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Advanced cooling systems and energy-efficient solutions

Presenters:

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Agenda

1. Welcome and introduction
2. Fundamentals and types of advanced cooling systems
3. Energy-efficient advanced cooling technologies
4. Optimized control strategies and BAS integration for advanced cooling systems
5. Financial benefits, incentives and funding opportunities available for cooling system retrofit projects

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Objectives

- Recognize the types of advanced cooling systems
- Describe the advanced cooling functionalities of heat pumps
- Describe how to implement optimized controls and setpoints to improve advanced cooling system performance
- Discuss optimized control strategies using building a building automation system (BAS) to improve system performance
- Assess the financial benefits from retrofitting equipment to advanced cooling systems

Fundamentals of advanced cooling systems

What are advanced cooling systems?

While there is not standard definition for what constitutes an advanced cooling system, the following are the two generally accepted categories:

- Cooling systems focused on enhancing energy-efficiency, improving indoor air quality and optimizing temperature control across various zones.

- Low-lift cooling systems (LLCSs) and thermally-activated building structures (TABSs) combined with model predictive control (MPC).

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Back to basics

- To understand the advantages and particularities of advanced cooling systems, it is important to look at the fundamentals of almost all cooling systems used in commercial buildings:

The vapour compression cycle

- Most advanced cooling systems build on existing technologies that have been around for a long time and are improved through more efficient design and control.

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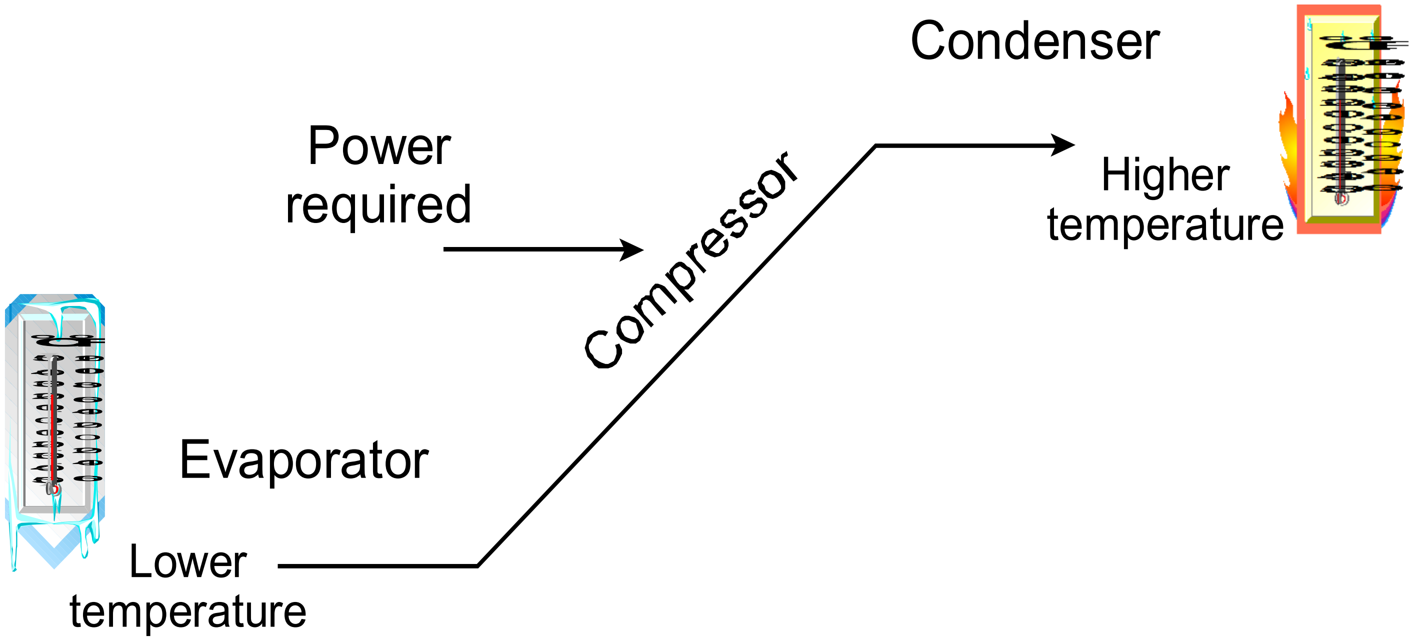
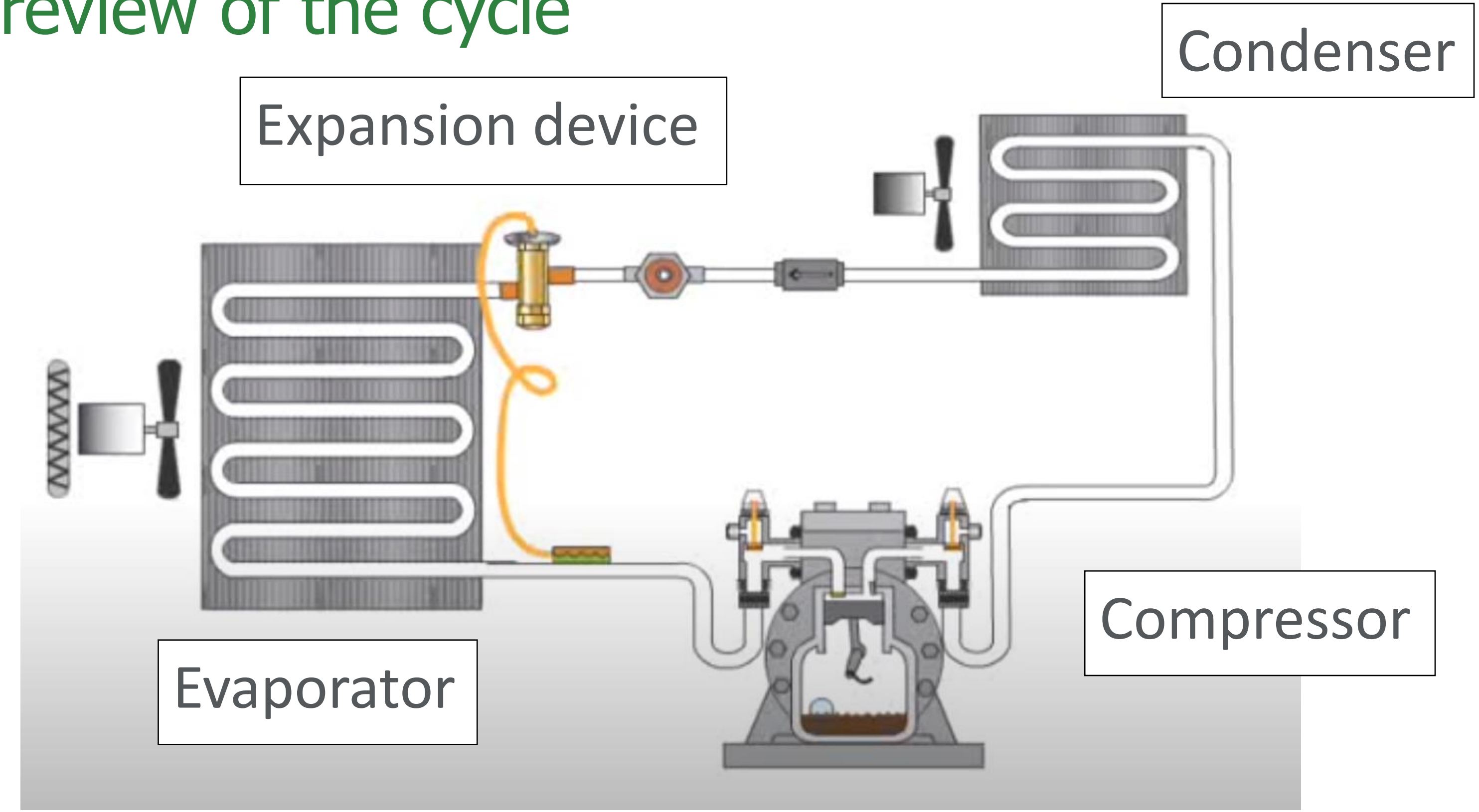
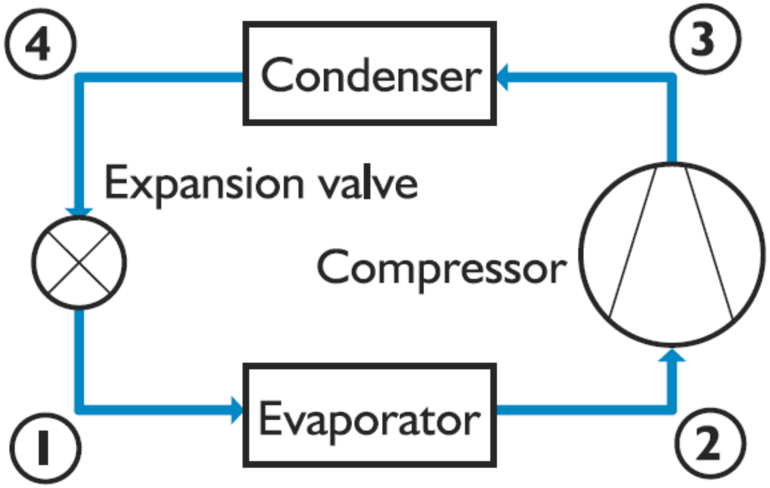
Vapour compression cycle: moving heat uphill

