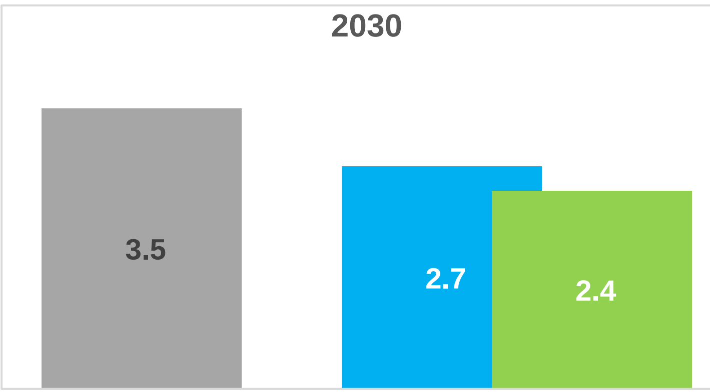
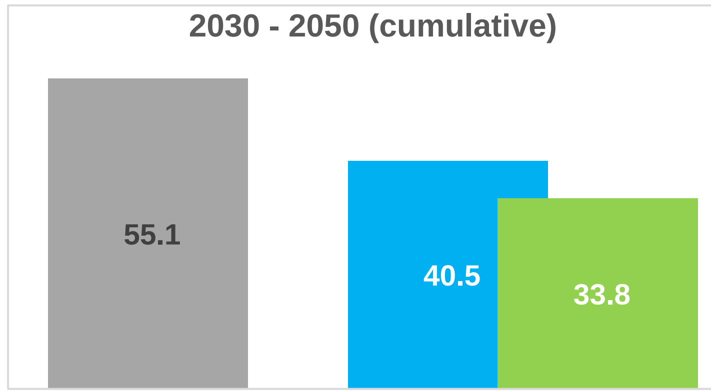
CASE STUDY – PRIMARY SCHOOL

- Primary school with 73,960 sf in 2 stories
- *Current Energy Code Design* reflects industry standards including:
    - Brick wall with steel frame backup wall
    - Central air handling units + hydronic BB, VAVs, packaged RTUs
    - Natural gas SHW
- *Optimized Design (NG)* scenario includes ERV on Central Air Handler, gas-fired heating system, fan coil units & natural gas SHW
- *Optimized Design (Elec)* scenario includes DOAS with ERV, variable refrigerant flow (VRF) heating and cooling system & natural gas SHW

EMISSIONS PERFORMANCE

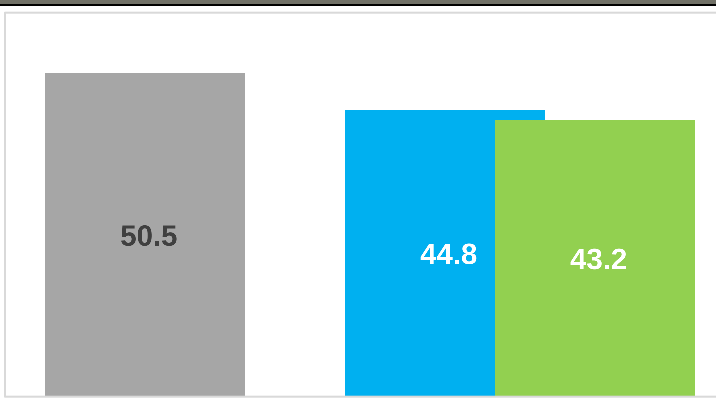
Operational Carbon Emissions (lbs.CO2e/sf)



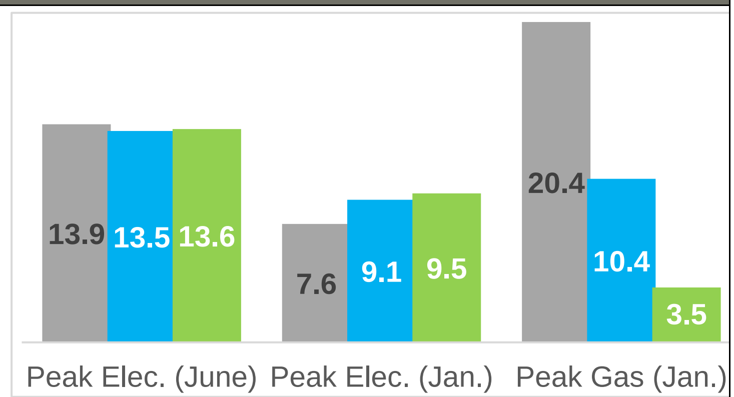


UTILITY IMPACTS

Site Energy Use Intensity (EUI, kBtu/sf)

