Lessons Learned from Laboratory-Specific Optimization Technologies for an Existing Campus and a New Facility with a Conserved Heritage Façade

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Abstract

The Canadian government is targeting a carbon neutral portfolio of owned and leased buildings by 2050. Net zero carbon includes additional challenges for laboratories so the methodology for existing and new laboratories high performance designs are emphasized through two case studies:

1. Existing research campus
2. New construction with a conserved heritage façade

Some of the key findings of the paper are: humidification is frequently a high enduse (12%-19%); receptacle equipment is typically the second highest enduse after heating when there is a data centre; the investment needed for the improvement of existing wall thermal resistance, may be too cost intensive for the resultant energy and carbon reduction; full calibration of an energy model may not be appropriate considering the irregularity of scientific research; and cascading return air from offices to laboratories can reduce outdoor air demands and saves 2.6% energy relative to the baseline.

Introduction

A 40% reduction in GHG emissions below 2005 levels by 2025, and a carbon neutral portfolio of owned and leased buildings by 2050 is being targeted by the Canadian government (Treasury Board of Canada Secretariat, 2021). Laboratories have additional design challenges to achieve carbon neutrality or zero carbon ready operations. These challenges include meeting operational requirements such as varied schedules for scientific research, higher maximum and minimum ventilation rates, strict temperature and humidity requirements, and high process load energy demand and heat gains (Charneux, 2012; ASHRAE, 2011; McIntosh, 2001; Wirozek, 2000; University of California, 2007).

Benchmarking is frequently applied in management and design of laboratory facilities to identify an appropriate design performance range. The International Institute for Sustainable Laboratories (I2SL) maintains a North American database of energy information for existing laboratory facilities as well as new facilities in design. Generally, laboratory facilities vary widely in their energy consumption but are typically much higher in energy use than other building types (office, warehouse, residential, recreation, etc.). This higher energy use is for the most part attributed to energy supplied to laboratory processes (coolers, furnaces, motors etc.) and ventilation heating and cooling for the high number of air changes required for laboratory spaces. The I2SL average from the North American data set is 962 kWh/m^2-yr (I2SL, 2022). A few examples of high-performance zero-energy or close to zero-energy laboratories are: the Natural Resources Canada, CANMET Materials Testing Laboratory in Hamilton, ON, Canada (AIA, 2022); Bristol College, John J. Sbrega Health and Science Building in Fall River, MA, USA (Widzinski & Crowell, 2018); California Air Resources Board (CARB) in Riverside, CA, USA (Hickman, 2022); and Georgia Tech University, Carbon-Neutral Energy Solutions Laboratory (CNES) in Atlanta, GA, USA (TRIATEK, 2022) which have EUIs of 100 to 300 kWh/m^2-yr. Once this EUI range is attained, it becomes easier to meet ambitions net-zero carbon targets with a financially appealing return. This paper presents two case studies of low carbon laboratory designs for a retrofit to an existing research campus and a new facility that includes the conservation of a heritage façade. The focus is on the calibration of the existing campus to utility data, and energy efficiency measures that are appropriate for existing or new laboratories.

Existing Research Campus

Background Info

This is a case study of an existing campus of research laboratory facilities consisting of approximately 20 buildings located in Ontario, Canada. The total floor area is 25,000 m^2 with individual buildings having floor areas ranging from 12 m^2 to 4,046 m^2. The laboratory buildings consist mainly of energy research including renewable systems, pilot plants, biomass, diesel, coal, and coke. The main buildings were built in 1968, while there are several semi-permanent trailers added for additional office space. The older buildings are under review for heritage designation, which is an additional factor to consider for potential retrofit decisions. The objective of the study is to determine four retrofit options following the Project GHG Options Analysis Methodology (PSPC, 2020), each with a different focus: Option 1) 24% better than NECB 2017; Option 2) cost neutral and low carbon over 40 years; Option 3) carbon neutral over 40 years; Option 4) hybrid option that is best for Canada which maximizes carbon reductions while achieving a slightly negative NPV.

