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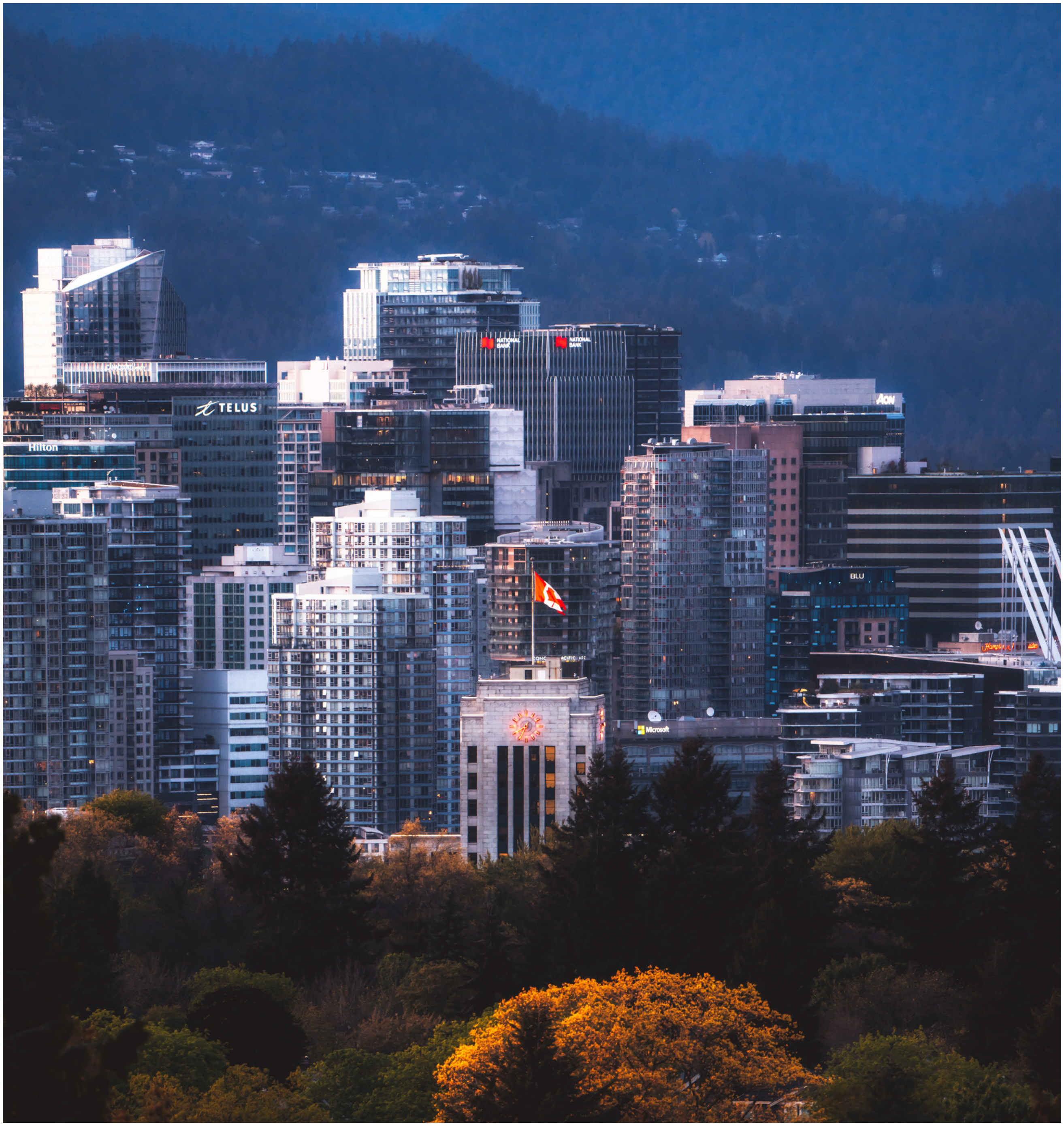

BUILDING SUSTAINABILITY & RESILIENCE GUIDE

A GUIDE OF **MITIGATION**, **ADAPATION** & **RESILIENCE** STRATEGIES FOR BUILDING MECHANICAL SYSTEMS. APPLICABLE TO BOTH NEW & EXISTING BUILDINGS.

ASHRAE British Columbia Chapter

Revision	Date	Revision Comments
1	August 2022	First Issue

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This publication is meant to be a source of general information, and is not meant as a substitute for direct expert assistance. If such level of assistance is required, the services of a competent, practicing professional should be sought.

For any inquiries regarding this guide, including requests to add content in future revisions, please contact sustainability@ashraebc.com.

PREFACE AND ACKNOWLEDGEMENTS

American Society of Heating and Air-Conditioning Engineers (ASHRAE) British Columbia Chapter

The British Columbia Chapter of ASHRAE was chartered on April 9th, 1952, with the inaugural meeting and formation of the BC Chapter of the American Society of Heating and Ventilating Engineers (ASHVE). Society President Ernest Szekely presented the Charter, at the Quadra Club in Vancouver, on April 9, 1952. There were 36 Charter Members, headed by our first Chapter President Eth Minaker. These 36 pioneer members had the foresight to establish a Chapter that grew to over 600 members, produced several Regional and Society representatives, and still remains a strong and active Chapter after 6 decades from its beginnings.

ASHRAE-BC Board of Governors: Sustainability Working Group

The ASHRAE British Columbia Chapter is governed by the Board of Governors, who is responsible for guiding the Chapter, promoting the goals of, and fulfilling the responsibilities of the ASHRAE Chapter.

The Sustainability Working Group was established in 2021, by the 2020/2021 Sustainability Chair, Max Lauretta. The Sustainability Working Group was tasked with developing this Building Sustainability & Resilience Guide, which is intended to aid the industry by providing information relating to climate change, including strategies to achieve climate change mitigation goals. Special thanks are owed to the following individuals, whose invaluable support aided in the publication of this guide:

- Max Lauretta (Chair)
- Mo Afshin
- Johnnie Allan
- Angela Bastian
- Warrick Brown
- Edward Chessor
- Holly Denby
- Mike Dixon
- Herorge Fernando
- Harvansh Maan
- Nathaniel Masters
- Randy Stuart
- Courtney Sung (Technical Editor)

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INTRODUCTION

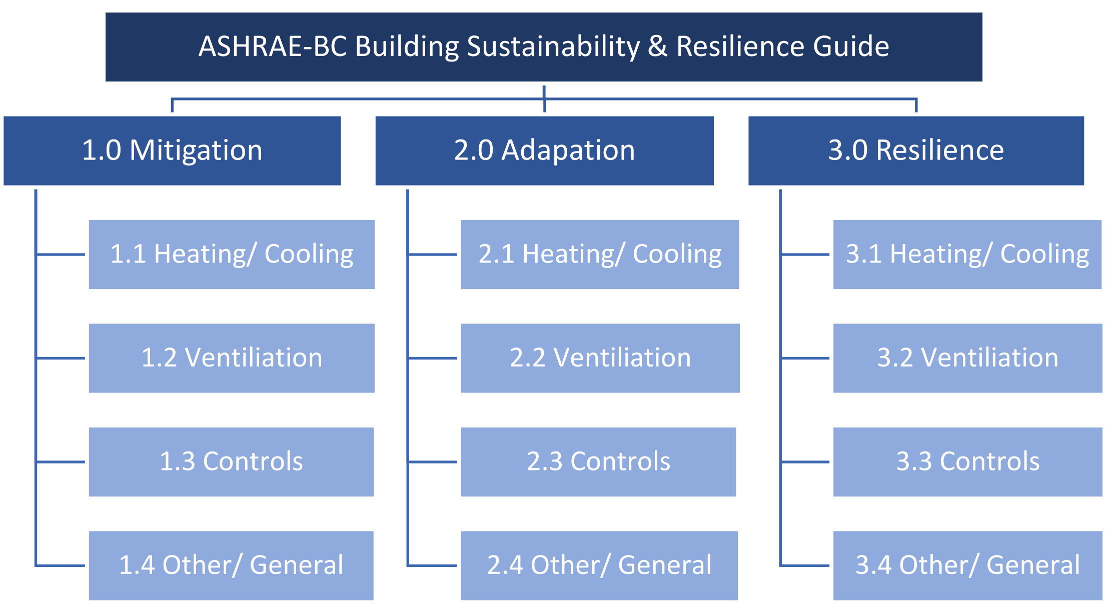
The Building Sustainability & Resilience Guide was developed with the intent of providing readers with an overview of mitigation, adaptation, and resilience strategies that can be applied to both new and existing buildings.

The guide was written to be used by a wide array of audiences, including technical readers. The intended audience of the guide includes, but is not limited to: engineers, consultants, architects, planners, building operators and maintenance teams, building owners, municipalities, commissioning agents, and sales engineers.

Note: Whilst the Sustainability Working Group has endeavored to ensure this guide contains as much information as possible, this is not a comprehensive guide. There may be other mitigation, adaptation, and resilience strategies that are not included here that may be more applicable to a specific system. Additionally, new information may become available, including new technologies, after the release of this guide that would be more appropriate for a specific project. This guide should be used in conjunction with other available information. This publication is meant to be a source of general information, however and is not meant as a substitute for direct expert assistance. If such level of assistance is required, the services of a competent professional should be sought.

HOW TO USE THIS GUIDE – QUICK NAVIGATION

The guide is organized into pillars *(e.g.,* Mitigation) and categories *(e.g.,* Heating / Cooling), which are shown in the flow chart below. ***CLICK ON THE BOXES IN THE FLOW CHART BELOW, TO JUMP TO THAT SECTION*****.** Use the “Return” button at the bottom of the page to jump back to this page. Each category is further divided into sections that are measures to either decarbonize or improve the sustainability of a building’s Heating, Ventilation, and Air Conditioning (HVAC) system. The Table of Contents also provides a streamlined way for readers to navigate the document.



REFERENCED ASHRAE CODES, STANDARDS & PUBLICATIONS

The following ASHRAE codes, standards and publications have been referenced in this guide as locations to find more information on specific sections. Follow the link to access the document from the ASHRAE bookstore.

	ASHRAE BOOKSTORE
ASHRAE Standard 15: Safety Standard for Refrigeration Systems	Link
ASHRAE 34: Designation & Safety Classification of Refrigerants	Link
ASHRAE Guideline 42p: Enhanced Indoor Air Quality In Commercial And Institutional Buildings	-
ASHRAE 52.2: Method Of Testing General Ventilation Air-Cleaning Devices For Removal Efficiency By Particle Size	Link
ASHRAE Standard 62.1: Ventilation For Acceptable Indoor Air Quality	Link
ASHRAE Standard 62.2: Ventilation For Acceptable Indoor Air Quality In Residential Buildings	Link
ASHRAE Standard 90.1- 2019: Energy Standard For Buildings Except Low-Rise Residential Buildings	Link
ASHRAE Standard 145.2: Laboratory Test Method For Assessing The Performance Of Gas-Phase Air-Cleaning Systems: Air-Cleaning Devices	Link
ASHRAE Standard 170-2017: Ventilation Of Health Care Facilities	Link
ASHRAE Standard 188-2018, Legionellosis: Risk Management For Building Water Systems	Link
ASHRAE Procedures For Commercial Building Energy Audits	Link
ASHRAE Design Guide For Dedicated Outdoor Air Systems	Link
2014 ASHRAE Best Practices For Designing Geothermal Systems	Link
2018 ASHRAE Handbook: Refrigeration	Link
2020 ASHRAE Handbook: HVAC Systems & Equipment	Link

GLOSSARY

Below are some acronyms of key terms and symbols that are used throughout the guide.

ΔT	Temperature Change	**EEM**	Energy Efficiency Measure
AHU	Air Handling Unit	**EMS**	Energy Management System
ASHRAE	American Society of Heating and Air-Conditioning Engineers	**GWP**	Global Warming Potential
BMS	Building Management System	**HVAC**	Heating Ventilation & Air Conditioning
COP	Coefficient of Performance	**IAQ**	Indoor Air Quality
DDC	Direct Digital Control	**MERV**	Minimum Efficiency Reporting Values
DHW	Domestic Hot Water	**ODP**	Ozone Depletion Potential
DOA	Dedicated Outdoor Air	**PV**	Photovoltaic
DX	Direct Expansion	**SEER**	Seasonal Energy Efficiency Ratio
ECM	Energy Conservation Measure	**VRF**	Variable Refrigerant Flow

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1.0 MITIGATION

The working definition that was used as a reference point for this section is taken from the United Nations Environment Programme (UNEP):

> *Mitigation refers to efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior.* [1]

1.1 HEATING/ COOLING

The following section offers suggestions to adjust and reduce emissions from heating, cooling, and domestic hot water systems. This section includes discussion on heat recovery and low carbon energy sources specifically related to the above systems.

1.1.1 REFRIGERANTS

Refrigerants are used in HVAC systems to facilitate heating or cooling. Refrigerants are an essential part of HVAC systems, due to their ability to transfer heat from spaces to the ambient in an efficient manner. However, refrigerants do contribute to the carbon emissions of a building and can sometimes be responsible for as much as 20% of a building's carbon emission[2]. Emissions from refrigerants and refrigerant systems can be significantly reduced if refrigerants with lower environmental impacts are selected, systems are correctly maintained, and at end of life, refrigerants are disposed of properly.

ASHRAE's position on refrigerants "is that the selection of refrigerants and their operating systems should be based on a holistic analysis of multiple criteria. ASHRAE promotes the responsible use and management of refrigerants during the processes of design, manufacturing, operation, and servicing of systems as well as at the end of life"[3]

This section will provide an overview of how to reduce emissions generated from refrigerant systems.

1.1.1.1 REFRIGERANT SELECTION

Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) are commonly used terms when discussing and selecting refrigerants. ODP quantifies the amount that something contributes to the breakdown of the ozone layer, relative to R11, which has an ODP of 1. ODP for refrigerants can range from 0 – 1, but the only commonly acceptable ODP value is 0. GWP is the amount of heat that one ton of gas will absorb over a certain period, relative to 1 ton of CO_2, which has a GWP of 1. Unlike ODP, GWP values can range from 0 to upwards of 10,000.

From predominately using refrigerants with high ODP and very high GWPs, the industry is in the process of transitioning to using refrigerants with 0 ODP and lower GWPs. This transition has

[1] Retrieved from: https://www.unep.org/explore-topics/climate-action/what-we-do/mitigation
[2] Retrieved from: https://www.integralgroup.com/news/refrigerants-environmental-impacts/
[3] Retrieved from: https://www.ashrae.org/file%20library/about/position%20documents/pd_refrigerants-and-their-responsible-use-pd-6.29.2020.pdf

been accelerated by governments around the world banning the use of certain refrigerants in a phased manner, starting with R22 being banned in 2020. The table below outlines some common categories of refrigerants and provides a brief description for each. A few examples of each are also provided but note this is not an exhaustive list of the refrigerants in each type. ASHRAE Standard 34-2019 provides more information on refrigerant numbers, toxicity, and flammability.

ODP & GWPS FOR COMMON REFRIGERANTS

Refrigerant Types	**ODP**	**GWP**	**Brief Description**
Chlorofluorocarbons (CFC)	1	10,900	CFCs contain chlorine and are ozone depleting, incombustible, and non-toxic. However, CFCs have been banned since the early 1990s for new construction. CFCs are slowly being transitioned out of the industry, but the conversion is not yet complete on existing buildings. Examples: R11, R12, R115
Hydrochlorofluorocarbons (HCFC)	0.055	1,810	HCFCs contain less chlorine than CFCs and similarly to CFCs, are incombustible and non-toxic. HCFCs are less damaging to the ozone compared to CFCs and are intended to help transition off CFCs as a temporary solution until 2030. Examples: R22, R123, R124
Hydrofluorocarbons (HFC)	0	650 – 4,000	HFCs do not contain chlorine, which therefore results in an ODP of 0 as they are not harmful to the ozone. However, as seen in their large GWP, HFCs can still have a large impact on global warming. HFCs are incombustible and non-toxic (*except R32 which is slightly flammable*). Examples: R32, R125, R134a, R-143a, R152a, R245c, R245fa, R404a, R407c, R410a, R507a, R508b.
Hydrofluro-olefins (HFO)	0	1-6 (631*)	HFOs are not harmful to the ozone layer. HFOs generally have low GWPs *(* except R-513a which has a GWP of 631).*

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			HFOs are an environmentally-friendly alternative to CFCs, HCFCs, and HFCs. HFOs are stable, non-toxic, and non-flammable. Examples: R513a, R1234ze, R1234yf, R514a (XP30), R1233zd, R-454B
Flurocarbons (FC)	0	8830	FCs do not contain chlorine and are extremely stable, but have a high GWP. Examples: R218
Hydrocarbons (HC)	0	<5	HCs are also referred to as isobutanes and are highly flammable. HCs are highly accepted by environmentalists due to their extremely low GWP. Example: R600a
Ammonia (NH_3)	0	0	Ammonia has been used as a refrigerant since 1840. Ammonia is hazardous at low concentrations and is slightly flammable. Ammonia is a self-alerting gas, making it is easier to identify leaks. Example: R717
Carbon Dioxide (CO_2)	0	1	Carbon dioxide is non-flammable, has low toxicity, and does not cause ozone depletion. While carbon dioxide is cheap and available in large quantities, carbon dioxide has low efficiency and high operating pressures, which makes it difficult to use. Examples: R744

According to an article published by American Society of Mechanical Engineers (ASME) [4], when selecting a refrigerant for the system, the five major factors that must be considered are: performance, safety, reliability, environmental acceptability, and simple economics As noted in the ASME article, it is important to “keep in mind that the relative importance of each depends upon the application and, of late, government regulations, which differ from one country to another.”

