Natural Resources Canada | Ressources naturelles Canada

Major Energy Retrofit Guidelines

for Commercial and Institutional Buildings

OFFICE BUILDINGS

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Natural Resources Canada's Office of Energy Efficiency
Leading Canadians to Energy Efficiency at Home, at Work and on the Road

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DISCLAIMER

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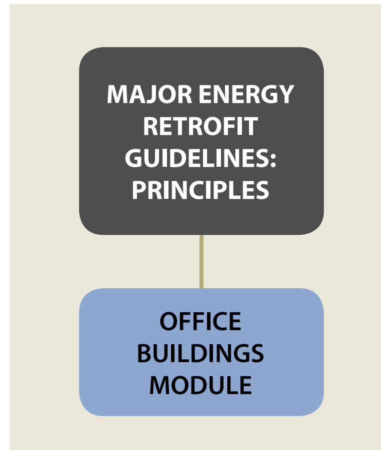
ENERGY RETROFIT OPPORTUNITIES IN OFFICE BUILDINGS

The Office Buildings Module complements the proven energy retrofit approach outlined in the Principles Module. This module, which should be considered as a companion document to the Principles Module, discusses strategies, priorities and opportunities specific to office buildings.



The Office Buildings Module is divided into three parts:

- **Energy Retrofit Opportunities in Office Buildings**: Provides an overview of Canadian office buildings. Subsections present background information on each retrofit stage and key retrofit measures, with a focus on small and medium-sized office buildings.
- **Case Study:** The case study showcases a successful major energy retrofit project.
- **My Facility**: This take-away section provides an energy efficiency opportunity questionnaire to assist you in identifying opportunities in your facility.

Office buildings overview

Call to action

Commercial and institutional buildings account for approximately one eighth of the energy used in Canada.[1] Over the next 20 years, the stock of commercial buildings is projected to grow by over 60%, and it is expected that 40% of existing buildings will be retrofitted.[2]

Office buildings refer to facility spaces used for general office, professional and administrative purposes. The floor area includes all supporting functions such as kitchens used by staff, lobbies, atriums, conference rooms and auditoriums, storage areas, and stairways.

1 Natural Resources Canada. 2013. *Energy Use Data Handbook*, 1990–2010.

2 Commission for Environmental Cooperation. 2008. *Green Building Energy Scenarios for 2030*.

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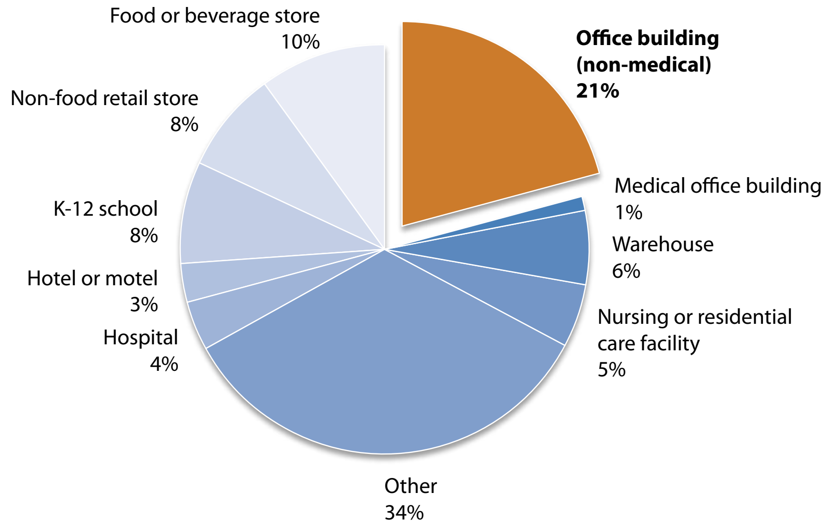
Case in point:
Bentall Kennedy and RBC
Mississauga, Ontario

Tenants' needs were top-of-mind when Bentall Kennedy and RBC installed a digital addressable lighting interface (DALI) system. To minimize the impact on tenants, the operations teams coordinated contractors' schedules and held regular meetings with floor representatives to provide information. The DALI system controls and adjusts the light output of every fixture based on occupancy, daylight and operating hours, providing a high degree of flexibility for the building's tenants, who work varied hours.

"A key element to the success of the project was the ongoing sharing of information with building occupants."

Source: CivicAction Alliance, Race to Reduce

Figure 1. Commercial/institutional energy use by subsector



Data source: NRCan 2012. *Survey of Commercial and Institutional Energy Use – Buildings 2009: Detailed Statistical Report.*

Figure 1 shows that within the commercial and institutional buildings sector, office buildings are the largest single energy-using subsector, accounting for more than one fifth of energy use. As the building stock ages, a tremendous opportunity exists to undertake major retrofits that will improve the energy performance of office buildings across the country.

By implementing a proven major energy retrofit strategy, beginning with benchmarking using ENERGY STAR Portfolio Manager, you can positively impact your building's bottom line.

Opportunities and challenges

The financial benefits of more energy-efficient buildings are widely known. Many organizations have invested in energy efficiency to improve the work environment and employee productivity, to improve building performance and financial returns, to cut energy costs, and to demonstrate their commitment to sustainability.

Opportunities

Energy savings are one of the principal benefits of a major retrofit project. Energy represents 30% of a typical office building's costs and is a property's single largest operating expense. Energy retrofits improve the operational bottom line. Energy savings can lead to higher net operating income and a higher building valuation. Lower operating costs can also make leasing rates more competitive, improving your building's competitive position in the leasing market. Lower energy consumption also limits your vulnerability to energy price fluctuations and reduces your greenhouse gas emissions.

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Beyond energy savings, a notable benefit of major energy retrofits is often an improved indoor environment. A high-quality indoor environment, including access to daylight and improved indoor air quality, leads to greater occupant comfort, health and productivity and tends to result in higher occupancy rates.[3] Energy-efficient buildings with high-quality indoor environments also have the opportunity to seek green building certification, which recognizes environmentally responsible, high-performance buildings that are valued in the real estate market by investors and tenants.

Finally, benchmarking your building's energy performance presents an opportunity in itself. Benchmarking at the start of a retrofit process and again during improvement phases allows you to measure relative improvements, justify expenditures and establish a new baseline to help monitor future performance.

Challenges

Common leasing arrangements can pose a barrier to implementing energy retrofits because of the disconnect between who pays for the retrofits and who receives the benefits. Such an arrangement is commonly referred to as a "split incentive" between the owner and the tenant. As a result, when it comes to financing energy retrofits, building owners and tenants often perceive the negotiation process as a zero-sum game of winners and losers, where one party pays while the other benefits. A survey of decision makers responsible for energy use in buildings published by the Institute for Building Efficiency in 2012[4] identified split incentives as one of the barriers to capturing energy savings in buildings.

Green leases (sometimes referred to as aligned leases, high-performance leases or energy-efficient leases) are one way to remove this barrier. Owners and tenants can agree on lease terms that share the benefits of lower utility bills, giving owners an incentive to invest and tenants an opportunity to achieve savings.

Two organizations have developed guides and templates for green leases:

- The Real Property Association of Canada's (RealPAC) *Green Lease Guide for Commercial Tenants,* available on their website: **realpac.ca/?page=GreenLeaseGuidefo**
- Building Owners and Managers Association's (BOMA) *Commercial Lease: Guide to Sustainable and Energy Efficient Leasing for High-Performance Buildings*, available for sale on their website: **store.boma.org/shopping_product_detail.asp?pid=52168**

Identify major retrofit triggers unique to your facility in order to optimize the timing of your projects and incorporate energy efficiency into your capital plan. For more information, see Section 2 of the Principles Module.

You should also plan to meet, or ideally exceed, the minimum performance requirements outlined in the most recent version of the *National Energy Code of Canada for Buildings* (NECB).

3 For a summary of recent research, see Rocky Mountain Institute *How to Calculate and Present Deep Retrofit Value: A Guide for Owner-Occupants*. p. 64. **rmi.org/retrofit_depot_deepretrofitvalue**.

4 Institute for Building Efficiency. **buildingefficiencyinitiative.org/resources/2012-eei-global-results-presentation**.

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Another significant challenge relates to the impact on the building's tenants. Unless the building has been vacated, tenants will be affected by any changes and should, therefore, be involved in the planning process. Loss of productivity as a result of the retrofit program will diminish the return on investment, so careful planning and timing is necessary.

Note: 1 gigajoule (GJ) is equal to 278 equivalent kilowatt-hours (ekWh), or the energy content of approximately 27 cubic metres (m^3) of natural gas.

Energy use profile

When planning your major retrofit project, consider the energy use profile for a typical Canadian office building. Although specific energy use profiles will vary, the example below can be used to provide a general indication of how you use your energy.

Figure 2. Energy use by energy source for the C/I sector

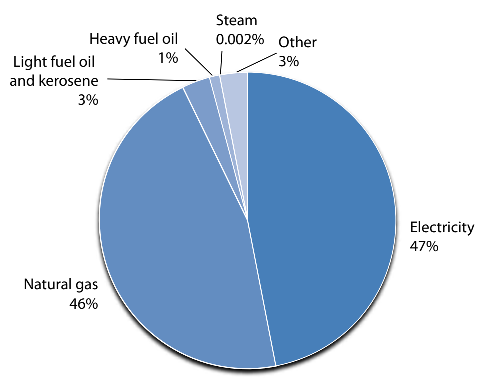
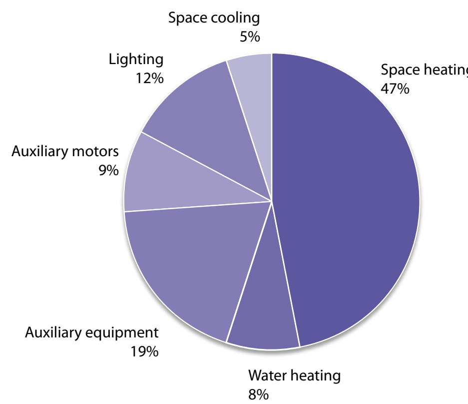


Figure 3. Energy use by end use for the C/I sector



Data source: NRCan 2011 Comprehensive Energy Use Database – CI Sector

Figure 2 shows the breakdown of consumption by energy source. Natural gas and electricity provide approximately equal shares of a typical commercial/institutional facility's energy requirements. Figure 3 shows the breakdown of consumption by end use. Space heating represents almost half of office building energy use, followed by auxiliary equipment (i.e. plug loads, such as computers and servers) and lighting.

Energy use intensity (EUI) in office buildings can vary widely and is influenced by weather conditions and specific operating characteristics such as weekly hours of operation, number of office workers, number of personal computers and servers, and the percentage of the facility's space that is heated and cooled.

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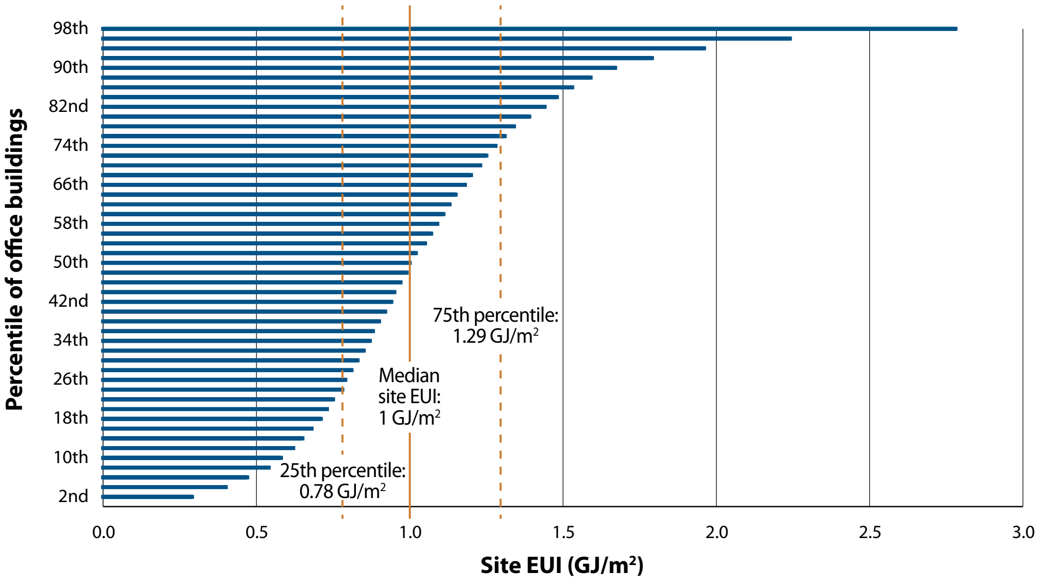
Figure 4 presents the overall distribution of normalized EUI for a Canada-wide sample of office buildings.

Figure 4. Distribution of site energy use intensity for Canadian office buildings



Source: ENERGY STAR Portfolio Manager, 2016

The solid vertical line shows that the median site EUI for office buildings entered in ENERGY STAR Portfolio Manager is 1 GJ/m^2 (25.81 ekWh/sq. ft.).[5] Buildings in the 25th percentile of this data set have EUIs lower than 0.78 GJ/m^2 (20.13 ekWh/sq. ft.), and those above the 75th percentile have EUIs greater than 1.29 GJ/m^2 (33.29 ekWh/sq. ft.). The national median EUI according to the *Survey of Commercial and Institutional Energy Use* 2009 is 0.9 GJ/m^2 (23.2 ekWh/sq. ft.).

Building owners and facility managers are encouraged to benchmark and track their energy performance using ENERGY STAR Portfolio Manager, the most comprehensive and only standardized energy benchmarking tool in Canada for commercial office buildings. Benchmarking allows you to compare your current energy use against past performance as well as against that of similar buildings. The results provide an excellent baseline to measure the impact of energy and water efficiency retrofits and are a powerful motivator to take action to improve building energy performance.

For many commercial and institutional building types, including office buildings, ENERGY STAR Portfolio Manager provides an ENERGY STAR rating that scores energy performance on a scale of 1 to 100, relative to similar buildings.

An ENERGY STAR score provides a snapshot of your building's energy performance. It does not by itself explain why a building performs a certain way or how to change the building's performance. It does, however, help you assess how your building is performing relative to its peers and identify which buildings in your portfolio offer the best opportunities for improvement.

5 The median EUI for office buildings according to the *Survey of Commercial and Institutional Buildings – 2009* is 1.20 GJ/m^2.

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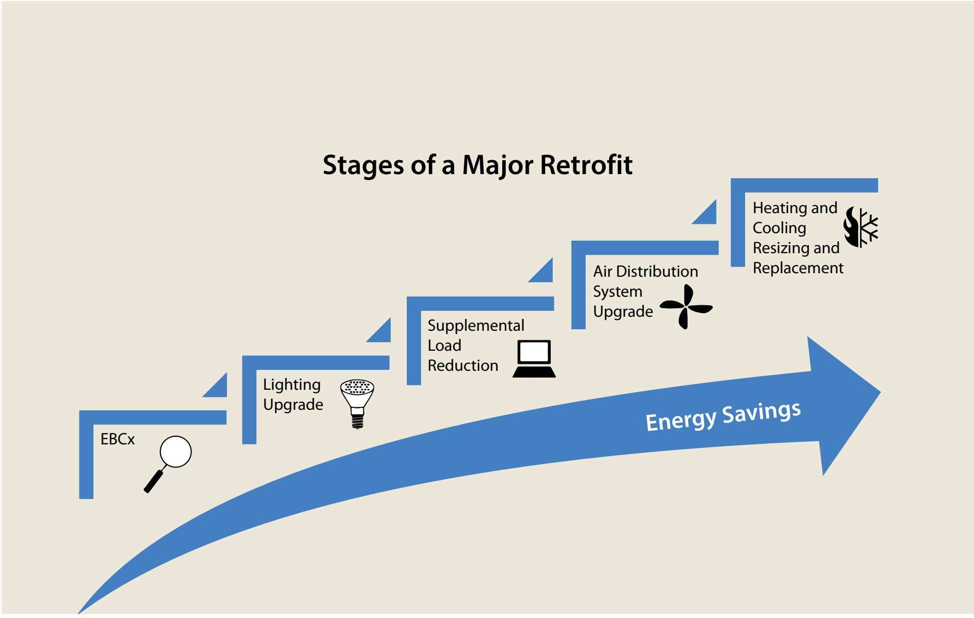
Staging project measures



As discussed in the Principles Module, implementing major retrofits in a staged approach is the most effective way of improving facility energy performance.

Each stage includes changes that will affect the upgrades performed in subsequent stages, thus setting the overall process up for the greatest energy and cost savings possible.

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Existing building commissioning

Commissioning is a first-order activity to improve an existing building's energy performance. Studies have shown that existing building commissioning (EBCx) in office buildings typically results in 22% energy savings, with a simple payback period of 1.1 years.[6]

Savings from commissioning are achieved by improving building operations and restructuring maintenance procedures. Natural Resources Canada's (NRCan) *Recommissioning Guide for Building Owners and Managers*[7] shows you how to reduce operational expenses through improved building operations.

In Section 1 of the Principles Module, we explained how an EBCx program has four phases: assessment, investigation, implementation and hand-off.

During the assessment and investigation phases, EBCx involves a detailed survey of the existing systems, including documenting the configuration and sequence of operations. The result is a collection of operational knowledge as well as a list of measures to correct any deficiencies.

During the implementation phase, any deficiencies are corrected, and the savings opportunities identified during the assessment and investigation phases may be implemented. The overall philosophy of the work done at this stage is to ensure that all systems, equipment and building controls are properly configured and fully operational.

The measures listed on the next page represent some of the typical improvements made under EBCx. It is important that all measures be implemented with suitable commissioning to ensure that system retrofits are optimized.[8]

Case in point:
World Exchange Plaza
Ottawa, Ontario

In 2011, Bentall Kennedy established a tenant engagement program at the World Exchange Plaza to reduce energy consumption and costs. Stemming from one-on-one meetings with tenants, two EBCx measures emerged. The first was to change the base building lighting from automatic activation at 6 a.m. to manual activation upon tenant arrival. The second was to change the Saturday HVAC schedule from 8 a.m. to 1 p.m. to tenant demand only. These two measures alone saved more than 525,000 kWh/year.

Source: CivicAction Alliance, Race to Reduce

6 Mills, E., Lawrence Berkeley National Laboratory. 2009. *Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions*. Prepared for California Energy Commission.

7 *Building Operation Optimization: Recommissioning Guide for Building Owners and Managers*. **nrcan.gc.ca/energy/efficiency/buildings/research/optimization/recommissioning/3795**.

8 The Canadian Standards Association's Z320-11 standard provides guidelines for the commissioning of buildings and all related systems and has been developed to deal with buildings and their major systems as a whole, rather than as individual stand-alone components. It can be applied to new construction as well as renovations of existing buildings or facilities. **http://shop.csa.ca/en/canada/building-systems/z320-11-/invt/27032582011**.

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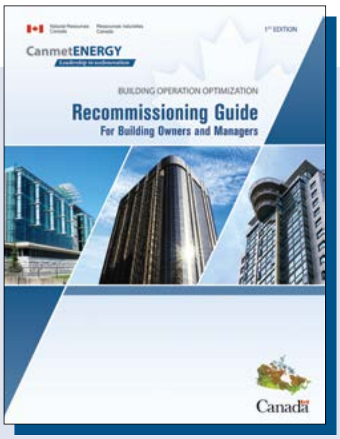

For more information on existing building commissioning, see NRCan's *Recommissioning Guide for Building Owners and Managers* to learn how to reduce expenses and increase revenue through improved building operations.

