UBC Archetype Study Report | Project R-09639.010

UBC Net Positive Modelling Study, 1138 Alumni Ave, Kelowna, BC

RDH BUILDING SCIENCE

To Glen McIntyre and Colin Richardson
UBC Campus Operations and Risk Management
1138 Alumni Ave
Kelowna BC V1V 1V7

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RDH Building Science Inc.
4333 Still Creek Drive #400
Burnaby BC V5C 6S6

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1 Introduction

1.1 Background

In 2016, RDH undertook a study for UBC's Vancouver campus to assist in developing energy performance requirements for net positive ready buildings by 2030 and a net positive campus by 2050. Five archetype buildings were identified, and energy models were developed based on the ASHRAE 90.1-2010 standard and typical UBC Vancouver construction practices.

This study updates the five baseline archetype models from the previous study to suit the UBC Okanagan (UBCO) campus typologies and climate, and to inform their new Climate Action Plan 2030. This work includes formulating ECM bundles to identify achievable energy and greenhouse gas emission targets specific to UBCO, and then completing costing and financial analysis to identify the most cost-effective strategies to achieve those targets. Applicability of the proposed strategies to existing building retrofits is also considered.

2 Methodology

2.1 Baseline Archetype Characteristics

The 2020 models from the previous 2016 UBC Net Positive Modelling Study were updated to reflect UBCO campus typologies and climate zones based on current UBCO construction practices. For example, full mechanical cooling was added to reflect typical practice and the high-rise student residence archetype was changed to a 6-storey wood-frame building. The campus rental archetype reflects a wood-frame building above a concrete podium with commercial retail units (non-food) on the ground level. All archetypes were assumed to be connected to the campus district energy system for hydronic heating, cooling, and hot water.

The following table summarizes the primary characteristics of each of the five archetypes. The building enclosure thermal performance assumptions were based on NECB 2015. In scenarios where two different HVAC systems were modelled, Option 2 (DOAS + FCUs) was assumed as the baseline for further analysis of ECMs and costing based on direction provided by UBCO. Detailed modelling assumptions are provided for each archetype in Appendix A.

TABLE 2.1 SUMMARY OF ARCHETYPE KEY CHARACTERISTICS					
	Student Residence	**Campus Rental Housing**	**Science/Lab Building (low fume hood density)**	**Lab Building (high fume hood density)**	**Classroom/Office Building**
Floor Area, m^2 (ft^2)	4,700 (51,000)	4,700 (51,000)	15,000 (161,000)	12,000 (129,000)	9,300 (100,000)
# of Storeys	6	6	5	4	6
Breakdown of Space Type	100% Residential (no kitchens)	L1: Commercial Retail Units (CRU), non-food retail L2 – L6: Residential (with suite kitchens)	28% Laboratory (low density fume hoods) 24% Office 8% Classroom 40% Circulation, amenity, etc.	49% Laboratory (high density fume hoods) 10% Office 13% Classroom 28% Circulation, amenity, etc.	46% Classroom and Lecture Hall 20% Office 34% Circulation and Amenity
Building Enclosure (NECB 2015)					
Exterior Wall	Wood frame with exterior insulation, R-20 (USI-0.278)	L1: Concrete with exterior insulation, R-20 (USI-0.278) L2 – L6: Wood frame with exterior insulation, R-20 (USI-0.278)	Concrete with exterior insulation, R-20 (USI-0.278)	Concrete with exterior insulation, R-20 (USI-0.278)	Concrete with exterior insulation, R-20 (USI-0.278)
Roof	Flat roof with XPS insulation, R-31 (USI-0.183)	Flat roof with XPS insulation, R-31 (USI-0.183)	Flat roof with XPS insulation, R-31 (USI-0.183)	Flat roof with XPS insulation, R-31 (USI-0.183)	Flat roof with XPS insulation, R-31 (USI-0.183)
Ground Floor	On grade, R-31 (USI-0.183)	On grade, R-31 (USI-0.183)	On grade, R-31 (USI-0.183)	On grade, R-31 (USI-0.183)	On grade, R-31 (USI-0.183)
Window	U-0.39 (USI-2.2)	U-0.39 (USI-2.2)	U-0.39 (USI-2.2)	U-0.39 (USI-2.2)	U-0.39 (USI-2.2)
Window SHGC	0.38	0.38	0.38	0.38	0.38

TABLE 2.1 SUMMARY OF ARCHETYPE KEY CHARACTERISTICS					
WWR	40%	40%	40%	40%	40%
Infiltration rate	0.2 L/s-m² enclosure area @ operating pressure				
Mechanical Systems					
HVAC Option 1	**Suites**: Centralized HRVs (70% effectiveness). Constant volume in-suite 4-pipe FCUs connected to district energy system providing heating and cooling to suites, controlled via local thermostats. Direct bathroom exhaust. **Corridors**: Make-up air unit providing tempered outdoor air to corridors for pressurization (20 cfm/unit), hydronic heating/cooling coil connected to district energy system, no heat recovery.	**Residential**: Same system types as Student Residence. MUA increased to 30 CFM/unit to account for dryer and kitchen exhaust. **CRUs**: Similar system types are residential portion, though separate zones/systems for CRU and Residential floors.	**Non-Lab Space:** VAV system with central cooling, connected to district energy system. Reheat and perimeter heat losses address by local hydronic baseboard convectors. Heat recovery, through 70% effectiveness. VAV air handler is turned off at night. **Lab Spaces:** 100% outdoor air is delivered to lab space via separate system with no re-circulation, heat recovery (40% effectiveness). 4-pipe FCUs for heating and cooling. Lab space has a fume hood density of 25 lineal meter of fume hood per 1,000 m^2 of lab area, with flow rate reduction, wind	Same system type as Science/Lab building. Lab space has a fume hood density of 35 lineal meter of fume hood per 1,000 m^2 of lab area, with flow rate reduction, usage responsive VFD, and low pressure drop. The fume hoods are 4 ft wide. The ventilation rate for the lab is driven by the general air change rate requirement.	Outdoor air is provided via VAV system, connected to district energy system for cooling and heating. Integrated heat recovery, 70% effectiveness. Reheat and perimeters heat losses address by local hydronic baseboard convectors.

TABLE 2.1 SUMMARY OF ARCHETYPE KEY CHARACTERISTICS					
			responsive VFD, and low pressure drop. The fume hoods are 6 ft wide. The ventilation rate for the science lab is driven by the general air change rate requirement.		
			The lab air handler design flow rate is based on the largest of: 1) 8 ACH 2) 100% open @ 188 L/s/m fume hood The operation flow rate during occupied hours is based on the largest of: 1) 8 ACH 2) 60% closed @ 45 L/s/m fume hood, 40% open @ 188 L/s/m fume hood The operation flow rate during unoccupied hours is based on the largest of: 1) 4 ACH 2) 95% closed @ 45 L/s/m fume hood, 5% open @ 188 L/s/m fume hood		

TABLE 2.1 SUMMARY OF ARCHETYPE KEY CHARACTERISTICS					
HVAC Option 2	N/A (applicable to archetypes with VAV)	N/A (applicable to archetypes with VAV)	**Non-lab space**: Outdoor air is provided via Dedicated Outdoor Air System (DOAS) with heat recovery, 70% effectiveness. 4-pipe FCUs in classroom/ office areas providing heating and cooling, connected to district energy system. **Laboratory**: Lab space modelled as described in Option 1.	**Non-lab space**: Outdoor air is provided via Dedicated Outdoor Air System (DOAS) with heat recovery, 70% effectiveness. 4-pipe FCUs in classroom/ office areas providing heating and cooling, connected to district energy system. **Laboratory**: Lab space modelled as described in Option 1.	Outdoor air is provided via Dedicated Outdoor Air System (DOAS) with heat recovery, 70% effectiveness. 4-pipe FCUs in classroom/ office areas providing heating and cooling, connected to district energy system.
Domestic Hot Water (DHW) or Service Hot Water (SHW)	Central storage tank system, district heating (to 120F) with electric water heater for top-up.	Central storage tank system, district heating (to 120F) with electric water heater for top-up.	Central storage tank system, district heating (to 120F) with electric water heater for top-up.	Central storage tank system, district heating (to 120F) with electric water heater for top-up.	Central storage tank system, district heating (to 120F) with electric water heater for top-up.
Occupant Schedules (per UBC Energy Modelling Guidelines)	NECB 2015 Table A-8.4.3.2(1)G	Residential: NECB 2015 Table A-8.4.3.2(1)G Retail M-Sat 7AM-9PM, Sun: 9AM-7PM based on ASHRAE 90.1-2013 User's Manual	Labs M-F 7AM-10PM, S-S 7AM-6PM Classrooms M-F 8AM-10PM, S-S Unoccupied Offices M-F 7AM-10PM, Sat 7AM-5PM, Sun Unoccupied Based on ASHRAE 90.1-2013 User's Manual	Labs M-F 7AM-10PM, S-S 7AM-6PM Classrooms M-F 8AM-10PM, S-S Unoccupied Offices M-F 7AM-10PM, Sat 7AM-5PM, Sun Unoccupied Based on ASHRAE 90.1-2013 User's Manual	Classrooms M-F 8AM-10PM, S-S Unoccupied Offices M-F 7AM-10PM, Sat 7AM-5PM, Sun Unoccupied Based on ASHRAE 90.1-2013 User's Manual

2.2 Energy Conservation Measures

A list of candidate Energy Conservation Measures (ECMs) appropriate to each archetype is provided in Table 2.2. The ECMs were selected based on the previous UBC Net Positive Modelling Study, other project experience, and with cost-effectiveness and market readiness in mind.

Individual ECMs were combined into two ECM bundles for modelling and costing: 1) Enclosure, 2) adding Mechanical measures to the Enclosure bundle. The bundles were modelled separately to better understand the impact of enclosure measures prior to adding the mechanical measures. The bundles are described for each archetype in Section 3.

One bundle each for the Student Residence, Lab Building, and Classroom Office archetype was modified after the initial results were presented, based on feedback from UBCO. These modified bundles are presented under each archetype section.

Two different baseline HVAC system types were modelled for select archetypes as described in Table 2.1. Although the DOAS + FCUs system has its disadvantages compared to VAV, such as higher maintenance due to terminal filter replacement, it has benefits such as higher heat recovery effectiveness and the ability to decouple the heating and ventilation system and thereby reduce fan and heating cooling energy. Further, the DOAS + FCUs baseline system has the potential to be improved in terms of fan energy and free cooling availability. Given that the baseline zone FCUs were modelled as on/off constant speeds, reduced fan energy can be achieved with variable or two-speed fans. Free cooling can be achieved by using a high-performance HRV that allows for bypass as needed. However, since the DOAS system is typically sized for the ventilation requirements, the free cooling ability is limited compared to the VAV system which is sized to provide a greater air flow rate than the ventilation requirement alone. Option 2 (DOAS + FCUs) is assumed as the baseline HVAC system for subsequent analysis of ECMs and costing based on previous discussion with UBCO.

<table>
<tr><th colspan="8">TABLE 2.2 ENERGY CONSERVATION MEASURES</th></tr>
<tr><th rowspan="2">ECMs</th><th rowspan="2">Student Residence</th><th rowspan="2">Campus Housing</th><th colspan="2">Science Lab (low-density)</th><th colspan="2">Lab (high-density)</th><th rowspan="2">Classroom/ Office</th></tr>
<tr><th>Lab</th><th>Non-lab</th><th>Lab</th><th>Non-lab</th></tr>
<tr><td colspan="8">Enclosure</td></tr>
<tr><td>Fixed windows, U-0.14, SHGC-0.37, VT 63%</td><td></td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Operable windows, U-0.17, SHGC-0.37, VT 63%</td><td>X</td><td>X</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>Reduced SHGC to 0.25, VT 57%</td><td>X</td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Electrochromic glazing</td><td>X</td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Walls R-30</td><td>X</td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Roof R-45</td><td>X</td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Airtightness – 0.6 ACH @ 50Pa</td><td>X</td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Operable exterior shades (E/S/W-facing façade)</td><td>X</td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Fixed exterior shades (E/S/W-facing façade)</td><td>X</td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Reduced window-to-wall ratio</td><td>X</td><td>X</td><td colspan="2">X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td colspan="8">Mechanical</td></tr>
<tr><td>90% efficient centralized HRV with bypass ventilating suites</td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>90% efficient centralized HRV with bypass (CRU only for Campus Housing)</td><td></td><td>X</td><td></td><td>X</td><td></td><td>X</td><td>X</td></tr>
<tr><td>Reduced corridor make-up air to corridors (10 cfm/unit)</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Reduced corridor make-up air to corridors (15 cfm/unit)</td><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Corridor supply air temperature nighttime setback of 18°C</td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nighttime free cooling air flush</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Variable speed FCUs with ECM motors (decoupling of DOAS and FCU if applicable)</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Radiant heating/cooling ceiling panels (instead of FCUs)</td><td></td><td></td><td>X</td><td></td><td>X</td><td></td><td>X</td></tr>
<tr><td>Aircuity sensors to reduce lab ventilation rate (minimum 4 ACH occupied / 2 ACH unoccupied)</td><td></td><td></td><td>X</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Make-up air provided to lab from non-lab space</td><td></td><td></td><td>X</td><td></td><td>X</td><td></td><td></td></tr>
</table>

TABLE 2.2 ENERGY CONSERVATION MEASURES							
Variable speed rooftop fan for lab stack exhaust			X		X		
Water-source heat pump for DHW top-up (from 120F to 140F) using DES hot water loop as source	X	X	X	X	X	X	X
DHW heat recovery	X	X	X	X	X	X	X

2.3 Emission Factors

Table 2.3 summarizes the emission factors used in the greenhouse gas analysis. The emission factor for electricity is based on B.C.'s integrated grid electricity emission intensity factor for 2020 (southern and western B.C.)[1], and the emission factors for the district energy system were provided by UBCO.

TABLE 2.3 EMISSION FACTORS

	Emission Factor (gCO_2e/kWh)
Electricity	40.1
District Energy – Heating	147.2
District Energy – Cooling	15.8

[1] https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/reporting/quantify/electricity

2.4 Energy Metrics

The output metrics reported on for the energy analysis are listed in the table below. The metrics are reported at building level as well as per space type within each building. To estimate the energy results per space type, each space type within the archetypes was modelled separately. The corridor area is left as corridor space within the model and is embedded in the space type results. The same geometry is used for each space type within the archetype to capture the same enclosure heat losses. This methodology provides a range of results for space types that are included in multiple archetypes, due to the different geometry as well as different corridor fractions.

Note that passive heat recovery measures such as HRVs directly reduce the heating demand of the space and therefore reduce TEDI. Active heat recovery measures, such as cooling the exhaust air and rejecting the heat to the heating loop, reduce the load on the heating source but do not reduce the heating demand of the space and therefore do not reduce TEDI.

TABLE 2.4 DEFINITION OF ENERGY METRICS

Metric	Unit	Definition
TEUI, Total Energy Use Intensity	$kWh/m^2/yr$	Annual energy use of the building, including heating, cooling, ventilation, service water heating, pumps, auxiliary HVAC equipment, lighting and plug load energy. TEUI does not include system efficiency of the DES plant.
TEDI, Thermal Energy Demand Intensity	$kWh/m^2/yr$	Annual heating energy demand for space conditioning and conditioning of ventilation air.
DHW, Domestic Hot Water	$kWh/m^2/yr$	Annual energy consumption for domestic hot water heating. DHW does not include system efficiency of the DES plant.
Annual Peak Heating Demand DES	W/m^2	Maximum heating energy required by the building for space conditioning and for conditioning of ventilation air. Peak heating demand does not include system efficiency.
Annual Peak Cooling Demand DES	W/m^2	Maximum cooling energy required by the building for space conditioning and for conditioning of ventilation air. Peak cooling demand does not include system efficiency.
Annual Peak Electricity	W/m^2	Maximum electricity required by the building.

2.5 Financial Analysis

A cost-benefit analysis was completed for each ECM bundle.

Incremental costing is based on 2020 material and labour costing obtained from product suppliers, RDH project experience, and industry reference documents such as RSMeans. Costs were originally determined for climate zone 4 and extrapolated to climate zones 5 using Altus Group's industry published cost factors for other regions[2].

ICCs for each ECM bundle relative to the baseline building are presented as a cost per square meter of floor area ($/m²). Two ICCs are shown for each bundle: the best, which is the least expensive, and worst, which is the most expensive, representing the approximate range of costs available in the market. Incremental costs for each measure are included for reference in Appendix E.

