FROM GREEN TO NET-ZERO ENERGY: A STUDY OF SCHOOL BUILDINGS IN CANADA

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Abstract

Changes in the patterns of life in the late 20th and early 21st century have created new challenges for educational systems. Greening the physical environment of school buildings has emerged as a response to these challenges and has led to the design and creation of energy-efficient K–12 school buildings. In the last few decades, the advancement of knowledge and technology has resulted in the successful construction of Net-Zero Energy school buildings. These buildings present state-of-the-art of energy efficiency and, at the same time, incorporate renewable energy strategies to offset the building energy consumption from non-renewable resources. The recent data on US net-zero energy schools shows that the number of these schools is growing exponentially; however, it is very challenging to build such schools in severely cold climates similar to cities in Canada. Significant energy-efficiency strategies are needed to achieve the net-zero energy status in cold climates. This study aims to describe and analyze the current status of energy-efficient and net-zero energy schools in Canada. The goal is to identify the best practices for the construction of net-zero energy schools in Canada by studying the existing energy self-sufficient schools in the coldest parts of the US. The study summarizes the lessons learned from the successful cases and presents useful information for school designers and builders in Canada.

Introduction

Each day, many of the world's population spend a significant amount of time in schools as students, teachers, and staff. Clearly, everybody in a school building is affected by the physical environment of the school. The impacts can be seen in student productivity, health, and satisfaction. Education under healthy conditions keeps minds active, reduces absenteeism, and improves the performance of students in tests. According to the US Green Building Council (USGBC) Center for Green Schools, students with a proper learning environment can enhance their academic skills and score higher on standardized tests than others. School buildings can be designed and constructed in a way that minimizes their harmful impacts on the environment. Increasing the indoor value of a building coupled with decreasing the outdoor negative impacts on the environment have been the main driving forces behind the creation of green schools. Moreover, schools have significant utility costs, hence applying green strategies will reduce those expenses to a large extent (USGBC, 2013). The saved money can be spent on other purposes, such as recruiting new teachers and obtaining important supplies like books, computers, and other materials. In addition to savings, the educational role of the school buildings can further promote the benefits of these schools. Figure 1 presents the main benefits of green schools.

In the current era, the quality of education systems is more important to parents. The concept of 21st Century School (21C School) is a community school model that provides an affordable and quality education system for children.

The 21C School notion was launched in 1988 and in 2014 there were more than 1,300 schools that have implemented the following six major principles: (1) guidance and support for parents; (2) childcare with universal access; (3) non-compulsory programs before/after school and during vacations; (4) focus on health, education, services, and overall development of children; (5) high-quality programs and services; and (6) professional training and advancement opportunities for education practitioners. The 21C School concept extends well beyond just information delivery and requires knowledge generation (School of the 21st Century, Yale University). Table 1 provides examples of the changes in a traditional school system compared to the desired features of a 21st century school.

School buildings can have significant influence in achieving 21C learning goals. The factory model of historical schools is now shifting to a model of green construction that utilizes the latest research in high performance green schools. As we are moving forward, the new and existing school buildings are built and retrofitted with the use of recent technologies that make a building more environmentally friendly and more energy efficient. Additionally, increasing number of educators and school boards encourage innovative designs and further motivate architects to rethink in a sustainable way. Legislators are also paving the way through allocation of funding to the schools. Third-party verification organizations are also playing a fruitful role to adjust the school buildings to the 21st Century School goals. The US Green Building Council has created a center for green schools and the LEED school rating system can measure how a K–12 school facility can support its occupant's health and save resources, energy and money. The Green Building Certification Institute (GBCI), the certification arm of the USGBC, reviews LEED applications and provides feedback on the registered projects. This Institute has certified more than 2000 K–12 schools (USGBC, 2017) and most of them have been built at little or no additional cost compared to the conventional schools. These green schools, on average, use 32% less water and 33% less energy than their conventional counterparts, and can save an average of $100,000 per year per school on direct operating costs (USGBC, 2009).

