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Major Energy Retrofit Guidelines

for Commercial and Institutional Buildings

HOSPITALS

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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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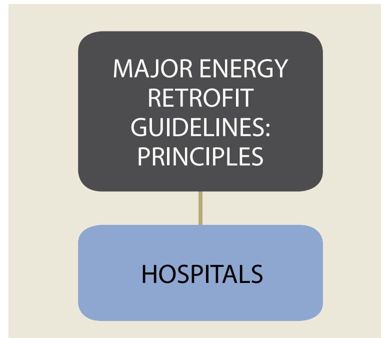
ENERGY RETROFIT OPPORTUNITIES IN HOSPITALS

PART 1

The Hospital 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 hospitals.

The Hospital Module is divided into three parts:

1. **Energy Retrofit Opportunities in Hospitals:** Provides an overview of Canadian hospitals. Subsections present background information on each retrofit stage and key retrofit measures, with a focus on small and medium-sized hospitals.
2. **Case Study:** The case study showcases a successful major energy retrofit project.
3. **My Facility:** This take-away section provides an Energy Efficiency Opportunity Questionnaire to assist you in identifying opportunities in your facility.



Hospitals include facilities that provide acute care services intended to treat patients for brief but severe medical conditions, including emergency medical care, physicians' services, diagnostic care, ambulatory care and surgical care. Acute care hospitals typically discharge patients as soon as they are deemed healthy and stable. Long-term care residences are not considered hospitals.

Hospitals 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]

Figure 1 shows that within the commercial and institutional buildings sector, hospitals are a significant energy using subsector, accounting for four percent of energy use.

Hospital facilities tend to be large and are intensive users of energy. In fact, hospitals have a higher energy use intensity (EUI) than any other facility type in the commercial and institutional sector with the exception of food and beverage stores. As the building stock ages, a tremendous opportunity exists to undertake major energy retrofits that will improve the energy performance and air quality of hospital facilities across the country, benefiting both patients and staff.

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.

[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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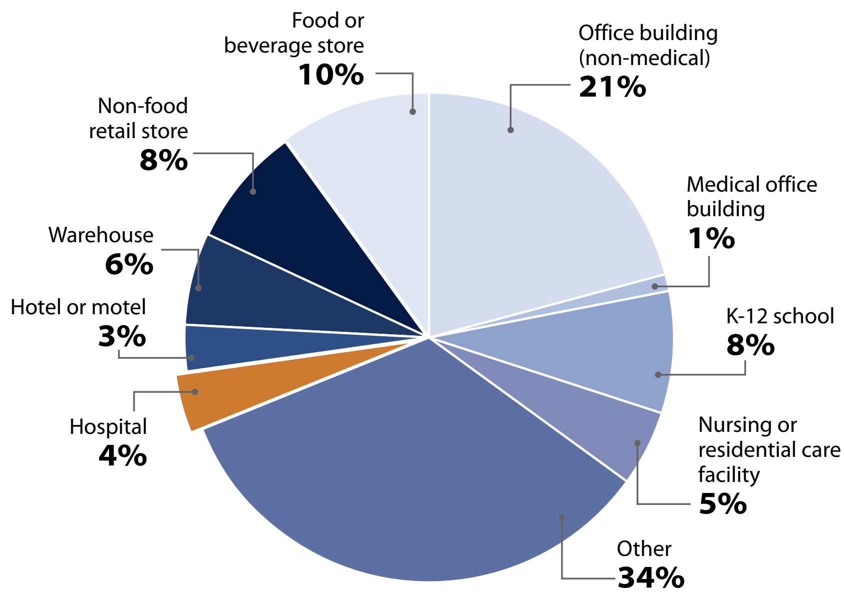
Figure 1. Commercial/institutional energy use by subsector



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

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).

Opportunities and challenges

The financial benefits of more energy-efficient buildings are widely known. Energy is a controllable expense and one of the few expenses that can be decreased without negatively affecting your operations. Many organizations have invested in energy efficiency to cut energy costs, to improve facility performance, to demonstrate their commitment to sustainability, and to improve the building environment for employees and patients.

There are numerous reasons why you may be initiating a major energy retrofit in your facility. Major capital equipment or building infrastructure, such as boiler or chiller systems, may be nearing the end of its useful life. You may be experiencing equipment control problems (e.g. increasing complaints from occupants), or you may have malfunctioning equipment as a result of deferred maintenance. Major changes in the way spaces are used may also trigger energy retrofits. Regardless of the triggering event, there are a number of common opportunities and challenges that apply to hospital facilities when undertaking major energy retrofits.

Opportunities

Energy savings are one of the principal benefits of a major retrofit project. Energy savings from improved operational efficiency lead to lower operating costs and allow funds to be deployed to address core medical services such as staffing, equipment and patient services. 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. Hospitals can reduce energy costs while maintaining or even improving patient care and employee health and productivity. These retrofits typically involve upgrades to lighting and HVAC systems; improving these systems can often lead to more precise control of the indoor environment and an enhanced environment of care.

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

A 2005 survey of 69 publically funded Ontario hospitals examined barriers to undertaking energy conservation efforts.[3] Two barriers were cited by more than half of respondents:

- Lack of staff resources (59%)
- Lack of available internal funds (55%)

In some cases, the first challenge is being addressed through utility or government support. For example, in Ontario, the HealthCare Energy Leaders Ontario (HELO) initiative provides the services of an energy efficiency service provider at no cost, to help facility managers develop energy efficiency projects and secure incentive funding. The initiative is led by the Canadian Coalition for Green Healthcare and the Canadian Healthcare Engineering Society, and funded by Ontario's Independent Electricity System Operator.[4]

Strategies to overcome the challenge of funding availability will vary by facility and jurisdiction, but facility managers and hospital administrators are increasingly recognizing the value of energy efficiency as a tool to address the impacts of funding limitations on overall operations without compromising patient care.

Retrofit timing presents unique challenges in hospital buildings occupied by patients. In addition to assessing major retrofit triggers such as equipment replacement schedules, administrators and property managers must consider disruption to patient care and facility function. Depending on the retrofit activities and the space affected, measures such as dust control, patient removal, or the use of negatively pressurized anterooms may be required.

Ventilation and control of indoor air quality (IAQ) play an important role in preventing the spread of infection in hospitals. The quality of indoor air must be considered the highest priority when undertaking energy retrofits that affect air distribution systems, which may present unique challenges.

Lack of energy data may be a challenge for hospitals composed of multiple buildings. In some cases, electricity and natural gas may not be metered at the building level, but rather bulk metered as they are delivered to the campus. In addition, steam/hot water and chilled water generated centrally on-campus may not be metered at the facility level. As measuring energy use is an important first step in energy management, consider adding metering where appropriate. At a minimum, electricity, natural gas, steam/hot water and chilled water should be metered at the building level.

[3] Ontario Hospital Association in Cooperation with the Ontario Power Authority and Sure Solutions. 2006. *Energy Efficiency Opportunities in Ontario Hospitals.*

[4] greenhealthcare.ca/Ontario-energy/

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Energy use profile

When planning your major retrofit project, consider the energy use profile for a typical Canadian hospital. Although specific energy use profiles will vary depending on the types of services provided on site, the example below can be used to provide a general indication of how you use your energy.

Figure 2. Energy use by energy source

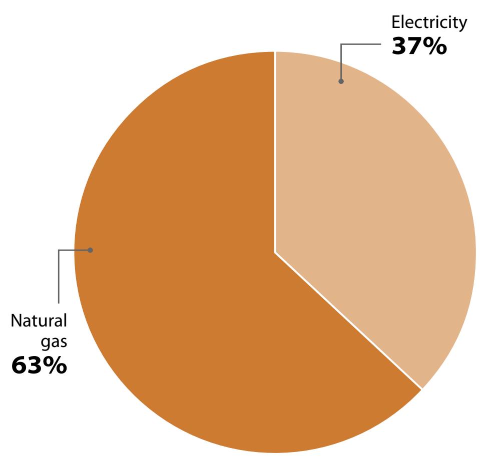
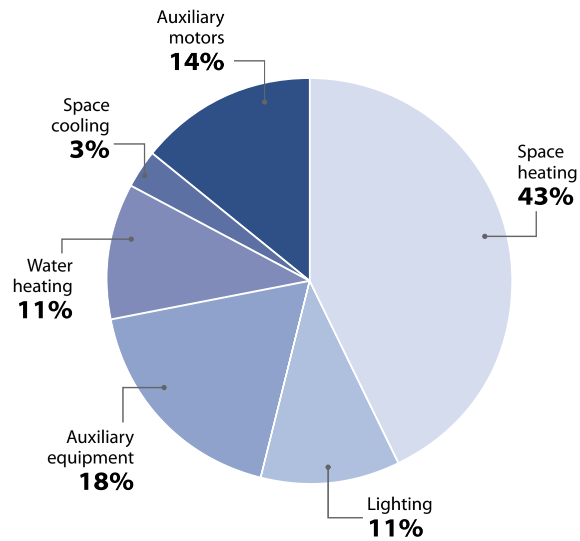


Figure 3. Energy use by end use



End use data for a typical hospital in the interior of British Columbia with climate conditions similar to other metropolitan areas across Canada.

Data source: FortisBC

Figure 2 shows the breakdown of consumption by energy source. In this example, natural gas provides approximately two thirds of the facility's energy requirements. Figure 3 shows the breakdown of consumption by end use. Space heating is the largest end use, followed by auxiliary equipment (e.g. computer equipment, medical equipment and food service equipment) and auxiliary motors (e.g. fans and pumps).

EUI in hospitals can vary widely and is influenced by weather conditions and specific facility and operating characteristics such as density of staff and patient beds, presence of on-site laundry and food preparation, laboratory space, and the percentage of the facility's space that is heated and cooled.

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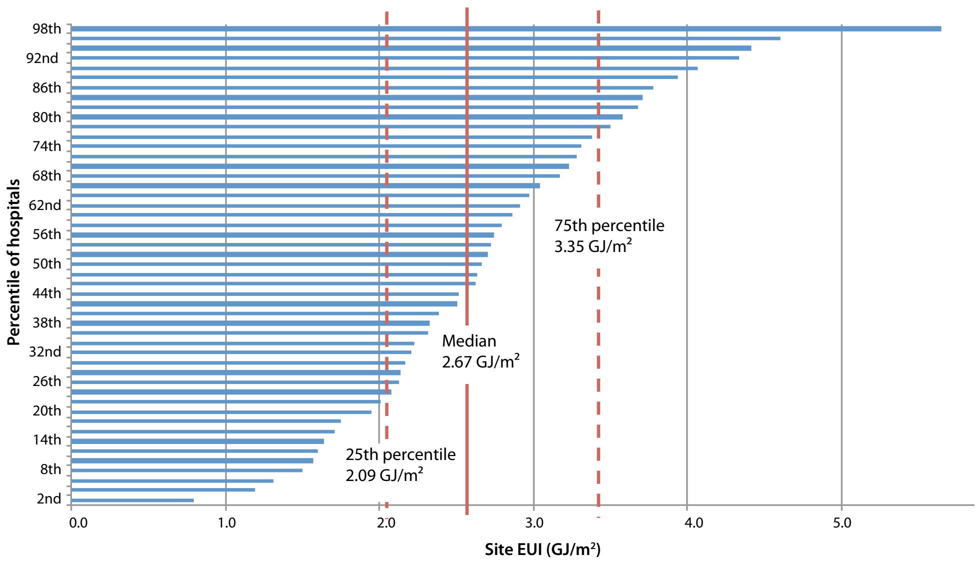
Figure 4 presents the overall distribution of normalized EUI for a Canada-wide sample of hospitals.

Figure 4. Distribution of site energy use intensity for Canadian hospitals



Source: ENERGY STAR Portfolio Manager, 2016

The solid vertical line shows that the median site EUI for hospitals entered in ENERGY STAR Portfolio Manager is 2.67 GJ/m^2 (68.90 ekWh/sq. ft.). Hospitals in the 25th percentile of this data set have EUIs lower than 2.09 GJ/m^2 (53.94 ekWh/sq. ft.), and those above the 75th percentile have EUIs greater than 3.35 GJ/m^2 (86.45 ekWh/sq. ft.). The national median EUI according to the *Survey of Commercial and Institutional Energy Use* 2009 is 2.4 GJ/m^2 (61.9 ekWh/sq. ft.).

Hospital 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. Benchmarking allows you to compare your current energy use against past performance as well as against that of similar facilities. 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 hospitals, 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 and identify which buildings offer the best opportunities for improvement.

The ENERGY STAR score for hospitals applies to an entire hospital complex, whether it is a single building or a campus of buildings.

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.

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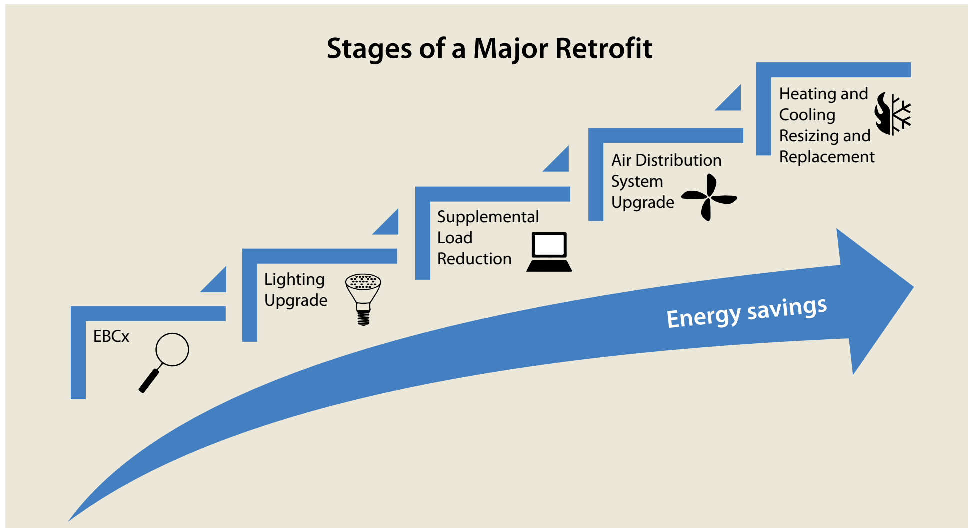
Staging project measures

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.