When selecting refrigerants it is also important to check whether a refrigerant available today will be available in years to come. The Canadian Government has released guidelines on which refrigerants will be banned in 2025[5]. The table below outlines the details of the current refrigerant phase out, and also indicates the GWP limits, and the date of phase out.

[4] Retrieved from: https://asmedigitalcollection.asme.org/memagazineselect/article/120/10/92/368600/Choosing-the-Right-RefrigerantGiven-Today-s
[5] Retrieved from https://laws-lois.justice.gc.ca/eng/regulations/SOR-2016-137/FullText.html

PRODUCTS CONTAINING OR DESIGNED TO CONTAIN AN HFC USED AS A REFRIGERANT

Product Description	Type of Use	Date of Phase Out	Global Warming Potential (GWP) Limit of Refrigerant Used in Product
Stand-alone, medium-temperature refrigeration system: a self-contained refrigeration system with components that are integrated within its structure and that is designed to maintain an internal temperature ≥ 0°C	Commercial or industrial	January 1, 2020	1, 400
	Residential	January 1, 2025	150
Stand-alone, low-temperature refrigeration system: a self-contained refrigeration system with components that are integrated within its structure and that is designed to maintain an internal temperature < 0°C but not < -50°C	Commercial or industrial	January 1, 2020	1, 500
	Residential	January 1, 2025	150
Centralized refrigeration system: a refrigeration system with a cooling evaporator in the refrigerated space that is connected to a compressor rack located in a machinery room and to a condenser located outdoors; designed to maintain an internal temperature ≥ -50°C	Commercial or industrial	January 1, 2020	2, 200
Condensing unit: a refrigeration system with a cooling evaporator in the refrigerated space connected to a compressor and condenser unit that are located in different locations; designed to maintain an internal temperature ≥ -50°C	Commercial or industrial	January 1, 2020	2, 200
Chiller: refrigeration or air-conditioning system that has a compressor, an evaporator, and a secondary coolant, other than an absorption chiller	Commercial or industrial	January 1, 2025	750
Mobile refrigeration system: a refrigeration system that is	Commercial or industrial	January 1, 2025	2, 200

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normally attached to, installed in, or operates in / with a means of transportation			

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***2018 ASHRAE HANDBOOK – REFRIGERATION.***
- ***ANSI/ASHRAE STANDARD 15, SAFETY STANDARD FOR REFRIGERATION SYSTEMS.***
- ***ANSI/ASHRAE 34-2019, DESIGNATION AND SAFETY CLASSIFICATION OF REFRIGERANTS.***
- ***UPDATE ON NEW REFRIGERANTS DESIGNATIONS AND SAFETY CLASSIFICATIONS, ASHRAE AND UNITED NATIONS FOR ENVIRONMENTAL PROGRAMME (UNEP).***

1.1.1.2 ORGANIZATIONAL REFRIGERANT MANAGEMENT PLANS

A Refrigerant Management Plan (RMP) outlines those strategies that an organization can implement to reduce or minimize the release of emissions into the atmosphere.

In the United States, to comply with the Clean Air Act, an owner is required to define and document a refrigerant compliance program, which includes a refrigerant-inventory management policy.[6] Typical components of an RMP include[7]:

1. prohibition on venting
2. evacuation requirements
3. leak repair requirements
4. leak reporting
5. technician certification
6. purchasing refrigerants
7. disposal requirements
8. recordkeeping requirements
9. responsibilities of key staff members (*e.g.*, building managers and occupational healthy and safety)

Regarding mitigating emissions, aside from guidance on leaks, reclamation and disposal of refrigerants are key components of complete refrigerant plans.

1.1.1.3 MONITORING AND MAINTENANCE

All refrigerant systems have a certain degree of leakage. The emissions from refrigerant systems are considered fugitive emissions, which are emissions resulting from accidental leaks. Proper monitoring and maintenance of refrigerant systems can help to reduce these fugitive emissions.

There are two types of testing and monitoring that can be implemented on refrigerant systems. The first is indirect, where an operator will look for signs of a leak through visual inspections of the piping or a loss of pressure in the system. The second type of testing is direct, where an

[6] Retrieved from: http://www.phaseoutfacts.org/compliance+management+plan.aspx
[7] Retrieved from: https://www.ehs.harvard.edu/sites/default/files/refrigerant_management_program.pdf

operator can use a hand-held detector to look for leaks or tracer dyes with a UV lamp to find leaks in the system.

For reference, some early signs of a refrigerant leak could include the following as underlined:

- Due to less overall refrigerant in the system, there may be a loss of cooling power, and supply air temperature will be less than expected. In addition, more electrical power may be required to achieve set points, which would result in higher electricity bills.
- If there is cracking or if there are holes in the refrigerant piping of indoor units, hissing sounds may emanate from the unit.
- If the coils cannot absorb enough heat, they may accumulate condensation causing the coils to freeze which could eventually even result in compressors needing to be replaced.
- There may be increased noise from the compressor.

With proper monitoring and maintenance of refrigerant systems, a building operator can ensure that emissions from leaks are minimized, and that the life of a refrigerant system is maintained.

1.1.2 LOW/ ZERO CARBON ENERGY SOURCES

Once project teams have taken all reasonable measures to reduce the energy demands of a building, decarbonization of the building's energy system becomes the primary target for further emissions reduction. Various longstanding and proven technologies are available to assist in the decarbonization effort, as well as some newer emerging technologies that may require additional care and effort in application.

1.1.2.1 HEAT PUMPS

Heat pumps, in their various forms, have been applied commonly to buildings for many decades. Recent developments in microprocessors and advanced manufacturing have resulted in higher efficiencies and system reliability. As regulators and project teams alike seek low-carbon strategies for buildings, heat pumps will only become more ubiquitous. Heat pumps use electrical energy to run their compressor(s) and draw most of their energy from ambient air or various forms of piped water loops.

Coefficient of Performance (COP) is a ratio used within heating and cooling systems to define efficiency and energy consumption. Simply, COP is the ratio of the amount of energy (ie heat) able to be supplied by the system or machine divided by the amount of energy (ie electricity) required. Depending on the application, average system COPs of 3.0 or more are readily achievable for heat pumps. When considering heating only, direct electric heating can only produce a maximum COP < 1, whilst the best gas condensing boilers can achieve a COP just below 1, and utilize non-renewable fuel sources.

Perhaps one of the most important advances has been in the low-temperature performance of commonly available air source heat pumps. Unlike in past decades, modern air source heat

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pumps are capable of operating at COPs above 1.5 at temperatures as low as -20°C, and may continue to generate heat at lower efficiencies at -30°C or below. This greatly widens the useful range of heat pump operation and increases the likelihood that backup fuel-fired systems can be omitted. Similar performance is available from commercial-grade Variable Refrigerant Flow (VRF) systems, central air source heat pumps, and packaged residential-scale equipment.

Designers must review low temperature heating performance for the specific equipment to be installed; not all heat pumps are designed to provide adequate heat, or heating range, in low ambient temperature conditions. Care must be exercised in cold climates to ensure all heating demands are satisfied under all foreseeable conditions. In locations with very low winter minimum ambient conditions, there may be no practical alternative to direct electric heating or gas fired heating.

Water-source heat pumps present additional flexibility in applications that air source systems may not, permitting their use in all climate types and across a wide range of building. It is straightforward to inject energy from a backup heating system into a water loop (such as in very cold climates), or to recover heating energy from year-round cooling sources (see also 1.1.5.1 Heat Recovery Chiller on page 16). As a connected loop, water loop heat pump systems naturally recover and reuse energy from zones with opposite demands: an external zone requiring heating will take part of its energy from interior zones requiring cooling in an office building, for example. In these applications, consideration must be given to ensuring that this heat balance can be maintained all year around, or a backup system is provided to account for any discrepancies.

The relatively low temperatures that heat pump water loops typically operate at also result in peak efficiencies from condensing gas boilers, reducing carbon intensity even for locations where fuel-fired peaking equipment is required.

1.1.2.2 GEOEXCHANGE

Directly related to the section above on heat pumps, geoexchange systems[8] involve open- or closed-piping buried in the ground, directing glycol or raw water through a heat pump system. Open systems draw water from aquifers, oceans or lakes, returning it back to the source after transferring heat to or from the fluid via heat pumps. Closed systems continuously circulate a water or glycol mixture through horizontal or vertical boreholes, transferring heat to (or from) the ground into the fluid. The water or glycol is then used as a source or sink by water source heat pumps inside the building.

The primary disadvantage to geoexchange systems tends to be their relatively high capital cost in comparison with air source heat pumps. Drilling tens (or even hundreds) of boreholes is costly and can complicate construction schedules. Due to highly variable geotechnical characteristics, test boreholes at the project site must be drilled in advance of fully committing to such a

[8] Commonly referred to as “geothermal” systems. Geoexchange systems use ambient ground temperatures and relatively shallow borehole systems of 50-100m depths. True geothermal systems connect to high temperature, high pressure water at depths of 3km or more into the earth’s crust.

system. Open systems can experience similar challenges when obtaining approvals from environmental authorities – a process that can be time-consuming and unpredictable. Both types have challenges in terms of maintaining long term performance and capacity. Open systems also require strict maintenance and cleaning regimens on the production and injection of borehole screens.

Despite these challenges, when applied correctly, geoexchange systems provide a very effective means of delivering low-carbon and high efficiency thermal energy to buildings. Deep ground and large bodies of water provide relatively stable temperatures in comparison with air, allowing these systems operate reliably in climates or weather conditions beyond the operational range of air source heat pumps. They also provide improvements in potential COPs when compared to equivalent air-cooled heat pumps, particularly at times of extremely low or high ambient temperatures. It is for these reasons that geoexchange should be considered if the building site has the capacity to accommodate geoexchange systems and the budget is available.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***2014 ASHRAE BEST PRACTICES FOR DESIGNING GEOTHERMAL SYSTEMS***

1.1.2.3 SOLAR THERMAL

Collecting, storing, and using solar thermal energy has become more common, more effective, and less expensive to do in recent years, with energy costs for many projects below $1,000USD/kW of installed capacity in 2020[9]. Solar thermal systems, able to generate high temperature water via evacuated tube or flat plate collectors, are especially well suited for domestic hot water production in buildings with regular occupancy and predictable demand profiles. Requiring only small amounts of electricity for circulation pumps and controls, solar thermal systems provide nearly zero-carbon energy.

Challenges to the application of solar thermal systems include:

- determining suitability of system for local solar incidence (including effects of adjacent buildings, typical cloud cover, and average solar intensity)
- balancing the system size for first cost and energy production capacity
- locating and coordinating panels with the project team (architectural, structural, building science)
- addressing over-heating issues during periods of high production and low demand
- system component stress due to elevated temperatures and temperature cycling
- integration and control of solar systems with traditional hot water plants

Most of these potential challenges now have standardized industry solutions that may be applied routinely, though specific implementations will vary depending on the goals of the

[9] Retrieved from https://solarthermalworld.org/sites/default/files/news/file/2021-07-11/irena_renewable_heat_generation_costs_2010_to_2020.pdf

individual project. For example, a hotel may install a small system to reduce their natural gas bills or to access carbon credits, while a government agency with a carbon-neutral mandate may install a more extensive system designed to provide nearly all of the facility's hot water from solar energy.

In any case, all solar systems must be properly integrated into the building's structure, envelope, architecture, and plumbing systems to be effective.

1.1.2.4 ADSORPTION CHILLERS

Adsorption chillers are thermally driven: they use heat energy to drive a chemical process that results in the production of chilled water, where typical chillers use the mechanical input work of a compressor motor to achieve the same goal. As their primary input is thermal energy, this makes adsorption chillers a serious consideration for any facility with consistent access to waste heat.

The obvious use case for adsorption chillers is in situations when one is closely coupled with an industrial or power generation process, whereby waste heat is consistently generated. The heat source being "waste" is crucial for two reasons:

- Adsorption chillers are relatively inefficient, with COPs less than 1.0.
- Adsorption chillers with a fuel-fired primary energy source would be extremely carbon-intensive. When using waste heat from another process, no additional emissions are required.

Coupling solar collectors with adsorption (or absorption) chillers is also tempting as a low carbon source, which would allow the excess energy from solar arrays not used for domestic hot water to be used instead to generate chilled water for cooling. Unfortunately, there are few situations that are economically viable and converting this solar energy directly to photovoltaic (PV) electrical energy is a more versatile and efficient strategy.

1.1.2.5 BIOMASS

Biomass heating systems burn wood byproducts in a combustion chamber to generate hot water. Biomass fuels are considered "near carbon neutral", but emission costs associated with harvesting, processing, and transporting the fuel means they are not truly carbon-neutral[10]. Biomass boilers produce both gaseous and particulate emissions, and accordingly their use does not alleviate localized pollution relative to other fuel sources.

While there are some complications associated with the handling of their fuel source (wood), the hot water they produce can be piped and pumped through heating and domestic hot water systems without any special provisions unique to biomass.

[10] Retrieved from https://www.eia.gov/energyexplained/biomass/biomass-and-the-environment.php

In certain locales and applications, biomass boilers can be an excellent low-carbon and low-cost fuel source. Generally, when close to a fuel source such as a mill, and when sufficient natural gas or electricity is not available, biomass boilers become more attractive.

1.1.3 TARGETS, BASELINES AND MONITORING

It is crucial to quantify the impacts of carbon mitigation strategies by modelling, followed by tracking and comparison of real-world building performance against project targets. Without setting targets and then logging this data using standardized metrics, it removes the ability to:

- select appropriate emissions targets, matched to the type of project
- assess the true carbon impacts of the project
- identify real-world deviations from the design or modelling
- implement operational changes to improve function
- compare real-world operational data against modelled data, and against similar facilities

1.1.3.1 TARGETS AND CALCULATED IMPACT OF GREENHOUSE GAS EMISSIONS

At present, most efficiency targets mandated by building codes focus on energy consumption (e.g.. National Code of Canada for Buildings) or energy cost (e.g. ASHRAE Energy Standard for Buildings Except Low-Rise Residential Buildings). These targets may result in moderate reduction of emissions by proxy, but do not incentivize the use of low-carbon fuel sources over higher-carbon sources. Emissions targets (typically denoted in $kgCO2/m^2$) intentionally shift the focus onto carbon intensity of projects; these emissions goals are usually paired with energy intensity limits as well. Targets may be established by local building codes, the municipality, sustainability ratings system[11], or the project team itself.

To identify and take full advantage of available emissions mitigation options, preliminary energy modelling by a qualified specialist consultant should be undertaken early in the design phase, preferably starting well in advance of the Development Permit application. Early modelling exercises (box modelling) allow for quick changes to the building envelope, orientation, fuel sources, and systems configuration that may be impractical later in design or construction. If a designer does not have enough information to generate a model with sufficient detail, a report or guideline document could be completed early on that provides options for consideration. In early design, when many aspects of the design are still considered fluid, it is highly recommended that the team target slightly more stringent energy and carbon targets than required. This creates a small buffer for compliance, which may help accommodate changes during detailed design and construction phases.

After establishing preliminary modelling results and identifying the primary mitigation strategies, the energy model should be updated to incorporate significant design changes relating to constructability, equipment substitutions, owner requests, or cost savings. Finally, as

[11] LEED v4.1 Beta Building Design and Construction 2021, https://www.usgbc.org/leed/v41

required by many municipalities, the results of the modelling should be submitted along with the design documents and specifications. This step is important for two reasons:

- It encourages project teams to vet the supporting modelling analysis more carefully and to provide analysis results in a consistent format.
- It provides data to the municipality, which may be used to compare against programs in other cities or against real-world building operational data.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE STANDARD 90.1- 2019: ENERGY STANDARD FOR BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS***

1.1.3.2 MONITORING AND OPERATIONAL ADJUSTMENTS

A program of monitoring and logging energy consumption data[12], and associated carbon emissions, should begin following completion of building commissioning. While the incentive for the building operator may be increased energy cost savings or reliability via system optimization, logging this data permits comparison of overall building performance and emissions against the energy modelling results generated in the design phase.

Comparing real-world energy consumption to the modelling results is not yet standard practice in industry, despite its potential benefits. Energy models use standardized climate and schedule inputs, meaning they will never map exactly to an operational building. However, comparisons of energy use to that predicted by the model can still yield important insights to building operation. This is especially true when delving deeper than simple “kWh per month” comparisons, where checks on daily, monthly, or seasonal system cycles may bring to light problems that slipped through the commissioning process, or opportunities that weren’t envisioned during design.

Once opportunities for improvement are identified, adjustments to system operation can be undertaken. Minor changes to control loops such as supply temperature reset schedules, economizer change-over setpoints, or setback and warmup sequences may yield worthwhile savings in both energy and emissions.

1.1.3.3 COMPARISON AGAINST PEER BUILDINGS

There is value in knowing the real-world carbon intensity of a specific project relative to peer buildings. However, a challenge with comparisons can be finding a data set to compare to in the first place. Operators of multi-building campuses or large corporations may have sufficient properties to generate comparison data, but for most projects, such a comparison would rely on collated data at the municipal or regional level.

[12] While much simpler to implement and automate with a Direct Digital Controls (DDC) system, this may be as simple as manually recording monthly utility bills.

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Having the data to make comparisons to peer buildings can enable many useful actions:

- identify building categories where tightened carbon or energy limits may be practical
- identify common operational challenges in comparison to widely used modelling assumptions
- provide high-level emissions data for overall building stock vs municipal, federal or provincial decarbonization mandates

Some local municipalities are compiling real world energy consumption data for buildings under their jurisdiction and are using this data to develop future improvement guidelines for new and existing buildings. The industry can expect peer building performance information to become more readily available in the near future, and the implementation of disclosure to municipalities for all buildings to become mandatory. The implications of this could lead to retrofitting metering to existing buildings, at the owners' cost. For new buildings it would be recommended to ensure that the metering strategy is reviewed by a qualified engineer, such that potential future reporting requirements are easily addressed.

