of the dampers. Review controls strategies including wheel speed control and bypass damper operations.

APPENDIX 3.2: BAS STRATEGIES FOR LOAD REDUCTION

Review the following BAS strategies and, if applicable, implement them as part of load reduction:

Scheduling and Optimal Start

The published outcomes from B.C. Hydro's Continuous Optimization Program show that reducing equipment runtimes is the number one low-cost opportunity in commercial buildings to minimize loads and energy consumption (BC Hydro, 2024).

Optimal start strategies analyze space and weather conditions to determine the best time to start up equipment to ensure that spaces are comfortable by the time occupants arrive – but not before. During colder weather, keep outside air dampers closed during the startup period to further reduce heating loads. Most modern BAS have optimal start features that dynamically adjust startup times based on ambient and building conditions. Different manufacturers use different approaches to optimal start, so take care to understand the approach.

For intermittently occupied spaces such as meeting or break rooms, occupancy sensors can allow the HVAC units and terminal devices to be disabled or setback while these areas are vacant.

While setback and start strategies save energy, they can also drive large peak heating loads as buildings recover from setbacks, which must be considered in terms of compatibility with heat pump-based heating systems. A controls strategy that considers demand reduction may lead to a slower response in achieving desired indoor conditions. The trade-off lies in balancing the benefits of pre-conditioning for comfort with the need to reduce energy use during peak demand, considering factors like building occupancy patterns and cost-effectiveness.

Dual Max VAV

Conventional practices often set minimum air volumes for VAV boxes to a fixed percentage of the design cooling airflow, typically ranging from 30% to 50%. This approach was taken primarily due to concerns with the "dumping" of air out of diffusers at low airflows, controllable minimum airflow, and having sufficient air for heating mode. However, high minimum setpoints can lead to unnecessary energy use for fan and heating systems, and can lead to overcooling during the summer when heating plants are disabled.

The energy and thermal comfort benefits of implementing a dual-maximum airflow logic (see Figure 73), as defined in ASHRAE Guideline 36 (ASHRAE, 2021), have been well documented in research (Arens, 2012). The referenced study of real-world implementation indicates overall energy savings in the range of 10% to 30%, with no negative impacts on thermal comfort in winter and improved thermal comfort in summer due to reduced overcooling in low-load zones.

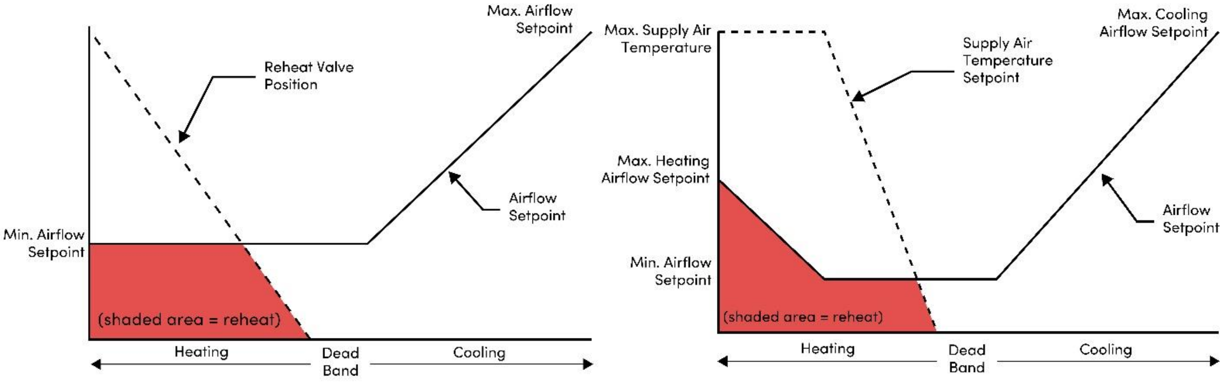


FIGURE 73: CONVENTIONAL VS. DUAL-MAX VAV CONTROL

Demand-Based Resets

Demand-based resets adjust HVAC systems in real-time based on real-time conditions, such as occupancy and thermal needs, rather than fixed settings. This approach minimizes energy consumption during unoccupied periods, contributing to cost savings and improving sustainability. These sequences use sensors and data to optimize energy efficiency and performance based on current demand. Demand-based resets can include:

- Temperature resets, including heating water supply temperature setpoint (HWST SP) resets and chilled water or condenser water (CHW or CW) setpoint resets.
- Pressure resets such as supply air pressure (SAP) resets in air handling systems.

Demand Control Ventilation (DCV)

Demand controlled ventilation (DCV) dynamically aligns ventilation needs with actual occupancy, effectively reducing heating and cooling demands. Its inclusion as a core element in electrification projects can prove valuable due to its relatively short energy-saving payback period.

Implementation of DCV in office and classroom-type buildings located in climate zones 3-5 has been shown to have potential energy savings between 17-32%, primarily in heating (O'Neill, 2017). Several factors can influence these savings, including:

- **Occupancy Patterns:** Varied occupancies offer higher potential savings.
- **Sensor Accuracy:** The accuracy of supply air CO_2 sensors and outdoor airflow sensors for multi-zone applications can strongly influence energy and ventilation performance.
- **Climate:** Colder climates yield more significant opportunities for reductions in heating load, and therefore higher energy savings.