Using energy modelling results and ICCs for each ECM bundle, a lifecycle economic analysis was completed to establish Net Present Value (NPV), Internal Rate of Return (IRR), and discounted payback period. NPV is also presented for the best- and worst-case scenarios for each ECM bundle. The cost-effectiveness of the ECM packages is compared for each archetype using the NPV and lifetime GHG emission reductions. The life-cycle costing results were used to evaluate the cost-effectiveness of future performance targets for reducing GHG emissions (i.e. $/tCO2e). The cost effectiveness is the average NPV divided by the lifetime GHG emission reductions relative to the baseline scenario.

Equipment replacement costs are included in the financial analysis where equipment lifetimes are within the timeframe for analysis. Maintenance activities, such as annual inspections, are excluded where maintenance cost differences between the baseline and high performance scenarios are negligible, but are included in the annual district energy demand charges provided by UBCO. Enclosure measures are assumed to not require replacement during the 40-year timespan of the financial analysis. Additional details are provided in Appendix B.

Discount rate, timeframe for analysis, and utility cost escalation assumptions were determined through consultation with UBCO. These values are shown in Table 2.5 and additional input details are provided in Appendix C. Note that the district energy system utility rates include the \$250/tCO_2e carbon cost. This cost has not been added on top of the utility cost. The 2% utility escalation rate is based on RDH's previous experience.

[2] Cost factor of 95 for the Southern Interior indexed to Vancouver from Altus Group 2019 Canadian Cost Guide.

TABLE 2.5 KEY FINANCIAL ANYLSIS VARIABLES	
Variable	**Value**
General Variables	
Timeframe for analysis	40 years
Discount Rate	5.75%
Utility Escalation rate	2%
Carbon Cost	250 $/tCO_2e
Utility Costs provided by UBCO	
Grid Electricity Cost	0.059 $/kWh
Grid Electricity Demand Charge	89.54 $/kW/yr
Net Energy Cost – District Energy (Heating)	0.079 $/kWh
Net Energy Cost – District Energy (Cooling)	0.029 $/kWh
Net Energy Demand Charge – District Energy (Heating)	120.90 $/kWh/yr
Net Energy Demand Charge – District Energy (Cooling)	176.88 $/kWh/yr

3 Baseline and ECM Bundle Results

The following section presents the energy and greenhouse gas analysis results for the baseline and Energy Conservation Measure (ECM) bundles for each archetype. A breakdown of energy consumption by fuel type and by end-use is provided, as well as a breakdown of the sources of greenhouse gas emissions at the building level. This section also presents the financial analysis results, including incremental capital cost, NPV, and cost effectiveness of each ECM bundle for reducing GHG emissions (i.e. $/tCO2e).

3.1 Student Residence Building

The results for the baseline archetype and the ECM bundles are provided for the Student Residence in this section.

3.1.1 Baseline Building

Figure 3.1 shows the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Student Residence baseline archetype. Table 3.1 summarizes the baseline model results.

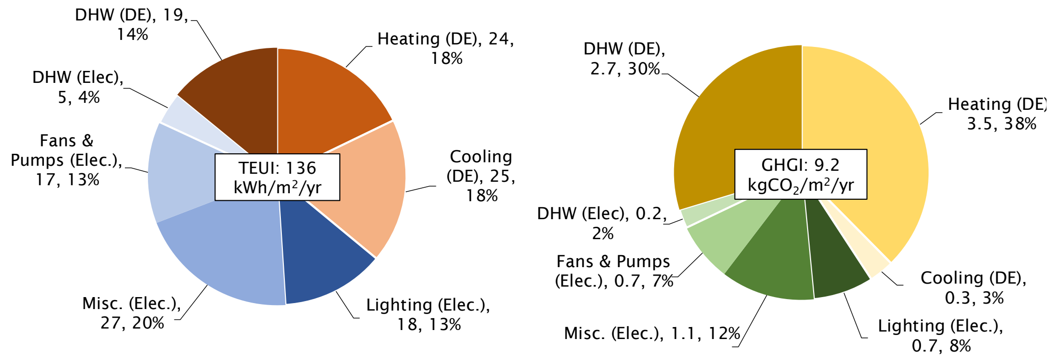


Figure 3.1 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity ($kgCO_2e/m^2/yr$) by end-use for the Student Residence baseline.

TABLE 3.1 SUMMARY OF RESULTS - STUDENT RESIDENCE BASELINE BUILDING	
	Student Residence Baseline Results
TEUI, kWh/m²/yr	136
TEDI, kWh/m²/yr	24
DHW, kWh/m²/yr	24
GHG, $kgCO_2e/m^2/yr$	9

3.1.2 ECM Bundles and Results

The dominant emission end-use for the baseline Student Residence is space heating, followed by domestic hot water. The Enclosure bundle for this archetype, therefore, focuses on reducing the space heating demand by reducing window-to-wall ratio and improving enclosure thermal performance. Although the Student Residence archetype is mechanically cooled, the Enclosure bundle also includes exterior shades to reduce cooling energy and peak electricity demand, as well as to improve resilience in the event of a power outage or extreme heat wave.

The Enclosure + Mechanical bundle for this archetype is additive to the Enclosure bundle and focuses on further reducing space heating and cooling demand via high-performance HRVs and improved corridor supply air temperature controls. The baseline model assumes that the make-up air unit provides 20°C air 24/7, while the heating energy reduction measure is to implement controls to reduce the supply air temperature at night to 18°C. The Enclosure + Mechanical bundle also improves the DHW system efficiency via heat pumps for hot water top-up, as well as reducing the hot water demand via domestic hot water heat recovery. Fan energy is reduced by replacing the constant volume FCUs with variable speed fans that operate at a lower fan speed at reduced heating or cooling loads.

TABLE 3.2 SUMMARY OF ECM BUNDLES – STUDENT RESIDENCE		
	Enclosure Bundle	**Enclosure + Mechanical Bundle**
ECMs	→ Operable windows, U-0.17 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa → Fixed exterior shades → Reduced window-to-wall ratio to 20%	Enclosure Bundle + → 90% efficient centralized HRV with bypass → Nighttime free cooling → Corridor supply air temperature nighttime setback → Variable speed FCUs → Water-source heat pump for DHW top-up → Domestic hot water heat recovery

Energy and GHG Results

Figure 3.2 and Figure 3.3 show the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Enclosure and Enclosure + Mechanical bundles, respectively.

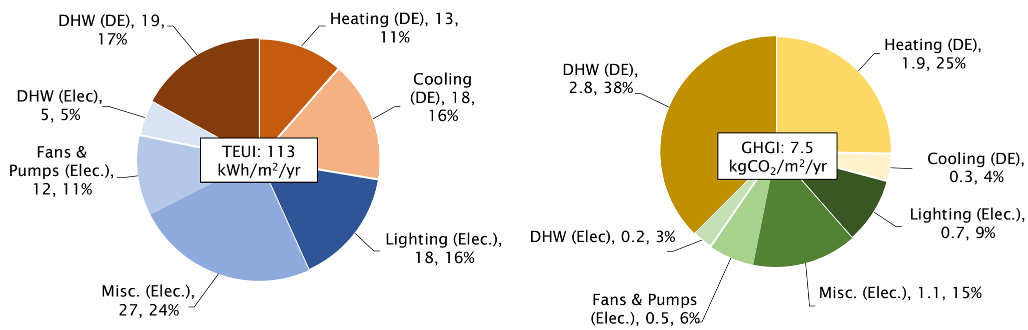


Figure 3.2 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO₂e/m²/yr) by end-use for the Student Residence Enclosure Bundle.

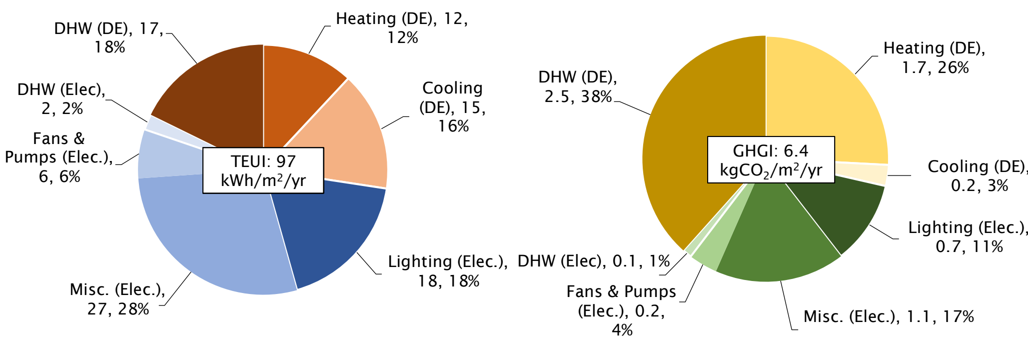


Figure 3.3 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO₂e/m²/yr) by end-use for the Student Residence Enclosure + Mechanical Bundle.

The Enclosure and Enclosure + Mechanical bundle results are summarized below, together with the baseline results. No space type breakdown results are presented since the Student Residence only consists of residential and corridor area.

TABLE 3.3 SUMMARY OF BASELINE AND ECM RESULTS – STUDENT RESIDENCE

	Baseline	Enclosure	Enclosure + Mechanical
TEUI, kWh/m²/yr	136	113	97
GHGI, kgCO_2e/m²/yr	9	7	6
TEDI, kWh/m²/yr	24	13	12
DHW, kWh/m²/yr	24	24	19
Annual Peak Heating DES, W/m²	32	15	14
Annual Peak Cooling DES, W/m²	24	15	14
Annual Peak Electricity, W/m²	10	9	9

1 Total Energy Use Intensity (TEUI) and Greenhouse Gas Intensity (GHGI) per space type area

The Enclosure bundle results in a significant reduction in space heating and cooling demand. The switch from double glazed windows to triple glazed windows in combination with reduced window-to-wall ratio result in an improved overall R-value of the enclosure and with that a reduced heating demand. The reduced window-to-wall ratio also reduces the solar heat gains through the windows, which has a positive impact on the cooling demand. The solar heat gains are further reduced by the fixed exterior shades on the south-, east-, and west-facing facades. The corridors are heated via the supply air, since there is no zone equipment making up for the perimeter heat losses the improved enclosure does not reduce the heating energy consumption for the corridors.

The improved heat recovery effectiveness included in the Enclosure + Mechanical bundle show a small reduction in space heating demand. This is because the majority of the ventilation heat losses are associated with the pressurization air provided to the corridor, and as such, the improvement in heat recovery effectiveness from 70% to 90% for the suite ventilation has a relatively minor impact. To reduce the ventilation heat losses further the corridor make-up air rate could be reduced; alternatively, the corridors could be ventilated via centralized HRVs.

The high-performance HRVs included in the Enclosure + Mechanical bundle show a larger relative impact on the cooling energy compared to the heating energy. The high-performance unit is assumed to allow for bypass, i.e. when the extract air and/or outdoor air temperature exceeds a certain limit the supply air bypasses the heat exchanger to avoid overheating the space. This feature also allows for nighttime free cooling; however, since the HRV unit is sized for ventilation requirements the free cooling ability is limited compared to a VAV system which would be sized to provide a greater air flow rate than the ventilation requirement alone.

The switch from constant to variable speed fans for the fan coil units result in a 50% reduction in fan energy. The implementation of heat pumps for hot water heating top-up reduces the electricity consumption, however, since the majority of the hot water heating is done by the district energy system this measure has a minor impact on the archetype’s GHGI based on the current emission factors.

Modified Bundle Results

Reducing the window-to-wall ratio of a building is a viable design strategy to reduce energy consumption and greenhouse gas emissions; however, it may not be desired for certain projects due to architectural considerations, reduced daylighting, or other reasons. The table below presents the energy and GHGI metrics for the Enclosure bundle with and without the reduced window-to-wall ratio measure. The measure also impacts the cooling, fan, and pump energy so the energy consumption for these end-uses is also presented. The percent increase in energy and greenhouse gas emissions due to the removed WWR reduction measure is also presented.

TABLE 3.4 STUDENT RESIDENCE ENCLOSURE BUNDLE WITH AND WITHOUT WINDOW-TO-WALL RATIO REDUCTION

	Enclosure bundle		Energy / GHG Increase[1] (%)
	With reduced WWR (20% WWR)	**Without** reduced WWR (40% WWR)	
TEUI, kWh/m²/yr	113	120	7%
GHGI, kgCO_2e/m²/yr	7.5	7.8	4%
TEDI, kWh/m²/yr	13	14	7%
Cooling energy, kWh/m²/yr	18	24	30%
Fan and Pump energy, kWh/m²/yr	12	14	13%
Annual Peak Heating DES, W/m²	15	20	28%
Annual Peak Cooling DES, W/m²	15	19	21%
Annual Peak Electricity, W/m²	9	9	0%

1) Increase in energy and GHG metrics for the Enclosure bundle without reduced WWR compared to the Enclosure bundle with reduced WWR

Financial Analysis Results

The incremental capital costs (ICCs) for the two Student Residence ECM bundles are presented in Figure 3.4. The ICCs for individual measures are provided in Appendix E.

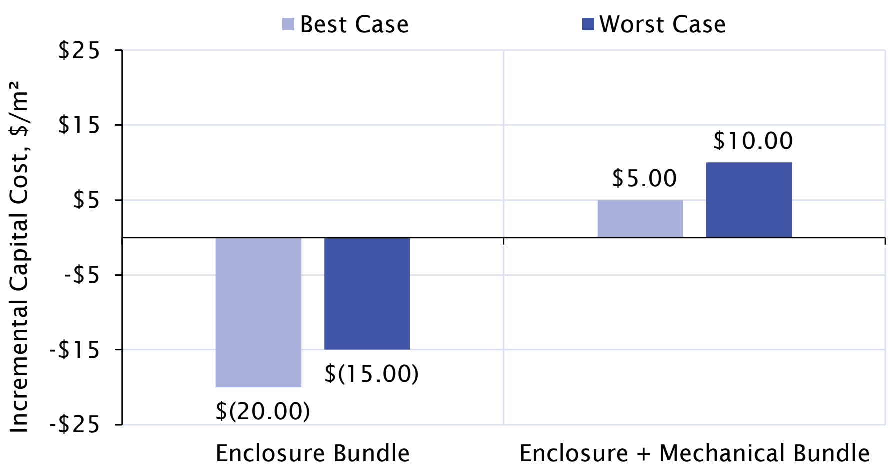


Figure 3.4 Student Residence - Incremental Capital Cost (light and dark blue bars for best and worst case, respectively) of ECM bundles compared to the baseline scenario.

In the Enclosure bundle, the major cost drivers are the additional roof insulation and the fixed exterior shades being added to the windows; however, these costs are more than offset by savings from the reduced window-to-wall ratio (from 40 to 20%). This results in a negative ICC for this bundle (i.e. net cost savings).

The ICC of the Enclosure + Mechanical bundle is $25-$35 more than that of the Enclosure bundle alone and the difference is primarily due to the cost of the upgraded mechanical equipment.

The nighttime free cooling and the corridor supply air temperature nighttime setback are assumed to be no additional cost over baseline as these ECMs would be implemented by adjusting the controls for systems that are already in place and would not require additional equipment.

In the Enclosure + Mechanical bundle, the DHW is preheated to 120˚F by the district energy system hot water loop and then topped-up to 140˚F with a water-source heat pump using the district energy system hot water loop as a source. Water-source heat pumps that reach temperatures of 140˚F or higher are available in the market, but are costly and in general larger than needed for the DHW system in this study, since heat pump is only being used for top-up and not to meet the full load. Given these factors, the water-source heat pump costed as part of the financial analysis is oversized compared to what would be required to top-up the hot water from 120°F to 140°F for this buildings, driving up the cost. The 90% efficient centralized HRV with bypass is another cost driver for this bundle, as this equipment is more costly than their standard efficiency counterparts.

The NPV for each bundle is shown Figure 3.5. Both bundles result in a positive NPV indicating utility cost savings over the lifetime of the building. In the case of the Enclosure bundle, this is expected as the initial cost of the bundle is less than that of the baseline. For the Enclosure + Mechanical bundle, the utility cost savings are due to the energy savings from the higher performance enclosure coupled with the more efficient mechanical equipment. Additional financial analysis details are provided in Table 3.5.