1.1.4 DOMESTIC HOT WATER

In some climates, Domestic Hot Water (DHW) energy loads may be higher than space heating loads, so proper sizing and design of DHW systems is important. As in other areas, decarbonization is achieved through a combination of conservation measures, and efficient heat-generator selection, considering the carbon impact of various sources.

Conservation starts with accurate and efficient load management. Selecting efficient low-flow fixtures, such as aerator faucets and reduced-flow showerheads, not only minimizes water use, but also the associated energy used. Efforts should be made to avoid oversizing piping, pumps, storage tanks, and/or heat generators. Piping runs should be kept as short as possible, to minimize pumping energy and heat losses in piping. Care should be taken to ensure that any flow branches that do not have a return loop associated (final run outs to fixtures) also be minimized in length to reduce delivery delays to the fixtures, which wastes both water and energy. Piping, pumps, and storage tanks should be well insulated in line with ASHRAE 90.1 and municipality guidelines.

The choice of heat generation will depend on local low-carbon sources. Where electrical generation is from low-carbon sources, Heat Pump Water Heaters (HPWHs) may be the low-carbon choice. HPWHs use a vapor-compression or sorption refrigeration cycle to extract energy from an air, ground, or water source. They may offer many times the energy output per energy input compared to electrical resistance methods or fossil-fuel heaters. They may also offer the opportunity for supplemental air cooling or dehumidification for occupants or other equipment. HPWHs often have upper temperature limitations, although high lift heat pumps are becoming more available. Larger storage may also provide the ability to generate heat when more economical or efficient.

Resistance electric water heaters may be of the storage type or tankless. The storage type uses electric immersion coils to provide the energy input. Tankless electric heaters, which provide inline heating

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activated by flow, may be well suited to point-of-use or booster applications. The large power requirements of on-demand heating can be a limiting factor, so some storage may be advisable to cover peak demand periods and minimize electrical infrastructure requirements.

Gas or oil-fired storage water heaters (direct-fired tanks) should be of the condensing type and well-insulated to minimize heat losses. Tankless water heaters have little storage volume and heat water as it passes through the device. These are a good choice for steady hot water demand, but they can suffer from high on/off cycling energy losses if the loads are small and/or infrequent (*e.g.,* hand washing). Some have a minimum flow requirement, which may not be satisfied by low-flow fixtures, so care should be taken to match the device with user requirements.

Where possible, consider preheating technologies, such as heat recovery, condenser water return, or solar thermal.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE STANDARD 90.1- 2019: ENERGY STANDARD FOR BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS***

1.1.4.1 RE-CIRCULATION

Hot water recirculation is used where piping lengths are long and immediate hot water is desired at the fixture. Recirculation is also required in larger systems to prevent system dead legs[13] and potential microbial growth. However, the added pumping required and the heat losses in return piping present an energy penalty. Therefore, recirculation pumps should be sized only as needed to maintain an adequate temperature and considered be given to scheduling off during periods where the need is not justified. Occupancy sensors can also be used for this purpose. Consultation with the design engineer would be required for any reduction in re-circulation systems flow rates or scheduling off when demand reduces, to ensure other health issues are not created.

1.1.4.2 REDUCE HEATING TEMPERATURES

Supply temperatures should also be kept to the minimum required for each DHW application. Where possible, group fixtures of similar use and temperature needs. Fixtures requiring recirculation should be piped separately from fixtures that do not. Heat traps between recirculation lines and less frequently used fixtures reduce losses in these lines. For higher temperature DHW needs (*e.g.*, commercial dishwashers), consider booster heaters or separate heaters for this use.

Note however, that appropriate measures should be taken to guard against Legionellosis. ASHRAE Standard 188 provides guidance on this. Scheduled anti-legionella measures, combined

[13] Dead legs are sections of domestic water systems where water either does not or rarely flows through.

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with tempering valves, can be used to provide anti-legionella protection while reducing the typical DHW supply temperatures as needed.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE STANDARD 188-2018, LEGIONELLOSIS: RISK MANAGEMENT FOR BUILDING WATER SYSTEMS***

1.1.4.3 HEAT RECOVERY FROM SEWER WASTE

Where it is possible to have domestic water drains in close proximity to the domestic cold supply, consideration should be given to heat exchangers that can allow some of the energy from drain water to be used to preheat incoming cold water. This reduces the energy required for heat generating devices to bring the water to required DHW temperatures. This is particularly useful for larger, constant DHW demands (*e.g.*, showers, commercial washers).

1.1.5 HEAT RECOVERY AND ENERGY STORAGE

Typically, raw efficiency of the system generating heating or cooling energy quickly becomes the focus in a design exercise. However, re-using energy for multiple purposes, and storing energy in advance of expected peaks, can yield substantial reductions in operating cost, energy consumption, and greenhouse gas emissions.

This section focuses on heat recovery associated with space heating, cooling, and domestic hot water production, generally as part of a hydronic or refrigeration system. For more information about heat recovery in air-based systems, please refer to 1.2.2 Exhaust Air Energy Recovery.

1.1.5.1 HEAT RECOVERY CHILLER

One of the most cost-effective methods of saving energy is identifying and capitalizing on coincident loads with the use of a Heat Recovery Chiller (HRC). In colder regions a building's heating load in the winter may be considerably larger than its cooling load, it is common to have year-round cooling requirements for server rooms, transformer rooms, elevator machine rooms, and interior zones with no connection to the outdoors. Conversely, in the summer, when a building is experiencing a net-cooling demand, there are often still hot water needs for plumbing fixtures, sanitization, and HVAC reheat and process equipment. These scenarios, as well as time during shoulder seasons where the heating and cooling loads are more closely matched, represent excellent opportunities to save energy and reduce emissions.

To take advantage of coincident loads, an HRC can be applied. These should be selected at sufficient capacity to address the coincident portion of the heating and cooling loads; which will introduce periods of down time for the HRC and will extend payback periods. For example, a building with 150 tons of peak cooling demand may only require 10 tons of cooling in the winter (e.g.a server room). Such a building may be well suited for a nominal 10-ton water-to-water heat recovery heat pump. This unit could run 24/7, 365 days per week to cool the data center while transferring heating energy to the building's heating water loop.

HRC systems can achieve extremely high COPs because they satisfy both heating and cooling demands with the electrical consumption of a single system. In comparison, a traditional solution might separately employ gas boilers for heating and a chiller for cooling. In many cases (especially with retrofits), the heating energy produced by the heat pump may displace higher emissions sources such as gas-fired boilers.

Application of HRCs must be done carefully, and take into consideration several factors including:

- operating temperatures of all connected water loops
- performance envelope (and limitations) of the proposed HRC
- consistency of coincident heating/cooling loads
- interplay with air-side heat recovery or economizer systems
- discharge of excess heat/coolth in situations where the heating and cooling loads are not matched
- consideration for water-cooled versus air-cooled HRCs, and the implementation of two pipe versus four pipe systems

1.1.5.2 THERMAL ENERGY STORAGE

Thermal Energy Storage (TES) systems involve producing and storing a chilled or heated thermal medium during periods of low demand, and then drawing on the stored energy to satisfy peak demands. Mediums used include, but are not limited to, water, ice, or a phase-change material.

Additionally, TES systems can capitalize on favorable ambient conditions. It is much more efficient to produce chilled water at night, and hot water during the peak heat of the day. If production can be timed to occur when efficiency is greatest, then stored to use later during operational peak times, this can provide healthy financial returns to the client. Furthermore, chilled water night-time production may also coincide with off-peak electricity rates, which further increase financial incentives.

Sized for the facility's 24-hour chilled water demand rather than peak cooling load, TES systems typically operate chillers and pumps during off-peak hours when electricity is cheapest and peaking power plants (typically coal or natural gas depending on region) are inactive. Ice is produced and stored when demand is low, and ice is melted to cool the building when demand increases. While not in widespread use at the time of writing, there are potential significant benefits to using an ice storage system, when conditions make them economically and practically feasible, such as:

- reduced electrical peak demand charges

  - load shifting to low demand night-time operation when lights and HVAC are minimized
  - reduced size of chillers overall (no need to meet instantaneous peak demand)
- temporary backup cooling during chiller downtime, or during power outages if pumps are provided with backup power
- reduced emissions from peaking power plants needed during peak summer cooling loads

Application of TES's are both specialized and nuanced; they are not appropriate for many building types or climates.

1.1.5.3 SOLAR THERMAL TANKS

Related to the solar thermal collection systems discussed in 1.1.2.3 Solar Thermal, solar thermal storage tanks act as the thermal "battery" needed to bridge the difference between solar production and system load at various points throughout the 24-hour cycle. As illustrated in the following figures of typical residential domestic hot water demand and solar incidence profile, the peak *availability* of solar energy rarely coincides with the peak *demand* of a building. Therefore, correctly sizing the storage tanks is crucial to maximizing utilization of the collectors. Note that the definition of "correct" will vary based on project goals, building use, building occupancy, geographic location, budget restrictions, local utility rate structures, and various other factors. Generally, an appropriately-sized system will satisfy the majority of the building's hot water demand during typical conditions but will not be sized for peak loads.

Tanks designed specifically for application within these systems are intended to operate at higher temperatures and with more extreme temperature swings across duty cycles than a comparable domestic hot water storage tank. There are two main reasons for this: first is that in order to maximize the solar energy absorbed and made ready for use within the building, it is advantageous to permit the collectors to keep sending thermal energy to the tanks, even after exceeding the 60°C /140°F typical temperature limit for domestic water or modern space heating systems. This, in turn, aids in increasing the utilization of the solar system while minimizing the size of the tanks used. Second, solar systems without adequate capacity control may experience elevated temperatures during periods of low demand, and moderate to high energy production. This may be particularly apparent during unoccupied seasonal periods (*e.g.*, unoccupied schools over summer) or within a single day (*e.g.*, a hotel experiencing a low occupancy rate for a day).

There are special considerations for solar thermal tanks and plant design, such as freeze protection (typically either through use of glycol or seasonal winterization). Safety considerations should also be made when applying stored thermal energy. Legionella may form if the tanks cannot be brought up to high temperature (65°C/ 130°F) regularly, requiring secondary top-up inputs. When using glycol for cold weather protection, adequate separation

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from the potable water system is necessary, which will generally require a vented, double-walled heat exchanger. Finally, when there is a risk of over production of solar energy, consideration must be given to a relief system for steam and pressure, as well as provisions for excess heat rejection (*e.g.*, dry coolers, radiators, secondary heating loops) or some means to reduce energy production from the solar array (*i.e.*, automatic or manual physical covers).

1.1.6 HEAT GENERATING EQUIPMENT

Generation and consumption of heat energy for buildings is one of the largest categories of greenhouse gas (GHG) emissions in North America. Heating in Canadian residential buildings account for 43.3 metric tons of CO_{2e} in 2018 alone[14]. Therefore, climate change mitigation must include both strategies for heat load reduction, and for reduction in carbon intensities of the heat generation systems installed.

1.1.6.1 ELECTRIFICATION

One of the most effective ways to mitigate emissions of gas heating systems is to switch from gas-fired boilers to electrified equipment. The immediate, total effectiveness of this strategy does depend on the local method of energy production, but even regions with fossil fuel-reliant electricity supplies may see some benefit. Most electric utilities are also trending towards lower emission technologies, as evidenced by the 45% drop in GHG intensity of Canada's electricity generation between 2005 and 2019[15]. It is also worth noting that electrification shifts emissions away from population centers and out to remote power stations, which may have a positive impact on local air quality.

While electrification may be as simple as using electric resistance heaters, including electric boilers, baseboard heaters, and air heating coils, energy costs to operate such systems are high compared both to gas-fired systems and heat pumps. This is due to their higher input energy cost relative to natural gas, and their efficiency, which is limited to a COP of 1.0. Modern air source heat pumps in their various forms can routinely operate at COPs of 2.5 or higher during moderately cold weather, reducing the electricity required to produce the same amount of heat.

1.1.6.2 GAS-FIRED PEAKING

In particularly cold climates (such as the Canadian prairies and American Midwest), it may be prohibitively expensive or outright impractical to rely on air source heat pumps for all a building's heating requirements. While heat pump technology has improved substantially in the last decade, all heat pumps are subject to performance degradation at low temperatures and have a minimum operating temperature.

In these cases, electrified systems (specifically heat pumps) may still be utilized, and large GHG reductions realized, as outdoor air temperatures may be within the range of efficient heat pump operation for many hours per year. For the remaining periods of very cold temperatures and

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[14] Retrieved from https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=res&juris=ca&rn=8&page=0
[15] Retrieved from https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021/towards-net-zero.html

high peak demands, natural gas boilers may be used. The key is to “right size” the heat pump systems to capture the maximum GHG and energy savings benefits for the lowest cost premium.

Where use of fossil fuels for heating is unavoidable, a few strategies can optimize energy output for a given energy cost and GHG emission:

- Use high efficiency condensing boilers.
- Design systems for return water temperatures of 120°F or below, and reset schedules tied to ambient air temperatures to maximize the condensation effect.
- Operate multiple boilers in parallel at low-fire, rather than a single boiler at high-fire.
- Permit modulation and reduce boiler on/off cycling by ensuring controls and pumping are set at variable speed.
- Use direct venting (duct combustion air directly to the boiler) to minimize outside wall openings.
- Concentric venting should also be considered, as this recovers heat from the exhaust by preheating incoming combustion air, thus increasing efficiency.

1.1.6.3 SIMULTANEOUS HEATING AND COOLING

A system design strategy that aligns very well with the broader goal of electrification and emissions reduction is the use of heat pumps for simultaneous heating and cooling. This involves arranging the HVAC system in such a way that, rather than rejecting or drawing heat from ambient outdoor air, the heat pumps are instead used to transfer heat within the building from zones in need of cooling to zones in need of heating. In this way, to the extent that heating and cooling loads occur simultaneously, two thermal demands may be satisfied for the energy cost of only one (with minor additional losses for running fans, pumping, etc…).

The systems most used to achieve this are Variable Refrigerant Flow (VRF) systems, condenser water-driven heat pump units, and 4-pipe heating and chilled water systems — although the same effect can also be partially realized through reduced compressor lift on Water Source Heat Pump (WSHP) systems with careful application.

Most buildings have at least some opportunities to take advantage of simultaneous heating and cooling. Some common examples include:

- heat recovered from year-round cooling of main electrical rooms in residential buildings
- heat recovered from year-round cooling of IT/data rooms in commercial or mixed-use buildings
- heat recovered from commercial space cooling used for domestic hot water production
- heat recovered from internal air conditioning zones

1.1.6.4 SOLAR THERMAL

As noted in the 1.1.6.1 Electrification mitigation strategy, gas-fired boilers and domestic water heaters may remain a requirement for projects located in remote sites, northern regions, or areas with particularly expensive electric utilities. While there is potential benefit in applying solar thermal collectors for many projects, the GHG mitigation for projects with gas-fired heating is particularly valuable. Evacuated tube solar thermal systems have the ability to generate high temperature water (60°C /140°F or above), making it possible during periods of sunny weather to shut down fuel-fired water heaters entirely.

With the goal of reducing GHG emissions as much as possible, sizing and selection of solar thermal systems — and associated tanks, pumping, and controls — should be focused on capturing and storing sufficient energy to address the majority of the typical demand peaks. Careful, site-specific study must be undertaken for each project to avoid over- or under-sizing.

As with all solar-based systems, energy collection is highly dependent on time of day and local cloud cover. The solar thermal portion of the system must be considered as an augment to the primary heating systems, which must typically be sized for the full demand even when solar systems are present.

1.1.6.5 DISTRICT ENERGY READY

District energy (DE) systems consist of a network of interconnected buildings, where heating and cooling is provided to buildings via underground pipes. A building that leverages the energy of a DE system is typically more efficient than a building that has its own heating or cooling equipment. The higher efficiency of a DE system is a product of the energy sharing between buildings. For example, heat that is rejected from one building can be used by another, and some DE systems use “free” heating and cooling such as leveraging geoexchange systems (including lakes and oceans). Systems that can use the heating and cooling energy from a DE system include space heating, space cooling, and domestic hot water. The DE system interacts with a building through an Energy Transfer Station (ETS), which in essence includes heat exchangers, pumps, and other equipment to transfer energy between the building and the DE system.

Some communities and municipalities may have future plans to install a community-wide DE system, which makes it useful for a building to be “DE Ready”. An example of this is the District of North Vancouver (DNV), which has a comprehensive overview for the technical criteria needed for a DE Ready building[16]. As the DNV’s document outlines, the major components of a DE Ready system include:

- space heating system design requirements
- space cooling systems design requirements
- prohibited HVAC systems
- HVAC hydronic system temperature differential
- domestic hot water design guidelines
- energy transfer station room requirements

[16] Full document can be accessed here: https://www.dnv.org/sites/default/files/edocs/ENG108-energy-ready-requirements.pdf

- building mechanical room requirements
- ETS electrical requirements

Not all buildings will benefit or are required to be DE Ready, but this can be an important consideration for engineers and owners when designing mechanical systems and allocating space in mechanical rooms.

1.1.7 HYDRONIC HEATING

Well-designed hydronic heating systems offer occupant comfort, flexibility (with respect to application), and energy efficiency. Application of heat via radiant methods result in less room air stratification, and draft minimization, which leads to increased occupant comfort at lower average room temperatures. Hydronic heating also reduces ambient noise and dust transport, further improving comfort.