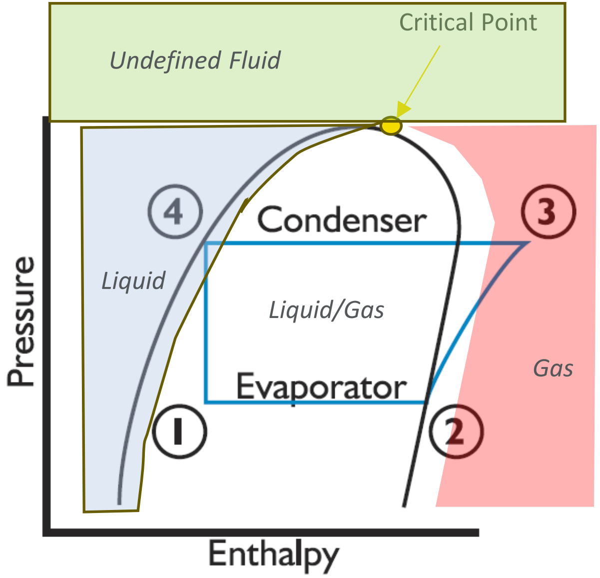


Quick review of the cycle



Vapour compression cycle explained





1. Low pressure/temperature liquid
2. Low pressure/temperature vapor
3. High pressure/temperature vapor
4. High pressure/temperature liquid

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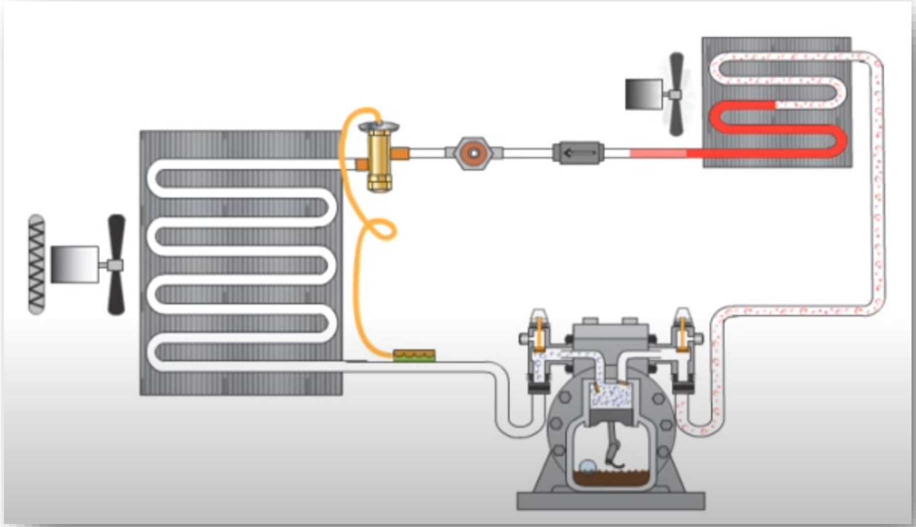
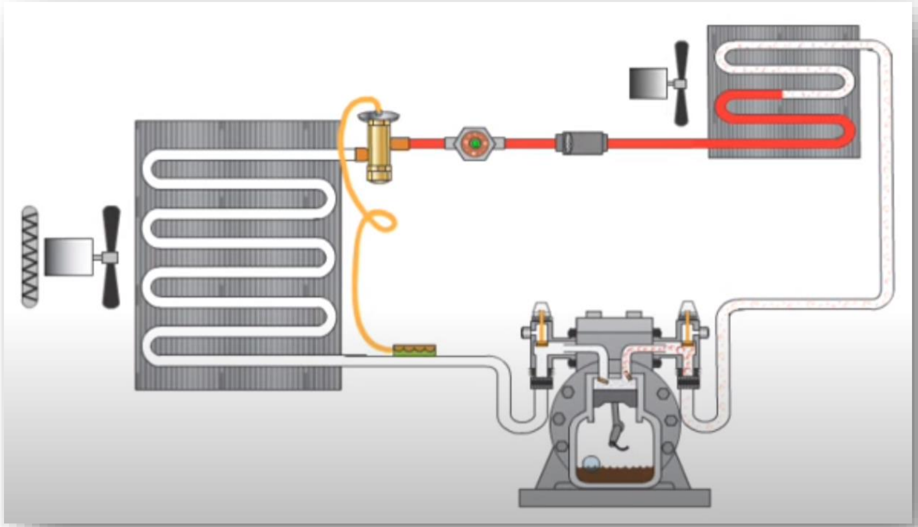
Compression

The compressor sends hot refrigerant gas to the condenser at high temperature and pressure.



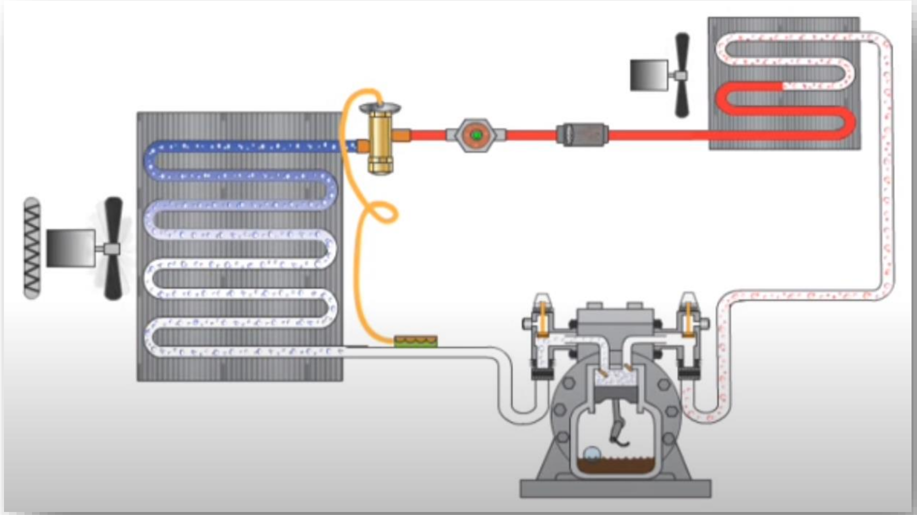
Condensing

The hot gas is turned into high pressure warm liquid at the exit of the condenser.