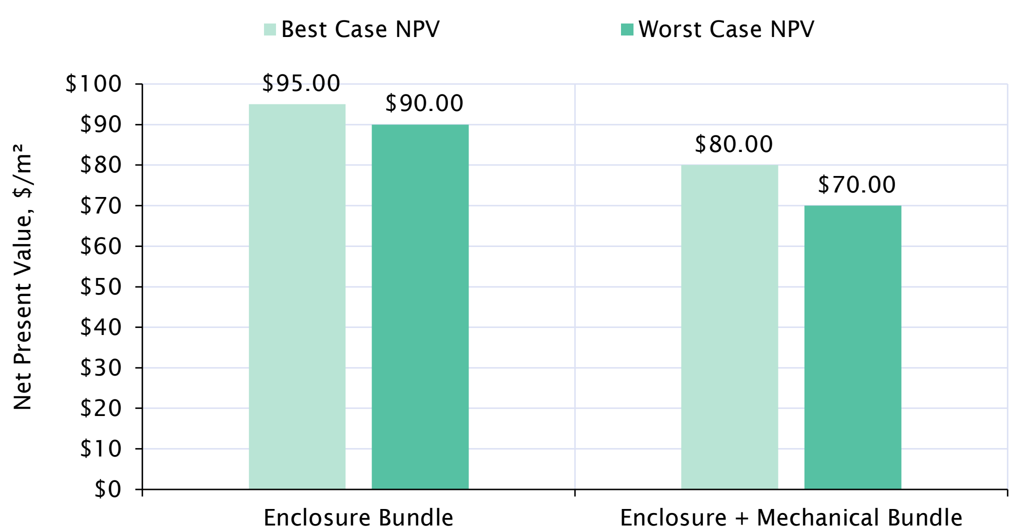


Figure 3.5 Student Residence – Net present value of ECM bundles relative to baseline scenarios (light and dark blue bars).

Internal Rate of Return (IRR) is the discount rate that would be required to set the NPV to zero over the 40-year analysis period. This is useful for estimating the profitability of investments. Positive IRR indicates that future cash flows can be significantly discounted for the net present value of the upgrade to break even over its lifetime. Negative IRRs occur when there is a large initial cost and small annual energy cost savings, and suggest that future cash flows must be worth more than present money (i.e. negatively discounted) for the net present value of the upgrade to break even over its lifetime. In the case of the Enclosure bundle, there is no IRR as the initial cost of the bundle is less than that of the baseline. Because NPV is positive for both bundles, no cost per tonne of carbon abatement is observed.

TABLE 3.5 ECONOMIC ANALYSIS FOR THE STUDENT RESIDENCE ECM BUNDLES

ECM Bundle	**Net Present Value ($/m²)**		**Internal Rate of Return (IRR, %)**		**Discounted Payback Period (Years)**	
	Best	**Worst**	**Best**	**Worst**	**Best**	**Worst**
Encl. Bundle	$95	$90	N/A	N/A	N/A	N/A
Encl. + Mech. Bundle	$80	$70	140%	69%	1	2

3.2 Campus Housing

The results for the baseline archetype and the ECM bundles are provided for the Campus Housing in this section.

3.2.1 Baseline Building

Figure 3.6 shows the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Campus Housing baseline archetype.

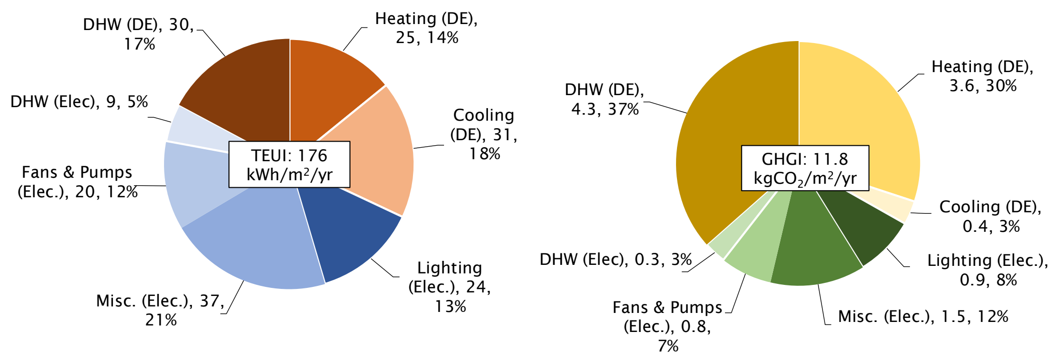


Figure 3.6 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity ($kgCO_2e/m^2/yr$) by end-use for the Campus Housing baseline.

Table 3.6 summarizes the Campus Housing baseline model results.

TABLE 3.6 SUMMARY OF RESULTS – CAMPUS HOUSING BASELINE BUILDING	
	Campus Housing Baseline Results
TEUI, kWh/m²/yr	176
TEDI, kWh/m²/yr	25
DHW, kWh/m²/yr	39
GHG, $kgCO_2e/m^2/yr$	12

3.2.2 ECM Bundles and Results

The dominant emission end-use for the Campus Housing is domestic hot water followed by space heating. The domestic hot water energy is higher per floor area compared to the Student Residence, as it is assumed that Campus Housing suites have kitchens and in-suite laundry.

The ECM bundles are similar to the Student Residence bundles, with the addition of a window measure specific to the CRU. The window-to-wall ratio remains slightly higher than for the Student Residence due to the high assumed glazed area for the ground floor CRU.

TABLE 3.7 SUMMARY OF ECM BUNDLES – CAMPUS HOUSING		
	Enclosure Bundle	**Enclosure + Mechanical Bundle**
ECMs	→ Res: Operable windows, U-0.17 → CRU: Fixed windows, U-0.14 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa → Fixed exterior shades → Reduced window-to-wall ratio to 25%	Enclosure Bundle + → 90% efficient centralized HRV with bypass → Nighttime free cooling → Corridor supply air temperature nighttime setback → Variable speed FCUs → Water-source heat pump for DHW top-up → Domestic hot water heat recovery

Energy and GHG Results

Figure 3.7 and Figure 3.8 show the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Enclosure and Enclosure + Mechanical bundles, respectively.

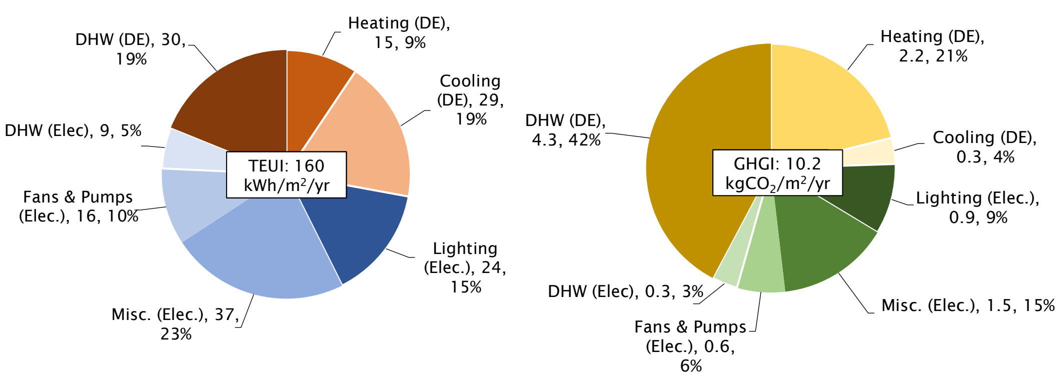


Figure 3.7 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO₂e/m²/yr) by end-use for the Campus Housing Enclosure Bundle.

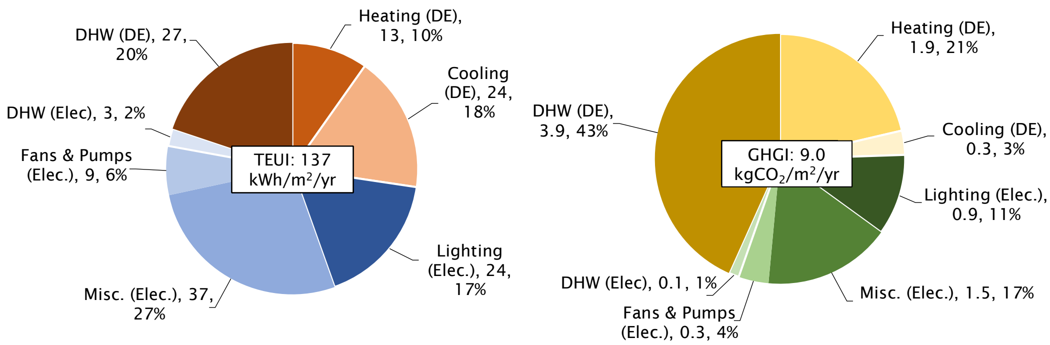


Figure 3.8 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO₂e/m²/yr) by end-use for the Campus Housing Enclosure + Mechanical Bundle.

The Enclosure and Enclosure + Mechanical bundle results are summarized below, together with the baseline results. The TEUI, GHGI, and TEDI results are presented by space-type below the whole building results. The DHW energy consumption, peak heating, peak cooling, and annual peak electricity results are provided per space type in Appendix D. The corridors are embedded in the results and the space type results are normalized by the whole building area, as described in Section 2.4.

TABLE 3.8 SUMMARY OF BASELINE AND ECM RESULTS – CAMPUS HOUSING			
	Baseline	Enclosure	Enclosure + Mechanical
TEUI, kWh/m²/yr	176	160	137
Residential	179	163	138
CRU	161	143	132
GHGI, $kgCO_2e/m^2/yr$	12	10	9
Residential	13	11	10
CRU	8	6	6
TEDI, kWh/m²/yr	25	15	13
Residential	26	17	15
CRU	20	8	5
DHW, kWh/m²/yr	39	39	30
Annual Peak Heating DES, W/m²	33	13	10
Annual Peak Cooling DES, W/m²	28	21	21
Annual Peak Electricity, W/m²	12	12	11

Similar to the Student Residence archetype, the improved thermal performance of the enclosure and addition of passive cooling measures in the Enclosure bundle result in a reduction in space heating and cooling energy consumption and peak demand for the residential and CRU space types. The high-performance HRV in the Enclosure + Mechanical bundle further reduces the space heating and cooling demand as discussed under the Student Residence results.

The domestic hot water measures show a higher relative impact for the Campus Housing compared to the Student Residence as it has a higher domestic hot water load, due to in-suite laundry and kitchens. However, since the majority of the hot water heating is done by the district energy system, the hot water reduction measures have a relatively small impact on the archetype's GHGI. To reduce the archetype's GHGI further the results suggest that efforts should focus on reducing emissions from the district energy system.

Although the CRU space type has a higher minimum outdoor air requirement, the space type results show that the residential area has a higher TEDI than the CRU area. This is because the residential area is heated and supplied with outdoor air 24/7. The TEUI is also higher for the residential area, mainly due to the higher domestic hot water energy consumption.

Financial Results

The incremental capital costs (ICCs) for the Campus Housing ECM bundles are presented in Figure 3.9.

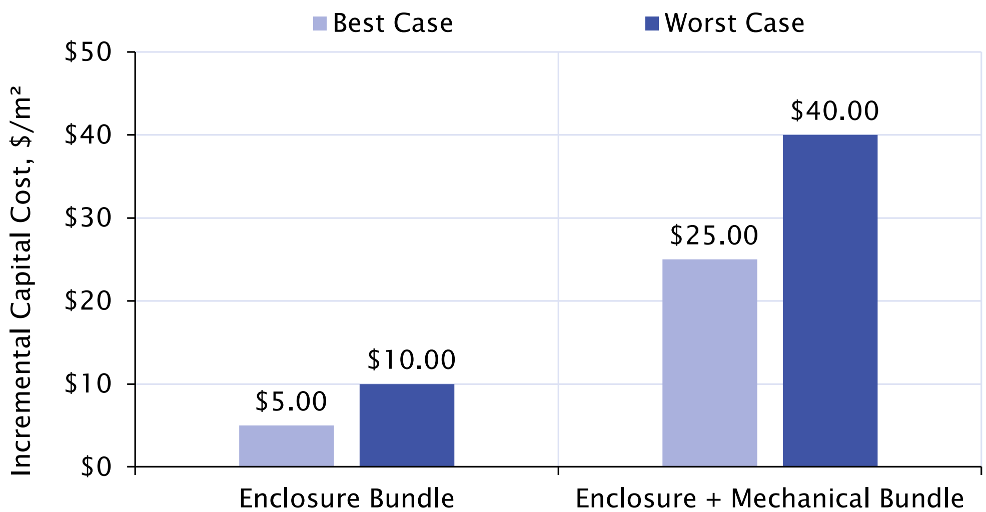


Figure 3.9 Campus Housing - Incremental Capital Cost (light and dark blue bars for best and worst case, respectively) of ECM bundles compared to the baseline scenario.

In the Enclosure bundle, the major cost drivers are the additional roof insulation and the fixed exterior shades being added to the windows; however, these costs are somewhat offset by the reduced window-to-wall ratio (reduced from 40 to 25%; slightly less than the student residence given the high glazing ratio of the CRU).

Similar to the Student Residence, the nighttime free cooling and the corridor supply air temperature nighttime setback are assumed to be no additional cost over baseline.

In the Enclosure + Mechanical bundle, the water-source heat pump used for top-up, and the high efficiency HRV, are the major cost driver for this archetype.

The NPV for each bundle is shown Figure 3.10. Both bundles result in a positive NPV. The positive NPV for the Enclosure bundle results from the energy savings gained by the improved enclosure. The Enclosure + Mechanical bundle benefits from, not only the higher performance enclosure, but from the energy efficient mechanical equipment, resulting in even greater utility cost savings. Additional financial analysis details are provided in Table 3.9.

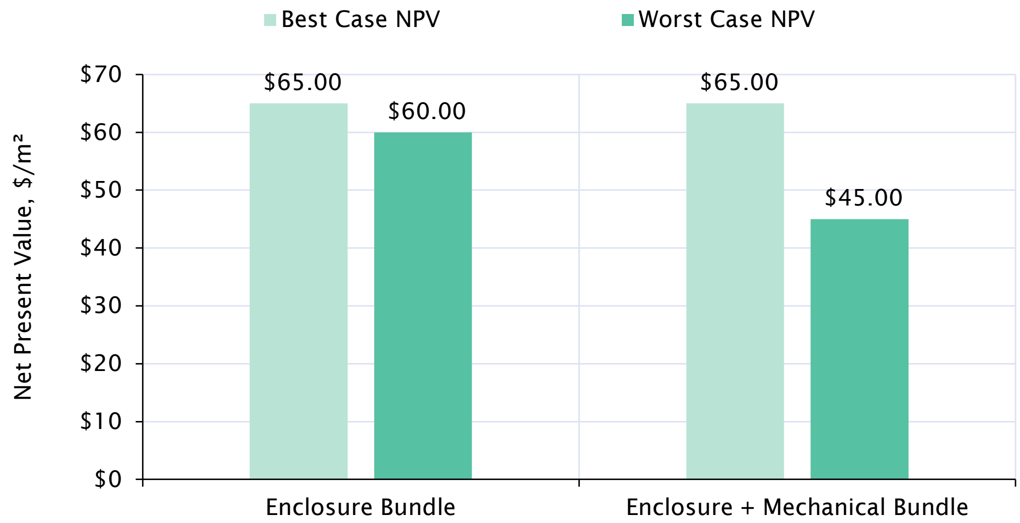


Figure 3.10 Campus Housing – Net present value of ECM bundles relative to baseline scenarios (light and dark blue bars).

Because NPV is positive for both bundles, no cost per tonne of carbon abatement is observed for this archetype.

TABLE 3.9 ECONOMIC ANALYSIS FOR THE CAMPUS HOUSING ECM BUNDLES						
ECM Bundle	**Net Present Value ($/m²)**		**Internal Rate of Return (IRR, %)**		**Discounted Payback Period (Years)**	
	Best	**Worst**	**Best**	**Worst**	**Best**	**Worst**
Encl. Bundle	$65	$60	98%	59%	2	2
Encl. + Mech. Bundle	$65	$45	25%	15%	5	8

3.3 Science Lab

The results for the baseline archetype and the ECM bundles are provided for the low-density Science Lab in this section.

3.3.1 Baseline Building

Two HVAC systems were modelled for the non-lab space in the Science Lab building, as described in Table 2.1. The non-lab space is ventilated and conditioned via a reheat VAV system in Option 1, and through a dedicated outdoor air system with 4-pipe FCUs in Option 2. The HVAC system for the lab space is unchanged between the two options.

HVAC Option 1

Figure 3.11 shows the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Science Lab baseline archetype with HVAC Option 1 (VAV).