The key to energy-efficient hydronic design is to ensure that the supply and return temperatures are always minimized. The higher the average temperature, the higher losses will be in unoccupied spaces (*e.g.*, wall cavities, mechanical rooms, etc…) Lower temperatures also generally lead to higher efficiency in heat-generating appliances.

While there are a wide variety of hydronic emitters, the designer should select those that can achieve the required output at lower temperatures. Designing for higher ΔT (supply temperature - return temperature) also allows lower flows, requiring less pumping energy. Attempts should be made to balance each space without relying on flow controls. While zone valves and mixing valves can be used to help achieve this, they should ideally only be used to "fine-tune" the application of heat in each space. In an efficient system, using outdoor reset, the heat input to the space through the emitters matches the heat loss of the space without needing to adjust flows.

A common temperature range would be 42°C supply, with a 35°C return. With a ΔT of 7°C, this is compatible with typical heat pump lifts, and has enough differential to efficiently drive heat transfer. In a situation where gas-fired boilers are used, these temperatures also take full advantage of a condensing system.

1.1.7.1 DE-COUPLING HYDRONIC HEATING AND DHW

In cases where heat loads are substantially larger than domestic hot water (DHW) loads – especially where DHW may only result in significant cycling – de-coupling hydronic heating and DHW generation should be considered. This should also be a consideration when hydronic supply temperatures are much lower than needed for DHW production for much of the year. Having to produce a high temperature for DHW, and then mixing down for the hydronic system, reduces efficiency. De-coupling also makes sense where one or the other requires a higher carbon heat generator.

In this scenario, another option could be to use a water-to-water heat pump to boost the space heating temperature to that required for DHW tank sterilization. The typical loop for space heating could have a 42^{0}C supply which connects into a water-to-water heat pump. The output

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side of the heat pump could produce water at 65^{0}C as required during sterilization, and lower during normal operation. This system would minimize the energy input to the larger heating system, but still provide required heat for the DHW system.

1.1.8 ENERGY AUDITS

Energy audits are conducted on buildings to determine a building's overall energy performance. The factors that are assessed in an energy audit include those affecting energy efficiency. Energy efficiency is defined as the amount of energy output ("energy out") divided by the amount of energy supplied to that piece of equipment ("energy in"):

$$\frac{energy\ output}{energy\ input} = energy\ efficiency$$

In other words, improving the energy efficiency of a building, or even a specific system, will reduce the amount of energy required to perform the same task. Energy audits provide designers with a means to assess the performance of a building and provide recommendations to either improve the energy efficiency, known as energy efficiency measures (EEMs), or to reduce the overall energy consumption, known as energy conservation measures (ECMs). The energy performance of a building can be improved by applying either EEMs or ECMs which further reduces GHG emissions.

1.1.8.1 ASHRAE ENERGY AUDITS

The level of detail for an energy audit can vary; ASHRAE has defined multiple levels for ASHRAE audits, and Better Buildings BC have provided an outline of the differences between the three ASHRAE audit levels:

ASHRAE LEVEL AUDITS DESCRIPTIONS[17]

ASHRAE Audit Level	Description
Level 1	The Level 1 audit is a simple audit that involves a basic walk-through assessment, review of utility bills and other applicable operating data, and interviews with operations staff. This basic evaluation is designed to identify glaring energy problems. With the detail of this audit, low-cost upgrades are proposed, energy efficiency projects can be prioritized, and it is determined if a more detailed audit is necessary.
Level 2	The Level 2 audit builds on the level 1 analysis with more detailed energy calculations and added financial analysis of proposed energy measures. This level of audit uses utility data over a longer period of time so that the auditor can better understand the building's energy use. The financial analysis at this level of audit is used to build the business case for implementing energy measures.

[17] Retrieved from https://betterbuildingsbc.ca/faqs/what-are-ashrae-energy-audits/

Level 3	The Level 3 audit builds on the Level 2 audit by doing a more in-depth analysis of energy use in the building. This can include sub-metering of major energy systems. The added level of detail in the analysis of the existing building and proposed energy measures means that cost and savings have an increased level of accuracy. This level of detail can provide higher quality, more accurate data, which is valuable major energy projects that can be capital intensive.

The cost of an energy audit increases with the level of energy audit that is required. A qualified professional would be able to assess which ASHRAE level audit is recommended for a specific building.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE'S PROCEDURES FOR COMMERCIAL BUILDING ENERGY AUDITS***

1.1.8.2 ENERGY CONSERVATION MEASURES AND ENERGY EFFICIENCY MEASURES

As mentioned above, the outcomes of an energy audit can include a list of recommended ECMs and EEMs. Below is a list of possible ECMs and EEMs[18] that may recommended through an energy audit (it should be noted that this is not a comprehensive list of ECMs and EEMs for a building and others could be identified during an energy audit):

- Utilize variable speed drives (VSDs) or variable frequency drives (VFDs) on motorized equipment (*e.g.*, pumps and fans) to improve the level of control.
- Utilize building management systems (BMSs) to better monitor and more efficiently control building systems.
- Utilize lighting controls, which could include occupancy sensors and times to reduce the energy consumption of lights.
- Install light emitting diodes (LEDs)as they use less power than conventional lights.
- Conduct boiler optimization/upgrades, which could include a complete boiler replacement to a highly efficient boiler such as a condensing boiler, or electric source heating such as heat pumps. Optimization measures could also assist in reducing annual energy usage.
- Chiller optimization/ upgrades could include a replacement of a chiller to a more efficient one. Optimization measures could also assist in reducing annual energy usage of the chiller.
- Building envelope upgrades may be applicable due to wear and tear or even poor construction, can result in substantial energy loss. Building envelope upgrades may include building sealing.
- Connection to district energy utilities (DEUs) may be recommended, however this is dependent on availability in a given municipality.

[18] The terms ECM and EEM are typically used interchangeably, due to a reasonable amount of overlap in the recommended measures

1.2 VENTILATION

Ventilation is the process of introducing air from outside of a space, or removing air from within a space, to control air contaminants, humidity, and temperature[19]. Ventilation is one of the most effective ways to increase indoor air quality and reduce the health risks caused by volatile organic compounds (VOCs), particulate matter, and other contaminated generated in indoor spaces.

Although essential to maintain healthy indoor air quality, ventilation loads make up a large portion of a building's total energy consumption. Strategies below may significantly reduce ventilation loads:

- Design ventilation rates per ASHRAE 62.1 (or 62.2 for residential buildings): Ventilation for Acceptable Indoor Air Quality. Avoid over-designing ventilation rates.
- Use a combination of filtration and ventilation to achieve the desired indoor air quality.
- When possible, use exhaust air energy recovery (EAER) systems with sensible effectiveness of 75% or more.
- For spaces with exhaust air classified as class 4 by ASHRAE Standard 62.1, where no cross contamination is allowed between exhaust and return air, consider using energy recovery systems with separated supply and exhaust air streams (*e.g.*, run-around loops)

Determining an optimal procedure is essential to achieving acceptable indoor air quality (IAQ) while minimizing energy use. ASHRAE 42P Guidelines identify potential areas to consider improving IAQ efficiently[20]:

- Ventilation Strategy
    - efficiency of heating and cooling components serving the ventilation system
    - cost of ventilation system
    - physical size of ventilation system
    - non-mandatory energy recovery requirements (in some cases, energy recovery may be reduced by introducing air cleaning systems)
- Air Cleaning Strategy (if needed)
    - efficiency of air cleaning system (as determined by third party tests based on ASHRAE Standard 145.2, ASHRAE Standard 52.2, ISO, or others)
    - airflow of the air cleaning system
    - cost of air cleaning system
    - physical size of air cleaning system
- Source Control
    - limit the introduction of contaminants during occupancy (*e.g.*, cleaning and pest management procedures)
    - assess outdoor concentrations of design compounds (as determined by investigation of regional and local outdoor air quality in accordance ASHRAE Standard 62.1)
        - *Note: using dilution (through ventilation) to maintain indoor air quality can increase contaminant concentrations within the indoor space if there are high concentrations of contaminants in the outdoor air. This is*

[19] ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality
[20] ASHRAE Guideline 42P: Enhanced Indoor Air Quality In Commercial And Institutional Buildings

particularly true for particulate matter (PM) and inorganics including, but not limited to: ozone, carbon monoxide, and nitrogen dioxide.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE STANDARD 62.1: VENTILATION FOR ACCEPTABLE INDOOR AIR QUALITY***
- ***ASHRAE STANDARD 62.2: VENTILATION FOR ACCEPTABLE INDOOR AIR QUALITY IN RESIDENTIAL BUILDINGS***
- ***ASHRAE 52.2 METHOD OF TESTING GENERAL VENTILATION AIR-CLEANING DEVICES FOR REMOVAL EFFICIENCY BY PARTICLE SIZE***
- ***ASHRAE 145.2 LABORATORY TEST METHOD FOR ASSESSING THE PERFORMANCE OF GAS-PHASE AIR-CLEANING SYSTEMS: AIR-CLEANING DEVICES***
- ***ASHRAE GUIDELINE 42P: ENHANCED INDOOR AIR QUALITY IN COMMERCIAL AND INSTITUTIONAL BUILDINGS***

1.2.1 CONDITIONED AIR

Ventilation can be introduced to the buildings through a central air handling unit (AHU), or through a dedicated outdoor air system (DOAS). A DOAS can potentially better control humidity, reduce energy costs, and be installed more efficiently[21]. This would generally be the preferred method of ventilation delivery, but building specifics need to be considered in any design.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE DESIGN GUIDE FOR DEDICATED OUTDOOR AIR SYSTEMS***

1.2.1.1 CONTROLS

Control strategies listed below can be used to reduce ventilation loads:

- Only use demand-controlled ventilation to introduce ventilation air when required, and avoid ventilating empty spaces.
- CO_2 or Passive Infra-Red (PIR) sensors can be used to initiate ventilation to a space for demand-controlled ventilation.
- Use enthalpy sensors to take advantage of mild outdoor air conditions for free cooling.
- Maintain positive indoor pressure to eliminate infiltration of unconditioned outdoor into the building.
- Minimize or shut off exhaust systems when not required and adjust outside air make up rates accordingly. This adjustment can be done through commissioning and air measurement, or by controlling to measured space pressures.

[21] ASHRAE Design Guide for Dedicated Outdoor Air Systems

1.2.1.2 FREE COOLING AND MIXED MODE VENTILATION

Free cooling, or natural ventilation, is a method to leverage outdoor air to heat or cool a building instead of using mechanical equipment. An economizer is used to properly utilize these conditions as needed. Including an economizer section within a ventilation system (*e.g.*, DOAS or ERV systems), will allow a building to take advantage of the mild shoulder season weather to reduce ventilation and heating/cooling loads. This is especially important when high efficiency energy recovery systems are used.

Mixed-mode ventilation is a method of using both natural ventilation and a mechanical system to provide optimal cooling and improve efficiency. Another advantage of this system is that increased outside air rates can reduce space CO_2 and particulate levels (assuming the outside air is sufficiently clean). This operation could also be implemented at night when buildings are unoccupied to "flush" buildings so they are ready for the next day.

1.2.1.3 FAN PERFORMANCE

ASHRAE 90.1 - 2019 introduced the fan energy index (FEI) – as defined by AMCA 208 – as a metric of the efficiency of fans and fan arrays. The minimum FEI requirement according to ASHRAE Standard 90.1 is 1.0. The lower a FEI rating of a fan, the less efficient it is.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE STANDARD 90.1- 2019: ENERGY STANDARD FOR BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS***

1.2.1.4 VARIABLE SPEED FAN SYSTEMS

It is suggested to use fan systems with VSDs, or include VFDs for fans, to modulate the ventilation rates as required by occupancy. The addition of VSDs or VFDs will allow more precise control of the fan, which can provide operators with the ability to turn down fans, resulting in reduced energy use.

A modern alternative to the VSD is an electronically commutated (EC) controlled fan, which provides all the same modulation control that a VSD gives, but is directly built into the motor. EC motors are not suitable as a retrofit strategy, but are becoming commonplace in new fans and air handling systems.

1.2.2 EXHAUST AIR ENERGY RECOVERY

Exhaust air energy recovery equipment can be used to significantly reduce ventilation loads in residential and commercial buildings. Several different energy recovery technologies are available in the market for different building applications. The most common available technologies are: fixed-plate energy exchanger (*e.g.*, energy recovery ventilators), rotary energy exchangers (*e.g.*, energy wheels), heat pipe heat exchangers, and fixed bed regenerators.[22]

When selecting an energy recovery system, it is important to consider the following:

Energy recovery effectiveness: sensible, latent, and total effectiveness indicate the performance of an energy recovery system. Most commercial energy recovery equipment is certified by Air-Conditioning, Heating and Refrigeration Institute (AHRI). A minimum sensible recovery effectiveness of 75% is recommended when selecting systems.[23] Most residential energy recovery equipment is certified by Home Ventilation Institute (HVI). A minimum sensible recovery efficiency (SRE) of 75% at 0°C is recommended for lower mainland. For the interior region of BC, a minimum SRE of 70% at -25°C is recommended.[24]

Exhaust air transfer ratio (EATR): this ratio indicates the percentage of exhaust air that leaks into the ventilation/outdoor air through the energy recovery equipment. This metric is especially important for class 2, 3, and 4 air[25]. ASHRAE Standard 62.1 limits the EATR of energy recovery equipment for different air classes as shown below:

- Class 1: air with low contamination concentration (*e.g.*, office building applications) has no EATR limitation.
- Class 2: air with moderate contamination concentration (*e.g.*, washroom exhaust) has an EATR limitation of 10%.
- Class 3: air with significant contamination concentration (*e.g.*, residential kitchen hood) has an EATR limitation of 5%.
- Class 4: air with highly objectionable fumes or gases, or air containing partially dangerous particles (*e.g*., lab fume hood), cannot be recirculated.

In addition, energy recovery equipment pressure drop (see the fan power section for details) and space available for heat recovery equipment, including the ability to divert ductwork/pipework from intended routes to usable recovery location.

The table below summarizes different energy recovery technologies with recommended applications for each:

ENERGY RECOVERY TECHNOLOGIES AND APPLICATIONS

[22] 2020 ASHRAE Handbook: HVAC Systems and Equipment
[23] As defined by AHRI Standard 1060: Standard for Performance Rating of Air-to-Air Exchangers
[24] As defined by CAN/CSA C439-18: Laboratory methods of test for rating the performance of heat/energy-recovery ventilators.
[25] As defined by ASHRAE Standard 62.1

Metric \ Technology	Enthalpy Wheels	Plate Exchangers	Heat Pipe	Run Around Loop
Sensible Effectiveness	55%-80%	45%-75%	30%-40%	30%-40%
EATR	1%-20%	0%-5%	0%-1%	0% (Separate Channels)
Application	High flow rate compact size	Low cross contamination -Low maintenance	Low cross contamination	Class 4 air retrofit

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- *2020 ASHRAE HANDBOOK: HVAC SYSTEMS AND EQUIPMENT*
- *ASHRAE STANDARD 90.1- 2019: ENERGY STANDARD FOR BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS*
- *ASHRAE STANDARD 62.1-2019: VENTILATION FOR ACCEPTABLE INDOOR AIR QUALITY*

1.3 CONTROLS

The controls of a building and HVAC system are essential to identifying opportunities for reducing energy use and/or improving energy efficiency of a building. A robust control and monitoring system plays an integral role in optimizing HVAC systems. Ensuring these controls provide resiliency within a building management system provides the ability to keep equipment efficiently operating. Controls are an ever-evolving piece of equipment and are often replaced multiple times in the normal lifespan of the mechanical equipment, each time improving in efficiency and functionality. Since this guide has been written, more advancements have and will continue to take place. Each type of control methodology should be reviewed and studied on an application-by-application basis.

1.3.1 CONTROL OPTIMIZATION

The performance of a building mechanical system is directly connected to the quality of controls. A lack of control or insufficient control will result in using more energy than is required or wasting energy. Optimal control of HVAC systems can achieve energy savings of up to 45%[26]. Control loops are also the foundation of an HVAC control system, as they serve to keep building mechanical systems producing or achieving a set desired result (*e.g.*, ambient temperature in a room). Therefore, the optimization of control systems is an essential component in reducing emissions.

1.3.1.1 RESPONSIVENESS, PREDICTIVENESS AND STABILITY

Within a control system are components that have a set level of responsiveness – in other words, they dictate how quickly the system can react to any given input. While improving

[26] Retrieved from https://www.sciencedirect.com/science/article/pii/S1876610215019852

responsiveness might result in diminishing returns for some systems, it is an important consideration in the design process. Typically, the faster a piece of equipment is, the more efficient it is. However, control systems are complicated and can sometimes rely on multiple systems simultaneously, so simply increasing the responsiveness of one piece of equipment may not result in an overall increase in performance.

Aside from the level of responsiveness, a control system can be designed to predict future tasks. With predictive controls, a building mechanical system spends less time working towards a desired setpoint *(e.g*., the temperature in a meeting room if the number of occupants has suddenly increased) and can instead ramp up mechanical systems in preparation for an event. Predictive controls are a fairly new advancement, relative to other components and technologies within an HVAC system, but they have, thus far, proven to increase the performance of a building system if properly implemented.

1.3.1.2 CONTROL LOOPS INTERDEPENDENCY

During commissioning of a control system, engineers and contractors will tune the control loops to ensure the system is operating as designed. When multiple loops are dependent on each other, this relationship can increase the time required to properly commission the system. Limiting the number of loops, including the number of zones, can help speed up the process of commissioning a system.

