Natural Resources Canada
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Major Energy Retrofit Guidelines

for Commercial and Institutional Buildings

K–12 SCHOOLS

Canada

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Pour les écoles du préscolaire au secondaire

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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 K–12 SCHOOLS

PART 1

The K–12 Schools 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 K–12 schools.

The K–12 Schools Module is divided into three parts:

1) **Energy Retrofit Opportunities in K–12 Schools:** Provides an overview of Canadian K–12 schools. Subsections present background information on each retrofit stage and key retrofit measures, with a focus on small and medium-sized schools.
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.

MAJOR ENERGY RETROFIT GUIDELINES: PRINCIPLES

K–12 SCHOOLS

K–12 Schools include facility space used as school buildings for kindergarten through secondary school students. This does not include college or university classroom facilities and laboratories; or vocational, technical or trade schools. The floor area includes all supporting functions such as administrative space, kitchens, lobbies, cafeterias, gymnasiums, and portable classrooms.

K–12 schools 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, energy use in the K–12 schools subsector is the third highest, behind offices and food & beverage stores, accounting for 8% of sector energy use. As the name implies, this subsector includes primary and secondary schools from kindergarten to grade 12. It does not include college, CEGEP, or university classroom facilities; vocational, technical or trade schools; or preschool and daycare buildings.

Roughly two thirds of K–12 schools in Canada were built before 1980.[3] As the building stock ages, a tremendous opportunity exists to undertake major retrofits that will improve the energy performance of K–12 schools across the country.

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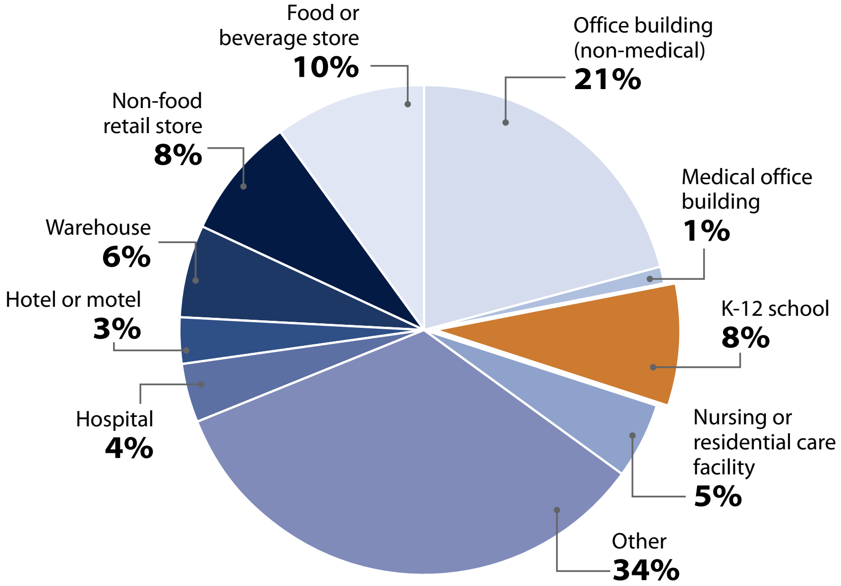
[1] Natural Resources Canada. 2013. *Energy Use Data Handbook, 1990-2010.*

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

[3] Natural Resources Canada. 2012. *Survey of Commercial and Institutional Energy Use – Buildings 2009: Detailed Statistical Report.*

Figure 1. Commercial/institutional energy use by subsector



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

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

Opportunities and challenges

Schools affect the lives of most Canadians. Stakeholders include not only students, teachers and staff, but also parents and the local community. We all have an important responsibility to ensure that our children spend their days in a safe and healthy environment that is conducive to effective learning and an interest in the effective use of available funding.

Although energy costs are the largest operating expense in Canadian schools after salaries, there are a host of pressing needs that cannot be overlooked, such as the health of students, test scores, and adequate teaching resources. The good news is that energy is one of the few expenses that can be decreased without negatively affecting classroom instruction. In fact, energy improvements can often lead directly to healthier classrooms and improved learning environments.

In addition to the non-energy benefits, there are numerous physical and technical reasons why you may want to initiate a major retrofit in your school. Major capital equipment or building infrastructure, such as the boiler or roof, may be nearing the end of its useful life. The school may be experiencing equipment control problems (e.g. insufficient heating), or have malfunctioning equipment as a result of deferred maintenance. Major internal space changes may also trigger a retrofit. Regardless of the reasons, there are a number of common opportunities and challenges that apply to K–12 schools when major retrofits are undertaken.

Opportunities

Cost savings are unquestionably one of the primary drivers for most school board investment in energy efficiency. Energy savings, which lead to reduced spending on utility bills, can help free up resources for other competing priorities. Lower energy consumption also limits vulnerability to energy price fluctuations and reduces greenhouse gas emissions.

Beyond energy savings, there are a number of benefits that may, in some cases, be dominant project drivers. Research suggests that academic performance is influenced by indoor air quality (IAQ), thermal comfort, acoustics and lighting.[4] Specifically, schools undertaking major retrofits also have an opportunity to improve the following:

- Indoor air quality: IAQ can be affected by gases such as radon and carbon dioxide (CO_2), mold, particulates such as dust and pollen, and chemicals such as formaldehyde. Poor IAQ affects children more than adults because children have higher breathing and metabolic rates, and it is linked to increased absences resulting from respiratory infections, allergies and asthma. By upgrading ventilation and filtration systems as part of your major retrofit project, IAQ can be improved.
- Thermal comfort: If classrooms are too cold or too warm, students have difficulty concentrating and actively participating in classroom activities. Retrofitting or replacing aging, inefficient heating and cooling equipment can improve thermal comfort and have a positive impact on academic performance.
- Lighting: Visual comfort is reached when the quantity, distribution and quality of light allows objects to be seen accurately, without tiredness.[5] Lighting retrofits that provide better colour quality, use indirect/direct lighting and enhance daylight in the classroom can all improve visual comfort. The California Energy Commission suggests that daylighting improves learning by up to 21%.[6]

Case in point:
York Catholic District
School Board
York Region, Ontario

The York Catholic District School Board's EcoChampions Program helps students visualize energy savings. Interval meters, installed in dozens of schools, are connected to the building automation system. Energy statistics from the meter are displayed on a monitor in the school foyer and in classrooms via the intranet. If preset energy consumption thresholds are exceeded, *Save Energy* LED signs in all classrooms and public areas flash, and an energy savings plan swings into action. As each tactic is introduced, students can log onto the intranet sit e or view the central system monitor to see the impact of their conservation efforts.

The total program cost, mainly for meters, LED fixtures and wiring, was approximately $7,000 per school, with a payback period of a little over two years.

Source: ***Green Schools Resource Guide,*** Ontario Ministry of Education

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[4] Kats, G. 2006. *Greening America's Schools: Costs and Benefits. Capital E.*

[5] educate-sustainability.eu/kb/content/parameters-visual-comfort.

[6] California Energy Commission. 2003. *Summary of Daylighting In Schools: Reanalysis Report.*

- Acoustics: Noises from outside the school, the hallways, other classrooms and building systems (e.g. fans, boilers, compressors) can negatively impact students' concentration. Major retrofits provide an opportunity not only to install quieter equipment, but also to reduce exterior noise by upgrading the envelope.
- Security and safety: Student and teacher safety can be enhanced by retrofitting exterior lighting, as well as lighting in hallways and stairwells.

A major retrofit project can also serve as a learning tool by providing valuable curriculum opportunities. Students can learn how energy is used in schools; actions they can take to reduce energy; and how energy relates to their math, science and environmental studies.

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

Challenges

Funding is often the primary barrier preventing the implementation of major retrofit projects in K–12 schools. School boards sometimes struggle to budget appropriately for operations, maintenance and capital projects. When budgets are thin, it is often more palatable to cut in these areas rather than make changes that will impact educational resources and teaching staff. The result is a negative feedback cycle in which a lack of preventative maintenance and deferred equipment replacement leads to inefficient equipment operation and higher energy costs.

Fortunately, innovative, cost-effective financing mechanisms can help to provide the needed capital. Energy performance service contracts are an example of a financing option that can be appropriate for school boards implementing major energy retrofits across a portfolio of buildings. Under one of these contracts, risk is transferred to a third party (an energy services company, or ESCo) that typically provides turn-key design and installation, and secures financing at its own risk. The ESCo verifies energy savings annually and receives a portion of their value. Savings are often guaranteed for a defined period of time.

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).

Energy use profile

When planning your major energy retrofit project, consider the energy use profile for a typical Canadian K–12 school. Although specific energy use profiles will vary, the example below can be used to provide a general indication of how you use your energy.

Figure 2. Energy use by energy source

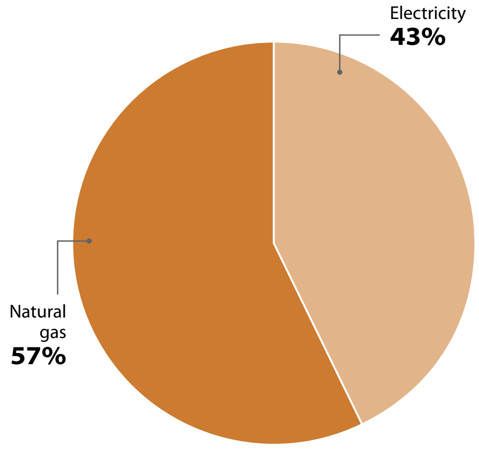
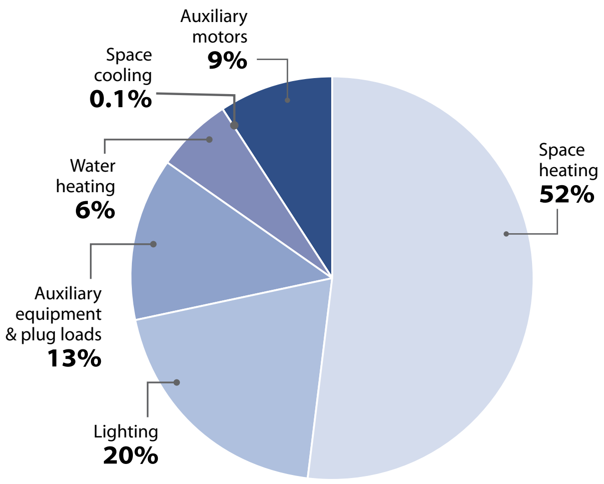


Figure 3. Energy use by end use



End use data for a typical medium-sized K–12 school in the interior of British Columbia with climate conditions similar to other metropolitan areas across Canada.

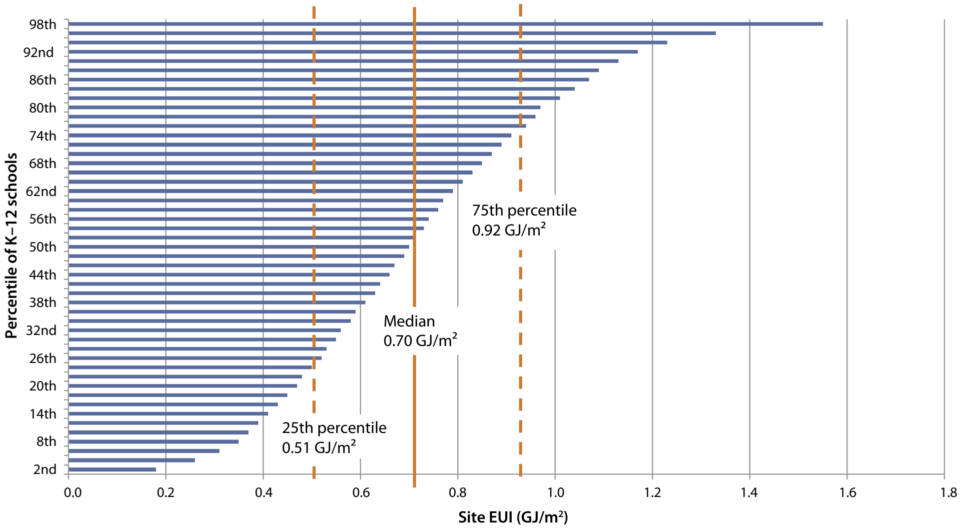
Data source: FortisBC

Figure 2 shows the breakdown of consumption by energy source. Natural gas provides more than half of a typical school's energy requirements. Figure 3 shows the breakdown of consumption by end use. Space heating is the largest end use, followed by lighting and auxiliary equipment & plug loads (e.g. plug loads such as computers, and miscellaneous equipment such as refrigerators and cafeteria food service equipment).