CO_2-based DCV is the most common form of DCV because CO_2 sensors are relatively inexpensive, and the occupant CO_2 generation rate is proportional to the occupant bioeffluent rate (Lau, 2014). However, in addition to ventilation required to dilute occupant bio effluent, the current ASHRAE Standard 62.1 lists "area-weighed" ventilation rates by space type to offset contaminants generated by non-occupants. Consequently, CO_2 cannot be used as a direct variable for the required ventilation rate since the area-weight component must be provided during occupied periods, even when the zone is empty, except for exempted spaces listed in ASHRAE Standard 62.1 (ASHRAE, 2022).

Several DCV controls strategies have been proposed over the past decade, and ASHRAE Guideline 36 (ASHRAE, 2021) includes the most recent strategies based on ASHRAE-sponsored research projects. Other often-overlooked DCV strategies include:

- **Occupancy Schedule-Based Demand Control Ventilation:** A cost-effective strategy for DCV involves adjusting ventilation according to the building's anticipated occupancy schedule. This practice is widespread in scheduled buildings like offices, where ventilation is often shut off during unoccupied periods. Extending this approach during occupied periods is feasible for spaces with well-understood and predictable occupancy patterns such as cafeterias, lecture halls, and theatres. However, caution is advised when applying this to spaces with less understood occupancy levels or patterns.

- **Occupancy Sensor-Based Demand Control Ventilation:** Occupancy sensors offer a cost-effective means of adjusting ventilation for zones with highly variable occupancy. When occupancy is detected, full ventilation is provided; when zones are vacant, ventilation is reduced to background levels. ASHRAE Standard 62.1 (ASHRAE, 2022) permits complete shutdown of outside air ventilation during occupied standby mode (i.e., vacant) for several types of spaces. Compared with occupancy schedule-based DCV strategies, this approach suits spaces with consistent occupancy levels when occupied, and minimizes the risk of under-ventilating spaces. However, this all-or-nothing strategy can often lead to overventilation and reduced energy savings for spaces with highly variable occupancy patterns.

- **Occupant Counter-Based Demand Control Ventilation:** This DCV strategy relies on sensors to estimate space occupancy and responds by supplying the calculated ventilation rate to meet ASHRAE Standard 62.1 requirements (ASHRAE, 2022). Several types of technology exist to enable this, including infrared beam systems at entrances, camera systems, thermal imaging, point-of-sale, and Wi-Fi or Bluetooth tracking. However, these are difficult to implement in practice and have not been commonly adopted. Space types that include ticket sales (arenas and theatres) or those accessed by turnstiles are examples where this type of DCV strategy could be implemented.

While minimum outdoor air volumes are commonly controlled using a minimum outdoor air damper position (percent open) as a proxy for the outdoor air percentage of the supply air, damper position rarely correlates with outdoor air volume. This ventilation control method does not meet the requirements of ASHRAE Standard 62.1 (ASHRAE, 2022), as simply setting a damper to a fixed minimum position does not guarantee that the required ventilation rates are met. Operating ventilation systems in this manner often leads to over- or under-ventilated buildings.

For single-zone air handling systems, outdoor air volume control using damper position works if there are no downstream dampers, which can change the relationship between outdoor air damper position and outdoor airflow. In these cases, single-zone systems can be recommissioned to establish the minimum damper position that correlates to the minimum required airflow.

For multi-zone air handling systems, retrofitting outdoor air monitoring into the existing system can ensure code-required ventilation is being provided to the building. ASHRAE Guideline 36 (ASHRAE, 2021) includes three different configurations to provide minimum outdoor air control.

High-Performance Sequences

ASHRAE Guideline 36 (ASHRAE, 2021) provides advanced controls sequences for various HVAC systems developed through ASHRAE-sponsored research and a consensus-based approach developed by industry experts. It offers a best-in-class performance library of standardized controls sequences that prioritizes energy efficiency, ease of operation, indoor air quality, and thermal comfort, and includes sequences for the load reduction strategies discussed in this section.

Demand Response

Demand response strategies play a crucial role in building electrification by freeing up electrical capacity that can be used to power new equipment. These strategies are especially valuable for buildings with high demand charges or large demand peaks, as they can lead to significant cost savings. Demand response strategies typically fall into one of two categories:

- **Load Shedding:** Temporarily reducing power consumption, such as by dimming lights, turning off non-essential equipment, or increasing deadbands on thermostats.
- **Load Shifting:** Moving energy use to times when demand is lower, such as pre-heating systems during off-peak hours.

Implementing these strategies effectively requires the integration of real-time electricity demand data with the building's BAS. With this energy data integrated, load shedding and load shifting strategies can be programmed to manage the load of BAS-connected equipment.

Load shedding strategies to consider for HVAC systems include:

- Relaxing space temperature setpoints by increasing deadbands or using temporary setbacks/setups.
- Controlling flexible loads such as fan and pump variable frequency drives (VFDs), multistage electric heating, and compressors.
- Integrating variable speed compressors.

Load shifting strategies to consider for HVAC systems include:

- Integrating thermal energy storage systems.

- Using early and gradual morning warmup strategies and proactive scheduling to shift loads away from peak periods while mitigating the need for electric resistance backup in heat pump systems during the coldest days.