Expansion

The warm high-pressure liquid is pushed through the expansion device and becomes a mixture of low-pressure liquid and gas.



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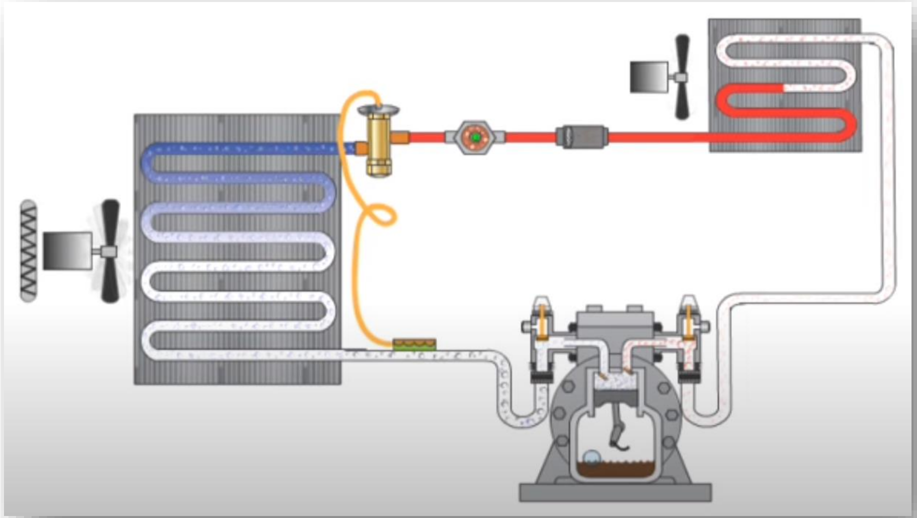
Evaporation

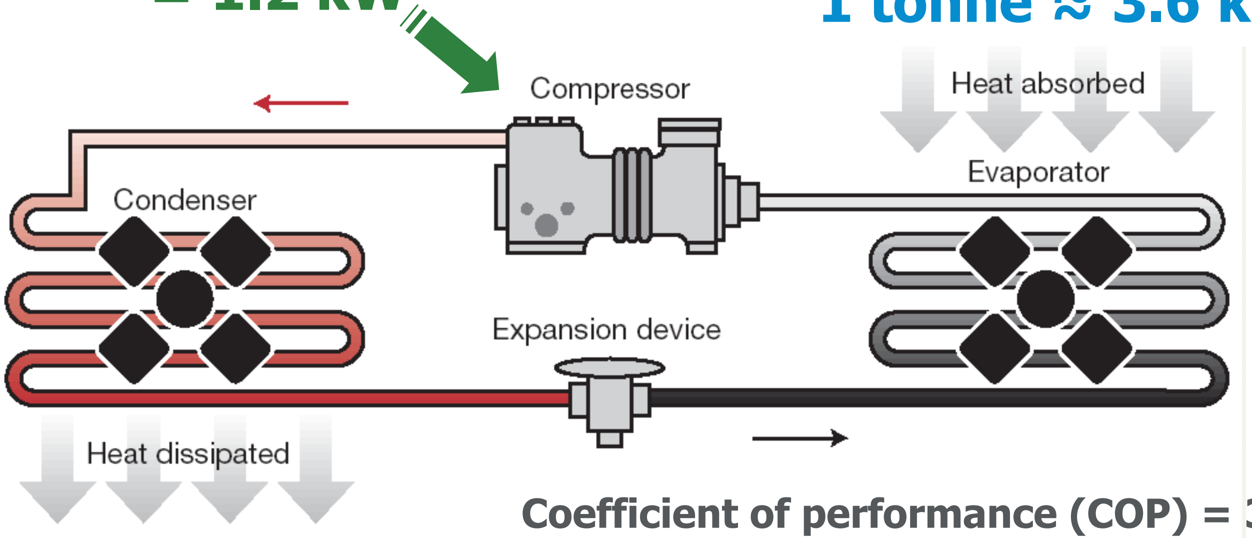
The low pressure and temperature liquid/gas is evaporated, producing cooling, and the resulting low-pressure gas is compressed again.



In summary

Power in = 1.2 kW

Cooling effect = 1 tonne ≈ 3.6 kW



Coefficient of performance (COP) = 3

Heat = 4.8 kW

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Terminology

Tonne = 12,000 British thermal unit (BTU)/hr (cooling capacity)

COP = coefficient of performance

COP_R = rate of heat removal / power

COP_H = rate of heat delivery / power

SCOP = seasonal COP

EER = energy efficiency ratio = BTU/Wh

SEER = seasonal EER (currently **SEER2** – more accurate/real world test)

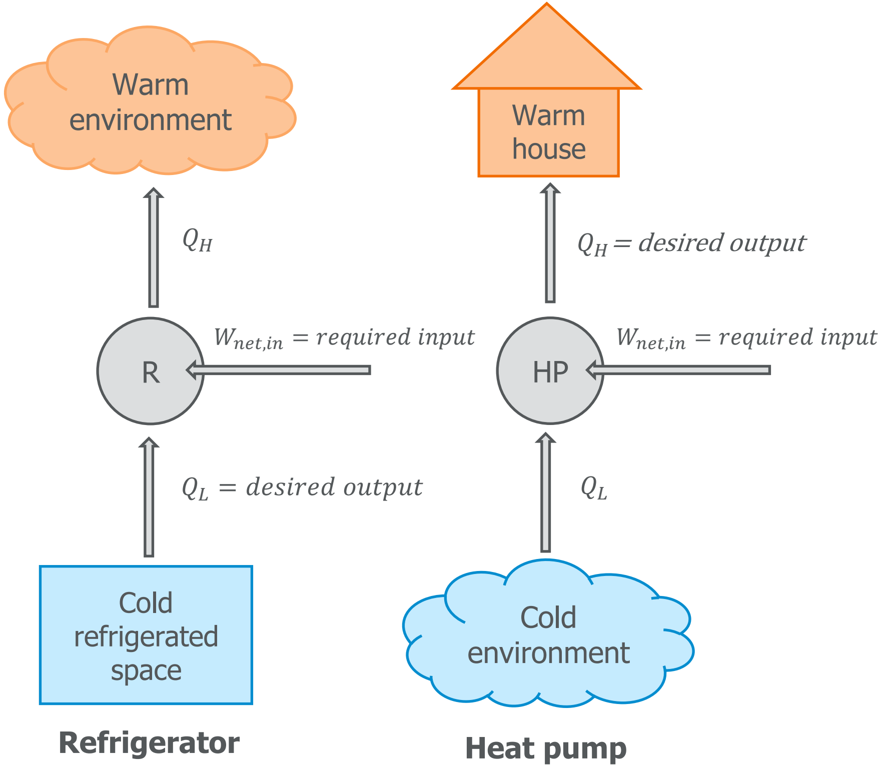
SCOP = SEER / 3.412

Coefficient of performance

Refrigeration (R) and heat pumping (HP)

$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{net,in}}$$

$$COP_{HP} = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Heating effect}}{\text{Work input}} = \frac{Q_H}{W_{net,in}}$$



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Are there adaptations for advanced cooling systems?

- In almost all instances…none!
  - Most advanced cooling systems (ACSs) use vapour compression systems in some form,
  - All the aforementioned principles and efficiencies apply equally to ACSs.

- ACSs seek to:
  - Minimize the difference between evaporating pressure and condensing pressure – LLCS.
  - Use equipment and devices that are significantly more efficient, such as compressors, heat exchangers and expansion devices.
  - Make use of storage devices to allow minimizing the lift and increasing part-load efficiencies.