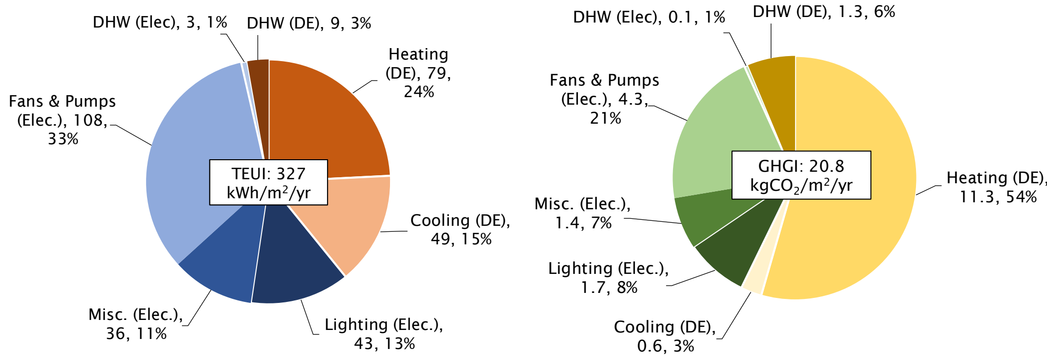


Figure 3.11 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO₂e/m²/yr) by end-use for the Science Lab baseline building with HVAC Option 1 (VAV).

HVAC Option 2

Figure 3.12 shows the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Science Lab baseline archetype with HVAC Option 2 (DOAS + FCUs).

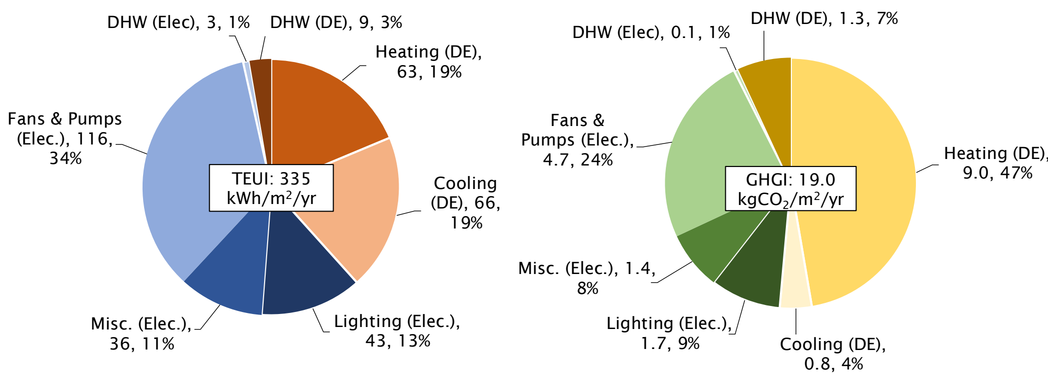


Figure 3.12 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO₂e/m²/yr) by end-use for the Science Lab baseline building with HVAC Option 2 (DOAS + FCUs).

Table 3.10 summarizes the Science Lab baseline model results together with UBC Vancouver's 2020 energy performance targets for comparison. The Science Lab baseline energy result for DHW is below UBC Vancouver's 2020 target; however, both HVAC options exceed the TEUI and TEDI targets, which is to be expected given the higher cooling demand in the interior region (although the Vancouver modelled lab also exceeded the targets).

Option 2 (DOAS + FCUs) is assumed as the baseline HVAC system for subsequent analysis of ECMs and costing.

TABLE 3.10 SUMMARY OF RESULTS – SCIENCE LAB BASELINE BUILDING

	Science Lab Baseline Results	
	Option 1 – VAV System	Option 2 – DOAS + FCUs
TEUI, kWh/m²/yr	327	335
TEDI, kWh/m²/yr	79	63
DHW, kWh/m²/yr	12	12
GHG, $kgCO_2e/m^2/yr$	21	19

The HVAC options result in similar TEUI; however, Option 1 (VAV) results in higher GHGI compared to Option 2 (DOAS + FCUs). The higher GHGI for Option 1 (VAV) is mainly due to greater heating energy use, given that the VAV system has centralized cooling that supplies air at 12-15°C and then reheats at zone level.

In contrast, Option 1 (VAV) results in lower cooling and fan energy. The VAV system has an air-side economizer and free cooling capability which reduces the need for mechanical cooling. Further, the VAV system fans throttle down to 40% as needed during occupied hours and turn off at night, with the heating set back temperature being met by local baseboards. In comparison, the 4-pipe FCUs in Option 2 (DOAS + FCUs) run at constant volume during occupied hours and cycle on at night to meet the heating set back temperatures. The reduced heating energy consumption seen for the DOAS system is thus offset by higher fan energy due to the constant speed and 24/7 availability schedule of the FCUs, and higher cooling energy as the baseline DOAS does not have a free-cooling mode.

3.3.2 ECM Bundles and Results

The dominant energy end use if fan energy, followed by cooling and heating. However, the GHGI is dominated by space heating as it currently has a higher emission factor than the district cooling and electrical end-uses. As such, GHGI will be most sensitive to changes in space heating for this archetype.

The Enclosure bundle focuses on reducing heating and cooling demand by implementing the same enclosure measures as evaluated for the residence archetypes.

The high energy use for space conditioning and fans is mainly associated with the ventilation requirements for the lab space. The Enclosure + Mechanical bundle therefore focuses on reducing lab ventilation rates, as well as switching from constant to variable speed fans for the FCUs and rooftop lab exhaust.

The lab ventilation rate for this archetype is air change driven. The Aircuity technology included in the Enclosure + Mechanical bundle measures contamination levels in the lab and allows for a reduced air change rate during occupied (to 4 ACH) and unoccupied conditions (to 2 ACH). The outdoor air rate to the lab can be reduced further by cascading exhaust air from the non-lab spaces to the lab, so that the outdoor air rate can be reduced while still meeting the air change rate requirements.

TABLE 3.11 SUMMARY OF ECM BUNDLES – SCIENCE LAB		
	Enclosure Bundle	**Enclosure + Mechanical Bundle**
ECMs	→ Fixed windows, U-0.14 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa → Fixed exterior shades → Reduced window-to-wall ratio to 25%	Enclosure Bundle + → Variable speed FCUs, decouple FCUs and DOAS → Nighttime free cooling → Install Aircuity sensors to reduce lab ventilation rate → Make-up air provided to lab from non-lab space → Variable speed rooftop fan for stack exhaust

Energy and GHG Results

Figure 3.13 and Figure 3.14 show the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Enclosure and Enclosure + Mechanical bundle, respectively.

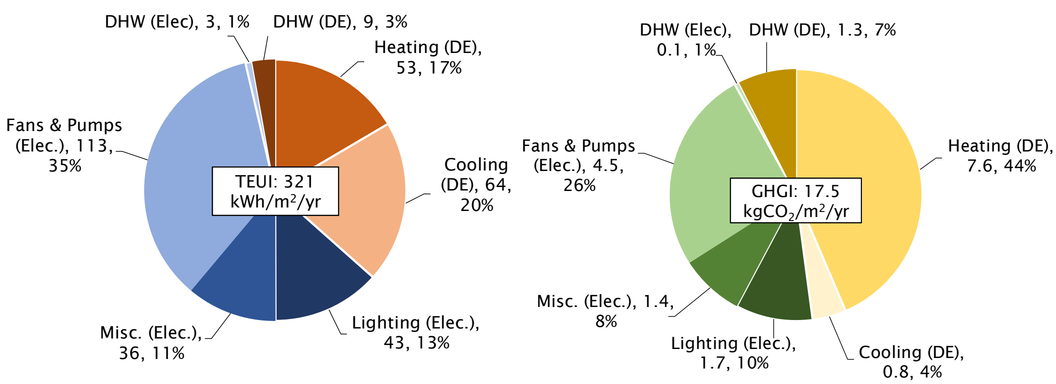
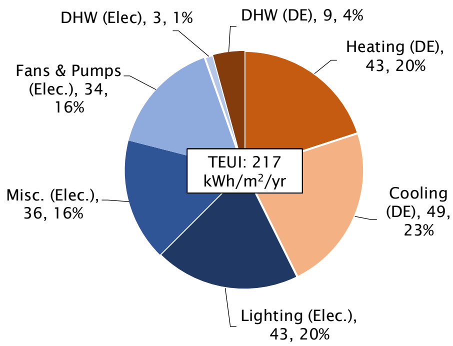


Figure 3.13 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity ($kgCO_2e/m^2/yr$) by end-use for the Science Lab Enclosure Bundle.



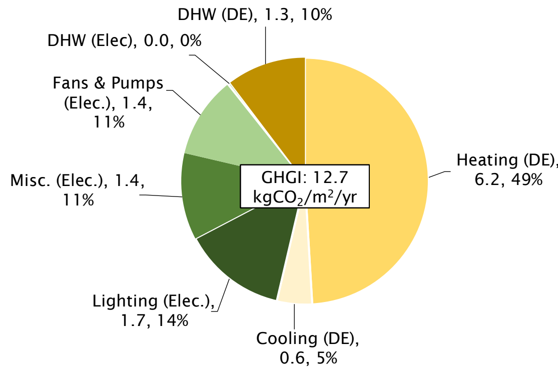


Figure 3.14 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity ($kgCO_2e/m^2/yr$) by end-use for the Science Lab Enclosure + Mechanical Bundle.

The Enclosure and Enclosure + Mechanical bundle results are summarized below, together with the baseline results. The TEUI, GHGI, and TEDI results are presented by space-type below the whole building results, the DHW energy consumption, peak heating, peak cooling, and annual peak electricity results are provided per space type in Appendix D. The corridors are embedded in the results, the space type results are normalized by the whole building area, as described in Section 2.4.

TABLE 3.12 SUMMARY OF BASELINE AND ECM RESULTS – SCIENCE LAB			
	Baseline	Enclosure	Enclosure + Mechanical
TEUI, kWh/m²/yr	335	321	217
Lab	566	544	334
Classroom	155	144	159
Office	119	104	112
GHGI, $kgCO_2e/m^2/yr$	19	17	13
Lab	34	32	20
Classroom	8	7	12
Office	6	5	8
TEDI, kWh/m²/yr	63	53	43
Lab	117	106	66
Classroom	14	7	44
Office	16	8	35
DHW, kWh/m²/yr	12	12	12
Annual Peak Heating DES, W/m²	48	39	28
Annual Peak Cooling DES, W/m²	79	71	40
Annual Peak Electricity, W/m²	30	30	23

The relative impact of the Enclosure bundle on the heating and cooling demand is lower compared to the residence buildings. This is because the heat losses are dominated by ventilation and the improved enclosure thermal performance has a smaller impact on the overall heating demand compared to a building with high enclosure heat losses and low ventilation heat losses. This is also demonstrated by the space type results breakdown, as the Enclosure bundle has a larger relative impact on the classroom and office space types compared to the lab space type. However, the improved enclosure thermal performance and passive cooling measures have other advantages, such as increased resilience in the event of a power outage. A well-insulated enclosure in combination with passive cooling measures also show benefits in terms of reducing peak cooling demand, and annual cooling energy as the climate warms.

The Enclosure + Mechanical bundle results in GHG savings, mainly due to the fan and heating energy reductions for the lab. The total fan energy is reduced by almost 70% as a result of the reduced ventilation requirements achieved with the Aircuity sensors, as well as the switch from constant to variable speed FCUs and rooftop fans for lab exhaust. Further, the heating energy demand is reduced by almost 20% due to reduced ventilation rates and reduced outdoor air intake. However, the space type analysis shows that the Enclosure + Mechanical bundle results in an *increase* in TEUI and TEDI for the classroom and office spaces. This is because the exhaust air from the non-lab space is transferred to the lab space to reduce the lab outdoor air intake, and as such there is no heat exchange between the non-lab supply and exhaust air, which results in an apparent increase in ventilation heating energy for the non-lab space. Overall, though, the Enclosure + Mechanical bundle reduces the whole building model TEUI.

The classroom TEUI is higher than the office TEUI, mainly due to higher lighting power density, cooling demand, domestic hot water load (due to higher occupancy density), and fan energy. The classroom has a higher ventilation requirement per floor area, leading to higher fan energy. Despite the higher ventilation requirement, though, the classroom heating energy is slightly lower than the office per floor area for the baseline and Enclosure bundle scenarios. This is partially because of the higher lighting and occupant load, which reduces heating demand and offsets the higher outdoor air intake, as well as the ventilation heat recovery which reduces ventilation heat losses. The difference in ventilation requirement and associated heat losses becomes more apparent in the Enclosure + Mechanical bundle as the HRV is removed.

Note that the space type area weighted results for the Enclosure + Mechanical bundle do not match the whole building results as the air transferred from the non-lab space to the lab space are different. For the space type analysis, only the corridor ventilation air is transferred to the lab to reduce the lab outdoor air intake, which results in a lower heating energy reduction compared to the whole building model since the ventilation air from all non-lab spaces are transferred in the whole building model.

Financial Results

The incremental capital costs (ICCs) for the Science Lab building ECM bundles are presented in Figure 3.15. The range between best and worst case costs were small for both bundles and ICCs have been rounded to the nearest $5.00.

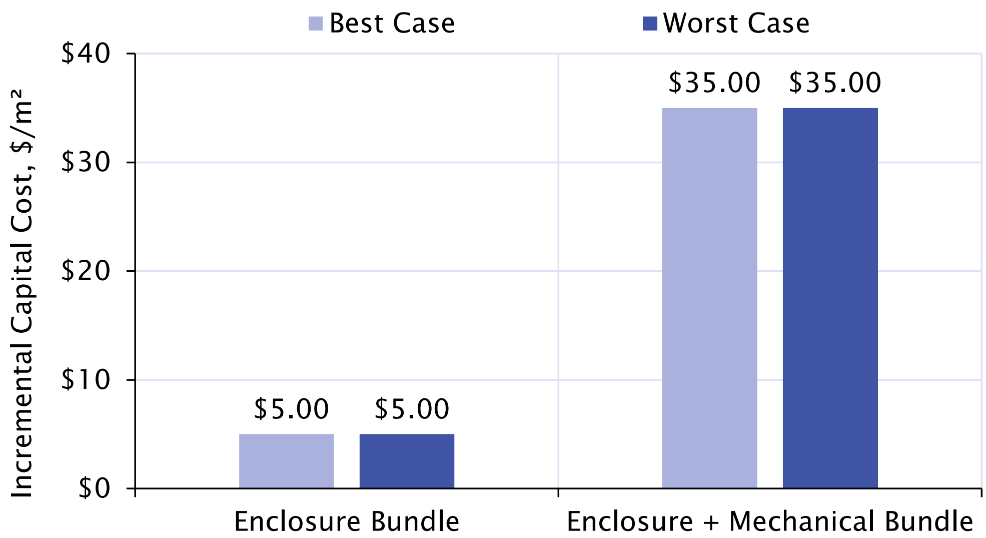


Figure 3.15 Science Lab - Incremental Capital Cost (light and dark blue bars for best and worst case, respectively) of ECM bundles compared to the baseline scenario.

In the Enclosure bundle, the major cost drivers are again the additional roof insulation and the fixed exterior shades being added to the windows, although these costs are partially offset by the reduced window-to-wall ratio (from 40 to 25%).

The nighttime free cooling is assumed to be no additional cost over baseline as this ECM would be implemented by adjusting the controls for a system that is already in place and would not require additional equipment.

In the Enclosure + Mechanical bundle, the additional of the Aircuity sensors is a significant cost driver. The Aircuity system includes many components (e.g. the sensor suite, air data router, cables, and tubing) which all add to the cost of the system, in addition to installation and implementation, which is dependent on the size of the building and the fume hood density.

The Enclosure + Mechanical bundle includes variable speed rooftop fans for stack exhaust; however, these fans have not been included in the financial analysis. The equipment supplier, Eco Supply, said that the cost could vary by orders of magnitude (a few hundred thousand dollars to a few million) and was unwilling to provide a cost without detailed design information including electrostatic pressure of the fans, the plume height, a description of the heat recovery plenum, the electrical supply available, the fan configuration, and the number of fans that are running and in standby. Additional analysis by a mechanical consultant would be required to determine a reasonable estimate of the cost.

The NPV for each bundle is shown Figure 3.16. Both bundles result in a positive NPV. Additional financial analysis details are provided in Table 3.13.