1.3.2 DETECTION, MONITORING, AND DIAGNOSTICS

A building management system (BMS) is a central control system for a building that manages and monitors equipment in the building. The equipment connected to a BMS can range from pumps and fans, to air handling units, chillers, and boilers. The BMS can also review and coordinate data from lighting systems, lifts, and domestic water systems. If the system uses digital controls to operate, then the BMS will be able to, at the very least, monitor, and directly control equipment. A building automation system (BAS) is sometimes used interchangeably as a description of a BMS, but is generally understood as being a system that is more advanced than a traditional BMS, with control and operation over all systems, not just the mechanical ones.

One major benefit of a BMS is that it provides building operators with a central location to review, visualize, and run diagnostics on equipment within a building. Since the BMS monitors energy consumption, a building operator can then identify opportunities to improve the energy performance of the building. If it is web enabled, this monitoring and review can occur remotely, saving the client money and time. However, an important component of a BMS is operator training. It is essential for a building operator to understand how to effectively use a BMS to be able to identify opportunities for building performance improvements, and therefore, reduce GHG emissions of the system.

1.3.2.1 PLUGGED FILTERS

Filters are a key component of an AHU, as they clean either outside or recirculated air, before supplying the air to the building. Over time, AHU filters can become clogged due to particulate

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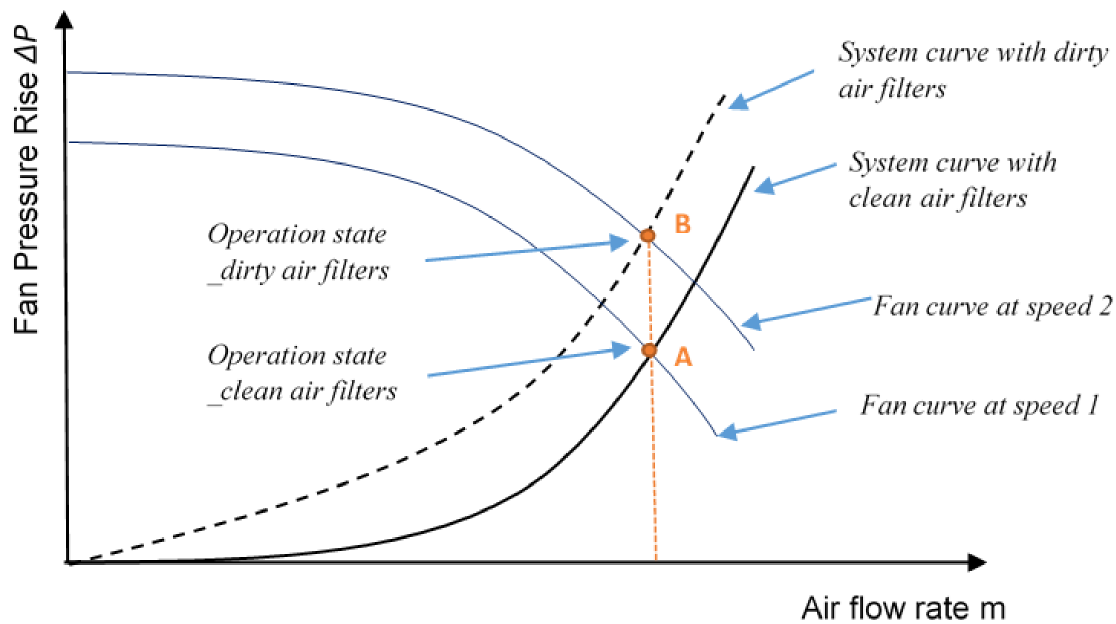
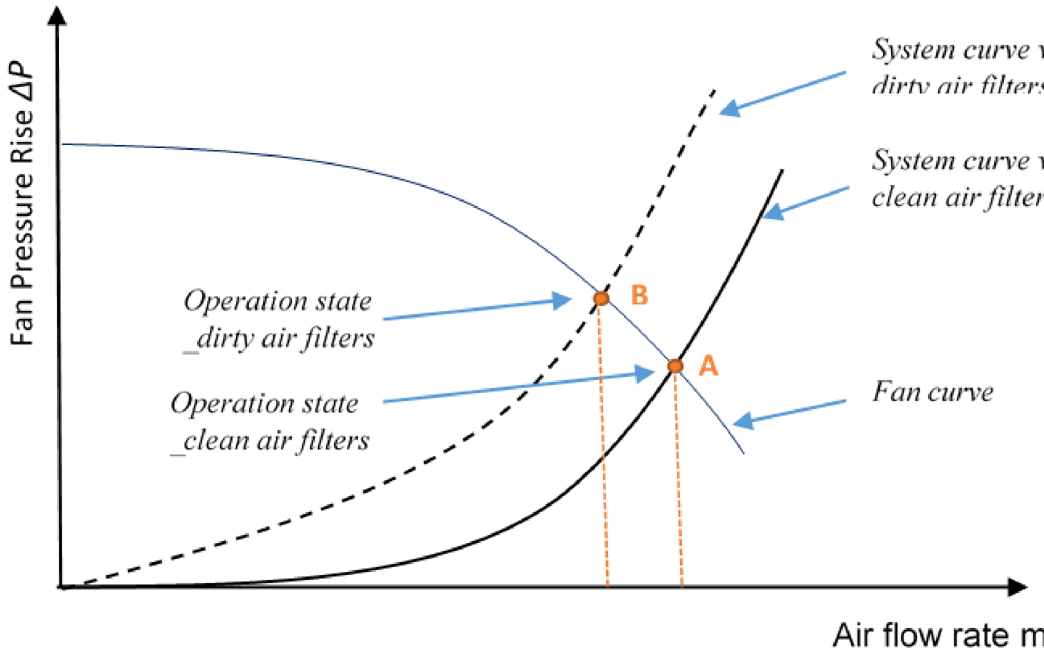
build-up in the filters. At significant levels, particulate build up can lead to a pressure drop across the filter, which results in the system's fans needing to speed up in order to maintain a consistent rate of air flow. A fan curve is provided below to show the impact of a dirty or clogged filter on the speed of a variable speed fan.



EFFECT OF DIRTY FILTER (VARIABLE SPEED FAN)[27]

An increase in fan speed will result in an increase of energy consumption. This also applies to pumping systems with filters because build-up in the filters will result in increased pressure in the system, and therefore increased energy use by the pump, as the pump speeds up to maintain the same rate of flow. In systems that do not have variable speed fans or pumps *(i.e.,* single speed fans and pumps), the flow rate provided by the system will decrease with an increase of pressure build up across the filters, as seen below.

[27] Retrieved from https://bigladdersoftware.com/epx/docs/8-9/engineering-reference/operational-faults.html



EFFECT OF DIRTY FILTER (CONSTANT SPEED FAN)[28]

A differential pressure sensor is used to measure the pressure across filters, which can identify when filters become plugged. In addition, if the pumps or fans are connected to the building management system (BMS), the speed of the motors can be monitored more accurately.

It is recommended to have differential pressure switches fitted across filters, with their outputs going to the BMS. Once the switch is triggered (when the differential pressure increases beyond a preset maximum) the BMS will report a dirty filter, which can then be changed or cleaned to improve system efficiency.

1.3.3 OCCUPANT AND OPERATOR TRAINING

A building that has an extremely comprehensive control monitoring system, but operators who do not know how to properly use them, is comparable to a building that does not have any control systems. It is imperative that building operators and occupants understand building performance control systems within a building.

While monitoring of a building can identify opportunities to improve energy efficiency or reduce energy consumption, training of staff and building occupants can improve decarbonization measures. When under control of the contractor for a building tuning period, buildings are likely to be operated as intended, meeting design energy targets. Once the building is handed-off to the owner however, energy has been known to sometimes significantly increase, especially where buildings are designed to the

[28] Retrieved from https://bigladdersoftware.com/epx/docs/8-9/engineering-reference/operational-faults.html

highest sustainability and performance levels and inadequate training is provided[29]. This energy increase can be minimized through adequate training and instruction for building operators.

A comprehensive operation and maintenance guide for the control system, alongside sufficient operator training, can maintain optimal performance of a building. As for building occupants, useful training can include educating occupants on how to reduce energy usage by refraining from opening windows, changing manual thermostats, and using high energy plug loads.

A strategy to improve building energy usage is offering visual displays of a building's energy consumption that occupants can see in real time. Competitions can be created between floors or areas of buildings, to encourage a mindful reduction in energy usage.

1.4 OTHER/ GENERAL

This section discusses strategies that do not specifically fall under heating/cooling, ventilation or controls, but are important and applicable mitigation strategies.

1.4.1 LOW CARBON ENERGY PROGRAMS

Low energy programs provide performance benchmarks, targets required to achieve the minimum requirements set out by that program. These programs can range in complexity and vary in the areas of a building that they address. For example, common programs in North America include Leadership in Energy and Environmental Design (LEED) certification and Passive House Building Certification, where each program provides performance requirements for specific areas of a building.

Some programs offer certifications to designers, such as ASHRAE's High-Performance Building Design Professional (HBDP) title that demonstrates a designer's ability to improve the energy efficiency of buildings. Certifications also provide designers with knowledge and tools to improve the sustainability of building projects.

Federal and provincial financial incentives may also be available for specific energy improvements. Energy efficiency incentives are typically specific to a geographic location, so it is advised to speak with local energy advisors on available incentives.

[29] Retrieved from https://www.tradelineinc.com/reports/2016-11/bridging-gap-between-designing-and-operating-high-performance-buildings

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2.0 ADAPTATION

The United Nations Framework Convention on Climate Change (UNFCC) describes adaptation as

> *"human-driven adjustments in ecological, social or economic systems or policy processes, in response to actual or expected climate stimuli and their effects or impacts".*[30]

Regarding buildings and their HVAC systems, this section of the guide focuses on measures that address actual, immediate climate stimuli such as the heat wave Canada experienced in July 2021, or the arctic blast in February 2021[31]. In contrast to anticipated, long-term changes, which are covered under 3.0 Resilience, this section addresses the expansion or modification of already existing HVAC systems, as well as changes to the operation of a building.

2.1 HEATING AND COOLING

This section offers suggestions for adjusting to increased outdoor air temperatures through the addition of thermal storage capacities, the installation of additional direct expansion (DX) systems (*e.g.*, split systems and heat pumps), the use of water or airside economizing, and the use of supplementary evaporative cooling to support air-cooled equipment. Furthermore, this section highlights solutions for adapting building systems in the situation of potential water scarcity.

2.1.1 INCREASED OUTDOOR AIR TEMPERATURE

With the threat of global warming, outdoor air temperatures have been increasing and are projected to continue to do so[32]. This section will discuss strategies to lower energy consumption of systems related to building cooling systems.

2.1.1.1 THERMAL STORAGE

Thermal storage is essentially a battery for a building's heating and cooling system. It uses a cooling system and an energy storage tank to shift all, or portions of, a building's cooling needs to off-peak, night-time hours. During these hours, chilled water or ice is made and stored inside energy storage tanks to then be used to cool the building during the day. This can be highly advantageous in locations where electricity usage is less expensive at night.

General guidelines for thermal storage are as follows:

THERMAL STORAGE SIZING GUIDELINES

Item	Sizing	Comments/ Notes
Chiller size	Size the chiller for 66% of the design day peak load.	Note: this depends on the building's cooling load profile. Chillers can be downsized aggressively

[30] Retrieved from https://www4.unfccc.int/sites/NAPC/Pages/glossary.aspx
[31] Retrieved from https://www.canada.ca/en/environment-climate-change/services/top-ten-weather-stories/2021.html
[32] Retrieved from https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

		depending on the type of building and its operating schedule.
Number of tanks	Size the tanks between 2 and 2.5 tanks for every 100 tons of design day peak load.	Example: 12-ton design day building load would require three thanks [(120 tons/100) x 2.5]. This is a rule of thumb and actual number of tanks will vary based on system ΔT and leaving temperatures required from the ice tanks.
Storage capacity charge time and chiller ice-making de-rate	Typical ice making duration – is 7 to 10 hours. Average air-cooled chiller ice making capacity is about 65% of nominal.	Example: an 80 ton nominal chiller will make about 52 tons (80 x 0.65) of ice per hour.
System ΔT and average ice-making temperatures	Size the air-handling units for 14° - 16°F ΔT. The higher the flowrate used during charge mode will results in about a 6°F ΔT, and average ice making supply/return temperatures of 23°/30°F and the end of ice making cycle supply/return temperatures pf 20°/26°F.	The actual supply and return temperatures are also a function of the chiller size versus the number and model of tanks(s). The chiller must be stable at the end of charge temperatures with sufficient freeze protection.
Storage footprint	Partial storage typically requires 0.25 - 1% of the conditioned space for a footprint.	
Plate and frame heat exchanger	Heat exchangers are used to separate the glycol loop from the water loop when the air handlers in an existing building are designed for water and are not replaced, when the building is large, or when the central plant is feeding a campus, making the use of anti-freeze solution throughout the system cost prohibitive.	

2.1.1.2 ADDITION OF COOLING EQUIPMENT

As the outdoor air temperatures increase, more heat is being transferred through external walls and roofs of buildings. This in turn increases the cooling load of the building and may result in needing additional cooling equipment. Split systems, air-source heat pumps, and chilled beams are a cost-effective and sustainable way to increase a building's cooling capacity. Ability to easily install these systems is dependent on available building infrastructure, plant space, and accessible pipe routing paths.

Some advantages of split systems include[33]:

[33] Retrieved from https://climateexperts.ca/blog/advantages-split-system-air-conditioner-2/

- Unlike other systems, a split system does not require any ductwork.
- Simple installation process, only requiring an opening for the connection between the indoor and outdoor unit (typically three inches diameter or less), electricity, and a suitable location to mount the unit.
- Split systems experience no losses through ductwork.
- In some cases, ductless air conditioners can exceed double the efficiency of a standard air conditioner, achieving above 30 Seasonal Energy Efficiency Ratio (SEER).
- Indoor ductless units can operate at as low as 19 decibels, which is significantly quieter than a window unit.

Advantages of air-source heat pumps (ASHP) are:

- ASHPs can be used for both heating and cooling, and can therefore, lead to cost savings.
- ASHPs are highly efficient and can dehumidify better than standard air conditioning units, which results in reduced energy consumption and more cooling comfort during the summer.

Advantages of chilled beams:

- Chilled beams have no moving mechanical parts or fans and require no electrical power.
- Chilled beams require no installation beyond hanging the unit and connecting it to the chilled water system.

Disadvantage of chilled beams:

- They require a secondary chilled water loop at a different temperature than the normal chilled water.
- Consideration also needs to be given to condensation but should not be an issue when a DOA system is installed.

2.1.1.3 AIRSIDE AND WATERSIDE ECONOMIZING

Airside and waterside economizing, also referred to as “free cooling”, leverage outdoor air conditions to reduce the cooling load on a system. Airside economizing brings outdoor air directly into the space when temperature and humidity are within a desirable range. Waterside economizing uses cold outdoor air to cool water used in cooling equipment, typically used with a cooling tower and water-cooled chiller. Retrofitting these systems is dependent on available space within plantrooms and ceilings, but should be considered when feasible.

2.1.1.4 EVAPORATIVE COOLING AIDS FOR AIR-COOLED AIR CONDITIONING UNITS

Air-cooled refrigeration systems reject sensible heat to the surrounding air often with a design outside air temperature of 35°C (95°F). However, with significantly higher outside air temperatures, the system’s ability to reject the required amount is diminished. This results in reduced cooling capacity and increased system wear. Adding adiabatic cooling can support the

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heat rejection through the evaporation of a liquid (normally water) which removes additional latent heat[34] from the surface to which the liquid is applied.

A fine water mist can be applied through sprinkler or garden hoses directed towards the condenser to cool down the air entering the cooling coil. Alternatively, evaporative cooling pads can be installed on the condenser. However, the following should be considered:

- Adding sprinklers should only be a temporary installation if permanent cooling pads are not installed as exposure to water can lead to premature wear on the condenser coils, fans, and housing, and is therefore not recommended for long periods of time.
- Sprinklers should be positioned in a safe distance from all electrical and controls equipment components and preferably not be positioned directly onto the equipment.
- Depending on the water quality and composition, evaporating ("flashing") water on the condenser coil can lead to built-up sediment on the coil reducing permanently its heat transfer capabilities. This again supports the use of pads, instead of a direct spray method.

Permanently installed evaporative pads and also improve performance of systems exposed to sand and dust storms. Evaporative pads would also help air-cooled equipment with reduced capacity and reliability because of recirculating air, in the case that recommended clearances were not considered during installation.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE HANDBOOK FOR HVAC SYSTEMS AND EQUIPMENT***

2.1.2 POTENTIAL WATER SCARCITY

In 2019, the council of Canadian Academies (CCA) named droughts and water scarcity as climate-related risks for Canada[35]. Unlike agriculture and forestry, buildings are not directly impacted by droughts. However, building owners and operators face rising water, wastewater, and water treatment costs in addition to increased pressure to implement water-saving strategies.

2.1.2.1 ZERO-WATER OR WATER EFFICIENT HEAT REJECTION

Although they are not as impacted by high temperatures, HVAC systems using a water-cooled heat rejection (particularly open loop systems) face significant potential water losses through evaporation during periods of high temperatures. There are different ways for how an existing open loop cooling tower system can be modified to reduce the water consumption, such as changing to a closed loop fluid cooler, adding a heat recovery chiller or air-source heat-pump, rejecting heat into ground loops, or improving cooling tower filtration practices. However, the feasibility of these projects greatly depends on the existing building system in place. Even

[34] ASHRAE Handbook for HVAC Systems and Applications
[35] Retrieved from https://cca-reports.ca/wp-content/uploads/2019/07/Report-Canada-top-climate-change-risks.pdf

though geothermal systems can be highly efficient (see 1.1.2.2 Geoexchange) establishing a geothermal field for an existing building can be difficult to do.