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A word on transcritical systems

- A type of advanced cooling system, but for specific applications, is called *transcritical*.
- It is mostly used for refrigeration purposes such as in grocery stores and arenas.
- It uses a vapour compression cycle using CO_2 as its refrigerant.
- In this cycle, the refrigerant never condenses, so there is no condenser!
    - It has a gas cooler: undersized gas cooler frequently need to be sprayed in the summer, often using a garden hose and sprinkler!

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What is transcritical and why use CO_2

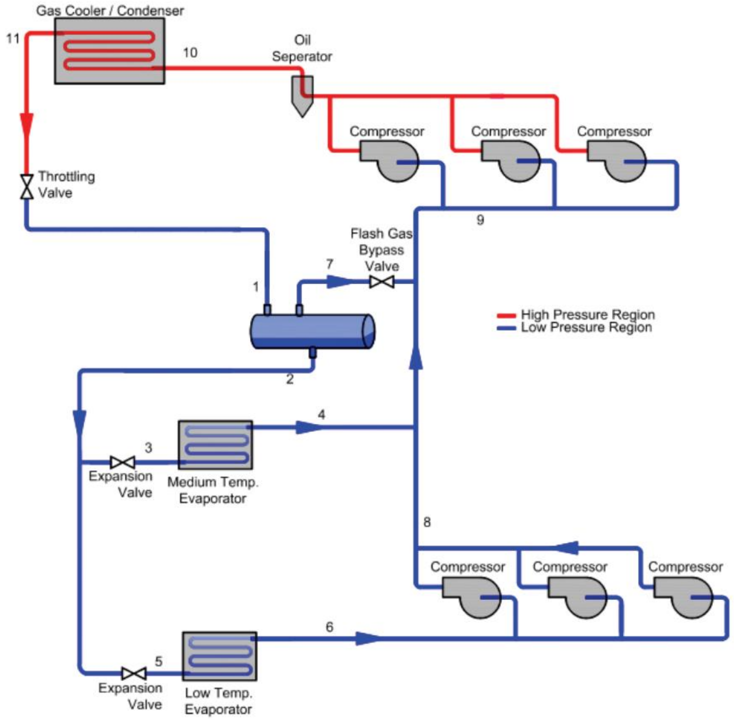
- What is transcritical CO_2 refrigeration?
  - In transcritical systems, the CO_2 operates sometimes or exclusively above the critical point.
  - Transcritical CO_2 systems include a gas cooler to dissipate heat and utilize a high-pressure expansion valve to control introduction into the evaporator.

- Benefits of transcritical CO_2 refrigeration
  - Environmental benefit from lower greenhouse gas (GHG) from the refrigerant
  - Lower refrigerant cost
  - Heat reclaim potential

Typical transcritical booster system

Multistage cycle

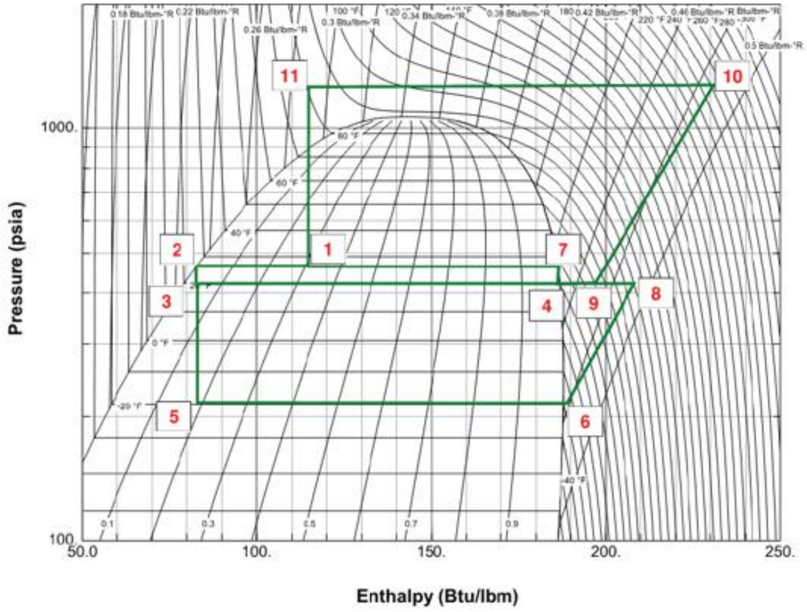
- The system is divided into two stages, low and high.
- The low stage operates at around 180 psig in low pressure and 400 psig in medium pressure.



Typical Transcritical Booster System Continued

Multistage cycle

- High-stage compressors take low stage discharge, medium temperature vapour and flash gas and compresses them up to a pressure sufficient to reject the heat from the system in the gas cooler/condenser.
- Gas cooler: refrigerant does not technically condense if it is operating in transcritical mode.
- High-side pressure can reach over 1,400 psig!



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Energy-efficient advanced cooling technologies

Benefits of advanced cooling systems

- When considering ACSs, energy is one of the main benefits.
- Other benefits vary by type of system considered but often include:
  - Reduction in peak demand
  - Load shifting capabilities
  - Better comfort conditions (advanced controls)
  - Improved humidity control (dehumidification)
  - Reduction in maintenance cost (e.g. no cooling tower)

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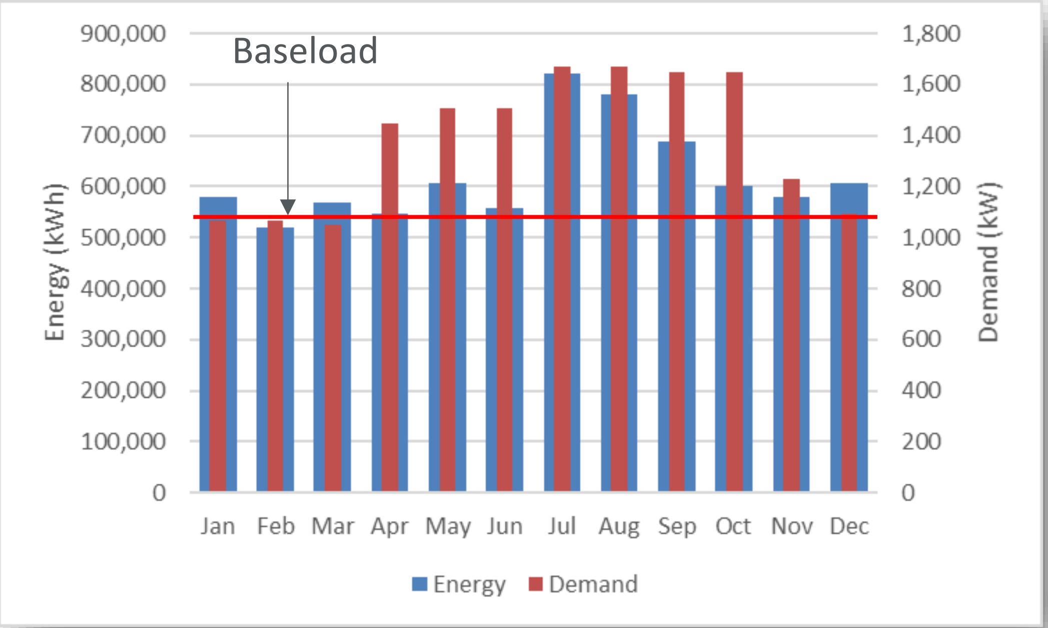
Know your cooling load and usage

- The first step when considering ACSs is to establish your current cooling usage and demand for existing buildings or predicted values for new constructions.
- Projections for future climate may be considered through available future weather data files. (https://climatedata.ca/resource/an-in-depth-look-at-weather-files/)

Baseload analysis with monthly data

- When determining electric baseload, look at both demand and energy.
- When was the chiller operating?
- What is the likely peak cooling load?