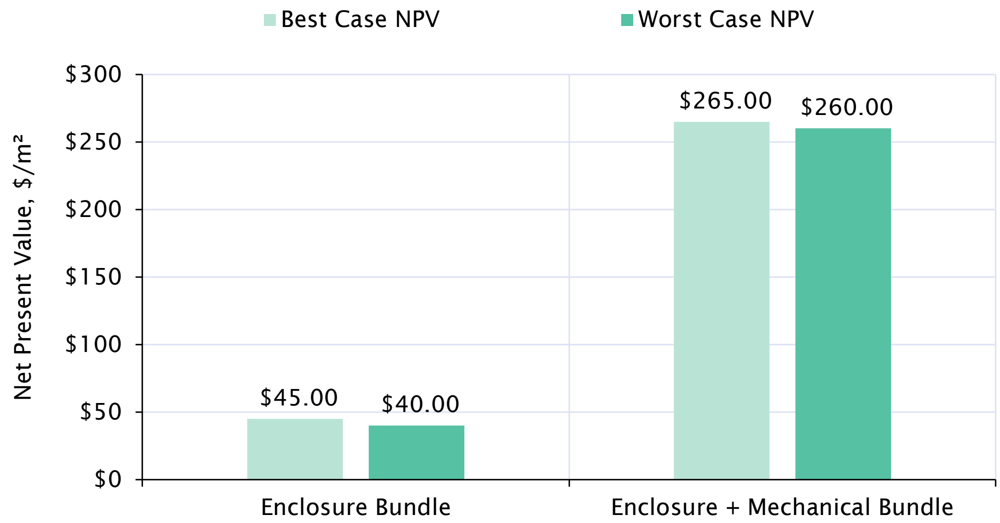


Figure 3.16 Science Lab – Net present value of ECM bundles relative to baseline scenarios (light and dark blue bars).

Because NPV is positive for both bundles, no cost per tonne of carbon abatement is observed for this archetype.

TABLE 3.13 ECONOMIC ANALYSIS FOR THE SCIENCE LAB ECM BUNDLES						
ECM Bundle	**Net Present Value ($/m²)**		**Internal Rate of Return (IRR, %)**		**Discounted Payback Period (Years)**	
	Best	**Worst**	**Best**	**Worst**	**Best**	**Worst**
Encl. Bundle	$45	$40	49%	48%	3	3
Encl. + Mech. Bundle	$265	$260	54%	52%	3	3

3.4 Lab Building

The results for the baseline archetype and the ECM bundles are provided for the high-density Lab in this section.

3.4.1 Baseline Building

Two HVAC systems were modelled for the non-lab space in the Lab building, as described in Table 2.1. The non-lab space is ventilated and conditioned via a reheat VAV system in Option 1, and through a dedicated outdoor air system with 4-pipe FCUs in Option 2. The HVAC system for the lab space is unchanged between the two options.

HVAC Option 1

Figure 3.17 shows the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Science Lab baseline archetype with HVAC Option 1 (VAV).

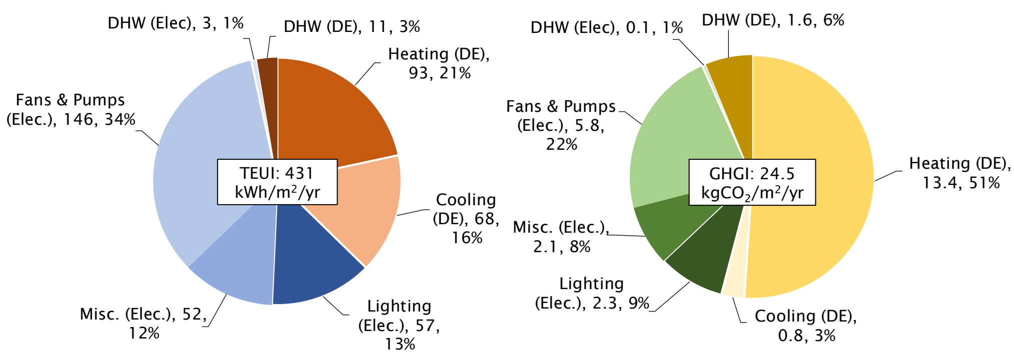


Figure 3.17 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO₂e/m²/yr) by end-use for the Lab baseline building with HVAC Option 1 (VAV).

HVAC Option 2

Figure 3.18 shows the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Lab baseline archetype with HVAC Option 2 (DOAS + FCUs).

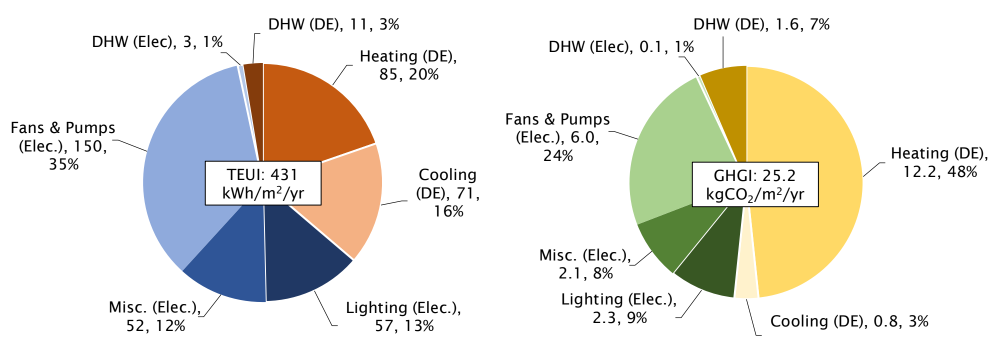


Figure 3.18 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO₂e/m²/yr) by end-use for the Lab baseline building with HVAC Option 2 (DOAS + FCUs).

Table 3.14 summarizes the Lab Building baseline model results together with UBC Vancouver's 2020 energy performance targets for comparison. The baseline energy result for DHW is in line with UBC's 2020 target; however, both HVAC options for the Lab Building exceed UBC Vancouver's 2020 TEUI and TEDI targets.

Option 2 (DOAS + FCUs) is assumed as the baseline HVAC system for subsequent analysis of ECMs and costing.

TABLE 3.14 SUMMARY OF RESULTS –LAB BASELINE BUILDING

	Lab Baseline Results	
	Option 1 – VAV System	Option 2 – DOAS + FCUs
TEUI, kWh/m²/yr	431	431
TEDI, kWh/m²/yr	93	85
DHW, kWh/m²/yr	14	14
GHG, kgCO_2e/m²/yr	25	25

The two HVAC options result in the same TEUI, for similar reasons as discussed for the Science Lab. There is a smaller difference in the breakdown of heating, fan, and cooling energy between the two HVAC options for the Lab Building compared to the Science Lab archetype. This is because a higher proportion of the energy use is associated with the lab space due to the higher fume-hood density and therefore higher energy use for ventilation and space conditioning. As such, the different HVAC system for the non-lab space has a smaller impact on the total energy use of the building.

3.4.2 ECM Bundles and Results

Similar to the Science Lab archetype, the dominant energy end use is fan energy, followed by heating and cooling, and the GHGI is dominated by space heating. The fan energy and space heating energy are higher per floor area than the Science Lab archetype due to the higher lab ventilation requirements.

As for the Science Lab archetype, the Enclosure bundle focuses on improving the enclosure thermal performance and the Enclosure + Mechanical bundle focuses on fan energy and heating demand reduction via reduced lab ventilation rates and variable speed fans.

The baseline lab ventilation rate for this archetype is air change driven. However, the fume hood exhaust requirement is slightly higher than the minimum air change rate that the Aircuity technology allows for both occupied and unoccupied conditions. This means that the ventilation rate cannot be reduced as much as for the Science lab. In practice, the ventilation rate can be reduced further if the lab is not used as much as it has been modelled, and/or if occupants are trained to close fume hoods when they are not in use.

TABLE 3.15 SUMMARY OF ECM BUNDLES – LAB BUILDING		
	Enclosure Bundle	**Enclosure + Mechanical Bundle**
ECMs	→ Fixed windows, U-0.14 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa → Fixed exterior shades → Reduced window-to-wall ratio to 25%	Enclosure Bundle + → Variable speed FCUs, decouple FCUs and DOAS → Nighttime free cooling → Install Aircuity sensors to reduce lab ventilation rate → Make-up air provided to lab from non-lab space → Variable speed rooftop fan for stack exhaust

Energy and GHG Results

Figure 3.19 and Figure 3.20 show the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Enclosure and Enclosure + Mechanical bundle, respectively.

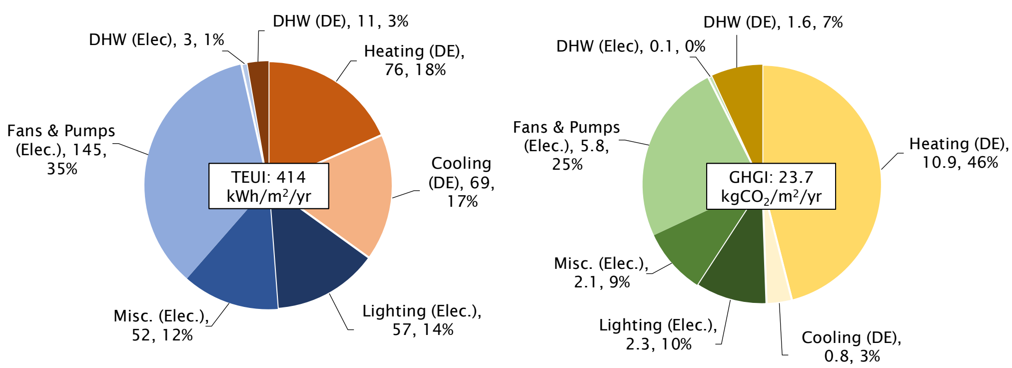


Figure 3.19 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO2e/m²/yr) by end-use for the Lab Enclosure Bundle.

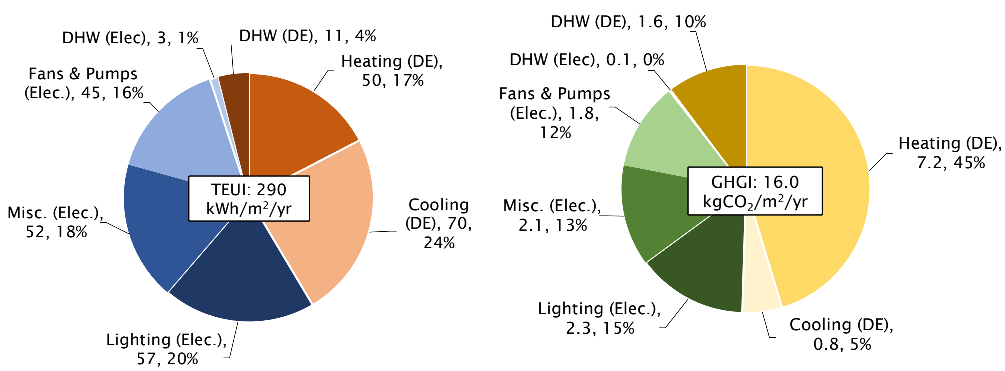


Figure 3.20 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity ($kgCO_2e/m^2/yr$) by end-use for the Lab Enclosure + Mechanical Bundle.

The Enclosure and Enclosure + Mechanical bundle results are summarized below, together with the baseline results. The TEUI, GHGI, and TEDI results are presented by space-type below the whole building results, and the DHW energy consumption, peak heating, peak cooling, and annual peak electricity results are provided per space type in Appendix D. The corridors are embedded in the results and the space type results are normalized by the whole building area, as described in Section 2.4.

TABLE 3.16 SUMMARY OF BASELINE AND ECM RESULTS – LAB			
	Baseline	Enclosure	Enclosure + Mechanical
TEUI, kWh/m²/yr	431	414	290
Lab	570	547	381
Classroom	168	153	177
Office	130	113	138
GHGI, $kgCO_2e/m^2/yr$	25	24	16
Lab	35	33	22
Classroom	8	7	12
Office	7	5	9
TEDI, kWh/m²/yr	85	76	50
Lab	118	108	72
Classroom	14	7	45
Office	16	8	39
DHW, kWh/m²/yr	14	14	14
Annual Peak Heating DES, W/m²	56	45	31
Annual Peak Cooling DES, W/m²	82	72	53
Annual Peak Electricity, W/m²	39	38	31

1 Total Energy Use Intensity (TEUI) and Greenhouse Gas Intensity (GHGI) per space type area

As discussed for the Science Lab, the Enclosure bundle for the Lab space results in smaller relative heating demand reductions due to the high ventilation heat losses and the Enclosure + Mechanical bundle results in significant fan and heating energy reductions due to the reduced ventilation requirements achieved with Aircuity sensors as well as the switch from constant to variable speed fans.

The TEUI is higher for the Lab Building compared to the Science Lab for all model scenarios. This is because the corridor fraction is lower and therefore the loads such as lighting and plug loads are higher per total floor area.

The Enclosure + Mechanical bundle results in lower TEUI reductions for the Lab space type compared to the Science Lab, mainly because of lower heating and fan energy reductions. This is because the lab air flow rate cannot be reduced as much as the Science lab, as discussed previously in this section.

Modified Bundle Results

The Lab Building in this study is utilizing a glycol run-around loop to recover heat from the lab exhaust air. Glycol run-around heat recovery consists of two separate coils installed between the outdoor air supply and the exhaust air streams. The two coils are connected by piping that exchanges heat via a water/glycol mixture. Glycol is used to guard against freezing during winter. In labs this system is used to prevent exhausted air from contaminating the outdoor air stream. However, this solution allows for a relatively low heat recovery efficiency of approximately 40%. Another solution to recover heat from the exhaust air is to install a heat recovery chiller serving a cooling coil in the exhaust air and reject the heat to the heating loop to reduce the heating demand on the district heating system (aka “active” heat recovery).

To understand the difference between the two heat recovery solutions, the glycol run around loop was replaced by active heat recovery in the Enclosure + Mechanical Bundle. The results show that the active heat recovery is beneficial in terms of energy consumption and greenhouse gas emissions. However, the Enclosure + Mechanical Bundle with active heat recovery show a significantly higher TEDI than the glycol run around loop scenario. This is because the active heat recovery measure does not directly reduce the heating demand of the space, as discussed in Section 0, and therefore does not reduce TEDI.

TABLE 3.17 COMPARISON OF LAB BUILDING ENCLOSURE + MECHANICAL BUNDLE WITH GLYCOL RUN AROUND LOOP VERSUS ACTIVE HEAT RECOVERY

	Enclosure + Mechanical Bundle		Energy / GHG Increase for active heat recovery[1] (%)
	Glycol run around loop	Active heat recovery	
TEUI, kWh/m²/yr	290	274	-6%
GHGI, $kgCO_2e/m^2/yr$	16.0	13.1	-18%
TEDI, kWh/m²/yr	50	91	81%
Heating energy - DE, kWh/m²/yr	50	28	-44%
Heat recovery chiller cooling energy kWh/m²/yr	-	6	-
Annual Peak Heating DES, W/m²	31	27	-13%
Annual Peak Cooling DES, W/m²	53	53	0%
Annual Peak Cooling Heat recovery chiller, W/m²	-	9	-
Annual Peak Electricity, W/m²	31	31	0%

1) Increase in energy and GHG metrics for the Enclosure + Mechanical bundle with active heat recovery instead of glycol run-around loop. A negative value means that there was a reduction.

Financial Results

The incremental capital costs (ICCs) for the Lab building ECM bundles are presented in Figure 3.21. Again, the range between best and worst case costs were small for both bundles.

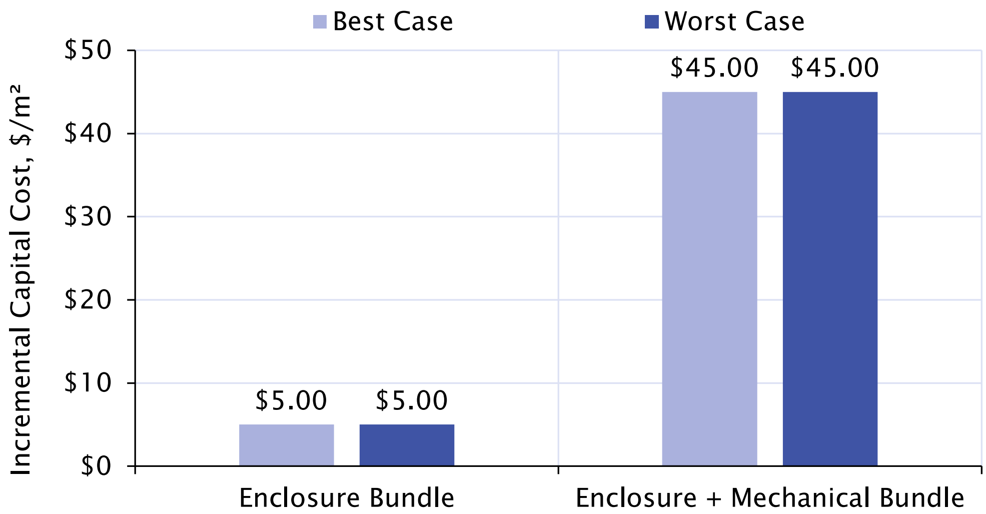


Figure 3.21 Lab Building - Incremental Capital Cost (light and dark blue bars for best and worst case, respectively) of ECM bundles compared to the baseline scenario.