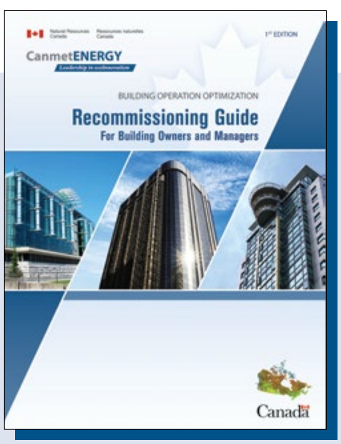
Existing building commissioning

Commissioning is a first-order activity to improve an existing building's energy performance. With heating and cooling systems that operate 12 months per year and ventilation systems that are designed with high air change rates, hospitals consume a lot of energy. This means the opportunity for existing building commissioning (EBCx) savings is more significant in hospitals than in other subsectors; in some cases, energy savings greater than 40% may be possible.[5]

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*[6] shows you how to reduce expenses and increase revenue 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.



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

[5] Hanlon et al. May 2010. "Hospital Retrocommissioning." *ASHRAE Journal.*

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

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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 below 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.[7]

EBCx measure list
✓ Schedule air handling system
✓ Employ temperature setback during unoccupied hours
✓ Close outside air dampers during morning warm-up in the heating season
✓ Perform early morning flush in the cooling season when conditions allow
✓ Employ optimum start control
✓ Confirm lighting control schedule
✓ Verify free cooling operation (air side)
✓ Verify free cooling operation (water side)
✓ Employ static pressure reset
✓ Correct damper operation
✓ Lower variable air volume box minimum flow set points
✓ Calibrate building automation system sensors
✓ Calibrate operating room ventilation for occupied and unoccupied modes
✓ Correct excessive simultaneous heating and cooling
✓ Verify steam traps
✓ Ensure that kitchen equipment is off outside of operating hours
✓ Repair missing or damaged pipe insulation
✓ Sequence boilers through controls
✓ Reset boiler supply temperature
✓ Sequence chillers through controls
✓ Employ chilled water reset
✓ Employ condenser water reset
✓ Take full advantage of available cooling towers
✓ Optimize boiler blowdown and combustion air control

[7] The Canadian Standards Association's Z320-11 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: shop.csa.ca/en/canada/building-systems/z320-11-/invt/27032582011. In addition, the Canadian Standards Association's Z8001-13 provides guidelines for the commissioning of health care facilities specifically: shop.csa.ca/en/canada/health-care-facility-engineering/z8001-13/invt/27000522013.

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The following six measures apply to equipment serving administrative, out-patient and other day-use areas of the hospital. These **do not** apply to patient care areas.

- **Schedule air handling system:** Equipment that runs longer than necessary wastes energy. Equipment schedules are often temporarily extended, then forgotten. Although much of the hospital has 24/7 occupancy for patient care, some areas are occupied only during daytime hours, and the ventilation system can be scheduled off during unoccupied periods. Check equipment scheduling in the building controls to ensure that it 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 portions are empty, i.e. letting the thermostat 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.
- **Close outside air dampers during morning warm-up in the heating season:** While warming the space before occupants arrive, make sure the outside air dampers are fully closed. This saves energy by heating recirculated air, rather than colder, outside air.
- **Perform early morning flush in the cooling season when conditions allow:** During the cooling season, pre-cool the space 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 optimum start control:** Many building direct digital control (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.
- **Confirm lighting control schedule:** Confirm that the lighting control schedule matches the actual occupancy. Controls should typically be configured to turn interior lights off at a set time, but not on; staff are expected to turn lights on when they arrive in the morning.

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The remaining measures apply to equipment serving the majority of hospital areas.

- **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.[8]

  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.[9]

- **Verify free cooling operation (water side):** Free cooling operates on the principle that during cool weather conditions, particularly at night for facilities with 24-hour operation, process cooling water can be produced by the cooling tower alone, bypassing the energy intensive chiller entirely. Free cooling reduces or eliminates the energy used by the chiller while efficiently maintaining strict temperature and humidity requirements. Free cooling can also offer an additional level of redundancy by providing a non-compressor cooling solution for portions of the year.

  Problems with water-side economizers can go unnoticed because mechanical cooling will compensate to maintain the chilled water set point. Optimizing the free cooling opportunities will reduce chiller energy consumption.

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8 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.

9 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.

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- **Employ static pressure reset:** Supply fans on variable air volume (VAV) systems are often controlled to maintain static pressure within ductwork at a single set point. A more efficient strategy, and one that is required by ASHRAE Standard 90.1-2013, is to use 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.[10]
- **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.
- **Calibrate operating room ventilation for occupied and unoccupied modes:** A typical operating room ventilation system delivers 20 to 25 air changes per hour (ACH) in occupied mode with 4 ACH of outside air; many older designs have air changes in excess of 30 ACH. Reducing the volume of air treated will not only reduce the heating and cooling energy, but the humidification-related energy as well. For example, a typical operating room HVAC system manages humidity in the cooling season by supplying air as low as 11 °C, then reheating it to room temperature — an energy-intensive practice.

[10] Taylor, Steven P. "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.

ASHRAE Standard 170 (now part of the 2010 Facility Guidelines Institute's *Guidelines for Design and Construction of Health Care Facilities)* requires operating rooms to have a minimum of 20 ACH. ASHRAE Standard 170 also allows the number of air changes to be reduced by up to 90% "when the space is unoccupied, providing that the required pressure relationship to adjoining spaces is maintained while the space is unoccupied and that the minimum number of air changes indicated is reestablished any time the space becomes occupied."[11]

Depending on the pattern of use of an operating room, which may be unoccupied 40% or more of the time, ventilation rate setbacks represent a significant opportunity to save on energy use.

- **Correct excessive simultaneous heating and cooling:** One of the most significant contributors to excessive energy consumption is simultaneous heating and cooling. Simultaneous heating and cooling of the air supplied to hospitals is intentionally done for temperature and humidity control. In the case of humidity control, the air is cooled below its dewpoint temperature to condense and remove moisture. This cooler, drier air is then typically reheated to the desired temperature in the zone, resulting in increased energy consumption.

  Energy savings are achieved by examining and adjusting control sequences, as well as supply air humidity and temperature set points. For example, zone temperature deadband (the temperature range in which neither heating nor cooling is provided to the zone) can be widened to prevent unnecessary "fighting" between heating and cooling systems. Over-ventilation can also be corrected to ensure that occupied/unoccupied air flows do not exceed the minimum rates allowed by code or standards.

- **Verify steam traps:** Many hospitals generate and use steam for heating and sterilization. Steam traps are essentially automatic valves that discharge condensate from the steam flow and maintain the proper operation of the steam distribution system. Because steam traps are exposed to harsh conditions, they will eventually leak or fail. When they fail in the open position or leak, energy is wasted from the loss of steam heat. One malfunctioning trap can cost thousands of dollars in wasted steam annually. Traps that fail in the closed position do not cause energy or water losses, but can cause significant capacity reduction and damage to the system.

  Approximately 20% of steam delivered by a central boiler is typically lost due to failed and leaking traps in existing buildings.[12] Depending on the size of your boiler plant, this can waste tens or even hundreds of thousands of energy dollars annually. Under your EBCx program, conduct a steam trap audit, using the services of a technician specifically trained in steam systems.

[11] ASHRAE Standard 170, article 7.1-subsection 1.c.

[12] U.S. Department of Energy by the Pacific Northwest National Laboratory. July 1999. *Steam Trap Performance Assessment*. DOE/EE-0193.

Figure 5. Pipe insulation

Photo courtesy of Claudette Poirier, Vancouver Island Health Authority

- **Ensure that kitchen equipment is off outside of operating hours:** Commercial kitchens are intense consumers of energy and water. Equipment such as ovens and hood exhaust fans are often left on for convenience during the course of the day and subsequently can be left on after the kitchen is closed.
- **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).
- **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.
- **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 6, 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 usage 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.

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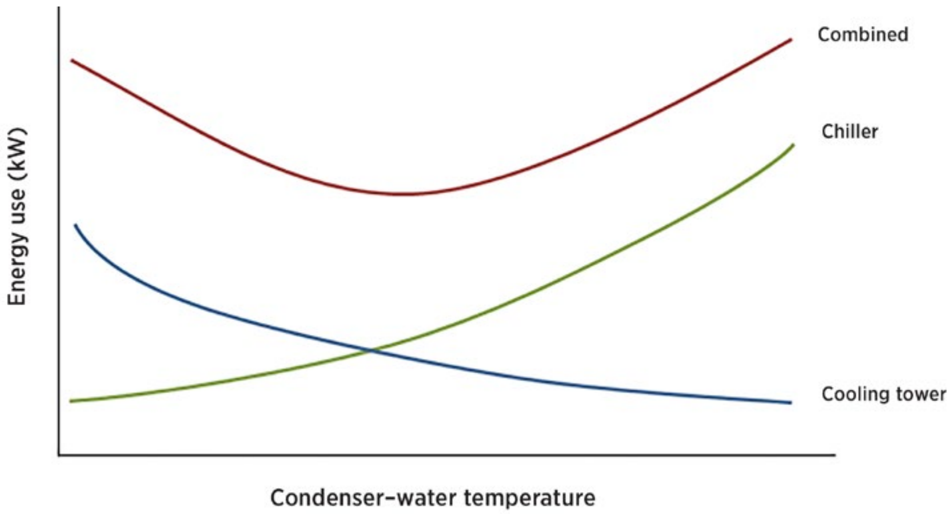
Figure 6. Energy impact of condenser water temperature



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, simply 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.
- **Optimize boiler blowdown and combustion air control:** Blowdown controls the buildup of solids in the boiler water; it protects the boiler's surfaces, enhances heat transfer (thus saving energy) and ensures a safe chemical concentration. Combustion efficiency is affected by accumulation of soot and other fouling in the combustion area and by excess combustion air. Proper tuning can extend boiler life and save significant energy. For example, for every 15% reduction in excess combustion air, boiler efficiency is improved by 1%.

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Lighting upgrades

Lighting consumes over 10% of the energy used in Canadian hospitals 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%[13] and have the potential to improve patient recovery, medical activities, and employee health and satisfaction. If one considers that prescribed lighting power densities (LPDs) from older codes are at least double the LPD 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 advancements in energy efficient lighting systems. The 1997 *Model National Energy Code of Canada for Buildings* permitted LPDs for hospitals ranging from 9.7 W/m^2 for waiting rooms to 75.3 W/m^2 for operating rooms. The *National Energy Code of Canada for Buildings* 2011 (NECB 2011) prescribes a maximum LPD of 6.7 W/m^2 for waiting rooms and 20.3 W/m^2 for operating rooms. These changes are largely the result of improved lighting technology efficiencies.

Guide to calculating LPD

1. Identify boundaries in the area of study, 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.

[13] Consortium for Building Energy Innovation. *Best Practices for Lighting Retrofits, Picking the Low Hanging Fruit*. Revised August 29, 2013. research.cbei.psu.edu//research-digest-reports/best-practices-for-lighting-retrofits.

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Hospital lighting requirements

Hospitals and health care facilities have some of the most rigorous lighting requirements of any setting. Doctors and nurses must have clean, clear, bright light with superior colour rendering to make accurate diagnoses, while warm, welcoming environmental lighting supports a tranquil environment for patients and visitors. Lighting therefore has to cater to the needs and preferences of various groups of individuals in different situations. For example, patient rooms require lighting that can both support complex visual tasks and provide a comforting environment for recovery.

Light has an incredible effect on people – both biologically and emotionally. Used effectively in health care facilities, it can enhance a patient's experience and play a key role in promoting well-being. Light impacts outcomes in health care settings by reducing depression among patients, decreasing length of stay in hospitals, improving sleep and circadian rhythms, lessening agitation among dementia patients, easing pain, and improving adjustment to night shift work among staff. A combination of daylight and electric light can meet these needs. Natural light should be incorporated into lighting design in health care settings, not only because it is beneficial to patients and staff, but also because it is light delivered at no cost and in a form that most people prefer.

Lighting-emitting diodes

Light-emitting diodes (LEDs) have advanced as a lighting source with high quality lighting at any tuned colour temperature and with low power requirements compared to incandescent, compact fluorescent and high-intensity discharge (HID) lighting. In some applications, LED is a suitable replacement for linear fluorescent. From soft indoor lighting for patient areas to welcoming, safe parking areas and entrances, advancements in LED lighting deliver versatility and quality well suited for health care applications. LED lighting can play an important part in reducing energy and maintenance costs, while at the same time improving both patient and staff experience.

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

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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.

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. They 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 exterior and parking lot lighting with LED lamps
✓ Replace fluorescent lamps in stairwells 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:** Exterior lighting is designed for security and safety purposes and is not concerned with the qualities that support colour rendering or detailed visual tasks. As such, LED lighting is well suited for exterior lighting applications and can offer savings greater than 40% over conventional HID.