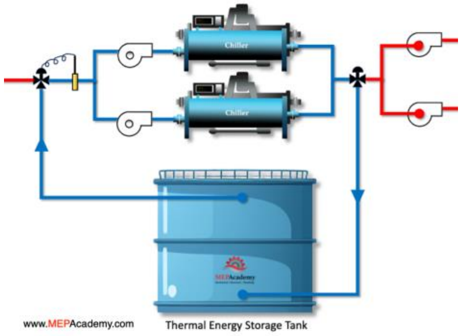
What is the electricity ratio for cooling?

- Using the baseload approach, it can be estimated that:
- Cooling represents approximately 10% of total electricity consumption;
- The demand profile allows for estimating a peak cooling demand of 600 kW with a corresponding peak cooling load of 2,900 kW based on a central cooling plant with centrifugal chillers (COP ~ 4.8).
- For cost estimations, **use energy and demand rates separately**, not the blended rate.

Cold storage

Ice and chilled water storage options:

- Cold storage is typically used for demand management.
- Most benefits are from demand management rather than energy savings.
- Energy efficiency gains are highly dependant on how the storage is charged and the overall heat losses of the storage system.



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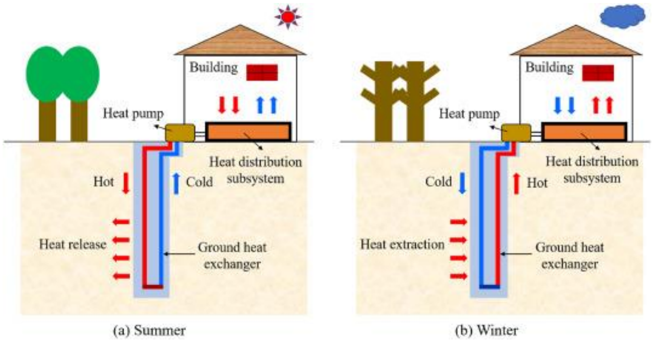
Ice versus water storage

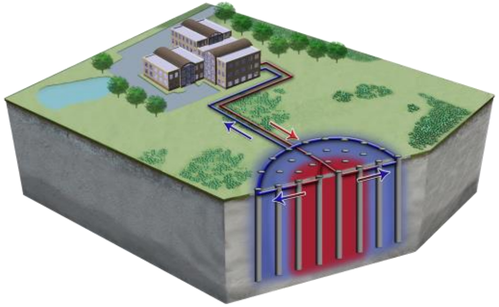
- A 6,000 L tank of water chilled to 2°C provides about 70 ekWh of cooling.
- A 6,000 L tank of ice provides about 550 ekWh of cooling.
- The maximum daily cooling load for a 1,000 m^2 office area is typically 1,100 ekWh and the peak hourly load is typically 50 to 100 ekWh.
  - Up to 8,000 L of water storage is needed to shift one hour of peak cooling!
- Using a chiller to build ice reduces its efficiency by 30 to 35%:
  - Freezing one 6,000 L tank will consume 40 kWh more electricity than direct cooling.

Ground-source heat pumps

- Conventional - direct utilization (DU) design
- With storage - borehole thermal energy storage (BTES) and grid amplified building energy seasonal storage (GABESS)



https://www.sciencedirect.com/topics/engineering/ground-source-heat-pump-system



https://underground-energy.com/our-technology/btes/

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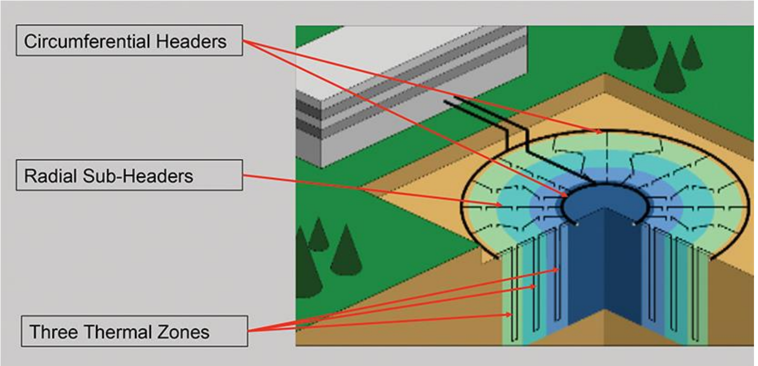
GABESS systems

- In a GABESS geothermal system, a bore field is dedicated to seasonal cold storage and a second bore field to seasonal hot storage.
- The bore fields can be charged during off-peak periods in the summer for the hot field and in the winter for the cold field.
- Charging is done using an air-source heat pump. The cold field can also be charged using natural cooling (e.g. adiabatic cooler) in the winter rather than only with the heat pump.



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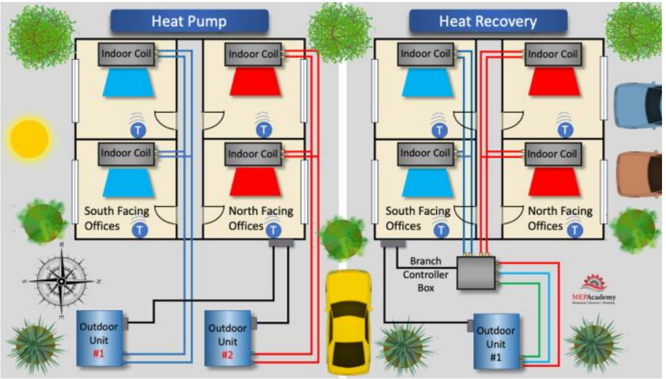
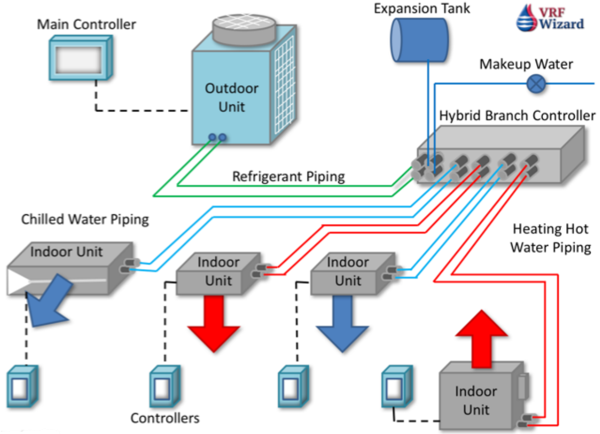
Variable refrigerant flow

Types:

- Heat pumps – two pipes
- Heat recovery – three pipes
- Hybrid heat recovery
  - Indoor distribution using water to reduce the amount of refrigerant within the building (approx. 30%-40% less).





https://vrfwizard.com/mitsubishi-vrf-hybrid-system/

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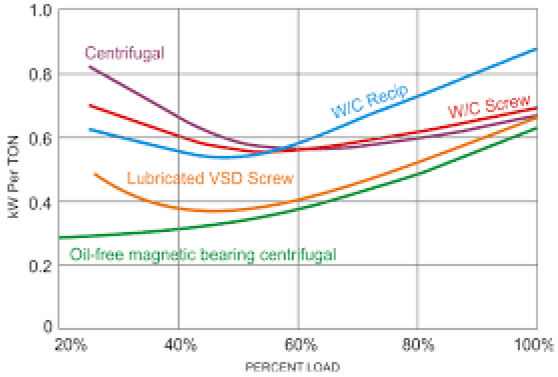
Magnetic bearing chillers

- Magnetic bearings eliminate the need for oil:
  - Oil reduces efficiency in traditional chillers.
- Integrated variable frequency drives (VFDs):
  - VFDs optimize compressor speed and control inlet guide vanes to precisely match the cooling load, ensuring efficient operation even at lower loads.
- Stable operation at varying loads:
  - Magnetic bearing chillers maintain stable operation, very efficiently at low loads, with significant variations in condenser water temperatures and chilled water setpoints.
- Even if they are becoming common, they are often not used optimally.