In the Enclosure bundle, the major cost drivers are again the additional roof insulation and the fixed exterior shades being added to the windows, with these costs being partially offset by the reduced window-to-wall ratio (40 to 25%).

Again, the nighttime free cooling is assumed to be no additional cost over baseline.

Similar to the Science Lab, the additional of the Aircuity sensors are a significant cost driver in the Enclosure + Mechanical bundle, due to the various components required and the installation and implementation of the system.

Also similar to the Science Lab, the Enclosure + Mechanical bundle includes variable speed rooftop fans for stack exhaust that have not been included in the financial analysis.

The NPV for each bundle is shown Figure 3.22. Additional financial analysis details are provided in Table 3.18.

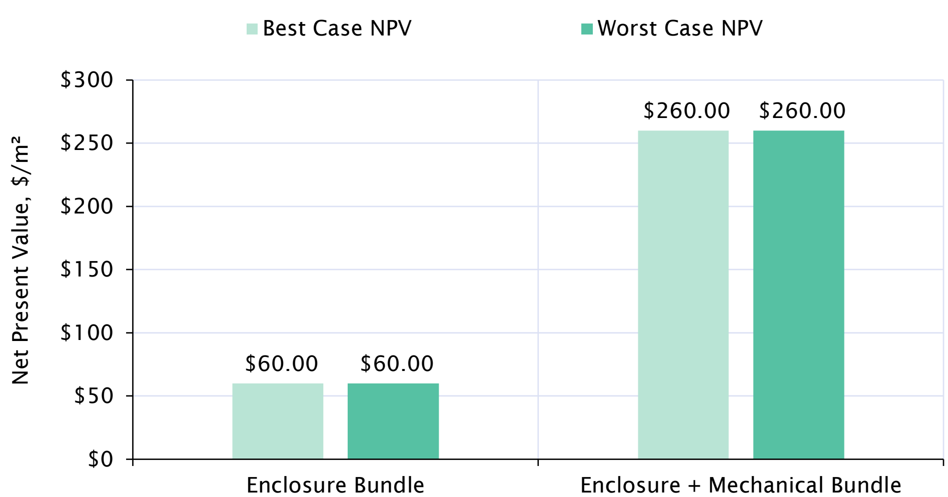


Figure 3.22 Lab Building – Net present value of ECM bundles relative to baseline scenarios (light and dark blue bars).

Because NPV is positive for both bundles, no cost per tonne of carbon abatement is observed for this archetype.

TABLE 3.18 ECONOMIC ANALYSIS FOR THE LAB BUILDING ECM BUNDLES						
ECM Bundle	**Net Present Value ($/m²)**		**Internal Rate of Return (IRR, %)**		**Discounted Payback Period (Years)**	
	Best	**Worst**	**Best**	**Worst**	**Best**	**Worst**
Encl. Bundle	$60	$60	62%	60%	2	2
Encl. + Mech. Bundle	$260	$260	42%	40%	3	3

3.5 Classroom Office

The results for the baseline archetype and the ECM bundles are provided for Classroom and Office Building in this section.

3.5.1 Baseline Building

Two HVAC options have been modelled for the Classroom and Office archetype, as described in Table 2.1. The Classroom and Office archetype is ventilated and conditioned via a reheat VAV system in Option 1, and through a dedicated outdoor air system with 4-pipe FCUs in Option 2.

HVAC Option 1

Figure 3.23 shows the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Classroom and Office baseline archetype with HVAC Option 1 (VAV).

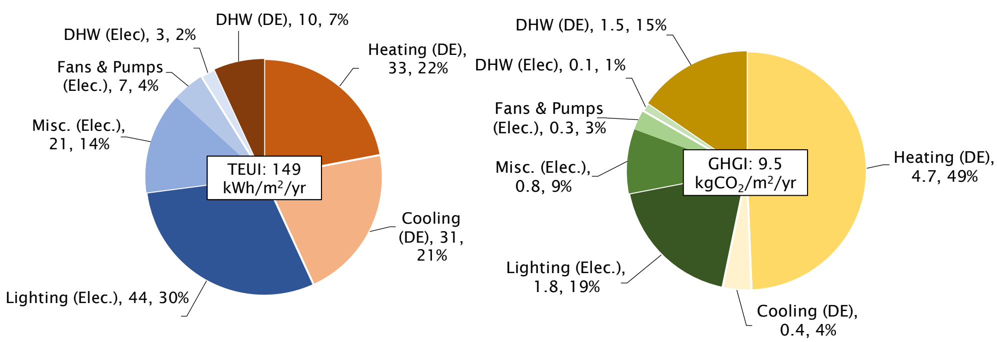


Figure 3.23 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity ($kgCO_2e/m^2/yr$) by end-use for the Classroom and Office baseline building with HVAC Option 1 (VAV).

HVAC Option 2

Figure 3.24 shows the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Classroom and Office baseline archetype with HVAC Option 2 (DOAS + FCUs).

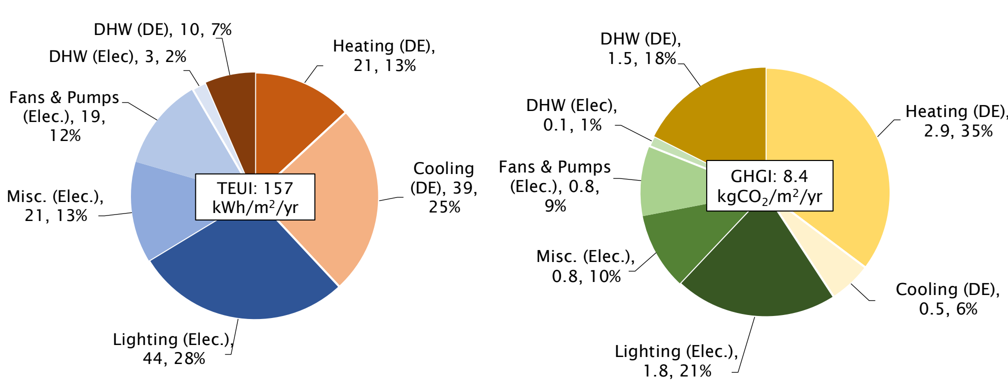


Figure 3.24 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity ($kgCO_2e/m^2/yr$) by end-use for the Classroom and Office baseline building with HVAC Option 2 (DOAS + FCUs).

Table 3.19 summarizes the Classroom and Office Building baseline model results. Option 2 (DOAS + FCUs) is assumed as the baseline HVAC system for subsequent analysis of ECMs and costing.

TABLE 3.19 SUMMARY OF RESULTS – CLASSROOM AND OFFICE BUILDING		
	Classroom Office Baseline Results	
	Option 1 – VAV system	Option 2 – DOAS + FCUs
TEUI, kWh/m²/yr	149	157
TEDI, kWh/m²/yr	33	21
DHW, kWh/m²/yr	13	13
GHG, kgCO_2e/m²/yr	10	8

The different HVAC options for the Classroom and Office archetype show a greater difference in TEUI and GHGI compared to the lab archetypes. Option 1 (VAV) results in a lower TEUI but a higher GHGI compared to Option 2 (DOAS + FCUs). The reduced heating energy consumption seen for the DOAS system compared to the VAV system is offset by higher fan and cooling energy, due to constant speed fans and lack of free-cooling mode. The higher GHGI seen for Option 1 (VAV) is because of the reheat at zone level.

3.5.2 ECM Bundles and Results

The dominant energy end use for the Classroom and Office Building archetype is lighting, followed by space conditioning (heating and cooling). Heating dominates the emission end uses. Lighting measures such as integrated LED luminaries and occupancy sensors are included in the baseline and further lighting reductions are not anticipated. Instead, the ECMs focus on reducing heating and cooling demand as those have a more significant impact on GHG emissions. The Enclosure package focuses on reducing heating and cooling demand by improving the thermal performance of the enclosure and adding passive cooling measures.

The Enclosure + Mechanical bundle focuses on reducing the heating and cooling demand via high-performance HRV units with improved heat recovery effectiveness and the ability to bypass the heat exchanger to avoid overheating the space. Decoupling of the FCUs and DOAS further reduces the heating and cooling energy, as well as fan energy (as the FCUs can now be turned off when there is a call for ventilation but not for heating or cooling). The Enclosure + Mechanical bundle also focuses on reducing domestic hot water energy consumption by implementing heat pumps for top-up.

TABLE 3.20 SUMMARY OF ECM BUNDLES – CLASSROOM AND OFFICE		
	Enclosure Bundle	**Enclosure + Mechanical Bundle**
ECMs	→ Fixed windows, U-0.14 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa → Fixed exterior shades → Reduced window-to-wall ratio to 25%	Enclosure Bundle + → 90% efficient centralized HRV with bypass → Nighttime free cooling → Variable speed FCUs, decoupling of FCUs and DOAS → Water-source heat pump for DHW top-up

Energy and GHG Results

Figure 3.25 and Figure 3.26 show the distribution of total energy use intensity and greenhouse gas intensity by end-use for the Enclosure and Enclosure + Mechanical bundle, respectively.

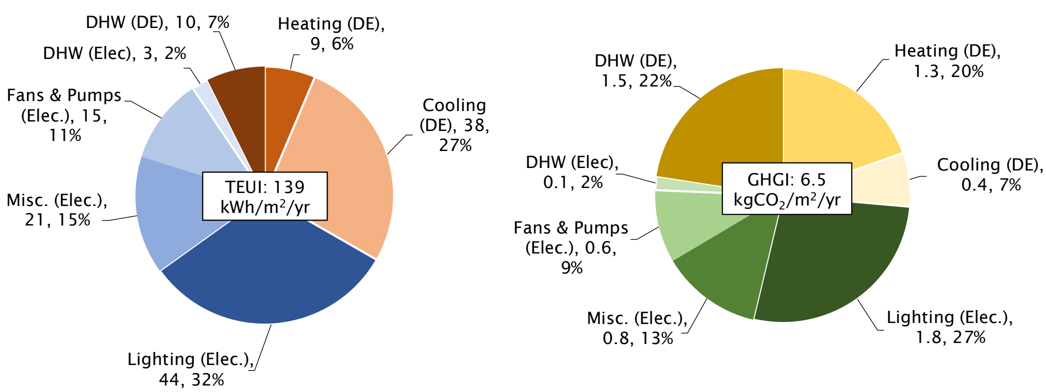


Figure 3.25 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO2e/m²/yr) by end-use for the Classroom and Office Enclosure Bundle.

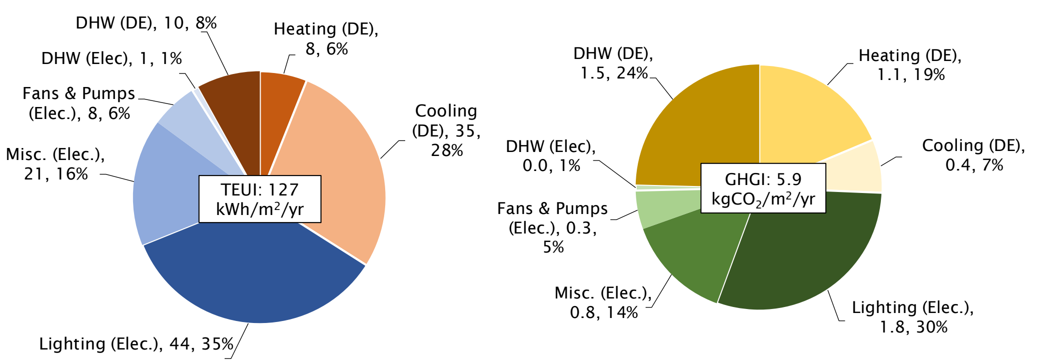


Figure 3.26 Total energy use intensity (kWh/m²/yr) and greenhouse gas emission intensity (kgCO2e/m²/yr) by end-use for the Classroom and Office Enclosure + Mechanical Bundle.

The Enclosure and Enclosure + Mechanical bundle results are summarized below, together with the baseline results. The TEUI, GHGI, and TEDI results are presented by space-type below, and the DHW energy consumption, peak heating, peak cooling, and annual peak electricity results are provided per space type in Appendix D. The corridors are embedded in the results and the space type results are normalized by the whole building area, as described in Section 2.4.

TABLE 3.21 SUMMARY OF BASELINE AND ECM RESULTS – CLASSROOM AND OFFICE			
	Baseline	Enclosure	Enclosure + Mechanical
TEUI, kWh/m²/yr	157	139	127
Classroom	166	149	138
Office	131	113	98
GHGI, kgCO_2e/m²/yr	8	6	6
Classroom	9	7	7
Office	8	5	5
TEDI, kWh/m²/yr	21	9	8
Classroom	19	8	7
Office	24	11	10
DHW, kWh/m²/yr	13	13	11
Annual Peak Heating DES, W/m^2	42	32	29
Annual Peak Cooling DES, W/m^2	51	39	39
Annual Peak Electricity, W/m^2	21	20	19

As seen for the residence archetypes, the Enclosure bundle results in reduced heating and cooling demand. The Enclosure + Mechanical bundle results in further heating and cooling demand reductions, as well as fan energy and DHW top-up energy reductions.

The Classroom and Office archetype achieves a lower TEDI than the residence archetypes. One of the reasons is the wall to roof ratio: the Classroom and Office wall to roof ratio is close to 1:1, whereas the residence archetypes have a wall to roof ratio closer to 3:1, and as such, the improved roof R-value has a higher impact on TEDI for the Classroom and Office archetype. Further, since the windows are assumed to be fixed (non-operable) the U-value that can be achieved is lower than the U-value seen for the operable windows in the residence archetypes, which contributes to a higher overall enclosure thermal performance. In contrast to the residence archetypes, the HVAC system is not operating 24/7, which reduces the ventilation heat losses and need for space conditioning. The ventilation heat losses are also lower for the Classroom and Office archetype since it does not have direct make-up air supplying the corridors; instead, the system is balanced via the heat recovery units.

In contrast, the classroom and office space type TEDI and TEUI are higher than the classroom and office spaces in the two lab archetypes. This is mainly because the Classroom and Office archetype has a higher form factor (enclosure to floor area ratio) than the lab archetypes, resulting in higher enclosure heat losses per floor area.

As discussed for the Science Lab, the classroom TEUI is higher than the office TEUI due to higher loads.

Modified Bundle Results

As with the Student Residence, the impact of the window-to-wall ratio was analyzed for the Classroom and Office archetype. Similar to the Student Residence archetype, the results show that reducing the window-to-wall ratio is beneficial in terms of reducing energy consumption and peak demand. However, the increase in energy and GHGI is smaller for the Classroom and Office archetype. This is because the window-to-wall ratio is reduced less for the Classroom and Office archetype (from 40% to 25%), compared to the Student Residence archetype (from 40% to 20%). Further, the Classroom and Office archetype has a higher building ventilation rate, and therefore a lower portion of the heat loss is associated with the enclosure losses.

TABLE 3.22 CLASSROOM AND OFFICE ENCLOSURE BUNDLE WITH AND WITHOUT WINDOW TO WALL RATIO REDUCTION

	Enclosure bundle		Energy / GHG Increase[1] (%)
	With reduced WWR (25% WWR)	**Without** reduced WWR (40% WWR)	
TEUI, kWh/m²/yr	139	144	3%
GHGI, kgCO_2e/m²/yr	6	7	2%
TEDI, kWh/m²/yr	9	9	6%
Cooling energy, kWh/m²/yr	38	41	9%
Fan energy, kWh/m²/yr	15	16	6%
Annual Peak Heating DES, W/m²	32	34	4%
Annual Peak Cooling DES, W/m²	39	45	14%
Annual Peak Electricity, W/m²	20	21	2%

1) Increase in energy and GHG metrics for the Enclosure bundle without reduced WWR compared to the Enclosure bundle with reduced WWR

Financial Results

The incremental capital costs (ICCs) for the Classroom Office ECM bundles are presented in Figure 3.27. The range between best and worst case costs were small for the Enclosure bundle.