Energy use intensity (EUI) in K–12 schools can vary widely and is influenced by weather conditions, whether the school is an elementary or secondary school, and by specific facility and operating characteristics such as the number of teaching staff, the student seating capacity, the gymnasium size, the presence of an indoor pool, and the percentage of the school's space that is heated and cooled.

Figure 4 presents the overall distribution of normalized EUI for a Canada-wide sample of K–12 schools.

Figure 4. Distribution of site energy use intensity for Canadian K–12 schools



Source: ENERGY STAR Portfolio Manager, 2016

The solid vertical line shows that the median site EUI for schools entered in ENERGY STAR Portfolio Manager is 0.70 GJ/m^2 (18.06 ekWh/sq. ft.). Schools in the 25th percentile of this data set have EUIs lower than 0.51 GJ/m^2 (13.16 ekWh/sq. ft.) and those above the 75th percentile have EUIs greater than 0.92 GJ/m^2 (23.74 ekWh/sq. ft.). The national median EUI according to the *Survey of Commercial and Institutional Energy Use* 2009 is 0.70 GJ/m^2 (18.06 ekWh/sq. ft.).

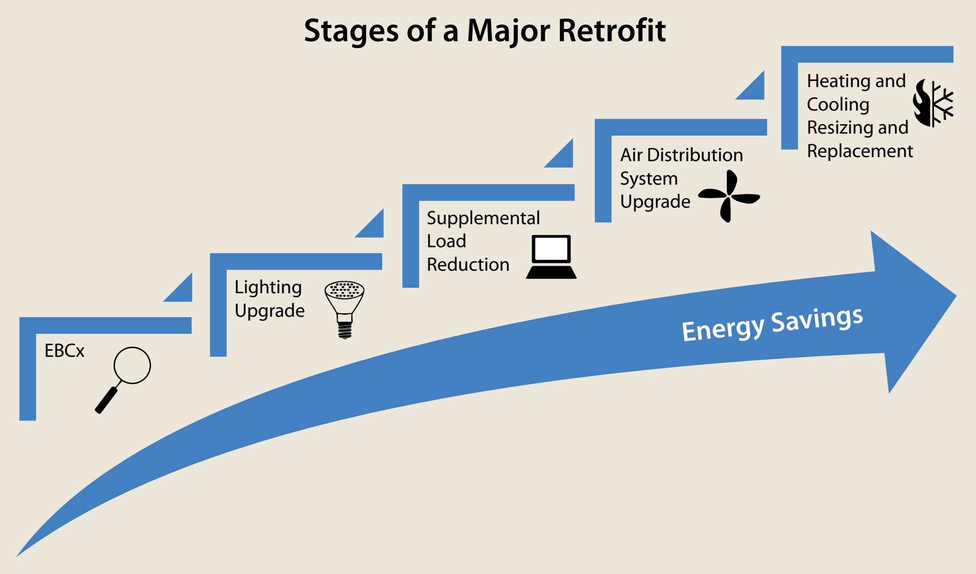
Schools are encouraged to benchmark and track their energy performance using ENERGY STAR Portfolio Manager, the most comprehensive and only standardized energy benchmarking tool in Canada for K–12 schools. Benchmarking allows you to compare your current energy use against past performance as well as 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 K–12 schools, ENERGY STAR Portfolio Manager provides an ENERGY STAR rating that scores energy performance on a scale of 1 to 100, relative to similar buildings.

Schools may have multiple buildings that are all integral to the primary activity. For example, one building might contain classrooms, a second the gymnasium, and another might be a portable. In this case, the campus can get an ENERGY STAR score as long as the energy for all buildings is metered and reported.

Staging project measures

As discussed in the Principles Module, implementing major energy 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. Studies have shown that existing building commissioning (EBCx) in K–12 schools typically results in 11% energy savings, with a simple payback period of 1.5 years.[7] Savings will be greater if a school has a particularly poor operations and maintenance program.

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*[8] and *Best Practices for School Facility Managers*[9] show you how to reduce operational expenses through improved building operations.

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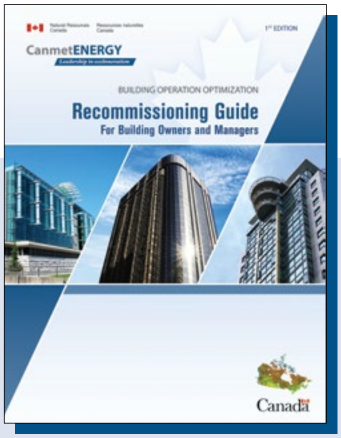
[7] Mills, E., Lawrence Berkeley National Laboratory. 2009. *Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions.* Prepared for California Energy Commission.

[8] *Building Operation Optimization: Recommissioning Guide for Building Owners and Managers*. nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/NRCan_RCx_Guide.pdf.

[9] *Best Practices Guide for School Facility Managers.* nrcan.gc.ca/energy/publications/efficiency/buildings/5945.

PART 1



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.

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

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

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

The measures listed 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.[10]

EBCx measure list

- ✓ Confirm lighting control schedule
- ✓ Schedule air handling system
- ✓ Employ temperature setback during unoccupied hours
- ✓ Verify free cooling operation
- ✓ Turn off heating coil valves in the cooling season
- ✓ Widen zone temperature deadband
- ✓ Reset supply air temperature
- ✓ Test and adjust ventilation flow rates
- ✓ Close outside air dampers during morning warm-up in the heating season
- ✓ Perform early morning flush in the cooling season when conditions allow
- ✓ Employ static pressure reset
- ✓ Correct damper operation
- ✓ Lower variable air volume box minimum flow set points
- ✓ Calibrate building automation system sensors
- ✓ Reset boiler supply temperature
- ✓ Repair missing or damaged pipe insulation

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

- **Confirm lighting control schedule:** Confirm that the lighting control schedule matches the actual occupancy, and explore opportunities to reduce hours of operation by reducing or eliminating after-hours activities (e.g. cleaning) by moving them to existing occupied hours. Controls should typically be configured to turn interior lights off at a set time, but not on; staff are expected to turn lights on when they arrive in the morning.
- **Schedule air handling system:** Equipment that runs longer than necessary wastes energy. Equipment schedules are often temporarily extended, then forgotten. Check that equipment scheduling in the building controls, mechanical timeclocks or thermostat settings matches occupancy as closely as possible.
- **Employ temperature setback during unoccupied hours:** One of the most cost-effective means of reducing energy consumption is by modifying the temperature set point of the building when it is empty, i.e. letting the thermostat setting go below the occupied period set point during the heating season, and above it during the cooling season. Setback temperatures typically range from 2 to 5 °C; however, the actual appropriate setback levels depend on the recovery time of your facility's HVAC equipment, i.e. the time it takes to bring the space temperature back to a comfortable level before staff and students arrive for the day. Review the set points for heating and cooling during unoccupied hours to ensure that setback temperatures are in place.
- **Verify free cooling operation:** 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.[11]

  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.[12]

Case in point:
Our Lady of Peace
Elementary School
Laval, Quebec

Our Lady of Peace elementary school reduced energy costs by 17% by undergoing a full commissioning program that included optimizing ventilation controls, and setting back temperatures overnight and on weekends. A $35,000 investment yielded energy savings of more than $7,000 per year, for a simple payback period of approximately five years.

Source: Natural Resources Canada

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[11] 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.

[12] 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.

- **Turn off heating coil valves in the cooling season:** Many air handler preheat coils and dual duct hot deck valves should be turned off in the cooling season to prevent accidental or unnecessary heating.
- **Widen zone temperature deadband:** Zone temperature deadband is the temperature range in which neither heating nor cooling is provided to the zone. By widening the zone temperature deadband, unnecessary "fighting" between heating and cooling systems is prevented, and energy consumption is minimized. This also mitigates heating and cooling system instability caused by short-term cycling between heating and cooling modes.
- **Reset supply air temperature:** Moderate weather, typically in spring and fall, permits a warmer supply air set point for cooling and a cooler supply air set point for heating.
- **Test and adjust ventilation flow rates:** School ventilation rates should meet the requirements of ASHRAE Standard 62.1. These requirements are set to maintain healthy indoor air quality (IAQ), something that is particularly important for schools. Poor IAQ impacts student performance and tends to affect younger children more than adults. Energy can be saved by ensuring that ventilation rates do not exceed ASHRAE requirements.
- **Close outside air dampers during morning warm-up in the heating season:** While warming the building before staff and students 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 building with 100% outside air (when outdoor air conditions permit) before starting mechanical cooling. To accomplish this, the controller senses acceptable outdoor air conditions and delivers an override signal to the outdoor air or economizer damper to open fully. During this operational mode, heat recovery must be disabled to take advantage of the free cooling.
- **Employ static pressure reset:** Supply fans on variable air volume (VAV) systems are often controlled to maintain static pressure within ductwork at a single set point. A more efficient strategy, and one that is required by ASHRAE 90.1-2010, is to use direct digital controls (DDC) to reset the pressure set point based on the zone requiring the most pressure. The static pressure set point can be automatically reset through a zone-level control feedback loop, which allows the supply fan to maintain the minimum air flow needed to keep individual zone conditions comfortable. Static pressure reset is an extremely effective method of reducing fan energy in VAV systems.[13]

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

- **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 larger schools), 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 two 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, CO_2 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.

- **Reset boiler supply temperature:** During the shoulder seasons, 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.

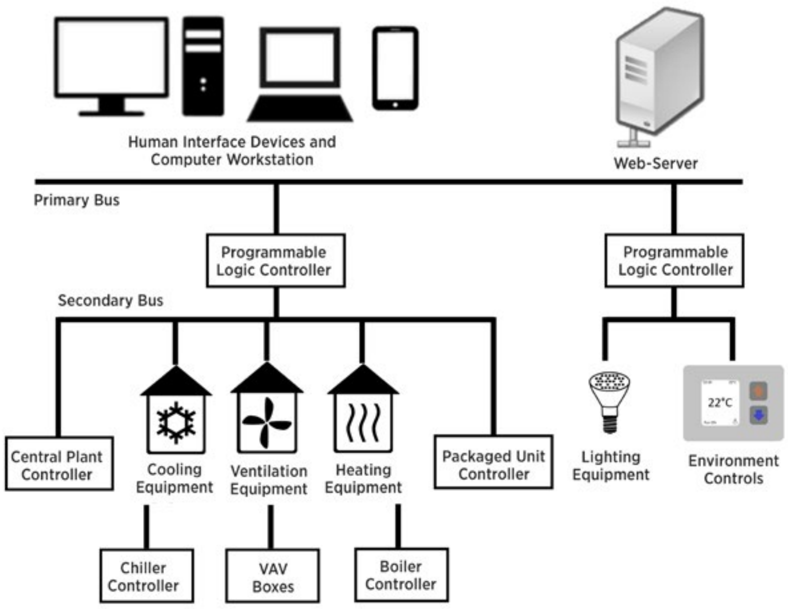
- **Repair missing or damaged pipe insulation:** Routine inspections of heating and cooling pipe insulation can identify spots that require repair. Without insulation, energy is wasted in the form of standby losses and cycling losses (e.g. heat loss in unoccupied spaces as hot water cycles through pipes).

Building automation system (BAS)

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

With the installation of a control system, several or all building systems can be connected to a central server (as shown in Figure 5), enabling an operator to monitor and adjust systems and their interactions. While this may not directly deliver energy savings, improving the controllability of building systems is an important strategy to enable energy savings. For this reason, BAS installation has become common practice amongst school boards.

Figure 5. Simplified open protocol BAS diagram



Over the past 25 years, DDC has become the dominant technology for controlling HVAC systems. DDC systems are also commonly used to control lighting systems and provide remote monitoring of security and fire alarm systems. All DDC systems are web-enabled to allow remote monitoring of HVAC, lighting and security systems.

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

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

Lighting upgrades

Lighting consumes approximately 20% of the energy used in Canadian K–12 schools 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%[15] and have the potential to improve student performance and absenteeism.[16] If one considers that prescribed lighting power densities from older codes are at least double the power density prescribed in current codes, an energy saving potential of 50% is possible, even without additional controls.

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

Lighting power densities (LPDs) have decreased due to advancements in energy-efficient lighting systems. The 1997 *Model National Energy Code for Buildings* permitted LPDs for K–8 schools to be 17.8 W/m^2 and secondary schools to be 19.7 W/m^2. The *National Energy Code of Canada for Buildings 2011* (NECB 2011) prescribes a maximum LPD of 10.7 W/m^2 for schools. 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.

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

[16] Collaborative for High Performance Schools. chps.net/dev/Drupal/node/48.