Methods

The methods used for this study are outlined below:

- Review existing documentation of buildings (building condition reports, previous energy audits, utility data, etc.).
- Conduct a detailed site survey and energy audit for all buildings (3.5 days of site visits).
- Utilize an integrated design approach with many interdisciplinary meetings and workshops with clients and stakeholders.
- Create preliminary energy models with detailed information from site surveys using a combination of IES VE and eQuest (which are both software that have been validated by ASHRAE-140 (ASHRAE, 2020)) (Figure 1). Two of the main buildings with larger loads were modelled in IES VE to calibrate the individual buildings to the submeters that were available. Submeter information was also used to understand the process load schedules. The remaining buildings were modelled in eQuest for ease of simulating many buildings in one energy model file. The results of each model were post-processed in MS Excel.
- Calibration of the models following ASHRAE Guideline-14 (ASHRAE, 2014) as best as possible (CV(RMSE) < +/-15%, NMBE < +/-5%). The baseline model was created from the calibrated model, but with updated airflows to meet ventilation requirements. The method of manual calibration was between a level 2 and level 4 calibration based on the data used which included: monthly utility bills, hourly electrical submetered data, energy audits, site surveys to verify envelope conditions and HVAC equipment nameplates/performance, an operations manager interview, and a questionnaire for the scientists to give detailed information on the process loads (Dimitri Guyot, 2020).
- Formulate individual energy conservation measures (ECMs) analysis and life cycle costing. Bundle ECMs as appropriate for option 1-3. Create a hybrid Option 4 that is the optimal solution for the project objectives.

The life cycle costing was completed by calculating the net-present value of the bundle of ECMs. Capital, carbon, energy, maintenance, replacement, and residual costs were determined on an individual ECM basis, and then the total net present values (NPVs) of the options were calculated. The equations (1) to (4) used for the NPV calculations are presented below.

$$NPV = \text{Capital Cost} + PV_{Energy} + PV_{Maintenance} + PV_{Carbon} + PV_{Replacement\ Cost} - \text{Residual Value} \quad (1)$$

$$PV_x = \sum_{k=0}^{n} \frac{Annual\ Value_k}{(1+Discount\ Rate)^k} \quad (2)$$

$$\text{Annual Value}_k = \text{Current Annual Cost x } (1+ \text{Escalation Rate})^k \quad (3)$$

$$\text{Residual Value} = \text{Capital Cost x } ((\text{EUL} - \text{Equipment Age})/\text{EUL}) \quad (4)$$

The shadow cost of carbon used was \$300/tonnes $CO_{2\text{-eq}}$, which is the cost to society as a result of the environmental damage associated with carbon emissions determined by the government of Canada. The assumptions for the life cycle cost escalation and discount rates are: 0% carbon escalation, 2.00% energy escalation, 1.90% long term construction cost escalation, 1.90% O&M escalation, 1.9% discount rate. The lifecycle costing was conducted using a 40-year analysis period. The capital costs are class D estimates at the 2020 price levels and include all presently foreseen costs, such as the materials and labour, commissioning, and design. Construction contingency and all tenant fit-up costs related to any required relocation of staff is not included.

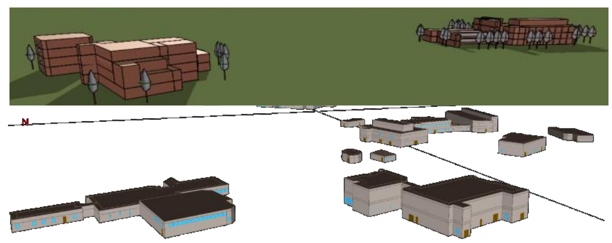

Figure 1: Campus IES VE model (top) and eQuest model (bottom).

Baseline Campus Model Information

The existing buildings have roof R-values ranging from 0.1-5.8 m^2-K/W, wall R-values of 0.14-3.35 m^2-K/W, window R-values of 0.26-0.43 m^2-K/W, basement walls R-values of 0.12-3.0 m^2-K/W, and slab on grade R-values of 0.05-0.18 m^2-K/W. The lighting is primarily fluorescent and HID interior application luminaires (T12 and T8) with an average lighting power density of 9.7 W/m^2. There are occupancy sensors in most office wings and trailers, and no daylight sensors. Regular receptacle loads are based on NECB 2017 default values (Office: 7.5 W/m^2, Laboratory: 10 W/m^2) and high science process-plug loads are estimated from the questionnaires and previous emissions study. Service hot water (SHW) throughout the campus is typically met either using natural gas-fired domestic water heaters or through the use of electric hot water tanks.