Beyond managing building-level electricity demand, demand response strategies can also be employed to manage utility grid limitations. So-called grid-interactive buildings enhance demand response strategies by directly communicating with the electricity grid and automatically reducing or shifting electricity usage during peak demand periods, a process known as automated demand response (ADR). The signals that guide these adjustments can come from several sources, including:

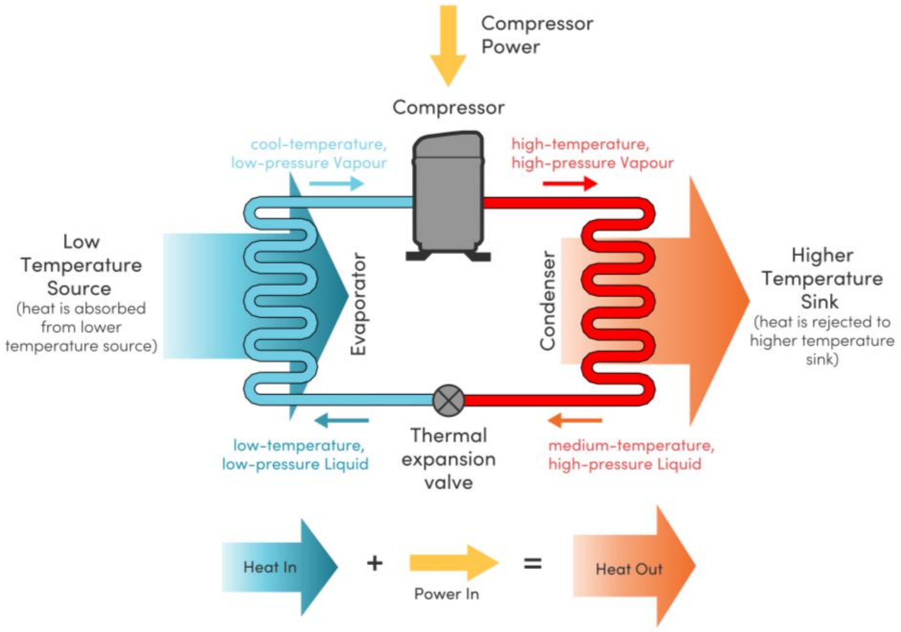
- **Prices**: Grid-interactive buildings can modulate their electricity consumption based on real-time pricing to reduce costs.
- **External Signals from the Grid**: Grid-interactive buildings can respond to direct signals from the grid, such as notifications of grid stress or demand response events, automatically adjusting their energy use to support grid stability.

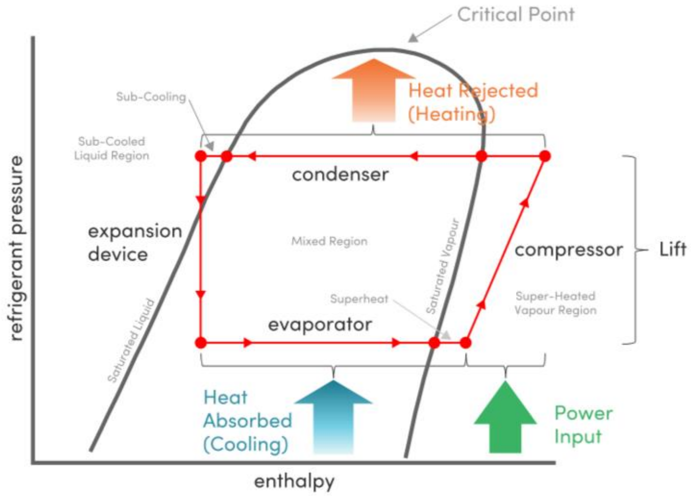
Grid interactivity and ADR are still relatively new practices for many utilities. The need for ADR is expected to grow as more buildings electrify and must share the electric grid resource.

Refer to the recently published ASHRAE Grid-Interactive Buildings for Decarbonization: Design and Operation Resource Guide (ASHRAE, 2023) for more information and guidance on applying ADR systems to existing buildings, including current best practices.

APPENDIX 3.3: HOW HEAT PUMPS WORK

Most commercially available heat pumps use the vapour compression cycle to move thermal energy, effectively “pumping” heat from a low-temperature source to a high-temperature sink (or load). This process is typically driven by a compressor in a cycle that exploits a refrigerant's physical properties to facilitate heat transfer. The cycle is illustrated in Figure 74.





Step 1 – Evaporation: Refrigerant, at low pressure and lower temperature than the source, absorbs heat from the heat source, evaporating as it absorbs heat.

Step 2 – Compression: Refrigerant vapour, initially at low pressure and a cool temperature, is mechanically compressed to high pressure and temperature.

Step 3 – Condensing: The refrigerant rejects heat to the heat sink at high pressure and temperature. This process condenses it into a liquid as it cools.

Step 4 – Pressure Drop: Refrigerant liquid, initially at medium temperature and high pressure, has its pressure reduced through a throttling device, which also causes a corresponding drop in temperature.

FIGURE 74: THE VAPOUR COMPRESSION CYCLE

Figure 74 illustrates that the process by which heat pumps generate heat can be represented on a pressure-enthalpy diagram. The large arrows depict where heat is transferred into and out of the cycle, and where power is input to drive the process. The inverted "U" shape represents the boundary of the refrigerant's phase change or mix region. Within this region, the temperature is directly proportional to the refrigerant pressure within the mixed region. The pressures at which the refrigerant evaporates and condenses determine the respective temperatures in the evaporator and condenser, which define the temperature capabilities of the heat pump. The limits of these temperatures, particularly on the condenser side, largely depend on the refrigerant type and compressor design of the particular heat pump.

The difference between the condensing pressure (and temperature) and the evaporator pressure (and temperature) is called the compressor lift. Lift is a primary driver of heat pump efficiency. The difference between the condenser and evaporator leaving fluid temperatures is often used as a proxy for lift due to practical and operational considerations.