Daylight harvesting

Daylight harvesting is a strategy that is especially relevant to schools. Staff and students spend up to 40 hours per week in school buildings, especially if they participate in after-school programs. Direct exposure to the outdoors and sunlight can have a significant positive effect on the health and productivity of the staff and students. Numerous studies have shown a strong correlation between access to daylight and student health and academic performance.

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 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.[17]

Daylighting is not just about adding windows. Uncontrolled direct beam light streaming in from windows creates undesirable conditions that will lead to closed blinds, negating the daylight strategy. In classrooms, gymnasiums, media centres and administrative offices, it is critical that sunlight be bounced, redirected or diffused so that direct radiation does not enter a part of the room where this could be problematic.

Visual comfort

Daylighting and electric lighting will maximize visual comfort in the space if designed and integrated properly. Electric lighting should be designed to meet Illuminating Engineering Society of North America (IESNA) recommended levels. Inappropriate light levels (too high or too low) can cause eyestrain and be a detriment to the quality of the learning environment. In addition, direct sun penetration should be minimized in classrooms because the resulting high contrast ratio will diminish visual comfort.

Further information on visual comfort can be found in *The IESNA Lighting Handbook* (IESNA 2000), chapter 2 "Vision: Eye and Brain" and chapter 4 "Perception and Performance."

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[17] *IESNA Advanced Lighting Guidelines,* 2001 Edition.

Successful daylight harvesting requires three key considerations:

Daylight penetration

Enhancing daylighting in existing schools is a challenging exercise, given that windows are fixed elements in the building. To optimize daylighting with existing window openings, consider doing the following:

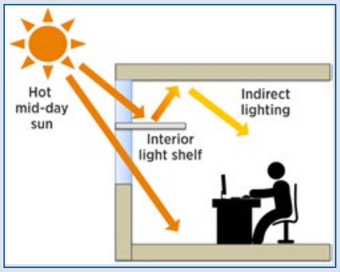
- **Maximize visible transmittance (T_{vis}):** T_{vis} is a property of glazing that indicates the fraction of visible light transmitted through the window. If new, high-performance windows are being installed, selections should be made to balance the amount of heat gain you want the windows to block and the amount of daylight you want them to transmit. While T_{vis} theoretically varies between 0 and 1, most values among double- and triple-pane windows are between 0.30 and 0.70. The higher the T_{vis}, the more light that is transmitted. To maximize daylight, T_{vis} values of 0.60 to 0.70 are recommended.
- **Add light shelves:** Although a single south-facing window can illuminate 20 to 100 times its unit area, the direct sunlight produces uncomfortable glare for occupants, working surfaces and computer screens. Light shelves bounce visible light up towards the ceiling then back down deeper into the room. To understand what configuration is best suited for your school, prepare a daylight model to predict the lighting levels and the distribution that may be expected.
- **Add skylights or roof monitors:** Skylights provide better lighting quality and more reliable energy savings than daylight designs relying solely on windows.[18] A good skylight design provides relatively uniform illumination throughout a space. However, some suggest that schools should avoid horizontal skylights in favour of roof monitors.[19] A roof monitor is a raised section of roof that includes vertical glazing, either south- or north-facing, or both. Monitors with south-facing glazing are preferred because they let heat and light in during the winter and keep the heat out in the summer.

Reflectance of interior surfaces

Lighting performance (daylight and electric lighting) is greatly affected by the reflectance of interior surfaces, such as walls, ceilings, flooring and furniture. Dark interior surfaces absorb light, while lighter surfaces reflect light, increasing levels of illumination throughout the space. For daylighting, increased reflectance reduces the contrast between daylight openings and interior surfaces, greatly improving visual comfort.

Light shelves can be installed inside or outside of the window. The example below shows an interior light shelf.

Figure 6.
Interior light shelf



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[18] Heschong Mahone Group Inc. 2004. *Modular Skylight Systems: Best Practices for Designing Skylights with Suspended Ceilings.*

[19] asumag.com/daylighting/know-how-skylights.

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.

Daylighting controls

Lighting controls have two forms: switching and dimming. Both strategies require sensors to provide feedback to the controls.

- Switching turns lights off when adequate daylight is available. Existing lighting circuits can be re-wired to enable separately circuited ballasts within each fixture or separately circuited light fixtures.
- Dimming provides gradual changes to the light output over the ballast's range, allowing a wide range of light output.

Direct replacement vs. designed retrofits

Direct replacement retrofits require little analysis and, as the term implies, are a one-for-one replacement of lighting sources and/or control devices. For instance, new 11-W light-emitting diode (LED) lamps can replace 50-W MR16 halogen incandescent lamps.

On the other hand, designed retrofits require analysis and design exercises to ensure that the resulting lighting layout and control strategy meets occupants' needs. Lighting designs need to address important elements such as luminance ratios, glare and colour qualities, in addition to the quantity of light. Most importantly for schools, classroom lighting design is critical to the success of creating productive learning environments. The NECB should also be consulted to ensure that maximum LPDs are not exceeded.

Table 1. Illuminance recommendations for school facilities

Application and task	Illuminance targets (lux)[20]
General classrooms	500[21]
Art studios	500
Shops	1,000
Gymnasiums	500
Reception desk	400
Teachers' lounge	200
Circulation corridors	50–100[22]
Stairs	50–100

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

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

[21] General area lighting supporting reading and handwriting tasks

[22] Depending on level of activities (high level and surveillance = 100, typical = 50)

When designing lighting modifications, the following principles apply:

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

Lighting measures are presented in three categories: core areas, gymnasium and exterior / parking lot lighting.

Core areas

The majority of spaces within a typical school fall within this category. For example, these measures apply to classrooms, staff rooms, offices, washrooms, cafeterias, corridors, stairwells, and areas such as mechanical rooms and janitor closets. Follow IESNA and NECB standards when redesigning lighting for these areas.

Of particular note, classroom lighting needs have changed significantly since the time when many Canadian schools were designed. Teachers now spend over 25% of instruction time using interactive whiteboards and overhead projectors to deliver lessons to students.

To accommodate different modes of teaching, lighting needs to be flexible, for example, T5 or T8 fluorescent lighting with dimming ballasts in combination with teacher-activated switching and dimming controls.[23]

Lighting measure list (core areas)

- ✓ Replace incandescent and compact fluorescent lamps that are used often with LED lamps
- ✓ Replace incandescent Exit signs with LED signs
- ✓ Replace wall switches in classrooms and other enclosed rooms with occupancy/vacancy sensors
- ✓ Replace T12 and older T8 fluorescent fixtures with higher-efficacy light sources with dimming control
- ✓ Install daylight sources and lighting control
- ✓ Use occupancy-based bi-level lighting in corridors and stairwells

HVAC implications of interior lighting retrofits

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

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

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[23] Lighting California's Future. 2010. *High Performance Retrofit Classroom Lighting Guide.*

- **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 lamp with a 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 wall switches in classrooms and other enclosed rooms with occupancy/vacancy sensors:** Occupancy sensors automatically turn lights on when occupancy is detected; vacancy sensors require manual activation of the wall switch to turn lights on. Vacancy sensors deliver the highest savings since the lights will never automatically turn on. A time-out period of 15 minutes is typical to avoid short cycling and reduced lamp life. The U.S. Environmental Protection Agency estimates savings potential under optimal conditions ranging from 25 to 75% of lighting energy depending on space type.[24]

- **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.

- **Install daylight sources and lighting control:** A well-designed daylighting strategy with photosensor lighting controls that switch off fixtures when adequate daylight is available can save significant energy as well as maintenance costs.

- **Use occupancy-based bi-level lighting control in corridors and stairwells:** Bi-level lighting provides full illumination when occupancy is detected and reduced illumination when unoccupied. Spaces that are not regularly occupied but require some lighting when unoccupied can reduce the lighting power by up to 50% during unoccupied periods.

Case in point:
Cardinal Carter
Catholic High School
Aurora, Ontario

The school cut energy use by 19% by replacing its 3,800 T12 lighting fixtures with T8s, and using motion sensors and LED Exit signs. Annual cost savings, which include lower maintenance costs associated with replacing burned out lamps, improved ordering and delivery of lamps, and better inventory control, are $27,000 per year.

Source: SaveONEnergy

Gymnasium

Lighting in gymnasiums is unique compared to the rest of the school given that gymnasiums typically have higher ceilings. High-bay lighting has traditionally come in the form of high-intensity discharge (HID) metal halide (MH). However, in recent years, standard HID lighting has been replaced by fluorescent or the new ceramic MH; most recently, high-bay LED fixtures have also entered the market.

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[24] 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.

Lighting measure list (gymnasium)

- ✓ Replace incandescent Exit signs with LED signs
- ✓ Replace high-intensity discharge lighting with high-bay fluorescent or LED fixtures
- ✓ Install daylight sources and lighting control
- ✓ Install occupancy sensors

- **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 high-intensity discharge lighting with high-bay fluorescent or LED fixtures:** Replacing quartz MH lighting with T5 high-output lighting offers 23% savings, while replacement with high-bay LED can result in savings of 30 to 50%.[25]
- **Install daylight sources and lighting control:** A well-designed daylighting strategy with photosensor lighting controls that switch off fixtures when adequate daylight is available can save significant energy as well as maintenance costs.
- **Install occupancy sensors:** Gymnasiums can be outfitted with occupancy sensors and multi-level lighting control.

Exterior / parking lot

Exterior lighting is designed for security and safety purposes and is not concerned with the qualities that support colour rendering or detailed visual tasks. Consequently, LED lighting is well suited for exterior lighting applications.

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.

Lighting measure list (exterior / parking lot)

- ✓ Replace building exterior and parking lot lighting with LED lamps
- ✓ Add photocell and timeclock controls to exterior lighting

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[25] High-bay LED lamps have a lower light output and may result in more fixtures compared to HID for the equivalent illumination.

- **Replace building exterior and parking lot lighting with LED lamps:** LED fixtures offer savings greater than 40% over conventional HID. Lamps or fixtures can be replaced one-for-one and require minimal design analysis.
- **Add photocell and timeclock controls to exterior lighting:** At a minimum, exterior lighting should be controlled by a photocell that shuts it off during daylit hours. If lighting is not required for security or safety purposes, using timeclocks to shut lights off outside of school hours can also save money and energy. For example, parking lot lighting can be turned on at sunset then off at 10 p.m.; on during early morning hours then off at sunrise. Astrological timeclocks offer enhanced control by automatically adjusting the timer to local sunrise and sunset times for optimal efficiency year round.

Supplemental load reduction

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

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

Power loads and equipment

This section addresses common equipment and devices used in the school environment (those located in classrooms, staff rooms, offices and cafeteria kitchens), as well as electrical distribution transformers.

Supplemental load measure list (power loads and equipment)

- ✓ Power off equipment when not in use
- ✓ Install vending machine controls
- ✓ Choose ENERGY STAR equipment
- ✓ Eliminate personal powered devices
- ✓ Implement an energy awareness program
- ✓ Install high-efficiency transformers

- **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 example, computer and monitor power management settings can be set to automatically power off using one of these approaches:
    - Staff enable the existing power management features on classroom and office computers and turn off computers at night.
    - School board IT department develops and deploys login scripts that control power management settings.
    - Third-party software delivers a computer power management policy across the school 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, school boards 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 office equipment, food service equipment, and vending machines.
- **Eliminate personal powered devices:** A growing number of energy consuming devices found in schools are not covered by ENERGY STAR (e.g. personal coffee pots, bar fridges, cup warmers, fans, heaters, audio equipment, computer peripherals, etc.). Although each device may draw only a small amount of power, the total can be significant. Schools can implement policies that discourage the use of such items or educate employees about wise use, such as turning devices off or unplugging them when not in use.
- **Implement an energy awareness program:** NRCan's *Implementing an Energy Efficiency Awareness Program*[26] can help school boards develop successful staff energy awareness programs. Another useful resource is the document *ENERGY STAR Guidelines for Energy Management*.[27] It provides information on creating a communications plan, and ideas, examples and templates that can

Case in point:
Vancouver District
School Board

The school board installed power management software on 10,000 school computers. The software saves 2.5 GWh of electricity per year, more than 7% of the district's total energy bill.

Source: Vancouver District School Board

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

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[26] publications.gc.ca/collections/collection_2013/rncan-nrcan/M144-244-2012-eng.pdf

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

Cafeterias: commercial kitchen equipment

A wide range of equipment, fixtures and appliances contribute to energy consumption in cafeterias, 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 are improved. Replacing existing equipment with new high-efficiency alternatives can save up to 70% of energy use.