  LED lighting technology has evolved significantly for both new installations and retrofits. With a number of LED lighting manufacturers recently entering the market, a wide selection of retrofit options is available to choose from, including retrofit kits that convert existing fixtures for operation with LED lamps.

- **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 lights on when occupancy is detected;

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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. The U.S. Environmental Protection Agency estimates savings potential under optimal conditions ranging from 25 to 75% of lighting energy depending on space type.[14]

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. The NECB should also be consulted to ensure that maximum LPDs are not exceeded.

Table 1. Illuminance recommendations for health care facilities

Application and task	Illuminance targets (lux)[15]
Ambulatory – charting station	300
Ambulatory – examination	1000
Ambulatory – general	500
Patient rooms – general	100
Patient rooms – over bed	500
Patient rooms – head of bed (patient use)	300
Nurses' station	500
In-patient corridors (daytime)	100
In-patient corridors (nighttime)	50
Pharmacy	500–1000
Radiology – general	500
Radiology – examination	1000
Surgical suites – examination	1000
Surgical suites – operating room	2000
Workshops	1000
Stairs	100
Lobbies (daytime)	300
Lobbies (nighttime)	150
Reception desk	400
Waiting area	200

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

[14] 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.

[15] Horizontal illuminance levels measured at 76 cm above floor, where at least half of the observers are 25 to 65 years old.

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The lighting needs of patients and medical professionals are very different. For a patient, it can be very important to create a calm and relaxing environment that they can personalize to suit their mood. In contrast, examination environments need to have bright and functional lighting to support diagnosis and help professionals perform more effectively. The diversity of purpose demands lighting quality specific to the space. Examples of lighting characteristics by space type are outlined in Table 2.

Table 2. Hospital lighting qualities

Area of hospital	Lighting quality
Entrance/shops	Welcoming ambience
Corridors	Brightly illuminated, daylight
Ward corridor	Brightly illuminated and dimmable
Waiting rooms	Welcoming, calming effect
Examination rooms	Variety of atmospheres: soothing and reassuring warm light to high illumination; high quality colour rendering assists in examinations and diagnosis
Imaging rooms	Calming environment
Patient rooms	Flexible lighting that accommodates patients' needs but also allows staff to work effectively, daylight
Offices	Relaxed or uplifting ambience, daylight
Outdoor/parking	Safe and comfortable, pleasant and inviting ambience

Source: Philips. *Designing people-centric hospitals using Philips lighting solutions.*

Lighting measure list (designed retrofits)

- ✓ Replace T12 and older T8 fixtures with higher-efficacy light sources with dimming control
- ✓ Combine ambient and task lighting strategies
- ✓ Make use of daylight harvesting
- ✓ Use occupancy-based bi-level lighting in stairwells and exit routes
- ✓ Install LED lighting
- ✓ Add a central lighting control system

- **Replace T12 and older T8 fluorescent fixtures with higher-efficacy light sources with dimming control:** Older T12 or T8 fluorescent lamps can be retrofitted or replaced with newer T8 or T5 fluorescent lamps and dimming electronic ballasts. Greater efficacy, combined with occupancy and daylighting control, can provide significant energy and cost savings.

- **Combine ambient and task lighting strategies:** Administration areas with open office spaces have traditionally had 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 administrative 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. One study reported an 11% improvement on tasks such as triple digit multiplication when subjects could control light levels with task lights.[16,17]

- **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.

  Daylight 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

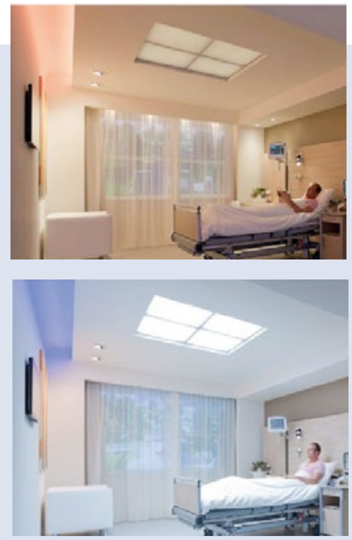

Figure 7. Multiple light sources in a patient room

Multiple light sources offer an adaptable and functional patient space. Here, recessed dimmable ambient lighting is supplemented with both daylighting and an overhead luminaire.

Source: Philips.

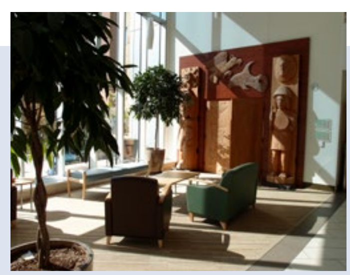

Figure 8. Hospital atrium daylighting

Photo courtesy of Claudette Poirier, Vancouver Island Health Authority

[16] 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/.

[17] 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.

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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.

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.[18] Sensors that automatically dim the lights in response to available daylight offer average energy savings of 30%.[19,20]

Beyond energy savings, access to sunshine can enhance occupant comfort during the heating season, improve functional lighting, and enable contact with the outside, including some of the biological effects of sunlight. A study found that 2% of patients and 62% of staff considered sunlight to be a nuisance, while 91% of patients and 31% of staff considered sunlight to be pleasurable. Furthermore, patients who were on the bright side of a hospital, and were exposed to 46% more daylight, perceived less stress and pain and took fewer analgesics than patients on the dim side of a hospital.[21]

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.

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.

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[18] IESNA *Advanced Lighting Guidelines*, 2001 edition.

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

[20] Lee, E. S. & Selkowitz, S. E. 2006. "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.

[21] worldhealthdesign.com/patient-and-staff-environments.aspx

- **Use occupancy-based bi-level lighting in stairwells and exit routes:** Spaces that are not regularly occupied, but require some lighting when unoccupied can reduce the lighting power by up to 50% during unoccupied periods. A time-out period of 15 minutes is typical to avoid short cycling and reduced lamp life.
- **Install LED lighting:** As previously discussed, LED fixtures are now acceptable replacements for incandescent fixtures and lamps, and exterior lighting. However, at the time of publishing, LED technology as a replacement for linear fluorescents is generally 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.

  One notable exception is the use of LED lighting for surgical field illumination. In addition to energy savings and demand reductions, LED lighting enhances visual acuity for the surgeon and improves the operating environment by facilitating lower, stable room temperatures.[22]
- **Add a central lighting control system:** Facilities that do not have lighting control systems and rely on people to turn lights off should consider adding a centralized system to control the lighting in administrative, out-patient and other day-use areas of the hospital. 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.

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.

[22] sustainabilityroadmap.org

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Power loads and equipment

This section addresses common equipment and devices used within the hospital environment, as well as electrical distribution transformers.

Although medical equipment does not typically fall within the scope of an energy retrofit, energy performance should be considered during the equipment procurement process.

MRI (magnetic resonance imaging) machines, which have components that must be continually cooled to low temperatures, are particularly energy intensive, using more than 400,000 kWh per year.

Supplemental load measure list (power loads and equipment)
✓ Power off equipment when not in use
✓ Install vending machine controls
✓ Choose ENERGY STAR equipment
✓ 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 computers and turn off computers at night in administrative, out-patient and other day-use areas of the hospital.
  - IT department develops and deploys login scripts that control power management settings.
  - Third-party software delivers a computer power management policy across the hospital network.
- **Install vending machine controls:** Vending machines are another example of equipment that can be powered down to save energy. Retrofit products are available that use motion sensors to turn machines off when spaces are unoccupied. The machines are powered back up when spaces are in use and at regular intervals to keep their contents cool.
- **Choose ENERGY STAR equipment:** ENERGY STAR-recommended products use 25 to 50% less energy than their traditional counterparts. Computers and other related equipment with the ENERGY STAR label save energy and money by powering down and entering "sleep" mode, or by turning off when not in use, and by operating more efficiently when in use. By purchasing and specifying energy-efficient products, hospitals can cut electrical energy use. Instituting an effective policy can be as easy as asking procurement staff to specify ENERGY STAR-qualified products such as computers, office equipment, lighting fixtures and lamps, kitchen equipment, and electronics.

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

Commercial kitchen equipment

A wide range of equipment, fixtures and appliances contribute to energy consumption in commercial kitchens, which means that there is also a wide range of possibilities for reducing energy.

Only 35% of the energy consumed in a typical commercial kitchen is used for cooking and food preparation; the rest is wasted within the room as heat. By using more energy-efficient equipment, not only is energy consumption reduced, but comfort and air quality is improved. Replacing existing equipment with new high-efficiency alternatives can save up to 70% of energy use.

Table 3 highlights typical savings for various efficient kitchen equipment and indicates whether ENERGY STAR-qualified products are available:

Table 3. Kitchen equipment and energy savings

Category	Equipment	Typical energy savings	Typical water savings	ENERGY STAR qualified
Refrigeration	Commercial refrigerators and freezers	35%	–	Yes
	Commercial ice machines	15%	10%	Yes
Sanitation	Commercial dishwashers	25%	25%	Yes
	Pre-rinse spray valves	Varies	55-65%	No
	Water heaters	5%	–	Yes
Food preparation	Commercial fryers	30-35%	–	Yes
	Commercial griddles	10%	–	Yes
	Commercial hot food holding cabinets	65%	–	Yes
	Commercial ovens	20%	–	Yes
	Commercial steamers	50%	90%	Yes

Source: NRCan. 2012. *ENERGY STAR Guide for Commercial Kitchens.*

Kitchen ventilation also has a significant impact on energy consumption. Energy demand can drop considerably if kitchen appliances are the right size, if heat is recovered from exhaust air, and if the ventilation system has a demand control system. Some kitchen appliances even have integrated solutions that reduce the need for exhaust air. Refer to the **Air distribution systems upgrade section** for more information.

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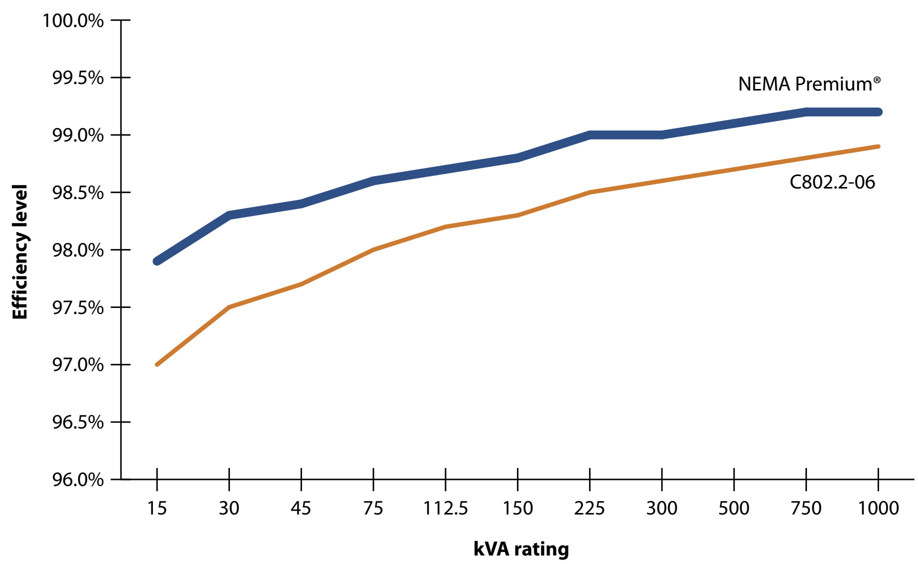
Of all the energy saving strategies adopted, the use of **staff green teams** at Island Health* in British Columbia provided the greatest annual savings with the shortest payback period. An investment of $120,000 in fiscal year 2013-14 netted savings of more than $80,000.

Source: Island Health 2013 Carbon Neutral Action Report

*Island Health includes more than 150 facilities on Vancouver Island, the Georgia Strait islands, and the communities north of Powell River and south of Rivers Inlet.

- **Implement an employee energy awareness program:** NRCan's *Implementing an Energy Efficiency Awareness Program*[23] can help hospitals develop successful employee energy awareness programs. Another useful resource is the *ENERGY STAR Guidelines for Energy Management*.[24] It provides information on creating a communications plan, and ideas, examples and templates that can be customized to help spread the word to hospital staff, patients and visitors.
- **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 9 shows the relative efficiencies of standard transformers vs. NEMA premium transformers.

Figure 9. 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.[25]

[23] oee.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/pdf/Publications/commercial/pdf/Awareness_Program_e.pdf

[24] energystar.gov/buildings/about-us/how-can-we-help-you/build-energy-program/guidelines

[25] Hammond Power Solutions Energy Savings Calculator, hpstoolbox.com/.

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- **Consider data centre retrofits:** The average data centre is many times more energy intensive than a typical hospital facility. 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.

  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*,[26] 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 ranges from 20 to 27 °C.
  - *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.

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**

[26] ASHRAE, ashrae.org/resources--publications/bookstore/datacom-series#thermalguidelines.

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- *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.