EBCx measure list

✓ Confirm lighting control schedule	✓ Calibrate building automation system sensors
✓ Schedule air handling system	✓ Employ optimum start control
✓ Employ temperature setback during unoccupied hours	✓ Correct over-ventilation
✓ Verify free cooling operation (air side)	✓ Correct imbalances between supply air and exhaust air
✓ Turn off heating coil valves in the cooling season	✓ Verify humidification set point
✓ Widen zone temperature deadband	✓ Sequence boilers through controls
✓ Reset supply air temperature	✓ Reset boiler supply temperature
✓ Close outside air dampers during morning warm-up in the heating season	✓ Sequence chillers through controls
✓ Perform early morning flush in the cooling season when conditions allow	✓ Employ chilled water reset
✓ Employ static pressure reset	✓ Employ condenser water reset
✓ Correct damper operation	✓ Take full advantage of available cooling towers
✓ Lower variable air volume box minimum flow set points	✓ Repair missing or damaged pipe insulation

- **Confirm lighting control schedule:** Confirm that the lighting control schedule matches the actual occupancy and explore opportunities to reduce hours of operation by reducing or eliminating after-hours activities (e.g. cleaning) by moving them to existing occupied hours. Controls should typically be configured to turn interior lights off at a set time, but not on; occupants are expected to turn lights on when they arrive in the morning.
- **Schedule air handling system:** Equipment that runs longer than necessary wastes energy. Equipment schedules are often temporarily extended, then forgotten. Check that equipment scheduling in the building controls, mechanical timeclocks or thermostat settings matches occupancy as closely as possible.
- **Employ temperature setback during unoccupied hours:** One of the most cost-effective means of reducing energy consumption is by modifying the temperature set point of the building when it is empty, i.e. letting the thermostat setting go below the occupied period set point during the heating season and above it during the cooling season. Setback temperatures typically range from 2 to 5 °C; however, the actual appropriate setback levels depend on the recovery

time of your facility's HVAC equipment, i.e. the time it takes to bring the space temperature back to a comfortable level before occupants arrive. Review the set points for heating and cooling during unoccupied hours to ensure that setback temperatures are in place.

- **Verify free cooling operation (air side):** In free cooling mode, a building's economizer and exhaust air dampers are fully opened to bring in the maximum amount of cooler, drier outdoor air. Strategies to control the free cooling opportunity include fixed enthalpy, differential enthalpy, differential dry-bulb, etc.

  Economizers are a commonly overlooked or forgotten maintenance issue with air handling units (AHUs). A study prepared by the New Buildings Institute in 2004 found that 64% of economizers failed due to broken or seized dampers and actuators, sensor failures, or incorrect control.[9]

  When an economizer is not controlled correctly, it can go unnoticed because mechanical cooling will compensate to maintain the discharge air at the desired discharge air set point. This may include periods of time when too much or too little outdoor air is being introduced through the AHU. Failure to correct or mitigate this situation will likely lead to increased fan, cooling and heating energy consumption.

  The impact of an improperly working economizer is significant. For example, across Canadian climate zones, a recent study found the average annual energy savings available from free cooling in a 5,000-m^2 building to be approximately 19,000 kWh.[10]

- **Turn off heating coil valves in the cooling season:** Many air handler preheat coils and dual duct hot deck valves should be turned off in the cooling season to prevent accidental or unnecessary heating.
- **Widen zone temperature deadband:** The zone temperature deadband is the temperature range in which neither heating nor cooling is provided to the zone. By widening the zone temperature deadband, unnecessary "fighting" between heating and cooling systems is prevented, and energy consumption is minimized. This also mitigates heating and cooling system instability caused by short-term cycling between heating and cooling modes.
- **Reset supply air temperature:** Moderate weather, typically in spring and fall, permits a warmer supply air set point for cooling and a cooler supply air set point for heating.
- **Close outside air dampers during morning warm-up in the heating season:** While warming the building before the occupants arrive, make sure the outside air dampers are fully closed. This saves energy by heating recirculated air, rather than colder, outside air.

9 New Buildings Institute, Review of Recent Commercial Roof Top Unit Field Studies in the Pacific Northwest and California, October 8, 2004. newbuildings.org/sites/default/files/NWPCC_SmallHVAC_Report_R3_.pdf.

10 Taylor, S. and Cheng, C. "Why Enthalpy Economizers Don't Work." *ASHRAE Journal*. November 2010. nxtbook.com/nxtbooks/ashrae/ashraejournal_201011/index.php?startid=79#/14.

- **Perform early morning flush in the cooling season when conditions allow:** During the cooling season, pre-cool the building with 100% outside air (when outdoor air conditions permit) before starting mechanical cooling. To accomplish this, the controller senses acceptable outdoor air conditions and delivers an override signal to the outdoor air or economizer damper to open fully. During this operational mode, heat recovery must be disabled to take advantage of the free cooling.
- **Employ static pressure reset:** Supply fans on variable air volume (VAV) systems are often controlled to maintain static pressure within ductwork to a single set point. A more efficient strategy, and one that is required by ASHRAE Standard 90.1-2013,[11] is to use direct digital controls (DDC) to reset the pressure set point based on the zone requiring the most pressure. The static pressure set point can be automatically reset through a zone-level control feedback loop, which allows the supply fan to maintain the minimum air flow needed to keep individual zone conditions comfortable. Static pressure reset is an extremely effective method of reducing fan energy in VAV systems.[12]
- **Correct damper operation:** For systems with zone dampers (VAV), periodically inspect the dampers, linkages and actuators for proper operation. In older buildings, where maintenance has not been rigorous, some zone dampers may be stuck in a fixed position, rendering them ineffective at regulating comfort. Evaluating and repairing them can be time-consuming and costly (especially in large buildings that may have hundreds of zones), but by inspecting a portion of zone dampers as part of your ongoing commissioning program, all dampers will be inspected within a given cycle (e.g. every five years).
- **Lower variable air volume box minimum flow set points:** VAV box manufacturers typically list a minimum recommended air flow set point for each box size and for each standard control option. However, when DDC is employed, the actual controllable minimum set point will depend on the specific requirements of the space involved and is usually much lower than the manufacturer's scheduled minimum. Reducing the minimum set point will result in lower fan power requirements.
- **Calibrate building automation system sensors:** Building automation systems rely on the information provided to them by various sensors throughout the building. Sensors for temperature, carbon dioxide and enthalpy (total energy content of air) are just a few examples. If the critical sensors in a building are inaccurate (i.e. out of calibration), the building systems will not operate efficiently, costs will increase, and comfort issues can result.

11 ANSI/ASHRAE/IES Standard 90.1-2013 — Energy Standard for Buildings Except Low-Rise Residential Buildings. ASHRAE, 2013. **ashrae.org/resources--publications/bookstore/standard-90-1**.

12 Taylor, Steven P. 2007. "Increasing Efficiency with VAV System Static Pressure Setpoint Reset." *ASHRAE Journal*, June 2007. **ashrae.org/resources--publications/periodicals/ashrae-journal/ASHRAE-Journal-Article-Index-2007**.

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- **Employ optimum start control:** Many building DDC systems have an optimum start control feature that, when enabled, reduces energy use by starting the building HVAC system so that the occupied set point is reached just as occupants arrive.
- **Correct over-ventilation:** Measure air flows against ASHRAE Standard 62[13] calculations to ensure that the system meets the minimum ventilation rates but does not result in increased energy consumption due to over-ventilation. To match ventilation rates according to varying occupancy rates, a demand control regime can be implemented whereby CO_2 sensors provide feedback to the HVAC system's outdoor air damper control to modulate the damper's position according to the occupant load in the space served by the system. This allows the outdoor air to be closed off during unoccupied periods, saving the portion of energy needed to condition outdoor air.
- **Correct imbalances between supply air and exhaust air:** Buildings should be neutrally or slightly positively pressurized compared to outside conditions. An air balancing should be conducted as part of the commissioning process to measure and assist in the corrective measures to restore proper balancing.
- **Verify humidification set point:** Verify that the humidification set point meets, but does not exceed, the minimal relative humidity requirements of ASHRAE Standard 55.
- **Sequence boilers through controls:** With multiple boilers, it is important to stage them in a manner whereby each boiler operates as efficiently as possible for the given load.
- **Reset boiler supply temperature:** During the shoulder seasons, facility heating loads can often be met with lower heating water temperatures. Resetting the supply water temperature based on outdoor air temperature helps match boiler output to the actual load and results in energy savings.
- **Sequence chillers through controls:** With multiple chillers, it is important to stage them in a manner whereby each chiller operates as efficiently as possible for the given load.
- **Employ chilled water reset:** As outdoor temperatures and humidity rise, the temperature of the chilled water needs to be colder to overcome the internal loads. Conversely, as outdoor temperatures and humidity decrease, the chilled water temperatures should increase to prevent overcooling and support occupant comfort. This strategy helps match chiller output to the actual load. Energy and demand savings can be realized by allowing chilled water temperatures to increase when conditions permit.

13 ANSI/ASHRAE Standard 62.1-2013 — Ventilation for Acceptable Indoor Air Quality. ASHRAE, 2013. ashrae.org/resources--publications/bookstore/standards-62-1--62-2.

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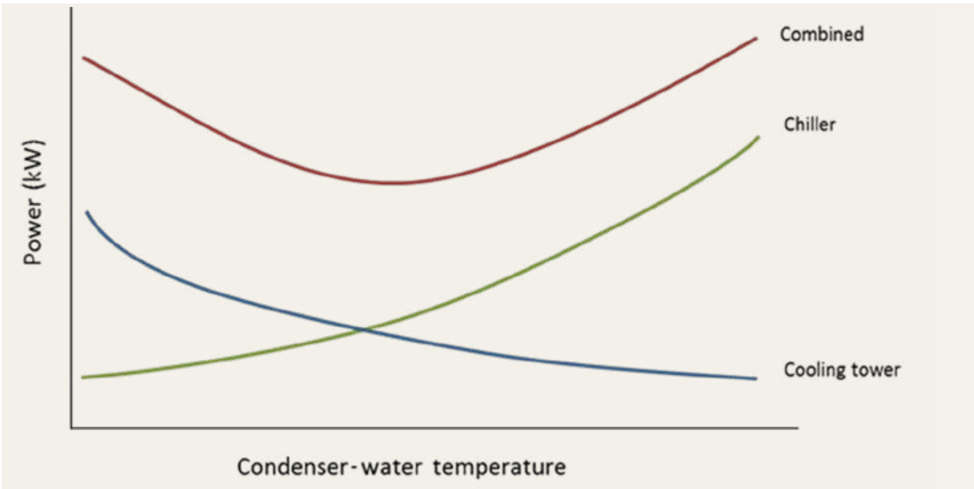
- **Employ condenser water reset:** Allowing condenser water temperatures to rise decreases the cooling tower fan power and increases the chiller power. As shown in Figure 5, the optimum operating temperature occurs at the point where these two opposing trends combine to produce the lowest total power use. However, the point of lowest power use changes depending on outdoor conditions (e.g. temperature, humidity). By implementing a reset schedule, condenser water temperatures can vary according to the outdoor conditions to maintain operations at or near the point of lowest system power requirements.

Figure 5. Energy impact of condenser water temperature



Source: © E Source

- **Take full advantage of available cooling towers:** Most chilled water plants have excess capacity, with one or more cooling towers not operating during low-load periods. To make the most of existing cooling towers, run condenser water over as many towers as possible, as often as possible, and at the lowest possible fan speed. This strategy is only available for chilled water systems that have the ability to vary the speed of the cooling tower fans and that include multiple chillers and cooling towers plumbed in parallel.
- **Repair missing or damaged pipe insulation:** Routine inspections of heating and cooling pipe insulation can identify spots that require repair. Without insulation, energy is wasted in the form of standby losses and cycling losses (e.g. heat loss in unoccupied spaces as hot water cycles through pipes).

Photo courtesy of Claudette Poirier, Vancouver Island Health Authority

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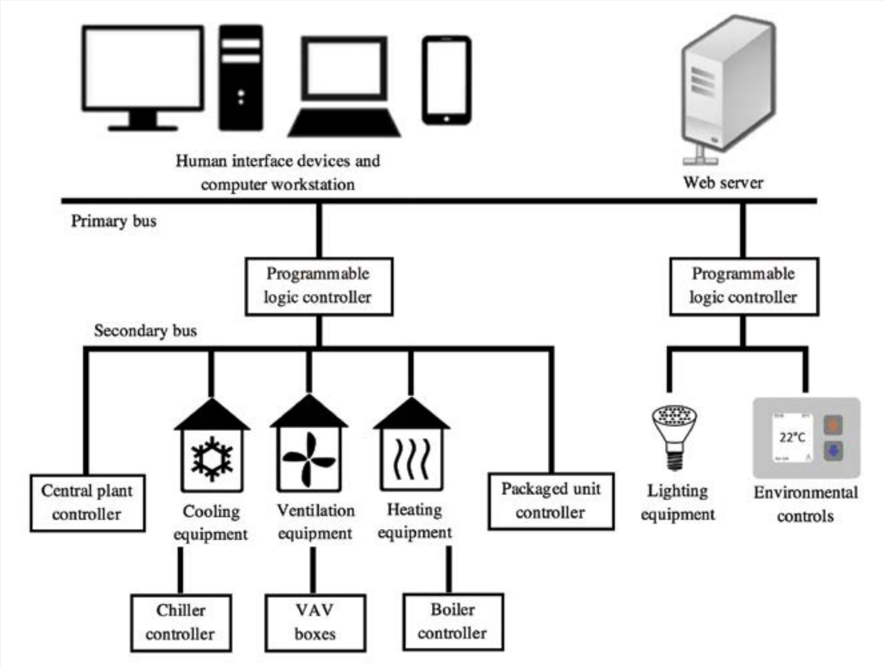
Building automation system (BAS)

Many older buildings do not have centralized control systems. Instead, they are often equipped with manual controls, simple electromechanical controls or pneumatic controls. These older controls typically do not provide accurate or timely feedback to operators and typically do not enable coordination between different building systems (e.g. buildings can be prone to simultaneous heating and cooling). Control adjustments are often made based on historical practice or "gut feel."

With the installation of a control system, several or all building systems can be connected to a central server (as shown in Figure 6), enabling an operator to monitor and adjust systems and their interactions. While this may not directly deliver energy savings, improving the controllability of building systems is an important strategy to enable energy savings. For this reason, BAS installation has become common practice in the office buildings sector.

Figure 6. Simplified open protocol BAS diagram



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Over the past 25 years, DDC has become the dominant technology for controlling HVAC systems. DDC systems are also commonly used to control lighting systems and provide remote monitoring of security and fire alarm systems. All DDC systems are web-enabled so that operators can remotely monitor their HVAC, lighting and security systems through their desktop computers or portable devices.

When purchasing a control system, consider installing a system that uses an open communications protocol. Using an open protocol makes it easier for control components made by one company to operate with controls supplied by another (interoperability). This will allow the most flexibility for optimized performance as well as future equipment replacement and upgrades. BACnet™[14] is an example of an open protocol that is commonly used.

14 ANSI/ASHRAE Standard 135-2012: BACnet – A Data Communication Protocol for Building Automation and Control Networks.

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Lighting upgrades

Lighting consumes approximately 12% of the energy used in Canadian office buildings and affects other building systems through its electrical requirements and the waste heat it produces. Upgrading lighting systems with efficient light sources, fixtures and controls reduces lighting energy use, improves the visual environment, and can impact the sizing of HVAC and electrical systems.

Lighting upgrades are often attractive investments with relatively low capital costs and short payback periods. Even simple upgrades can reduce lighting energy consumption between 10 and 85% and have the potential to improve employee health and productivity.[15] If one considers that prescribed lighting power densities from older codes are at least double the power density prescribed in current codes, an energy saving potential of 50% is possible, even without additional controls.

Lighting and the *National Energy Code of Canada for Buildings*

Lighting power densities (LPDs) have decreased due to the migration from paper-based to computer-based office activities. The 1997 *Model National Energy Code for Buildings* permitted LPDs for offices ranging from 19.4 to 36.7 W/m^2, depending on the activity and layout configuration. The NECB 2011 prescribes a maximum LPD of 9.7 W/m^2 for offices. These changes are largely the result of improved lighting technology efficiencies and a transition to an ambient and task lighting strategy.

Guide to calculating LPD

1. Identify boundaries in the area of study, and measure and calculate the floor area in square metres.
2. Collect input power or amperage for each lighting fixture type in the area. This should be available on an electrical data label applied to fixtures. Do not use lamp wattages. Where input power is indicated in watts, use this value. Where input current is provided in amperes, multiply the amperage by the voltage (120 V or 347 V) to obtain the wattage.
3. Calculate the sum of the fixture input wattages and divide by the area to determine LPD in watts per square metre.

Key lighting terms

- **Colour rendering index (CRI):** A 1-to-100 measure of the ability of a light source to reveal the colours of various objects correctly in comparison with an ideal or natural light source. A CRI of 100 is ideal.
- **Fixture efficiency:** The ratio of lumens emitted by a light fixture to the lumens emitted by the lamp(s) installed in that fixture.
- **Lighting efficacy:** A measure of light output per unit power input. Measured in lumens per watt (lm/W).
- **Lighting power density (LPD):** A measure of connected lighting load per unit floor area. Measured in watts per square metre (W/m^2).
- **Lumen:** A unit measuring total light output emitted by a light source (lm).
- **Luminaire:** A complete lighting unit (lamp, fixture, lens, ballast, wiring, etc.).
- **Lux:** A unit of measure of illumination equal to one lumen per square metre (lx). The imperial unit is the foot-candle (fc), equal to one lumen per square foot.

15 Consortium for Building Energy Innovation. *Best Practices for Lighting Retrofits, Picking the Low Hanging Fruit*. Revised August 29, 2013. http://cbei.psu.edu/best-practices-for-lighting-retrofits/.

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Lighting retrofits take two basic forms: direct replacement retrofits and designed retrofits.

Direct replacement retrofits

Direct replacement retrofits require little analysis and, as the term implies, are a one-for-one replacement of lighting sources and/or control devices. For instance, new 11-W light-emitting diode (LED) lamps can replace 50-W MR16 halogen incandescent lamps. Direct replacement retrofits should not negatively impact occupant safety, comfort or productivity.

To test the impact of direct replacement retrofits, it can be useful to apply them to one floor or to a designated area as a test case for an occupant impact study.

Lighting measure list (direct replacement retrofits)
✓ Replace incandescent and compact fluorescent lamps that are used often with LED lamps
✓ Replace incandescent exit signs with LED signs
✓ Replace building exterior and parking lot lighting with LED lamps
✓ Replace fluorescent lamps in stairways and exit routes with LED lamps
✓ Replace wall switches in enclosed rooms with occupancy/vacancy sensors

- **Replace incandescent and compact fluorescent lamps that are used often with LED lamps:** For example, MR16 incandescent lamps are commonly used in pendant and recessed fixtures. Savings of almost 80% are available by directly replacing a 50-W MR16 lamp with an 11-W LED with a colour rendering index (CRI) of 92.
- **Replace incandescent exit signs with LED signs:** Exit signs can be replaced entirely or converted to LED with a retrofit kit. Savings are significant given that exit signs are on 24 hours, seven days a week.

- **Replace building exterior and parking lot lighting with LED lamps:** LED fixtures offer savings greater than 40% over conventional high-intensity discharge (HID) fixtures.
- **Replace fluorescent lamps in stairwells and exit routes with LED lamps:** Because stairwells and exit routes are typically lit 24 hours, seven days a week, converting to LED can provide significant savings.

- **Replace wall switches in enclosed rooms with occupancy/vacancy sensors:** Occupancy and vacancy sensors turn lights off when spaces are empty. Occupancy sensors automatically turn the lights on when occupancy is detected; vacancy sensors require manual activation of the wall switch to turn lights on. Vacancy sensors deliver the highest savings since the lights will never automatically turn on. A time-out period of 15 minutes is typical to avoid short cycling and reduced lamp life.

  According to a U.S. Department of Energy survey, 60% of office buildings remain lit after business hours. Even during business hours, 25% of the floor area in most office spaces is enclosed (e.g. closed offices, conference rooms, copy rooms, bathrooms and storage areas), with 40% of that space only sporadically used (i.e. occupied only 10 to 70% of the time).[16]

  The U.S. Environmental Protection Agency (EPA) estimates savings potential under optimal conditions ranging from 25 to 75% of lighting energy, depending on space type.[17]

Designed retrofits

Unlike direct replacement retrofits, designed retrofits require analysis and design exercises to ensure that the resulting lighting layout and control strategy will meet occupants' needs. Lighting designs need to address important elements such as luminance ratios, glare and colour qualities, in addition to the quantity of light.