Table 2 highlights typical savings for various kitchen equipment and indicates whether ENERGY STAR-qualified products are available:

Table 2. 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.*

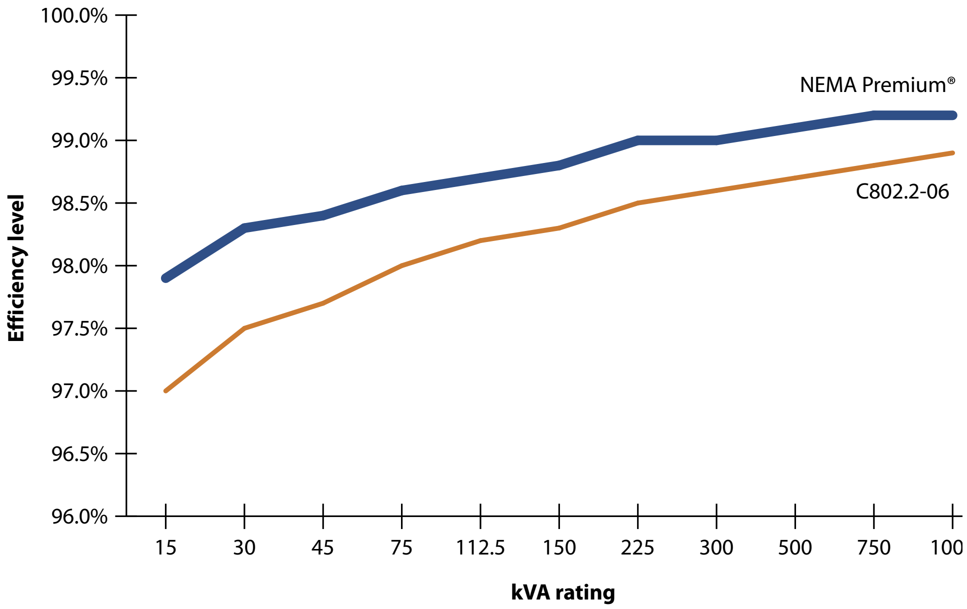
Kitchen ventilation also has a significant impact on energy consumption. Energy demand can drop considerably if kitchen appliances are the right size, if heat is recovered from exhaust air, and if the ventilation system has a demand control system. Some kitchen appliances even have integrated solutions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

be customized to help spread the word to staff and students. Student energy awareness material and curriculum packages are also available from BC Hydro and ENERGY STAR:

- BC Hydro has collaborated with educators and curriculum specialists to develop resources that provide valuable information on energy efficiency, energy alternatives and conservation. A full suite of programs targeting specific grades from Kindergarten to Grade 12 are available online: bchydro.com/community/youth_education.html
- ENERGY STAR Kids is a website dedicated to students and teachers with engaging interactive online material for children and links to lesson plans for teachers: **www.energystar.gov/index.cfm?c=kids.kids_index**

- **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 7 shows the relative efficiencies of standard transformers vs. NEMA premium transformers.

Figure 7. 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.

Case in point:
Vancouver District School Board

Four Vancouver District School Board secondary schools audited their refrigerator appliances and needs, identifying 43 aging and inefficient refrigerators. All were removed, and of these, 23 were permanently retired and 20 were replaced with new ENERGY STAR-rated models. Savings are estimated at 40,000 kWh (worth about $4,000) annually. All removed appliances were sent for recycling.

Source: Vancouver District School Board

Replacing a single 75-kVA transformer (98% efficient) with a NEMA premium-efficiency transformer (98.6% efficient) reduces annual transformer losses by approximately 30%, based on 260 days/year, 15% loading for 16 hours/day and 100% loading for 8 hours/day.[28]

Envelope

This section describes options that can be taken to improve the building envelope (roof, walls, foundation, windows and doors). The most common parameters affecting heat flow through the building envelope are conduction, solar radiation and infiltration. Conduction relates to the conductivity of the materials in the envelope assembly and their ability to conduct or resist simple heat flow from hot to cold. Performance is most often represented in RSI-values (or R-values), 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 the air leakage through building elements, such as around windows, doors, envelope intersections, physical penetrations and mechanical openings. Figure 8 shows how heat flows into and out of a building through the envelope.

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.

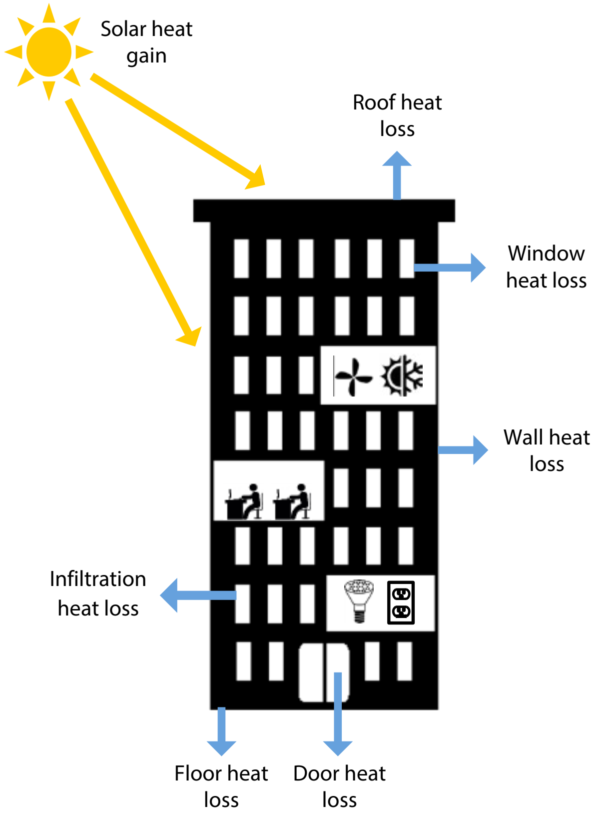
Conversion:

RSI = R ÷ 5.678

R = RSI x 5.678

1 RSI = R-5.678

Figure 8. Building envelope heat transfer



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

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).

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. Building pressure should be neutral or very slightly positive. This condition can be verified by an air balancing to measure supply and exhaust air flows. Imbalances can be corrected by addressing the differences between the aggregate supply and exhaust air streams.

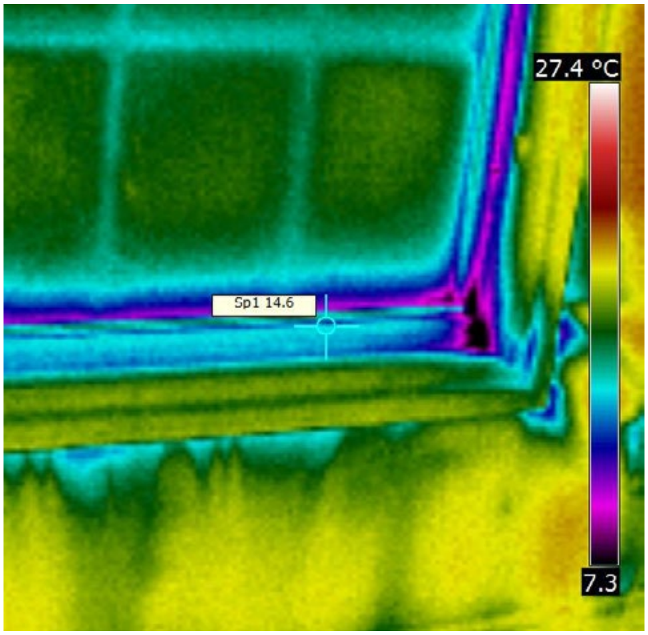
  Some signs of infiltration are obvious, such as observed daylight around a closed door; identifying others may require the use of thermographic imagery, which allows for visualization of temperature differentials. Figure 9 demonstrates how infrared imagery can help identify problems related to infiltration 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.

Replacing windows and building envelope sealing were among the many retrofits done to all of the schools in **Saskatoon Public Schools**, the largest school board in Saskatchewan.

Total savings for all retrofits over a 10-year period are in the order of $13 million. The projects also reduced the maintenance backlog by more than $2.3 million through numerous infrastructure improvements.

Figure 9. 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 at the top. Since K–12 schools are generally no more than three storeys high, stack effect is typically less significant compared to other subsectors. Regardless, elevator shafts and stairwells provide a low-resistance path for the rising air, so it is imperative that penetrations such as roof hatches and roof access doors are well sealed.

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

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

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

  Fluid-applied air barriers are often preferred for their relative ease of detailing and installation as compared to sheet material. Fluid-applied air/water barriers have long been used in drainable exterior insulation finish systems (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%.[29]

- **Add insulation:**

  Roof insulation

  Since a school'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)

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

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.

  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.

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

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.[30]

The text box on page 30 provides a more detailed discussion of each of these criteria, along with a discussion of various window components and assemblies.

Doors

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

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

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[30] The SHGC will influence the resulting visible light transmittance (T_{VIS}); the lower the SGHC, the lower the T_{VIS}. In other words, increased shading from heat gains lowers the T_{VIS}.

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.

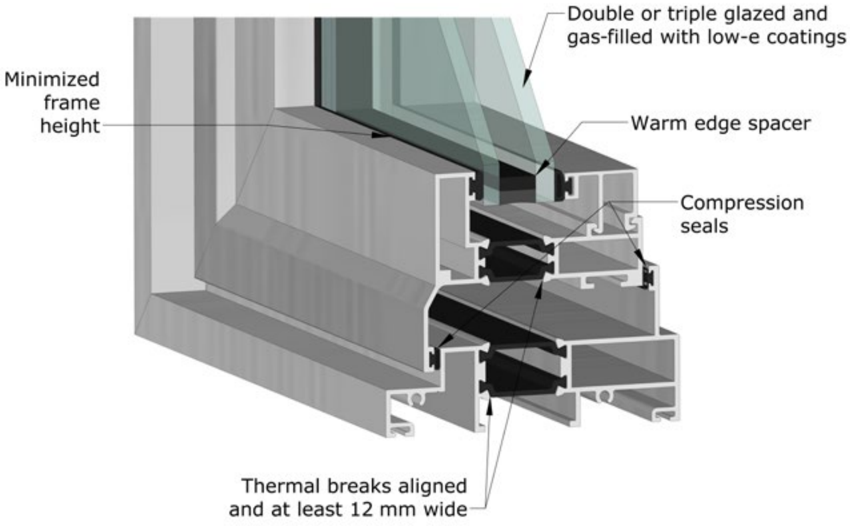
IGU performance is determined by:

- 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 10. 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

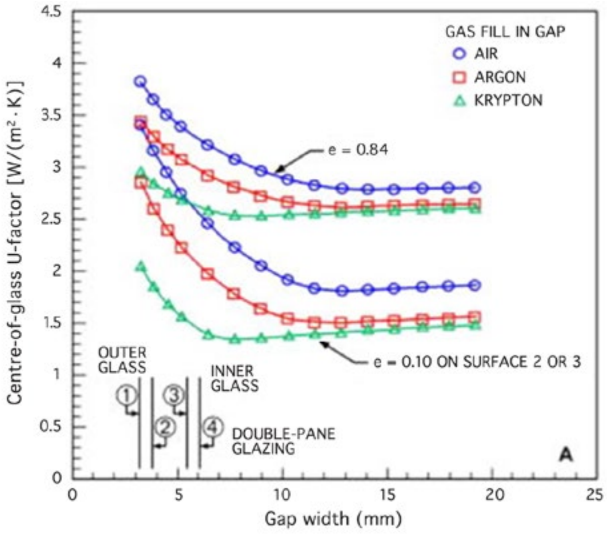
A window's U-factor incorporates the thermal properties of both the frame and the glazing. Since the sash and frame represent approximately 10 to 30% of the total area of the window unit, the frame's properties significantly influence the total window performance.

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

Figure 11. Gas fill thermal performance



Source: © *ASHRAE Handbook – Fundamentals*. 2012. 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.

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.

Five main types of equipment distribute air within schools:

1) Central furnace/fan-coil equipment that consists of either engineered built-up systems or furnaces (small schools). Air is conditioned centrally with hot and chilled water coils or direct-fired heat exchangers with direct expansion evaporator cooling coils.
2) Central air handlers with distributed zone fan coils.
3) Central air handlers with distributed zone heat pumps.
4) Rooftop units (RTUs) with heating and sometimes cooling.
5) Vertical or horizontal unit ventilators installed within each classroom that condition air with hot water coils and, if the school is zoned for air conditioning, chilled water or direct expansion evaporator cooling coils.