This study focuses on the primary energy efficiency and the application of renewable energy strategies as implemented in a handful of exemplary US NZE schools located in climate zones 5 and 6. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) classifies the Central and North America climate into 8 zones with zone 1 as the warmest and 8 as the coldest. Applying the strategies taken by US schools will help Canadian K–12 school buildings to be one step closer to achieving NZE schools.

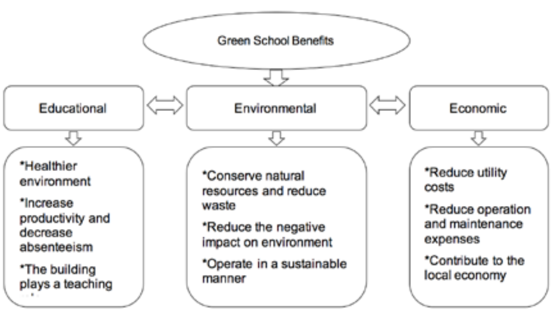

Figure 1: Notable benefits of green schools.

Shown Left: **Typical classroom, US 1960s**	**Shown Right:** **A classroom at the Lady Bird Johnson Middle School in Irving, Texas**
Time-based	Outcome-based
Focus: Memorization of discrete facts	Focus: What students know, can do, and are like after all the details are forgotten
Textbook-driven	Research-driven
Passive learning	Active learning
Students work in isolation	Students work collaboratively
Teacher-centered	Student-centered
Little to no student freedom	Great deal of student freedom
Fragmented curriculum	Integrated and interdisciplinary
Grades averaged	Grades based on what was learned
Teacher is judge	Self, peer, and other assessments
Print is the primary vehicle of learning and assessment	Performance, projects, and multiple forms of media are used for learning and assessment
Factory model	Global model

Table 1: 20th century vs. 21st century classroom. (Source: "21st century schools" website.)

Schools in Canada

Canada is the second largest country in area in the world with a population of about 35 million people, and it is one of the world's five largest energy producers (ranked 3rd in the production of natural gas and 6th in electricity). In 2010, Canadians spent about $163 billion on energy (almost 11% of the country's gross domestic product) and consumed over 7,600 petajoules of energy, most of which was refined petroleum products (41%), followed by natural gas accounted for 31% and electricity (24%). The transportation sector consumed the most energy in 2010 (34%) followed by the combined residential and agricultural sectors (20%). Among its 10 provinces and three territories, Ontario, Alberta, and Quebec together consumed the most energy (74%) of the total energy demand in 2010. According to the International Energy Agency (IEA), the building sector is the second largest energy user in Canada. Commercial and institutional buildings comprise a noticeable portion of the building sector. The top three end uses in commercial and institutional buildings is space heating (51%), auxiliary equipment (14%), and lighting (9%) (OEE, 2007, 2010).

Based on the Survey of Commercial and Institutional Energy Use (SCIEU) in 2009, there are approximately 18,425 elementary and secondary schools in Canada with the overall average of 350 students per school. These schools, with more than 83 million square meter of floor area, consume over 64 petajoules of energy (peta=1015), which is less than one percent of the country's energy consumption. As shown in Table 2, on average, schools in Canada annually consume 214 kWh/m^2-yr (68 KBtu/Ft^2-Yr) which is very close to the 236 kWh/m^2-yr energy consumption of their US counterparts. However, due to the harsh weather conditions in some parts of the country, we may expect a higher energy use intensity in those regions. In general, Canada's climate varies wildly depending on geography. In winter, there is a large climate gap between its perma-frost top in the north and the southern four-season regions. In December, some places may receive eight hours of daylighting while some parts receive none. Table 3 presents ASHRAE climate zones for various regions in Canada.