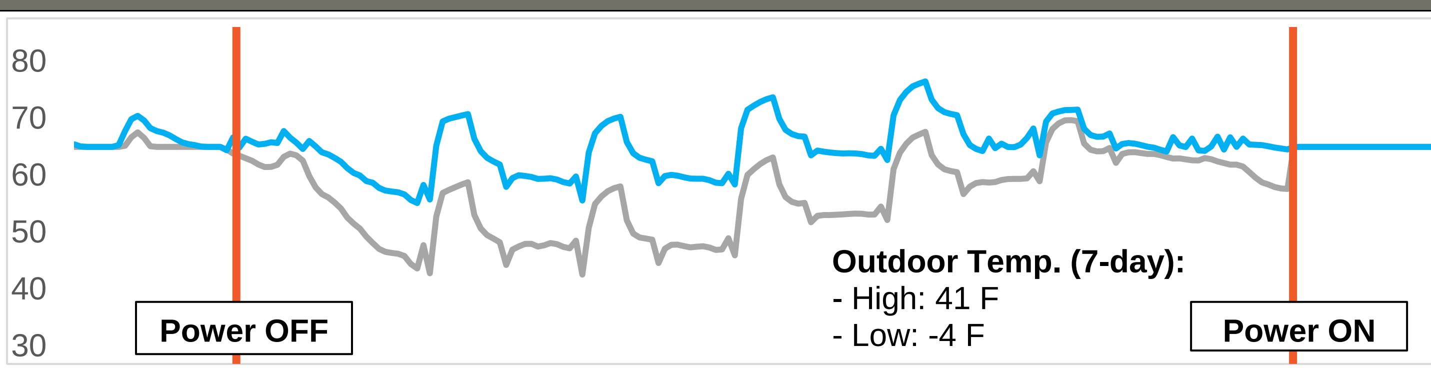


Building Peaks, Summer and Winter (Btu/hr/sf)



RESILIENCY IMPACTS

Indoor Temperature During Winter Power Outage (°F, 7 days in January)



LEGEND / FINANCIAL PERFORMANCE

Design Case	First Cost $/sf	First Cost % Change	50-year Lifecycle Cost $/sf	50-year Lifecycle Cost % Change
Current Energy Code (NG)	$486	n/a	$577	n/a
Optimized Design (NG)	$491	+1.0%	$569	-1.4%
Optimized Design (Elec.)	$499	+2.7%	$566	-1.9%

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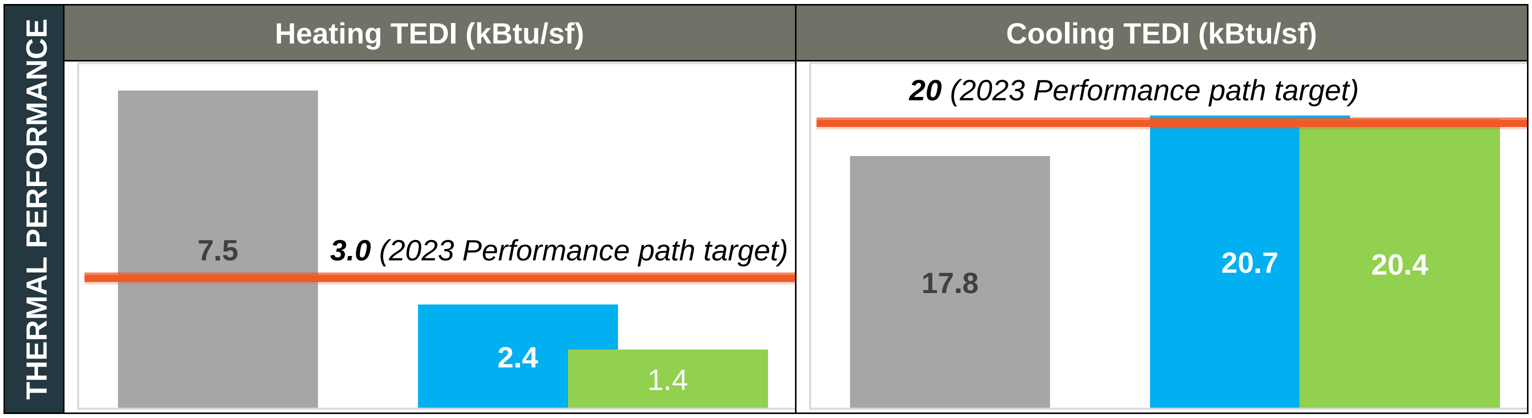
GOALS

TEDI (*Thermal Energy Demand Intensity):* represents annual **heating OR cooling load per gross floor area** of a building. Heating/cooling load is defined as amount of energy needed to meet thermostatic requirements of the space. The TEDI metric requires energy modeling and includes internal loads and anticipated building operation schedules. Outdoor air ERVs and other site energy recovered systems are included. Efficiency of active cooling & heating equipment is excluded (or assumed to be neutral at 1.0 COP) and resultant energy is represented as TEDI.