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

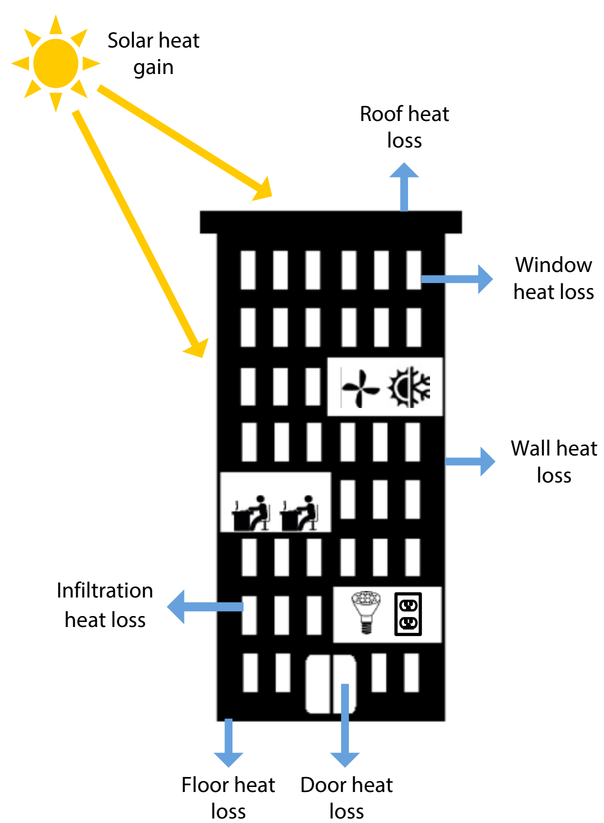
R = RSI × 5.678

1 RSI = R-5.678

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 though 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 10 shows how heat flows into and out of a building through the envelope.

Figure 10. 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, exhaust/intake dampers when closed, etc.).

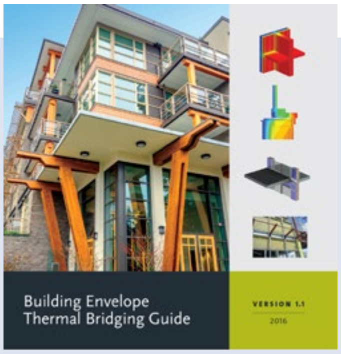
Supplemental load measure list (envelope)
✓ Reduce infiltration
✓ Add an air barrier
✓ Add insulation
✓ Upgrade windows and doors

- **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. The energy impacts of unintended infiltration on building energy use have been shown to be significant. As HVAC equipment and other building systems continue to become more efficient, the energy loss associated with building envelope leakage is representing an even greater percentage of total building energy consumption.

  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. Although hospitals have negatively pressurized zones for infection control, the overall building pressure should be neutral or very slightly positive to minimize infiltration. 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 11 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).

  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.



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.

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 inches water column).

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

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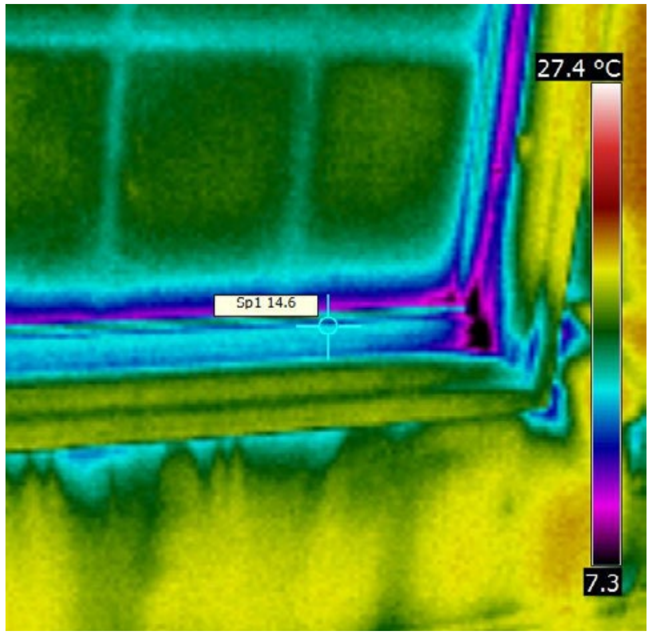
Figure 11. Infrared imagery showing leakage around a window



Infiltration can be exacerbated by stack effect, which is caused by warmer air rising up through the building and escaping though 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.

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- **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 to 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 (EIFSs) 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, energy modelling of 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 2%. 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 12.6%.[27]

- **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.

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·K/W (R-20)
Roof 5.464 m^2·K/W (R-31)

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

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

[27] Impacts assessed using an Arborus Consulting in-house energy model.

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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**

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.

- **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.

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.[28]

The text box on page 32 provides a more detailed discussion of each of these criteria, along with a discussion of various window components and assemblies.

[28] 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}.

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.

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 door closures 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.

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.

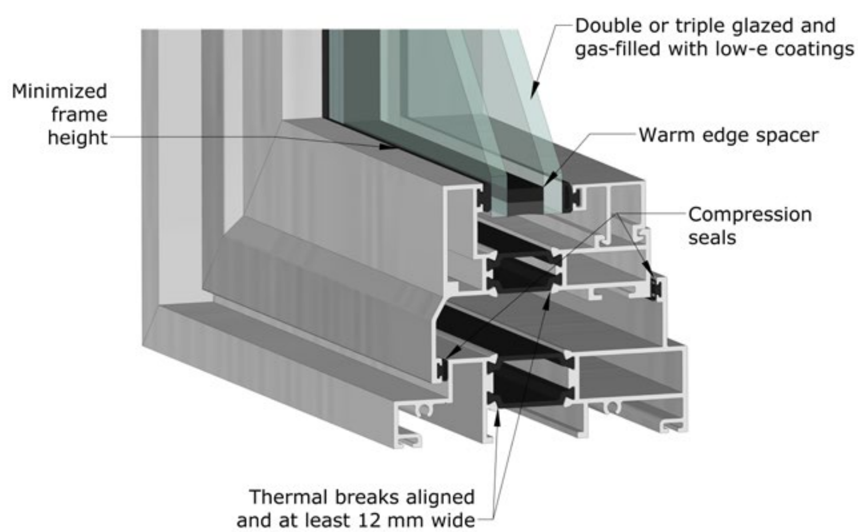
IGU performance is determined by:

- 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 12. Features of an energy-efficient window



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

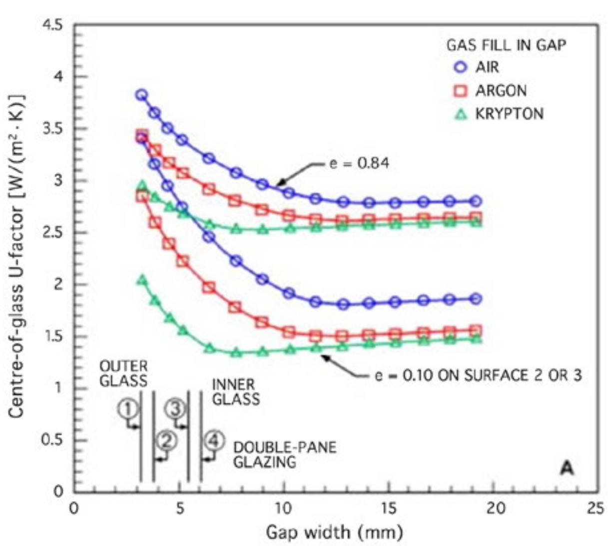
A window's U-factor incorporates the thermal properties of both the frame and the glazing. Since the sash and frame represent approximately 10 to 30% of the total area of the window unit, the frame's properties significantly influence the total window performance.

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 the 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 13 plots the relative performance of air, argon and krypton gas fills.

Figure 13. 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 then be tested. Contact an experienced energy modeller to work with you on this analysis.

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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.

In hospitals, where air quality control is paramount, the air distribution equipment plays an important role in preventing the spread of infection. Most buildings base their ventilation rates on ASHRAE Standard 62, which specifies the minimum amount of outdoor air that needs to be brought into the building, depending on its type and use; hospitals require special attention to infection control as directed by the CSA Standard Z317.13-12: *Infection Control During Construction, Renovation, and Maintenance of Health Care Facilities*.

Hospitals need to be carefully zoned to provide isolation and negatively pressurized spaces to minimize the risk of transmission of any infectious disease. Even with these additional design considerations, there are opportunities to minimize the effect on energy consumption by reducing ventilation levels when spaces are unoccupied.

Retrofits

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

Conditioning outside air is one of the most energy intensive jobs that the HVAC system performs, so your first step should be to minimize the amount of outside air that needs to be conditioned. 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

Case in point:
Kingston General
Kingston, Ontario

Seven new air handling systems were installed with new building controls in the labour and delivery area, some operating rooms and on two medical floors, saving more than $100,000 per year. HVAC units and pumps were fitted with new high-efficiency electric motors and variable frequency drives.

Source: **Save On Energy**

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Air distribution systems measure list

- ✓ Start with first-order measures
- ✓ Use demand control ventilation
- ✓ Right-size fans
- ✓ Install variable speed-drives
- ✓ Replace existing air filters with electronic air cleaners
- ✓ Install heat recovery on exhaust air streams
- ✓ Install solar air heating in make-up air systems
- ✓ Install a hydronic heat recovery system
- ✓ Install a variable refrigerant flow system
- ✓ Replace mixed-air delivery with a dedicated outdoor air system
- ✓ Replace mixing ventilation system with displacement ventilation
- ✓ Replace steam humidifiers with atomizing type

- **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.

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

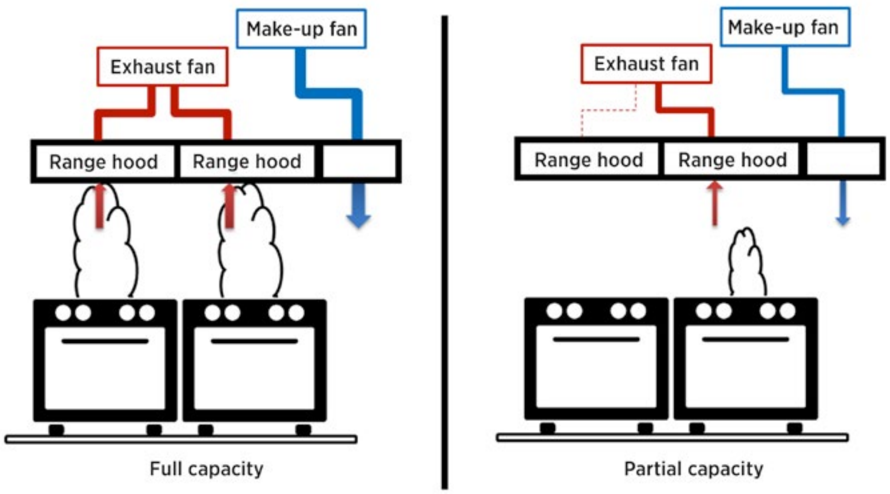
Kitchen hood exhaust

DCV can also be applied in hospital kitchens; however, instead of controlling ventilation using CO_2 sensors, hood exhaust fans are controlled in response to temperature, optical, or infrared sensors that monitor cooking activity, or direct communication with cooking appliances.

Food preparation equipment and kitchen ventilation can be large energy consumers in hospital kitchens. Exhaust hood air flow is the most significant source of this energy consumption. The first step in reducing energy is to reduce exhaust air flow by using high-efficiency hoods with low capture and containment air flow rates. The second step is using DCV to further reduce exhaust air flow when cooking is not taking place under the hood, as shown in Figure 14.

With a kitchen DCV system, the hood operates at full design air flows whenever cooking activity is at full capacity, but is reduced when reduced load cooking is taking place. The system controls both the make-up fan and hood exhaust fan to ensure balance in the ventilation system. Such systems can save 60% or more on kitchen ventilation energy.[29]

Figure 14. Demand control ventilation in a commercial kitchen



[29] energystar.gov/about/2015-emerging-technology-award-demand-control-kitchen-ventilation.

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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.

- **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 variable speed-drive (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.

- **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, facilities 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.

- **Install heat recovery on exhaust air streams:** Heat recovery from building exhaust air can be used to pre-condition the ventilation air for the building. However, the type of recovery medium will depend on what spaces require complete separation from the exhaust stream and what spaces can accept return/exhaust air in the supply. For example, in-patient areas require that the supply air not be contaminated with exhaust air (for infection control), while administration offices can be served by mixed air that includes return air from the space.

There are several heat recovery systems available:

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 an effectiveness in the range of 55 to 65%.

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%. Energy recovery wheels are acceptable in hospital applications provided that contaminants from the exhaust stream are not introduced into the supply stream.

Reverse flow devices have two large, heavy, metal cassettes (typically aluminum) with a high thermal mass. In these devices, a large damper is used to alternate the outdoor and exhaust air streams between the two cassettes in sequence. The thermal mass of the cassettes is used to alternately store and release energy as the direction of flow is reversed. Reverse flow devices, with a winter sensible effectiveness of 90%, are the highest-efficiency energy recovery devices available on the market; however, they can be quite expensive and may require structural changes to the roof, so a full life-cycle cost-benefit analysis should be performed before selecting this option.

Run-around coils are the first choice wherever air flows are required to remain entirely separate. In these systems, the sensible heat carried by the exhaust air is transferred to the supply air flow indirectly, via a water/glycol liquid medium in the pumped circuit. Supply air and exhaust air heat exchangers can be located at entirely separate locations with a run-around coil system. The sensible effectiveness of run-around coil systems ranges from 50 to 75%, depending on the air flow velocity, coil design and controls.

- **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. Roof-mounted systems must meet separation clearances from air exhaust and plumbing vents to prevent contamination of the make-up air stream.

  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).

Laboratory facilities

Labs provide diagnostics for the health care services in the hospital. In addition to laboratory equipment, the facility may be equipped with fume hoods and biological cabinets, which have dedicated exhaust and make-up air requirements. To save energy, the exhaust and make-up air should be variable volume and have heat or energy recovery from the exhaust air stream.