Figures 2, 3, and 4 show the energy consumption type, number of floors, and the building sizes for schools in Canada. Natural gas is the main source of energy, and the majority of schools are a single story building between 10,000 and 50,000 square feet (930 to 4,650 sq.m).

Unit	Site EUI Mean	Site EUI Median
GJ/sq.m-yr	0.77	0.71
kwh/sq.m-yr	213.9	197.2
kbtu/sq.m-yr	67.80	62.52

Table 2: Canadian school energy use intensity.

Unit	Zone	Dominant Climate
Alberta (AB)	7	Very Cold
British Columbia (BC)	5	Cool
Manitoba (MB)	7	Very Cold
New Brunswick (NB)	6	Cold
Newfoundland (NF)	6	Cold
Northwest Territories (NW)	8	Subarctic
Nova Scotia (NS)	6	Cold
Nunavut	8	Subarctic
Ontario (ON)	6	Cold
Prince Edward (PE)	6	Cold
Quebec (PQ)	7	Very Cold
Saskatchewan (SK)	7	Very Cold
Yukon Territory (YT)	8	Subarctic

Table 3: Dominant climate conditions in Canada, ASHRAE Climate Zone Classification.

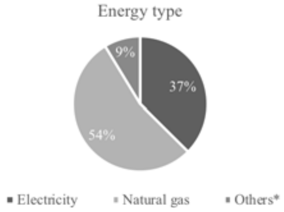

Figure 2: Canadian K-12 school's energy consumption type. (Source: SCIEU, 2009.)

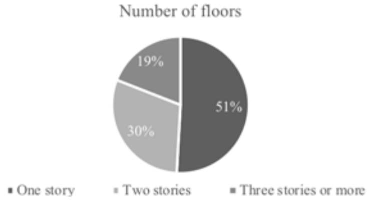

Figure 3: Canadian K-12 schools' number of floors. (Source: SCIEU, 2009.)

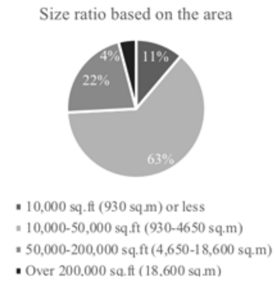

Figure 4: Canadian K-12 school sizes. (Source: SCIEU, 2009.)

Green Schools in Canada

The Canada Green Building Council (CaGBC) was formed in 2002–2003 as an expansion of the green building council in Canada and is the license holder for the LEED green building rating system in that region. According to the CaGBC, Canada has over 450 registered educational facilities for LEED certification (CaGBC, 2015). Filtering the data given in the Canada LEED Project Profile database resulted in over 225 registered K–12 schools (K-9 and high school), out of which nine have been awarded as LEED Certified, 25 as LEED Silver, 22 as LEED Gold, one as LEED Platinum, and the remainders are still under the process. This number of green schools is evidence of the green school movement in Canada. In 2013, CaGBC joined the Global Coalition for Green Schools and started the Canadian Coalition for Green Schools. The coalition comprises several initiatives including: Green Apple Day of Service, the Greenest School in Canada and on Earth competitions, and the CaGBC pilot project for K–12 schools in order to support communities in the transformation of their schools. A transformed school has benefits beyond just saving energy, resources, and money. According to the Green Building Council, green schools can result in 65% reduction in asthma cases among elementary students through improved indoor air quality, 20% faster progression in math, 26% faster progression in reading, 10% progression in overall student performance through proper daylighting, as well as a 3% reduction in teacher turnover.

David Suzuki Public School in Ontario is a LEED Platinum-Certified school, which is state-of-the-art among Canadian green schools. Another successful example of Canadian green schools is the LEED Gold-Certified Samuel Brighouse Elementary School in British Columbia. The main features of these two energy-efficient schools are described in the following parts.