When undertaking a designed lighting retrofit, consider ambient lighting needs separately from specialized accent and task lighting needs. For ambient lighting, you can achieve significant performance improvements by designing a lighting layout and choosing fixtures that deliver more lumens where you want them per connected watt (efficacy). Task and accent lighting can then be used in specific areas.

Reducing the number of fixtures or lamps through layout improvements will also reduce lighting power. In this case, your lighting design process will likely involve lighting level simulations in order to ensure that the final result meets all of the lighting quality requirements for the space.

16 U.S. Department of Energy, Energy Information Administration. 2003 Commercial Building Energy Consumption Survey. eia.gov/consumption/commercial/data/2003/.

17 U.S. Environmental Protection Agency. *Putting Energy into Profits: ENERGY STAR® Guide for Small Business.* energystar.gov/ia/business/small_business/sb_guidebook/smallbizguide.pdf.

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It is important that lighting levels are appropriate for occupants' needs and the tasks they need to do. It is equally important not to **underlight** – the electrical energy saved is often offset by a greater loss in human performance or productivity.

More important than the quantity of light is the **quality** of light. The most efficient light sources mounted in the best luminaires may save energy, but will not produce much value for the owners and occupants if they are applied improperly.

Lighting not only affects the energy performance of other building systems, but it also has a direct impact on the comfort, mood, productivity, health and safety of its occupants and can affect the visual look and appeal of a building. A successful lighting upgrade will, therefore, combine energy efficiency with improved light quality and architectural aesthetics.

Table 1. Illuminance recommendations for office facilities

Application and task	Illuminance targets (lux)[18]
General office – handwriting and reading	500[19]
General office – screen and keyboard	300[20]
Meeting rooms	300
Reception desk	400
Waiting area	200
Circulation corridors	50
Stairs	50
Lobbies – daytime	100
Lobbies – nighttime	50

Source: *The Lighting Handbook*, 10th Edition, Illuminating Engineering Society of North America (IESNA)

When designing lighting modifications, the following principles apply:

- Design lighting layouts in accordance with the principles of the Illuminating Engineering Society of North America (IESNA) standards.
- Ensure that lighting power density is equal to or lower than that prescribed by the NECB.
- Use the most efficient light source for the application. For example, high-performance fluorescent systems as the primary light source for most commercial spaces; LEDs in place of incandescent bulbs.
- Use daylight whenever possible, but avoid direct sunlight, as it introduces glare issues. Install controls to reduce the use of electric lights in response to daylight.
- Use automatic controls to turn off or dim lights as appropriate.
- Plan for and carry out the commissioning of all lighting systems to ensure that they are performing as required. Create a schedule to recommission systems periodically.

18 Recommended maintained horizontal illuminance levels measured at 76 cm above floor, where at least half of the observers are 25 to 65 years old.

19 General area lighting supporting the task.

20 General area lighting (ambient) where task lighting is provided for reading and handwriting tasks.

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Lighting measure list (designed retrofits)
✓ Delamp where possible
✓ Add specular reflectors
✓ Combine ambient and task lighting strategies
✓ Make use of daylight harvesting
✓ Install addressable ballasts
✓ Install LED lighting
✓ Add a central lighting control system

- **Delamp where possible:** Delamping removes unnecessary lamps or fixtures in areas with greater-than-needed illumination. This can, however, lead to inadequate light distribution in a space. In some cases, a lamp centering kit is required to ensure that light distribution within a fixture is appropriate. Before delamping, you need to answer the following two important questions:

i. Will the reduced light levels be adequate for the task?

The IESNA has developed recommended light levels for most lighting tasks. If removing lamps or fixtures does not reduce light levels below those recommended, delamping may be a good strategy.

A good rule of thumb for office ambient lighting is to maintain at least two 4-foot lamps for every 5.95 m^2 (64 sq. ft.). Actual ambient light levels will vary depending on reflectance values, partition heights and locations, and age of lamps.

Furthermore, depending on how ballasts and lamps are wired, remaining lamps may experience flicker or have lower output or a shortened lifespan. This is the case with series-wired ballasts. With parallel-wired ballasts, lamp removal will not negatively affect the remaining lamp(s).

ii. Does the type of ballast make a difference?

Parallel-wired ballasts can usually be delamped without problems. It is recommended to check with the manufacturer if the ballast is rated to operate with fewer lamps than the label states.

Ballasts wired in series (rather than in parallel) with one lamp removed will not light the remaining lamps properly and will fail if left in operation. In a series-wired ballast, all of the lamps must be removed from the ballast. Furthermore, an electronic ballast will continue to draw up to 10 W, and it is therefore recommended that the power to the ballast be terminated.

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Specular reflectors can be applied to new fixtures (specified as part of the luminaire) and are easily retrofitted to existing fixtures. With increased luminaire efficiency, you can remove more lamps while still delivering the required light levels.

Combining **ambient and task lighting strategies** produces energy savings in three ways. First, locating the light source closest to the task produces the most efficient light levels needed. Second, since task illumination levels do not have to be maintained uniformly throughout the space, ambient levels can be lower. Third, some occupants will not use task lights, and empty offices or workstations do not have to be fully lit, saving even more energy.

- **Add specular reflectors:** Specular reflectors are luminaire components with highly polished surfaces that reflect more light and increase the overall light output and luminaire efficiency. The best reflectors on the market can deliver up to 98% reflectance and increase light output from a luminaire by up to 20%.

  The reflectors do not provide energy savings on their own. However, the application of specular reflectors can increase luminaire efficiency, thereby reducing the number of lamps or luminaires required for adequate light levels. Specular reflectors are a complementary application to a delamping strategy.

  An older standard four-lamp luminaire, for example, will have an efficiency of between 55 and 65%, depending on ballast specification and cleanliness of the luminaire. By adding a specular reflector, removing two lamps and repositioning the remaining lamp sockets for balanced light distribution, luminaire efficiency can be increased to 85%.[21]

- **Combine ambient and task lighting strategies:** Historically, the most common lighting design for commercial buildings has been general lighting, in which a single type of luminaire is laid out in a regular grid or pattern to produce relatively uniform light throughout a room. General lighting that has been designed to meet the task lighting requirements of the space typically delivers far more light than necessary for building circulation (i.e. non-task). Lighting energy can be reduced by more than 40% simply by lowering the ceiling light intensity and providing workers with individual LED task lights.

  Today's lighting strategies include a combination of task and ambient lighting. Task lighting delivers the illumination levels to occupants where they need it, allowing ambient lighting to be delivered at lower levels. IESNA lighting design standards require that luminance ratios for task to ambient lighting not exceed 3:1. Most office task types require 500 to 600 Lux of task illumination, and therefore, ambient light levels should not be less than approximately 200 Lux for a comfortable work environment.

  This shift to ambient and task lighting improves employee comfort and satisfaction, and offers health and productivity benefits. A multiple building study recorded a 19% reduction in headaches for workers who had separate task and ambient lighting as compared to workers with ceiling-only combined task and ambient lighting.[22] Another study reported an 11% improvement on tasks

21 Specifier Reports, Specular Reflectors, National Lighting Product Information Program, Vol.1, Issue 3, July 1992. **lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRSpecRe.pdf**.

22 Çakir, A. E. *Light and Health: Influences of Lighting on Health and Well-being of Office and Computer Workers.* Berlin, Germany: Ergonomic Institut für Arbeits- und Sozialforschung. 1991. **ergonomic.de/beitraege/light-and-health-influences-of-lighting-on-health-and-well-being-of-office-and-computer-workers/**.

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such as triple digit multiplication where subjects could control light levels with task lights.[23, 24]

- **Make use of daylight harvesting:** Daylight harvesting makes use of natural light as a source of illumination. Buildings that use daylight (and can therefore switch off or dim electric lighting) have the potential to cut energy use, reduce peak demand and create a more desirable indoor environment. However, it takes careful planning to achieve all the potential benefits from a daylighting system, and it can be challenging in existing buildings where windows and other light openings are already fixed.

  Sensors for dimming or on/off controls of perimeter lights can reduce electric lighting whenever daylight is available. Sensors that automatically dim the lights in response to available daylight offer average energy savings of 30%.[25, 26] Equally important, the use of daylight as the dominant light source impacts productivity. A field study at a software development company found that occupants who worked on computers in a windowed office spent approximately 15% more time working than their co-workers in interior offices with no daylight.[27] Another field study identified a 15% reduction in absenteeism among workers with access to daylight.[28]

  Light control devices, such as light shelves, as shown in Figure 7, illustrate how undesired direct daylight can be reflected toward the ceiling, providing a desirable diffused and even light penetration into the interior space.

Using **natural light** for interior lighting requires special attention to the various elements of lighting design. One negative side effect of daylight in a building's interior is glare. Direct sunlight can cause very uneven luminance ratios that are distracting or uncomfortable to occupants. Daylighting control devices and treatments are critical to maintaining comfortable workspaces that support the productivity of occupants.

23 Nishihara, N., et al. *Productivity with task and ambient lighting system evaluated by fatigue and task performance*. 2006. **bsria.co.uk/information-membership/information-centre/library/item/productivity-with-task-and-ambient-lighting-system-evaluated-by-fatigu-jun-2006/**.

24 Schwartz, B. S., et al. "Lost Workdays and Reduced Work Effectiveness Associated with Headache in the Workplace." *Journal of Occupational and Environmental Medicine*. 1997. **journals.lww.com/joem/Abstract/1997/04000/Lost_Workdays_and_Decreased_Work_Effectiveness.9.aspx**.

25 U.S. Department of Energy, Energy Information Administration. 2003 Commercial Building Energy Consumption Survey. **eia.gov/consumption/commercial/data/2003/**.

26 Lee, E. S. & Selkowitz, S. E. *The New York Times Headquarters Daylighting Mockup: Monitored performance of the day lighting control system*. Energy and Buildings. 2005. **sites.energetics.com/buildingenvelope/pdfs/56979.pdf**.

27 Figueiro, M., M. Rea, et al. *Daylight and Productivity: A Field Study*. ACEEE Summer Study (on Energy Efficiency in Buildings) Proceedings (Panel 8, Paper 6). Pacific Grove, CA: ACEEE. 2002. **eceee.org/library/conference_proceedings/ACEEE_buildings/2002/Panel_8/p8_6**.

28 Thayer, B. M. *Daylighting & Productivity at Lockheed*. Solar Today. 1995. **bristolite.com/Interfaces/media/Lockheed%20Martin%20Productivity%20Study%201983.pdf**.

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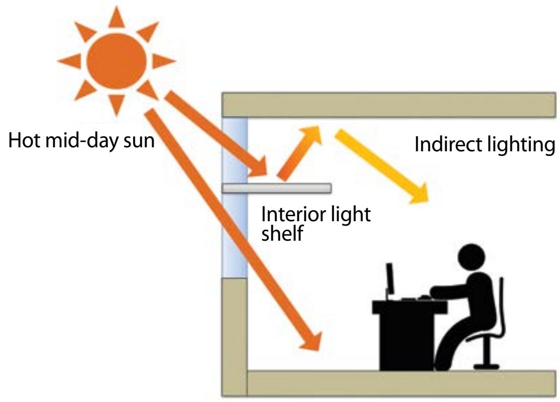
Case in point:
Bentall Kennedy and RBC
Mississauga, Ontario

Bentall Kennedy and RBC installed a DALI system at their 7,620-m^2 (82,000-sq. ft.) facility in Mississauga. DALI systems electronically monitor and control each light fixture individually and automatically adjust the light output based on occupancy, daylight and operating hours. The system was chosen because the building's floor plates are large, and the different users on each floor had variable and extended working hours.

Lighting energy for the building accounted for about 6.3 million kWh/year. Following installation, energy use was cut in half.

Source: CivicAction Alliance, Race to Reduce

Figure 7. Light shelves



In addition to occupancy benefits, daylighting enjoys a significant advantage over electric lighting because the spectral content of natural light produces about 2.5 times as many lumens per unit of cooling load. This ratio can be improved further if daylight is introduced through high-performance glazing with a low-emissivity coating. When daylight can produce light levels comparable to or higher than electric lighting, electric lights can be turned off. This saves energy not only from the lighting itself, but also by reducing the portion of the building's cooling load attributable to the lights by about half. Furthermore, these savings tend to coincide with energy peaks on hot summer days.[29]

To take advantage of daylighting, suitable controls are needed to reduce the electric lighting load while preserving the quality and quantity of light in the space.

Lighting controls have two forms: switching and dimming. Switching turns lights off when adequate daylight is available; dimming provides gradual changes to the light output of the light fixtures in response to the quantity of daylight available. Both strategies require sensors to provide feedback to the controls.

Dimming control

Dimming is continuous over the ballast's range, allowing a wide range of light output, which is preferable for many applications because it is typically more acceptable to occupants. The cost of dimming ballasts makes this option more expensive than switching, but it yields greater energy savings.

Switching control

Switching may be bi-level (on, 50% output, and off) based on separately circuiting ballasts in each fixture or separately circuiting select light fixtures, or multi-level (on, 66%, 33% and off) based on separately circuiting ballasts operating the lamps in three-lamp fixtures.

29 IESNA *Advanced Lighting Guidelines*, 2001 edition.

The advantages of switching include a lower initial cost and simpler design and commissioning. The disadvantages of switching are lower energy savings and less flexibility compared to continuous dimming.

In occupied spaces, multi-level switching may be preferable to on/off switching because it offers smaller changes in light output. In high-ceiling applications, users generally do not notice changes in light level that are less than one third of the current light level.

- **Install addressable ballasts:** If a major lighting retrofit is to be performed, you may wish to consider installing new or retrofitted light fixtures with addressable ballasts. These systems offer optimal daylight usage, task-appropriate lighting levels, and occupancy/vacancy controls.

- **Install LED lighting:** When LED fixtures first entered the market, they were expensive and had limitations on colour and brightness. Advances in LED technology and manufacturing, however, have produced lower cost fixtures with suitable colour ranges and lumen output. Furthermore, LED lamp life is estimated to be 50,000 hours, compared to 24,000 to 36,000 hours for compact fluorescents and 18,000 hours for high-bay HID fixtures. Lamp replacement costs are an important consideration when assessing the application of LED fixtures as a retrofit option. LED fixtures are now acceptable replacements for incandescent fixtures and lamps, exterior lighting and, in some cases, fluorescents.

  That being said, at the time of publishing, LED technology as a replacement for area lighting in offices is still cost prohibitive, even though advancements in the lighting source and fixture manufacturing are quickly closing the cost gap. Because this technology moves so quickly, LED options should be discussed with your lighting designer.

- **Add a central lighting control system:** Buildings that do not have lighting control systems and rely on people to turn lights off should consider adding a centralized lighting control system. Wherever possible, lighting should be turned on at the start of the day by the first occupants to arrive and not controlled by an automatic on signal. Best practices also suggest providing an all-off schedule as early as practical after normal occupancy hours and zoning lighting to allow minimal lighting to be manually turned on for the reduced number of occupants who remain or return after hours. Lighting zones require switches accessible to the occupants for this strategy to be successful. In order to eliminate the risk of leaving the lights on all night, periodic off signals (e.g. every hour) can be programmed. Control strategies such as these require occupant training to support the conservation program objectives and deliver the required comfort and safety elements for employees who work after hours.

HVAC implications of interior lighting retrofits

Lighting systems convert only a fraction of their electrical input into useful light output; much of the rest is released directly as heat. Any lighting upgrades that reduce input wattage also reduce the amount of heat that must be removed by the air conditioning system.

Although this decreases the need for air conditioning in summer, it also reduces the available heat from lighting during winter months. The precise effect on any given building can be determined by computer simulation. On the whole, installing energy-efficient lighting is a very effective measure to drop peak electrical demand, reduce energy consumption and lower utility costs.

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Supplemental load reduction

Supplemental load sources are secondary load contributors to energy consumption in buildings (occupants, computers and equipment, the building itself, etc.). These loads can adversely affect heating, cooling and electric loads. However, the effect of supplemental loads can be controlled and reduced through strategic planning, occupant engagement and energy-efficient upgrades. With careful analysis of these sources and their interactions with HVAC systems, heating and cooling equipment size and upgrade costs can be reduced. These upgrades can reduce wasted energy directly and provide additional HVAC energy savings.

Supplemental loads can be decreased by reducing equipment energy use and by upgrading the building envelope for improved thermal performance.

Power loads and equipment

This section addresses equipment and devices used by the occupants (those located at individual workstations or in common areas, such as kitchens), and electrical distribution transformers.

Supplemental load measure list (power loads and equipment)
✓ Power off equipment when not in use
✓ Choose ENERGY STAR equipment
✓ Eliminate personal powered devices
✓ Implement an employee energy awareness program
✓ Install high-efficiency transformers
✓ Consider data centre retrofits

- **Power off equipment when not in use:** The first step in energy savings is turning off equipment and devices when they are not in use. For computers and monitors, power management settings can be set to automatically power off, using one of these approaches:
  - Employees enable the existing power management features on their computers and turn off computers at night.
  - The IT department develops and deploys login scripts that control power management settings.
  - Third-party software delivers a computer power management policy across the company network.

- **Choose ENERGY STAR equipment:** ENERGY STAR-recommended products use 25 to 50% less energy than their traditional counterparts. Office equipment with the ENERGY STAR label saves energy and money by powering down and entering "sleep" mode or turning off when not in use and by operating more efficiently when in use. By purchasing and specifying energy-efficient products, organizations can cut electrical energy use and space cooling loads. Instituting an effective policy can be as easy as asking procurement staff to specify ENERGY STAR qualified products, such as office equipment, electronics, and lighting fixtures and lamps.

- **Eliminate personal powered devices:** A growing number of energy consuming devices found in offices are not covered by ENERGY STAR (e.g. personal coffee pots, cup warmers, fans, under-desk heaters, audio equipment, computer peripherals, etc.). Although each device may draw only a small amount of power, the total can be significant. Companies can implement policies that discourage the use of such items or educate employees about wise use, such as turning devices off or unplugging them when not in use.

- **Implement an employee energy awareness program:** NRCan's *Implementing an Energy Efficiency Awareness Program*[30] can help owners and managers develop successful employee energy awareness programs. Another useful resource is the *ENERGY STAR Guidelines for Energy Management*.[31] It provides information on creating a communications plan, and ideas, examples and templates that can be customized to help spread the word to employees, customers and stakeholders.

- **Install high-efficiency transformers:** Replace existing transformers at the end of their service life with high-efficiency transformers. In the past several years, there has been an accelerated rate of change to introduce energy efficiency standards for transformers in North America. As a result, manufacturers are offering more efficient transformers that have fewer losses than older models. The new National Electrical Manufacturers Association's (NEMA) premium efficiency transformer designations (CSA C802) require 30% fewer losses than previous regulations. Figure 8 shows the relative efficiencies of standard transformers vs. NEMA premium transformers.

For more information about ENERGY STAR products, visit NRCan's ENERGY STAR in Canada: **nrcan.gc.ca/energy/products/energystar/12519.**

30 **oee.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/pdf/Publications/commercial/pdf/Awareness_Program_e.pdf**

31 **energystar.gov/buildings/about-us/how-can-we-help-you/build-energy-program/guidelines**

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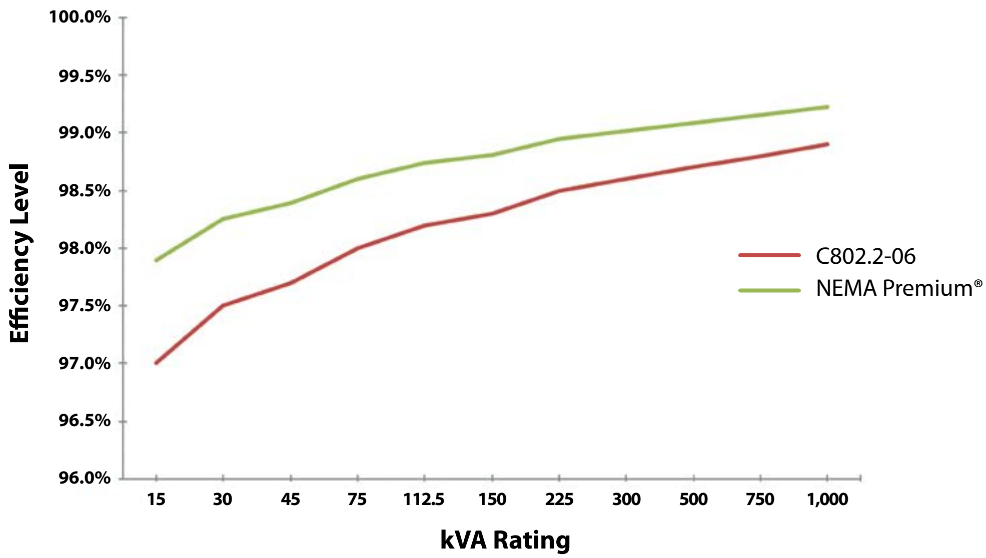
Figure 8. Standard vs. NEMA premium-efficiency levels



The benefits of replacing transformers with energy-efficient models include fewer losses in the electrical transformation and reduction in cooling load for the rooms housing the transformers.