Space cooling is provided to most laboratories and offices through air-cooled chillers or smaller packaged terminal air conditioning (AC) units/heat pumps. Process spaces, including the pilot plant (small-scale energy plant that is used for research) in building 1 and the coal plant in building 2 are not cooled. Constant speed pumps are assumed for the primary/secondary chilled water loop. There are no heat rejection devices. The assumed efficiencies for DX cooling and air-cooled chillers are 3.5 COP and 2.8 COP, respectively.

The central heating plant (CHP) is manually operated and consists of three boilers (two boilers at 3.4 MW each and one boiler at 2.8 MW which is used as a main boiler during lower power demand periods). The hot water temperature is 93-104ºC for shoulder seasons and 121ºC (max 149ºC) for the winter. The secondary source of heating for some buildings comes from small gas fired reheat boilers, since some laboratories require precise control of humidity levels and will need reheat during the dehumidification process. Chilled water is used for dehumidification which overcools the air and then must be reheated. The fuel type is primarily natural gas.

Calibration of Campus Model

A manual iterative calibration process was used since many details of the buildings were known. The calibration strategies used to address uncertainty are described as follows. IES VE allows for auto-sizing HVAC components after having all other inputs to the energy model and calculating the heating and cooling loads of the rooms and systems. Fan power and supply airflows were auto-sized after inputting information from the building automation system (BAS) set points, as well as the as-built drawings, and building operator interview details. Where the values indicated by the previous studies were accurate, they were used during calibration, such as the Building Energy Audit, the Building Condition Report, and the Standard Operating Procedures. Most air handling units (AHUs) are makeup air units (MAUs) with 100% outside air capacity and they contribute to the majority of the energy consumption. The other AHUs are mixed air units, where the outdoor air (OA) has been sized based on a minimum OA damper position of 10%. An iterative process was used to determine the correct infiltration rate. The base assumption was to start with the NECB 2017 code minimum of 0.25 L/s.m^2 of exterior exposed surface area (National Research Council Canada, 2017). All other known parameters were added. Only then was the infiltration increased gradually to account for building age and excessive amount of fresh air intakes within the building to accommodate the laboratory spaces MAUs, which can increase the infiltration within the building. The final utilized infiltration was 0.30 L/s.m^2.

The process load equipment was estimated from two main sources, a Process Load Questionnaire in addition to a previously existing study that quantified average process load schedules and demand for some of the major equipment. However, there was missing information which had to be approximated based on conversations with scientists working in the laboratories. The initial simulations showed that that the peak demand was almost double the utility data's peak demand, even though the electrical energy consumption was quite close to the campus utility data. This indicated that the initial simulations had too many coincident peaks of process loads. The approach was to then distribute the demand to even out the peak, and extend the hours the process equipment to reduce the peak electrical demand that remained within the range of variation described by the users of the science process equipment, while maintaining the total electrical energy consumption.

The final baseline energy model did not meet the ASHRAE Guideline 14 tolerances, but it came close at 0% NMBE and 17% CV(RMSE) values (Figure 2, Table 2). This was determined as the most appropriate calibrated model, since the variation in loads from the model to the utility data was mostly attributed to irregular science process loads. Therefore, it would not be practical to calibrate the model more closely to the utility data.

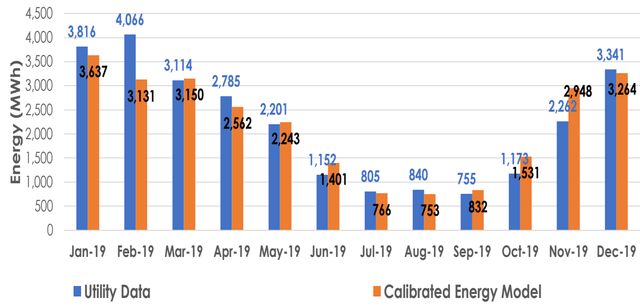

Figure 2: Total energy consumption for utility data and baseline energy model

Options Results

Over 42 different ECMs were modelled individually to determine energy, carbon and utility cost savings. The energy, GHG and utility savings relative to the existing campus are presented in Table 1, Figure 3, Figure 4, and Figure 5.