DAVID SUZUKI PUBLIC SCHOOL

David Suzuki Public School in Windsor, Ontario, is the first certified LEED Platinum school in Canada, and can be regarded as the most notable energy-efficient school in the country. The 58,000 square feet (5,400 sq.m) building offers its services to around 500 students and benefits from the variety of green strategies including 71% energy savings, 47% indoor water saving, and 15% raw materials savings. Some of these effective strategies include:a 20 cubic meter rainwater cistern, low-flow water fixtures, a geothermal system, solar hot-water-heating panels, solar wall for intake, green roof, light wells, photovoltaic panels, wind turbines, and an air condition indicator in each classroom that shows when windows should be opened for natural ventilation. The school has a 38 kW grid-tied photovoltaic system funded by the Government of Ontario Green Schools Initiative that is able to generate up to 46,000 kWh of clean and renewable energy annually and limit the energy density of the building to 79 kWh/m²-yr. The building has been greatly successful in playing a teaching role to its occupants through the visibility of its green features. The PV system is affixed to a superstructure that forms a canopy over the main entry of the school and is highly visible as a symbol of the school's commitment to the environment. The rainwater harvesting system has a clear pipe in the hallway that shows rainwater being sent from the roof to the concrete cistern below ground. A classroom with the green roof has a visible rooftop solar sun tracker and the mechanical rooms have transparent walls so that students can see the geothermal technology. These visible strategies used in the school provide students with a first-hand view of how sustainability works.

SAMUEL BRIGHOUSE ELEMENTARY SCHOOL

Samuel Brighouse Elementary School is a two-story elementary school located in Richmond, British Columbia and accommodates about 500 students. The approximately 50,000 square-foot (4,777 square-meter) building, completed in 2011, includes classrooms, administration space, a library, community space, and a renovated gymnasium. These areas are designed in a way to reflect the goal of transparency, collaborative learning, and connecting to the nature and the community. The building benefits from a wide range of green strategies. By use of water management strategies, the consumption of potable water is reduced to almost half of the consumption of a similar building. It also consumes 57% less energy compared to a model building under MNECB (Canada National Energy Code for Buildings). Strategies like daylight harvesting, solar shading, natural ventilation, and the use of triple glazed windows, as well as a well-insulated envelope have lowered the building's energy consumption. The ground source geothermal system provides heating and cooling energy and solar collectors provide domestic hot water. The school building also has a green roof that directs run off to a constructed wetland and is oriented east-west to take advantage of passive strategies. The designed annual energy use intensity was between 60 and 70 kWh/m²-yr and it was built to LEED Gold certification standards.

Net-Zero Energy Schools

Numerous schools around the world have successfully accomplished sustainable goals. Today, the efforts taken in this area is moving one step forward to solve a former challenge of creating a net-zero energy (NZE) school facility. The rising number of such schools during the past five years proves the growing demands, the successful implications, and the buildability of such schools. A net-zero energy school should first comply green school design criteria then meet the net-zero energy concept. A NZE school is an energy-efficient facility which uses on-site renewable energy to offset its total energy consumption over the course of a year. The definition of a net-zero energy school does not set a maximum limit for the annual energy use intensity (EUI) of a school building, however, energy efficiency is necessary. As shown by the data published by the New Buildings Institute (NBI, 2014, 2018) and according to the current best practices in this area, this maximum limit for schools is usually placed somewhere between 20 to 30 KBtu/Ft²-yr, which varies from case to case based on their geographical location and climate zone.

The current sustainable design practices in the field of green schools have led to the design and construction of several net-zero energy ready K–12 schools in the US. These energy-efficient schools are either designed as net-zero capable schools that are waiting for funding to install solar panels in the future, or they have a very close performance to an energy neutral building and hence they are called net-zero ready schools (In Europe they are referred to as "near zero"). At the time of this study, no school has been announced to be net-zero energy in Canada. The two schools mentioned earlier (David Suzuki and Samuel Brighouse) can be considered as good examples of net-zero ready schools.