MAJOR TIPPING POINTS

Two primary building systems offered the greatest reduction in heating demand reduction for the Primary School prototype building:

Envelope System Performance: Heat loss in the envelope represents over 80% of total heating energy in the Primary School prototype. Significant heating load reduction can be achieved with three targeted performance improvements in the envelope system:

1. **Thermal bridge mitigation**: The thermal performance of the building envelope is improved through mitigation of common thermal bridges. The optimized U-factor for the Above-Grade Wall assembly is U-0.055 including thermal bridge accounting.
2. **Infiltration / Air leakage verification**: The effectiveness of the envelope system is improved through building envelope commissioning and testing to achieve more stringent air leakage maximum requirements.
3. **Window thermal performance**: improved thermal performance of windows reduces heating demand as well as increases thermal comfort of building occupants which results in more consistent thermostatic setpoints.

	Current Energy Code	Optimized Design
HEATING ENERGY (kBtu/sf/yr)	9.6 (NG)	3.2 (NG) 0.9 (Elec)
ABOVE-GRADE WALL	U-0.055 C406 15% performance improvement applied, de-rated for thermal bridges	U-0.055 with thermal bridge accounting and mitigation
WINDOW	Fixed Windows (65%): U-0.38 Operable Windows (35%): U-0.45 C406 15% performance improvement applied WWR 22%	Fixed Windows (65%): U-0.25 Operable Windows (35%): U-0.30 WWR 22%
INFILTRATION	1.0 cfm/sf (limited inspections, no testing)	0.40 cfm/sf (required inspections and testing)
VENTILATION	Air Handlers supply 100% OA with cooling demand, ERV with 50% efficiency	DOAS (Elec only) + ERV – 75% sensible efficiency

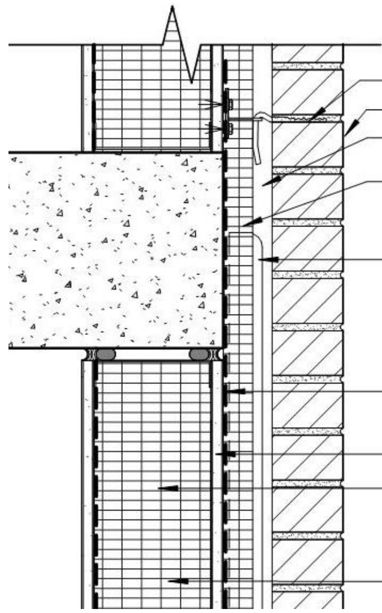
Ventilation & Heat Recovery: The ventilation system heating load represents 20% of the total heating energy in the Primary School Prototype, with potential greater impact if ventilation rates are increased due to health concerns. Dedicated Outdoor Air Systems (DOAS) with high rates of energy recovery significantly reduce the ventilation heating loads particularly in buildings with higher ventilation rates.

DEFINITIONS / REFERENCES / TECHNICAL NOTES

Current Energy Code Design: Corresponds to 9th edition of chapter 13 of 780 CMR with amendments effective from February 7,2020 & Stretch energy code as amended by Appendix AA. The base code for energy portions are based on 2018 International Energy Conservation Code.

Infiltration: The uncontrolled inward air leakage into a building caused by the pressure effects of wind or the effect of differences in the indoor and outdoor air density or both.

Thermal Bridge: elements that interrupt areas of uniform thermal resistance in the building envelope. Metal studs, brick ledges and window lintels, uninsulated slab edges, parapets, panel connections and girts, wall to floor intersections, curtain wall connections, wall to wall intersections, and balconies are all significant sources of thermal bridges. Mitigation includes thermal breaks and architectural details which minimize discontinuities. The *Building Envelope Thermal Bridging Guide* by BC Hydro[1] and the *Thermal Envelope Tool* by BC Housing[2] provide extensive resources related to thermal bridging and mitigation strategies.



Clear field thermal bridge: an area-based thermal transmittance associated with elements of a building envelope assembly which repeat at regular intervals. Examples of clear field thermal bridges include metal or wood studs, brick ties, and cladding attachments such as z-girts.

Linear thermal bridge: a length-based thermal transmittance associated with horizontal, vertical, or diagonal elements within the building envelope and with length measured along the exterior surface of the building envelope. Examples of linear thermal bridges include balconies or floor assemblies which penetrate walls in the building envelope, fenestration perimeter interfaces, parapets, and shelf angles. Linear thermal transmittance is heat flow divided by length and by the temperature difference between the interior and exterior sides of the assembly, represented by a Ψ-value (Psi-Value) in units Btu/hr•ft•°F (W/mK).

Point thermal bridge: an element-based thermal transmittance associated with a discrete element that penetrates the building envelope. Examples of point thermal bridges include a beam penetrating a wall, a column penetrating a roof or floor, and an anchor or connection used to attach an element to the building and not otherwise addressed as a clear field thermal bridge or linear thermal bridge. Point thermal transmittance is heat flow divided by the temperature difference between the interior and exterior side of the assembly, represented by a X-value (Chi-Value) in units Btu/hr•°F (W/K).

Building Envelope commissioning (BECx): process meant to provide quality assurance for building enclosure. Building envelope commissioning is required per IECC2021 energy code.

Blower door test: a test that is used to determine air leakage of a building/ section of a building. A blower door is a powerful fan that pressurizes a building. Typical blower tests are performed at pressure equivalencies of 50 Pascals. Standards such as ASHRAE use code minimum reference values at 75 Pascals(75PA).