Some older schools were designed to be naturally ventilated, so depending on the age of the facility, air distribution equipment may not exist.

Constant vs. variable volume

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

Constant volume systems

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

Variable air volume systems

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

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

Comfort and air quality

The typical temperature range in schools is 20 to 26 °C (22 °C +/-2 °C in winter; 24 °C ± -2 °C in summer). The lowest cost option to reduce HVAC system energy is to expand the allowable ranges for indoor temperature and humidity, i.e. lowering the temperature set point during the winter months. By carefully studying the thermal comfort needs in a typical classroom environment, you can determine the acceptable range for temperature and humidity. These comfort ranges can be found in ASHRAE Standard 55.[31]

ASHRAE Standard 55 comfort range example

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

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

You should also consider the indoor air quality and the amount of ventilation air required by building occupants in each space type. Conditioning outside air is one of the most energy-intensive loads that the HVAC system faces, so your first step should be to minimize the amount of outside air that needs to be conditioned. Calculate the required exhaust and ventilation air according to ASHRAE Standard 62.1[32] using the actual occupancy rates, rather than the default occupancies provided in the standard. Then apply demand control using CO_2 as a proxy for actual occupancy. CO_2 can be metered at the return duct to the RTU with the control system providing a reset signal to the outdoor air damper to open or close according to the CO_2 in the space.

Retrofits

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

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[31] Thermal Environmental Conditions for Human Occupancy. ashrae.org/resources--publications/bookstore/standard-55.

[32] Ventilation for Acceptable Indoor Air Quality. ashrae.org/resources--publications/bookstore/standards-62-1--62-2.

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

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

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

Air distribution systems measure list

✓ Start with first-order measures

✓ Install demand control ventilation

✓ Replace constant volume with variable air volume in multi-zone systems

✓ 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 variable refrigerant flow system

✓ Replace mixed-air delivery with a dedicated outdoor air system

✓ Replace mixing ventilation system with displacement ventilation

✓ Install high-volume, low-speed fans in gymnasiums

✓ Install high-induction swirl diffusers in gymnasiums

✓ Retrofit shop exhaust systems

Gymnasiums are often good candidates for demand control ventilation, as they tend to have highly variable occupancy through time.

A good indicator of adequate ventilation in a school building is the level of carbon dioxide (CO_2). ASHRAE has recommended that a level of 700 parts per million (ppm) CO_2 above ambient (outdoor levels) be used to indicate a supply of 7.5 L/s (15 cfm) of outside air per person.

According to ASHRAE guidelines, CO_2 levels in excess of 700 ppm above ambient indicate an inadequate supply of outside air to the building occupants. With ambient levels of 400 ppm (2014), the maximum recommended CO_2 levels are 1 100 ppm.

- **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.

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

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

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

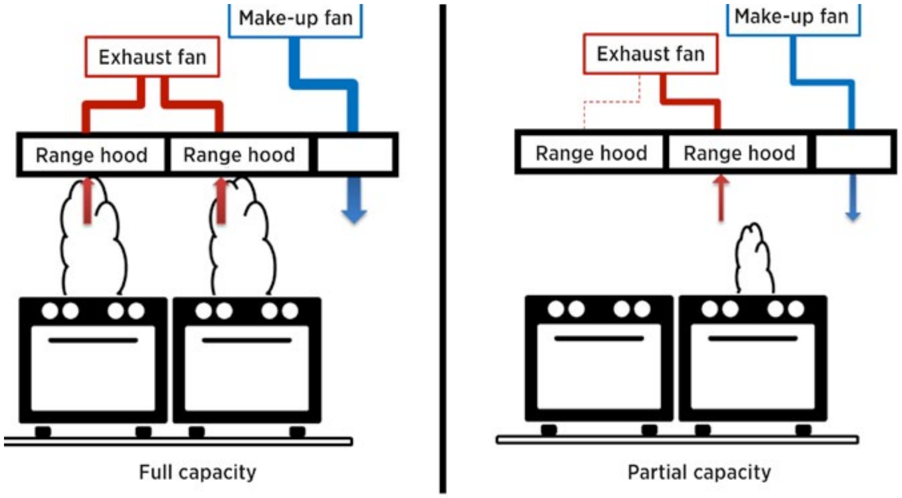
Kitchen hood exhaust

DCV can also be applied in school cafeterias; 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 to direct communication with cooking appliances.

Food preparation equipment and kitchen ventilation can be large energy consumers in school cafeterias. 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 12.

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.[33]

Figure 12. Demand control ventilation in a commercial kitchen



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

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

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

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 and installing a variable speed-drive, 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, building owners may be able to lower outdoor air levels through a monitoring program to provide further energy savings.

  - *Longer service life and less maintenance.* Electronic air cleaners have lower maintenance requirements than conventional air filters, which typically require that pre-filters be changed quarterly.

- **Install heat recovery on exhaust air streams:** Heat recovery is a requirement of the NECB for some new buildings and offers favourable energy savings. There are three basic types of heat recovery that are well-suited for typical K–12 schools: heat core, energy/enthalpy wheel and reverse flow.

  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 the 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%.

  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.

- **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- or roof-mounted forms. Gymnasiums typically have large wall and roof areas that can make a retrofit relatively easy to implement.

  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).

Sensible heat transfer is related to changes in air temperature.

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

If the connection to the gymnasium's AHU is not simple, wall-mounted solar collectors can be used to destratify air inside the gymnasium. Preheated outdoor air from the collector is mixed with the warm air near the gymnasium ceiling to destratify and ventilate the space, allowing the gymnasium's AHU to be turned down or shut off as the warm high-level air is redistributed to the gymnasium floor. See the text box on page 43 for more information on destratification.

- **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 schools 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.

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 is required from the central system; all conditioning is performed in the zone by the VRF units.

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

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

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

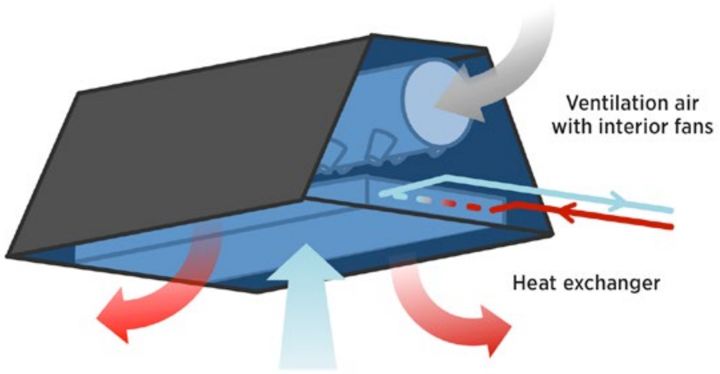
Chilled beams

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.

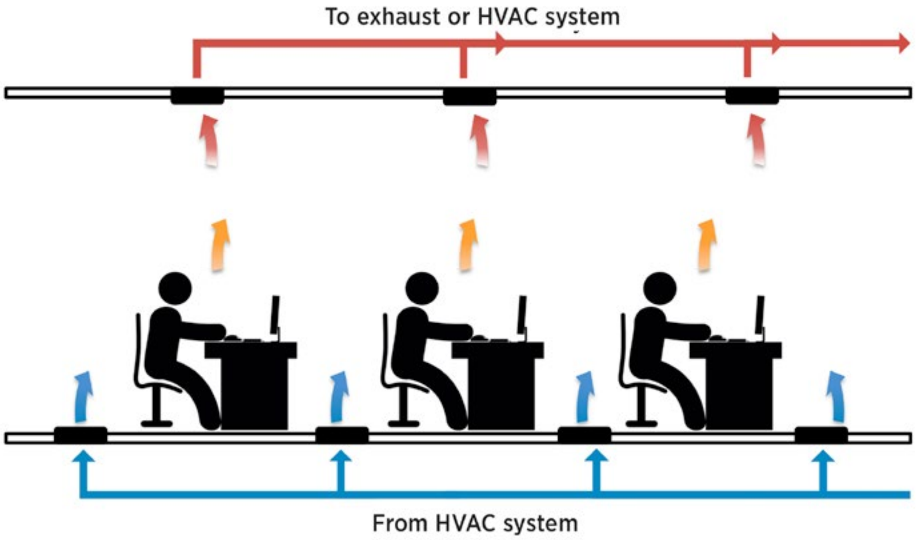
Active chilled beams are designed to supply the ventilation air through a nozzle that induces classroom air through a chilled or heating coil in the beam before mixing with the ventilation air. One unit of supply ventilation air can move between two and six units of secondary air through the beam, significantly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

Figure 13. Chilled beam heating



- **Replace mixing ventilation system with displacement ventilation:** Conventional constant or 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, as shown in Figure 14. The air travels horizontally at a 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.

Figure 14. Displacement ventilation



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 classroom.
- *Reduced outdoor air volumes.* A DV system's superior ventilation effectiveness allows a reduction in outdoor air volumes, reducing the energy required to heat and cool the supply air.

- **Install high-volume, low-speed fans in gymnasiums:** High-volume, low-speed (HVLS) fans are considered air movement systems, not just cooling systems. They move and mix large volumes of air, and they do so very efficiently. As a result of the masses of air they move, they are very effective in aiding cooling, heating (through heat destratification) and ventilation.

  HVLS fans are typically 2.4 to 7.3 m (8 to 24 ft.) in diameter to move large volumes of air at very low speeds. This creates a gentle but significant air flow that has an immediate cooling effect in a hot room. A 7.3-m (24-ft.) fan can move up to 177,830 litres of air per second (376,804 cubic feet per minute). Ideally, an HVLS fan will send a column of air down and out 360° toward the walls, back up to the ceiling and back through the fan. That pattern, known as floor jet circulation, naturally exchanges the air in very large spaces.

Destratification saves heating energy by bringing heat down to floor level where it is needed to keep occupants comfortable. Mixing the air also reduces ceiling temperatures, which reduces heat losses through the roof.

Cooling energy is saved due to the movement of large masses of air at the right speed for the evaporative cooling effect of 3.3 to 4.4 °C (6 to 8 °F). As a result, thermostats can be set higher; up to 8 °C (15 °F) warmer without compromising comfort.

The importance of destratification

Destratification can be used throughout the heating season to save energy in large rooms such as gymnasiums. It is well known that warm air rises, and in spaces with high ceilings, it is not uncommon to find air temperatures at the top of the space, near the roof, that are 10 to 30 °C higher than the temperature at the floor.

> The formula for heat loss through the roof is:
> $\mathbf{Q = (1/RSI) \times A \times (T_{in} - T_{out})}$, where RSI represents the level of insulation, A represents the roof area and $(T_{in} - T_{out})$ represents the temperature difference between the interior and exterior.

Since the insulation levels (RSI) and roof area (A) are fixed, the amount of heat loss through the roof is a function of the temperature difference between the interior and exterior $(T_{in} - T_{out})$. Therefore, if space temperatures are highly stratified during the heating season, the space ends up being significantly overheated to maintain desirable temperatures in the occupied zone.

The following example demonstrates how the rate of heat loss changes depending on the space temperature near the ceiling. In this example, the space has a roof area of 2,500 m^2 and a roof RSI-value of 5.46 (R-31).

Case #1: without destratification	*Case #2: with destratification*
Outdoor temperature = -10 °C Ceiling temperature = 30 °C	Outdoor temperature = -10 °C Ceiling temperature = 15 °C
Q = 1/5.46 x 2,500 x [30 – (-10)] = 458 x (40) = 18,315 W	Q = 1/5.46 x 2,500 x [15 – (-10)] = 458 x (25) = 11,450 W

Heat loss through the roof is reduced by 37% by lowering the ceiling temperature 15 °C, or in other words, 37% less heat is required to maintain the same space temperature in the occupied zone. Additional savings will result from a reduction in heat loss through the upper part of the walls.

- **Install high-induction swirl diffusers in gymnasiums:** In some cases, there may not be enough space available to accommodate HVLS fans. In these cases, swirl diffusers may be a better choice. High-induction swirl diffusers create an air distribution pattern that directs the conditioned air to the occupant zone. The result is better air mixing and reduced stratification.
- **Retrofit shop exhaust systems:** Metal, wood and other trade shops within schools consume large quantities of energy to provide make-up air for local exhaust ventilation systems. They also produce a wide range of contaminants (e.g. heavy particles, dust, smoke) during shop activities. The local exhaust stations designed to remove contaminants typically require high air velocities and large quantities of exhaust and make-up air.

  Start by considering whether a recirculation air cleaner is suitable for your school's shop. Exhaust systems that clean and recirculate the air have a larger capital cost over conventional exhaust make-up systems but often have short payback periods when the cost of heating cold winter make-up air is considered.