In the US, climate zone 4 has the greatest number of net-zero energy schools. There are several NZE schools in zone 5 but only a few examples are in zone 6. However, in Canada, only a small part (BC) is located in climate zone 5 and the vast area of the country is located in climate zones 6 and higher. To build a successful net-zero energy school project in most regions of Canada, there is a strong need to investigate strategies applicable for the cold climate zones. This study focuses on key drivers of energy efficiency used by a handful NZE schools located in US cold climate zones (zones 5 and 6). Applying these strategies will help Canadian K–12 school buildings to be one step closer to achieving NZE schools.

Strategies to be Adopted by Canadian Schools

In this section of the study, six schools that are designed to be net-zero energy and are constructed in the US are selected. These suitable examples are located in the coldest climate zones of the US and have taken various strategies to fight the dominant cold weather. The implemented strategies are outlined in Table 4.

School	Climate Zone	Photovoltaic	Optimized Orientation	Multi-Story Building	Natural Ventilation	Daylighting	Geo-exchange	Solar Thermal	High Performance Envelope	High Performance Lighting	High Performance HVAC	Automated Sensors
Putney School Field House	6	þ	þ		þ	þ	þ	þ	þ	þ	þ	þ
Sangre de Cristo	6		þ		þ	þ	þ		þ	þ	þ	þ
Evie Garrett Dennis	5	þ	þ	þ	þ	þ	þ		þ	þ	þ	þ
East Bay MET School	5	þ	þ	þ	þ	þ	þ	þ	þ	þ	þ	þ
New York P.S. 62	5	þ	þ	þ	þ	þ	þ	þ	þ	þ	þ	þ
Cambridge MA - MLK School	5	þ	þ	þ	þ	þ	þ		þ	þ	þ	þ

Table 4: Energy-efficiency strategies taken by outstanding US schools in cold climates.

The following tables present more information on each one of the schools shown in Table 4. These strategies are essential to reduce the energy consumption of the building to a level that can be offset by renewable energy sources. In most cases, the technical feasibility of building net zero is tied to the space limits for implementing renewable sources of energy (Hakim et al., 2018).

LEED Gold	
Year Completed	2011
Building Area	80,000 SF
EUI	22 KBtu/Ft²-yr
Construction Budget	$18,700,000
Cost per Sqft	$234
Students	400

Table 5: Sangre De Cristo K-12 School, Mosca, Colorado.

The main features for the Sangre De Cristo K–12 School are:

- Optimized East-West orientation
- Envelope design includes concrete masonry and metal panels, spray foam insulation to reduce air infiltration, and thermal bridging
- Horizontal GeoExchange field
- Demand control ventilation and energy recovery ventilators
- Each classroom has its own thermostat, lighting, and shade controls
- Electric lighting, mechanical system, and plug loads are connected to the building's automation system and can be viewed by teachers and students on a monitor in the lobby

LEED Platinum	
Year Completed	2015
Building Area	68,068 SF
EUI	33 KBtu/Ft²-yr
Construction Budget	$58,000,000
Cost per Sqft	$850
Students	444

Table 6: New York P.S. 62 School, Staten Island, New York.

The main features for the New York P.S. 62 School are:

- Ultra-insulated building envelope with R-23 precast concrete walls and 4'' rigid insulation between panels
- Optimized orientation
- Daylighting strategies such as dimmable skylight fixtures and occupancy sensors are designed
- High-efficiency HVAC system with GeoExchange system, energy recovery ventilation (ERV), and demand control ventilation
- Vegetable greenhouse garden and low energy kitchen equipment
- 2000 PV panels with rating 606kW will cover the roof and south facade of the building
- Solar thermal hot water system to serve domestic hot water (DHW) needs

East Bay Met School, Newport, Rhode Island	
Year Completed	2014
Building Area	20,400 SF
EUI	29 KBtu/Ft²-yr
Construction Budget	$8,800,000
Cost per Sqft	$318
Students	100

Table 7: East Bay Met School, Newport, Rhode Island.