The simplest way to reduce the energy required by operating fume hoods is to ensure that the sash is always in the lowest possible operating position. This simple action can substantially lower the amount of energy used and will provide for the safest working environment.

At the Toronto Medical Discovery Tower, an awareness campaign was designed to remind lab users to close fume hoods. Only half the fume hoods used to be closed when not in use; a year after the campaign, compliance was close to 100%.

Source: University Health Network

Case in point:
Hotel Dieu Hospital
Kingston, Ontario

Hotel Dieu Hospital credits the installation of a new 890-kW (250-ton) chiller with reduced steam use. The chiller operates as a heat recovery chiller in the winter by extracting heat from the building's exhaust air and returning it to the building as heat. The energy saved by the upgrade paid for the equipment that needed to be replaced.

Source: SaveOnEnergy

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/humidifcation is required from the central system; all heating and cooling is performed in the zone by the VRF units.

- **Install a hydronic heat recovery system:** Heat demand in a hospital can be grouped into three general categories: central ventilation heating, envelope losses, and zone air tempering (zone reheat). Many hospitals are served by 100% outdoor air supply systems with air-to-air heat recovery. However, these systems only recover heat when ventilation heating is required. For much of the year, more energy is available in the exhaust air than can be recovered for supply air. To capture this available energy, a heat recovery chiller can recover the additional heat from the exhaust air stream and apply it to zone-level reheat coils. A retrofit study at a hospital in Washington state found that 93% of the zone reheat energy was served by the heat recovery chiller with an average coefficient of performance (COP) of 4.0 (one unit of energy in with four units of energy out). The advantage of this system is the delivery of heat to the zones with a heating efficiency of 400% versus a boiler system operating at 80 to 90% efficiency. In this study, the 32,500-m^2 hospital saved $120,000 per year from this retrofit.[30] Refer to the Domestic hot water measure list under the **Heating and cooling resizing and replacement section** for more information on heat recovery chillers.

- **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. 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.

- **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.

[30] McClanathan, Jeremey. June 2014. *ASHRAE Journal.*

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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 due to 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

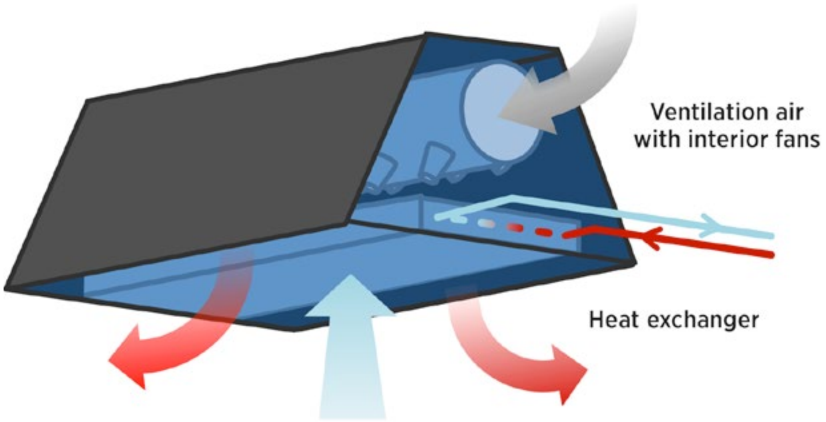
Chilled beams

Chilled beam systems are an example of space conditioning systems that have been designed to work with DOAS.

Chilled beams condition air directly in the space where they are located. Despite the name, they are applicable to both cooling and heating. While there are two types of chilled beams, passive and active, only active chilled beams are suitable for Canadian climate zones.

Active chilled beams are designed to supply the ventilation air through a nozzle that induces room air through a chilled or heating coil in the beam before mixing with the ventilation air. One unit of supply ventilation air can move between two and six units of secondary air through the beam, significantly reducing the volume of air required from the air handler.

Figure 15. Chilled beam heating



- **Replace mixing ventilation system with displacement ventilation:** Conventional variable volume ventilation systems supply a mixture of outdoor and returned indoor air to a space through ceiling diffusers. The velocity of the supply air has to be high enough to ensure that the air reaches the breathing zone of the room and is sufficiently mixed with the room air to achieve space temperature set points. Displacement ventilation (DV) supplies air at a low level closer to the breathing zone. The air travels horizontally at low level and rises when it encounters a heat source. Pollutants are entrained in the rising hot air, which travels vertically and is not mixed with room air. The air at high level can then be exhausted outside or returned to the AHU for filtering. DV therefore has superior ventilation effectiveness over conventional ceiling delivery systems.

  DV systems can be used with central VAV AHUs or packaged rooftop units. In addition to their superior ventilation effectiveness, they are also much quieter than conventional systems due to lower supply air velocities. Energy is saved through:

  - *Reduced cooling demand.* Air can be supplied at 18 °C (65 °F) instead of the traditional 13 °C (55 °F) in cooling mode. This saves cooling energy by reducing the load on chilled water equipment and increasing the free cooling hours for the space.
  - *Reduced outdoor air volumes.* DV systems' superior ventilation effectiveness allows a reduction in outdoor air volumes, reducing the energy required to heat and cool the supply air.

- **Replace steam humidifiers with atomizing type:** Atomizing humidifiers (also known as "adiabatic" humidifiers) reduce cooling load, reduce water waste and, in warm, dry conditions, are the most energy-efficient humidification systems. A high-pressure pump propels purified, unheated water through dispersion nozzles that produce ultra-fine water droplets. Rather than heating the water to produce steam, the high-pressure atomizing system uses heat already in the air to evaporate these water droplets.

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 a rooftop unit (RTU) with heating and direct expansion cooling, complete with supply and, possibly, return fan.

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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

Boilers provide hospitals with steam or hot water for critical needs such as space heating and process loads, including sterilization and humidification. Many existing boilers 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.

Before you decide to retrofit a boiler, you must first consider current system maintenance. If the boiler has not been well maintained, you will 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.

The main campus of St. Michael's Hospital in Toronto underwent a major energy efficiency retrofit in 2010. Annual costs have been cut by 19%, and greenhouse gas emissions by 7,000 tonnes. Among other measures, the hospital:

- Replaced the steam humidification system with a high-pressure water system
- Simplified the steam network and installed a high-temperature hot water system
- Installed a single closed-loop domestic hot water system
- Installed three new chillers with heat recovery capabilities
- Shut down the absorption chiller
- Optimized the chilled-water network
- Implemented a new ventilation system schedule

Source: **St. Michael's Hospital's Energy Conservation and Demand Management Plan**

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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. In many cases, heating loads will have changed since the existing boilers were installed, and replacing the boiler will provide better load matching. By using modular or multiple boilers instead of redundant boilers, additional efficiencies may be delivered for summer heating requirements.

Process steam

Steam is often required for sterilization, laundry and kitchen equipment. As these loads are intermittent, consider point-of-use steam equipment rather than steam boilers. Steam boilers have maximum efficiencies of approximately 84%, compared to 95% for condensing hot water heaters.

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:

Table 4. Gas-fired boiler efficiency ratings

Boiler size	Rating	NECB 2011 minimum efficiency	Best available
<88 kW	AFUE	85%	97%
88–733 kW	Combustion efficiency (E_c)	82.5%	95%
88–733 kW	Thermal efficiency (E_t)	83%	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
✓ Replace boiler control system
✓ Eliminate flow-restricting valves
✓ Replace standard-efficiency or oversized pumps with highly efficient units right-sized for the reduced loads
✓ Control heating water pumps with variable speed-drives
✓ Install a boiler stack economizer
✓ Replace burners
✓ Install turbulators in firetube boilers
Replacement measures
✓ Replace with condensing boiler
✓ Replace with modulating boiler
✓ Replace with hybrid boiler system
✓ 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 addressing a number of issues related to fuel combustion, water treatment and set points. It is also important to ensure that boilers are properly sequenced and that heating pipes are properly insulated. 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.

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Figure 16.
Variable speed-drives

Photo courtesy of Claudette Poirier, Vancouver Island Health Authority

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:** Typically, for much of the heating season, zones only require partial heating to maintain comfort conditions. By reducing the speed of the pump to provide only the amount of heating water needed to offset the actual building heat loss, pumping energy is reduced. 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%.[31] 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.

- **Install a boiler stack economizer:** A stack economizer is an air-water heat exchanger that captures heat from flue gases to preheat the boiler feedwater. Stack economizers become feasible for boilers 590 kW or larger, where at least 60% of the recoverable waste heat can be used to preheat cold water. Boilers must have a forced-draft burner and must not be condensing type.

- **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.

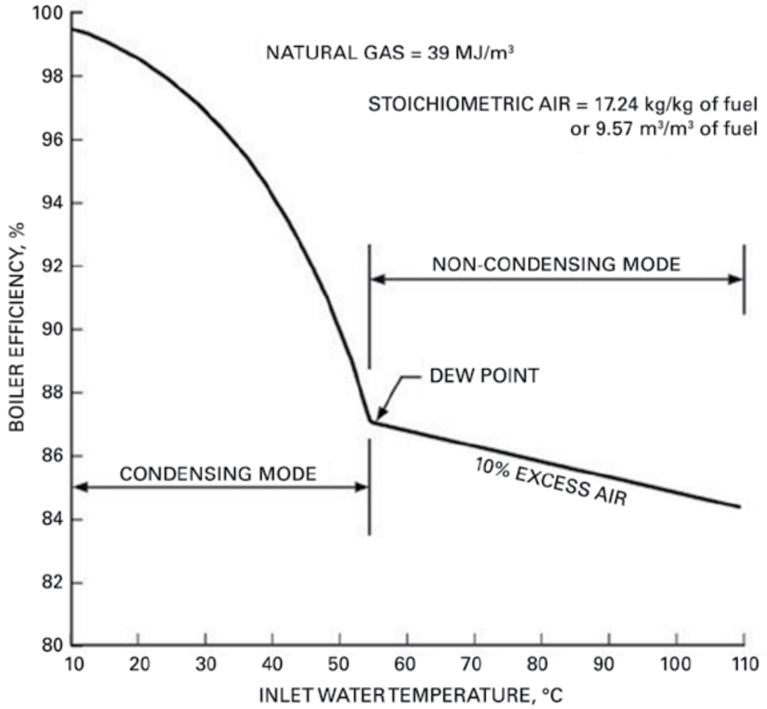
[31] The formula is $1 - (0.9)^3 = 0.27$.

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%.

  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 18, 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 18. Return water temperature and its impact on boiler efficiency



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

Figure 17. Condensing boiler

Photo courtesy of Claudette Poirier, Vancouver Island Health Authority

For hospital campuses, it may make sense to install one or more small boilers in specific facilities to meet summer loads for space and water heating rather than operating larger central campus boilers. The attractiveness of this option will depend, in part, on the performance of the central boiler at part load.

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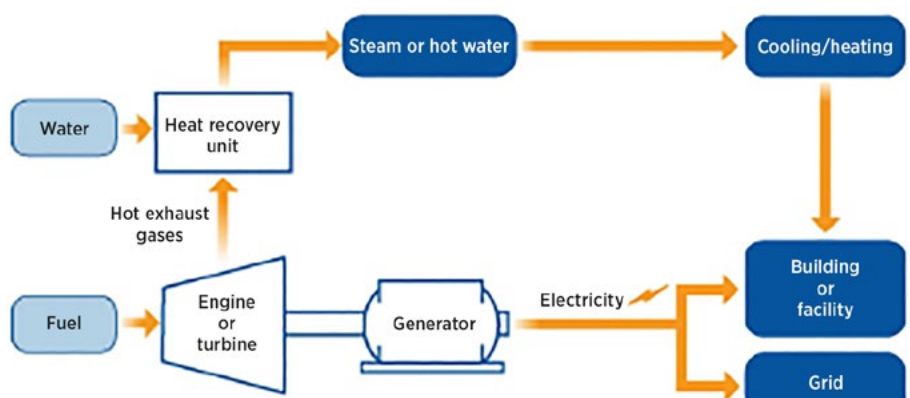
- **Replace with modulating boiler:** A modulating boiler adjusts its output by sensing the outdoor air and/or return air temperature and then adjusting the firing rate as low as possible to meet the heating needs. Modulation saves energy by improving dynamic efficiency during periods of light loads. 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).

A less costly option compared to fully modulating boilers 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 full firing rate). These units cost less than modulating units, but are also less efficient.

Cogeneration for hospitals

Most commonly known as combined heat and power (CHP), these systems generate electricity from a reciprocating engine (internal combustion engine) or turbine and recover the waste heat for thermal applications such as building heating (as shown in Figure 19). Hospitals are prime candidates for CHP due to their year-round thermal energy demand and the necessity for a stable and uninterrupted power supply. CHP can be designed to provide electricity and thermal energy in the event of a power outage from the utility, providing additional power reliability benefits.

Figure 19. Combined heat and power schematic



Source: U.S. Environmental Protection Agency, **epa.gov/chp/what-chp**

CHP can obtain overall system efficiencies greater than 80%. The following simplified financial analysis illustrates how the value of energy delivered by a CHP system compares to separately-supplied electrical and natural gas. Additional savings from demand reduction by the CHP system have not been shown.