A popular retrofit for existing buildings is the change from an open loop cooling tower to an adiabatic fluid cooler since the major components of the hydronic loop can be re-used. However, when designing a retrofit, it is important to note that although adiabatic coolers have made significant progress in the last years, their cooling process is less efficient than an open tower. Hence, an adiabatic cooler with a larger footprint might be needed. Furthermore, although water consumption decreases significantly with an adiabatic fluid cooler, the system might require more fan energy. High-efficiency fans and control sequences can help minimize the power consumption. In this situation the importance of water conservation versus energy conservation would need to be considered.

Another popular building retrofit is the addition of a heat-recovery chiller which can lower the required amount of heat that needs to be rejected through an open-loop cooling tower. As mentioned in 1.1.5.1 Heat Recovery Chiller, heat recovery chillers reject heat from their cooling process into the building's hot water loop (heating or domestic hot water) which can help heat rejection during high temperatures and can supplement the heating equipment during the cold periods if year-round cooling for certain spaces if required.

A third popular way to reduce water consumption in an open loop cooling tower system is to increase the "cycles of concentration". Existing cooling towers could be operating at four cycles of concentration, however this should be targeted to increase to six as a minimum, resulting in a reduction of water consumption of up to 20%, and waste discharge by up to roughly 50%. Improving the cycles of concentration may require treatment and filtration to the makeup water, as well as changing the chemical treatment and filtration process for the open loop system.

2.1.2.2 WATER LEAK MONITORING SYSTEMS

Traditional water leak monitoring systems are often installed in areas that require permanent cooling and are easily damaged through the presence of water *(e.g.*, data centers and electrical vaults). However, these sensors are less suitable for tracking excessive water consumption during a heat wave, or detecting a leak in the piping system if the sensor is not directly exposed to water.

Incorporating water meters into the building automation system would provide building operators with a means to track and measure water consumption. It would be recommended to not only install a water meter on the supply line to measure the overall consumption of the building, but also to add a meter on the supply line of the cooling tower to quantify the water consumption used by the air conditioning system.

Furthermore, water leaks can be detected by monitoring makeup water for the hydronic loop, whether it be through a glycol tank or city water usage. Increased amounts of makeup water, particularly if it cannot be explained through increased evaporation on a cooling tower, are distinct signs that the loop is losing water. Another way to identify water leaks is at night when all systems are shut down – if the water meter is still increasing then there is likely to be a leak. However, this method does not indicate where the leak is located. The more sub-water meters throughout the building, the easier it will be to find a leak. For example, if there is one water meter per floor or office, then the leak could at least be narrowed down to a more specific location, after which manual tracing and detection can occur.

2.1.2.3 RAINWATER AND GREY WATER HARVESTING

Another method to reduce reliance on scheme water is to harvest rainwater when available, or to treat collected grey water for re-use. There are considerable costs associated with installing large enough tanks to make the process viable, and grey water treatment also incurs chemical and electrical costs. In most capital cities, due to the low cost of water, these schemes do not provide financial return, but could be considered where water is scarcer.

2.2 VENTILATION

The following subsection highlights modifications of a building's ventilation for adaptation to various outdoor air conditions, such as increased forest fire activities leading to a high smoke particulate load.

2.2.1 INCREASED FOREST FIRE ACTIVITY

Buildings have experienced irritating, harmful concentrations of indoor smoke particulate during episodes of high outdoor concentrations of wildfire smoke. Entire communities have been evacuated to avoid the negative health effects of high smoke concentrations.

For several years health authorities have recognized that air conditioned commercial and institutional buildings can often be places of refuge from wildfire smoke. However, when smoke enters a healthcare facility, this often triggers an evacuation, and has resulted in expensive remediation work to return the facility to normal operations. Adequate planning and preparation can ensure that health care facilities remain places of refuge in the event of major fires.

Buildings should have a wildfire emergency response plan to implement, should the need arise. This may involve installing additional filtration on the outside air systems, or at times completely shutting down the outside air systems. Shutting down the outside air systems is a possibility only if the internal CO_2 concentrations are monitored to ensure they do not exceed safe levels; it is generally accepted that a CO_2 level of 1000 PPM is a safe upper level target for typical buildings, however if there is severe smoke outside the premises, it may be safer to rise above this 1000 PPM barrier, instead of introducing smoke-laden air.

2.2.1.1 ADEQUATE FILTRATION AND BUILDING PRESSURIZATION

The addition of Minimum Efficiency Reporting Values (MERV) 13 filters will remove enough wildfire smoke particulate to protect most occupants from smoke exposure. ASHRAE Standard 52.2 list the MERV rating for mechanical filters from MERV 1 to MERV 16. A higher MERV number means a higher efficiency to remove particles ranging in sizes from 0.3-micron diameter up to 10 microns in diameter. If all supply air provided to a building has passed through MERV 13 or 14 filters before entering the building, wildfire smoke will not affect most of the occupants. If supply air filters are not fully sealed, smoke will pass around the filter and enter the air stream.

Another challenge is preventing infiltration through the building envelope. All building envelopes are prone to leaks – some more than others – and this vulnerability is usually proportional to building age. Strategies are available to "tighten" a building envelope but they are generally expensive or difficult to implement. This also does not address the issue of the leakiest parts of the façade: doors and windows. Doors are required to open for the building to function, and windows can usually be opened by occupants who may not consider the potential effect this can have on air quality.

If a building has an excess of supply air over the amount of air that is exhausted, the building will be positively pressurized, and leaks will tend to flow outward. As such, opening doors and windows will not exact an inrush of unconditioned outside air (or bushfire smoke when applicable). If the indoor pressure is less than outdoor, or negatively pressurized, it is recommended for building operators to find a way to positively pressurize the building. This will help energy usage within the building, control of internal temperatures, and protect from smoke ingress.

There are several paths to achieve continuous positive pressure:

- Reduce leakage, especially through the upper half of the building envelope. Note: elevator shafts and machine rooms can be significant paths of infiltration.
- Increase the flow of filtered outdoor air.
- Reduce exhaust air flows after discussing with those in affected areas.

A low-cost option is to reduce the exhaust air flow rates, as there is no energy penalty and it is not as costly as sealing a building., A simple implementation of this is to turn off exhausts connected to a fume hood or other equipment when the equipment is not in use. This can be done with a run-on timer or motion sensor. Any modification to the exhaust air flow rates or regimes would need to be checked by an engineer to ensure compliance with design codes is still achieved.

Wind will have an impact to the building pressurization, as wind pressure will change the pressure differential across walls and roof. The upwind on a wall of a building is also an area of concern during a wildfire smoke event, as successful building pressurization will also demand a positive pressure difference. It may be useful to install a differential pressure sensor three to four meters above grade on each wall, and one near the middle of the roof, and to connect them to your BMS to monitor key areas. When designing or implementing adaptation measures, it is useful to check weather data to determine a design wind speed for wildfire smoke conditions. The differential pressure sensors in combination with a BMS connection wind direction indicator and anemometer on a mast above the highest part of the roof will provide building operators with an overview of pressurization performance.

Below are some steps for preparing for events of increased wildfire smoke in outdoor air:

- Determine which outside air supply systems have the fan capacity to readily accept MERV 13 or 14 filters.
- Have the filters available on site, ready to install as needed.
- During a normal weather day (both temperature and wind speed/direction), check and record:
    - the air flow direction at an open door or window on each wall
    - the air velocity through each of those openings
    - pressure sensors as described above, if available
- Ensure adequate controls on supply and exhaust air flows.

In the case that a building does need to be evacuated, it is recommended to keep the HVAC system operational, up to when the building starts to burn or senses smoke in the outside air systems. Very few buildings can be sealed off enough to keep smoke out without the assistance of mechanical ventilation. To assist in this pressurization during an evacuation, the exhaust fan systems could be shut down.

2.2.2 EXTREME OUTDOOR AIR TEMPERATURES

When buildings are faced with extreme outdoor air temperatures, particularly air-to-air heat recovery systems, changes or additions to existing ventilation system can help to improve system performance.

2.2.2.1 AIR-TO AIR HEAT RECOVERY

Air-to-air heat recovery, also known as exhaust-air energy recovery, uses conditioned exhaust air to pre-heat the incoming outside air during wintertime, or pre-cool it during summer. This can be achieved through different techniques which either transfer total energy (latent and sensible heat) or sensible heat only.

The table below displays an overview of current energy-recovery technology:

CURRENT ENERGY RECOVERY TECHNOLOGIES

	Type	**Effectiveness**	**Induced Pressure Drop**	**Application Considerations**
Coil Loop	Sensible heat	35% - 55% sensible effectiveness	0.2 to 0.7 in. H_2O	• capacity modulation using variable-speed pump or mixing valve • no cross leakage • very flexible design • small footprint

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				• inside and outside coils can be spaced apart • one outdoor coil can be assigned to multiple indoor ones
Heat Pipe	Sensible heat	30% - 55% sensible effectiveness	0.2 - 0.8 in. H_2O	• capacity modulation usage • bypass dampers or tilt control • low cross leakage • compact
Fixed Plate Heat Exchanger	Sensible heat	55% to 70% sensible effectiveness	0.3 - 1.0 in. H_2O	• capacity modulation using face-and-bypass dampers • very little cross leakage around the edges of the fins • cost effective in smaller sizes
Fixed Membrane Heat Exchanger	Sensible and latent heat	60% - 65% sensible effectiveness 40% - 55% latent effectiveness	0.9 - 3.0 in. H_2O	• capacity modulation using external bypass dampers • minimal cross leakage • less susceptible to frost than other technologies • cores only available in small sizes (< 3000 cfm)
Sensible Assisted Membrane	Sensible and latent heat	72% - 77% sensible effectiveness 40% - 60% latent effectiveness	0.8 - 1.1 in. H_2O	• the sensible assisted membrane has a fixed plate HEX and a fixed membrane stacked on each other • capacity modulation using bypass dampers • little cross leakage • less susceptible to frost than other technologies
Total Energy Wheel	Sensible and latent heat	65% - 80% sensible effectiveness 60% - 70% latent effectiveness	0.8 - 1.1 in. H_2O	• capacity modulation using bypass dampers • some cross leakage • self-cleaning of dry particles

2.2.2.2 IMPACT OF AIR-TO-AIR HEAT RECOVERY ON EXISTING SYSTEMS

Adding a heat/energy recovery device has a significant impact on the operation of a ventilation system. Benefits of air-to-air heat recovery include a reduced heating or cooling load which can help offset the impact of extreme temperatures, particularly if the equipment is undersized or is operating outside its design temperatures. The following notes need to be considered when retrofitting existing equipment or buildings:

- Every energy-recovery device will induce an additional pressure drop to the system, which leads to increased fan energy or even the need to upgrade the supply fan to overcome the increase static pressure. Consider whether the benefit of the energy recovery device exceeds the additional energy needed to drive the system.
- In some cases, modification of the existing ductwork might be required, which needs to be factored into the analysis and payback period.
- To maximize energy savings for some air-to-air heat recovery measures, dynamic control is required to realize benefit (*e.g.*, bypassing the energy wheel in mild weather when economizing can be used).

It is recommended to work with an engineering consultant to perform a system review before adding heat-recovery devices.

2.3 CONTROLS

Building management systems (BMSs) or building automation systems (BASs) are crucial in modifying the operation of a building due to external stimuli such as extreme temperatures or a decreased outdoor air quality due to wildfires. To respond to these external conditions accurately and in a timely manner, a predictive system or monitoring system is needed, paired with a change in the ventilation operation.

2.3.1 INCREASED FOREST FIRE ACTIVITY

The purpose of including a monitoring system for air quality, whether it be indoor or outdoor air, is to preserve a healthy indoor environment for the building's occupants.

2.3.1.1 PREDICTIVE SYSTEMS AND REAL TIME MONITORING

Predictive and real-time monitoring systems offer an advantage because a change in the ventilation mode can happen automatically, achieving air quality improvements much quicker when compared to using a manual override. There are different options for where and how to measure particulate matter, the key indicator for forest fires, and to trigger a system response:

Since the Covid-19 pandemic, more buildings have installed indoor air quality sensors to monitor IAQ indicators such as CO_2, VOCs, and in some cases, particulate matter. These sensors can be used to trigger a change in ventilation mode. A disadvantage of changing the ventilation mode based on indoor sensors is that the pollutants must enter the space in order to be detected. The system is reactive only once an issue is observed, so there will be a delay in rectifying the matter. During that time, the IAQ would be below normal limits. However, indoor air measuring is easy to implement and is useful for identifying issues that may have eluded other monitoring systems, and should be part of any overall air quality measurement system.

Another way to monitor and measure particulate matter (PM) could be through installing an outdoor particulate sensor, which is a precise way to measure the PM concentration at the building if they are installed correctly. It is recommended to protect these sensors from direct sunlight, wind, and to avoid close proximity to louvres and other air disturbances to mitigate false alarms.

The advantage of outdoor air measurement is that the system can react to changes before the particles reach in the indoors, protecting the occupants in the process. As well as particle sensors on buildings, the system could also react to third party particle sensors, such as those provided by official government channels, or from other private buildings. The advantage of this is that changes in the air quality can be detected before even reaching your building, particularly if the sensor is upwind of a building's location (or between a building and the fire front).

Weather services and apps often provide an IAQ quality level indicator which could be used as a trigger. However, a disadvantage of this method is that these values are often measured at a local weather station and may not be relevant to the location of the building. Furthermore, incorporating internet data into the BMS coding requires some work and ongoing maintenance, and the data would not be as reliable as a hard-wired sensor.

The use of sensors to predict and adjust indoor air quality must be specifically considered for each project, looking at available budget, data, and occupant wants and needs. Where budget and availability permit, a combination of indoor, outdoor and external sensors should be used to provide the best outcome for the building's IAQ.

2.3.1.2 SMOKE MITIGATION CONTROL SEQUENCES

Smoke mitigation control sequences could be approached as follows:

1. If the air quality declines (as shown in directly measured data or official reports), decrease the amount of outside air to the minimum requirements and stop economizing. Reduce the exhaust fans (if possible, being careful to still meet statutory exhaust flow rates) to positively pressurize the building to reduce outside air infiltration. In an ideal scenario, pressurization of the building should be measured by pressure sensors and the speed of exhaust fans adapted to maintain the desired building pressure. However, temporary manipulation of the building pressurization may be sufficient to assist during the worst times of smoke presence.
2. If the first step does not see enough improvement in air quality, or if the internal conditions are being reported by the building occupants as harmful, start the process of reducing the exhaust flow rates and outside air flow rates below that of the statutory minimums. This should occur in consultation with an engineer and should be exacted as a temporary measure only. A risk assessment needs to be carried out, where the risk of the smoke to occupants is compared to the risk of reducing outside air and exhausts.

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A smoke mitigation control strategy can also incorporate additional filtration devices such as activated carbon pre-filters or MERV 13 or 14 filters. These filters can be expensive to operate and replace, so the recommendation is to only install and use them as needed.

2.3.2 ABNORMAL WEATHER CONDITIONS

Outlined below are controls strategies which will use a building management system (BMS) to mitigate the effects of extreme temperatures to the same control strategies will also reduce the risk of equipment damage or failure during these extreme weather conditions.

2.3.2.1 CONTROL STRATEGIES FOR HIGH TEMPERATURES

Control strategies for high temperatures help to reduce the cooling demand in the building, which improves the ability of the HVAC system to provide continuous operation. Control strategies include pre-cooling the building, reducing load through lighting control, and modifying equipment operations to focus cooling in critical spaces.

When facing a heat wave, it is recommended to extend the run-time of cooling equipment and adjust the unoccupied set-point. For example, on weekends, commercial office buildings operate their HVAC system on reduced hours to save energy. However, during a heat wave, these reduced hours can cause the building to heat up significantly over the weekend, increasing the cooling demand on Monday morning.

Additionally, starting the HVAC equipment earlier by using optimal start and lowering the unoccupied set-point are ways to pre-cool indoor spaces, especially if cooling is critical *(e.g.,* in electrical vaults or medical offices).

2.3.2.2 UNOCCUPIED ECONOMIZING AND PRE-COOLING

Unoccupied economizing is an efficient way to pre-cool a building in the late-night/early-morning hours without using chilled water or direct expansion (DX) cooling. Its function is to cool the space by exchanging warm inside air with cool, dry outdoor air. The intent is to minimize – or possibly eliminate – the need for mechanical cooling when the space initially becomes occupied. This control strategy saves energy and operating costs by leveraging outdoor air conditions.

2.3.2.3 NIGHT SETBACK AND OPTIMAL START

The night setback and optimal start control strategies reduce the number of hours that the system needs to operate and saves energy by avoiding the need to maintain the building's indoor temperature at occupied setpoint even though the building is unoccupied. Night setback allows the indoor temperature to drift from the occupied setpoint when the schedule switches from occupied to unoccupied. Optimal start looks at the outdoor air temperature and trend data from days prior to determine the optimal time to start the HVAC systems so the building is properly conditioning when the schedule switches from unoccupied to occupied. Time-of-day scheduling is programmed at the system controller level which communicates to the unit controllers serving their respective zones.

Reducing the outside air intake to the minimum requirement and creating positive pressure within the building are two crucial strategies in reducing the cooling load. Furthermore, energy recovery devices pre-cool the incoming air with conditioned exhaust air and should be used if they are available.

Furthermore, controlling the lighting of a building can have a tremendous impact on the cooling load, particularly in retail stores. Control strategies such as demand lighting control (usually implemented through a motion sensor) or the more sophisticated daylight harvesting control, lower energy consumption as well as the heat injected into the space through lights. It is also important to consider the type of light fixtures used in the building. Fluorescent lamps have a greater heat loss than LEDs and hence contribute more to cooling demand. Changing lighting fixtures to LEDs is a low-cost upgrade that will save energy and improve cooling system performance.