Option 1, the minimal intervention option, included the following ECMs: R-40 roof, R-3 windows, R-23 walls for office trailers, R-8 for large overhang doors, air sealing to achieve 0.25 L/s-m^2 air leakage, daylight and occupancy sensors and controls, re-lamping to LEDs, optimize laboratory ventilation and air change rates, right-sizing office AHUs with 85% efficient ERV, like-for-like replacement of laboratory MAUs with 40% efficient runaround coils, best in class water-cooled chillers and fluid coolers (COP 6.5), natural gas condensing boilers in select buildings and at the central heating plant. They also included temperature setbacks, outside air schedule strategies (ramp down OA from 24-hours to 12-hour operation, 25% of labs remain at 24-hour operation), and demand-controlled ventilation (DCV) in offices. Option 1 achieves 36% energy savings relative to the NECB 2017 baseline and Option 4 saves 72% energy relative to the existing campus baseline.

Option 2 ECMs have a small improvement over Option 1 to improve the benefits of the capital investment, while achieving an overall neutral NPV over 40 years. Option 2's upgraded ECMs include: improving windows to R-5.6, new decoupled ventilation system of dedicated outdoor air system (DOAS) with energy recovery ventilators (ERVs) for offices and runaround coils for labs, replacing the distributed heating and cooling plants with centralized heat recovery chillers, and electrifying humidification and domestic hot water (DHW). Option 2 maintains the same ECMs as Option 1 for the roof, trailer walls, overhead doors, lighting, laboratory ventilation rates, condensing boilers, temperature setbacks and scheduling, and DCV.

Option 3 aimed at maximizing carbon emission reductions without limitations on capital costs and NPV. Option 3 saved 92% energy relative to the existing campus with the following upgraded ECMs of: R-23 walls for all campus buildings, complete LED retrofit including fixtures, new VAV fume hoods and right-size exhaust equipped with occupancy sensors, controls, alarms, and night setback, DOAS with active chilled beams for offices with ERV, replace existing plants with a centralized ground source heat pump heat recovery chiller with a supplementary electric boiler, water cooled chiller for summer operation, ground PVs and wind turbines with battery storage. Option 3 ECMs that were carried over from Options 1 were: roof, overhead doors, daylight and occupancy sensors and controls, laboratory ventilation rates, temperature setbacks, scheduling of OA, and DCV. Option 3 ECMs that were carried over from Options 2 were: windows, humidification, and DHW.

Table 1: Summary of energy, GHG, and utility cost savings relative to existing campus.

Metric Evaluation	Option 1: 24% Better than NECB 2017	Option 2: Cost Neutral	Option 3: Carbon Neutral	Option 4: Best Value
Tonnes of GHG savings/year	1,747	2,532	3,740	3,478
GHG Emissions (tonnes CO_2-eq)/year	2,082	1,297	89	351
% Greenhouse Gas Savings	46%	66%	98%	91%
kWh/m²/year Energy Savings	486	677	1,034	811
Net-Energy Use (kWh/m²/year)	641	450	93	316
% Energy Savings	43%	60%	92%	72%
% Utility Cost Savings	37%	48%	86%	35%

Option 4 ECMs were the same as Option 3 except for the renewable energy; Option 4 only had roof PVs on major buildings for a total area of 2,426 m² (inclination: 10°; cell temperature: 35°C; efficiency: 18%; 0.45m spacing between PV rows).