DOAS- Dedicated Outdoor Air System: System dedicated to providing ventilation air needs for a building or space. DOAS units are equipped with handling latent & sensible loads of condition outside air and are independent from primary heating or cooling needs of the space.

Balanced ventilation: A balanced ventilation systems is designed to maintain a neutral pressure of the interior space with respect to outdoors. This system as opposed to supply only or exhaust only system is required to provide two streams of air into the space to balance supply and exhaust. This ensures a space is not infiltrating/ exfiltrating conditioned air to the outdoors.

[1] *https://www.bchydro.com/powersmart/business/programs/new-construction.html*
[2] *https://thermalenvelope.ca/*

BUILDING SYSTEMS (PRIMARY SCHOOL)

ENVELOPE SYSTEMS		CURRENT ENERGY CODE	OPTIMIZED DESIGN
Roof	*Type*	Flat, built-up roof, composite metal decking, insulated above deck	
	Insulation	R-40 nominal insulation* R-35 derated for thermal bridge accounting/mitigation	R-45 nominal insulation R-40 derated for thermal bridge accounting/mitigation
	Thermal bridging mitigation	None	Thermal isolation pads at mech dunnage & parapet structural thermal breaks
Exterior Wall	*Type*	Steel-framed wall, brick finish system	
	Insulation	R-19 cavity + R-8.4 c.i.*	R-19 cavity + R-21 c.i. U-0.055 (incl. thermal bridge accounting)
	Thermal bridging mitigation	None	Stand-off or thermally broken brick shelves, and thermal isolation pads Thermal isolation blocks at base brick courses
Slab on grade	*Type*, *Insulation*	6” concrete slab; R-10 for 24” vertical	
Window	*Type, WWR*	Metal-framed window, 22%	
	Assembly Max U-value	U-0.33 (fixed)* U-0.39 (operable) U-0.42 (skylights)	U-0.23 (fixed) U-0.28 (operable) U-0.20 (skylights)
	Thermal bridging mitigation	None	Thermal insulation pads at windowsills, jambs and head
Infiltration	*Flow requirement*	1.0 cfm/sf at 75Pa	0.40 cfm/sf at 75PA
	Other	No testing required	Testing and BECx required
Component performance alternative	Equation 4-2 compliance	Yes	Yes

**15% better performance required to meet C406.7*

MECHANICAL SYSTEMS		CURRENT ENERGY CODE	OPTIMIZED DESIGN	
			Gas	*Electric*
Ventilation	*Type*	Packaged rooftop units (RTU) + Variable air volume (VAV) AHUs		Dedicated outdoor air system (DOAS)
	Capacity (CFM)	59,000	55,000	37,000
	Energy Recovery	50% effectiveness	75% effectiveness	
Heating	*Plant/source*	Boiler		Variable refrigerant flow (VRF) system
	Capacity (kBTU/hr)	2,600	1,400	1,320
	Terminals	Baseboards		VRF fan coil units
Cooling	*Plant/source*	Direct expansion (DX)		DX + VRF system
	Capacity (ton)	196		58 (DX) + 110 (VRF)
	Terminals	VAV and CAV terminals		VRF fan coil units

PLUMBING	HOT WATER	SERVICE HOT WATER
Plant	Boiler	Natural gas SHW Heaters
Capacity (GPM)	*Current Energy Code*: 165 GPM *Optimized Design*: 90 GPM	5.84 GPM (peak) Consumption: 1.55 gal/occ-day + 578 gal/day (kitchen)
Pumping Type	Variable speed	Constant speed
Pump Power (W/GPM)	16.0 W/GPM	8.0 W/GPM

ELECTRICAL SYSTEM (ALL CASES)
Includes: lighting, plug loads, kitchen, elevators, HVAC and service hot water system
Peak electricity loads and the resulting transformer load is determined by the building’s cooling load and therefore is consistent across all building prototype scenarios
Total Transformer load: 300 kVA (x2)

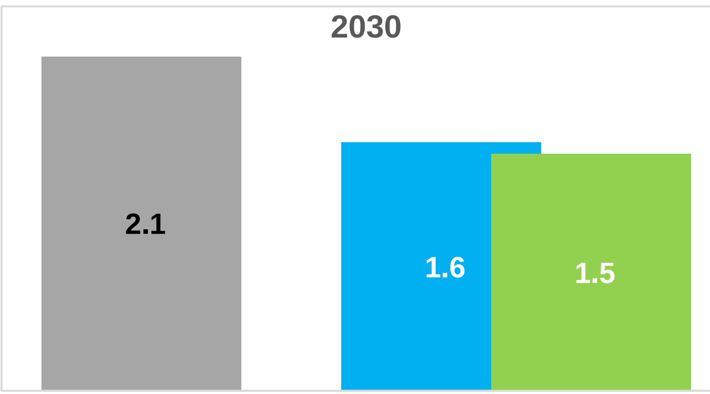
LIGHTING SYSTEM (ALL CASES)
All installed lighting (interior and exterior) systems are to meet the minimum requirements of installed lighting power densities (0.61 W/ft^2 building average) as required in Current Energy Code plus additional efficiency required per C406.3.