2.3.2.4 DAYLIGHT HARVESTING AND LIGHTING UPGRADES

Daylight harvesting is an automatic control strategy that uses natural daylight to offset the lighting requirements of a space to reduce energy consumption. It is most effective in spaces that have large exterior windows or skylights that consistently receive ample daylight. The control strategy consists of automatic lighting controls that measure the amount of natural light in the space and adjust the lighting output accordingly. Taking advantage of naturally occurring sunlight can reduce energy consumption and building lighting costs by as much as 25%[36]. Not only is this appealing from an economic standpoint, but natural light is also more pleasing and psychologically beneficial for humans compared to artificial light[37]. In 2019, ASHRAE Standard 90.1 Energy Standards for Buildings was updated to include requirements on energy saving strategies, such as daylight harvesting, for standard lighting designs.

How to optimize daylight harvesting and lighting control:

1. Install light shelves on the inner surfaces of windows to control how the light reflects into the space. Light shelves disperse the light more evenly throughout the space and reduce glare and direct sunlight from bothering the occupants.
2. Integrate the building's lighting system into the building management system for better control and visibility
3. Prioritize Spaces and Ensure Continuous Equipment Operation

During summer months, the cooling demand will surpass the capacity of the installed HVAC system. This is because HVAC systems are carefully selected such that the balance between capital cost, efficient operation, and peak output is met. Sizing an HVAC plant

[36] Retrieved from http://www.greeneducationfoundation.org/green-building-program-sub/learn-about-green-building/1224-daylight-harvesting.html
[37] Retrieved from http://www.greeneducationfoundation.org/green-building-program-sub/learn-about-green-building/1224-daylight-harvesting.html

to provide capacity that is only used one hour per year would not be an effective use of space and resource.

Since cooling capacity is limited, it is essential to prioritize cooling for critical spaces, such as server rooms, electrical vaults, or medical spaces. Providing preferred cooling to these rooms or floors will come at the expense of reduced cooling in other parts of the building. One strategy could be to cool down common areas rather than individual offices, and encourage tenants to work in those areas. Another would be to modify the space setpoints in the non-critical areas to reduce the building's cooling demand. Cooling could also be temporarily suspended to transient spaces, such as entry lobbies, lunch spaces, and end of trip spaces.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE STANDARD 90.1- 2019: ENERGY STANDARD FOR BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS***

2.3.2.5 CONTROL STRATEGIES FOR LOW TEMPERATURES

Inherent to low temperatures is the risks of freezing and bursting water pipes. Since water damage is most detrimental to a building, most heating systems are sized with redundancy, such that there is less a concern of meeting the heating demand during a severe cold period (as the redundant equipment can be used for full duty).

When facing a severe cold snap, it is important to ensure that hydronic loop components, which are exposed to outside air, are winterized properly and that safety features such as freeze stats are working correctly.

With air-handler and make-up air units, it is important to ensure that hydronic cooling coils are either heat traced or completely drained to avoid freezing when exposed to ambient conditions.

Similarly to the strategies proposed in the increased outdoor air temperature strategies section, reducing the outside air intake to acceptable minimums is important in reducing the heating load and lowering the risk of freezing in extreme cold conditions.

A building should be programmed to maintain a minimum temperature that is above the freezing point, 24 hours a day, 7 days a week, regardless of occupancy. This minimum setpoint could be just above zero, but it is recommended to keep this temperature at 15^{O}C, as this will reduce the time taken for the building to be brought up to operational temperature when again occupied. To facilitate this, it is important that any heating plant is always enabled, and that back-up systems are also serviced and operational.

For hydronic loops using glycol, it is crucial to confirm that the glycol concentration meets the specifications. For systems without glycol, an outdated method of preventing freezing was to continue the circulation of water, however this comes at an energy penalty and only works if

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water makes it to all parts of the circuit. A more energy efficient strategy would be to ensure the conditioned spaces are kept above freezing, and that any equipment in an unconditioned space is heat traced.

2.4 OTHER/ GENERAL

This section discusses strategies that do not specifically fall under heating/cooling, ventilation or controls, but are important and applicable adaptation strategies.

2.4.1 BUILDING REACTION PLAN

Having a building reaction plan is recommended to help adapt to extreme weather conditions. The strategies identified in these plans, such as adjusting the sequence of operation for equipment, implementing additional control strategies, or upgrading equipment, usually requires preparation and capital funding. Therefore it is important to develop and implement this plan before extreme weather events transpire. Extreme weather events will often arrive with only a few days' notice, rendering it unlikely to be able to implement strategies reactively. Additionally, contractors are often in high demand during a heat wave and might not be available to implement a particular plan.

If proposed changes to the building operation will impact tenants or staff, it is recommended to communicate this them in advance. For example, if working from home is encouraged during extreme weather events (*e.g.*, "snow days" or "heat days"), some areas are not cooled to maintain the temperature in critical spaces.

Building owners and managers are encouraged to work with a consulting engineer and/or their HVAC/BMS service provider to develop a plan suitable for their building. The plan should consider the following points:

- Identify critical spaces and the equipment needed to operate during a major weather event, especially if any equipment is defined as life safety.
- Ensure that these critical demands are prioritized in a BMS system, whether embedded in the regular sequence of operations (SOO) or when switching to an emergency SOO. Furthermore, ensure that a back-up plan is in place, in case the system fails. This should include the estimated time that an HVAC system can be down before critical parameters (*e.g.*, temperatures, particulate matter concentrations) will be reached.
- Identify opportunities to reduce the cooling demand of the building (*e.g.*, turn off lights or implement lighting strategies, reduce occupancy and plug loads within the building, or limit the operation of commercial kitchens) if this is possible for your building and the tenants. Communicate changes beforehand to achieve buy-in and manage expectations of building staff and tenants.
- Provide facilities staff with standard work procedures, including inspection checklists, to maintain critical assets during extreme weather events.

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- Summarize the equipment and the level of risk if exposed to certain hazards, including considerations for adapting the current system to more extreme weather events during planned upgrades.

The above points are only some suggestions as they relate to building HVAC systems. An emergency building response or reaction plan typically has many more components *(e.g.,* evacuation routes and shelter measures) over and above the ones in this report.

3.0 RESILIENCE

The following section focuses on resiliency relating to decarbonization in the built environment. The below definition of resilience is from ASHRAE's Industry Statement on Resilience 2016:

"Resilience is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events"[38].

3.1 HEATING/ COOLING

This section offers suggestions to prepare heating and cooling systems in buildings, with predicted increases in outdoor air temperatures and changes in decrease in outdoor air quality.

3.1.1 INCREASED OUTDOOR AIR TEMPERATURE

With assessments of long-term climate change generally referencing target average global temperature increases of 0.5-2.0°C, it has now become clear that the frequency and severity of extremely hot weather is increasing, and that the heat island effect in cities can further exacerbate this risk[39]. Above certain thresholds, this heat will at best reduce comfort and productivity, and at worst, pose a dangerous threat to human health. This trend creates the need to build resiliency into building systems to increase the ability and reliability of cooling during extreme heat.

3.1.1.1 GROUND-SOURCE HEAT PUMPS

Ground temperatures are far more stable than air temperatures and are essentially constant all year at significant distances from the surface[40]. In many locations, daily air temperature changes may be larger than annual seasonal swings of near-surface ground temperatures throughout most of Canada and the US[41]. Ground-coupled heat pumps, or "geoexchange" systems, take advantage of these stable year-round temperatures to provide high efficiency heating and cooling throughout the year during extreme temperature swings which could render air-source equipment inefficient or even inoperable.

These systems (also discussed in 1.1.2 Low/ Zero Carbon Energy Sources) tend to come at a price premium relative to air source heat pumps, but their advantages in terms of all-weather heating and cooling reliability can make them worthwhile. Ensuring they are sized for cost-effectiveness (i.e., less than 100% of heating demand in colder climates) and with fields or loops for at least a 50-year ground temperature gradient are important factors for success. Bear in mind that some leaks are possible over the life of the system, and that loss of a loop is a permanent loss of capacity; ability to isolate and abandon loops is important.

[38] Retrieved from https://www.ashrae.org/file%20library/technical%20resources/resiliance%20activities/statement_2016-0425.pdf
[39] Retrieved from https://www.cambridge.org/ca/academic/subjects/earth-and-environmental-science/climatology-and-climate-change/global-climate-change-impacts-united-states
[40] Ground temperatures near the surface are affected by air temperature, solar incidence, geology, ground cover, and various other factors which are much less relevant at depths below 30 feet. Beyond a depth of 30 feet, the ground temperature will be approximately equal to the average annual air temperature for that region.
[41] 2021 ASHRAE Handbook: Fundamentals

Ground coupled systems include “closed loop” and “open loop” arrangements. Closed loop systems use a sealed loop of piping buried in the ground to circulate glycol and transfer heat to or from the surrounding ground, while open loop systems draw from an above- or below-grade water source and return it back to the source after extracting energy from it in the building. Both have challenges with their application, although careful planning by the project team can help overcome them.

As noted in 1.1.2 Low/ Zero Carbon Energy Sources, the heat pumps used for these systems must be selected with appropriate operating temperature ranges, which includes a wider band of entering water temperatures than a standard water source heat pump is designed to utilize.

3.1.1.2 MODULAR AND FUTURE COOLING EQUIPMENT

While it may not always be practical to include full cooling systems during initial construction of all buildings, it is usually possible to plan for additional or upgraded cooling systems for minimal initial capital cost. Considering some basic principles to permit future building owners and occupants to improve cooling can make the difference between those future upgrades being economically feasible or not. Impacts of insufficiently cooled buildings may include lower rents, dangerous conditions for occupants, service disruptions, or even damage to certain building elements.

The most fundamental consideration is ensuring electrical capacity for any future cooling system. Where the building heating systems are already electrified, the same electrical service will generally be able to support full or partial cooling without upsizing any electrical infrastructure. The design team would simply need to conduct high-level cooling load calculations to make estimates on future cooling capabilities, and to advise building owners of ultimate limitations of the original building’s electrical distribution in supporting these systems.

Where heating systems are based primarily on fossil fuel energy, making allowances for full cooling solutions may be impractical; however, partial cooling may remain quite viable. Examples of such partial systems with lower electrical draw include:

- retrofit of central ventilation systems with DX coils and condensing units
- provision of through-wall cap-offs for tenant-supplied, in-room air conditioners within rental suites

Physical space for future cooling equipment is another important consideration. Options are drastically reduced if a cooling upgrade necessitates relocation of walls and major services. Making space in the original design for a future rooftop condenser, ceiling mounted fancoil, or additional chiller module raises the chances that a future cooling addition will be practicable. An extra 10m^2 of mechanical space during initial construction is relatively inexpensive; adding it ten years after construction may be effectively impossible.

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3.1.1.3 EQUIPMENT DESIGNED FOR HOT CLIMATES

Most cooling equipment is tested and rated using standardized methods and operating conditions, such as those of AHRI Standard 340/360[42]. While data from these standardized testing programs give useful capacity and efficiency metrics, they do not provide insights on performance near maximum temperatures of ambient outdoor air (or entering water, depending on equipment type) that the equipment may operate under. As a rule, efficiency and capacity drop off steeply as temperatures rise beyond the intended design temperatures.

Beyond simply losing efficiency and cooling capacity at these higher temperatures, all cooling equipment will become completely unable to function beyond a certain temperature. While this limit is tied to the physics of all refrigeration systems, some equipment can operate at higher temperatures than others. Cooling systems with evaporative heat rejection are typically able to operate more reliably at higher ambient temperatures, with the obvious downside of water consumption. During a heat wave, whether an air conditioner shuts down at 40°C or 43°C can have a drastic impact on occupant safety, integrity of infrastructure, and various other operational factors (cooling systems protecting electrical and telecommunications infrastructure within buildings is particularly important).

It is strongly recommended that the project team investigate and understand maximum operating temperatures for the specific cooling equipment being planned for installation. It is also important for building operators and owners to understand the system design temperature versus the system operating temperature. The former is the ambient temperature at which the air conditioning equipment will provide 100% capacity and maintain internal temperatures as designed. The latter is the point at which the equipment will cease to operate.

3.1.1.4 EMERGENCY COOLING ZONES

Where provision of complete cooling systems is not being considered in new or existing buildings, other limited options may be exercised that can still provide relief and safety to building occupants during hot weather. One such idea is the concept of "emergency cooling zones". These zones represent a very small percentage of the total constructed building area and are intended to provide short-term refuge for overheated or at-risk occupants to "retreat" to and recover in temporarily during a heat wave. Categories of at-risk people include, but are not limited to, those working outdoors, the elderly, young children, and those with medical conditions. Some examples of the forms these spaces can take include:

- air-conditioned general purpose amenity spaces
- shaded outdoor area with water misting systems
- basement-level rooms with sufficient ventilation

[42] AHRI 340/360 requires testing at ambient outdoor air temperatures of 35.0°C for air-cooled equipment, and 29.4°F entering water temperature for water-cooled equipment.

- nearby offsite spaces, pre-negotiated and planned, such as a shopping mall or an office building

It should be noted that for any emergency cooling zone to be effective, it needs the means to cool down a large number of occupants and also re-hydrate them. Drinking fountains or general-purpose sinks are highly recommended, along with a store of basic supplies to treat dehydration and heat-related conditions such as heat exhaustion.

3.1.1.5 RETROFIT OPPORTUNITIES

Existing buildings present a particular resilience challenge when combating rising summer temperatures: envelopes and HVAC systems designed for the climate of 20 years ago will have a reduced capacity to protect occupants today. Even so, while complete solutions are unlikely, many opportunities exist to improve indoor conditions during hot weather through retrofits.

Building envelopes have a long-expected service life but must eventually be replaced. When these replacements happen, they are an excellent opportunity to improve air tightness and upgrade window performance. Making such improvements will have positive effects on peak sizing and effectiveness of mechanical equipment (where cooling is provided), and will improve indoor comfort during hot, sunny weather.

A wide variety of options for providing complete or partial cooling through retrofit of mechanical systems are possible, depending on the existing systems in place. For example, it may be straightforward to add a DX cooling coil and condensing unit to an existing rooftop makeup air unit, or to add heat pumps with wall cassettes and controls to reserve existing electric baseboards as backup heat only. A more complex conversion may include addition of partial cooling to a hydronic radiant floor heating system; such an upgrade would require careful assessment of existing pipe insulation and electrical distribution, as well as precise controls to protect against condensation forming on pipes or in floors.

It is recommended that competent design professionals are involved in any retrofit or replacement projects where new cooling systems are considered desirable. Inappropriate re-purposing of heating-only systems for cooling applications can easily cause problems with ventilation, refrigerant safety, and air quality due to condensation and mold.

3.1.1.6 PREDICTIVE ENERGY MODELING

While traditionally used to demonstrate compliance with performance or sustainability targets, energy modelling can play a crucial role in planning and executing resiliency upgrades to new and existing buildings.

It is beginning to become commonplace to run models based on future forecast weather data, considering the predicted impacts of climate change over the next 50 years. In running these simulations, it is theoretically possible to answer some very useful questions:

- Which spaces become overheated, and why? What are the solar loads, occupant density, and air temperature?
- To what extent are spaces predicted to overheat in the future, compared to today?
- How effective will cooling systems, sized for current codes, be in the future during more frequent heat waves?
- Are the specified cooling systems anticipated to become under-sized prior to the end of their useful service life?
- How sensitive is the building to overheating based on geometry, orientation, albedo, shading, heat island effect, and other factors?

Especially where the building owner will be retaining and operating the building for decades, the cost to conduct such energy modelling studies during the design phase of a project is negligible in comparison to the insights it may yield for initial construction and long-term operation and planning.

3.1.2 DECREASED OUTDOOR AIR TEMPERATURE

While climate change is generally associated with higher temperatures, scientists also expect it to increase the geographic area, intensity, and duration of "cold snaps" in certain regions of the United States and Canada[43]. This means that:

- Equipment may be expected to operate in colder temperatures than typical for the local region.
- Unseasonable cold snaps may occur after building operators have already configured systems for spring or summer operation.

As the effects of climate change intensify, engineers and facility operators need to plan building design and operation to accommodate both quick temperature variations and temperatures extremes. Ensuring systems have adequate capacity, reliability, and control methods to respond to extreme cold weather events will make facilities more resilient and able to avoid knock-on effects such as freeze damage or inability to maintain acceptable indoor conditions for occupants.

3.1.2.1 SYSTEM REDUNDANCY

One means of accommodating unexpectedly cold weather is to provide redundant heating systems. This may take the form of backup boilers or electric resistance heat, supporting normally operating low-carbon systems such as VRF or heat pumps. It may also be as simple as providing redundant equipment, ensuring that failure or maintenance of a single piece of equipment does not place the facility in jeopardy. A sensible practice is to select two heat generating units at 60% - 75% of peak design heating load, or to provide a single backup unit in an N+1 configuration where smaller modular equipment is used.

Fuel source diversity can also play a role; having backup gas boilers help protect the system operation in the case of an extended power outage or cold weather beyond the normal range of

[43] Retrieved from https://www.ucsusa.org/resources/does-cold-weather-disprove-climate-change

heat pump systems. While critical pumps and fans may be placed on backup generator power to circulate heat from boilers, electrical demand from heat pumps or electric resistance is typically too large to be operated by onsite power generation systems. Other equipment, such as packaged rooftop units are available with two-stage heating using air source heat pumps as the first[t] stage and gas burners as second stage.