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District cooling – a possible advanced approach

- District cooling systems are not inherently more efficient!
- They represent a **transfer of responsibility** for the production performance of the required cooling:
    - The efficiency of cold production is dependant on the design of the district cooling system – e.g. deep lake water cooling is **very** efficient, said to use 10% of the energy of a conventional system.
    - Distribution energy and losses must be considered.
    - It is well suited for thermal storage and peak demand management.
    - In-building distribution system efficiency and optimal control remain central to optimal district cooling system performance.

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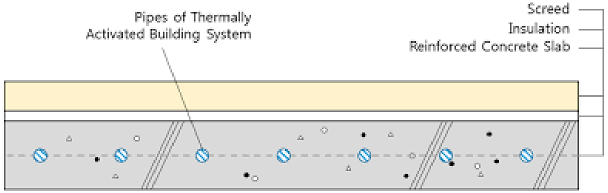
Thermally activated building structures (TABSs)

Thermally activated building structures (TABSs) are a type of radiant heating and cooling system where pipes embedded within structural building elements (floors, ceilings or walls) circulate water (or another fluid) to control the temperature of surfaces. Such systems leverage building thermal mass (ability to store heat) to regulate indoor temperatures, providing both heating and cooling.

- **Energy efficiency:** TABSs can be highly energy efficient, especially when used with low-temperature heating and cooling sources like geothermal energy or waste heat.
- **Thermal comfort:** By controlling the surface temperature, TABSs provide a more uniform and comfortable temperature distribution compared to traditional HVAC systems, with less air movement and temperature fluctuations. MPC/MFC is a good complement to a TABS.



- **Reduced energy costs:** By utilizing building thermal mass, TABSs reduce peak energy demand and potentially lower energy consumption overall.

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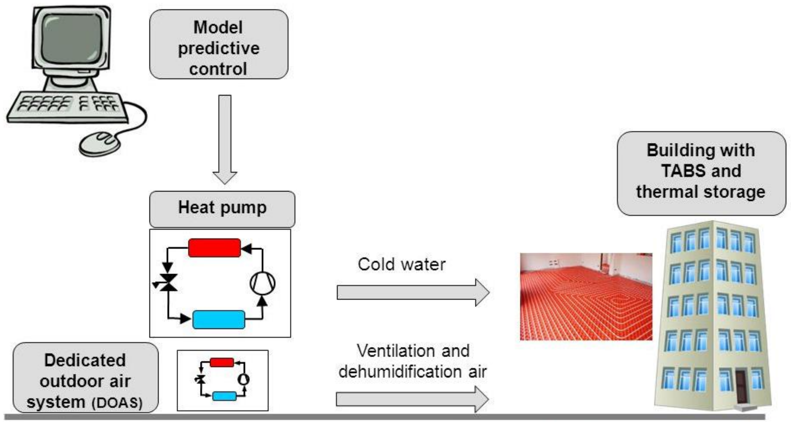
Low-lift cooling systems (LLCSs)

- Low-lift cooling systems consist of a high-efficiency, low-lift chiller, radiant cooling, thermal storage, and model predictive control (or model-free control) to pre-cool thermal storage overnight.
- An effective design approach for low-lift cooling is to use integral building thermal mass for thermal storage.

Low-Lift Cooling System (LLCS) delivers cold water to Thermally Activated Building Surfaces (TABS). Cooling is optimized by the Model Predictive Control (MPC) algorithm.



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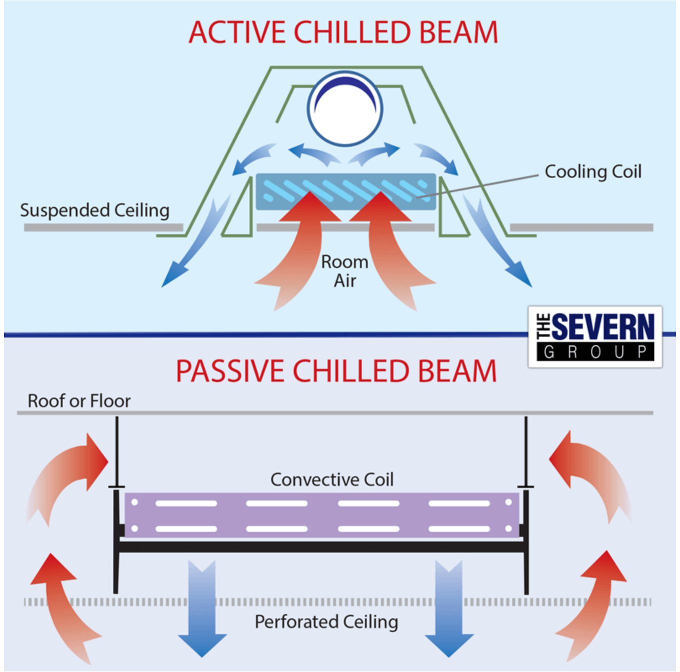
Chilled beam systems

Chilled beam systems can be used in LLCSs, but only if the cooling plant is properly designed:

- Chilled beams require warmer chilled water, providing possible higher chiller efficiency.
- Primary air needs colder water to dehumidify the primary air.
  - A separate system is ideal.



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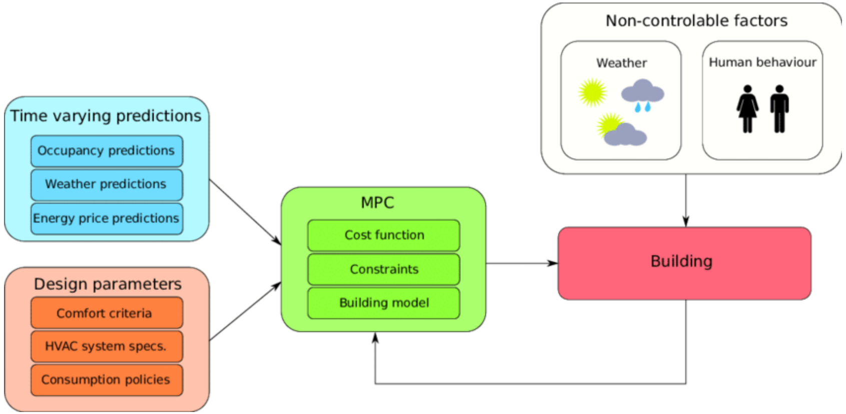
Optimized control strategies and BAS integration for advanced cooling systems

Model predicitve control (MPC)