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Financial analysis

Natural gas generator specifications:

2,000 kW, loaded, as is typical, to 80% = 1,600 kW

@ 43.7% electrical efficiency, the total input power = 1,600 kW/0.437= 3,660 kW

Total energy input of CHP

3,660 kW x 8,760 hrs./yr. = 32,061,600 kWh or 115,421,760 MJ

@ 38 MJ/m^3 of natural gas = 3,037,414 m^3 annually

@ \$0.25/m^3 = **\$759,354** annually

CHP electricity output

1,600 kW x 8,760 hrs./yr. = 14,016,000 kWh

@ \$0.11/kWh = **\$1,541,760** annually

CHP thermal output

@ 43.2% thermal efficiency, available heat = 13,850,611 kWh (49,862,200 MJ)

Equivalent heat delivered by boiler

@ 90% boiler efficiency: 49,862,200 MJ/0.9 = 55,402,444 MJ input

@ 38 MJ/m^3 of natural gas = 1,457,959 m^3 annually

@ \$0.25/m^3 = **\$364,490** annually

Equivalent cost of delivered energy

Combined heat and power: **\$759,354**

Separate heat and power: \$1,541,760 + \$364,490 = **\$1,906,250**

As illustrated, the financial benefit of cogeneration can be significant. In this case, nearly 65% cost savings were obtained.

The Nanaimo Regional General Hospital uses an underground concrete thermal labyrinth filled with water vessels to pre-condition the outdoor air supplied to its emergency room. Similar to ground-source heat pumps, the thermal storage vessels leverage stable underground temperatures by capturing heat in the winter and transferring it to the incoming air.

Source: Vancouver Island Health Authority

- **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 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 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 (GSHP); 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.

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.[32] 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.

Conditions for the installation of a GSHP are most favourable 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.

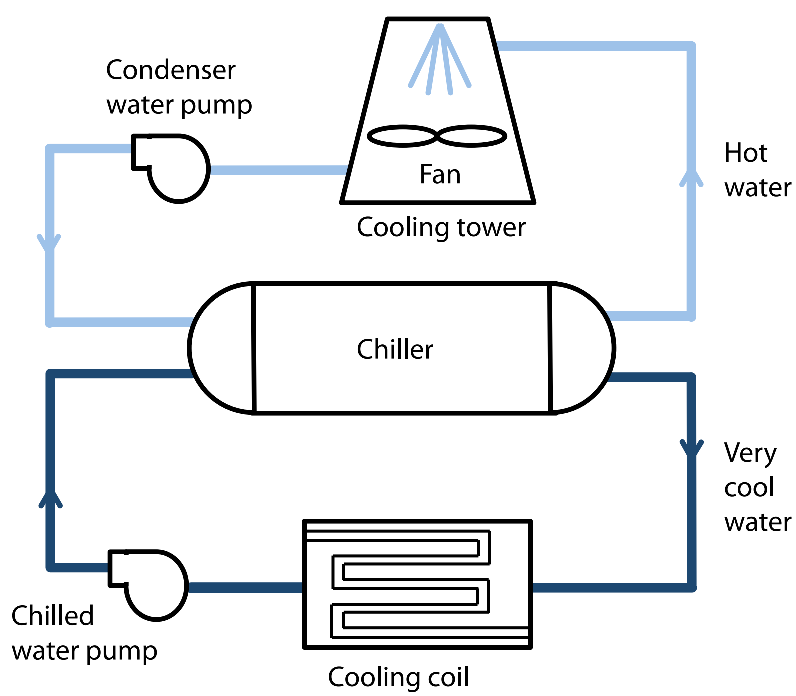
[32] Geothermal Heat Pumps Deliver Big Savings for Federal Facilities, Federal Energy Management Program, DOE/EE-0291.

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.[33]

Chillers are at the heart of these central cooling 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 20 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.

Figure 20. Chiller plant



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) then 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

[33] Natural Resources Canada. Commercial and Institutional Building Energy Use Survey 2000.

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.

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, decision makers 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.

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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.

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).[34] 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. Numerous countries support a planned, orderly phase-down of HFCs on a GWP-weighted basis with the Montreal Protocol:

- 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.

While CO_2 has been the standard refrigerant in certain industrial applications for some time, it is now being applied to a wider range of system applications and is being advanced as a natural refrigerant for cooling buildings.

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

[34] The Heating, Refrigeration and Air Conditioning Institute of Canada.

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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 eight measures apply:

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

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.

- **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.
- **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.

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- **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%.[35] 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.

  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 1000-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.

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.

[35] The formula is $1 - (0.9)^3 = 0.27$.

- **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.

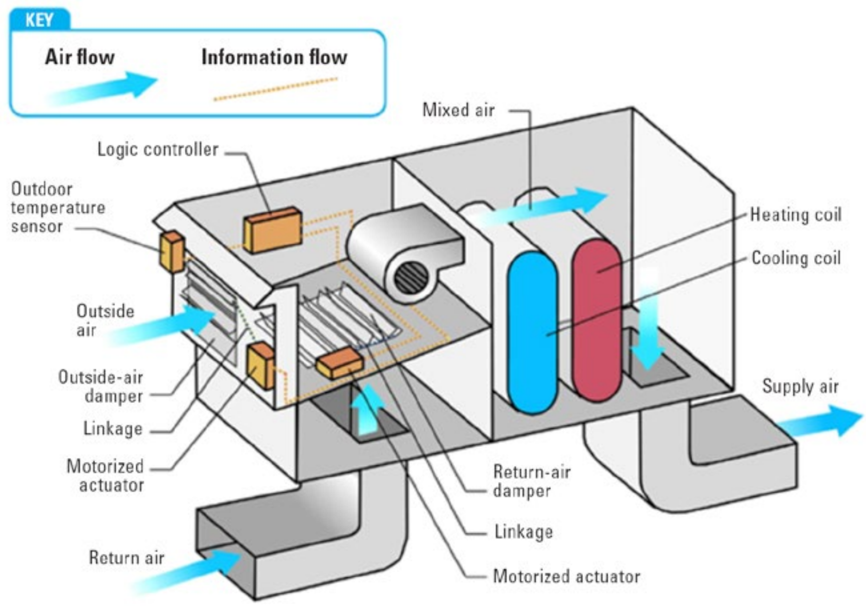
Chiller plant upgrade summary

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.

Rooftop units

Some office and support areas of hospitals are heated and cooled by self-contained, packaged rooftop units (RTUs). 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 21.

Figure 21. 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, then 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.

Table 5 illustrates how ASHRAE's cooling efficiency standards have evolved.

Table 5. 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

PART 1

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 compressor control to reduce runtime
✓ Add economizer damper
✓ Add heat or energy recovery
✓ Replace rooftop units

PART 1

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[36] 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 wasn't 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.

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

PART 1

- **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. 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 turn-down 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

Domestic water heating represents over 10% of the energy used in Canadian hospitals, a significant load compared to other sectors. Luckily there are a number of opportunities to save energy.

Heating and cooling measure list (domestic hot water)
✓ Install low-flow aerators and showerheads
✓ Preheat domestic water from chiller heat rejection
✓ Preheat domestic water with heat recovery chillers
✓ Preheat domestic water with solar thermal technology
✓ Replace boiler/heater with more efficient unit

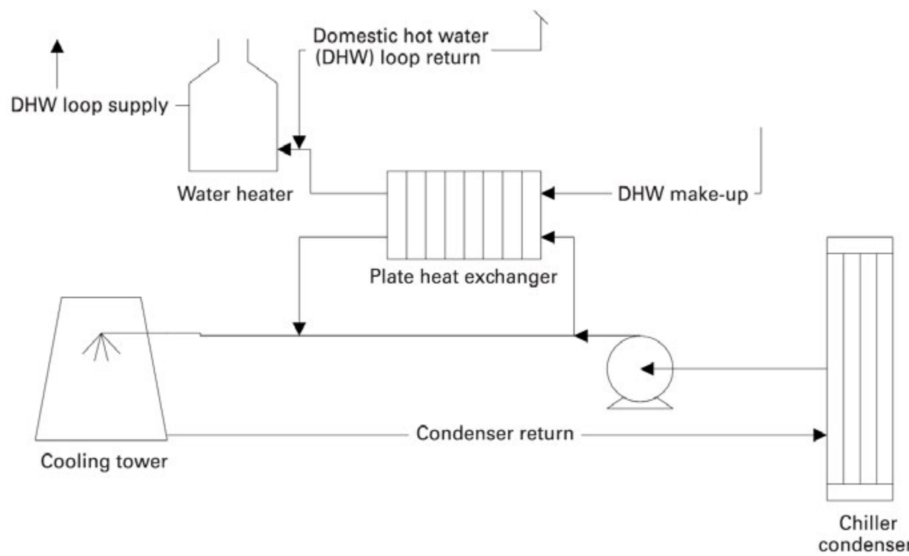
The Pacific Northwest National Laboratory (PNNL) has created a **Rooftop Unit Comparison Calculator** (**pnnl.gov/uac/costestimator/main.stm**) that compares high-efficiency equipment with standard equipment in terms of life-cycle cost.

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.

- **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.

- **Preheat domestic water from chiller heat rejection:** Heat recovery from chillers, as shown in Figure 22, is a viable option for hospitals because chilled water and domestic hot water are required year-round on a continuous basis. Rather than paying to reject heat, hospitals can recover heat and benefit twice: the recovered heat reduces purchased heat (and cost) and the ancillary power necessary to reject the heat. Moreover, because the heat recovery removes heat from the chiller heat rejection loop (condenser loop), less heat rejection occurs at the cooling tower, reducing tower fan run time.

Figure 22. Condenser heat recovery



Analysis of chiller heat recovery by the Pacific Northwest National Laboratory showed that energy savings from condenser water heat recovery resulted in a payback period of approximately six years.[37]

[37] Winiarski, D.W. 2004. *Analysis of IECC2003 Chiller Heat Recovery for Service Water Heating Requirement for New York State*. Pacific Northwest National Laboratory.

- **Preheat domestic water with heat recovery chillers:** During low cooling loads, large centrifugal chillers have limited potential for heat recovery, but smaller modular heat recovery chillers or water-source heat pumps can supply water at 49 °C (120 °F) or higher while simultaneously creating chilled water. Heat is transferred via a plate heat exchanger connected to the chilled-water loop or a stainless steel heat exchanger integral to the heat recovery chiller. Data is required to understand the relationship between the facility's year-round cooling load and its domestic hot water load to properly assess the feasibility of this measure.

  In addition to heat being rejected to the chilled-water loop directly from various building zones, heat can be rejected into the loop from the exhaust air stream. Refer to the hydronic heat recovery measure under the **Air distribution systems upgrade stage** for more information.

- **Preheat domestic water with solar thermal technology:** For hospitals in regions with adequate sunshine availability, solar hot water systems can be designed to deliver 50 to 60% of the domestic hot water demand. In some regions, systems can deliver close to 80%.

  Solar collectors for domestic water heating come in two forms, flat plate and evacuated tube.

  Flat plate collectors (see Figure 24) consist of a painted metal absorber panel attached to copper pipes where water or a heat transfer liquid passes through. The absorber and pipes are encased in a metal frame, surrounded by thick insulation to help retain the collected heat, and protected by a sheet of glass or glazing, which creates an insulating air space.

Figure 23. Plate heat exchanger for chiller heat recovery

Photo courtesy of Claudette Poirier, Vancouver Island Health Authority

Figure 24. Flat plate collectors

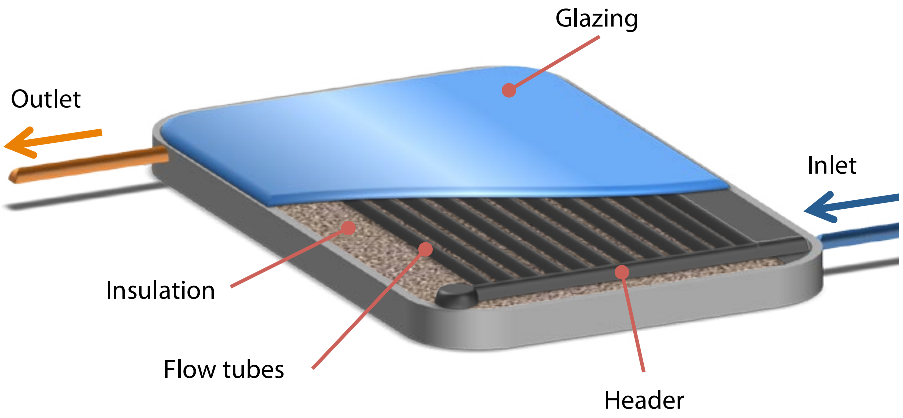


Photo courtesy of Claudette Poirier, Vancouver Island Health Authority

PART 1

Hospital laundries

Under normal conditions, the use of cold water washing, potentially with the introduction of ozone for additional cleaning efficiency, is often recommended as an energy efficiency measure in large laundries. However, given that a primary objective within hospital laundry facilities is infection control, the use of cold water may not be acceptable for all linens. Refer to the guidance of industry organizations such as The Healthcare Laundry Accreditation Council and the Centers for Disease Control and Prevention (CDC) regarding the processing of linens.

Energy conservation measures for hospital laundries include using energy-efficient washer-extractors with low water use and high extraction speeds, drain water heat recovery, advanced moisture-sensing dryer controls to prevent over-drying, and dryer exhaust heat recovery.

RETScreen is a decision-support tool that can run the simulations required to help you determine whether solar hot water heating is an option for your facility.

Evacuated tube collectors (see Figure 25) are the most efficient collectors available, and can work well in temperatures as low as -40 °C (-40 °F) and in overcast conditions. They consist of heat pipes surrounded by glass tubes under a vacuum. Each tube works like a thermos, with the evacuated air space around the heat pipe providing an almost perfect insulator and delivering highly efficient solar collection under cold outdoor air temperatures. Individual tubes can be replaced as needed; however, these collectors can cost twice as much per square foot as flat plate collectors.