Finally, creating "emergency injection" interconnections between hydronic heating and domestic hot water systems may be worth exploration in some circumstances. Capacity from large central domestic hot water heaters can be shunted into hydronic heating systems via double wall heat exchangers and "emergency heat injection" control loops (or even with manual changeover). With this method, significant redundancy can be created with a minimum of additional equipment, while allowing the normal space heating capacity to come from low-carbon energy sources.

3.1.2.2 PREDICTIVE MODELING AND CONTROLS

Many facilities undergo seasonal adjustments to controls to best suit the expected upcoming weather conditions. These adjustments may be automatic, but in practice are often performed manually by operations staff based on calendar date or when a change in season is perceived. Changes may include everything from supply temperature reset schedules to seasonal shut down of plant equipment.

With the potential for unpredictable cold snaps, facilities should be designed and operated in such a way that they can quickly adjust to rapid temperature swings. Automatic controls generally, and predictive controls specifically, are key in responding effectively to these swings. Automatic controls, typically part of a Direct Digital Control (DDC) system, monitor outdoor air temperatures and current system operation, adjusting setpoints, schedules, equipment staging, and various other temperature-dependent variables in response. A system that can detect and respond to unseasonably cold weather without manual input is more likely to avoid disruption.

Even more effective than traditional automatic controls systems are a more modern variant emerging that includes predictive control algorithms. Using inputs such as weather forecasting, thermal modelling and measured building conditions, predictive control algorithms can leverage the building thermal capacity and known characteristics of the heating system to both reduce energy consumption and maintain comfortable indoor conditions[44]. Such a system could also be employed to adjust system operation to avoid "hard faults", such as by preemptively activating backup heat sources or adjusting setpoints to keep systems within equipment operating limits.

At present, there are few packaged and commercially available controls systems using predictive control algorithms, due to various factors including computational burden and complexity[45]. As

[44] Retrieved from: https://doi.org/10.1016/j.enbuild.2010.10.022
[45] Retrieved from: https://ieeexplore.ieee.org/document/7040202?arnumber=7040202

controls systems continue to become more sophisticated and more cloud-based, such systems are likely to increase in adoption.

3.2 VENTILATION

3.2.1 OUTDOOR AIR QUALITY

Maintaining Indoor air quality (IAQ) limits through proper ventilation is essential for human health. Buildings need to be resilient when it comes to the provision of ventilation, and systems must be in place to ensure poor outdoor air quality doesn't transfer into poor indoor air quality. ASHRAE specifically details the IAQ requirements in Standards 62.1 and 62.2.

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE STANDARD 62.1: VENTILATION FOR ACCEPTABLE INDOOR AIR QUALITY***
- ***ASHRAE STANDARD 62.2: VENTILATION FOR ACCEPTABLE INDOOR AIR QUALITY IN RESIDENTIAL BUILDINGS***

3.2.1.1 MONITORING

IAQ is often dismissed due to it not being apparent to the naked eye, however monitoring IAQ can provide the ability for the invisible to be visible. There are many methods to monitor IAQ and improving the IAQ can only be actioned by first introducing monitoring.

The primary monitoring method today is sensor technology. Sensors can be duct mounted in the ventilation equipment or located in occupant space. New buildings will generally employ both as this will help identify problem areas and tailor solutions specifically. The primary chemicals the sensors monitor are CO_2, VOCs, particulates and to a lesser extent NO_2[46]. Once sensors are in place to monitor these chemicals, you will be able to then understand and subsequently improve the IAQ of your building.

Another method of monitoring IAQ is through pressure sensors on filter systems. Filtration is required for all mechanical ventilation systems. It is common practice for filters to be cleaned or replaced on a scheduled basis. By using pressure sensors in the mechanical equipment, the system will be able to tell you when the filters have been blocked or have reached a maximum operating threshold. When that happens, a notification is sent through the BMS, and the filters can be cleaned or replaced by the maintenance or facility staff.

3.2.2 INCREASED OZONE LEVELS

Ozone in the air humans breathe can be harmful to health, especially on hot sunny days when ozone is at its highest concentrations. Even relatively low levels of ozone can cause adverse health effects. People most at risk to ill effects from ozone inhalation include people with asthma, children, older

[46] More information on CO_2, VOCs particulates and NO2 can be found here: https://www.ashrae.org/File%20Library/Technical%20Resources/Standards%20and%20Guidelines/Standards%20Addenda/62-2001/62-2001_Addendum-ad.pdf

adults, and people who are active outdoors, especially outdoor workers[47]. In addition, mean ozone concentration in outdoor air is projected to increase in many regions. The follow sections outline two methods to reduce ozone build up.

3.2.2.1 VENTILATION RATES AND LEAKAGE

Turning off ventilation systems overnight or during unoccupied periods (*i.e.*, on weekends) may reduce concentrations of ozone-derived products inside a building, even though ozone concentration levels in outdoor air are often at their lowest overnight.

During occupied periods, adjusting ventilation rates may help reduce ozone concentrations in spaces. For example, reducing outdoor air flowrates to minimum levels during periods of high outdoor ozone concentrations. However, studies have shown, that preventing ozone pollution in indoor environments is better achieved by limiting indoor ozone concentration via filtration rather than adjusting ventilation rates[48]. Therefore, adjusting ventilation rates should be considered in combination with considerations to implement filtrations and air cleaning devices, can help reduce ozone concentrations in occupied spaces.

If a building has high leakage, outdoor air with potentially high ozone concentrations will be able to enter the building via these cracks and gaps, bypassing filtration systems. Ensuring spaces are positively pressurized along with reducing air leakages as much as possible, can also help reduce ozone concentrations.

3.2.2.2 OZONE NEUTRALIZATION SYSTEMS

Ozone is reactive because the third oxygen atom attaches to other molecules very easily, with a tendency to revert to its lesser state, leaving only O_2 behind. Activated carbon filters are a technology that has numerous molecular spots for the ozone molecules to attach to. A pilot study by William Fisk et al[49], found that filters with carbon stages removed an estimated 60% - 70% of ozone from the air, compared to a negligible removal by filters without activated carbon.[50].

3.3 CONTROLS

Building and HVAC Controls play an integral role in monitoring and optimizing HVAC systems. Ensuring these controls provide resiliency within a building management system provides the ability to keep equipment efficiently operating. Controls are an ever-evolving piece of equipment. Keep in mind, since this guide has been written, more advancements have and will continue to take place. Each type of control methodology should be reviewed and studied on an application-by-application basis.

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[47] Retrieved from https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution
[48] Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6856811/
[49] Retrieved from https://www.osti.gov/biblio/1050670
[50] Retrieved from https://molekule.science/ozone-removal-methods-filters-to-use-in-your-home/

3.3.1 MONITORING AND OPTIMIZATION

Recent extreme weather events, natural disasters, and cyber incursions have brought the vulnerability of the electric system into sharp focus. These events have demonstrated that planning for long-duration power interruptions caused by high-impact, low-probability events will require new approaches to control systems above and beyond previous efforts. [51]

3.3.1.1 ENERGY MANAGEMENT SOFTWARE

One of the toughest areas to reduce facility costs—especially for larger buildings like schools, hospitals, and factories—is energy management, especially without a designated energy management professional or energy management system. An energy management system (EMS) is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation and/or transmission system. Basically, an EMS is a system to control and monitor energy-consuming devices, like HVAC, fans, pumps, dampers, and lighting.

3.3.1.2 CLOUD BASED TECHNOLOGY

Cloud-based energy management systems have three main features. First, they enable remote communication to critical facility equipment like HVAC systems and lighting. Second, cloud-based EMSs take active control of this equipment, optimizing performance and monitoring for problems. Third, they monitor energy usage and provide detailed facility reporting and optimization tools.

By using advanced controls and wireless technologies, a cloud-based EMS takes active control. In the case of HVAC systems, the EMS implements security and coordinates operation of the multiple HVAC systems in a facility. This results in consistent temperatures, limits local user adjustments, and reduces system runtimes. Most facilities achieve a 25% reduction in HVAC equipment runtime and an improvement in comfort.[52]

3.3.1.3 INTEGRATED SENSORS

Integrated sensors are integral to building management systems and ensuring the proper functionality of equipment. Ensuring the accuracy and resiliency of these sensors is integral into proper operation of equipment. The BMS relies on these integrated sensors to provide feedback on operation, temperature, CO_2 levels and pressures. Sensors provide a visualization into system operation and aids in troubleshooting when problems occur.

3.3.2 MAJOR WEATHER EVENT

Climate change has increased the likelihood of major weather events to happen, including extreme storms, tornadoes, hurricanes, and thunderstorm. A common effect of major weather events is the

[51] Retrieved from https://pubs.naruc.org/pub/531AD059-9CC0-BAF6-127B-99BCB5F02198

[52] Retrieved from https://entouchcontrols.com/benefits-of-cloud-based-energy-management-systems

increased likelihood of loss of power. Grid outages can be costly in terms of economic impact, social impact, and public health. The following strategies can help reduce the impact of such power outages.

3.3.2.1 GRID OUTAGE / BACKUP GENERATOR OR POWER SOURCE

A backup generator can provide continuity of operation for HVAC systems in case of power/grid outages. Backup generators are seldom used and as a result are sometimes not regularly maintained. Hence, they might fail to function properly in case of an actual emergency. Regular full-load testing and timely maintenance should be carried out for backup generators. Additionally, adequate fuel should be stored for generators. Fuel can also spoil so it is important that it is regularly used and topped up in case of emergencies.

3.3.2.2 CONTROL SYSTEMS ON UPS POWER

Uninterrupted power supply (UPS) act as an emergency power system that provides a backup source of energy during utility power failures. A UPS can help the system run until the power generator can come online and can help prevent data loss by giving time to equipment to save status. It also protects a system against power surges and sags.

3.3.2.3 REDUNDANCY

A level of redundancy should be carefully considered when designing a backup power system. It is critical to factor in failures within an emergency system. Instead of providing one large generator or battery backup, a system must be spread over multiple generator and batteries.

N+1 redundancy system refers to backup system that is broken into N components, then one extra component is added. For instance, if in an emergency a building requires a total of two generators to run its critical systems, then a should be provided with 2+1, or 3, generators.

1+1 redundancy is a system when there are two separate power sources that can each supply the full power for running the critical systems of a building. Both the systems are always active. If one system fails, then the other system can meet the needs of the building systems without any interruption in power supply.

3.4 OTHER/ GENERAL

This section discusses strategies that do not specifically fall under heating/cooling, ventilation or controls, but are important and applicable resiliency strategies.

3.4.1 ENVIRONMENTAL FACTORS

The past decade has been the hottest in recorded history. Floods, cyclones, wildfires, and heat waves have become increasingly common. By some estimates, building more resilient infrastructure can help us save $4.2 trillion from climate change damages[53]. Throughout the life, due to factors which both natural and human-induced events, a building can be subjected to short-term and long-term stressors.

[53] Retrieved from https://www.worldbank.org/en/news/press-release/2019/06/19/42-trillion-can-be-saved-by-investing-in-more-resilient-infrastructure-new-world-bank-report

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Hence, it is critical to construct buildings that are more resilient which will not only help in adapting to the changing environment but also in protecting its occupants in case of extreme events and recovery.

3.4.1.1 SEISMIC RESTRAINTS

An earthquake can damage not only a buildings structural component (such as piers and beams) but also its non-structural components including mechanical, electrical, plumbing, and fire protection systems (MEP-F). Seismic restraints for MEP-F components are crucial for both safety and financial reasons. Damaged infrastructure can cause financial expenses in three ways: the lost function of a building, the expense of repairing, and the expense of cleaning up the damage. There is also an increased risk of fire which can be caused due to ruptured gas lines.

The Federal Emergency Management Agency (FEMA) guide "Installing Seismic Restraints for Mechanical Equipment"[54] shows equipment installers how to attach mechanical equipment to a building in order minimize earthquake damage. This guide enlists various attachments known as seismic restraint devices which include vibration isolation systems, roof attachment systems, cable or strut suspension systems, and steel shapes. The table below outlines a few categories of seismic restraint system for various mechanical equipment. This is not an exhaustive list - FEMA 412 provides in-depth information on a number a different type of seismic restraint systems used.

SEISMIC RESTRAINT ATTACHMENTS FOR TYPICAL EQUIPMENT

Typical Equipment	How is equipment to be installed	Attachment type
Any compressors except housed or skid-mounted	Mounted directly to the floor	Rigid
	Floor-mounted on vibration isolators using restrained springs or open springs and snubbers	Vibration-isolated
Any rooftop AHU	Roof mounted on post and beam	Post and beam

3.4.1.2 FLOOD PROTECTION

The original placement of HVAC equipment such as heat pumps, air conditioning compressors, fuel storage tanks and various electrical systems such as wirings, fixtures, fuse, and circuit breaker panels are based on standard construction practice and the builder's economic concerns. That is why this equipment might be placed in areas that are exposed to flood waters.

Building systems components can get seriously damaged once they are exposed flood waters. HVAC systems, plumbing appliances and electrical equipment including service panels, meters, outlets, and switches should be placed above flood levels using pedestals or platforms.

[54] Retrieved from https://mitigation.eeri.org/resource-library/building-professionals/installing-seismic-restraints-for-mechanical-equipment-fema-412

Alternatively, such equipment should be placed in waterproof enclosures by using floodwalls. For example, a concrete flood wall can be used to surround equipment such as furnaces and water heaters. In case of flooding, aboveground fuel tanks are vulnerable to flotation. If an aboveground fuel storage tank cannot be elevated above flood levels, these tanks should be anchored with metal straps or cables that hold the tank to the ground anchors. This is critical because the flood water can force the tank to float which can cause the connection to rupture leading to fuel leakage.

3.4.2 ARCHITECTURAL FACTORS

3.4.2.1 HIGH PERFORMANCE MOISTURE PROTECTION

The building enclosure can be made more resilient by using weather resistant barrier (WRB) which helps in keeping the weather out. A weather resistant barrier is an important part of achieving energy efficiency for buildings. A modern WRB protect the walls of a structure from water and air infiltration along with moisture accumulation within the wall systems. Modern WRB's are both air and water resistant and permeable to vapor which ensures a building is energy efficient, healthy, and comfortable.

3.4.2.2 AIR SEALING

Air tightness is about eliminating unintended cracks, gaps, holes, splits, and tears where air can move in and out of the conditioned space of a building. These gaps and cracks can amount to 50% of heat loss through the external building envelope of a building. Air tightness helps in avoiding heat loss as it reduces the uncontrolled air movement in and out of the building. The reduced heat loss also makes the building envelope more efficient.

3.4.2.3 SUPER INSULATION AND HIGH-PERFORMANCE WINDOWS

Superinsulation is an approach to building design, construction and retrofitting that uses high levels of insulation and airtightness that dramatically reduces heat loss. High performance windows are a combination of insulated frames made of non-conductive materials and two or three glass panes separated by insulating spacers. The insulated frames are usually made of wood, fiberglass, or vinyl. The space between the glass layers is filled with non-toxic and low conductive gases like argon or krypton. Glass panes are coated with low-emissivity coating that reflects sunlight. The super insulation and airtight envelope mean that during a power outage caused by a weather event, the heat loss will be slow, and it will take longer for the temperature to reduce with even having a heat source. They will help in achieving resilience called passive survivability.

3.4.3 AIRBORNE INFECTIOUS AEROSOL

There are many airborne viruses which can affect human health and are readily transmissible, from the common cold to more extreme variants, hence it is important to control the air borne exposure of such viruses. Changes to heating, ventilation, and air-conditioning systems can help reduce the airborne

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exposures. Filtration and ventilation provided by HVAC systems reduces the airborne concentration of viruses and thus the risk of transmission through the air.

3.4.3.1 FILTERS

ASHRAE Epidemic Task Force recommends that building owners improve the efficiency of filters that are being used in the HVAC systems. The most commonly used filters in building systems are mechanical filters. MERV is a term that is used to describe the efficiency of mechanical filters.

ASHRAE recommends use of at least MERV 13 mechanical filters and prefers MERV 14 or more to reduce the transmission of infectious aerosols. Though a higher MERV rating provides high filtration efficiency, it also requires higher air pressures to push the air though the filters. Precautions must be taken to ensure that increasing filter efficiency in an HVAC system does not hamper the system's ability to maintain the required indoor temperature and humidity conditions.

3.4.3.2 AIR CHANGE RATES

Air changes per hour is defined as the number of times all the air of the room is replaced with completely new air in one hour. Air changes can help reduce the presence of pollutants in an occupied space and thereby help maintain healthy living conditions. ASHRAE 62.1 provides minimum ventilation requirements in commercial and residential applications. Higher air change rates improve filtration which helps in removing the hazardous particles and infectious viruses at a faster rate.

The below table provides a summary of the ASHRAE recommended air changes per hour for common building types:

ASHRAE RECOMMEND AIR CHANGES

Location Type	Suggested Outdoor Air Ventilation rate (air changes per hour)
Homes	0.35-1
Hotel rooms	1-2
Offices	2-3
Retail shops	2-3
Sports facilities	4-8

FOR MORE INFORMATION, SEE THE FOLLOWING ASHRAE CODES, STANDARDS AND PUBLICATIONS:

- ***ASHRAE STD 62.1-2016 VENTILATION FOR ACCEPTABLE INDOOR AIR QUALITY***
- ***ASHRAE 52.2 METHOD OF TESTING GENERAL VENTILATION AIR-CLEANING DEVICES FOR REMOVAL EFFICIENCY BY PARTICLE SIZE***
- ***(FOR HIGHER VIRUS RISK ENVIRONMENTS) ASHRAE 170-2017 STATES THE RECOMMENDED NUMBER OF OUTDOOR AIR CHANGES PER HOUR.***

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