Figure 74 also illustrates the flow of heat through the system. Understanding the system energy flow helps with defining applicable efficiency terms. As indicated in the figure, the heat leaving the condenser is the sum of the heat absorbed at the evaporator plus the rate of electrical energy input into the compressor (ignoring component heat losses). This relationship is true both for systems operating as a heat pump to provide heating and operating as a chiller to provide cooling.

The efficiency of heat pumps and chillers is typically characterized by the term coefficient of performance (COP). The most basic definition of COP is:

$$\text{COP}=\frac{\text{Useful Energy Transfer}}{\text{Energy Input Required}}$$

A higher COP indicates a more efficient system, as more useful energy can be transferred per unit of energy input into the heat pump. It is essential to understand and denote what "useful energy transfer" is when stating a COP to avoid inconsistent comparisons. Three common types of COP are defined below:

Heating COP:

$$\text{COP}_\text{H}=\frac{\text{Net Heating Capacity}}{\text{Total Input Power}}$$

Cooling COP:

$$\text{COP}_\text{C}=\frac{\text{Net Cooling Capacity}}{\text{Total Input Power}}$$

Total COP:

$$\text{COP}_\text{TOT}=\frac{\text{Net Heating Capacity} + \text{Net Cooling Capacity}}{\text{Total Input Power}}$$

Total COP is also commonly called the total efficiency ratio (TER). For cooling applications, the term kW/ton is widely used to express efficiency, calculated as the power input divided by the useful cooling expressed in tons (1 ton = 3.52 kW = 12,000 BTU/h). This term is effectively the inverse of the cooling COP; as such, a lower value indicates better efficiency. The energy efficiency ratio (EER) is another efficiency factor commonly used for cooling. The EER is the useful cooling output (in BTU/h) divided by the electrical input (measured in W).

It is important to understand which COP or efficiency value is being referenced when comparing equipment efficiency in specifications and selections. For example, mistakenly using the cooling COP when referring to a heating process can result in an underestimation of COP by 20-30%. Even worse, mistaking the total COP (or TER) for the heating COP can result in overestimating systems' efficiencies by as much as 80-100%.

The theoretical limit of efficiency for any heat pump is defined by the Carnot efficiency, which is determined by the evaporation temperature (T_{evap}) and the condensing temperature (T_{cond}), both measured in absolute units (Kelvin or Rankine). A crucial point to understand is that the Carnot efficiency demonstrates the significant impact of compressor lift – defined as the difference between condensing and evaporation temperatures – on overall efficiency, as it forms the denominator in the COP calculations. For COP comparisons between different operating conditions, leaving evaporator and condenser fluid temperatures are typically used as proxies for evaporator and condenser temperatures in water-to-water applications, with air temperature and leaving fluid temperature used in air-to-water applications.

Carnot Efficiency for Heat Pump

$$\mathrm{COP_{H,Carnot}} = \frac{\mathrm{T_{cond}}}{\mathrm{T_{cond}} - \mathrm{T_{Evap}}}$$

Carnot Efficiency for Cooling

$$\mathrm{COP_{C,Carnot}} = \frac{\mathrm{T_{evap}}}{\mathrm{T_{cond}} - \mathrm{T_{Evap}}}$$

In practice, real-world systems cannot achieve Carnot efficiency due to inherent inefficiencies in actual processes, such as friction, temperature gradients, and limitations related to materials and operations. Typical efficiencies in real-world scenarios range from 40-60% of the Carnot efficiency, depending on specific heat pump designs and manufacturing characteristics.

Nevertheless, understanding the Carnot efficiency is beneficial for assessing potential efficiency changes due to temperature variations and validating manufacturer claims. It also quantitatively demonstrates how crucial lift is to efficiency.

Positive Displacement vs. Dynamic Compressors

Positive displacement compressors work by trapping a specific volume of refrigerant gas and then compressing it to a higher pressure by reducing its volume. Positive displacement compressors maintain a relatively constant volumetric flow rate over a wide range of differential pressures because they draw a fixed vapour volume in each cycle's compression mechanism.

Dynamic compressors impart kinetic energy to the refrigerant gas, increasing its velocity and converting it into pressure. Volumetric flow rate and capacity vary over a range of pressure ratios, and the pressure ratio (or lift) must reduce as volumetric flow capacity decreases. Unlike positive displacement compressors, which can maintain high lift at reduced capacities, dynamic compressors are subject to compressor surge at low-load, high-lift conditions that can strain and, if not controlled, damage the compressor. Modern, variable-speed centrifugal chillers use speed control, inlet guide vanes, and onboard controls to prevent chillers from entering surge conditions.

Common Compressor Types

Common compressor types, along with capacity control and application considerations, are outlined in Table 23.

TABLE 23: HEAT PUMP COMPRESSOR TYPES AND APPLICATION CONSIDERATIONS

COMPRESSOR TYPE	BENEFITS	DRAWBACKS	TYPICAL APPLICATIONS	CAPACITY CONTROL
Reciprocating	Can be applied over a wide range of load and lift conditions, and various options exist for stepped or step-less capacity control.	High maintenance requirements compared to other compressors. High noise and vibration levels.	Sizeable industrial refrigeration plants and, more recently, high-lift water-to-water heat pump applications.	Variable speed drive (VSD).
Screw	Long service life with minimal maintenance. Tend to be smaller and lighter than similar-capacity centrifugal or reciprocating compressors. Often better part-load performance at high-lift conditions than centrifugal compressors.	More expensive than reciprocating and scroll compressors.	Applications that required high lift at reduced capacities. Often used for medium-sized water-to-water chillers or heat recovery applications	Slides vanes. Adding a VSD provides better part-load efficiency.
Scroll	Quiet, compact, energy-efficient, and cost-effective.	Limited service lift. Typically require complete replacement rather than service and repair.	Among the most widely used compressors in HVAC-R. Commonly found in packaged unitary equipment and modular air- and water-to-water heat pumps.	Staging of multiple compressors or VSD.