Replacing a single 75-kVA transformer (98% efficient) with a NEMA premium-efficiency transformer (98.6% efficient) reduces the annual transformer losses by approximately 30%, based on 260 days/year, 15% loading for 16 hours/day and 100% loading for 8 hours/day.[32]

- **Consider data centre retrofits:** The average data centre is 10 to 100 times more energy-intensive than a typical office building. Less than half of the energy used by a typical data centre powers its IT equipment; the remaining energy is consumed by cooling systems, uninterruptible power supply (UPS) inefficiencies, power distribution losses and lighting. Continuously measuring and benchmarking energy consumption is critical in determining the efficiency of your data centre, identifying better performing strategies and distinguishing it from the building energy data. As new strategies are implemented, energy benchmarking will enable comparisons of performance to validate the improvements and support further optimization.

32 Hammond Power Solutions Energy Savings Calculator, hpstoolbox.com/.

With today's best practices, energy savings of 20 to 50% are possible, and the life and capacity of existing data centre infrastructure can be extended. Retrofit opportunities include:

- *Optimizing space temperature*. Space temperature should be designed for the equipment and not staff. ASHRAE's publication, *Thermal Guidelines for Data Processing Environments*,[33] outlines recommendations for air flow, filtration, humidity and temperature. The allowable range for temperatures supplied to IT equipment is 15 to 31 °C, whereas ASHRAE Standard 55 recommendations for occupant comfort range from 20 to 27 °C (see page 39).
- *Optimizing the central plant*. Typically, a central cooling plant and air handlers are more efficient than distributed air conditioning units. Begin with an efficient water-cooled variable speed chiller, add high-efficiency air handlers and low-pressure drop components, and finish with an integrated control system that minimizes unnecessary dehumidification and simultaneous heating and cooling. Use temperature resets to allow use of medium-temperature chilled water (13 °C or higher). Warmer chilled water improves chiller plant efficiency and eliminates the need for the chiller during many hours of operation (tower cooling). Opportunities may also exist to seasonally recover heat from the chiller in order to heat the rest of the building during the heating season.
- *Free cooling*. Provided that acceptable temperature and humidity conditions can be delivered, free cooling should be considered and can be accomplished through direct use of outdoor air or using a water-side economizer.
- *Right-sizing*. Data centre cooling systems are often oversized to accommodate future or uncertain loads. As a result, they often operate at inefficient part loads. Therefore, it makes sense to design for modular growth of the mechanical equipment. Include variable speed fans, pumps and compressors, and right-size all the plant equipment. Overbuilding in advance of actual needs makes many sub-systems operate inefficiently.
- *Liquid cooling of racks and servers*. On a volume basis, water can be up to 3,500 times more effective than air and cools servers and appliances more efficiently than air conditioning. Liquid-cooled server racks and liquid-cooled servers for use in data centres with high server density are currently available from a small number of manufacturers. More widespread market acceptance is likely as the technology matures.

In addition to energy retrofit opportunities, there are a number of opportunities to improve the energy efficiency of **data centres**, such as installing ENERGY STAR qualified servers, designing energy smart layouts (e.g. cool aisle/hot aisle configuration), and optimizing server use through consolidation and virtualization.

For more information:
nrcan.gc.ca/energy/products/categories/data-centres/13741

33 ASHRAE, **ashrae.org/resources--publications/bookstore/datacom-series#thermalguidelines**.

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The RSI (R-Value Système International) value of insulation is a measurement of its thermal resistance.

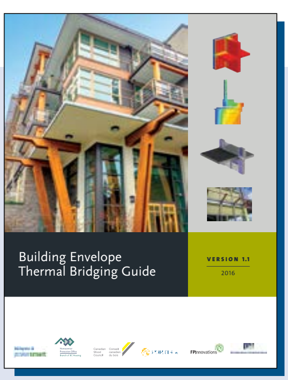
RSI is presented in $m^2 \cdot K/W$.
R-value is presented in sq. ft.· °F·h/Btu.

Conversion:

RSI = R ÷ 5.678

R = RSI × 5.678

1 RSI = R-5.678

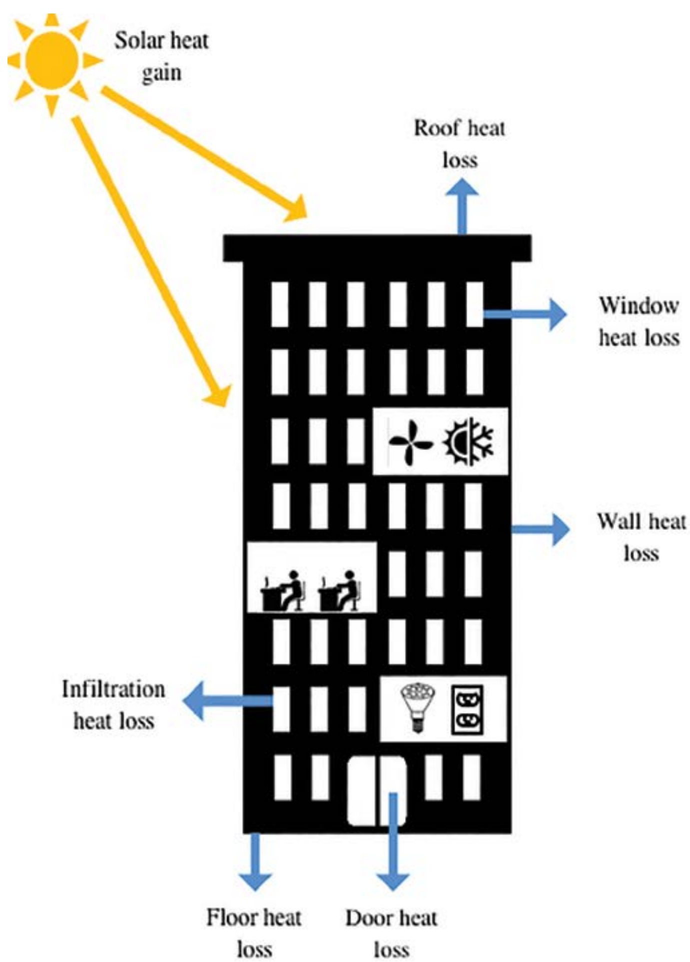


For more information on building envelope construction in general, and thermal bridging in particular, see Morrison Hershfield Ltd.'s *Building Envelope Thermal Bridging Guide*, available through BC Hydro.

Envelope

This section describes options that can be taken to improve the building envelope (roof, walls, foundation, windows and doors). The most common parameters affecting heat flow through the building envelope are conduction, solar radiation and infiltration. Conduction relates to the conductivity of the materials in the envelope assembly and their ability to conduct or resist simple heat flow from hot to cold. Performance is most often represented in RSI-values or R-values (see sidebar) or resistance to flow. Solar radiation brings wanted heat gains through the windows during the heating season and unwanted heat gains during the cooling season. Infiltration relates to air leakage through building elements, such as around windows, doors, envelope intersections, physical penetrations and mechanical openings. Figure 9 shows how heat flows into and out of a building through the envelope.

Figure 9. Building envelope heat transfer



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Conduction is largely addressed by the quantity and quality of insulation and the reduction of thermal bridging. Solar radiation is controlled through the solar heat gain coefficient of the windows and/or devices such as window shades, roof overhangs and awnings. Infiltration is addressed through the air barrier and quality of sealing around envelope openings and weather stripping for operable openings (e.g. windows and doors, garbage chutes, exhaust/intake dampers when closed, envelope penetrations such as balconies, etc.).

Supplemental load measure list (envelope)
✓ Reduce infiltration
✓ Add an air barrier
✓ Add insulation
✓ Upgrade windows and doors
✓ Consider a cool roof option

- **Reduce infiltration:** Infiltration, or air leakage, is the uncontrolled flow of air through the envelope (either outside air in, or conditioned air out). Although designers understand that the problem exists, they have either largely ignored it or have accounted for it in the design of the heating and cooling systems. One U.S. study estimated that infiltration is responsible for an estimated 15% of the heating load and 4% of the cooling load in office buildings.[34]

  Infiltration can also be exacerbated by a positively or negatively pressurized building. The effects of building pressurization will be experienced when a door is opened: a distinct flow of air will be felt either entering or leaving the building. Building pressure should be neutral or very slightly positive. This condition can be verified by an air balancing to measure supply and exhaust air flows. Imbalances can be corrected by addressing the differences between the aggregate supply and exhaust air streams.

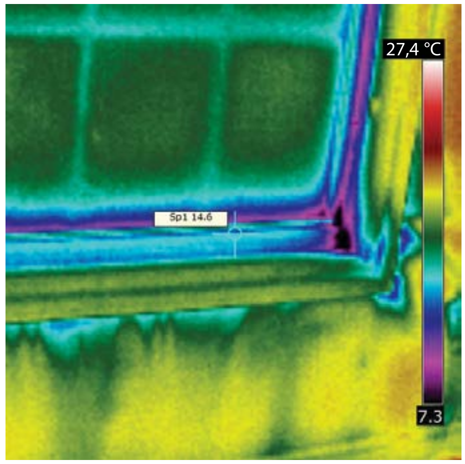
  Some signs of infiltration are obvious, such as observed daylight around a closed door; identifying others may require the use of thermographic imagery, which allows for visualization of temperature differentials. Figure 10 demonstrates how infrared imagery can help identify problems related to infiltration or envelope thermal weakness (note the low surface temperature related to parts of the window, window frame, and structural framing around and below the window).

The ASTM* standard, which is referenced in the 2012 *International Energy Conservation Code* (IECC) and the *International Green Construction Code* (IGCC), requires that a building's infiltration rate not exceed 2 L/s per square metre of wall area (0.4 cubic feet per minute per square foot of wall area) at a pressure difference of 75 Pa (0.3 inch water column).

*ASTM, formerly the American Society for Testing and Materials, is an organization that helps develop and deliver international voluntary consensus standards.

34 Emmerich and Persily. *Energy Impacts of Infiltration & Ventilation in U.S. Office Buildings Using Multizone Airflow Simulation*. Proceedings of IAQ and Energy 98 Conference. 1998.

Figure 10. Infrared imagery showing leakage around a window



Smoke pencils are another tool used to identify areas of leakage. When the smoke pencil is held near a potential leak, the movement of the smoke will indicate whether or not there is leakage. The building needs to be pressurized in order for this investigative tool to be effective.

Infiltration can be exacerbated by stack effect, which is caused by warmer air rising up through the building and escaping through openings at the top of the building. The rising warm air creates a negative pressure at the base of the building, drawing in outdoor air through openings and areas of leakage. The stack effect is reversed during the cooling season, but has a minimal impact when compared to the heating season. The extent of the stack effect is determined by the height of the building, wind speed, and how well the building is sealed near the top. Elevator shafts and stairwells provide a low-resistance path for the rising air, so it is imperative that penetrations such as roof hatches and roof access doors are well sealed.

Fixing air infiltration is usually a low-cost measure, often addressed through the addition or replacement of weather stripping or caulking. Air infiltration can lead to condensation and moisture buildup, and can also be an indication that water is getting into the building envelope. Both of these issues can lead to the formation of mold, and, in some cases, structural damage to envelope components. This additional risk increases the importance of correcting these deficiencies. A building science professional (engineer or architect) should be hired to deliver the envelope diagnostics necessary to properly address all sources of air and water infiltration.

- **Add an air barrier:** Although less obvious than the sources of infiltration outlined above, the presence of an air barrier wrapping the building envelope is an essential component for proper sealing. A properly functioning air barrier system provides protection from air leakage and the diffusion of air due to wind, stack effect and pressure differentials caused by mechanically introducing or removing air into or from the building. Buildings that have a properly installed air barrier system can operate efficiently with a smaller HVAC system because the mechanical system does not have to compensate for a leaky building. In some cases, the reduction in mechanical equipment size and cost can offset the cost of the air barrier system. Buildings without air barriers, or with inadequate ones, run the risk of reducing the lifespan of the building envelope, negatively impacting occupant comfort and increasing energy costs.

Air barriers can be applied to a building exterior using several approaches. Combined air/water barrier materials are one of the more common approaches. Mechanically fastened building wraps, self-adhered membranes, and fluid-applied membranes can also be used as air/water barriers for exterior walls.

Fluid-applied air barriers are often preferred for their relative ease of detailing and installation as compared to sheet material. Fluid-applied air/water barriers have long been used in drainable exterior insulation finish systems (EIFS) and are now becoming increasingly common with other exterior cladding types.

Insulating and adding or improving the continuity of the air barrier has a much greater impact on the energy savings than adding insulation alone. For example, in one study, a 5,000-m^2 building in Toronto with a baseline infiltration rate of 7.9 L/s/m^2 (1.55 cfm/sq. ft.) retrofitted with 50 mm (2 inches) of insulation and no improvement to the air barrier saw an energy performance improvement of only 4%. By comparison, adding the same amount of insulation and reducing infiltration to 2.0 L/s/m^2 (0.4 cfm/sq. ft.) led to an energy performance improvement of 37%.[35]

- **Add insulation**:

Roof insulation

Since a building's roof can be a major source of heat loss and gain, the best way to reduce heat transfer through the roof is by adding insulation. This can be added without interruption to the building occupants and is an option that should be examined when considering a life-cycle replacement of the roof. An energy analysis may show that energy savings are significant enough to warrant an early roof replacement to add the insulation.

Wall insulation

Insulation can be added to wall cavities or to the exterior of a building. Exterior-applied insulation is the most common due to the complexity and interruptive nature of insulating from the interior. Furthermore, a continuous layer of insulation outboard of the wall framing has superior performance over non-continuous insulation within the wall cavity. Adding wall insulation is often combined with window replacement, since window openings sometimes need to be "boxed out" to suit the increased depth of the wall assembly.

From a life-cycle perspective, the **best time to increase roof insulation** levels is when the roof needs replacement. This has the advantage of capturing the investment cost in the building's asset management plan and isolating the incremental cost of additional insulation for the energy retrofit cost-benefit analysis.

NECB 2011 minimum wall and roof RSI-values for climate zones 5, 6 and 7:

Zone 5
(e.g. Vancouver, Toronto)
Wall 3.597 $m^2 \cdot K/W$ (R-20)
Roof 5.464 $m^2 \cdot K/W$ (R-31)

Zone 6
(e.g. Ottawa, Montréal)
Wall 4.049 $m^2 \cdot K/W$ (R-23)
Roof 5.464 $m^2 \cdot K/W$ (R-31)

Zone 7A
(e.g. Edmonton)
Wall 4.762 $m^2 \cdot K/W$ (R-27)
Roof 6.173 $m^2 \cdot K/W$ (R-35)

35 Norris, Chris, energy-manager.ca/feature-articles/the-beneficial-energy-conservation-effect-of-air-barriers.html.

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Case in point:
Telus William Farrell
Vancouver, BC
(LEED-Existing Buildings Gold)

The Telus building was fitted with a glass exterior set almost one metre from the existing building. The facade creates a manageable insulating air space that acts as a thermal buffer and facilitates natural ventilation. Exhaust fans powered by photovoltaic cells automatically adjust to moderate the building's internal temperature. Windows are manually operable, offering employees additional comfort and giving them the flexibility to manage their own work environment.

Source: Sauder School of Business, University of British Columbia. 2010

- **Upgrade windows and doors**:

Windows

Windows have an impact on a building's operating costs and on the health, productivity and well-being of occupants. Windows not only have a dominant influence on a building's appearance and interior environment, but can also be one of the most important components impacting energy use and peak electricity demand.

Heat gain and loss through windows can represent a significant portion of a building's heating and cooling loads. Using natural light can reduce electric lighting loads and enhance the indoor environment. When specifying replacement windows, therefore, both the quality of light they introduce into the building as well as their thermal performance must be considered.

The rate of heat loss of a window is referred to as the U-factor (or U-value). The lower the U-factor, the greater a window's resistance (RSI-value) to heat flow and the better its insulating properties.

Windows have the poorest thermal performance of any component in a building's envelope. Even the best windows provide lower RSI-values than the worst walls and roofs. In addition, windows represent a common source of air leakage, making them the largest source of unwanted heat loss and gain in buildings.

Window selection

All of the climate zones in Canada are dominated by heating requirements rather than cooling. As such, your windows should be selected with the following criteria:

- **Minimize heat loss** by selecting the lowest U-value (highest RSI-value) for the entire assembly.
- **Minimize window emissivity** by selecting windows with low emissivity (low-e) in order to minimize heat radiated through the window.
- **Control solar heat gain.** The solar heat gain coefficient (SHGC) can differ depending on orientation to allow beneficial solar gains from one side (e.g. a south-facing wall with an SHGC of 0.6), while limiting solar gains on other sides (e.g. east- and west-facing walls with SHGCs of 0.25) for occupant comfort during the early and later parts of the day.
- **Maximize visible light transmittance**, T_{VIS}, for daylighting.[36]

The text box on page 34 provides a more detailed discussion of each of these criteria, along with a discussion of various window components and assemblies.

36 The SHGC will influence the resulting T_{VIS}; the lower the SGHC, the lower the T_{VIS}. In other words, increased shading from heat gains lowers the T_{VIS}.

Doors

Doors may be viewed similarly to operable windows, in that they are typically composed of insulating opaque sections and insulating glass units (IGUs), and that there are often significant areas of air leakage between fixed and operable elements. Modern doors offer superior thermal properties and attention to weather stripping.

The NECB prescriptive path requires new buildings to be designed with vestibules and self-closing devices for all regular access doors. Since the energy saving and comfort benefits are applicable to existing buildings, vestibules should be added where feasible.

Loading docks

Roll-up loading dock doors can be a source of significant heat loss due to poor thermal properties of the doors, infiltration and operational practices. In recent years, loading dock doors have been greatly improved, and it is recommended that the condition of existing doors be examined to determine if a replacement would correct poor performance issues.

There is an even stronger business case to consider dock seals and dock shelters, because they provide an environmental barrier that significantly reduces infiltration. Dock seals and shelters can be easily retrofitted to the outside of the building to save energy.

- **Consider a cool roof option:** A "cool roof" reflects the sun's heat away from the roof, rather than transferring it to the building mass. Cool roofs increase occupant comfort by keeping the building cooler during the summer; as a result, air conditioning needs are decreased, which saves air conditioning energy costs. Furthermore, a reflective cool roof experiences less solar loading on the membrane, potentially extending the service life of the roof. However, in a heating-dominated climate, the energy savings from air conditioning may be offset by the loss of beneficial heat gains during the heating season. Results are typically site-dependent based on factors such as roof slope and snow loading. To learn more about cool roofs, visit **coolroofs.org**.

Windows: heat loss

The U-factor of a window may be referenced for the entire window assembly or only the Insulated Glass Unit (IGU). The nationally recognized rating method by the National Fenestration Rating Council (NFRC) is for the whole window, including glazing, frame and spacers. Although centre-of-glass U-factor is also sometimes referenced, it only describes the performance of the glazing without the effects of the frame. Assembly U-factors are higher than centre-of-glass U-factors due to glass edge transmission and limitations in the insulating properties of the frame. High-performance double-pane windows can have U-factors of 1.7 $W/m^2 \cdot K$ (0.30 Btu/hr-sq. ft. • °F) or lower, while some triple-pane windows can achieve U-factors as low as 0.85 $W/m^2 \cdot K$ (0.15 Btu/hr-sq. ft. • °F).