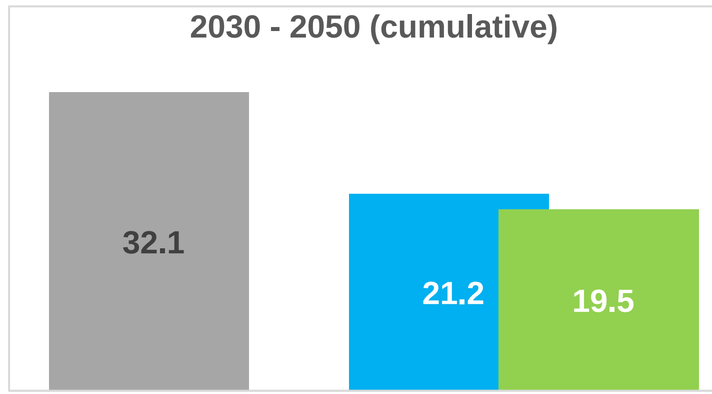
CASE STUDY – SECONDARY SCHOOL

- Secondary school with 328,000 sf in 4 stories
- *Current Energy Code Design* reflects industry standards including:
    - Brick veneer with steel frame backup wall
    - Central air handling units & hydronic BB, VAVs, packaged RTUs
    - Natural gas SHW
- *Optimized Design (NG)* scenario includes DOAS with ERV, gas-fired heating system, fan coil units & natural gas SHW
- *Optimized Design (Elec)* scenario includes DOAS with ERV, electric heat pump boiler system, fan coil units & natural gas SHW

EMISSIONS PERFORMANCE

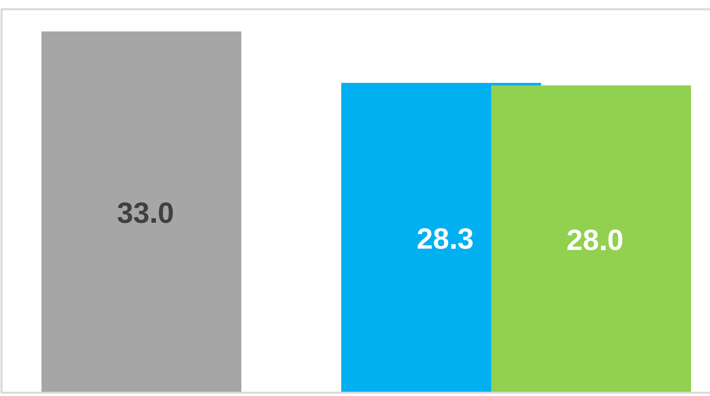
Operational Carbon Emissions (lbs.CO2e/sf)



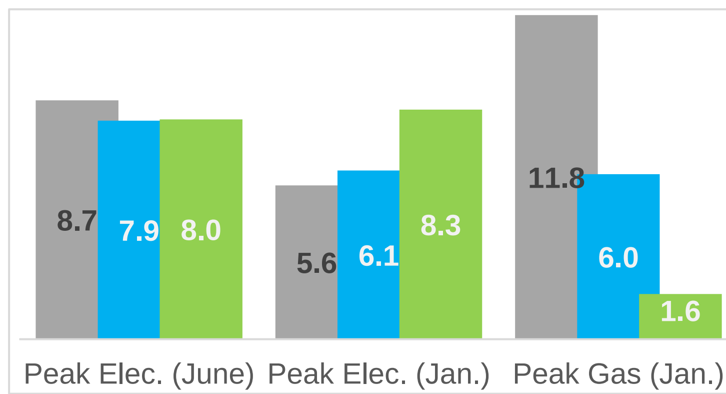


UTILITY IMPACTS

Site Energy Use Intensity (EUI, kBtu/sf)