Centrifugal	Energy efficient. Economical for high-capacity systems.	Subject to surge at low-load, high-lift conditions.	Energy efficient, and often preferred for large refrigeration systems. High efficiency in low-lift applications makes them an excellent option for the first stage in cascaded heat recovery systems.	Combination of inlet guide vanes and VSD.

Centrifugal Compressors for Heat Recovery

Centrifugal compressors operate using high-speed rotating impellers to accelerate refrigerant gas. Kinetic energy from the impellers is transferred to the refrigerant and is converted into pressure as the gas moves through the compressor’s diffuser.

Capacity control of centrifugal compressors is achieved by the combination of VSD and inlet guide vanes. In general, speed is first modulated until any further drop in speed produces insufficient lift; then, inlet guide vanes are modulated to regulate capacity. It is not possible to vary the compressor speed of a centrifugal compressor without a corresponding drop in lift. The compressor's speed determines the lift capability, with the inlet guide vanes being used for capacity modulation.

Heat pump or heat recovery applications require careful consideration of expected load profiles and corresponding lift (temperature) requirements. For heating applications, centrifugal compressors are best applied to base loads at a consistent lift, where operating conditions are predictable and do not drive the compressor into surge.

Centrifugal compressors are often ill-suited for high-lift, variable-load applications. In such cases, multi-stage compressors are typically better suited but still require a thorough understanding of the compressors' unloading capability across the expected operating range. In heat recovery applications, capacity control through a variable frequency drive (VFD) rarely provides the expected performance unless heating water temperatures can be reset in proportion to the heating load. A constant-speed centrifugal chiller with inlet guide vanes is often more cost-effective in these scenarios.

APPENDIX 3.4: EXISTING DHW SYSTEM ASSESSMENT CHECKLIST

Data Collection:

- ☐ Are trend logs and BAS programming and graphics available to confirm current operation (e.g. DHW storage setpoint, storage tank temp, DHW leaving water temp, DHW system status, DHW recirculation pump status, etc.)? Trend logs can be particularly useful in assessing energy performance and distribution losses.
- ☐ Gather historical water usage data to understand hot water consumption patterns.
- ☐ Collect data on hot water supply temperatures at the generation source and distribution points.

DHW Generation & Storage System:

- ☐ What is the configuration of the DHW system (i.e., central vs distributed)?
- ☐ What is the fuel source, capacity, and efficiency of DHW generation equipment?
- ☐ What is the volume of DHW storage available?
- ☐ What is the storage temperature setpoint? Does it meet current code requirements and ASHRAE recommendations for Legionella control?
- ☐ What is the condition of the piping and equipment insulation associated with the generating and storage equipment?
- ☐ Where is the DHW system located? What is the incoming DCW pressure? Is there any boost pump for DCW makeup in the system?

DHW Distribution System:

- ☐ Does the system have a master thermostatic mixing valve to control distribution temperature?
- ☐ What is the material and condition of the piping risers? Do the risers need to be replaced? Riser replacement can provide a more favourable business case for exploring distribution options beyond the status quo.
- ☐ What is the condition of the insulation? Conduct spot checks to assess piping insulation's extent, condition, and thickness.

DHW Temperature Maintenance System:

- ☐ How is DHW recirculation (if present) controlled? Does an aquastat or operating schedule control recirculation? Is information available on the pump flow rate?
- ☐ Are DHW recirculation loops balanced? Is there any balancing report or DHW recirculation pump design schedule showing the GPM and pump electrical information?
- ☐ What is the configuration of DHW recirculation systems concerning building pressure zones? Have the systems been appropriately designed?

End-Uses:

- ☐ What are the end uses of the building?
- ☐ What are the fixture flow rates? Take inventory of existing fixtures and flow rates.
- ☐ Are there any complaints from occupants regarding the availability or temperature of DHW?

APPENDIX 3.5: ADDITIONAL CONSIDERATIONS FOR DHW SYSTEM PRESSURES

Retrofits of existing buildings are typically constrained in terms of where equipment can be located; the easiest and often only place to site new equipment is where the old equipment it is replacing was located. When electrifying DHW systems, the designer must carefully understand the system pressures before starting the design. Buildings above 20 storeys can exert more than 1,034 kPa (150 psig), the typical rated pressure, on equipment located in lower levels. Increased pressure ratings are possible but can substantially increase equipment costs.

Distribution Pressure Zones

Plumbing codes limit distribution pressure to fixtures to a maximum of 550 kPa (80 psi). For tall buildings, this requires pressure zones off the main riser, which limit pressure using pressure-reducing valves (PRVs). This typically requires a pressure zone every 5 to 8 floors, depending on floor-by-floor height and the developed length of piping.

A thorough understanding of the water pressure zoning for the building is important to confirm if the existing DHW recirculation systems are designed to accommodate the pressure zones. One of the most common mistakes with DHW design in high-rise buildings is attempting to recirculate DHW through system PRVs. This does not work and can cause recirculation pumps to deadhead against the PRVs when there is no fixture flow demand, or cause water to circulate backward when one pump serves multiple pressure zones (Allinson, 2014). Identify and remediate issues with the existing recirculation system as part of a DHW system retrofit to ensure hot water is available to fixtures promptly.