Windows: assembly

Windows can be broken out into two main components: the IGU and the frame.

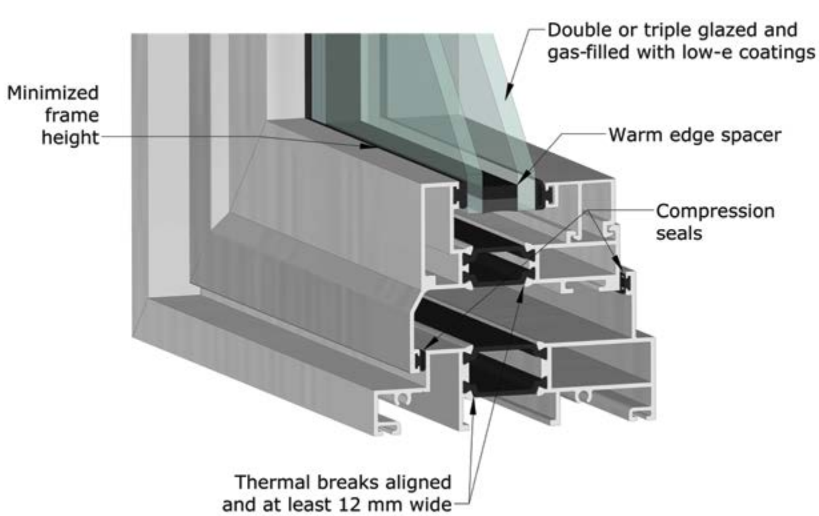
IGU performance is determined by:

- Number of glass panes (double or triple glazed)
- Quality of insulating spacer between glass panes
- Type of coating (such as low-e)
- Type of gas in the sealed glazing unit
- Depth of spacing between the panes of glass

Frame performance is determined by:

- Frame material (conductive or not)
- Thermal conductivity of spacer (thermally broken or not)

Figure 11. Features of an energy-efficient window



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Windows: insulating spacers

IGUs generally use metal spacers. They are typically aluminum, which is a poor insulator, and the spacers used in standard edge systems represent a significant thermal bridge or "short circuit" at the IGU edge. This reduces the benefits of improved glazings. "Warm edge spacers," made of insulating material, are an important element of high-performance windows.

Windows: frames

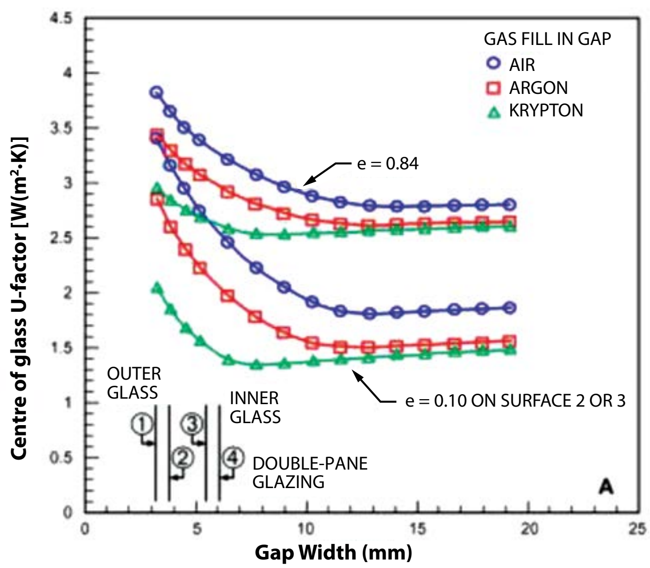
A window's U-factor incorporates the thermal properties of both the frame and the glazing. Since the sash and frame represent approximately 10 to 30% of the total area of the window unit, the frame's properties significantly influence the total window performance.

At a minimum, window frames need to be thermally broken for a cold climate. The overall U-factor of an aluminum frame is improved by almost 50% when thermally broken. Non-metal frames, such as wood, vinyl or fiberglass, can improve the U-factor by 70% due to the non-conductive properties of the material and the option to inject insulating material into the hollow cavities of the frame.

Windows: gas fills

Manufacturers generally use argon or krypton gas fills, with measurable improvement in thermal performance of the IGU. Both gases are inert, non-toxic, clear and odourless. Krypton has better thermal performance than argon, but is more expensive. Figure 12 plots the relative performance of air, argon and krypton gas fills.

Figure 12. Gas fill thermal performance



Source: © *ASHRAE Handbook – Fundamentals.* 2013. ashrae.org

Windows: coatings

Window coatings can have a meaningful impact on building heating and cooling loads. The performance of these coatings is typically discussed in terms of two related metrics: emissivity and solar heat gain coefficient.

> **Emissivity** is the ability of a material to radiate energy. All materials, including windows, emit (or radiate) heat. Reducing a window's emittance can greatly improve its insulating properties.

Standard clear glass has an emittance of 0.84, meaning that it emits 84% of the energy possible and reflects only 16%. By comparison, low-emissivity (low-e) glass coatings can have an emittance as low as 0.04, emitting only 4% of the energy and reflecting 96% of the incident long-wave, infrared radiation. Low emittance reduces heating losses in the winter by reflecting heat back into the building and reduces cooling loads in the summer by reflecting heat away from the building.

> **Solar heat gain coefficient** (SHGC) is a ratio indicating the amount of the sun's heat that can pass through the product (solar gain). The higher the number, the greater the solar gain. The SHGC is a number between 0 and 1. Products with an SHGC of less than 0.30 are considered to have low solar gain, while those with SHGCs above this threshold are considered to have high solar gain.

In a heating-dominated climate, windows with a low SHGC lead to lower cooling loads but higher heating requirements due to the loss of welcomed heat gains in the winter. In some cases, the SHGC may vary depending on the building's orientation. For instance, on the west facade of a building, the SHGC would be designed to be lower than the south facade due to the sun's low angle and higher solar loading during the late afternoon and evening during summer months. This will have a significant impact on occupant comfort along the west facade. Finally, the SHGC will influence the resulting visible light transmittance (T_{VIS}); the lower the SHGC, the lower the T_{VIS}. In other words, increased shading from heat gains lowers the T_{VIS} and resultant opportunity for daylighting.

Windows: emerging advanced technologies

Emerging glazing technologies are now, or will soon be, available. Insulation-filled and evacuated glazings improve heat transfer by lowering U-factors. Switchable glazings, such as electrochromics, change properties dynamically to control solar heat gain, daylight, glare and view. Integrated photovoltaic solar collectors involving window systems that generate energy can also form part of the building envelope.

Recommendation: To determine which window specifications will deliver the greatest energy savings and occupant comfort, a whole-building energy model is recommended. Once the building geometry, thermal properties and systems configuration are populated in the model, different window specifications can be tested. Contact an experienced energy modeller to work with you on this analysis.

Curtain walls and window walls

Evaluating curtain and window walls (glazing wall systems) for performance improvement is similar to evaluating windows. Windows have only vision glazing, whereas curtain and window walls have both vision glazing and opaque (spandrel) panels mounted in a metal frame system. Overall thermal performance is a function of the glazing infill panel (the IGU), the frame, construction behind the spandrel and column cover areas, and the perimeter details affecting air leakage.

At the curtain wall perimeter, maintaining continuity of the air barrier reduces air flows around the curtain wall. Integration of perimeter flashings helps ensure watertight performance of the curtain wall and its connection to adjacent wall elements. Proper placement of insulation at the curtain wall perimeter reduces energy loss and potential condensation issues.

The most effective way to increase a curtain wall's performance is by evaluating the system as a whole, rather than looking at the performance of individual components. For instance, the U-Value of the IGU and spandrel panel does not completely represent the performance of the wall system. Framing configuration (i.e. the amount of framing) and degree of thermal isolation are very important factors in the performance of the whole assembly.

To properly assess replacement opportunities for glazing wall systems, thermal performance modelling, building science evaluation and daylight simulations should be incorporated.

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When examining any HVAC opportunities, it is important to first re-evaluate the original HVAC design to determine if the system sizing and configuration is suitable for the current occupancy.

A U.S. Environmental Protection Agency (EPA) study found that almost 60% of building fan systems were oversized by at least 10%, with an average oversizing of 60%. "Right-sizing" a fan system, or better matching fan capacity to the requirements of the load, is a recommended measure to save energy in air distribution systems.

Air distribution systems upgrade

The HVAC system regulates the temperature, humidity, quality and movement of air in buildings, making it a critical system for occupant comfort, health and productivity.

Two main types of equipment distribute air within commercial buildings:

- Furnace/fan-coil equipment that consists of either engineered built-up systems or furnaces (small buildings). Air is conditioned with hot and chilled water coils or direct-fired heat exchangers with direct expansion evaporator cooling coils.
- Rooftop units (RTUs) are the most common type of system conditioning commercial buildings and are covered later in the module.

Constant vs. variable volume

Air handling systems can either be constant volume or variable air volume.

Constant volume systems

Constant volume (CV) systems are the simplest type of air distribution system and are common in existing commercial buildings. When the supply fan is on, a constant volume of air flows. There is no modulation of the fan power or discharge dampering at the fan or at the terminal ends of the duct runs. CV systems are suitable for conditioning a single space (also called a zone), but are less effective and efficient when serving different spaces or occupancies.

In some cases, when a CV system is applied to a multi-zone distribution, it is designed to vary the temperature of air delivered to each zone. To meet the differing cooling loads, "terminal reheat" or "zone reheat" is frequently added. The system is sized to provide cooling to the zone with the peak load, and all zones with less cooling load have their air reheated as it enters the zone. This is inefficient, as the system simultaneously heats and cools. These types of systems, therefore, are prime candidates for replacement under a major energy retrofit.

Variable air volume systems

Variable air volume (VAV) systems offer substantial energy savings over CV systems and are more commonly applied to commercial office buildings. In a VAV system, the ductwork from the air handler distributes air to mixing boxes in multiple zones throughout the building. Air flow is modulated at the mixing boxes either by opening or closing dampers, or with fans inside the box. Modern VAV systems can handle changing load requirements by varying the amount of heated or cooled air circulated to the conditioned space in response to varying loads. Used in combination with variable speed-drives (VSDs), this reduction in flow lowers the fan power needed, saving energy.

Converting an existing CV system to a VAV system is a cost effective option for many building owners, because it allows the system to turn itself down in response to changing demand.

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Comfort and air quality

The lowest cost option to reduce HVAC system energy is to expand the allowable ranges for indoor temperature and humidity, i.e. allowing temperature and humidity levels to rise during the summer months and lower during the winter. By carefully studying the thermal comfort needs of the occupants in each space type, you can determine the acceptable range for temperature and humidity. These comfort ranges can be found in ASHRAE Standard 55.[37]

ASHRAE Standard 55 comfort range example

Acceptable temperature and humidity ranges depend on activity levels and clothing. Two comfort ranges are provided for an office environment where occupants are expected to have low metabolic activity levels. One is for 1.0 clo (clo is a measure of clothing insulation; 1.0 clo represents a three-piece suit or equivalent); the other is for 0.5 clo (e.g. skirt and light blouse or light trousers and short-sleeved shirt).

For example, at 50% relative humidity, and 1.0 clo, the comfortable temperature range is between roughly 20 °C and 25 °C. At 0.5 clo the comfortable temperature range is between roughly 24 °C and 27 °C.

You should also consider the indoor air quality and the amount of ventilation air required by building occupants in each space type. Conditioning outside air is one of the most energy-intensive loads that the HVAC system faces, so your first step should be to minimize the amount of outside air that needs to be conditioned. Calculate the required exhaust and ventilation air according to ASHRAE Standard 62.1,[38] using the actual occupancy rates, rather than the default occupancies provided in the standard. Then apply demand control using CO_2 as a proxy for actual occupancy. CO_2 can be metered at the return duct to the RTU with the control system providing a reset signal to the outdoor air damper to open or close according to the CO_2 in the space.

37 Thermal Environmental Conditions for Human Occupancy. **ashrae.org/resources--publications/bookstore/standard-55**.

38 Ventilation for Acceptable Indoor Air Quality. **ashrae.org/resources--publications/bookstore/standards-62-1--62-2**.

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Retrofits

The recommended approach is to start by assessing opportunities in the zone (conditioned space) and work back toward the air handling unit (AHU). For example, in a VAV system, fixing or replacing zone damper control will result in better comfort for the occupants, while reducing the amount of conditioned air required from the AHU.

In recent decades, there have been significant changes in the way building HVAC systems are designed. Many new systems are designed with VAV delivery, better ventilation distribution effectiveness and superior controls. Dedicated outdoor air systems (DOAS) are also being adopted in more advanced building designs as a means to reduce the amount of conditioning required for outdoor air. Optimizing the air distribution system not only delivers energy savings and maintains or improves indoor air quality, but it may also provide greater savings by reducing the required heating and cooling equipment capacity.

Air handling systems have numerous components that affect system operation and performance. Improvements to the air distribution system can be put into four categories:

- Adjusting ventilation rates to conform with code requirements or occupant needs
- Implementing energy saving controls
- Taking advantage of free cooling where possible
- Optimizing the efficiency of distribution system components

Air distribution systems measure list
✓ Start with first-order measures
✓ Use demand control ventilation
✓ Replace constant volume with variable air volume in multi-zone systems
✓ Right-size fans
✓ Install variable speed-drives
✓ Install heat recovery on exhaust air streams
✓ Install solar air heating in make-up air systems
✓ Install a variable refrigerant flow system
✓ Replace mixed-air delivery with a dedicated outdoor air system
✓ Replace existing air filters with electronic air cleaners

- **Start with first-order measures:** The first-order measures are designed to reduce the load at the zone level with the intent of reducing requirements on the air handler and supporting heating and cooling systems. Optimizing space conditions and performance at the zone level balances occupants' needs with the need to minimize the energy required to deliver comfortable conditions. An existing building commissioning (EBCx) program is often the first step in this optimization.

  The assessment phase of an EBCx program involves collecting configuration and operational conditions of a building's air handling systems. Thermostat settings, operational schedules and damper operations are examples of elements that would be confirmed and documented in the initial commissioning report, along with any deficiencies requiring correction during the implementation phase.

  Refer to the **Existing Building Commissioning** stage for a list of potential operational measures.

- **Use demand control ventilation (DCV):** DCV ensures that a building is adequately ventilated, while minimizing outdoor air flows. Typically, sensors are used to continuously monitor CO_2 levels in the conditioned space, allowing the AHU to modulate the outdoor air ventilation rate to match the demand established by the occupancy needs of the space or zone (CO_2) is considered a proxy for the level of occupancy; the higher the CO_2, the more people in the space and therefore the more outdoor air required).

  Historically, building ventilation systems were designed to operate at constant or pre-determined ventilation rates, regardless of occupancy levels. Since ventilation rates are normally based on maximum occupancy levels, running fans and conditioning the excess outdoor air wastes energy during periods of only partial occupancy.

  DCV systems continuously match the outside air supply to the actual occupancy levels, leading to significant energy savings over constant volume systems. CO_2 sensors should be used in zones that are densely occupied with highly variable occupancy patterns, such as conference rooms, multipurpose spaces, and lunch rooms or cafeterias. For other zones, occupancy sensors should be used to reduce ventilation when a zone is temporarily unoccupied. Economizer controls should always override DCV in control sequences.

Parking garage DCV

Similar to building DCV, ventilation in enclosed or semi-enclosed parking garages may be converted from constant to variable volume based on demand. Demand is typically measured using vehicle pollutant concentrations, usually CO, as a proxy.

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Power factor is the ratio of real power to apparent power. A higher ratio (closer to one) means that these two values are closer together, which results in fewer losses in the electrical distribution equipment and for utilities.

Case in point:
First Canadian Place
Toronto, Ontario

As a result of a major energy efficiency retrofit, Brookfield Properties achieved LEED (Leadership in Energy and Environmental Design) Gold Existing Buildings certification in 2012. One of the measures undertaken was to retrofit the building's 16 constant flow AHUs with VSDs. Demand decreased by 208 kW, and usage was reduced by over 700,000 kWh/year.

"We had some comfort issues in the building before, and we've noticed that calls have started to drop. We've been able to give tenants a better comfort zone." – Fernando Dias, Senior Operations Manager.

Source: Toronto Hydro

- **Replace constant volume with variable air volume in multi-zone systems:** Typical air flow requirements for VAV systems are about 60% that of CV systems. The conversion of an older CV reheat, multi-zone, or dual-duct system to a modern, energy-efficient VAV system is a task to be undertaken with an experienced HVAC engineer.

  To determine the potential energy savings, you will need to model it against the existing case. Determining the return on investment is largely a function of the accuracy of the implementation costs. A schematic-level design of the system is the minimum requirement to develop a cost estimate for such an implementation.

- **Right-size fans:** Oversized fan motors result in a poor power factor, and since most utilities charge additional fees based on power factors less than 90%, right-sized fans may save both electrical energy and demand costs.

  Replacing fans with smaller, right-sized units has a low first cost and provides better occupant comfort and longer equipment life. When selecting a right-sized motor, consider upgrading to a premium-efficiency motor, installing a VSD, and using energy-efficient belts to deliver the greatest savings.

- **Install variable speed-drives:** VSDs are an efficient and economical retrofit option for any fan or pump that has a variable load. VSDs vary the motor speed depending on actual operating conditions, rather than operating continuously at full speed. When used to control fans and pumps, a 20% reduction in fan/pump speed can result in an energy reduction of almost 50%.

  VSDs are an important component in an energy-efficient VAV system. As loads decrease and VAV terminals close down, the fan speed can be reduced accordingly. Many existing VAV systems are configured with a constant speed fan and bypass damper or "dump box," where the excess air that is not delivered to the supply terminals is dumped into the return air plenum. This is a poor design, which was adopted due to the lower installed cost.

- **Install heat recovery on exhaust air streams:** Heat recovery is a requirement of the NECB for some new buildings and offers favourable energy savings. There are two basic types of heat recovery that are well suited for typical commercial office buildings: heat core and energy/enthalpy wheel.

  Heat core devices contain a cross flow core where the outdoor air and exhaust air, separated by thin aluminum or plastic walls, pass through small channels that allow for the rapid exchange of heat between the air streams. Since the air streams are separated, heat core devices recover predominantly sensible heat, with effectiveness in the range of 55 to 65%.

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Energy or enthalpy wheels are placed with half of the wheel in the exhaust air stream and half in the outdoor air stream. The wheel rotates continuously, allowing heat and moisture absorbed from one air stream to be picked up by the other cooler, and typically drier, air stream; this provides latent energy transfer in addition to the sensible energy. Energy wheels tend to have good heat recovery performance with a sensible effectiveness between 60 and 72% and a latent effectiveness between 50 and 60%.

Sensible heat transfer is related to changes in air temperature.

Latent heat is the energy absorbed or released during a phase change from a gas to a liquid or vice versa.

- **Install solar air heating in make-up air systems:** This type of system is well suited for preheating outdoor air in cases where heat recovery cannot be implemented or where ventilation systems are designed for over-ventilation. Solar collectors come in either wall-mounted or roof-mounted forms. While solar walls can be difficult to implement in a commercial office building retrofit, rooftop systems may be a more viable option.

  Under favourable conditions (i.e. low wind), collectors have efficiencies upwards of almost 90% and are able to deliver between 493 and 1,031 kWh/m^2 (collector area)/year. Costs vary between \$530 and \$700 per collector, with each collector delivering 118 L/s (250 cfm). Total system costs range from \$15 to \$17 per L/s (\$7 to \$8 per cfm).