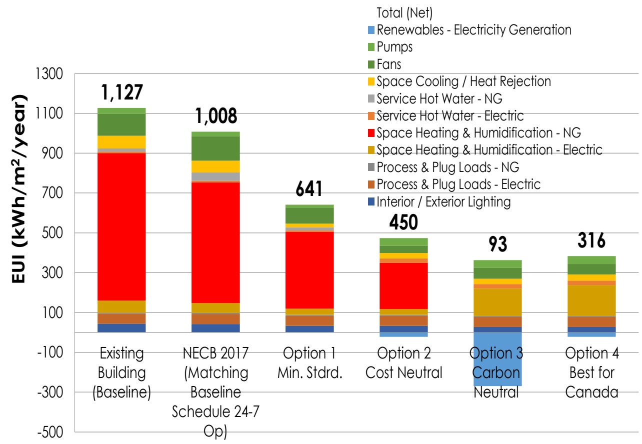

Figure 3: EUI comparison of options by end use

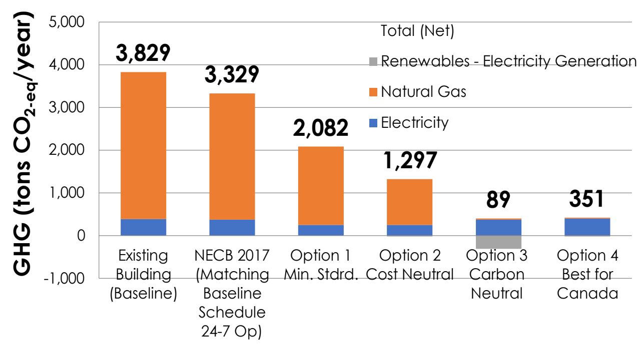

Figure 4: Operational carbon emissions of options by fuel source

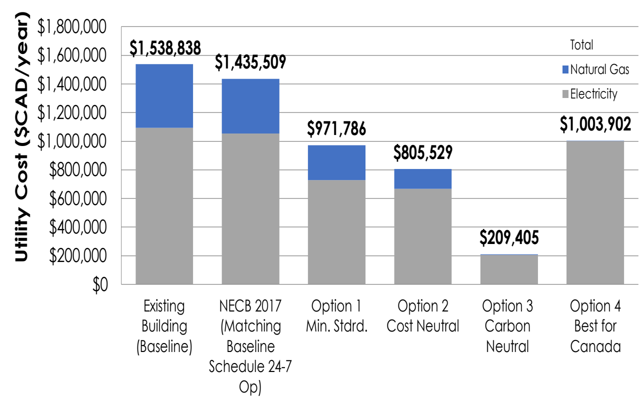

Figure 5: Utility cost comparison of options

The NPV relative to Option 1 for Options 2-4 are presented in and Table 3.

The present value of Option 1, the minimum departmental standard is the basis from which the NPV of all other options are compared against. The preferred hybrid Option

4 has an NPV of -$19.1M over 40 years, relative to Option 1.

The energy results show that although Option 4 is not quite a net-zero energy building, it has improved over Option 2 and Option 1. The energy savings over the baseline amount to 72%. In comparison to the baseline, the space heating energy, one of the originally largest end uses, has been reduced by 81% in Option 4. Most other end uses have been reduced dramatically. When excluding the energy offsets due to the renewables, the EUI of Option 4 is 384 kWh/m^2/year, which is far lower than the I2SL Average Benchmark for existing laboratories of 962 kWh/m^2/year.

New Laboratory with Conserved Heritage Façade

Background Info

This case study is about the design of a new laboratory facility in New Brunswick, Canada, which is in ASHRAE climate zone 6. The building will be constructed on a site with a heritage building that cannot be conserved in its entirety. Therefore, the main façade of the heritage building will be conserved, while also aiming for ambitious zero carbon or zero carbon ready targets including: LEED Platinum, less than 40 kWh/m^2 TEDI, 100% GHG emissions reductions, and net-zero energy.

Figure 6: IES VE model of the new laboratory design (aerial view)

Methods

Our strategy to develop the building design was to:

- Focus first on passive strategies;
- Incorporate high performance active strategies; and
- Use energy modelling to inform design.

The methods for this energy modelling study are outlined below:

- Conduct an integrated design process including many multi-disciplinary meetings with mechanical engineers, senior sustainability consultants, architects, and electrical engineers.
- Coordinate detailed energy model inputs including HVAC inputs (equipment capacities, fan powers, airflows, schedules, pump powers, etc.), review mechanical thermal loads of the building, coordinate with architectural for envelope design and daylighting strategies, IT data center equipment plug loads, and more.
- Organize several workshops with the client and science stakeholders to determine strategies that were practical for the project and ensure all project information is accurate.
- Create a detailed energy model of the schematic design in IES VE (Figure 6). Trouble shoot the model by looking at HVAC component results, unmet hours, and mechanical loads to ensure everything is operating as it should according to the design. Update the energy model as the designs changed.
- Energy model and results peer review by a senior building performance engineer/senior energy modeller.
- Model individual energy concervation measures (ECMs) for different passive and active strategies.
- The building is assumed to be fully electrified because electricity purchased for this building is aimed to be net zero carbon starting in 2025. The current carbon emissions of the New Brunswick grid of 300 g CO2-eq/kWh from the National Inventory Report 1990-2018: Greenhouse Gas Sources and Sinks in Canada were used in the analysis (Environment and Climate Change Canada, 2018).
- The baseline design model was created using inputs from a previous feasiblity study