  If air recirculation is not possible, then high-efficiency (90 to 93%) gas-fired make-up air units or units connected to a high-efficiency central heating system should be used and properly interlocked to avoid supplying air when the local exhaust is off.

  Clothing insulation (clo) units are typically higher in shop areas, so free cooling minimum temperatures can be dropped to extend free cooling hours. During warmer weather, shop garage doors can also be opened to allow for passive make-up and interlocked with the make-up air unit to prevent its operation while the doors are open.

Case in point:
York Region District School Board, Ontario

The York Region District School Board oversees the management of more than 425 portables. As of January 2012, retrofits to its portable classrooms included upgrading lighting; installing lighting, temperature and ventilation controls; and adding roof and wall insulation.

Source: York Region District School Board Energy Conservation and Demand Management Plan.

Portable classroom tune-up

A single portable classroom designed to house 30 students would typically have a floor area of 70 to 90 m^2 (750 to 1,000 sq. ft.). Portable classrooms are an anomaly in the building code. A portable is considered to be a Part 3 assembly occupancy; however, it is essentially a Part 9 small building construction, and its energy efficiency requirements are dictated by the *National Building Code of Canada* (NBC), rather than the NECB. Certain provinces, such as British Columbia and Ontario, have provincial codes that describe the requirements for a portable's basic construction, fire safety, accessibility and plumbing (where applicable) under Part 9 of the provincial building code.

While new, more energy-efficient portable classrooms can be sourced, older models may be retrofitted to improve issues such as controls with limited functionality, poorly performing windows, considerable air infiltration and minimal insulation.

Portable classroom measure list

- ✓ Add a programmable thermostat
- ✓ Reduce infiltration
- ✓ Add an air barrier
- ✓ Add a high-efficiency furnace
- ✓ Add insulation
- ✓ Upgrade windows and doors
- ✓ Add a heat recovery ventilator
- ✓ Upgrade lighting

- **Add a programmable thermostat:** Programmable thermostats allow you to set specified occupied and unoccupied set points, schedule setback temperatures, and turn off ventilation during unoccupied periods. More advanced options available on the market allow for vacancy/occupancy sensing, programmable 365-day control options, and wireless communication with facility building automation systems.

- **Reduce infiltration:** Infiltration, or air leakage, is a significant factor in energy performance and occupant comfort. Use blower doors, smoke pencils and thermographic imagery to identify breaches in the air sealing. (See also **Supplemental load reduction**)

- **Add an air barrier:** An air barrier that wraps the building envelope is an essential component for proper sealing.

- **Add a high-efficiency furnace:** Residential-scale furnaces are suitable for portable classrooms and have combustion efficiencies of up to 98%.

- **Add insulation:** Add 25 to 50 mm of continuous rigid insulation to the exterior walls, and add insulation to under floor and attic space in accordance with NECB requirements.

- **Upgrade windows and doors:** Upgrade windows and doors in accordance with NBC energy efficiency requirements. (See also **Supplemental load reduction**)

- **Add a heat recovery ventilator:** Adding a heat recovery ventilator is an energy-efficient solution that will deliver the proper ventilation for a healthy indoor environment.

- **Upgrade lighting:** Use more efficient lamps, add lighting controls, and investigate the possibility of daylight harvesting. (See also **Lighting upgrades**)

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 gas heating and direct expansion cooling, complete with a supply and, possibly, return fan.

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

Case in point:
Samares School Board, Quebec

Since 2005, the Samares School Board (serving the regions of Joliet, Montcalm and D'Autray) has saved more than $5 million in energy costs. Through a combination of integrated geothermal, biomass, solar and wind power, the schools have completely eliminated their consumption of fuel oil and reduced greenhouse gas emissions by 85%.

Source: ecosystem-energy.com/case-studies/samares-school-board/

Central heating systems

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

Retrofit or replacement

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

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

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

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

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

Efficiency ratings

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

Table 3. Gas-fired boiler efficiency ratings

Boiler size	Rating	NECB 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%

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
✓ 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 ensuring that a heating water reset is in place. It is also important to ensure that heating coil valves are turned off in the cooling season 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 rate to the pump in order to meet system design flow, 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.

- **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 perform 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%.[34] With proper controls, lower heating water flow rates enabled by VSD pumps can also be coordinated with a hot water temperature reset schedule to meet loads accurately and efficiently. Low heating loads, for example, might be most efficiently met by creating warmer heating water and reducing the flow rate to save pump energy.
- **Replace burners:** New burners for all types of boilers and fuels are commercially available, and many suppliers offer burner retrofit parts for modifying burners rather than fully replacing them. This can often achieve significant improvements at lower cost than a full replacement.

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

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

Case in point:
Commission scolaire
des Laurentides
Sainte-Agathe-des-Monts,
Quebec

The school board's $6.7 million investment in major energy efficiency retrofits included upgrading the lighting system, installing a building automation system, upgrading HVAC and boilers, and installing geothermal, air-source heat pumps and hybrid heating systems. The retrofits have a combined simple payback period of 11 years, reduce natural gas use by 63% and electricity use by 16%, and save more than $370,000 per year in energy costs.

Additional benefits include a reduction in the deferred facility renewal backlog — paid for through energy cost savings — improved comfort and lighting quality, maintenance cost reduction, and greenhouse gas emissions reductions of 63%.

Source: Ameresco

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

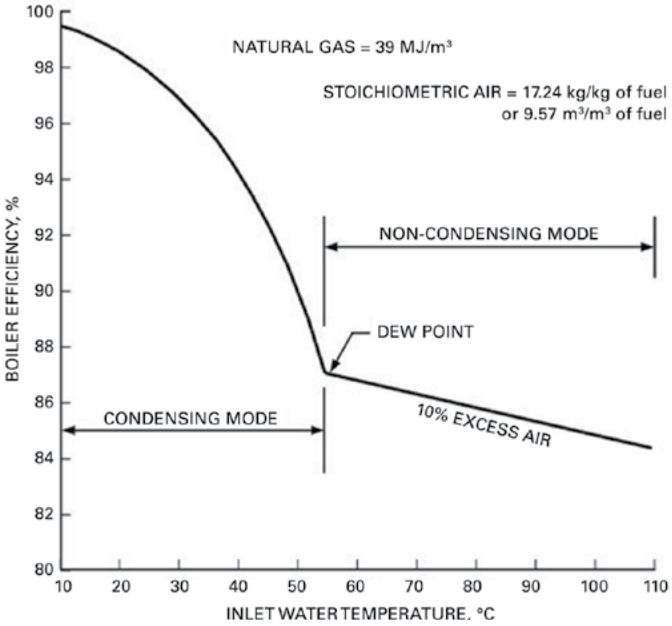
Boilers must operate with an excess supply of oxygen in the combustion gases to ensure complete combustion of the fuel, thereby yielding maximum heat energy. However, too much oxygen cools the flame, so the control of air and fuel levels is paramount to optimal efficiency.

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 15, 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. A major retrofit may provide the opportunity to resize terminal coils to ensure an appropriate return water temperature.

Figure 15. Return water temperature and its impact on boiler efficiency



Source: ©ASHRAE, ashrae.org. *2012 ASHRAE Handbook — HVAC Systems and Equipment*

- **Replace with modulating boiler:** A modulating boiler adjusts its output by sensing the outdoor air and/or return air temperature and then adjusting the firing rate as low as possible to meet the heating needs. Modulation saves energy by improving dynamic efficiency during periods of light loads. Modulation also provides accurate load tracking and precise temperature control, while minimizing energy waste. Modulating boilers achieve efficiencies of up to 88% and are the most efficient choice where heating demands do not permit return water temperatures less than 54.4 °C (130 °F).

- **Replace with hybrid boiler system:** A hybrid boiler system consists of condensing and non-condensing boilers controlled to deliver the maximum efficiency over the heating season. Depending on the system design and heat loss from the building, distribution water temperatures may not be suitable for a condensing boiler. This is often the case during peak heating conditions. Therefore, when outdoor temperatures are coldest, it is more economical to operate a modulating non-condensing boiler, since the elevated return water temperatures will not permit condensing operation. However, during the majority of the season, when heating demands are much less than peak, supply 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 may 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.

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

Biomass boilers

Biomass boilers are an alternative to propane, oil or electric boilers for rural schools without access to natural gas. The most suitable biomass boiler is one that combusts wood pellets, due to the auto-feed and burn-rate control available. As shown in Table 4, wood pellets are the lowest cost option where natural gas is not available. Silos can be used to store large quantities of pellets, and augers can be used to automatically feed the boilers. Boilers can be installed either in the boiler room or in a detached energy shed. The latter option generally has the least impact on the existing building.

Table 4. Cost and efficiency of biomass boiler fuel types

Fuel type	Cost of fuel*	Efficiency	$/GJ**
Electric resistance heat	$0.14/kWh	1.0	$38.89
Heat pump	$0.14/kWh	2.5 Average COP	$15.56
#2 fuel oil	$1.28/litre	0.83	$39.75
Propane	$0.77/litre	0.83	$36.65
Natural gas	$0.33/m^3	0.83	$10.39
Firewood***	$28/m^3 ($100/cord)	0.83	$17.65
Wood pellets	$220/metric tonne ($200/ton)	0.83	$13.92

*Pricing varies by region.

**$/GJ = Dollars per GJ of heat delivered to building.

***Assumes a 50/50 mix of maple and beech dried to 20% moisture content. The price is for a 4 ft. x 8 ft. x 16 in. face cord (1.2 m^3), split and delivered. The efficiency of all wood-burning boilers is assumed to be the same as that of gasification type boilers.

A hybrid option is also available. To reduce capital costs, the pellet boiler can be sized to meet 60% of the building heating load. The pellet system would deliver an estimated 80% of the building's heating energy, while an existing or new propane boiler would run during peak demand and serve as back-up.

Case in point: Sieur de Coulonge (Mansfield, Quebec) and Cité de la Haute-Gatineau (Maniwaki, Quebec)

As part of a larger school board retrofit project, biomass boilers were installed in these two schools. The boilers supply most of the schools' heating demand, and local wood pellets from forestry residue, which would otherwise be landfilled, are used as the fuel source. In all, Hauts-Bois-de-l'Outaouais school board retrofit projects, which also included the installation of geothermal systems and lighting upgrades, save the school board about $450,000 per year in energy costs and have reduced greenhouse gas emissions by 54%. These significant improvements were made possible with Integrated Energy Performance Contracting (IEPC), a deep energy retrofit approach that addresses the whole building and provides performance guarantees that target lowest overall project costs and highest energy savings, resulting in significant greenhouse gas abatement.

Photo courtesy of Ecosystem.

- **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 either 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.

Air-source heat pumps

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

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

Ground-source heat pumps

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

Replacing conventional heating and air conditioning systems with GSHPs typically saves 15 to 25% of total building energy use in commercial buildings.[35] 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 are less financially attractive than other heating and cooling options. Furthermore, because building cooling loads in schools are significantly less than heating, there is an imbalance in the energy that is exchanged with an earth heat sink. Over time, a significant imbalance, where more heat is extracted than is returned, will result in a reduction in the heat pump's COP.

Most favourable conditions exist when a school does not have access to natural gas, and especially when existing equipment is at the end of its expected service life and replacement is necessary regardless of the resulting efficiency gains. Detailed annual energy calculations and 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.

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

Case in point:
École L'Odyssée-des-Jeunes
Laval, Quebec

This school's geothermal system was installed in 2011 at a cost of $930,000, one third of which was provided through government and utility incentives. Annual savings are $62,000 for a simple payback period of 10 years.

"To significantly reduce energy consumption required to heat* existing schools, geothermal systems can be a good option to consider,"** said Jean-Sébastien Provencher, Project Director, Ecosystem, the energy consulting firm hired by the school board to conduct the retrofit. "The fact that heating and cooling loads can be precisely identified in existing buildings makes it easier to design the system for actual needs. It limits oversizing, as can be the case in new buildings, which helps reduce construction costs and maximize profitability."

Photo courtesy of Ecosystem.

*Reducing heating energy consumption is a priority for schools, since most are closed during the summer and therefore have relatively small cooling loads.