- **Install a variable refrigerant flow (VRF) system:** VRF systems are composed of distributed heat pumps that serve zone conditioning needs. Systems can be configured to deliver simultaneous heating in some zones and cooling in others, a functionality required by many commercial buildings during shoulder seasons and sometimes year-round in those with large interior zones. For example, the south side of a building may experience heat gains, and thus require cooling, while the north side requires heating. It is also common for interior zones to require cooling due to internal loads, while the perimeter requires heating due to envelope heat loss. With a three-pipe VRF system, cooling heat rejection is transferred to the zones requiring heating. VRF systems are 25% more efficient than traditional HVAC systems; however, because these systems rely exclusively on electricity, which is generally more expensive than natural gas, a cost-benefit analysis should be conducted to determine if VRF is a viable option for your facility.

VRF systems are ideal for retrofits. The heat pump units are small, quiet and suitable for installing in the ceiling space, and the refrigeration piping between the heat pump units and condensers is small in diameter. The ventilation ductwork can be reduced in size since only outdoor air and de/humidification is required from the central system; all heating and cooling is performed in the zone by the VRF units.

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Case in point:
MDS Nordion
Ottawa, Ontario

MDS Nordion installed a solar air heating system in 2007. The solar preheated air generated by the wall-mounted system is drawn into the building's ventilation system, reducing the standard heating load. Avoided energy cost savings were estimated at almost $10,000/year (based on 2007 energy prices). With grants and incentives provided by the federal and provincial governments, the payback period was less than four years.

Source: solarwall.com

- **Replace mixed-air delivery with a dedicated outdoor air system:** Compared to standard air delivery systems, such as VAV, a DOAS delivers the correct amount of outdoor air directly to each zone, or to the supply side of each local HVAC unit. The outdoor air may be partially conditioned as it enters the building through energy recovery equipment, with final conditioning occurring at the zone-level HVAC equipment.

  A DOAS generally requires 20 to 70% less outdoor air than a standard delivery system to assure proper ventilation air distribution to each space. This reduces the energy required to condition the outdoor air. A DOAS:

  - Requires less overall heating energy because of a reduction in outdoor air conditioning
  - Eliminates zone reheat
  - Requires less overall cooling capacity
  - Requires less overall cooling energy for much of the year by taking advantage of the latent cooling already done by the dedicated outdoor air unit
  - Requires less overall fan air flow and, therefore, less fan energy

- **Replace existing air filters with electronic air cleaners:** Electronic air cleaners use two filtration technologies: a passive filter that relies on density to capture contaminants, along with electrostatic attraction to improve filtration. They have multiple benefits for HVAC systems:

  - *Lower fan power*. The static pressure drop resulting from electronic air cleaners is typically 250 Pa (1 inch) less than conventional air filters. This lowers the power consumption by the fan or allows smaller fans to be selected if the existing AHU is being replaced.
  - *Improved indoor air quality*. Electronic air cleaners can filter auto emissions, bacteria and volatile organic compounds from carpets, furniture and cleaning products. By improving indoor air quality, building owners may be able to lower outdoor air levels through a monitoring program to provide further energy savings.
  - *Longer service life and less maintenance*. Electronic air cleaners have lower maintenance requirements than conventional air filters, which typically require that pre-filters be changed quarterly.

Heating and cooling resizing and replacement

This section covers the two main heating and cooling system types, central and unitary, as well as domestic hot water systems.

Central systems consist of boilers and chillers that serve air handlers and convectors.

Unitary systems are often characterized by a packaged heating and cooling unit, such as an RTU with heating and direct expansion cooling, complete with supply and, possibly, return fan.

In keeping with the staged approach to retrofits, heating and cooling equipment can take advantage of load reductions achieved in earlier stages. Not only will the heating and cooling systems benefit from improved equipment efficiencies, but the system capacities may also be reduced, yielding even greater energy savings. Furthermore, many existing systems are oversized to begin with, so it may be possible to justify replacing the current system with a properly sized one or retrofitting it to operate more efficiently.

Central heating systems

The majority of commercial building central heating systems are served by hot water boilers. Many of these are more than 20 years old and operate at efficiencies of 60 to 70% due to poor design, inadequate control, piping/pumping and radiation deficiencies, excessive cycling, etc. Modern boilers can achieve efficiencies as high as 97%, converting nearly all the fuel to useful heat.

Retrofit or replacement

Boiler retrofits and replacements involve specific criteria that must be evaluated before a decision is made. These criteria impact several areas of a boiler system:

- Product life-cycle costing: Consider service life and efficiency trade-offs when choosing the boiler type (condensing versus non-condensing).
- Operations: Present and long-term needs, operating hours, downtime impact, etc.
- Physical plant: Mechanical floor area, access, power, piping systems, processes, operating personnel, etc.
- Budget considerations: Available capital expenditures, utility incentives, energy savings.

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Before you decide to retrofit a boiler, you must first consider current system maintenance. If the boiler has not been well maintained, you'll probably need to replace the entire system; however, if the boiler has been maintained on a regular basis, retrofitting may be the best option. To make this determination, have a professional inspect the boiler.

While the tendency is to replace older systems with new equipment, do not underestimate the value of regular maintenance to control energy costs. Something as seemingly minor as losing flow through dirty air filters can cause a boiler system to work inefficiently. Often, employees forget to check filters, or they wait until they look dirty, which is usually several months too late.

While retrofitting is initially less expensive than purchasing a new boiler system, you must also consider whether retrofitting is the most cost-effective option in the long run.

Efficiency ratings

Boiler efficiencies are commonly expressed as combustion (E_c), thermal (E_t) or annual fuel utilization efficiency (AFUE). Combustion and thermal efficiencies describe steady state efficiency; AFUE is a non-steady state measure that includes a boiler's performance when it is operating at part load and idling between calls for heat (an estimate of full operational efficiency). The minimum gas-fired boiler ratings for new buildings are described in the NECB as follows.

Table 2. Gas-fired boiler efficiency ratings

Boiler size	Rating	NECB minimum efficiency	Best available
<88 kW	AFUE	85.0%	97%
88–733 kW	Combustion efficiency (E_c)	82.5%	95%
88–733 kW	Thermal efficiency (E_t)	83.0%	95%
>733 kW	Combustion efficiency (E_c)	83.3%	85–95%

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Heating and cooling measure list (central heating systems)	
Retrofit measures	
✓ Start with first-order measures	✓ Control heating water pumps with variable speed-drives
✓ Replace boiler control system	✓ Replace burners
✓ Eliminate flow-restricting valves	✓ Install turbulators in firetube boilers
✓ Replace standard-efficiency or oversized pumps with highly efficient units right-sized for the reduced loads	
Replacement measures	
✓ Replace with condensing boiler	✓ Replace with hybrid boiler system
✓ Replace with modulating boiler	✓ Replace with heat pump system

If you decide to **retrofit**, consider these options:

- **Start with first-order measures:** Existing boiler plants can be optimized by ensuring that a heating water reset is in place, as well as by sequencing for multiple boilers. Refer to the **Existing Building Commissioning** stage for further details.
- **Replace boiler control system:** New developments in boiler controls create opportunities for substantial efficiency gains, including measures such as hot water temperature reset based on outdoor temperatures, optimizing the air-to-fuel ratio, improving multi-boiler staging, and adding circulation pump variable speed control.
- **Eliminate flow-restricting valves:** This measure reduces pump energy use. If valves are installed to control flow by inducing a pressure drop, energy saving measures include completely opening the valves and converting to variable speed controls, trimming the impeller or staging pumps.
- **Replace standard-efficiency or oversized pumps with highly efficient units right-sized for the reduced loads:** Most induction motors that drive pumps reach peak efficiency at about 75% loading and are less efficient when fully loaded. Wherever possible, pumps should be sized so that much of their operating time is spent at or close to their most efficient part-load factor. If a pump is oversized, it likely operates at an inefficient loading factor and negatively impacts the electrical system's power factor, potentially leading to higher demand charges.

Boilers must operate with an excess supply of oxygen in the combustion gases to ensure complete combustion of the fuel, thereby yielding maximum heat energy. However, too much oxygen cools the flame, so the control of air and fuel levels is paramount to optimal efficiency.

- **Control heating water pumps with variable speed-drives:** VSDs can ensure that pumps are performing at maximum efficiency at part-load conditions. The power required to operate a pump motor is proportional to the cube of its speed. For example, in a pump system with a VSD, a load reduction that results in a 10% reduction in motor speed reduces energy consumption by 27%.[39] With proper controls, lower heating water flow rates enabled by VSD pumps can also be coordinated with a hot water temperature reset schedule to meet loads accurately and efficiently. Low heating loads, for example, might be most efficiently met by creating warmer heating water and reducing the flow rate to save pump energy.
- **Replace burners:** New burners for all types of boilers and fuels are commercially available, and many suppliers offer burner retrofit parts for modifying burners rather than fully replacing them. This can often achieve significant improvements at lower cost than a full replacement.

  The potential for efficiency gains from new burners is a function of the difference between the old and new technologies. Levels of fuel and unburned fuel (from incomplete combustion) and the amount of excess air between the new and old burners will dictate the performance improvement potential. Furthermore, the burner size and turndown capability (i.e. the ability to operate efficiently at less than full load) will impact the losses associated with inefficient low loads and on/off cycling duty.

  With respect to size/turndown capability, most gas burners exhibit a turndown ratio (the ratio of capacity at full fire to its lowest firing point before shutdown) of 10:1 or 12:1 with little or no loss in combustion efficiency. However, some burners offer turndown ratios of 20:1. A higher turndown ratio reduces burner startups, provides better load control, saves wear and tear on the burner, and reduces purge air requirements, all resulting in better overall efficiency.
- **Install turbulators on firetube boilers:** Turbulators are devices that create turbulence in heat exchangers, including flame-containing boiler tubes, creating more heat contact with the tube walls. This results in greater heat transfer through the tube wall and less heat wasted through exhaust streams, which saves on heating costs by requiring less fuel to produce the same amount of heat.

If **replacement** is your best option, four measures can be considered: high-efficiency condensing boilers, high-efficiency non-condensing (modulating) boilers, hybrid systems and heat pumps.

- **Replace with condensing boiler:** Condensing technology recovers the latent energy contained in the condensing flue gases – part of the energy that normally disappears up the chimney in other heating systems. With condensing technology, the water vapour contained in the flue gases condenses on the cooler heat exchanger surfaces of the boiler, transferring heat into the boiler water. The heat released from condensation is transmitted directly into the boiler water, minimizing thermal flue gas losses. The seasonal efficiency of condensing boilers can reach up to 97%.

39 The formula is $1 – (0.9)^3 = 0.27$.

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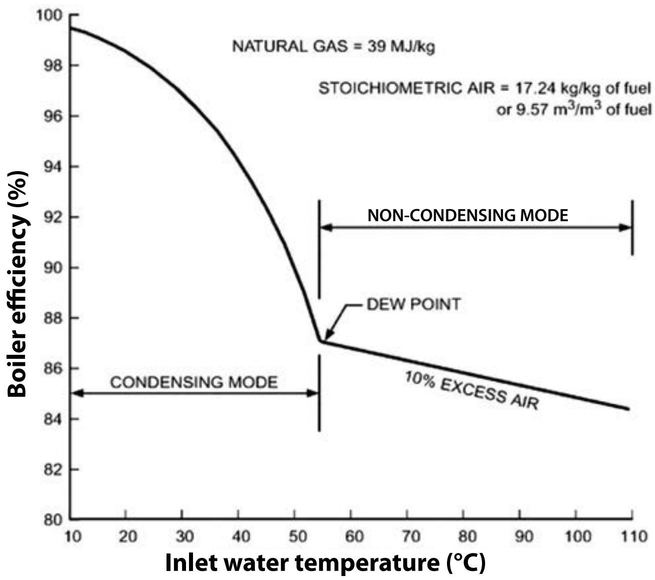
The first cost of condensing boilers is higher than that of traditional non-condensing boilers. The challenge a designer faces is to ensure that return water temperature to the boiler stays below 54.4 °C (130 °F); otherwise, boiler efficiency drops significantly, as shown in Figure 13, and the condensing boiler operates in non-condensing mode. Under these conditions, the premium paid for the higher condensing efficiencies is lost, thus reducing the return on investment.

Figure 13. Return water temperature and its impact on boiler efficiency



Source: 2012 *ASHRAE Handbook – HVAC Systems and Equipment*

- **Replace with modulating boiler:** A modulating boiler adjusts its output by sensing the outdoor air and/or return air temperature and then adjusting the firing rate as low as possible to meet the heating needs. Modulation saves energy by improving dynamic efficiency during periods of light loads. Modulation also provides accurate load tracking and precise temperature control, while minimizing energy waste. Modulating boilers achieve efficiencies of up to 88% and are the most efficient choice where heating demands do not permit return water temperatures less than 54.4 °C (130 °F).
- **Replace with hybrid boiler system:** A hybrid boiler system consists of condensing and non-condensing boilers controlled to deliver the maximum efficiency over the heating season. Depending on the system design and heat loss from the building, distribution water temperatures may not be suitable for a condensing boiler. This is often the case during peak heating conditions. Therefore, when outdoor temperatures are coldest, it is more economical to operate a modulating non-condensing boiler since the elevated return water temperatures will not permit condensing operation. However, during the majority of the season, when heating demands are much less than peak, supply

A less costly option compared to a fully modulating boiler is the multi-staged boiler. Rather than having the fully adjustable firing range of modulation, multi-staged boilers offer a set firing percentage. For example, a four-stage boiler will have four incremental firing rates (100%, 75%, 50% and 25% of the full firing rate). These units cost less than modulating units, but are also less efficient.

temperatures can be decreased, with return water temperatures below the 54.4 °C (130 °F) threshold for condensing operation.

To overcome these seasonal demand differences, a boiler system that uses a smaller condensing boiler during the shoulder seasons and a larger non-condensing boiler during the winter season will provide a better return on investment. The hybrid system will stage the boilers to engage the condensing boiler until return water temperatures no longer permit condensing operations. At this point, the system will engage the modulating non-condensing boiler and turn off the condensing boiler.

- **Replace with a heat pump system:** Heat pumps transfer heat by circulating a refrigerant through heat exchange coils, completing a cycle of evaporation and condensation. In one coil (evaporator), the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed on the way to the other coil (condenser), where it condenses at high pressure. At this point, it releases the heat it absorbed in the evaporator. The heat pump cycle is reversible, whereby heat can be absorbed from the indoor environment and rejected outdoors or absorbed from outdoor air and rejected into the indoor environment. Heat pumps may be air source or coupled to the ground or a body of water. Ground-coupled units are often referred to as ground-source heat pumps (GSHPs); the industry at large has adopted the term "geo-exchange" for non-air-source heat pumps. A geo-exchange heat pump can be either open loop, which circulates ground or surface water to the heat pump, or closed loop, which circulates fluid in a closed loop and exchanges heat through the pipe walls. Systems can be centralized or distributed for multi-zone control and distribution.

  Distributed heat pumps used in VRF systems have efficiency advantages over centralized systems and can be fed by an air-source heat pump, a ground heat exchanger or a central boiler. The benefit of these systems is that heat can be exchanged directly within the building loop, reducing the thermal load on the ground heat exchanger or central boiler. Refer to the *Install a VRF system* measure under the **Air Distribution System Upgrade** stage for further details.

Generally speaking, commercial office buildings are good candidates for retrofits because they are maintained at reasonably standard temperature set points (18 to 22 °C) for at least 40 hours per week. However, in a heating-dominated climate with high electricity costs and low natural gas costs, heat pump retrofits are often less financially attractive than other options. Most favourable conditions are present when existing equipment is at the end of its expected service life and replacement is necessary regardless of the resulting efficiency gains. Detailed estimates of costs and savings over the expected lifetime of the heat pump system should be determined to properly assess the financial feasibility of any given project.

Ground-source heat pumps

Ground-source heat pumps (GSHPs) require the installation of a ground loop that can be horizontal (trenches) or vertical (bore holes). The capacity of the closed-loop heat pump is dictated by the length of the exchange loop pipe in the ground. A GSHP has a relatively consistent performance due to the stable temperatures in the earth or body of water. Performance is expressed as a coefficient of performance (COP) that typically ranges from 3 to 4, meaning that for every one unit of electricity input, three to four units of energy are delivered.

Replacing conventional heating and air conditioning systems with GSHPs typically saves 15 to 25% of total building energy use in commercial buildings.[40] In addition to energy savings, GSHPs reduce summer peak electricity demand due to the lower power required for cooling.

GSHPs have lower operating costs that contribute considerably to their life-cycle cost-effectiveness. The technology is less prone to malfunction, requires about 25% less refrigerant (compared to same size air-source refrigeration systems), requires less maintenance and has a longer service life than other heating and cooling technologies, and has no outdoor equipment that is subject to inclement weather or other abuse (e.g. branches, construction accidents, vandalism). However, in a heating-dominated climate with high electricity costs and low natural gas costs, heat pump retrofits may be less financially attractive than other heating and cooling options.

40 Geothermal Heat Pumps Deliver Big Savings for Federal Facilities, Federal Energy Management Program, DOE/EE-0291.

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Air-source heat pumps

Air-source heat pumps (ASHPs) exchange energy with outdoor air. In cooling mode, they extract heat from the indoor air stream and reject it to the outside air. In heating mode, they absorb low-grade heat from outdoor air and upgrade it (through compression) for rejection into the indoor air stream. In a heating-dominated climate, it can be a challenge for ASHPs alone to meet the heating needs of the building; supplemental heating from other sources is typically required.

Advancements have been made in recent years to extend the heating performance to lower outdoor temperatures. This new breed of cold climate heat pumps offer full capacity heating down to -15 °C and reduced heating capacity down to -25 °C. These heat pumps are available up to a capacity of 14 kW (4 tons), which limits their application to small buildings or where split systems are acceptable.

Central cooling systems

Chilled-water systems are a common approach to cooling medium and large buildings (9,000 m^2 [~100,000 sq. ft.] or more). They feature separate central chillers and air handlers, with a network of pipes and pumps to connect them. Although only 25% of all Canadian commercial/institutional building floor space is cooled by chillers, about 43% of all buildings larger than 9,000 m^2 contain chilled-water systems.[41]

Chillers are at the heart of these systems and are often the focus of efficiency assessments, due largely to the technology and control improvements offered by manufacturers. However, focusing solely on chiller efficiencies won't necessarily lead to the most cost effective savings. The best way to produce energy and demand savings is to consider the operation of the entire chiller plant using an integrated approach. Figure 14 shows an example of typical chiller plant operation. Pumps and fans in the system, for example, have a role to play in delivering the most cost effective approach.

41 Natural Resources Canada. Commercial and Institutional Building Energy Use Survey 2000.

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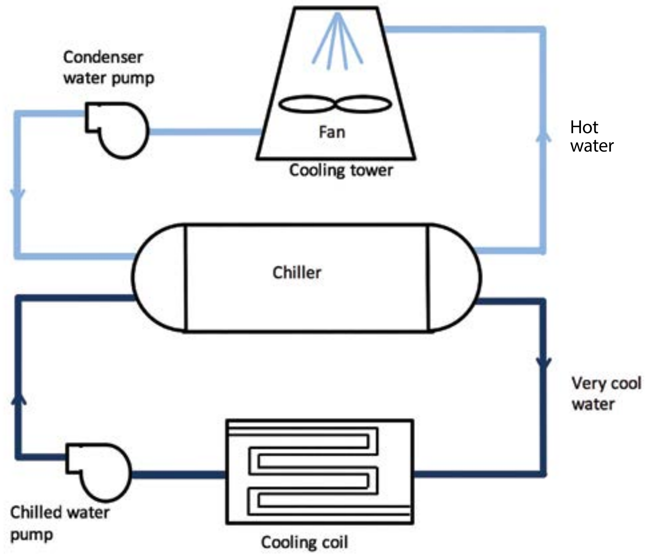
Figure 14. Chiller plant



Chiller operating efficiency

Assuming good operating conditions, many older centrifugal chillers have a full-load COP around 4.0 (full-load operating efficiencies of 0.80 kW input/ton cooling capacity). Most of today's new high-efficiency chillers have a full-load COP around 7.0 (full-load efficiency of 0.50 kW/ton). More importantly, new chillers have much higher part-load efficiencies than older chillers. Given that most chillers operate under part-load conditions 95% of the time or more, improved part-load operating efficiencies are key to achieving significant cost savings.