Figure 25. Evacuated tube collectors

Photo courtesy of Claudette Poirier, Vancouver Island Health Authority

Collector for collector, evacuated tubes can cost around 20 to 40% more to buy than flat plate collectors. However, price alone should not be used to determine which collector to select. Through simulation, the year-round performance of the two collector options can be compared. In cool climates, evacuated tube collectors will generally have a lower cost per GJ of heat supplied.

- **Replace 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.

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 from 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.

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 hospitals**

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

UNIVERSITY HEALTH NETWORK: A CASE STUDY

The Toronto General Hospital, pictured above, is one of several UHN facilities that has reduced costs through energy efficiency retrofits.

Photo courtesy of the University Health Network

A focus on patient and planet-centred care, together with a strong social marketing approach, cuts energy costs and creates long-term behaviour change.

> "We went from being a 'lights on' to a 'lights off' kind of place. We wouldn't have succeeded in saving energy if we hadn't paid attention to the culture of our organization."
>
> Kady Cowan, Energy Steward, UHN

The University Health Network (UHN) includes the Toronto General, Toronto Western and Princess Margaret Hospitals, and the Toronto Rehabilitation Institute (TRI). Combined, these facilities employ more than 13,000 people.

Although the effects of climate change on health have only recently been receiving mainstream attention, the implications of energy use on health and climate change have long been a part of the UHN's Environmental Management System (EMS). Its energy strategy, *Operation TLC – Care to Conserve*, combines building efficiencies, technology, and a community-based social marketing (CBSM) approach[38] to identify and implement energy efficiency measures.

Getting informed

Between 2007 and 2010, the UHN received a grant from the Ontario Power Authority's Conservation Fund to hire outside expertise to conduct existing building commissioning (EBCx) and energy audits and make recommendations.

Prior to that, however, the UHN relied primarily on EMS data and staff knowledge to undertake energy efficiency projects. "We were one of the first health care organizations in North America to address sustainability before it was popular, so we had to develop a lot of our own tools," explained Kady Cowan, Energy Steward, adding that the network's building performance data dates back to 2000.

[38] Community-based social marketing is typically used to foster more sustainable behaviour. It identifies the real and perceived barriers to behaviour change and offers solutions to overcome those obstacles. See cbsm.com for more information.

"We're very fortunate to have a dedicated energy department that works with staff, because those facility managers know the history of the buildings and are tuned in to what's needed where and when," she said. "We've spent years developing those relationships, so we don't need to bring those people up to speed."

Identifying energy opportunities and solutions

Building-wide EBCx and energy audits have been completed at all hospital locations. For fiscal year 2013/14, savings from EBCx alone were about $780,000.

System-specific audits (steam traps, chillers, building envelope, water use, etc.) have been completed or are underway at all locations and are planned on an ongoing basis.

Site energy teams identify potential measures for further investigation and develop business cases and action plans.

UHN Energy & Environment Staff monitor building systems and trends, and investigate specific equipment and systems, as well as emerging technologies and behaviour change theories with the potential for energy efficiency.

Energy and environmental factors are included in the capital planning process.

All members of the UHN community are encouraged through *Operation TLC* to identify and present energy efficiency opportunities.

Major benefits

- ✓ Efficient building operations conserve energy and contribute to patient and employee comfort through more stable temperatures and better indoor air quality and lighting.
- ✓ Utility costs are a significant portion of the UHN's operating budget. The cost savings associated with investments in energy efficiency can be put toward patient care and other hospital needs. Total energy savings have topped $2.5 million per year.
- ✓ Energy efficiency is important to UHN staff. Actively promoting energy management helps align personal and organizational values and supports an engaged workplace where employees are more likely to contribute to the UHN's energy management goals.
- ✓ Optimizing building equipment and systems can often eliminate or delay the need to replace or add new building infrastructure.

PART 2

A focus on people

The UHN recognized early on that the support and ideas of its own people would be a key ingredient to success. "We attribute our energy savings to behaviour programs, because without paying attention to the culture of our organization, we wouldn't have succeeded anywhere else," said Cowan.

The UHN chose a CBSM approach to energy efficiency. Obtaining a commitment and recognizing efforts are two of the key tools used in CBSM, because studies show that people who publicly commit to an action are more likely to do it and to agree to subsequent actions. UHN employees publicly pledge a commitment to action in staff meetings, and the Golden Light Switch trophy is awarded to departments that have demonstrated a commitment to energy efficiency.

The six staff members of the UHN's Energy & Environment department are supported by the 600+ members of the network's green teams and the approximately 130 energy experts recruited from staff champions.

The department offers face-to-face training on a variety of topics to more than 3,000 staff every year, and all new employees receive energy awareness training along with information on other environmental topics. "We do a lot of one-on-one training and meet with all the green teams and energy experts regularly," said Cowan. "We have standardized our meetings so that there is a formal time when all the groups get together and talk about opportunities, challenges, projects so that they don't get left behind."

The UHN also offers e-learning modules and has an active social media presence. Its *Talkin' Trash* blog site features hundreds of articles and updates on all of the UHN's energy and environment initiatives. Employees are also updated on energy consumption on a regular basis through green team meetings and through quarterly scorecards. Each quarter, energy targets are set per facility, and employees are encouraged to find ways to meet them.

Shut the Sash!

Fume hoods draw out exhaust air and bring in fresh air, requiring energy to heat, cool, humidify and dehumidify all that air. The Green Team at the Toronto Medical Discovery Tower learned that closing the fume hood sash would save energy. The team began a behaviour change campaign to remind lab users to "Shut the Sash!" The campaign included an orientation presentation, reminder stickers, regular spot checks and a pizza draw.

Before the campaign began, only 47% of fume hoods were closed when not in use. One month after the campaign began, compliance shot up to 88%. After a year, compliance was 95% or more.

Lighting

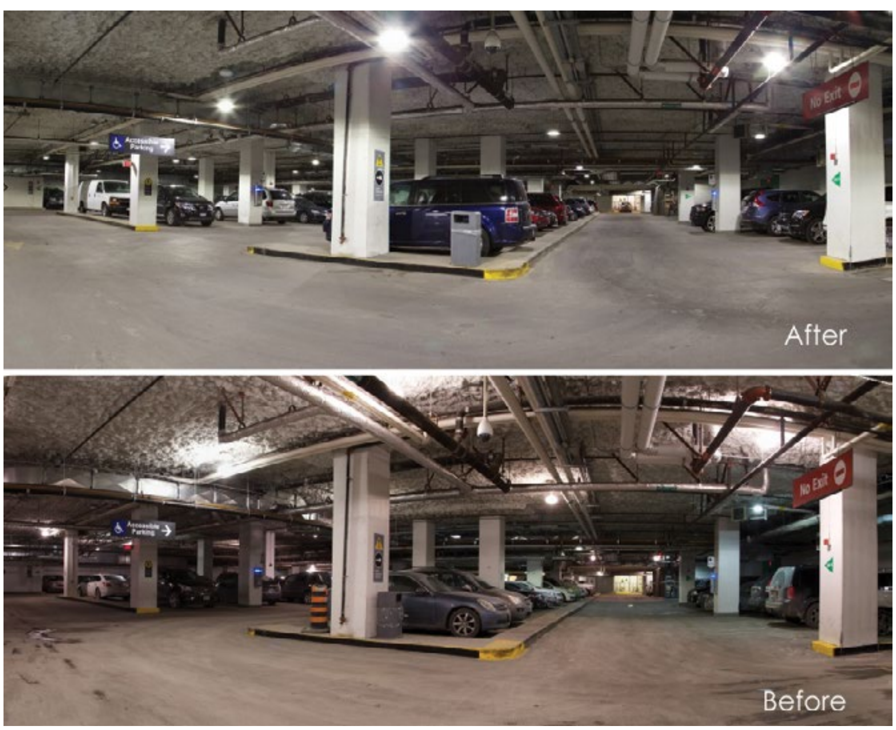
Energy-efficient lighting with optimized controls is the standard for all new lighting at the UHN. For example, occupancy and daylight sensors were installed in elevator lobbies with on/off control on 10 floors of the Toronto General Hopsital, providing an estimated consumption savings of 30%.

“Retrofitting an existing space for new controls is typically more difficult than in a new space, because it requires wiring you don’t have,” said Chad Berndt, Energy Project Manager. “Instead, we used a new system with wireless daylight and occupancy sensors. The sensors communicate wirelessly with a powerpack that turns lights on and off. The system is simple to install, relatively low-cost and functions well. It’s also worth noting that the sensor batteries last 10 years and will flash when they need to be replaced.”

Retrofits have been completed or are underway at all locations, with LED lighting being the standard for most capital projects. LEDs have a much longer lamp life, so the bulbs don’t need to be purchased as often and are less expensive to maintain.

In the parking garage of the Peter Munk building, shown in Figure 26, halogen and metal halides were replaced with LEDs, cutting energy use by 56%. At around 5,000 hours, metal halides will lose 40% of their lumen output, whereas LEDs lose only 20% after 100,000 hours. In a garage that’s lit 24 hours per day, that’s over 11 years! Additional savings come from staff not having to monitor light output or replace bulbs.

Figure 26. Garage lighting before and after LED retrofits



PART 2

At the TRI's University Centre, two walk-in freezers and two walk-in refrigerators were retrofitted to use Enwave chilled water to cool the condenser refrigerant. Through building piping, the warmed water is eventually returned to Enwave to be cooled again and reused. Water consumption has been reduced by more than 2,000 m^3 per year; annual savings are about $5,650 with a payback period of only three months.

HVAC

Among routine repair and replacement measures, 34 variable speed-drives are being installed on supply, return and exhaust fan motors at Princess Margaret; Toronto Western recently replaced a constant air volume system with a new variable air volume system and is converting its constant speed chilled-water pumping system to variable speed.

The TRI's University Centre is connected to **Enwave's deep lake water cooling system**, which also provides air conditioning to hundreds of other downtown Toronto buildings. This has enabled the UHN to reduce the amount of HVAC equipment installed at the site (there are no chillers or cooling towers), leaving more space for patients.

"Much less energy is required to cool spaces with deep lake water than with a conventional chiller/cooling tower system, because transferring heat to 4 °C lake water is more efficient than running a refrigeration cycle to transfer heat to warm outdoor air," explained Mike Kurz, Energy Project Manager. "Electricity use can be reduced by up to 90% over conventional cooling systems."

Roof/envelope

A cool roof was added to the Princess Margaret Hospital in 2012. The white roof reflects the sun's rays, prevents the building from heating up as much as it would with a traditional roof, and lowers the energy needed to run the air conditioning system.

Water

A new water treatment program for the Toronto Western Hospital cooling towers—part of the chiller plant used to cool the hospital—reduced water use by more than 16,000 litres per year and maintenance costs by $18,000 per year. Water treatment is used to prevent corrosion of equipment, build-up of scale and growth of bacteria, which can decrease the performance of equipment, cause serious damage and, for bacteria, lead to potential health concerns.

Monitoring

The UHN's EMS uses a real-time energy monitoring system to track energy use so that equipment can be adjusted to optimal performance. Utility use, costs and changes are also tracked and reported at several levels:

- Monthly overall consumption reports and progress toward conservation targets are provided to site executive and facilities managers.
- Monthly cost reports, detailing the effects of utility rates, weather and changes in consumption (from conservation efforts and new loads) are provided to site executive and UHN finance teams.

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- Weekly electricity reports and progress toward conservation targets are provided to site facilities managers.
- Real-time electricity use is visible to all UHN staff through the organization's intranet.
- Quarterly consumption and progress toward conservation targets are reported as part of the UHN's balanced scorecard.
- Annual consumption and comparison to previous years' consumption are part of Energy & Environment's annual report.
- A detailed list of recently completed, ongoing and potential energy projects at the UHN is updated monthly.

"We use a lot of adjacent indicators of success, the things that are happening in the buildings that weren't before: for example, requests for renovations. Those requests are analyzed for their energy impact, and the analysis is reported to the CFO, CEO and VPs," said Cowan. "That never used to happen before. That's a concrete cultural shift that has ultimately made all our projects possible."

Figures 27 and 28 show the energy baselines, targets and actual consumption for a selection of TRI and UHN facilities. Figure 27 shows data for the four TRI centres, whose combined total floor area is more than 93,000 m^2 (~1 million sq. ft.). Figure 28 shows data for five UHN hospital and research facilities: the Toronto General Hospital (TGH), the Toronto Western Hospital (TWH), the Princess Margaret Hospital (PMH), the Toronto Medical Discovery Tower (TMDT) and the Krembil Discovery Tower (KDT). At more than 214,000 m^2 (~2 million sq. ft.), the Toronto General Hospital is the largest of the facilities.