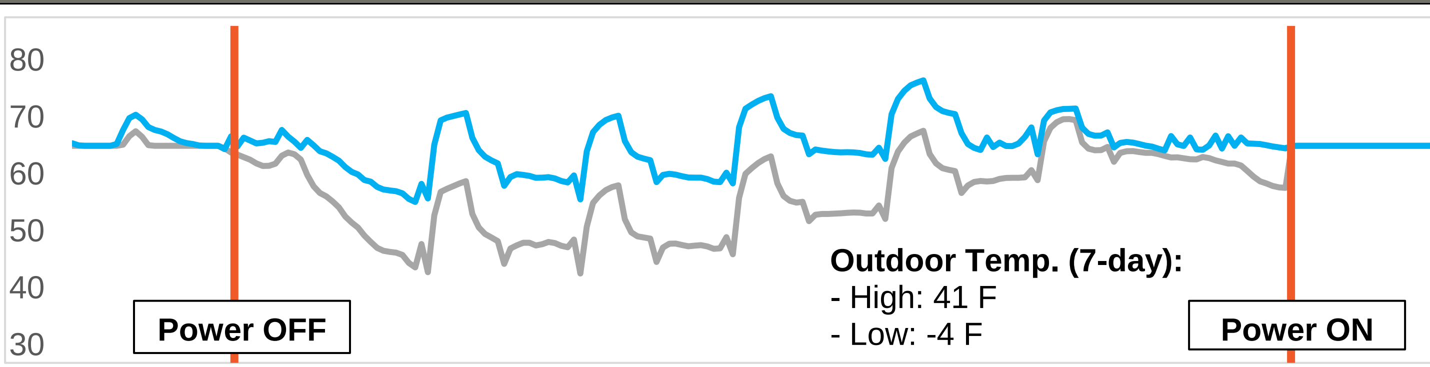


Building Peaks, Summer and Winter (Btu/hr/sf)



RESILIENCY IMPACTS

Indoor Temperature During Winter Power Outage (°F, 7 days in January)



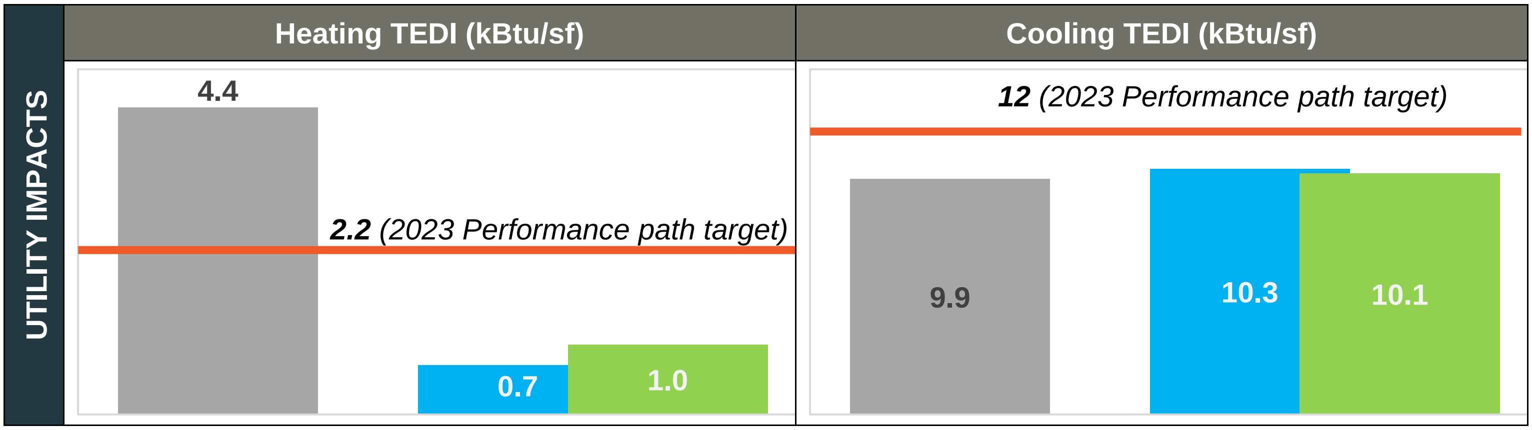
LEGEND / FINANCIAL PERFORMANCE

Design Case	First Cost $/sf	First Cost % Change	50-year Lifecycle Cost $/sf	50-year Lifecycle Cost % Change
Current Energy Code (NG)	$525	n/a	$599	n/a
Optimized Design (NG)	$526	+0.2%	$585	-2.3%
Optimized Design (Elec.)	$529	+0.8%	$584	-2.5%

**Prior to Mass. Save Incentive*

GOALS

TEDI (*Thermal Energy Demand Intensity):* represents annual **heating OR cooling load per gross floor area** of a building. Heating/cooling load is defined as amount of energy needed to meet thermostatic requirements of the space. The TEDI metric requires energy modeling and includes internal loads and anticipated building operation schedules. Outdoor air ERVs and other site energy recovered systems are included. Efficiency of active cooling & heating equipment is excluded (or assumed to be neutral at 1.0 COP) and resultant energy is represented as TEDI.



MAJOR TIPPING POINTS

Two primary building systems offered the greatest reduction in heating demand reduction for the Secondary School prototype building:

Envelope System Performance: Heat loss in the envelope represents 75% of total heating energy in the Secondary School prototype. Significant heating load reduction can be achieved with three targeted performance improvements in the envelope system:

1. **Thermal bridge mitigation**: The thermal performance of the building envelope is improved through mitigation of common thermal bridges. The optimized U-factor for the Above-Grade Wall assembly is U-0.055 including thermal bridge accounting.
2. **Infiltration / Air leakage verification**: The effectiveness of the envelope system is improved through building envelope commissioning and testing to achieve more stringent air leakage maximum requirements.
3. **Window thermal performance**: improved thermal performance of windows reduces heating demand as well as increases thermal comfort of building occupants which results in more consistent thermostatic setpoints.