To accurately estimate the energy savings that could be achieved by replacing an existing chiller, a load profile can be constructed for the existing chiller. A load profile shows how much energy a chiller uses at each point in its full operating range, from its minimum to its peak load. This load profile can be compared to the manufacturer's load profile for a replacement chiller and used to estimate how much energy the replacement chiller would use.

Right-sizing

Both cooling equipment efficiency and a facility's cooling loads may change over time. Furthermore, chillers are often oversized, resulting in decreased annual operating efficiency. Although installing a VSD will improve part-load efficiency, it is more efficient to properly match the size of the chiller to the load.

Do the math: To illustrate the impact of load reductions and the resulting lower capital cost investment with the cooling plant, consider a 10.76-W/m^2 (1-W/sq. ft.) reduction in the lighting power density in a 9,290-m^2 (100,000-sq. ft.) building.

The result of the decreased lighting load would allow a chiller capacity reduction of about 80 kW (23 tons) (assuming 80% of the waste heat reaches the conditioned space). If a typical chiller costs $125 per kW ($450 per ton), an 80-kW reduction would reduce the first cost of a new chiller by more than $10,000.

Source: U.S. EPA

Note: 1 ton of cooling capacity = 3.5 kW or 12,000 Btu/hr

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The Montreal Protocol, a treaty first signed in 1987 to phase out the production of ozone-depleting chemicals, has been a major influence in developing alternate refrigerants and equipment.

The main refrigerant types on the market are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs). All CFCs, including CFC-11 and R-12, were phased out in 1996 and are no longer available for new equipment. The industry successfully transitioned away from refrigerants most harmful to the ozone layer, and manufacturers now use HCFCs such as R-22 and R-123, as well as HFCs such as R-134a, R-410a and R-407c.

The case for chiller replacement

Chillers have a typical service life of 20 to 25 years (chillers that are well maintained can operate for 30 years or more) and are considered to be a capital-intensive investment. Although lower operating costs are a strong motivation to replace older chillers, managers must weigh other factors – the chiller's condition, age and reliability, how building loads have changed, and maintenance requirements – before determining the true value of replacement.

Refrigerants

Most chillers manufactured before 1995 used chlorofluorocarbon (CFC) refrigerants, which have high ozone depleting potential (ODP). However, given that these refrigerants have not been available for almost two decades, the chance of large refrigeration systems using these refrigerants is remote.

More than 95% of commercial and residential air conditioning units and more than 50% of commercial refrigeration equipment in Canada operates on hydrochlorofluorocarbon (HCFC) refrigerants (primarily R-22).[42] Many commercial refrigeration units were converted to HCFCs from CFCs. HCFC refrigerants imported into and manufactured in Canada were eliminated from the supply chain in 2010, and no HCFC-22 (R-22) equipment has been manufactured in or imported into Canada since then.

HCFC refrigerants are considered transitional. Beginning in 1996, their use was capped, and the cap will decrease incrementally until worldwide production is eliminated in 2030. However, equipment using HCFC refrigerant R-123 has a phase-out date of 2020. Therefore, chiller replacement plans should not include those using HCFC refrigerants such as R-123.

Hydrofluorocarbon (HFC) refrigerants have replaced CFCs and HCFCs. Unlike CFCs and HCFCs, HFCs contain no chlorine and pose no known harm to the ozone layer, but it has been established that HFCs are greenhouse gases with a global warming potential (GWP) much greater than CFCs and HCFCs. The industry is seeking new refrigerants that are low in both ozone depletion and global warming potential.

42 The Heating, Refrigeration and Air Conditioning Institute of Canada.

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R-134a has no scheduled phase-out date and is used in centrifugal chillers, water-cooled screw chillers, and air-cooled positive displacement chillers.

R-410a and R-407c have no scheduled phase-out date and are used in smaller air-cooled positive displacement chillers and packaged rooftop equipment.

Chilled-water plants are complex and thus present many retrofit efficiency opportunities. The recommended approach is to look for opportunities that deliver upstream savings. For instance, by reducing resistance in the piping system, a designer might be able to reduce capital costs by specifying a smaller pump and chiller. Starting at the valves and ending at the cooling tower fan can yield upstream capital cost and energy savings.

An integrated system approach is key to improving the overall efficiency of a chiller plant. This is important for two reasons. First, it is difficult to make generalizations about specific opportunities. Delivering the most cost-effective chiller plant requires a building-specific design that considers energy and demand prices, building load profile, local climate, building features, operating schedules, and the part-load operating characteristics of the available chillers. Second, modifying the design or operation of one component often affects the performance of other system components. For example, increasing the chilled water flow can improve chiller efficiency, but the extra pumping power required can result in an overall *reduction* of system efficiency. The following nine measures apply.

Heating and cooling measure list (central cooling systems)	
✓ Start with first-order measures	✓ Upgrade the chiller compressor
✓ Eliminate flow-restricting valves	✓ For chillers without a variable speed-drive, use low-voltage soft starters
✓ Insulate chilled-water pipes	✓ Replace an old or oversized standard-efficiency chiller with a properly sized high-efficiency water-cooled unit
✓ Replace standard-efficiency or oversized pumps with highly efficient units right-sized for the reduced loads	✓ Install water-side economizers to allow cooling towers to deliver free cooling when weather conditions permit
✓ Control chilled-water pumps with variable speed-drives	

It is important to note that the list of measures recommended for the chiller plant requires a detailed engineering assessment to determine which measures to apply and the magnitude of savings.

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When replacing an existing chiller, select one that will be most efficient under the conditions it is likely to experience. Even though chiller performance can vary dramatically depending on loading and other conditions, designers frequently select chillers based on full-load, standard condition efficiency. However, chillers spend most of their operating time in the 40-to-70% load range under conditions that can be considerably different from standard. To select the chiller that will have the lowest operating costs, determine what the actual operating conditions are likely to be, and then consider how efficiently the unit will operate under those conditions.

- **Start with first-order measures:** Existing chiller plants can be optimized by ensuring that chilled and condenser water resets are in place, as well as by sequencing for multiple chillers and cooling towers. Refer to the Existing Building Commissioning stage for a list of potential operational measures.
- **Eliminate flow-restricting valves:** This measure reduces pump energy use and returns less heat to the chiller. If valves are installed to control flow by inducing a pressure drop, energy-saving measures include completely opening the valves and converting to variable speed controls, trimming the impeller, or staging pumps.
- **Insulate chilled-water pipes:** Insulation helps ensure that the chilled water only absorbs heat from the conditioned spaces where it is intended to do so.
- **Replace standard-efficiency or oversized pumps with highly efficient units right-sized for the reduced loads:** Most induction motors that drive pumps reach peak efficiency at about 75% loading and are less efficient when fully loaded. Wherever possible, pumps should be sized so that much of their operating time is spent at or close to their most efficient part-load factor. If a pump is oversized, it likely operates at an inefficient loading factor and introduces reactive power into the electrical system, which could result in charges for poor power factor from the electrical utility.
- **Control chilled-water pumps with variable speed-drives:** VSDs can ensure that pumps are performing at maximum efficiency at part-load conditions. The power required to operate a pump motor is proportional to the cube of its speed. For example, in a pump system with a VSD, a load reduction that results in a 10% reduction in motor speed reduces energy consumption by 27%.[43] However, it is necessary to ensure that flow rates through chillers are maintained at safe levels. With proper controls, lower chilled-water flow rates enabled by VSD pumps can also be coordinated with a chilled-water temperature reset schedule to meet loads accurately and efficiently. Low cooling loads, for example, might be most efficiently met by creating colder chilled water and reducing the flow rate to save pump energy.
- **Upgrade the chiller compressor:** For a centrifugal compressor, install a VSD to allow the chiller to run at lower speeds under part-load conditions. This yields a higher efficiency than is typically achieved by ordinary centrifugal chillers that control part-load operation with inlet vanes. However, there is a limit on how flows controlled by VSD can be cost-effective. In applications where there are extended periods with very low loads (e.g. 10% of full load), it may be more cost-effective to install a separate small chiller just for these loads.

43 The formula is 1 – (0.9)3 = 0.27.

For reciprocating and screw chillers, replace the existing compressor with one that uses new magnetic bearing technology. These achieve much better efficiency than any other compressor type in the under 1,000-kW (300-ton) capacity range. Chillers using magnetic bearing compressors can achieve a seasonal COP of 9.5 (an integrated part-load value, IPLV, of 0.37 kW/ton), as compared with a seasonal COP of 6.0 (an IPLV of 0.60 kW/ton) for standard screw- and scroll-based chillers, producing significant savings.

- **For chillers without a variable speed-drive, use low-voltage soft starters:** The motor windings of constant speed compressors experience great stress when the chiller is first started due to the high inrush of current. This can eventually lead to motor failure. Soft starting gradually raises the voltage and current to avoid the high inrush. Soft starting itself does not save energy, but it does allow chillers, which are otherwise left running because of operator concern for wear and tear from frequent starts, to be shut off.
- **Replace an old or oversized standard-efficiency chiller with a properly sized high-efficiency water-cooled unit:** If the existing chiller is nearing the end of its life or is in need of substantial maintenance, consider retiring it early to capitalize on the savings that a new high-efficiency model can deliver. This can be particularly fruitful if the existing chiller is already oversized or if load reductions achieved through other stages in the building upgrade process allow the chiller to be downsized.
- **Install water-side economizers to allow cooling towers to deliver free cooling when weather conditions permit:** Under the right climate conditions, water-side economizers can save a lot of energy by using the cool outdoor air to chill the water, instead of the chiller. In many regions of Canada with cool, dry climates, economizers can provide more than 75% of the cooling requirements.

  The most common type is an *indirect* economizer that uses a separate heat exchanger. This allows for a total bypass of the chiller, transferring heat directly from the chilled-water circuit to the condenser-water loop. When the wet-bulb temperature is low enough, the chiller can be shut off and the cooling load can be served exclusively by the cooling tower.

Chiller plant upgrade summary

Before pursuing any of the opportunities listed in these guidelines, it is important to evaluate the performance of the chiller plant as an integrated system. Although an integrated approach requires more effort than simply picking measures independently, it produces more savings. VSD pumps, fans and compressors provide greater operational flexibility and efficiency, but require a control system that can coordinate their operations with the rest of the system. Existing controls may not be able to provide the advanced functions necessary for efficient operation and should therefore be upgraded as well.

Case in point:
Toronto-Dominion Centre
Toronto, Ontario
(LEED-Existing Buildings: Operations and Maintenance Gold)

In 2010, the Toronto-Dominion (TD) Centre became the first property in Canada to receive the Canada Green Building Council's (CaGBC) LEED-Existing Buildings: Operations and Maintenance Gold accreditation. One of the most innovative projects to be undertaken was in the way that the TD Centre sourced a portion of its energy. In upgrading the chiller system, the building was linked through Enwave's deep lake water cooling to the waters of Lake Ontario. By effectively outsourcing 46,000 kW (13,000 tons) of the building's chiller capacity annually, the company was able to reduce its energy consumption in this area by 90%.

Source: Green Commercial Real Estate, Office Assets, 2010 and Enwave Energy Corporation.

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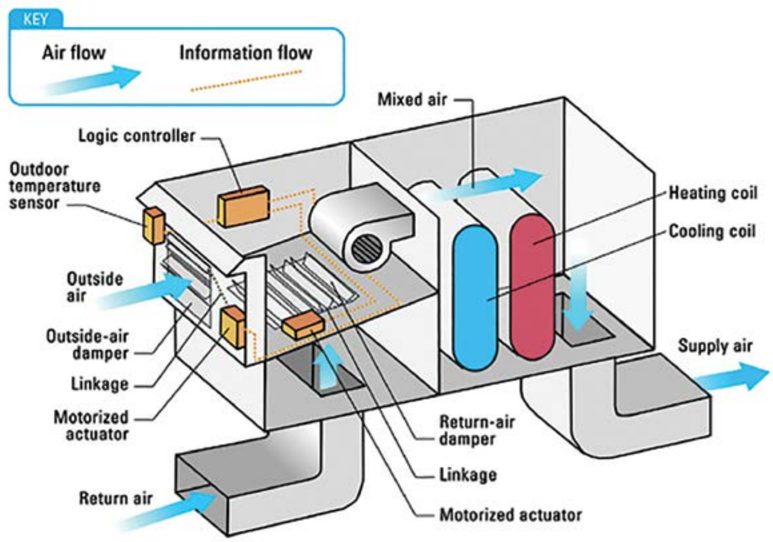
Rooftop units

More than a third of Canadian commercial/institutional building floor space is conditioned by self-contained, packaged rooftop units (RTUs).[44] RTUs are typically configured with natural gas combustion or electric duct heaters for heating and direct expansion (DX) refrigeration cooling. In some cases, heat recovery wheels or cores are included as well. The RTU may also be configured as a heat pump or, in rare cases, the RTU heating may be delivered through a hot water coil served by a central boiler plant. In addition, units may be constant volume or variable volume. A typical RTU setup is shown in Figure 15.

Figure 15. Typical rooftop unit



Source: U.S. EPA

RTU efficiencies have improved dramatically over the past 15 years, and there are control-based retrofit technology options available that can deliver savings in excess of 50%. Depending on the efficiency and age of the RTU, there is a business case for complete replacement or retrofit upgrades. For instance, if the RTU is 15 years (the expected service life) or older, replacement is probably the better option. If the RTU is only 5 years old, retrofitting may be a viable option. Moreover, if a constant volume distribution system is being replaced with variable volume, then RTU replacement will be necessary to provide the variable air supply with control feedback from the distribution boxes.

The heating efficiency of older existing RTUs may range from 60 to 75%, while new RTUs can achieve greater than 80% efficiency for non-condensing units, and upwards of 90% efficiency for condensing units.

44 Natural Resources Canada. Commercial and Institutional Building Energy Use Survey 2000.

Table 3 illustrates how ASHRAE's cooling efficiency standards have evolved.

Table 3. Evolution of RTU efficiency standards

90.1-1999	90.1-2000	90.1-2004	90.1-2010		CEE Tier II		RTU challenge
EER	EER	EER	EER	IEER	EER	IEER	IEER
8.7	10.1	10.1	11.0	11.2	12.0	13.8	18.0

The following cooling efficiency metrics for RTUs are defined by the Air-Conditioning and Refrigeration Institute (ARI), a trade association representing air conditioner manufacturers:

- Energy efficiency ratio (EER), defined as the rate of cooling in Btu/hour divided by the power input in watts at full-load conditions, is a measure of full-load efficiency. The power input includes all inputs to compressors, fan motors and controls.
- Integrated energy efficiency ratio (IEER), defined as the cooling part-load efficiency on the basis of weighted operation at various load capacities, applies to RTUs with cooling capacities equal to or greater than 19 kW (5.4 tons).
- Seasonal energy efficiency ratio (SEER) describes the seasonally adjusted rating based on representative residential loads, unlike EER, which describes the efficiency at a single rating point. SEER applies only to RTUs with a cooling capacity of less than 19 kW. Although units less than 19 kW that use three-phase power are classified as commercial, they still use the residential SEER metric. This is because these small units are similar to the single-phase units used in residential applications, which have a large part of the market share in this size range. Older units of less than 19 kW often have a SEER rating as low as 6.

The Consortium for Energy Efficiency (CEE), a non-profit organization that promotes the adoption of energy-efficient technologies, defined the 1993 Tier 1 minimum efficiency recommendation as having an EER of at least 10.3, 9.7 and 9.5, respectively, for the small, large, and very large RTU size categories.

Under the U.S. Department of Energy's Rooftop Campaign, which promotes adoption of efficient RTUs, efficiency specifications have increased to a minimum IEER of 18 for units 35 to 70 kW (10 to 20 tons) as a challenge to manufacturers. The industry has responded favourably, and a number of manufacturers now have units that meet this aggressive target, many of which are available in the Canadian market.

Heating and cooling measure list (rooftop units)

- ✓ Convert constant volume system into variable flow system with demand control and economizer
- ✓ Add heat or energy recovery
- ✓ Add compressor control to reduce runtime
- ✓ Replace rooftop units
- ✓ Add economizer damper

PART 1

The Pacific Northwest National Laboratory (PNNL) has created a **Rooftop Unit Comparison Calculator** (pnnl.gov/uac/costestimator/main.stm) that compares high-efficiency equipment with standard equipment in terms of life-cycle cost.

This online screening tool provides estimates of life-cycle cost, simple payback, return on investment and savings-to-investment ratio. The simulations use U.S. locations for weather; however, for Canadian locations with the same climate zones, the tool may provide a reasonable estimate of the cost-benefit analysis.

Retrofitting RTUs for energy savings usually takes the form of controls, rather than adding energy saving equipment (such as heat recovery) or motor replacement. However, opportunities do exist to add energy saving equipment in some cases. Under the **retrofit** category, the following four measures are applicable:

- **Convert constant volume system into variable flow system with demand control and economizer:** In the current market, there are two packaged technologies that have been recognized by utilities as acceptable for conservation incentive programs. For constant volume RTUs greater than 26 kW (7.5 tons), a fully packaged advanced rooftop controller retrofit package that converts a CV system into a variable flow system with demand control and economizer is available. A field study by the Pacific Northwest National Laboratory[45] provided independent analysis of this technology, with results showing a reduction in normalized annual RTU energy consumption between 22 and 90%, with an average of 57% for all RTUs.
- **Add compressor control to reduce runtime:** For RTUs smaller than 26 kW, packaged controllers that reduce air conditioning energy are available. These devices control the compressor cycles to reduce the runtime, while continuing to deliver the cooling expected from the unit. Typical air conditioning systems are designed to meet the peak load conditions, plus a safety margin, and operate continuously until the room's thermostat set point temperature is reached. However, under most operational conditions, maximum output is not required, and the system is oversized for the load. Simple controllers that detect thermodynamic saturation of the heat exchanger turn off the compressor to avoid overcooling. Industry experience has shown an average of 20% cooling energy savings.
- **Add economizer damper:** Some RTU models can accommodate an economizing damper as a manufacturer's option. In cases where the economizer damper was not included in the original product selection, adding the economizer will deliver energy savings.
- **Add heat or energy recovery:** Similarly, some RTU models can accommodate heat or energy recovery ventilators as a manufacturer's option. In cases where these options were not included in the original product selection, adding them will deliver energy savings.

There is often a favourable business case for **replacement** of existing RTUs with new high-efficiency units. With the potential for combined heating and cooling savings of 50% or more, it can sometimes be cost-effective to replace an RTU before the end of the equipment's expected life span.

- **Replace rooftop units:** Replacing an existing RTU will bring numerous efficiency gains, especially where high-efficiency units are specified with variable speed fans and compressors, energy recovery, and condensing gas combustion. RTUs are sized according to their cooling capacity (kW or tons), with nominal heating capacities set according to the cooling capacity. Careful attention to product specifications is required to identify high-efficiency gas combustion options.

45 Advanced Rooftop Control (ARC) Retrofit: Field-Test Results. pnl.gov/main/publications/external/technical_reports/PNNL-22656.pdf.

PART 1

Replacing an existing RTU with a new generation advanced RTU will bring numerous efficiency gains and increased occupant comfort through better control. Significant advances in the performance of RTUs have been made since 2011. Furthermore, when considering replacement, the equipment size should be revisited to ensure right-sizing. Some of the features available with the new generation advanced RTUs include:

- Insulated cabinets for improved energy efficiency and acoustics
- Multi-staged or modulating heating control with turndown ratio of 10:1
- Condensing-type heating with AFUE up to 94%
- Variable speed electronically commutated fan motors
- Variable speed scroll compressors with superior part-load efficiency
- Heat and energy recovery from exhaust air
- Demand controlled ventilation using CO_2 sensors
- Heat pump option
- SEER up to 18; IEER up to 21
- Remote energy monitoring and operational supervision

Domestic hot water

Although water heating comprises only a small portion of the total energy use in Canadian office buildings (~8% or less), there are a number of opportunities to save energy.