The baseline design model inputs for envelope and internal gains are presented in Table 4. The baseline energy model HVAC systems are as follows: fan coil units (FCUs) for atriums, DOAS and active chilled beams (ACBs) with 40%-50% effective heat recovery for offices and laboratories, GSHP sized for 20% of peak heating (and also provides cooling), auxiliary electric boiler, and electric DHW boiler that is preheated by the GSHP.

Results

The baseline design energy model has an annual energy use of 6,109 MWh/year, an EUI of 203 kWh/m^2/year, and TEDI of 46 kWh/m^2/year. These energy metrics are close to the benchmarking and targets for the project but can still be improved further. For this reason, additional individual ECMs were modelled, and the results are presented in Figure 8. The end-use breakdown of the baseline design is shown in Figure 7. The highest savings were realized by the solar wall integrated with roof photovoltaics at 7.7% energy savings and 140 tonnes $CO_{2\text{-eq}}$ carbon savings. Due to lack of roof and ground space additional renewables could not be used in conjunction with this preferred system. Thermal storage water tanks provided 5.7% energy savings and 104 tonnes $CO_{2\text{-eq}}$ savings. The ground source heat pump system performed 9.8% and 7.2% better than a DOAS with FCU and DOAS with variable refrigerant flow (VRF) systems respectively. Other significant savings were found with 15% WWR (2.9%), cascading air from offices to laboratories (2.6%), light shelves (2.4%), and solar thermal preheat for ground source heat pump (GSHP) (2.4%).

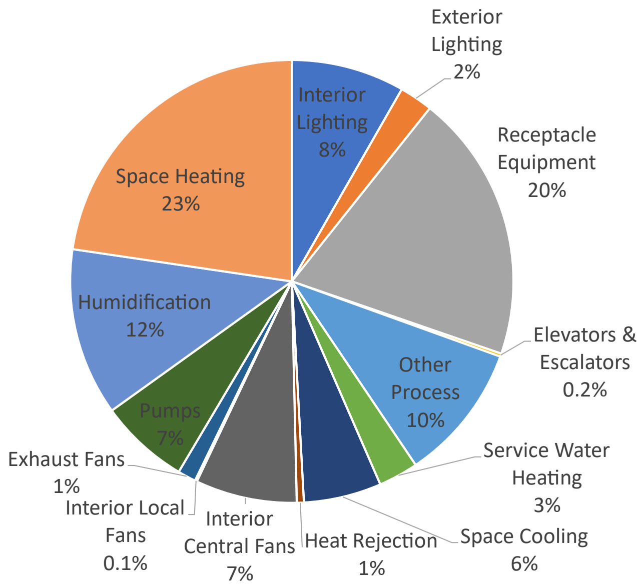

Figure 7: End use breakdown by percentage of total energy use

Limitations of Studies

Existing Laboratory:

The emissions of non-electric and non-natural gas science process loads were not accounted for in the models. Only the power and internal gains were accounted for. The non-electric and non-natural gas (propane, coal, coke, diesel) emissions were negligible due to the low frequency of use throughout the year.

New Laboratory:

The results for this case study are based on the schematic design, therefore are still preliminary in nature. The next steps of the project will include a life cycle costing analysis which will determine the final recommended design with additional ECMs based on energy, carbon, and life cycle costing results.

Discussion and Conclusions

This paper provides two examples of net zero carbon laboratories, the challenges faced and the ECMs used to achieve the targets. Further humidification and data center energy reduction opportunities can be realized through innovative technologies, after reducing the dominant heating loads first. Measures that optimize outdoor air rates through scheduling, sensors and controls paired with a DOAS system and energy recovery reduce energy use the most, since the majority of heating loads are attributed to the high outdoor air rates of laboratories. A central ground source heat pump and backup chiller for the laboratory campus can save 35% energy use relative to the baseline, however it has a high capital cost of $16.8M that most clients may not have, so driving down the costs of high efficiency technologies will meaningfully help reduce operational carbon emissions of laboratories.