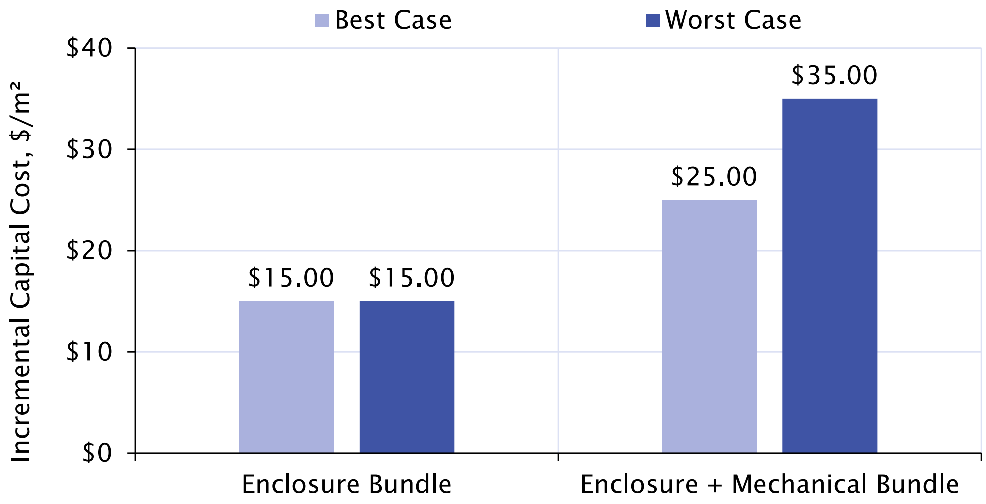


Figure 3.27 Classroom Office - Incremental Capital Cost (light and dark blue bars for best and worst case, respectively) of ECM bundles compared to the baseline scenario.

In the Enclosure bundle, the major cost drivers are again the additional roof insulation and the fixed exterior shades being added to the windows, with these costs being partially offset by the reduced window-to-wall ratio.

Similar to the two lab archetypes, the nighttime free cooling is assumed to be no additional cost over baseline.

In the Enclosure + Mechanical bundle, the water-source heat pump used for top-up is a major cost driver for this archetype. Similar to the Student Residence and Campus Housing, the water-source heat pumps available in the market are generally larger than needed for the DHW system and are thus oversized compared to what would be required for top-up. The 90% efficient centralized HRV with bypass is another cost driver.

The NPV for each bundle is shown Figure 3.28. Both bundles result in a positive NPV. Similar to the other archetypes, the positive NPV for the Enclosure bundle results from the energy savings gained by the improved enclosure. The positive NPV for the Enclosure + Mechanical bundle results from the combination of the high-performance enclosure and the energy efficient mechanical equipment. Additional financial analysis details are provided in Table 3.23. Because NPV is positive for both bundles, no cost per tonne of carbon abatement is observed for this archetype.

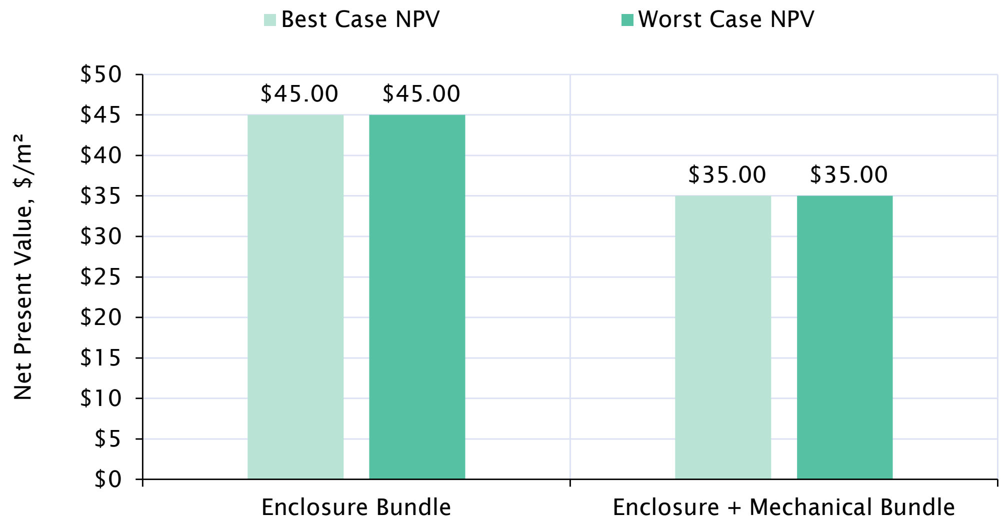


Figure 3.28 Classroom Office – Net present value of ECM bundles relative to baseline scenarios (light and dark blue bars).

TABLE 3.23 ECONOMIC ANALYSIS FOR THE CLASSROOM OFFICE ECM BUNDLES						
ECM Bundle	**Net Present Value ($/m²)**		**Internal Rate of Return (IRR, %)**		**Discounted Payback Period (Years)**	
	Best	**Worst**	**Best**	**Worst**	**Best**	**Worst**
Encl. Bundle	$50	$45	33%	30%	4	4
Encl. + Mech. Bundle	$50	$35	20%	14%	6	9

4 Existing Building Considerations

All of the buildings on UBCO's campus are relatively new. The original campus buildings were constructed in 1992, with significant additions around 2010. The 1992 era buildings are heated by the district medium and low temperature energy systems. Cooling is typically provided by air source chillers at each building and equipment is being upgraded over time to enable broader use of the low temperature DES for heating. The newer non-residential buildings are typically heated and cooled by water source heat pumps supplied by the DES, with packaged gas fired boilers for supplemental heat, peaking and backup.

For the residential buildings, only the newest residence is connected to the DES (low temp), which supplies a WSHP to 4-pipe hydronic distribution system. Domestic hot water is pre-heated by the ASHP, then topped up by gas boilers. The other newer residence has a standalone ASHP supplying a 4-pipe hydronic system with electric boiler backup. The ASHP + boiler backup also heats the DHW. The other residences commonly have packaged equipment for heating of common areas and PTACs for dorm rooms.

Windows and curtainwall are typically thermally broken double glazed, aluminum framed. Brick veneer and conventional metal framing with fibreglass batts in the stud walls and a small amount of continuous insulation outboard of the stud walls is a common wall assembly for the original campus buildings. Interior polyiso typically acts as the air barrier (with air sealing issues identified in the Administration Building Enclosure Report by Williams Engineering).

Below is a summary of typical energy use intensity by existing building category, compared to the modelled new building EUIs identified in this report.

TABLE 4.1 COMPARISON OF EXISTING AND NEW BUILDING ENERGY USE INTENSITY

Building Type	**Energy Use Intensity (kWh/m^2/yr)**			
	2020 Existing Baseline - Actual*	**New building – Modelled Baseline**	**New building + enclosure ECMs**	**New building + enclosure + mech ECMs**
Residence (no kitchens)	142	136	113	97
High Fume Hood Density Lab	443	431	414	290
Low Fume Hood Density Lab	315	335	321	217
Classroom/Office	163	157	139	127

*Baseline EUI is as reported in the Energy Team report excerpt provided by UBCO.

Existing building performance at UBCO is comparable to the modelled baselines, and compares favourably to existing building databases. For example, ASHRAE 100-2018 Energy Efficiency in Existing Buildings, sets the following energy use intensity targets for comparable building use types (Climate Zone 5C):

TABLE 4.2 ASHRAE 100 EUI TARGETS (40^{TH} AND 25^{TH} PERCENTILE)		
Building Use Type	**40^{th} PERCENTILE, kWh/m²*yr**	**25^{th} PERCENTILE EUI, kWh/m²*yr**
Apartment, 5+ units	165	131
Dormitory	198	163
Laboratory	693	571
College/University	249	205
Admin/Professional Office	150	124
Government Office	188	154

The targets listed above represent the top performing 40^{th} and 25^{th} percentile of commercial buildings within the U.S. Commercial Building Energy Consumption Survey (CBECS) database. The definitions of building types in ASHRAE 100 (and the CBECS) database do vary from the building types defined in this study, although they can be used as reference points. These values could also be compared to the space type EUI breakouts provided for the new building analysis to establish area-weighted existing building targets (the area weighted method aligns with the ASHRAE 100 methodology for target setting).

4.1 Applicable ECMs by Building Type

Below are summaries and considerations for applying the previously modelled ECMs to existing buildings on campus.

Enclosure measures for existing buildings are typically only recommended when renewals are already planned to address end-of-life or failed components. Window systems in the oldest buildings will now be 30+ years old and may be failing. It is recommended that high performing walls, roofs, and windows (with similar U-values as the new building standards), and low SHGC glazing be considered at the time of window renewal. Buildings that have apparent solar heat gain issues (e.g. very high cooling demand in summer and/or numerous complaints) may consider the addition of passive solar strategies, which could be considered at any time. For mechanical measures, the viable strategies will depend on the system installed at a given building.

In addition to the measures described in the tables below, it is recommended that all existing building projects consider the following at time of renewal:

→ Ensure that any new HVAC and domestic hot water equipment is compatible with the DES

→ Connect existing systems to the DES where feasible

→ Implement demand controlled systems where possible

→ Update M&V practices to align with UBCO technical guidelines and standards

TABLE 4.3 SUMMARY OF POTENTIAL ECMS– EXISTING STUDENT RESIDENCE

Easy/Low Cost – do any time	Recommended at Time of Renewal	Challenging or Infeasible
→ Nighttime free cooling → Corridor supply air temperature nighttime setback	→ Operable windows, U-0.17 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa – recommend a less stringent target to be met at time of enclosure renewal → Water-source heat pump for DHW top-up → Domestic hot water heat recovery – could be done anytime if current piping configuration/placement allows	→ 90% efficient centralized HRV with bypass – if not already present, will need to consider duct routing options. Typically only recommended to resolve ventilation or condensation issues given cost and installation challenges. → Reduced window-to-wall ratio to 20% - changes to basic building form are not considered viable in most cases → Fixed exterior shades – structural, cost, thermal bridging implications. Recommend considering other ways to reduce solar

TABLE 4.3 SUMMARY OF POTENTIAL ECMS– EXISTING STUDENT RESIDENCE		
		heat gain (operable shades, landscaping, etc.)

TABLE 4.4 SUMMARY OF POTENTIAL ECMS – EXISTING CAMPUS HOUSING		
Easy/Low Cost – do any time	**Recommended at Time of Renewal**	**Challenging or Infeasible**
→ Nighttime free cooling → Corridor supply air temperature nighttime setback	→ Res: Operable windows, U-0.17 → CRU: Fixed windows, U-0.14 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa – recommend a less stringent target to be met at time of enclosure renewal → Water-source heat pump for DHW top-up → Domestic hot water heat recovery – could be done anytime if current piping configuration/placement allows	→ 90% efficient centralized HRV with bypass – if not already present, will need to consider duct routing options. Typically only recommended to resolve ventilation or condensation issues given cost and installation challenges. → Reduced window-to-wall ratio to 20% - changes to basic building form are not considered viable in most cases → Fixed exterior shades – structural, cost, thermal bridging implications. Recommend considering other ways to reduce solar heat gain (operable shades, landscaping, etc.)

TABLE 4.5 SUMMARY OF POTENTIAL ECMS – EXISTING SCIENCE LAB		
Easy/Low Cost – do any time	**Recommended at Time of Renewal**	**Challenging or Infeasible**
→ Nighttime free cooling	→ Fixed windows, U-0.14 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa – recommend a less stringent target to be met at time of enclosure renewal → Install Aircuity sensors to reduce lab ventilation rate - could be done anytime, although if lab spaces not already using VAV system, will need to retrofit. → Variable speed rooftop fan for stack exhaust – good option for strobic fans, although not needed if system uses high stacks	→ Reduced window-to-wall ratio to 25% - changes to basic building form are not considered viable in most cases → Fixed exterior shades – structural, cost, thermal bridging implications. Recommend considering other ways to reduce solar heat gain (operable shades, landscaping, etc.) → Make-up air provided to lab from non-lab space – viability will depend on existing space and ducting configuration as well as controls and scheduling capabilities → Variable speed FCUs, decouple FCUs and DOAS

TABLE 4.6 SUMMARY OF POTENTIAL ECMS – EXISTING LAB BUILDING		
Easy/Low Cost – do any time	**Recommended at Time of Renewal**	**Challenging or Infeasible**
→ Nighttime free cooling	→ Fixed windows, U-0.14 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa – recommend a less stringent target to be met at time of enclosure renewal → Install Aircuity sensors to reduce lab ventilation rate - could be done anytime, although if lab spaces not already using VAV system, will need to retrofit. → Variable speed rooftop fan for stack exhaust – good option for strobic fans, although not needed if system uses high stacks	→ Reduced window-to-wall ratio to 25% - changes to basic building form are not considered viable in most cases → Fixed exterior shades – structural, cost, thermal bridging implications. Recommend considering other ways to reduce solar heat gain (operable shades, landscaping, etc.) → Make-up air provided to lab from non-lab space – viability will depend on existing space and ducting configuration as well as controls and scheduling capabilities

TABLE 4.7 SUMMARY OF POTENTIAL ECMS – EXISTING CLASSROOM AND OFFICE		
Easy/Low Cost – do any time	**Recommended at Time of Renewal**	**Challenging or Infeasible**
→ Nighttime free cooling	→ Fixed windows, U-0.14 → Walls R-30 → Roof R-45 → Airtightness – 0.6 ACH @ 50Pa – recommend a less stringent target to be met at time of enclosure renewal → Water-source heat pump for DHW top-up	→ 90% efficient centralized HRV with bypass – if not already present, will need to consider duct routing options → Reduced window-to-wall ratio to 25% - assume no changes to basic building form → Fixed exterior shades – structural, cost, thermal bridging implications. Recommend considering other ways to reduce solar heat gain (operable shades, landscaping, etc.)

5 Closure

We trust this report adequately summarizes the ECMs and performance potential of the five archetypes representative of UBCO new construction buildings, along with considerations for existing buildings.

Yours truly,

Christina Love Digitally signed by Christina Love Date: 2021.12.22 17:12:51-08'00'

Malin Ek | M.Sc., CPHD
Climate Change Analyst
mek@rdh.com
T 778-370-6912
RDH Building Science Inc.

Reviewed by
Christy Love | P.Eng., CPHC
Principal, Senior Project Manager
clove@rdh.com
T 778-557-7042
RDH Building Science Inc.

Appendix A
Detailed List of Assumptions

GENERAL

Project Name	9639.010 UBCO Archetype Study
Archetype	Student Residence
Construction Year	New Construction (2020 Baseline)
Site Location	Kelowna, BC
Weather File	Kelowna CWEC 2016
Software	OpenStudio v.2.7.0

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Building Summary	**Baseline**	**Units**	**Reference/Description**
Storeys	6	-	Model geometry from UBC Net Positive Modelling Study (2016 06 27)
Breakdown of Space Type	90% Residential 10% Corridor/Lobby	-	
Conditioned Floor Area	4,700	m²	
Number of Suites	48		
Aveage Suite Size	88	m²	
Average # of Bedrooms per Suite	3	-	
Enclosure Performance	**Baseline**	**Units**	**Reference/Description**
Exterior Wall Above Grade	0.278	m^2-K/W	R-20. Wood frame with exterior insulation (NECB 2015)
Suspended Slab	0.183	m^2-K/W	R-31. Slab on grade (NECB 2015)
Main Roof	0.183	m^2-K/W	R-31. Flat roof with rigid insulation (NECB 2015)
Fenestration		**Units**	**Reference/Description**
Window-to-Wall Ratio (WWR)	40%	%	
Windows Installed Overall U-value	2.20	W/m^2-K	NECB 2015
Window Installed Overall SHGC	0.38	-	
Infiltration		**Units**	**Reference/Description**
Infiltration Rate	2.0	L/s/m² @ 75Pa	UBC Modelling Guidelines v2.0
Mechanical			
HVAC Summary	**Baseline**	**Units**	**Reference/Description**
Ventilation System Description	Constant volume in-suite 4-pipe FCUs connected to district energy system providing heating and cooling to suites, controlled via local thermostats. Ventilation provided by in-suite HRVS. Corridor pressurization through make-up air units providing tempered outdoor air.		
Heating/Cooling System Description			
Heating/Cooling Plant	**Baseline**	**Units**	**Reference/Description**
System Description			
System Description	District energy system for heating and cooling	-	
Plant Efficiency	100%	%	
Hot Water Supply/Return Temperature	60˚C (140˚F) / 38˚C (100˚F)	˚C (˚F)	
Cold Water Supply/Return Temperature	6.7˚C (44˚F) / 13.3˚C (56˚F)	˚C (˚F)	
Pumps			
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	
Domestic Water Heating	**Baseline**	**Units**	**Reference/Description**
System Description	Central storage tank system, district energy connection with electric water heater for top-up.	-	
Plant Efficiency	100%	-	
Building Peak Load	0.14	l/s	Based on 0.001 l/s/person, delta T of 82F. UBC Energy Modeling Guidelines v2.0.
Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 Appendix A - A.2.1
DHW Hot Water Supply Temperature	60˚C (140˚F)	˚C (˚F)	
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	