	Current Energy Code	Optimized Design
HEATING ENERGY INTENSITY (kBtu/sf/yr)	5.5 (NG)	0.9 (NG) 0.6 (Elec)
ABOVE-GRADE WALL	U-0.055 C406 15% performance improvement applied, de-rated for thermal bridges	U-0.055 with thermal bridge accounting and mitigation
WINDOW	Fixed Windows (65%): U-0.38 Operable Windows (35%): U-0.45 C406 15% performance improvement applied WWR 22%	Fixed Windows (65%): U-0.25 Operable Windows (35%): U-0.30 WWR 22%
INFILTRATION	1.0 cfm/sf (limited inspections, no testing)	0.40 cfm/sf (required inspections and testing)
VENTILATION	Air Handlers supply 100% OA with heating / cooling demand, no energy recovery	DOAS + ERV – 75% sensible efficiency

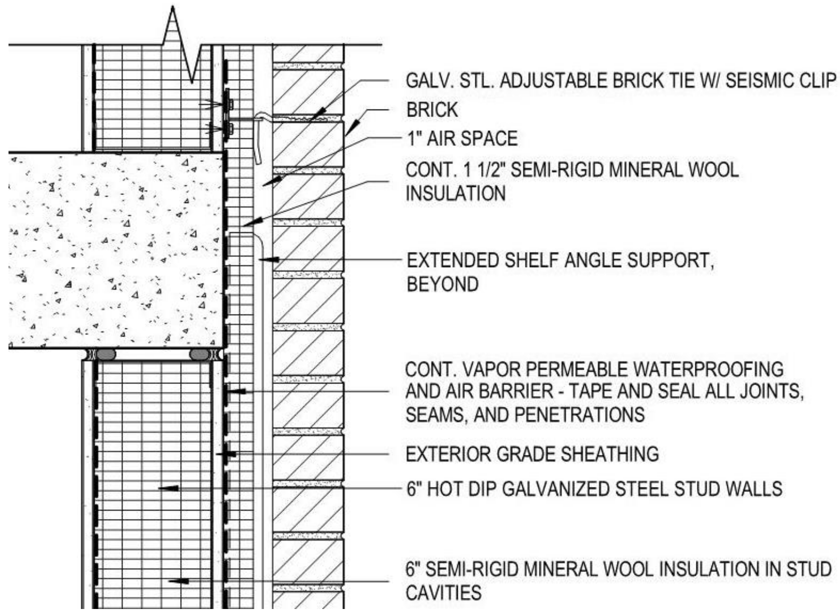
Ventilation & Heat Recovery: The ventilation system heating load represents 25% of the total heating energy in the Secondary School Prototype, with potential greater impact if ventilation rates are increased due to health concerns. Dedicated Outdoor Air Systems (DOAS) with high rates of energy recovery significantly reduce the ventilation heating loads particularly in buildings with higher ventilation rates.

DEFINITIONS / REFERENCES / TECHNICAL NOTES

Current Energy Code Design: Reflects industry standard design which achieves 10% site energy savings over ASHRAE 90.1 2013 Appendix G and MA Amendments as required by the 9th edition of chapter 13 of 780 CMR with amendments effective from February 7,2020 & Stretch energy code as amended by Appendix AA.

Infiltration: The uncontrolled inward air leakage into a building caused by the pressure effects of wind or the effect of differences in the indoor and outdoor air density or both

Thermal Bridge: elements that interrupt areas of uniform thermal resistance in the building envelope. Metal studs, brick ledges and window lintels, uninsulated slab edges, parapets, panel connections and girts, wall to floor intersections, curtain wall connections, wall to wall intersections, and balconies are all significant sources of thermal bridges. Mitigation includes thermal breaks and architectural details which minimize discontinuities. The *Building Envelope Thermal Bridging Guide* by BC Hydro[1] and the *Thermal Envelope Tool* by BC Housing[2] provide extensive resources related to thermal bridging and mitigation strategies.



Clear field thermal bridge: an area-based thermal transmittance associated with elements of a building envelope assembly which repeat at regular intervals. Examples of clear field thermal bridges include metal or wood studs, brick ties, and cladding attachments such as z-girts.

Linear thermal bridge: a length-based thermal transmittance associated with horizontal, vertical, or diagonal elements within the building envelope and with length measured along the exterior surface of the building envelope. Examples of linear thermal bridges include balconies or floor assemblies which penetrate walls in the building envelope, fenestration perimeter interfaces, parapets, and shelf angles. Linear thermal transmittance is heat flow divided by length and by the temperature difference between the interior and exterior sides of the assembly, represented by a Ψ-value (Psi-Value) in units Btu/hr•ft•°F (W/mK).

Point thermal bridge: an element-based thermal transmittance associated with a discrete element that penetrates the building envelope. Examples of point thermal bridges include a beam penetrating a wall, a column penetrating a roof or floor, and an anchor or connection used to attach an element to the building and not otherwise addressed as a clear field thermal bridge or linear thermal bridge. Point thermal transmittance is heat flow divided by the temperature difference between the interior and exterior side of the assembly, represented by a Χ-value (Chi-Value) in units Btu/hr•°F (W/K).