Code Considerations

Electrification of existing DHW systems can provide an opportunity to bring existing systems into compliance with current codes and standards. The current codes should be consulted, as code requirements are continually updated. Key considerations include:

- **Plumbing Fixture Maximum Flow Rates:** The BC Building Code and Vancouver Building Bylaw (VBBL) prescribe maximum flow rates for plumbing fixtures. Reducing flow rates will reduce DHW requirements. Refer to Section 9.2.1 for considerations for plumbing fixture retrofits.
- **Hot Water Temperature Maintenance Systems:** To ensure quick hot water delivery to users, hot water temperature maintenance systems are required for hot water systems with a developed length longer than 30 m (100 feet) or supplying more than four storeys. This can be achieved through recirculation or a self-regulating heat tracing system.
- **Pressure-, Temperature-, and Vacuum-Relief Devices:** Water heaters require several safety devices to prevent catastrophic equipment failure and harm to occupants. Revise hot water systems against current code requirements and update as necessary.
- **Hot Water Storage Temperature:** The VBBL requires that storage-type water heaters operate at no lower than 60°C (140°F) to protect against Legionella formation. However, this requirement creates challenges for heat pump systems, which rely on large storage volumes with longer recovery times than is typical for gas-fired systems. Some heat pump systems, such as single pass CO_2 refrigerant

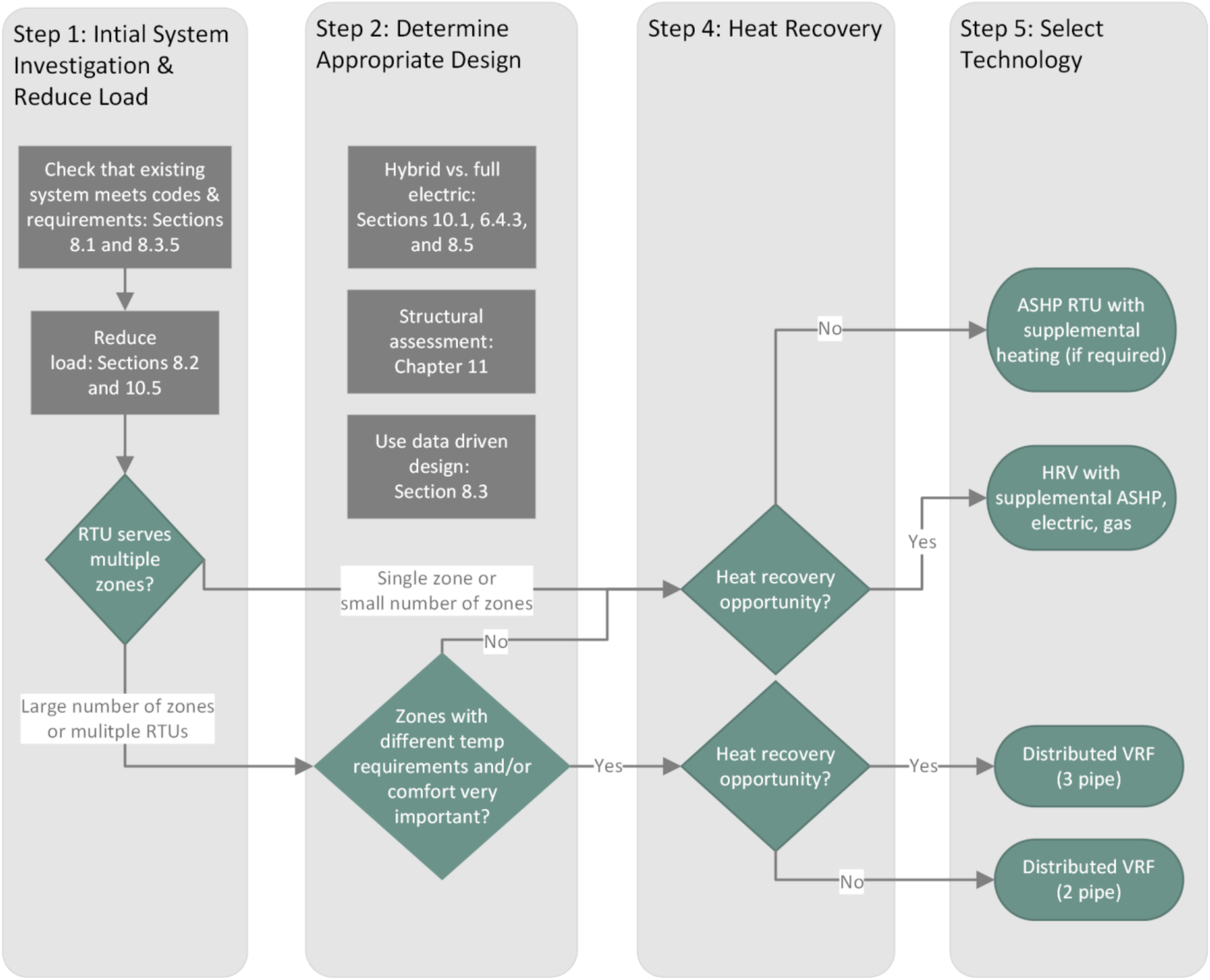
systems, have a requirement to maintain lower temperature (<35°C) swing tanks to supply suitable entering water. In cases like these, a variance may be required from the AHJ to approve the configuration. It may be acceptable to demonstrate that any DHW in the building is heated to at least 60°C before being distributed. However, it is best to consult with the AHJ to understand their requirements.