Below are the lessons learned about the nuances of energy modelling for laboratories and the best energy efficiency measures.

Existing Laboratory Campus:

- Meeting the ASHRAE Guideline 14 to calibrate a laboratory model may not be appropriate due to the irregularity of scientific research. Use electricity demand data if available to determine a reasonable distribution of science process peak loads.
- Due to the heritage character of the major buildings envelope and cost of upgrading walls, adding insulation was not viable. Increased insulation was considered for the office trailers since a PEER method kept costs lower.
- Improving airtightness through envelope upgrades, temperature setbacks and outside air schedule strategies, DCV in offices, optimizing laboratory ventilation, air change rates and exhaust air, variable air volume fume hoods optimization through sensors and controls, and upgrading the HVAC systems to be active chilled beams with DOAS and ERV for offices/laboratories, have a large impact on the energy savings due to the reduction of direct outdoor air conditioning.
- There are many inefficiencies in the existing central heating plant that uses high temperature hot water, where a new central ground source heat pump and backup chiller could save 35% of the energy use compared to the baseline. However, this would require $16.8M capital cost to remove the existing distribution piping and install the new central plant and distribution piping.
- Humidification is typically a high enduse (19%) due to strict humidity ranges that are required for specific lab spaces (40%-60%).
- The most effective option at reducing GHG emissions for the amount of capital cost invested is Option 4 which costs $16,335/GHG tonnes saved/year in comparison to the other options (Option 1: $19,856, Option 2: $17,064, Option 3: $31,398). The lifecycle cost per GHG tonnes saved over lifetime (40 years) is also the lowest for Option 4 at $928 (Option 1: $1574, Option 2: $1074, Option 3: $1332).

New Laboratory:

- IES VE allowed the modelling of complex ECMs with less approximations than a simplified model. Earth tubes connected to the dynamic buffer zone behind the heritage façade were determined to be too cost intensive for the low energy savings (5%) it would provide. Instead the heritage façade will be deconstructed and reconstructed to meet the same performance as the high-performance new envelope sections of the building.

- External louvres had a savings of only 0.6% (with 27% WWR), while lighting shelves provided 2.4% energy savings and improved daylight distribution inside.
- Outdoor air rates for laboratories (42,760 L/s) can be reduced by cascading return air from offices and public spaces (9884 L/s), to save 2.6% energy relative to the baseline.
- The second highest end use for this building after heating was the receptacle equipment, due to the high data center load of 500 kW.

Nomenclature

ACBs – Active chilled beams

COP – Coefficient of performance

CV(RMSE) – Coefficient of variation of the root-mean-square-error

DHW – Domestic hot water

DOAS – Dedicated outdoor air system

DX – Direct expansion

ECM – Energy conservation measure

EUI – Energy use intensity

EUL – End of useful life

ERV – Energy recovery ventilator

FCU – Fan coil units

GHG – Greenhouse gas

GSHP – Ground source heat pump

HID – High intensity discharge

LCCA – Life cycle costing analysis

NMBE – Normalized mean bias error

NPV – Net present value

O&M – Operations and maintenance

OA – Outdoor air

PV – Present value

PEER – Prefabricated exterior energy retrofits

SHW – Service hot water

TEDI – Thermal energy demand intensity

VRF – variable refrigerant flow

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Table 2: Existing campus calibration results relative to ASHRAE Guideline 14-2014

Baseline Calibration to 2019 Utility Data	Monthly Calibration Tolerance		Complies with ASHRAE 14 (Y/N)	Complies Partially with ASHRAE 14 (Y/N)
	MBE (%)	CV(RMSE) (%)		
ASHRAE 14-2014 Tolerance	± 5%	± 15%		
Campus Total Energy Used	0%	17%	N	Y: *MBE – Y, CV(RMSE) - only 2% off*
Campus Total Electricity Consumption	-1%	7%	Y	Y : *MBE – Y, CV(RMSE) – Y*
Campus Peak Electrical Demand	7%	9%	N	Y: *MBE - only 2% off, CV(RMSE) - Y*
Campus Natural Gas Consumption	0%	25%	N	Y: *MBE – Y, CV(RMSE) - only 10% off*

Table 3: Existing campus LCCA comparison of options all in ($CAD).