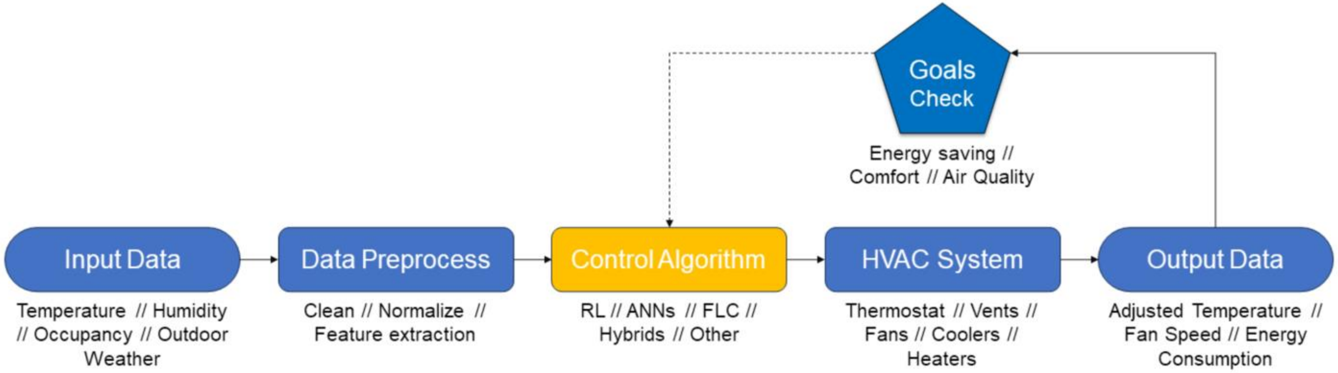
Model-based predictive controls use energy consumption trends and expected changes in environmental conditions and occupancy to adapt and optimize building operation:

- Optimal control of district heating and cooling systems
- Management of ice banks for cooling applications
- Control of radiant heating and cooling systems
- Short-term office temperature control
- Demand response



Model-Free Control (MFC)

Model-Free Control Leverages data analytics and AI-driven forecasting to enable proactive system adjustments to optimize performance of the system based on upcoming weather, occupancy, etc.



Model-Free HVAC Control in Buildings: A Review, Energies 2023, 16(20), 7124

Some control aspects to be considered

- The colder the supply temperature, the lower the plant efficiency.
- Low temperature differential (low Delta T syndrome) is a significant source of lower performance for ACSs and has multiple root causes:
  - Poor supply air temperature (SAT) settings
  - Dirty coils
  - Over-pumping
  - Bypassing flow
  - Improperly setup coils and heat exchangers
  - And more
- Know your system and its part-load performance and avoid using rules of thumb for controls, especially for ACSs.

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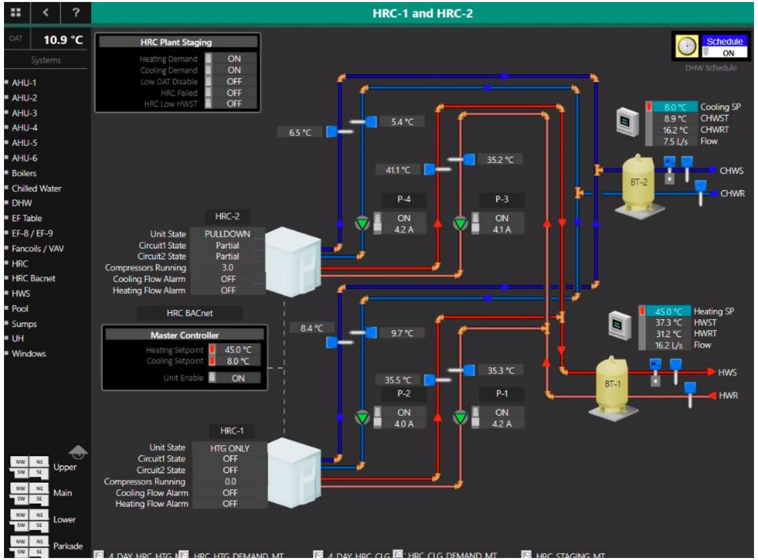
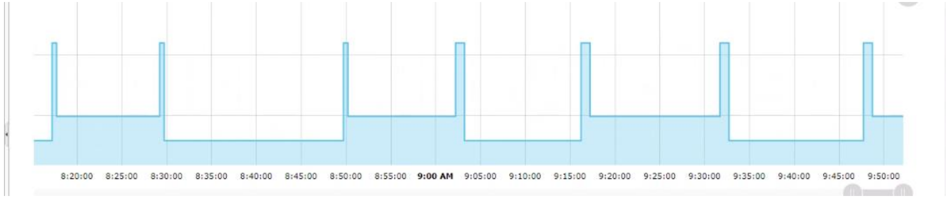
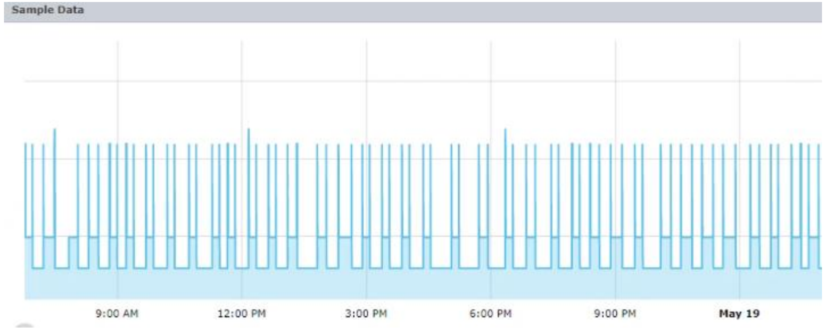
The risk of poor control

- An advanced system can result in lower efficiency than to an old conventional one!







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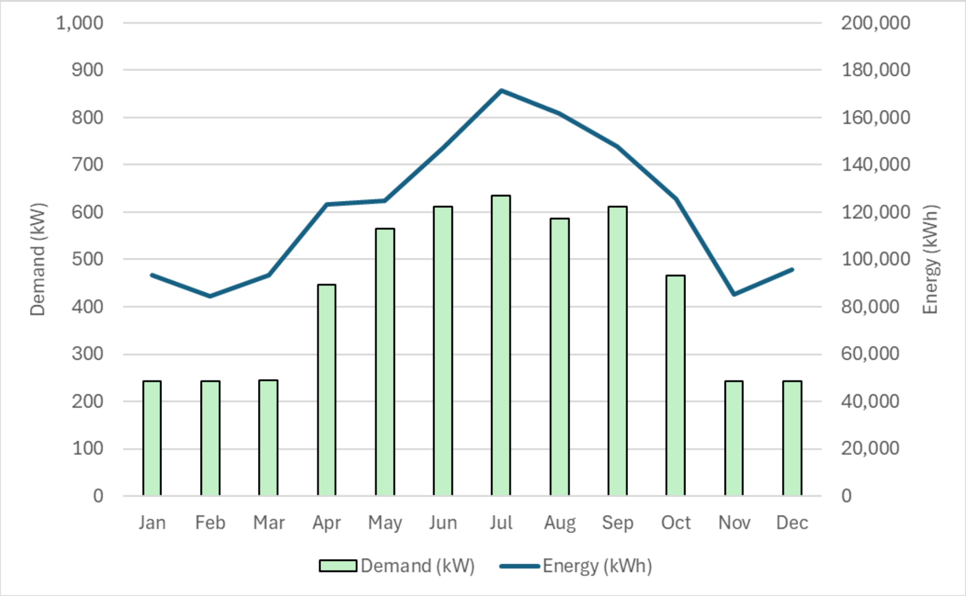
Financial benefits, incentives, and funding opportunities available for cooling system retrofit projects

An office building in Toronto

- 10,000 m² office building
- 21.7 kWh/ft²/year
- Electricity: 13.51 kWh/ft²/year
- Natural gas: 8.16 kWh/ft²/year