- **Hot Water Distribution Temperature:** The VBBL requires the temperature of recirculation loops to be maintained at no lower than 49°C (120°F). This requirement for Legionella control needs to be considered along with user safety to prevent scalding (ASSE, 2023).
- **Riser Replacement:** Assess the condition of both the DHW supply and recirculation risers as part of electrification retrofits. In many cases, the conditions of the risers have already been documented in previous building condition assessment (BCA) reports.

Appendix 4: Example Pathways

The following pathway diagrams are intended to serve as baseline templates that can guide LCE design. These pathways should be used references only; specific considerations will vary depending on the building, and may include factors not noted in the templates. Additionally, while these pathway diagrams describe a linear approach, as illustrated in Chapter 6, low-carbon electrification is best approached through an iterative process, with several disciplines and stakeholders collaborating to inform and advance projects.

UNITARY HVAC SYSTEM

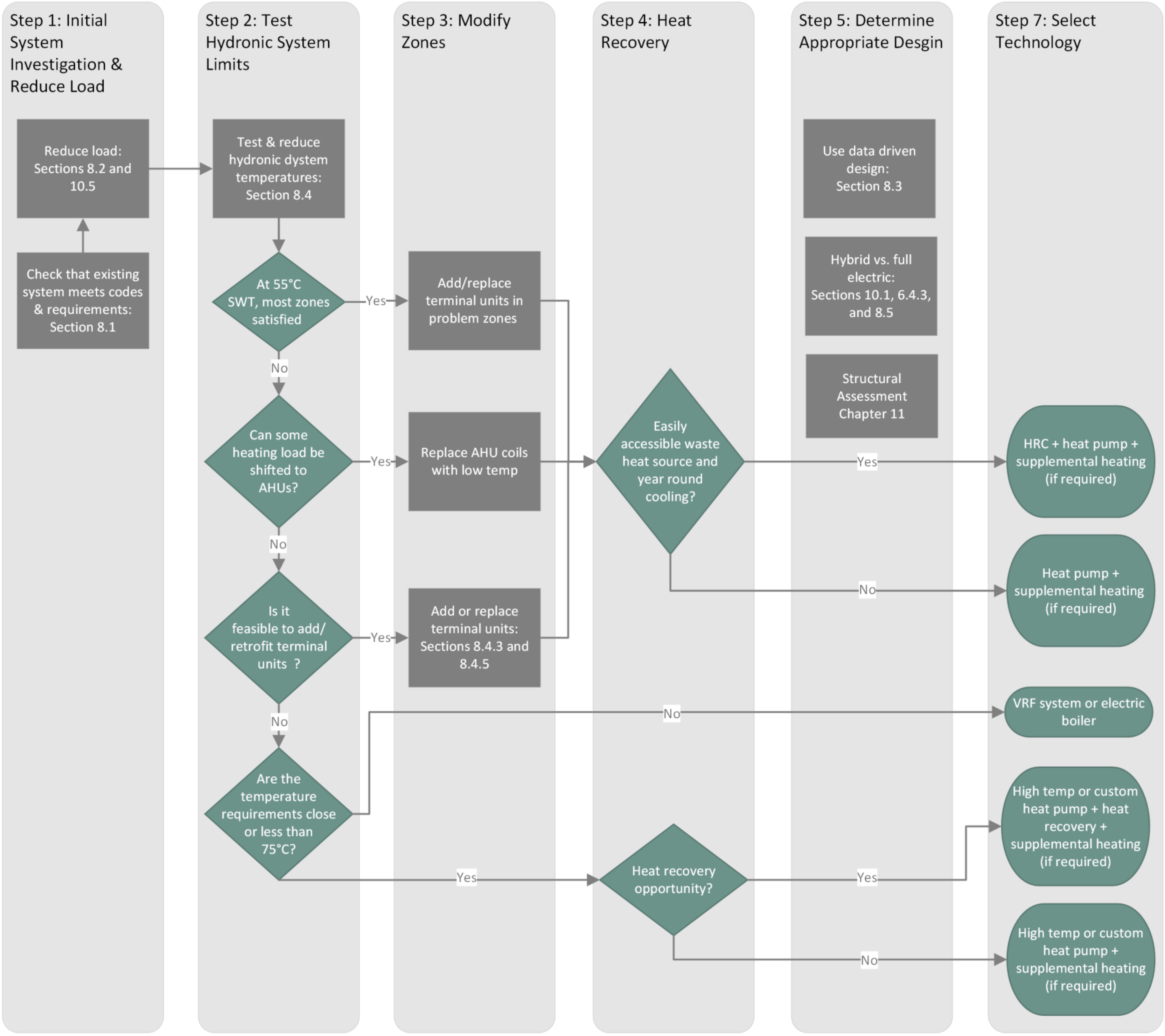


ASHP System Considerations:
- See Section 7.5.2
- Ensure that the selected unit is operating within normal operating range not at the limits
- Heat recovery as an add on should be evaluated to determine if it makes financial sense
- If structural limitations exist consider multiple small packaged ASHPs or units with separate condensing units.

VRF Considerations:
- If refrigerant circuit sized exceed code maximums, multiple smaller VRFs may be required.
- See section 7.5.4

VRF & Outdoor Air:
- Typically a dedicated outdoor air unit would be added to supply fresh air. Depending on outdoor air requirements, heat recovery ventilation may make sense for this unit.