Building Envelope commissioning (BECx): process meant to provide quality assurance for building enclosure. Building envelope commissioning is required per IECC2021 energy code.

Blower door test: a test that is used to determine air leakage of a building/ section of a building. A blower door is a powerful fan that pressurizes a building. Typical blower tests are performed at pressure equivalencies of 50 Pascals. Standards such as ASHRAE use code minimum reference values at 75 Pascals(75PA).

DOAS- Dedicated Outdoor Air System: System dedicated to providing ventilation air needs for a building or space. DOAS units are equipped with handling latent & sensible loads of condition outside air and are independent from primary heating or cooling needs of the space.

Balanced ventilation: A balanced ventilation systems is designed to maintain a neutral pressure of the interior space with respect to outdoors. This system as opposed to supply only or exhaust only system is required to provide two streams of air into the space to balance supply and exhaust. This ensures a space is not infiltrating/ exfiltrating conditioned air to the outdoors.

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[1] *https://www.bchydro.com/powersmart/business/programs/new-construction.html*
[2] *https://thermalenvelope.ca/*

BUILDING SYSTEMS (SECONDARY SCHOOL)

ENVELOPE SYSTEMS		CURRENT ENERGY CODE	OPTIMIZED DESIGN
Roof	*Type*	Flat, built-up roof, composite metal decking, insulated above deck	
	Insulation	R-40 nominal insulation* R-35 derated for thermal bridge accounting/mitigation	R-45 nominal insulation R-40 derated for thermal bridge accounting/mitigation
	Thermal bridging mitigation	None	Thermal isolation pads at mech dunnage & parapet structural thermal breaks
Exterior Wall	*Type*	Steel-framed wall, brick finish system	
	Insulation	R-19 cavity + R-8.4 c.i.*	R-19 cavity + R-21 c.i. U-0.055 (incl. thermal bridge accounting)
	Thermal bridging mitigation	None	Stand off or thermally broken brick shelves, and thermal isolation pads Thermal isolation blocks at base brick courses
Slab on grade	*Type**,** Insulation*	6” concrete slab; R-10 for 24” vertical	
Window	*Type, WWR*	Metal-framed window, 22%	
	Assembly Max U-value	U-0.32 (fixed)* U-0.38 (operable) U-0.38 (skylights)	U-0.23 (fixed) U-0.28 (operable) U-0.20 (skylights)
	Thermal bridging mitigation	None	Thermal insulation pads at windowsills, jambs and head
Infiltration	*Flow requirement*	1.0 cfm/sf at 75Pa	0.40 cfm/sf at 75PA
	Other	No testing required	Testing and BECx required
Component performance alternative	Equation 4-2 compliance	Yes	Yes

15% better performance required to meet C406.7

MECHANICAL SYSTEMS		CURRENT ENERGY CODE	OPTIMIZED DESIGN	
			Gas	*Electric*
Ventilation	*Type*	Air handling units	Dedicated outdoor air system (DOAS)	
		Auditorium, gym, cafeteria - Packaged rooftop units (RTU)		
	Capacity (CFM)	86,500	68,500	
	Energy Recovery	50% effectiveness	75% effectiveness	
Heating	*Plant/source*	Boiler (gas, mid efficiency)	Boiler (gas, condensing)	Boiler (heat pump)
	Capacity (kBTU/hr)	4,500	3,600	3,300
	Terminals	Variable air volume (VAV) + Baseboards	Fan coil units (FCU)	
Cooling	*Plant/source*	Chiller (water cooled) + Direct expansion (RTUs)		
	Capacity (ton)	600 (chiller) + 93 (DX)		
	Terminals	VAVs	Fan coil units, constant air volume (CAV) terminals	

PLUMBING	HOT WATER	CHILLED WATER	SERVICE HW
Plant	Boilers	Chillers	Natural gas SHW Heaters
Capacity (GPM)	*Current Energy Code*: 400 *Optimized Design*: 330	*Current Energy Code*: 655 *Optimized Design*: 970	All cases: 31 (peak)
Pumping Type	Variable speed	Constant speed (primary), Variable speed (secondary)	Constant speed
Pump Power (W/GPM)	16.0 W/GPM	19.0 (primary) 22.0 (secondary)	8.0 W/GPM

ELECTRICAL SYSTEM (ALL CASES)
Includes: lighting, plug loads, kitchen, elevators, HVAC and service hot water system
Peak electricity loads and the resulting transformer load is determined by the building’s cooling load and therefore is consistent across all building prototype scenarios
Total Transformer load: 300 kVA (x2)

LIGHTING SYSTEM (ALL CASES)
All installed lighting (interior and exterior) systems are to meet the minimum requirements of installed lighting power densities (0.61 W/ft^2 building average) as required in Current Energy Code plus additional efficiency required per C406.3.