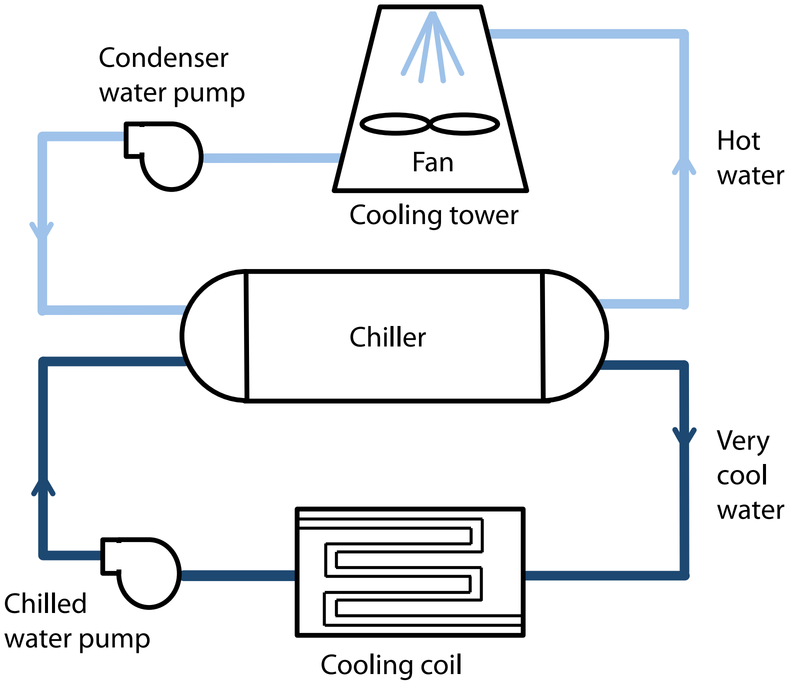
**Will depend on suitability of soil conditions and energy rates (low electricity rates help to make geothermal systems more cost effective).

Central cooling systems

Although many existing schools have limited or no space cooling, the trend is changing. Larger new facilities and recently retrofitted schools are beginning to install central cooling systems. To account for this trend, this section provides direction for schools that are planning to add central cooling equipment to existing buildings and for schools that have relatively recent central cooling plants.

Chillers are at the heart of 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 16 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 16. Chiller plant



Chiller operating efficiency

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

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 design, operating schedules, and the part-load operating characteristics of the available chillers. Second, modifying the design or operation of one component often affects the performance of other system components. For example, increasing the chilled water flow can improve chiller efficiency, but the extra pumping power required can result in an overall *reduction* of system efficiency. The following five measures apply:

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.

Heating and cooling measure list (central cooling systems)

- ✓ 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
- ✓ Install a properly sized high-efficiency water-cooled chiller
- ✓ Install water-side economizers to allow cooling towers to deliver free cooling when weather conditions permit

- **Eliminate flow-restricting valves:** This measure reduces pump energy use and returns less heat to the chiller. If valves are installed to control flow rate to the pump in order to meet system design flow, 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.

- **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%.[36] 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.

- **Install a properly sized high-efficiency water-cooled chiller:** If a new chiller is being installed, 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 conditions. 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.

- **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.

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[36] The formula is 1 – $(0.9)^3$ = 0.27.

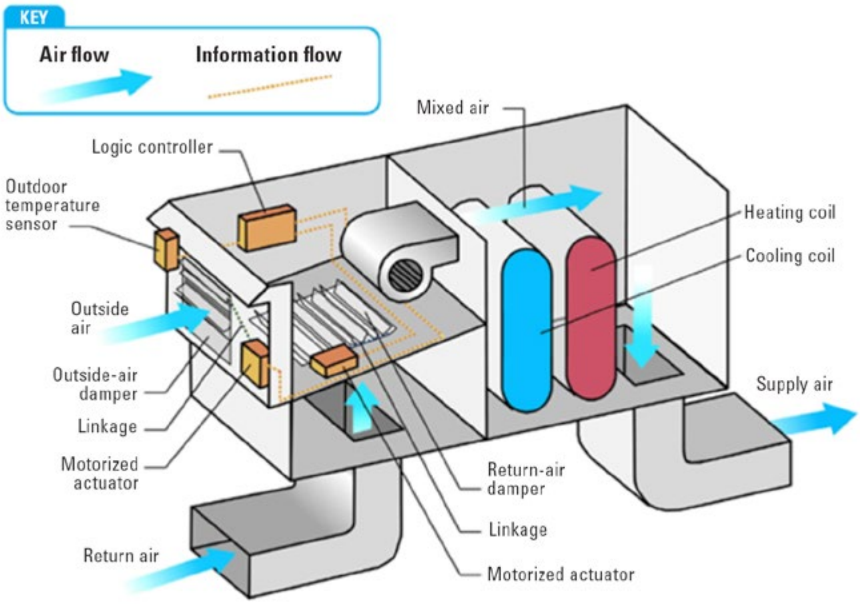
Chiller plant upgrade summary

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

More than a third of Canadian commercial/institutional building floor space is conditioned by self-contained, packaged rooftop units (RTUs).[37] 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 17.

Figure 17. Typical rooftop unit



Source: U.S. EPA

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

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

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

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

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

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[38] 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

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

operate continuously until the room's thermostat set point temperature is reached. However, under most operational conditions, maximum output is not required, and the system is oversized for the load. Simple controllers that detect thermodynamic saturation of the heat exchanger turn off the compressor to avoid overcooling. Industry experience has shown an average of 20% cooling energy savings.

- **Add economizer damper:** Some RTU models can accommodate an economizing damper as a manufacturer's option. In cases where the economizer damper was not included in the original product selection, adding the economizer will deliver energy savings.
- **Add heat or energy recovery:** Similarly, some RTU models can accommodate heat or energy recovery ventilators as a manufacturer's option. In cases where these options were not included in the original product selection, adding them will deliver energy savings.

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

- **Replace rooftop units:** Replacing an existing RTU will bring numerous efficiency gains, especially where high-efficiency units are specified with variable speed fans and compressors, energy recovery, and condensing gas combustion. RTUs are sized according to their cooling capacity (kW or tons), with nominal heating capacities set according to the cooling capacity. Careful attention to product specifications is required to identify high-efficiency gas combustion options. 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. Equipment should also be configured for demand controlled ventilation. Some of the features available with current advanced RTUs include:
    - Insulated cabinets for improved energy efficiency and acoustics
    - Multi-staged or modulating heating control with turndown ratio of 10:1
    - Condensing-type heating with AFUE up to 94%
    - Variable speed electronically commutated fan motors
    - Variable speed scroll compressors with superior part-load efficiency
    - Heat and energy recovery from exhaust air
    - Demand controlled ventilation using CO_2 sensors
    - Heat pump option
    - SEER up to 18; IEER up to 21
    - Remote energy monitoring and operational supervision

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.

Domestic hot water

Although water heating comprises only a small portion of the total energy use in Canadian K–12 schools (~6%), there are still opportunities to save energy.

Heating and cooling measure list (domestic hot water)
✓ Install low-flow aerators and showerheads
✓ Schedule recirculation system
✓ Replace existing boiler/heater with more efficient unit
✓ Turn off central water heater during summer and install on-demand heaters in dedicated spaces

- **Install low-flow aerators and showerheads:** Reduced flow through faucets and showerheads reduces the consumption of hot water. Installing water efficient fixtures is the lowest cost measure to reduce energy, and replacements can be easily done by operations staff. Products are available that deliver flow rates as low as 0.95 L/min for faucets and 4.7 L/min for showerheads.

- **Schedule recirculation system:** Some schools use an inline pump to circulate hot water through the domestic hot water distribution system so that hot water is readily available for use. Scheduling the circulation to operate only during occupied hours saves the electrical energy associated with pump use. Thermal losses from the circulation pipe are also reduced. The simplest method of scheduling the recirculation pump is to add a timeclock and program it to match occupancy hours. The implication for staff working outside of normal occupancy periods is that they may not have instantaneous hot water at the faucet.

- **Replace existing boiler/heater with more efficient unit:** Existing hot water 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.

- **Turn off central domestic water heater during summer and install on-demand heaters in dedicated spaces:** During the summer months (July and August), schools are often vacant except for sparse custodial staff and contractors carrying out cleaning, maintenance or repairs. During this period of low occupancy, energy can be saved by turning off the central hot water system and dedicating a janitor closet and washroom or two for summer use. These spaces can be outfitted with on-demand electric water heaters to eliminate all standby losses.

On-demand water heaters are tankless, heating the water as it passes through the heat exchanger. These types of heaters are about 20% more efficient than gas-fired tank type heaters,[39,40] and the savings are attributed to a lack of storage losses in conventional tank systems.

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

IMPORTANT:
Managing *Legionella* in hot and cold water systems

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

Risk 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.

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[39] ENERGY STAR. ENERGY STAR Certified Water Heaters. energystar.gov/productfinder/product/certified-water-heaters/results

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

PART 1

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

- *Recommissioning Guide for Building Owners and Managers*
- *Energy Management Best Practices Guide*
- *Energy Management Training Primer*
- *Improve Your Building's Energy Performance: Energy Benchmarking Primer*
- *Energy benchmarking for K-12 schools*

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

SIMCOE COUNTY DISTRICT SCHOOL BOARD: A CASE STUDY

PART 2

A team approach, energy policies and standards, and a sustainable funding model save money and energy.

> “Taking a team approach to energy conservation is critical to success, and the diversity of the team is important. Sustainable energy conservation programs require more than just the involvement of the typical energy people; you need to involve the Board, staff, teachers and students”
>
> Jessica Kukac, Environmental Systems Co-ordinator,
> Simcoe County District School Board

One of Ontario’s largest public education systems, the Simcoe County District School Board (SCDSB) has 106 schools and learning centres throughout 4,800 km^2 of Simcoe County in south central Ontario.

Trillium Woods Elementary School, one of several schools retrofitted, was given an energy makeover with an emphasis on optimizing what they already had. Total energy consumption dropped by 68%.

Photo courtesy of Simcoe County District School Board

Incentives to action

In 2009, the Ontario Ministry of Education created the Energy Efficient Schools (EES) initiative. The $550 million fund covered costs related to energy audits, energy efficiency retrofits and equipment replacement. Funds were allocated based on the number of schools within each board; the SCDSB received more than $9.6 million to be spent over two years. It also received incentives from utilities, such as the Ontario Power Authority, Enbridge and Union Gas, for specific retrofit projects completed.

As a requirement of Ontario’s ***Green Energy and Green Economy Act***, the Board also prepared a five-year energy conservation and demand management (ECDM) plan that includes energy consumption and savings targets for each school.

The staged approach to retrofits

Once the EES funding was received, the Board hired Enerlife, an energy consulting firm, to identify conservation measures. Energy consumption data from each of the 106 schools was collected and assessed, relative to other SCDSB schools and to other school boards across Canada. Of those, 35 schools were identified as optimal candidates for energy efficiency improvements.

Benchmarking the schools helped to identify the type of retrofit measures that would result in optimal savings; the measures were then refined once a building performance audit was completed at each school.

“The funding from the Energy Efficient Schools initiative provided an opportunity to initiate retrofits and system upgrades, which resulted in offset energy use and utility cost avoidance,” said Kayla Kalalian, the Board’s environmental systems co-ordinator. “We’re currently reviewing the utility data and identifying the next set of schools to be retrofitted. The energy savings from this phase will pay for the next phase of retrofits.”

Benchmarking showed what could be done. The energy audit identified the why, where and how—fans, lighting, building automation, etc.

What was done?

The Board’s retrofit projects fell into three categories: mechanical retrofits and existing building commissioning, lighting, and building automation systems.

“We were surprised that some of our newer schools with lots of integrated technology were not performing as well as we expected,” said Kalalian. “Benchmarking showed us how, in some instances, simple operational changes could make a school more energy efficient.”

Existing building commissioning

Despite being built in 2004, Trillium Woods Elementary School’s energy performance had weakened between 2009 and 2010. Investigation revealed air flows below design levels, and fan and heating pump power that was double the standard for efficient systems. Many of these low-hanging fruit measures were remedied quickly.

HVAC modifications helped improve air flow and reduce power use. Measures included cleaning and repairing air intakes and filters, right-sizing the school’s heat pumps, reducing fan power, and modifying controls.

Commissioning measures like those completed at Trillium Woods were undertaken at 18 of the 35 schools for total annual savings of $280,000.

Energy Reductions:

Electric demand: 480 kW

Electricity consumption: 1,800,000 kWh

Natural gas consumption: 340,000 m^3

Total energy savings: 19,000 GJ

Building automation systems

At nine of the schools, the building automation systems were either replaced or modified to make the best use of the heating, cooling and ventilation systems. Control modifications included identifying — and stopping — any equipment left running at night, limiting the use of air conditioning during cool weather, and eliminating it entirely before May 1 and after September 30.