Bundle	Annual Utility Cost	Annual O&M Costs	Annual Carbon Costs	Capital Cost	40-Yr Lifecycle Cost	40-Yr NPV relative to Option 1
Option 1	$972K	$85K	$625K	$34.7M	$110.0M	$0 (Benchmark)
Option 2	$806K	$108K	$389K	$43.2M	$108.8M	$1.1M
Option 3	$209K	$ 138K	$27K	$117.4M	$199.3M	-$89.3M
Option 4	$1.0M	$ 98K	$105K	$56.8M	$129.1M	-$19.1M

Table 4: New laboratory envelope inputs (left) and internal gains inputs (right)

Element	R-Value or U-value
Roof: high performance	8.8 RSI (R50)
Exterior walls (non-curtain wall)	8.0 RSI (R45)
Heritage Façade	8.0 RSI (R45)
Ground contact floor	6.3 RSI (R36)
Basement walls	5.2 RSI (R30)
Ground exposed floor	5.46 RSI (R31)
Windows and curtain wall glazing: metal framing with thermal break, triple pane with argon, low-E coating: SHGC=0.27; VT=0.44	1.58 USI (R3.6)
Curtain wall - opaque spandrels	0.70 USI (R8)

Internal Gain	Average
Lighting	6.2 W/m^2
Office Equipment	7.5 W/m^2
Laboratory Equipment	64.6 W/m^2
Computer Room / IT	500 kW
All Other Equipment	1.9 W/m^2
People	19.9 m^2/person

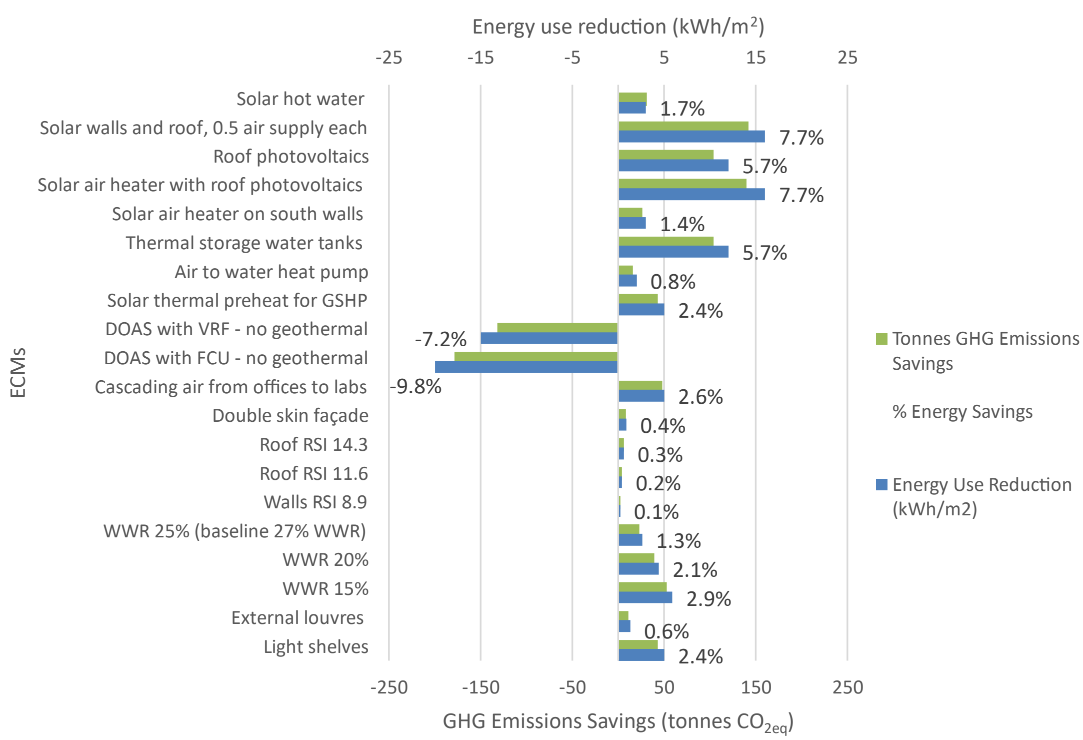

Figure 8: New laboratory additional individual energy conservation measures results. Energy savings and GHG emissions savings relative to baseline (203 kWh/m^2, 1833 tonnes CO_{2eq}).