Figure 27. Operation TLC: energy saving targets at TRI facilities

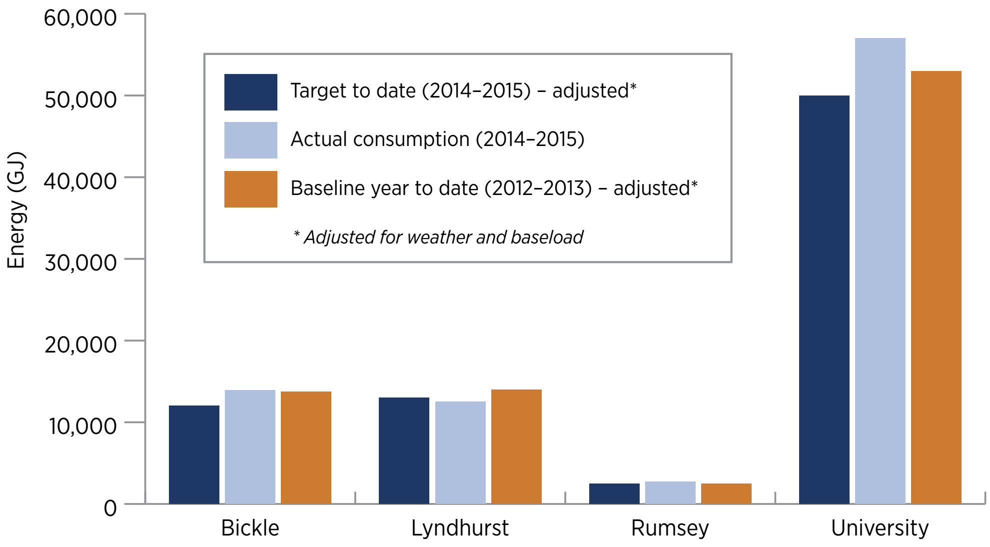

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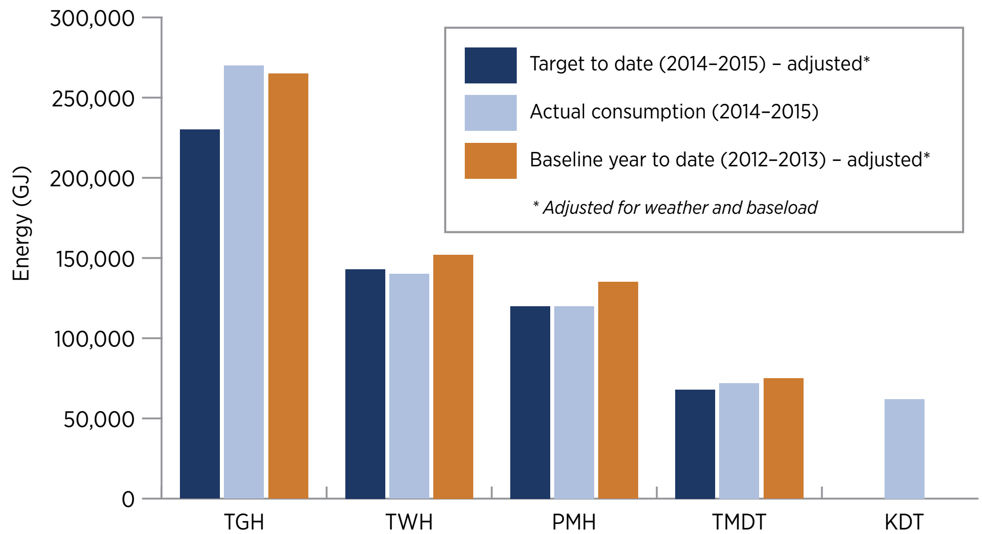
Figure 28. Operation TLC: energy saving targets at UHN facilities



How were the retrofits financed?

Financial resources were available to incorporate energy efficiency into capital and redevelopment projects, as well as for hiring dedicated energy team staff. The UHN also made use of utility incentive programs, such as the Ontario Power Authority's Conservation Fund and Toronto Hydro's Embedded Energy Manager program.

The UHN has also built relationships with various external stakeholders, including NRCan (to promote ENERGY STAR-rated equipment), the Canadian Coalition for Green Health Care, the Canadian Healthcare Engineering Society, the Ontario Hospital Association and Practice Greenhealth.

> "We lead from the middle. Yes, we have our senior leaders who demonstrate their commitment, but without acknowledging all the front-line staff, we wouldn't have a program. We have found a way to join the two together, because one without the other doesn't work."
>
> Kady Cowan

Challenges and advice

In the realm of building science, energy efficiency is still fairly new, so developing buy-in, trust and the business case is an ongoing challenge for the UHN. "Many people are risk averse, and their priorities lie elsewhere," said Cowan. "Over the years, however, we've aligned energy management as one of the organization's priorities, so employees must fit it in."

That being said, the UHN relied on the historical knowledge and expertise of its own staff to conduct much of its energy efficiency work. "Many organizations bring in experts that don't necessarily have a connection to the organization," said Cowan.

Environmental policies also help with the process. "We list ENERGY STAR-recommended products in our green purchasing policy, and it's also in our construction and design guidelines," said Cowan. "Our IT department has converted most of its computers over, and we recommend ENERGY STAR models when fridges are being replaced."

Cowan said that technological fixes and the savings they provide can slide after time. After almost 15 years of energy efficiency projects, many of the low-hanging fruit initiatives have now been completed, and the UHN's behaviour programs will help sustain technological fixes over the long term.

The UHN has fielded questions from around the world from other health care organizations that want to improve energy efficiency. "We're in the health care business," said Cowan. "We understand what the constraints are and what the culture is, so we can transfer that knowledge to others."

PART 3 MY FACILITY

The following take-away section provides a summary of the retrofit measures applicable to hospitals 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 labelled:

❑ **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: ____________________

# of workers (main shift): ____________________

Hospital bed capacity: ____________________

Onsite laundry? ____________________

% that can be heated/cooled: ____________________

PORTFOLIO MANAGER OUTPUTS

ENERGY STAR score: ____________________

Site EUI: ____________________

Source EUI: ____________________

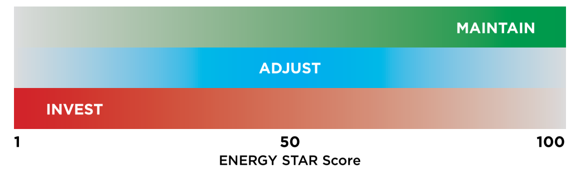
Median property EUI: ____________________

TARGETS

ENERGY STAR score target: ____________________

Site EUI target: ____________________

Figure 29. ENERGY STAR score interpretation



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

Hospital – Energy efficiency opportunity questionnaire

EBCx

- Is the air handling system on a schedule? [Pg. 8]
- Are the zone temperature set points set back/forward during unoccupied hours? [Pg. 8]
- Are the outside air dampers closed during morning warm-up during the heating season? [Pg. 8]
- Is an early morning flush performed regularly during the cooling season? [Pg. 8]
- Does the HVAC system follow an optimum start control strategy in the morning? [Pg. 8]

Lighting upgrades

Direct replacement

- Have frequently used incandescent and CFL fixtures been replaced with LED fixtures? [Pg. 16]
- Have incandescent Exit signs been replaced with LED signs? [Pg. 16]
- Has exterior and parking lot lighting been replaced with LED lighting? [Pg. 16]
- Have fluorescent fixtures in stairwells and exit routes been replaced with LED fixtures? [Pg. 16]
- Have wall switches been replaced with occupancy/vacancy sensors in enclosed rooms? [Pg. 16]

Supplemental load reduction

Power loads and equipment

- Is equipment being turned off when not in use? [Pg. 22]
- Have vending machine controls been added? [Pg. 22]
- Is ENERGY STAR equipment being used where applicable? [Pg. 22]
- Does the hospital have an energy awareness program? [Pg. 24]
- Have transformers been replaced with energy-efficient models? [Pg. 24]
- Has the data centre been retrofitted? [Pg. 25]

Air distribution systems upgrade

- Is there a DCV system? [Pg. 36]
- Are fans and fan motors right-sized? [Pg. 38]
- Have VSDs been added to pumps and fans with variable loads? [Pg. 38]
- Have existing air filters been replaced with electronic air cleaners? [Pg. 38]
- Is heat recovered from exhaust streams? [Pg. 38]
- Is outdoor air preheated with a solar air heating system? [Pg. 39]

Heating and cooling resizing and replacement

Central heating

- Have existing boilers' control systems been replaced? [Pg. 45]
- Have flow-restricting valves been eliminated? [Pg. 45]
- Have pumps been replaced and right-sized? [Pg. 45]
- Are pumps being controlled with VSDs? [Pg. 46]
- Has a boiler stack economizer been installed? [Pg. 46]
- Have new burners been installed on existing boilers? [Pg. 46]
- Have turbulators been installed in firetube boilers? [Pg. 46]

- ❑ Do the lighting and occupancy schedules match? [Pg. 8]
- ❑ Does the air handling equipment have a properly functioning economizer to enable free cooling? [Pg. 9]
- ❑ Are water-side economizers functioning properly? [Pg. 9]
- ❑ Is the VAV system static pressure set point automatically reset through a zone-level control feedback loop? [Pg. 10]
- ❑ Are VAV zone dampers operating properly? [Pg. 10]
- ❑ Is it possible to reduce the minimum flow set points at VAV boxes? [Pg. 10]
- ❑ Have BAS sensors been calibrated recently? [Pg. 10]
- ❑ Has operating room ventilation been calibrated for occupied and unoccupied modes? [Pg. 10]
- ❑ Has simultaneous heating and cooling been minimized? [Pg. 11]
- ❑ Has a steam trap audit been conducted? [Pg. 11]

Designed retrofits

- ◇ Have linear fluorescent fixtures been replaced with high-efficiency lamps and dimming control? [Pg. 19]
- ◇ Has ceiling light intensity been lowered and workers provided with individual LED task lights (where applicable)? [Pg. 19]
- ◇ Does the lighting design maximize the use of available daylight? [Pg. 19]
- ◇ Is occupancy-based bi-level lighting being used in corridors and stairwells? [Pg. 21]
- ◇ Have all LED options been considered? [Pg. 21]
- ◇ Has a centralized lighting control system been installed? [Pg. 21]

Envelope

- ◇ Have infiltration issues been addressed? [Pg. 27]
- ◇ Has an air barrier been added or improved? [Pg. 29]
- ◇ Do the roof and wall insulation levels meet NECB requirements? [Pg. 29]
- ◇ Have the windows and doors been upgraded? [Pg. 30]
- ◇ Is a hydronic heat recovery system being used? [Pg. 40]
- ◇ Is there a VRF system? [Pg. 40]
- ◇ Has the mixed-air delivery system been replaced with a DOAS? [Pg. 40]
- ◇ Has the mixing ventilation system been replaced with DV? [Pg. 42]
- ◇ Have steam humidifiers been replaced with atomizing type? [Pg. 42]
- ◇ Has a new condensing boiler been installed? [Pg. 47]
- ◇ Has a new modulating boiler been installed? [Pg. 48]
- ◇ Has a new hybrid boiler system been installed? [Pg. 50]
- ◇ Has a new heat pump system been installed? [Pg. 50]

Central cooling

- ◇ Have flow-restricting valves been eliminated? [Pg. 55]
- ◇ Have pumps been replaced and right-sized? [Pg. 55]
- ◇ Are pumps being 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. 56]
- ◇ Have old/oversized standard efficiency chillers been replaced with properly sized high-efficiency water-cooled units? [Pg. 56]
- ◇ Have water-side economizers been installed to allow cooling towers to deliver free cooling when weather conditions permit? [Pg. 57]

Hospital – Opportunity Questionnaire (continued)

EBCx	Lighting upgrades	Supplemental load reduction	Air distribution systems upgrade	Heating and cooling resizing and replacement

EBCx

- ❑ Is kitchen equipment turned off outside operating hours? [Pg. 12]
- ❑ Has missing or damaged pipe insulation been repaired? [Pg. 12]
- ❑ Have multiple boilers been sequenced to operate most efficiently? [Pg. 12]
- ❑ Is there a heating water reset control strategy? [Pg. 12]
- ❑ Have multiple chillers been sequenced to operate most efficiently? [Pg. 12]
- ❑ Has a chilled water reset control strategy been implemented? [Pg. 12]
- ❑ Has a condenser water reset control strategy been implemented? [Pg. 12]
- ❑ Is full advantage being taken of cooling towers? [Pg. 13]
- ❑ Has boiler blowdown and combustion air control been optimized? [Pg. 13]

Measures by space type

Hospital campuses may present a number of measures specific to various space types. These include the following:

Laboratories

- ◇ Have laboratories been converted to variable volume make-up air? [Pg. 39, 60]
- ◇ Is heat or energy recovery being employed? [Pg. 38]
- ❑ Are fume hood sashes shut when not in use? [Pg. 39, 68]

Central plant

- ◇ Have supplementary summer boilers been added? [Pg. 47]
- ◇ Have cogeneration opportunities been explored? [Pg. 48]

Laundry

- ◇ Have energy-efficient washer-extractors been installed? [Pg. 64]
- ◇ Have dryers with advanced moisture-sensing controls been installed? [Pg. 64]
- ◇ Has dryer exhaust heat recovery been added? [Pg. 64]
- ○ Has drain water heat recovery been added? [Pg. 64]

Campus challenges

- ◇ Has individual building metering been implemented? [Pg. 3]

Kitchen

- ◇ Has DCV been installed? [Pg. 36]
- ◇ Has point-of-use steam generation been installed? [Pg. 44]
- ❑ Is kitchen equipment being turned off outside operating hours? [Pg. 12]
- ○ Is ENERGY STAR equipment being used where applicable? [Pg. 22]

Parking garages

- ○ Has parking lot lighting been replaced with LED lighting? [Pg. 16, 69]
- ○ Has DCV using CO sensors been added? [Pg. 36]

Heating and cooling resizing and replacement

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. 61]

Domestic Hot Water

- ○ Have low-flow aerators and showerheads been installed? [Pg. 62]
- ◇ Is water being preheated from chiller heat rejection? [Pg. 62]
- ◇ Is water being preheated with heat recovery chillers? [Pg. 63]
- ◇ Is water being preheated with solar thermal collectors? [Pg. 63]
- ◇ Have hot water boilers/heaters been replaced with high-efficiency units? [Pg. 64]