Lighting

At 23 of the 35 schools, lighting was upgraded to 25-W T8s in classrooms and corridors, and T5 high-output lighting in gymnasiums, and occupancy sensors were added. The overall number of fixtures was reduced, and building controls were modified to better suit actual occupancy.

At Bradford District High School, swapping 32-W lamps for 25-W ones, installing occupancy sensors, and using LED lighting and T5 fixtures cut annual electricity consumption by 19%.

"Through this process, we developed a standard for lighting as part of our *Policies and Standards Guide*," said Kalalian. Light levels and power densities are set for different room types, and the standard is now included in tender documents.

Major benefits

- ✓ Between 2009 and 2013, retrofits performed at 35 schools saved the SCDSB more than $3.5 million in energy costs, roughly one quarter of the schools' annual energy budget.
- ✓ Applying the same approaches to the Board's other schools has the potential to reduce energy use annually by a further 30%, generate an additional $1 million in savings and cut greenhouse gas emissions by more than 5,000 tonnes.
- ✓ The Board established standards and best practices for all future new construction and retrofit projects, including for operational procedures and new equipment.
- ✓ The energy savings from the first 35 schools have been reinvested to fund future school retrofits as well as operational training and best practices workshops.
- ✓ For the past several years, the SCDSB has ranked among the top 10 school boards in the country for energy performance.

Monitoring and verification

Most schools' energy use is monitored monthly using a combination of the building automation system, interval meters and the Ministry of Education's utility consumption database.

In addition, energy intensity targets were developed for new and existing schools based on the actual performance of the top performing schools. The targets for existing elementary and secondary schools are 0.47 GJ/m^2 (12 ekWh/sq. ft.) and 0.58 GJ/m^2 (14 ekWh/sq. ft.), respectively, and targets for new construction elementary and secondary schools are 0.39 GJ/m^2 (10 ekWh/sq. ft.) and 0.47 GJ/m^2 (12 ekWh/sq. ft.), respectively. These targets align with ENERGY STAR Portfolio Manager's 25th percentile as well as ASHRAE's *Advanced Energy Design Guide* for K–12 schools, which aims to achieve a 50% energy use reduction compared with ASHRAE 90.1-2004. More than one quarter of all the Board's schools have already reached those targets, and many more are close to achieving them.

Training and education

To capitalize on potential savings from low- and no-cost operational changes, in February and March 2010, two workshops were held with school board staff, chief custodians, operators, and principals or vice-principals of specific schools. Each school's group worked together to come up with a comprehensive action plan for their school. All attendees were given access to an online data system so that they could track the results of their actions.

In addition, chief custodians are required to take a building operations and communications course, run by the Board, which is offered at various schools throughout the district.

"Custodians are the operators of these buildings and have a big role in energy conservation," said Kukac. "When they have a say in how buildings are operated, a feeling of ownership is instilled, and they naturally take a greater pride in their work and school."

The Board also adopted the **Ontario EcoSchools** program in 2008, with 22 schools currently certified at various levels. The majority of schools have also established Green Teams, which play an important role in engaging students, parents and teachers in environmental stewardship.

How can our school benefit from Simcoe's experience?

Kalalian said that the Board's biggest hurdle was finding the necessary capital for energy efficiency projects. "Prior to the EES program, there was limited funding to do those types of energy efficiency upgrades specifically. Our ECDM plan has been set up to be self-funding so that we can continue to make our schools as energy efficient as possible."

Kalalian noted that "it is important that energy conservation is considered when funding new school construction. With utility cost increases, maintenance, changing weather patterns and growing populations, long-term energy conservation begins at the design process. Buildings, especially new ones, should be tested to ensure that they are operating to the standard they were designed to, and that any discrepancies are corrected immediately. This will avoid new buildings having to be retrofitted five years after opening."

Even though each school has different energy issues, Kalalian says that many of the most common retrofits can be replicated across many types and sizes of buildings. Lighting upgrades, for example, are a relatively simple project. The SCDSB's standards for lighting and other equipment and systems also makes it that much easier for schools to follow best practices.

"We developed the energy intensity standards to ensure that there was continuity in all future retrofits and new school designs," said Kalalian.

Based on the success that the SCDSB has had with its retrofit program, Kalalian recommends that audits and existing building commissioning be a first step. "This ensures a systematic, tailored approach for each building, which will optimize energy savings."

Overall, Kukac advised that school boards take a team approach to energy conservation. "The critical elements are having maintenance, design and construction teams that are attentive and communicate their ideas, and having a supportive board and management that celebrate the success of these programs and communicate that to the broader school board community."

> " With the ever increasing cost of electricity and natural gas, we need to make great efforts to save energy in every way possible to help offset the increasing utility budget. Because of the work we've done in energy efficiency programs, we have been successful in maintaining a stable utility budget line despite the recent increases in utility costs. "
>
> Kayla Kalalian

PART 3

MY FACILITY

The following take-away section provides a summary of the retrofit measures applicable to K–12 schools 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 performance 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 employees: ____________________

Seating capacity (# of students) ____________________

Gymnasium floor area: ____________________

% of school that can be heated/cooled: ____________________

PORTFOLIO MANAGER OUTPUTS

ENERGY STAR score: ____________________

Site EUI: ____________________

Source EUI: ____________________

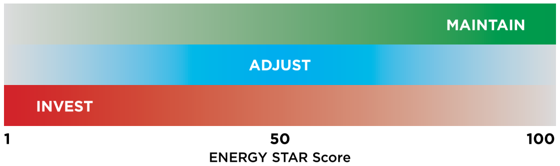
Median property EUI: ____________________

TARGETS

ENERGY STAR score target: ____________________

Site EUI target: ____________________

Figure 18. ENERGY STAR score interpretation



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

K-12 Schools – Opportunity Questionnaire

EBCx

- ☐ Do the lighting and occupancy schedules match? [Pg. 9]
- ☐ Is the air handling system on a schedule? [Pg. 9]
- ☐ Are the zone temperature set points set back/forward during unoccupied hours? [Pg. 9]
- ☐ Does the air handling equipment have a properly functioning economizer to enable free cooling? [Pg. 9]
- ☐ Are the heating coil valves turned off during the cooling season? [Pg. 10]

Lighting upgrades

Core areas

- ○ Have frequently used incandescent lamps and CFLs been replaced with with LED lamps? [Pg. 18]
- ○ Have incandescent Exit signs been replaced with LED signs? [Pg. 18]
- ○ Have occupancy/vacancy sensors been installed in classrooms and other enclosed rooms? [Pg. 18]
- ◇ Have linear fluorescent fixtures been replaced with high-efficiency lamps and dimming control? [Pg. 18]
- ◇ Have daylight sources and lighting control been installed? [Pg. 18]

Supplemental load reduction

Power loads and equipment

- ○ Is equipment being turned off when not in use? [Pg. 21]
- ○ Have vending machine controls been added? [Pg. 21]
- ○ Is ENERGY STAR equipment being used where applicable? [Pg. 21]
- ○ Has a policy regarding personal powered devices been implemented? [Pg. 21]
- ○ Has an energy awareness program been implemented? [Pg. 21]
- ◇ Have transformers been replaced with energy-efficient models? [Pg. 23]

Air distribution systems upgrade

- ◇ Is there a DCV system? [Pg. 36]
- ◇ Has the CV reheat, multi-zone, or dual-duct system been converted to a modern VAV system? [Pg. 38]
- ◇ Are fans 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. 39]

Heating and cooling resizing and replacement

Central heating

- ◇ Have existing boilers' control systems been replaced? [Pg. 48]
- ◇ Have flow-restricting valves been eliminated? [Pg. 48]
- ◇ Have standard-efficiency or oversized pumps been replaced with efficient, right-sized units? [Pg. 48]
- ◇ Are heating water pumps being controlled with VSDs? [Pg. 49]
- ◇ Have new burners been installed on existing boilers? [Pg. 49]
- ◇ Have turbulators been installed in firetube boilers? [Pg. 49]

- ☐ Is the zone temperature deadband wide enough? [Pg. 10]
- ☐ Is the supply air temperature reset depending on outdoor conditions? [Pg. 10]
- ☐ Has the ventilation rate been tested and adjusted? [Pg. 10]
- ☐ Are the outside air dampers closed during morning warm-up during the heating season? [Pg. 10]
- ☐ Is an early morning flush performed regularly during the cooling season? [Pg. 10]
- ☐ Is the VAV system static pressure set point automatically reset through a zone-level control feedback loop? [Pg. 10]
- ☐ Are the VAV zone dampers operating properly? [Pg. 11]
- ☐ Is it possible to reduce the minimum flow set points at VAV boxes? [Pg. 11]

- ◇ Is occupancy-based bi-level lighting being used in corridors and stairwells? [Pg. 18]

Gymnasium

- ○ Have incandescent Exit signs been replaced with LED signs? [Pg. 19]
- ◇ Has HID lighting been replaced with high-bay fluorescent or LED lighting? [Pg. 19]
- ◇ Have daylight sources and lighting control been installed? [Pg. 19]
- ◇ Have occupancy sensors been installed? [Pg. 19]

Exterior / parking lot

- ○ Has exterior and parking lot lighting been replaced with LED lighting? [Pg. 20]
- ○ Are photocell or timeclock controls being used? [Pg. 20]

Envelope

- ◇ Have infiltration issues been addressed? [Pg. 25]
- ◇ Has an air barrier been added or improved? [Pg. 27]
- ◇ Do the roof and wall insulation levels meet NECB requirements? [Pg. 27]
- ◇ Have the windows and doors been upgraded? [Pg. 28]

- ◇ Is outdoor air preheated with a solar air heating system? [Pg. 39]
- ◇ 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. 41]
- ◇ Have HVLS fans been installed in gymnasiums? [Pg. 42]
- ◇ Have high-induction swirl diffusers been installed in gymnasiums? [Pg. 44]
- ◇ Has the shop exhaust system been retrofitted? [Pg. 44]

- ◇ Has a new condensing boiler been installed? [Pg. 50]
- ◇ Has a new modulating boiler been installed? [Pg. 51]
- ◇ Has a new hybrid boiler system been installed? [Pg. 51]
- ◇ Has a new heat pump system been installed? [Pg. 54]

Central cooling

- ◇ Have flow-restricting valves been eliminated? [Pg. 58]
- ◇ Have standard-efficiency or oversized pumps been replaced with efficient, right-sized units? [Pg. 59]
- ◇ Are chilled-water pumps being controlled with VSDs? [Pg. 59]
- ◇ Has a properly sized high-efficiency water-cooled chiller been installed? [Pg. 59]
- ◇ Have water-side economizers been installed to allow cooling towers to deliver free cooling? [Pg. 59]

K-12 Schools – Opportunity Questionnaire (continued)

EBCx	Lighting upgrades	Supplemental load reduction	Air distribution systems upgrade	Heating and cooling resizing and replacement
☐ Have the BAS sensors been calibrated recently? [Pg. 11] ☐ Is there a heating water reset control strategy? [Pg. 11] ☐ Has missing or damaged pipe insulation been repaired? [Pg. 11]				**Rooftop units** ◇ Has the CV system been converted to a variable flow system with demand control and an economizer? [Pg. 62] ◇ Have compressor controllers been installed on RTUs to reduce runtime? [Pg. 62] ◇ Have economizer dampers been added? [Pg. 63] ◇ Has heat or energy recovery been added? [Pg. 63] ◇ Have old RTUs been replaced with new high-efficiency units? [Pg. 63] **Domestic hot water** ○ Have low-flow aerators and showerheads been installed? [Pg. 64] ○ Is the hot water recirculation system on a schedule? [Pg. 64] ◇ Has the hot water boiler/ heater been replaced with a high-efficiency unit? [Pg. 64] ◇ Is the central water heater turned off during summer and an on-demand heater installed in dedicated space? [Pg. 64]

Portable tune-up

- ○ Have programmable thermostats been installed and commissioned? [Pg. 45]
- ◇ Have infiltration issues been addressed? [Pg. 45, 25]
- ◇ Has an air barrier been added or improved? [Pg. 45]
- ◇ Have heating systems been replaced with new high-efficiency furnaces? [Pg. 45]
- ◇ Do attic, wall and under-floor insulation levels meet NECB requirements? [Pg. 45]
- ◇ Have windows and doors been upgraded? [Pg. 45, 28]
- ◇ Is heat recovered from exhaust streams? [Pg. 45]
- ◇ Have linear fluorescent fixtures been replaced with high-efficiency lamps and dimming control? [Pg. 45, 18]
- ◇ Have daylight sources and lighting control been installed? [Pg. 45, 18]