HYDRONIC HEATING AND CENTRALIZED VENTILATION SYSTEM



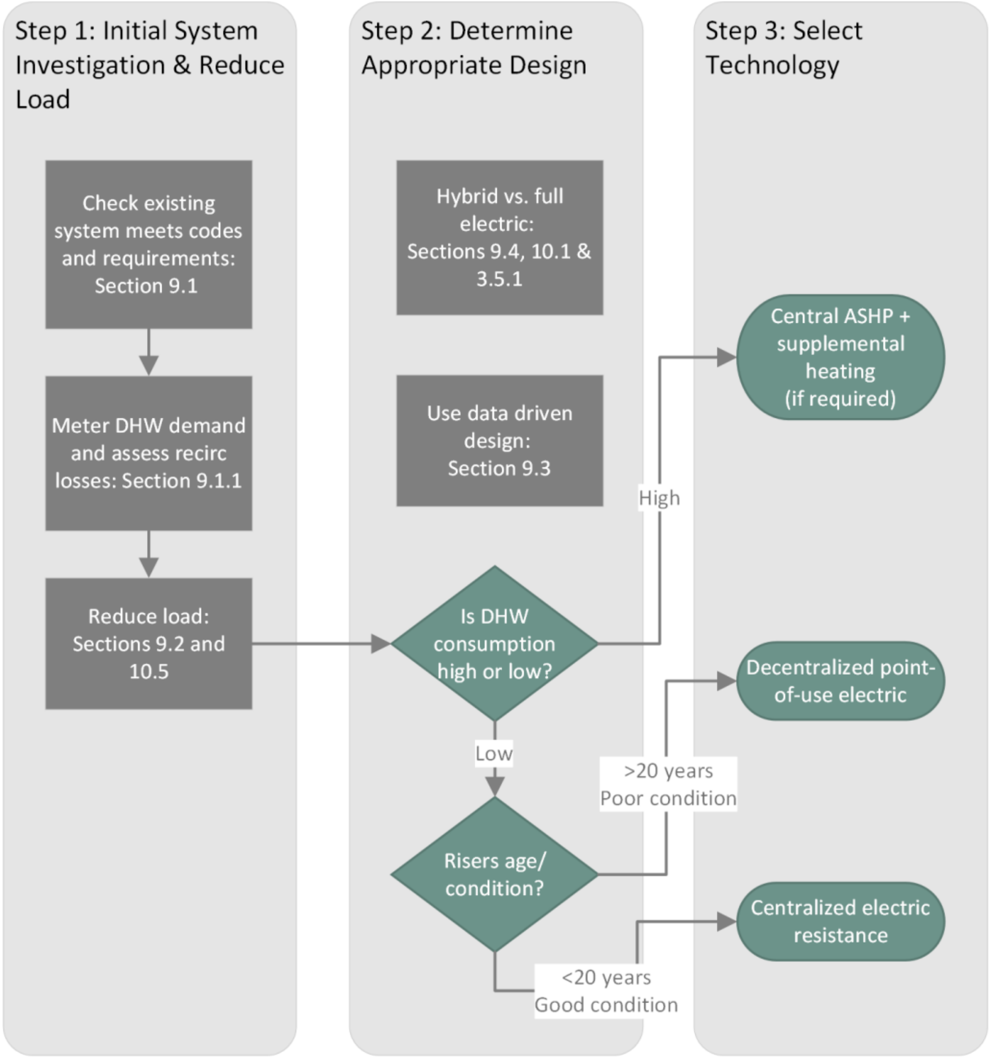
Heat Pump System Considerations:
- Section 7.5.1 for Centralized hydronic heat pump considerations
- Heat pump cannot provide cooling unless system is designed for that
- Ensure that the selected unit is operating within normal operating range not at the limits
- If applicable, assess heat recovery as an add on (it may make financial sense)
- See Section 8.5 for Supplemental Heating

Considerations for VRF:
- See Section 7.5.4 for VRF considerations

Considerations for Electric Resistance Boiler:
- See Section 8.5 Supplemental Heating
- See Section 10.5 to reduce demand charges

High Temperature Heat Pump System Considerations:
- These are typically less efficient than standard heat pumps and often require more than one module Ex. Air to water heat pump, water to water heat pump to reach the high temperatures

DHW SYSTEM



Step 1: Initial System Investigation & Reduce Load

Check existing system meets codes and requirements: Section 9.1

Meter DHW demand and assess recirc losses: Section 9.1.1

Reduce load: Sections 9.2 and 10.5

Step 2: Determine Appropriate Design

Hybrid vs. full electric: Sections 9.4, 10.1 & 3.5.1

Use data driven design: Section 9.3

Is DHW consumption high or low?

High

Low

Risers age/ condition?

>20 years Poor condition

<20 years Good condition

Step 3: Select Technology

Central ASHP + supplemental heating (if required)

Decentralized point-of-use electric

Centralized electric resistance

Legionella:
Ensure designs incorporating storage are capable of maintaining 60°C to mitigate Legionella growth.
- See Section 9.11 Controls and Appendix 3.5 Code Considerations

Central ASHP System Considerations:
- If the DHW consumption is high, decentralized DHW systems are not recommended. If the risers are in poor condition, replacement should be considered and evaluated.
- Ensure that the selected unit is operating within normal operating range not at the limits
- Review Section 9.6 for Heat pump technologies and considerations
- Review section 9.3 For Data Driven Design & 9.9 For DHW Storage Technologies
- Review Section 9.10 For Supplemental Heating

Decentralized Point of Use Electric Considerations:
- Electrical infrastructure can make or break the business case for decentralized point of use. This measure requires careful consideration of electrical distribution system capacity and condition
- See Section 9.7.2 and 9.7.3

Centralized Electric Resistance
- Review section 9.7 For Technologies