Annual costs of $221,000/yr

- Electricity: $196,000
- Natural gas: $25,000



Based on demand price of $10/kW/month and energy price of $0.10/kWh

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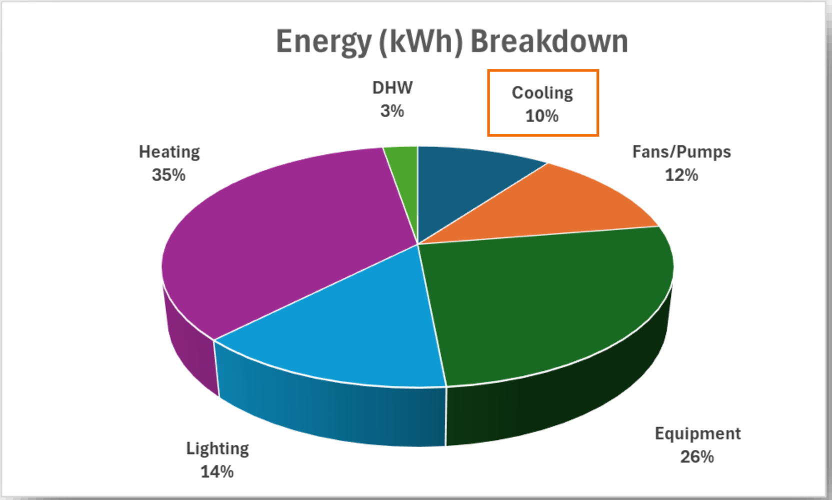
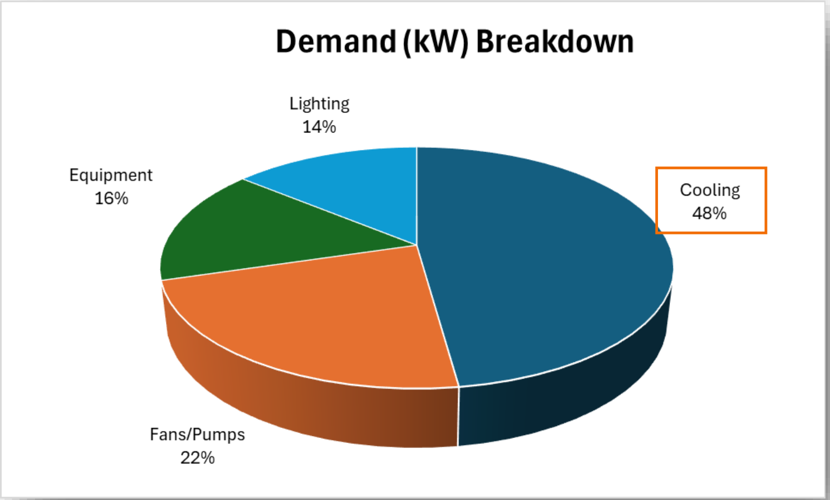
Impact of cooling on demand, energy and cost

- Cooling is 18% of annual costs





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Cost reduction with advanced cooling (Class B)

- Assuming a 40% energy reduction and a 30% demand reduction:
- Energy saved = 95,000 kWh and $9,500/yr
- Demand saved = 522 kW-months and $5,200/yr
- Total potential savings of $14,700/yr

Based on demand price of $10/kW/month and energy price of $0.10/kWh

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Cost reduction with advanced cooling (Class A)

- Assuming a 40% energy reduction and a 30% demand reduction:
- Energy saved ~ 95,000 kWh and $3,000/yr
- Demand saved ~ 522 kW-months and $5,200/yr
- Reduction in GA ~ 90 kW and $27,000/yr
- Total potential savings of $35,200/yr

Based on demand price of $10/kW/month and energy price of $0.03/kWh and GA price of $60/kW/peak

Cost reduction with thermal storage only (Class A)

- Thermal storage capacity required for three hours:
  ~ 3,400 kWh
- Reduction in contribution to each Global Adjustment (GA) peak:
- ~ 300 kW

Total potential savings of $90,000/yr.

Based on demand price of $10/kW/month & energy price of $0.03/kWh & GA price of $60/kW/peak

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Applicable incentives

Energy Performance Program

- $0.15/kWh for energy consumed on weekdays between June 1 and September 30 (inclusively), during the hours of 3 p.m. and 9 p.m. (EDT)
- $0.04/kWh for savings during non-summer peak hours

Retrofit Program

- $1,800/kW of peak demand savings or $0.20/kWh of energy savings for custom projects
- Unitary incentive amounts for energy-efficient products

Existing Building Commissioning Program

- Staged incentives for investigation, implementation and persistence of savings.

Questions and answers

- Any questions?

Save on Energy's Capability Building Program

- Save on Energy's Capability Building Program helps increase awareness about energy-efficiency opportunities, enhance knowledge and develop skills in organizations and communities across Ontario so they can undertake energy-efficiency actions and participate in Save on Energy programs.
- The program includes tools such as workshops, webinars, training courses, coaching, peer learning and information resources, including guides and videos.

Learn more at https://saveonenergy.ca/Training-and-Support
Register at www.saveonenergytraining.ca

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Training courses – incentives

Save on Energy offers incentives of up to 50% for ~20 training courses, plus certification exam fees, including:

- Achieving Net-Zero Buildings
- Energy Management and the ISO 50001 Standard
- HVAC Optimization for High Performance Sustainable Buildings
- Certified Energy Manager (CEM)
- Certified Measurement and Verification Professional® (CMVP)

Learn more at https://saveonenergy.ca/Training-and-Support/Training-Courses

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Training courses – incentives for Enbridge customers

Enbridge customers are eligible for incentives of up to 75% for three courses:

- Dollars to $ense Workshops: up to $500 a day
- Certified Sustainable Building Operator® (CSBO): up to $2,250 for course fees
- Certified Energy Manager® (CEM): up to $2,500 for course fees

Post-webinar support

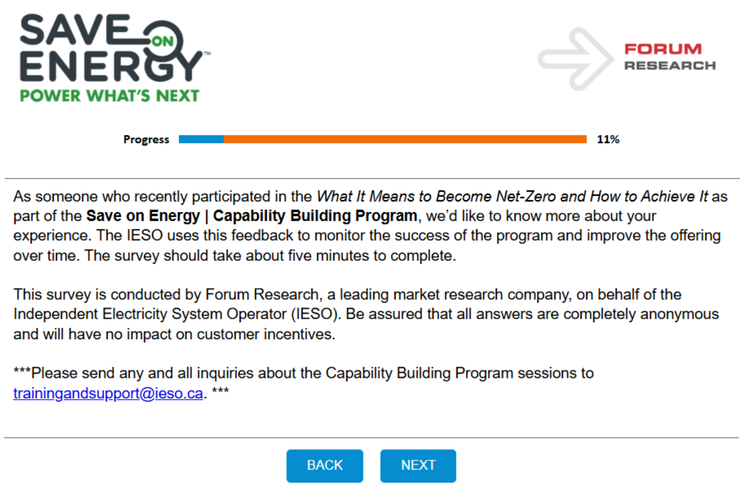
One-on-one coaching: tailored support for managing energy resources effectively

Post-webinar support intake form

Coaching sessions conducted virtually: phone, video calls and email

Designed for organizations, new or old, seeking guidance

Upcoming survey: we want your feedback!



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FORUM RESEARCH

Progress 11%

As someone who recently participated in the *What It Means to Become Net-Zero and How to Achieve It* as part of the **Save on Energy | Capability Building Program**, we'd like to know more about your experience. The IESO uses this feedback to monitor the success of the program and improve the offering over time. The survey should take about five minutes to complete.

This survey is conducted by Forum Research, a leading market research company, on behalf of the Independent Electricity System Operator (IESO). Be assured that all answers are completely anonymous and will have no impact on customer incentives.

***Please send any and all inquiries about the Capability Building Program sessions to trainingandsupport@ieso.ca. ***

BACK NEXT

- Check your email! A survey is coming your way soon.
- Why? Help us improve our training programs.
- Who? Conducted by Forum Research on behalf of the IESO.
- Time? Takes only five minutes to complete.
- Confidentiality: your responses are anonymous and will not impact participation or incentives.

The survey will be sent from:
surveyinfo@forumresearch.com

Thank you!

SaveOnEnergy.ca/Training-and-Support

trainingandsupport@ieso.ca

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