The main features for the East Bay Met School are:

- Natural daylighting through optimized building orientation
- Super-insulated shell and airtight envelope
- LED lighting/daylighting control
- Cool roof (reflective roof)
- Innovative ventilation system
- 150kW photovoltaic system
- Geothermal heat pump
- Solar thermal storage tank
- Energy tracking with EPA portfolio manager

LEED Platinum	
Year Completed	2009
Building Area	16,800 SF
EUI	11 KBtu/Ft²-yr
Construction Budget	$6,000,000
Cost per Sqft	-

Table 8: Putney School Field House, Putney, Vermont.

The main features for the Putney School are:

- 36.8 kW sun-tracking photovoltaic cells produce over 50,000 kWh a year
- Super-insulated envelope (R-45 walls, R-60 roof)
- White reflective roof
- Sky lighting for approximately 40% of floor area
- Efficient interior and exterior lighting fixtures
- Occupancy and daylighting sensors, carbon dioxide sensors
- Efficient air-to-air heat pump system
- Heat recovery on building exhaust air
- Automatic natural ventilation (windows on automatic night time flushing)
- Triple insulated, low-e windows
- Controlled air infiltration and thermal bridging

Evie Garrett Dennis Campus, Denver, Colorado	
Year Completed	2010
Building Area	186,500
EUI	26 KBtu/Ft²-yr
Construction Budget	$42,700,000
Cost per Sqft	$189
Students	1278

Table 9: Evie Garrett Dennis Campus, Denver, Colorado.

The main features for the Evie Garrett Dennis are:

- Optimized East-West orientation for daylight harvesting
- Solar tubes, daylight sensors, and occupancy sensors are integrated
- Carbon-dioxide sensors and demand control ventilation
- 288kW of photovoltaic array
- GeoExchange mechanical system for energy recovery ventilators

LEED Platinum	
Year Completed	2015
Building Area	169,000 SF
EUI (expected)	30 KBtu/Ft²-yr
Construction Budget	$84,550,000
Cost per Sqft	$500
Students	740

Table 10: MLK School, Cambridge, Massachusetts.

The main features for the MLK School are:

- Automatic lighting dimmer system
- Daylight harvesting
- 100 geothermal wells, hybrid system
- Photovoltaic cells
- Energy-efficient plug loads
- Automatic equipment control
- Some cold food days (no heating equipment will be used)

Conclusions

The ever-growing environmental concerns has resulted in the appearance of the energy self-sufficiency movement. The rising number of net-zero energy schools around the world is a proof of this movement. In fact, this progress has been made possible through the advancement of technologies and techniques in capturing renewable energies and utilizing energy-efficient devices. Successful existing net-zero energy schools in the US, such as the Lady Bird Johnson Middle School, have increased the popularity of NZE schools and proved the potential of this concept to be adapted in a larger scale. In our perspective, school facilities are a very suitable starting point for a market shift towards net-zero energy targets. Among different building types, it is less complicated to achieve net-zero energy K–12 schools. NZE schools can significantly reduce energy costs during the life of the building. Meanwhile, they can play a fruitful role in teaching young students about energy-efficient strategies.

Canadian schools have shown noticeable improvement in reducing energy consumption over time. There are several successful LEED certified schools in Canada and a few of them can be considered as net-zero ready schools. Although the weather conditions in Canada make the achievement of the NZE status more difficult, the attainment of other zero energy building types in Canada can prove the buildability of NZE schools in the country. The energy-efficient strategies taken by selected outstanding US schools in its coldest parts should be incorporated in the early construction design phase of new schools in Canada. In this study, the availability of renewable energy sources, and the financial expenditures to implement energy-efficient strategies have not been discussed. Further studies should be undertaken to pave the way for successfully obtaining zero energy schools in Canada. The authors recommend more detailed research on integrating energy and economic policies for schools in Canada which can motivate many other building types to achieve net-zero energy status.

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