Heating and cooling measure list (domestic hot water)	
✓ Install low-flow aerators and showerheads	✓ Replace existing boiler/heater with more efficient unit
✓ Schedule recirculation system	✓ Replace storage-based system with on-demand

- **Install low-flow aerators and showerheads:** Reduced flow through faucets and showerheads reduces the consumption of hot water. Installing water-efficient fixtures is the lowest cost measure to reduce energy, and replacements can be easily done by operations staff. Products are available that deliver flow rates as low as 0.95 L/min for faucets and 4.7 L/min for showerheads.
- **Schedule recirculation system:** Many buildings use an inline pump to circulate hot water through the domestic hot water distribution system so that hot water is readily available for use. Scheduling the circulation to operate only during occupied hours saves the electrical energy associated with pump use. Thermal losses from the circulation pipe are also reduced. The simplest method of scheduling the recirculation pump is to add a timeclock and program it to match occupancy hours. The implication for occupants working outside of normal occupancy periods is that they may not have instantaneous hot water at the faucet.

- **Replace existing boiler/heater with more efficient unit:** Existing hot water boilers/heaters more than 20 years old operate at efficiencies of 60 to 80%. They can be replaced with new units that achieve efficiencies as high as 95% when condensing.
- **Replace storage-based system with on-demand:** In smaller buildings with fewer washrooms, it may be possible to replace a central water heater with an electric on-demand heater near the point of use or a central gas-fired on-demand heater. On-demand water heaters are tankless, heating the water as it passes through the heat exchanger. These types of heaters are about 20% more efficient than gas-fired tank type heaters,[46,47] and the savings are attributed to a lack of storage losses in conventional tank systems.

  On-demand water heaters come in two basic types. Small electric units that mount close to the point of use are very useful when there are only one or two lavatories. Larger, centralized gas-fired units are more applicable for multiple lavatories. On-demand water heaters are typically more expensive than the storage type, and a full cost-of-ownership analysis would be useful to determine if there is an economic benefit.

IMPORTANT: Managing Legionella in hot and cold water systems

Legionella bacteria are commonly found in water and can multiply where nutrients are available and water temperatures are between 20 and 45 °C. The bacteria remain dormant below 20 °C and do not survive above 60 °C. Legionnaires' disease is a potentially fatal type of pneumonia, contracted by inhaling airborne water droplets containing viable Legionella bacteria.

Risk of Legionella can be controlled through water temperature. Hot water storage should store water at 60 °C or higher. Hot water should be distributed at 50 °C or higher (using thermostatic mixer valves at the faucet to prevent scalding). These temperature criteria should be respected when designing any retrofits to your domestic hot water system.

See the *American Society of Plumbing Engineers (ASPE) 2005 Data Book - Vol.2,* Ch.6 - Domestic Water Heating Systems Fundamentals for more details.

46 ENERGY STAR. ENERGY STAR Certified Water Heaters. **energystar.gov/productfinder/product/certified-water-heaters/results**

47 Natural Resources Canada, Office of Energy Efficiency. Energy Efficiency Ratings. Water heaters, gas. **oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.search-recherche&appliance=WATERHEATER_G**

PART 1

Natural Resources Canada offers a wealth of resources and guidance to help you improve the energy efficiency of your buildings:

- *Recommissioning Guide for Building Owners and Managers*
- *Energy Management Best Practices Guide*
- *Energy Management Training Primer*
- *Improve Your Building's Energy Performance: Energy Benchmarking Primer*
- *Energy benchmarking for commercial office buildings*

For these and other resources, visit our website at **nrcan.gc.ca/energy/efficiency/eefb/buildings/13556.**

Email: **info.services@nrcan-rncan.gc.ca**

Toll-free: 1-877-360-5500

PART 2 MISSISSAUGA EXECUTIVE CENTRE: A CASE STUDY

MEC2, pictured above, was built in the late 1970s. Energy efficiency upgrades completed between 2005 and 2013 reduced natural gas and electricity use, saving 30% on energy costs.

Note to readers: Although many of the upgrades were similar across all four buildings, this case study focuses on MEC2, the oldest of the buildings.

Photo courtesy of Colliers International

A staged approach helps the Mississauga Executive Centre reap energy efficiency benefits

> "I've been at this a long time. Twenty-four years ago, when I worked at a hotel, we switched to CFLs [compact fluorescent lamps]. People thought we were crazy spending $30 for a single bulb, but today, energy efficiency isn't even questioned."
>
> – Wade Warner, General Manager
> Property Operations, Eastern Canada, Colliers International

The Mississauga Executive Centre (MEC) comprises four buildings in the heart of Mississauga, Ontario, all of which were certified LEED Gold for Existing Buildings in 2013.

MEC is managed by Colliers International, the world's third largest commercial real estate services provider. As part of a growing move toward corporate sustainability, Colliers recognized its role in encouraging energy conservation and was the first real estate services company to measure its carbon footprint. It works with portfolio managers and owners to set and achieve targets.

For MEC, that meant setting an energy reduction target of 20% by 2012. In 2011, Colliers set a further target of reducing greenhouse gases by 20% by 2015.

Major benefits

- ✓ Between 2007 and 2012, MEC2's energy use was reduced by 30%.
- ✓ Capital expenditures for retrofits have totalled about $2.5 million for all four MEC buildings.
- ✓ Projects typically have a three- to four-year payback.
- ✓ Most upgrades were done as part of Colliers' asset renewal program.

The staged approach to retrofits

In 2007, an energy audit established baseline energy information for all four MEC buildings. Baseline scores were established for each building using ENERGY STAR Portfolio Manager. Not surprisingly, MEC2, the oldest of the four buildings, had the lowest ENERGY STAR score (53 out of a possible 100). A number of projects had already been completed prior to the audit, but the process did reveal a number of new opportunities.

> "We became more orderly as we went along, so now we know that the best way to retrofit is to first conduct an audit, get your benchmark, then implement the projects and track performance."
>
> – Wade Warner

"Our initial reaction to the baseline was that only complicated or expensive projects remained," recalls Warner. But as they delved deeper into the numbers, they found that there were still a lot of simple projects, with good returns, that could be done.

The energy audit, as well as staff training opportunities, illustrated the benefits of using the staged approach to retrofits recommended by Natural Resources Canada. All staff take the Seneca College building systems course, and other training is also available to them. Warner is also a LEED accredited professional.

What was done?

Lighting

Between 2002 and 2003, lighting for all the MEC buildings was upgraded from T12 lamps and ballasts to energy-efficient T8 electronic ballasts, T8 fluorescent lamps and high-efficiency interior reflectors. The project involved replacing about 25,000 fixtures and installing new lighting control panels.

Annual energy savings from lighting alone are estimated at approximately $560,000. The payback period was two years, with a simple return on investment of about 50%. In addition, annual emissions of sulphur dioxide and carbon dioxide were reduced by 12 tonnes and 2,500 tonnes, respectively, and the old T12 lamps were recycled for their mercury, other metals and glass.

Envelope and domestic hot water

An infrared scan of the roof and curtain wall was conducted, and air leaks that were evident from the scan were repaired. A new controller was installed on all domestic hot water boilers. The controller determines the heat load by using a strap-on temperature sensor that monitors the boiler's outflow water temperature and the rate at which the temperature is changing. It then adjusts the burner run pattern to match the heat load.

PART 2

HVAC

Variable speed-drives were installed on all fans and on the cooling towers. An atmospheric boiler was switched for a new high-efficiency model, and the reciprocating chiller was replaced in 2013 with a 1,300-kW (370-ton) high-efficiency unit that was connected to the free cooling system. Control panels were replaced with new ones so that all new equipment communicates with MEC2's building automation system.

As illustrated in Table 4, once the upgrades were complete, the ENERGY STAR scores for all four buildings showed marked improvements.

Table 4. ENERGY STAR score improvements

Building	2010	2011	2012	2013	2014
MEC1	74	75	79	87	89
MEC2	***53***	***50***	***71***	***82***	***84***
MEC3	85	86	88	87	87
MEC4	72	73	90	94	93

How were the retrofits financed?

The vast majority of the retrofit projects were part of MEC's capital renewal process – equipment or system replacements that would need to be done regardless of energy use or costs. The property owners provided the financing, and the savings were used to offset the capital costs.

Table 5. Retrofit financing

MEC2	
Total initial investment	$625,000
Net operating income (NOI) impact of energy savings	$160,000/year
Capitalization rate (reflects the 2014 office building market in the suburban Greater Toronto Area)	6.5%
Additional asset value using the income method, i.e. $160,000 / 6.5%	~$2,500,000

"Our target was a 20% reduction in energy use by 2012, and we exceeded that," Warner says. He cautions, however, that because of rising energy costs, some projects did not appear to save money at the outset. "For some projects, we were paying the same amount [in utility costs], but I tell the accounting folks that the bill would have been a lot higher had we not done it."

Additional savings came from utility programs. In 2010, energy monitoring technology was installed to track energy use in real time. An energy manager with Enersource (made available through the Ontario Power Authority's [OPA] SaveONenergy program) also helped to identify new projects and navigate the application process for utility incentives. For example, on an investment of approximately $390,000, Enersource provided an incentive of $76,000 for the chiller replacement; MEC2 also received a rebate of $11,694 from Enbridge for the boiler replacement.

How can I benefit From MEC2'S experience?

Warner says that, although he and his staff faced few technical or process-related issues, his biggest initial challenge was battling traditional ideas.

"Staff likes to stick with what they know, and new ideas may appear threatening at first. With staff training, they are more energy aware and, in most cases, they find that things operate better than before."

For those new to the process, Warner advocates the staged approach recommended by Natural Resources Canada.

"An energy audit at the start will provide many low- and no-cost opportunities," he says. But, he adds, "The best and lowest cost first step is to turn things off when they are not required. A night-time walk through your building can yield some surprising opportunities when you find what's still running when everyone has gone home."

PART 3

MY FACILITY

The following take-away section provides a summary of the retrofit measures applicable to office buildings in the form of a questionnaire. This tool complements ENERGY STAR Portfolio Manager by providing direction on how to set improvement goals based on your ENERGY STAR score.

The appropriate next steps for your facility will vary depending on your ENERGY STAR score:

- If your facility has a **low score**, you are likely a good candidate for a major retrofit **investment**. Investing in major retrofits and undertaking a staged approach will likely have the greatest impact on your bottom line.
- If your facility has an **average score**, you are likely a good candidate for **adjustment**. Opportunities to make adjustments at your facility may involve a combination of major retrofit measures, less complex upgrades, and improved operations and maintenance practices.
- If your facility has a **high score**, you should focus on **maintaining** your score. In addition to maintaining your performance by focusing on ongoing building optimization, you should regularly assess major retrofit opportunities, particularly with respect to asset management.

The **questionnaire** is organized by:

Retrofit stage: Each column of questions represents a specific retrofit stage. Stages are presented from left to right in the order of the staged approach recommended in NRCan's *Major Energy Retrofit Guidelines: Principles Module*.

ENERGY STAR score: Within each column, measures have been labelled as Maintain, Adjust or Invest by the unique shape and colour of their checkboxes:

❑ **MAINTAIN**

❍ **ADJUST**

✧ **INVEST**

Facilities that are good candidates for investment should consider all measures; facilities are that good candidates for adjustment may choose to focus on Adjust and Maintain measures; facilities that want to maintain their score may choose to focus primarily on Maintain measures.

PART 3

Instructions

1. Benchmark your facility using ENERGY STAR Portfolio Manager and determine your ENERGY STAR score.
2. Assess the nature of the opportunities at your facility by answering the questionnaire with Yes, No or Not Applicable. The result should be a shortlist of relevant opportunities for your facility.
3. Consult the various sections of this module for more details on the relevant measures to confirm applicability. Once you have reviewed the details, you may find that some of the shortlisted opportunities should be labelled Not Applicable, or may not be of interest to your organization.

Measure costing

The return on investment for specific measures varies greatly based on many facility- and location-specific factors. You should always analyze costs and savings based on your specific situation. However, measures labeled:

❑ **MAINTAIN** are generally low-cost measures with payback periods under three years.

❍ **ADJUST** are generally low- or medium-cost measures with payback periods up to five years.

✧ **INVEST** are often higher-cost capital replacement measures. Payback periods for these measures typically exceed five years and in some cases may need to be justified with a renewal component (e.g. upgrade roof insulation when replacing a roof near the end of its life). These measures typically require detailed financial analysis to ensure a sound business case.

My Facility – Benchmarking Results

PORTFOLIO MANAGER INPUTS

Gross floor area: ____________________

Weekly operating hours: ____________________

# of computers: ____________________

# of workers on main shift: ____________________

% that can be heated/cooled: ____________________

PORTFOLIO MANAGER OUTPUTS

ENERGY STAR score: ____________________

Site EUI: ____________________

Source EUI: ____________________

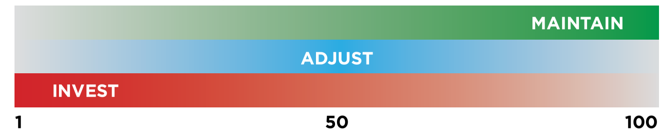
Median property EUI: ____________________

TARGETS

ENERGY STAR score target: ____________________

Site EUI target: ____________________

ENERGY STAR score interpretation



Adapted from the U.S. EPA's *Energy Performance Rating System*

Office buildings – energy efficiency opportunity questionnaire

EBCx

- ❑ Do the lighting and occupancy schedules match? [Pg. 8]
- ❑ Is the air handling system on a schedule? [Pg. 8]
- ❑ Are the zone temperature set points set back/forward during unoccupied hours? [Pg. 8]
- ❑ Does the air handling equipment have a properly functioning economizer to enable free cooling? [Pg. 9]
- ❑ Are the heating coil valves turned off during the cooling season? [Pg. 9]
- ❑ Is the zone temperature deadband wide enough? [Pg. 9]
- ❑ Is the supply air temperature reset depending on outdoor conditions? [Pg. 9]
- ❑ Are the outside air dampers closed during morning warm-up during the heating season? [Pg. 9]
- ❑ Is an early morning flush performed regularly during the cooling season? [Pg. 10]
- ❑ Is the VAV system static pressure set point automatically reset through a zone-level control feedback loop? [Pg. 10]
- ❑ Are the VAV zone dampers operating properly? [Pg. 10]

Lighting upgrades

Direct replacement

- ❍ Have frequently used incandescent fixtures been replaced with LED fixtures? [Pg. 16]
- ❍ Have incandescent Exit signs been replaced with LED signs? [Pg. 16]
- ❍ Have exterior light fixtures been replaced with LED fixtures? [Pg. 16]
- ❍ Have fluorescent fixtures in stairways and/or exit routes been replaced with LED fixtures? [Pg. 16]
- ❍ Have wall switches in enclosed rooms been replaced with occupancy/vacancy sensors? [Pg. 17]

Designed retrofits

- ✧ Have unnecessary lamps or fixtures been removed (delamping)? [Pg. 19]
- ✧ Does the lighting design take advantage of specular reflectors? [Pg. 20]
- ✧ Has the ceiling light intensity been lowered and workers provided with individual LED task lights? [Pg. 20]

Supplemental load reduction

Power loads and equipment

- ❍ Is equipment being turned off when not in use? [Pg. 24]
- ❍ Is ENERGY STAR equipment being used where applicable? [Pg. 25]
- ❍ Has a policy regarding personal powered devices been implemented? [Pg. 25]
- ❍ Has an employee energy awareness program been implemented? [Pg. 25]
- ✧ Have transformers been replaced with energy-efficient models? [Pg. 25]
- ✧ Has your data centre been retrofitted? [Pg. 26]

Envelope

- ✧ Have infiltration issues been addressed? [Pg. 29]
- ✧ Has an air barrier been added or improved? [Pg. 30]
- ✧ Do the roof and wall insulation levels meet NECB requirements? [Pg. 31]
- ✧ Have the windows and doors been upgraded? [Pg. 32]
- ✧ Does the building have a "cool roof"? [Pg. 33]

Air distribution systems upgrade

- ✧ Is there a DCV system? [Pg. 41]
- ✧ Has the CV reheat, multi-zone, or dual-duct system been converted to a modern VAV system? [Pg. 42]
- ✧ Are fans and fan motors right-sized? [Pg. 42]
- ✧ Have VSDs been added to pumps and fans with variable loads? [Pg. 42]
- ✧ Is heat recovered from exhaust streams? [Pg. 42]
- ✧ Is outdoor air pre-heated with a solar air heating system? [Pg. 43]
- ✧ Is there a VRF system? [Pg. 43]
- ✧ Has the mixed-air delivery system been replaced with a DOAS? [Pg. 44]
- ✧ Have existing air filters been replaced with electronic air cleaners? [Pg. 44]

Heating and cooling resizing and replacement

Central heating

- ✧ Have existing boilers' control systems been replaced? [Pg. 47]
- ✧ Have flow-restricting valves been eliminated? [Pg. 47]
- ✧ Have pumps been replaced and right-sized? [Pg. 47]
- ✧ Are heating water pumps being controlled with VSDs? [Pg. 48]
- ✧ Have new burners been installed on existing boilers? [Pg. 48]
- ✧ Have turbulators been installed in firetube boilers? [Pg. 48]
- ✧ Has a new condensing boiler been installed? [Pg. 48]
- ✧ Has a new modulating boiler been installed? [Pg. 49]
- ✧ Has a new hybrid boiler system been installed? [Pg. 49]
- ✧ Has a new heat pump system been installed? [Pg. 50]

Central cooling

- ✧ Have flow-restricting valves been eliminated? [Pg. 56]
- ✧ Are chilled water pipes insulated? [Pg. 56]
- ✧ Have pumps been replaced and right-sized? [Pg. 56]

- ❑ Have minimum flow set points at VAV boxes been reduced? [Pg. 10]
- ❑ Have the BAS sensors been calibrated recently? [Pg. 10]
- ❑ Does the HVAC system follow an optimum start control strategy in the morning? [Pg. 11]
- ❑ Is the HVAC system over-ventilating? [Pg. 11]
- ❑ Have supply and exhaust air imbalances been corrected? [Pg. 11]
- ❑ Does the humidification set point exceed minimum requirements? [Pg. 11]
- ❑ Have multiple boilers been sequenced to operate most efficiently? [Pg. 11]
- ❑ Is there a heating water reset control strategy? [Pg. 11]
- ❑ Have multiple chillers been sequenced to operate most efficiently? [Pg. 11]
- ❑ Has a chilled water reset control strategy been implemented? [Pg. 11]
- ❑ Has a condenser water reset control strategy been implemented? [Pg. 12]
- ❑ Is full advantage being taken of cooling towers? [Pg. 12]
- ❑ Has missing or damaged pipe insulation been repaired? [Pg. 12]

- ✧ Does the lighting design maximize the use of available daylight? [Pg. 21]
- ✧ Does the lighting system use addressable ballasts? [Pg. 23]
- ✧ Have all LED options been considered? [Pg. 23]
- ✧ Has a centralized lighting control system been installed? [Pg. 23]

- ✧ Are chilled water pumps controlled with VSDs? [Pg. 56]
- ✧ Have new compressors been installed on existing chillers? [Pg. 56]
- ✧ Have low-voltage soft starters been installed on chillers without VSDs? [Pg. 57]
- ✧ Have old/oversized standard-efficiency chillers been replaced with properly sized high-efficiency water-cooled units? [Pg. 57]
- ✧ Have water-side economizers been installed to allow cooling towers to deliver free cooling when weather conditions permit? [Pg. 57]

Rooftop units

- ✧ Has the CV system been converted to a variable flow system with demand control and an economizer? [Pg. 60]
- ✧ Have compressor controllers been installed on RTUs to reduce runtime? [Pg. 60]
- ✧ Has an economizer damper been added? [Pg. 60]
- ✧ Has heat or energy recovery been added? [Pg. 60]
- ✧ Have old RTUs been replaced with new high-efficiency units? [Pg. 60]

Domestic hot water

- ❍ Have low-flow aerators and showerheads been installed? [Pg. 61]
- ❍ Is the hot water recirculation system on a schedule? [Pg. 61]
- ✧ Have hot water boilers/heaters been replaced with high-efficiency units? [Pg. 62]
- ✧ Have storage-based hot water systems been replaced with tankless? [Pg. 62]