Airside System Description	Baseline	Units	Reference/Description
System Description	Outdoor air delivered via centralized HRVs to FCUs. Make-up air units provide outdoor air to corridors for pressurization.	-	
Suite System			
System Description	Centralized HRVs	-	Ducting outdoor air to local FCUs
Outdoor Air Rate	23 (45) / suite Total = 1080 (2160)	l/s (cfm)	7.5 l/s/person (15 cfm/person) ASHRAE 62.1-2001 (per UBC Energy Modelling Guidelines v.2.0)
Fan Type	Constant Air Volume	-	
Fan Power - Supply	0.50	W/cfm	
Fan Power - Exhaust	0.50	W/cfm	Exhausts from bathroom continuously
Fan Schedule	On 24/7	-	
Heat Recovery Effectiveness	0.70	%	
Corridor System			
Outdoor Air Rate	453 (960)	l/s (cfm)	Based on 20 cfm/suite
Fan Type	Constant Air Volume	-	
Fan Power	0.65	W/cfm	
Fan Schedule	On 24/7	-	
Heat Recovery Effectiveness	n/a	%	
Heating Type	Hydronic cooling coil connected to district energy system	-	
Heating Efficiency	-	-	
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	-	
Supply Air Temperature	20˚C (68˚F)	˚C (˚F)	Tempered supply air
Zone Heating / Cooling Devices	Baseline	Units	Reference/Description
System Description	In-suite 4-pipe FCUs	-	
Design Air Flow	Autosized	-	Re-circulate to meet heating/cooling
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35˚C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8˚C (55˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Fan Type	Constant Air Volume	-	
Fan Schedule	On 24/7	-	
Fan Power	0.3	W/cfm	

Lighting and Process Loads

Lighting	Baseline	Units	Reference/Description
Residential Suite - Lighting Power Density	5.0	W/m²	BC Hydro Energy Modeling Guideliens Section 5.6 (per UBC Energy Modelling Guidelines v2.0)
Residential Suite - Schedule	Fractional	-	
Corridor - Lighting Power Density	5.3	W/m²	25% below ASHRAE 90.1-2013 Table 9.6.1 to account for LED and occupancy sensors
Corridor - Schedule	Fractional	-	
Process Loads	**Baseline**	**Units**	**Reference/Description**
Residential Suite - Plug Loads	2.68	W/m²	Low-density load: No in-suite laundry, no dishwashers. BC Hydro Energy Modeling Guideliens Section 5.6 (per UBC Energy Modelling Guidelines v2.0)
Residential Suite - Schedule	Fractional	-	
Elevator	2 elevators @ 14.6 kW/each	-	BC Hydro Energy Modeling Guidelines Section 5.8
Occupancy	**Baseline**		
Occupant Density	0.034	Occupant/m²	3 ppl per suite
Occupant Schedule	Fractional	-	NECB 2011 Table A-8.4.3.2.(1)G (per UBC Energy Modeling Guidelines v2.0)
Heating/Cooling Setpoint/Setback	**Baseline**		
Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
Cooling Setpoint/Setback	25 / 26	˚C	UBC Energy Modeling Guidelines v2.0

GENERAL

Project Name	9639.010 UBCO Archetype Study
Archetype	Campus Rental Housing
Construction Year	New Construction (2020 Baseline)
Site Location	Kelowna, BC
Weather File	Kelowna CWEC 2016
Software	OpenStudio v.2.7.0

ARCHITECTURAL

Building Summary	**Baseline**	**Units**	**Reference/Description**
Storeys	6	-	Model geometry from UBC Net Positive Modelling Study (2016 06 27)
Breakdown of Space Type	L1: 100% Commercial Retail Units (CRU), non-food retail L2-L6: 90% Residential, 10% Corridor/Lobby	-	
Conditioned Floor Area	4,700	m²	
Number of Suites	40		
Aveage Suite Size	88	m²	
Average # of Bedrooms per Suite	2	-	
Enclosure Performance	**Baseline**	**Units**	**Reference/Description**
Exterior Wall Above Grade	0.278	m^2-K/W	R-20. L1: Concrete with exterior insulation. L2-L6: Wood frame with exterior insulation (NECB 2015)
Suspended Slab	0.183	m^2-K/W	R-31. Slab on grade (NECB 2015)
Main Roof	0.183	m^2-K/W	R-31. Flat roof with rigid insulation (NECB 2015)
Fenestration		**Units**	**Reference/Description**
Window-to-Wall Ratio (WWR)	40%	%	
Windows Installed Overall U-value	2.20	W/m^2-K	NECB 2015
Window Installed Overall SHGC	0.38	-	
Infiltration		**Units**	**Reference/Description**
Infiltration Rate	2.0	L/s/m² @ 75Pa	UBC Modelling Guidelines v2.0
Mechanical			
HVAC Summary	**Baseline**	**Units**	**Reference/Description**
Ventilation System Description	Constant volume in-suite 4-pipe FCUs connected to district energy system providing heating and cooling to suites and CRU and controlled via local thermostats. Ventialtion provided via local HRVs. Residential corridor pressurization through make-up air units providing tempered outdoor air.		
Heating/Cooling System Description			
Heating/Cooling Plant	**Baseline**	**Units**	**Reference/Description**
System Description			
System Description	District energy system for heating and cooling	-	
Plant Efficiency	100%	%	
Hot Water Supply/Return Temperature	60˚C (140˚F) / 38˚C (100˚F)	˚C (˚F)	
Cold Water Supply/Return Temperature	6.7˚C (44˚F) / 13.3˚C (56˚F)	˚C (˚F)	
Pumps			
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	
Domestic Water Heating	**Baseline**	**Units**	**Reference/Description**
System Description	Central storage tank system, district energy connection with electric water heater for top-up.	-	
Plant Efficiency	100%	-	
Building Peak Load	0.19 (residential) 0.18 (CRU)	l/s	Residential rate: 0.0016 l/s/person based on CoV Energy Modeling Guidelines v2.0. Average of 3 people per suite. 40 W/person for CRU (NECB 2015)
Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 Appendix A - A.2.1 for Residential. NECB 2015 Schedule C for CRU.
DHW Hot Water Supply Temperature	60˚C (140˚F)	˚C (˚F)	
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	

Airside System Description	Baseline	Units	Reference/Description
System Description	Outdoor air delivered via FCUs with integrated heat recovery to the suites and CRU. Direct bathroom exhaust. Make-up air units provide outdoor air to residential corridors for pressurization.	-	
Suite System			
System Description	In-suite HRVs	-	Ducting outdoor air to local FCUs
Outdoor Air Rate	23 (45) / suite Total = 900 (1907)	l/s (cfm)	7.5 l/s/person (15 cfm/person) ASHRAE 62.1-2001 (per UBC Energy Modelling Guidelines v.2.0)
Design Air Flow	autosized	-	
Fan Type	Constant Air Volume	-	
Fan Power - Supply	0.50	W/cfm	
Fan Power - Exhaust	0.50	W/cfm	Exhausts from bathroom continuously
Fan Schedule	On 24/7	-	
Heat Recovery Effectiveness	0.70	%	
Corridor System			
Outdoor Air Rate	566 (1,200)	l/s (cfm)	Based on 30 cfm/suite, higher compared to Student Residence to account for dryer and kitchen exhaust
Outdoor Air Fraction	100%	-	
Fan Type	Constant Air Volume	-	
Fan Power	0.65	W/cfm	
Fan Schedule	On 24/7	-	
Heat Recovery Effectiveness	n/a	%	
Heating Type	Hydronic cooling coil connected to district energy system	-	
Heating Efficiency	-	-	
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	-	
Supply Air Temperature	20˚C (68˚F)	˚C (˚F)	Tempered supply air
CRU			
System Description	HRV ducting OA to local FCUs		Ducting outdoor air to local FCUs
Outdoor Air Rate	1,176 (2,492)	l/s (cfm)	Based on 1.5 l/s/m^2, ASHRAE 62.1-2001 Table 2
Outdoor Air Fraction	100%	-	
Fan Type	Constant Air Volume	-	
Fan Power - Supply	0.50	W/cfm	
Fan Power - Exhaust	0.50	W/cfm	
Fan Schedule	On/Off	-	
Heat Recovery Effectiveness	0.70	%	
Zone Heating / Cooling Devices	**Baseline**	**Units**	**Reference/Description**
System Description	4-pipe FCUs	-	
Design Air Flow	Autosized	-	Re-circulate to meet heating/cooling
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8˚C (55˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Fan Type	Constant Air Volume	-	
Fan Schedule	Residential: On 24/7 CRU: On/Off	-	FCUs providing CRU cycle on at night to meet heating/cooling load
Fan Power	0.3	W/cfm	

Lighting and Process Loads

Lighting	Baseline	Units	Reference/Description
Residential Suite - Lighting Power Density	5.0	W/m²	BC Hydro Energy Modeling Guideliens Section 5.6 (per UBC Energy Modelling Guidelines v2.0)
Residential Suite - Schedule	Fractional	-	
Corridor - Lighting Power Density	5.3	W/m²	25% below ASHRAE 90.1-2013 Table 9.6.1 to account for LED and occupancy sensors
Corridor - Schedule	Fractional	-	
CRU - Lighting Power Density	15.1	W/m²	ASHRAE 90.1-2013 User's Manual - Retail
CRU - Schedule	Fractional	-	ASHRAE 90.1-2013 User's Manual - Retail
Process Loads	**Baseline**	**Units**	**Reference/Description**
Residential Suite - Plug Loads	5.00	W/m²	Medium-density load: No in-suite laundry, no dishwashers. BC Hydro Energy Modeling Guideliens Section 5.6 (per UBC Energy Modelling Guidelines v2.0)
Residential Suite - Schedule	Fractional	-	
CRU - Plug Load	3.2	W/m²	ASHRAE 90.1-2013 User's Manual Table 5-1
CRU - Schedule	Fractional	-	ASHRAE 90.1-2013 User's Manual - Retail
Elevator	2 elevators @ 14.6 kW/each	-	BC Hydro Energy Modeling Guidelines Section 5.8
Occupancy	**Baseline**		
Residential Suite - Occupant Density	0.034	Occupant/m²	3 ppl per suite
Residential Suite - Schedule	Fractional	-	NECB 2011 Table A-8.4.3.2.(1)G (per UBC Energy Modeling Guidelines v2.0)
CRU - Occupant Density	0.0014	Occupant/m²	ASHRAE 90.1-2013 User's Manual Table 5-1
CRU - Schedule	Fractional	-	ASHRAE 90.1-2013 User's Manual - Retail
Heating/Cooling Setpoint/Setback	**Baseline**		
Residential - Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
Residential - Cooling Setpoint/Setback	25 / 26	˚C	UBC Energy Modeling Guidelines v2.0
CRU - Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
CRU - Cooling Setpoint/Setback	25 / 26	˚C	UBC Energy Modeling Guidelines v2.0

GENERAL

Project Name	9639.010 UBCO Archetype Study
Archetype	Science/Lab Building (low fume hood density) - HVAC OPTION 1
Construction Year	New Construction (2020 Baseline)
Site Location	Kelowna, BC
Weather File	Kelowna CWEC 2016
Software	OpenStudio v.2.7.0

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Building Summary	**Baseline**	**Units**	**Reference/Description**
Storeys	5	-	Model geometry from UBC Net Positive Modelling Study (2016 06 27)
Breakdown of Space Type	28% Laboratory (low density fume hoods) 24% Office 8% Classroom 40% Circulation, amenity, etc.	-	
Conditioned Floor Area	13,760	m²	
Enclosure Performance	**Baseline**	**Units**	**Reference/Description**
Exterior Wall Above Grade	0.278	m^2-K/W	R-20. Concrete with exterior insulation
Suspended Slab	0.183	m^2-K/W	R-31. Slab on grade (NECB 2015)
Main Roof	0.183	m^2-K/W	R-31. Flat roof with rigid insulation (NECB 2015)
Fenestration		**Units**	**Reference/Description**
Window-to-Wall Ratio (WWR)	40%	%	
Windows Installed Overall U-value	2.20	W/m^2-K	NECB 2015
Window Installed Overall SHGC	0.38	-	
Infiltration		**Units**	**Reference/Description**
Infiltration Rate	2.0	L/s/m² @ 75Pa	UBC Modelling Guidelines v2.0
Infiltration Schedule	Fractional	-	Infiltration rate is reduced during occupied hours due to pressurization
Mechanical			
HVAC Summary	**Baseline**	**Units**	**Reference/Description**
Ventilation System Description	Non-lab Space: VAV system with central cooling, connected to district energy system. Hydronic heating in perimeter zones. Lab Space: Individual AHU providing 100% outdoor air to lab spaces, 4-pipe FCUs for heating and cooling.		
Heating/Cooling System Description			
Heating/Cooling Plant	**Baseline**	**Units**	**Reference/Description**
System Description			
System Description	District energy system for heating and cooling	-	
Plant Efficiency	100%	%	
Hot Water Supply/Return Temperature	60˚C (140˚F) / 38˚C (100˚F)	˚C (˚F)	
Cold Water Supply/Return Temperature	6.7˚C (44˚F) / 13.3˚C (56˚F)	˚C (˚F)	
Pumps			
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	
Domestic Water Heating	**Baseline**	**Units**	**Reference/Description**
System Description	Central storage tank system, district energy connection with electric water heater for top-up.	-	
Plant Efficiency	100%	-	
Building Peak Load	Office: 51 W/person Classroom: 65 W/person Lab: 180 W/person	l/s	Office: ASHRAE 90.1-2013 User's Manual Classroom and Lab: NECB 2015 Table A-8.4.3.3.(1)B per UBC Energy Modeling Guidelines v2.0
Schedule	Fractional	-	Office: ASHRAE 90.1-2013 User's Manual Classroom and Lab: NECB 2015
DHW Hot Water Supply Temperature	60˚C (140˚F)	˚C (˚F)	
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	

Airside System Description	Baseline	Units	Reference/Description
Non-Lab Space (Office, classrooms, circulation, amenity, etc.)			
System Description	VAV with central cooling		
Design Air Flow	Max = Autosized Min = 40%		
Outdoor Air Rate	Office: 10 l/s/person Classroom: 8 l/s/person Corridors: 0.50 l/s/m2 CO2 sensors in meeting rooms & classrooms	l/s/person or l/s/m2	ASHRAE 62.1-2001 Table 2
Fan Type	Variable Speed	-	ASHRAE 90.1-2013
Total Fan Power	1.4	W/cfm	Per ASHRAE 90.1-2013 Table 6.5.3.1-1
Economizer	yes	-	ASHRAE 90.1-2013
Fan Schedule	On/Off	-	AHU is turned off at night, space heating and loads met by re-heat coil and baseboards. ASHRAE 90.1-2013 User's Manual
Heat Recovery Effectiveness	Sensible: 0.7 Latent: 0.6	%	
Heating Type	-	-	
Heating Efficiency	-	-	
Heating Supply Air Temperature	-	-	
Cooling Type	Central cooling coil connected to district energy system	-	
Cooling Efficiency	n/a	-	
Cooling Supply Air Temperature	12.8˚C (55˚F), reset to 15.6˚C (60˚F) under minimum cooling load condition	˚C (˚F)	ASHRAE 90.1-2013 G3.1.3.12
Lab Space			
System Description	AHU providing 100% outdoor air	-	No re-circulation
Design Air Flow	28,435 (60,256)	l/s (cfm)	Based on 8 ACH
Outdoor Air Rate	Occupied: 28,435 (60,256) Unoccupied: 14,217 (30,128)	l/s (cfm)	Based on 8 ACH occupied, 4 ACH unoccupied
Fan Type	Variable Speed	-	
Total Fan Power	0.9	W/cfm	MAU supply fan + fume hood
Rooftop Stack Discharge Exhaust Fan Type	Constant Air Volume	-	Sized for peak fume hood exhaust flow
Rooftop Stack Discharge Exhaust Fan Power	1.2	W/cfm	
Fan Schedule	On 24/7	-	
Heat Recovery Effectiveness	0.40	%	Glycol heat recovery run-around loop
Zone Heating / Cooling Devices	**Baseline**	**Units**	**Reference/Description**
Non-Lab Space (Office, classrooms, circulation, amenity, etc.)			
Heating Type	Hydronic re-heat coil + Hydronic baseboard convector in perimeter zones	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	-	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	-	˚C (˚F)	
Lab Space			
System Description	4-pipe FCUs	-	
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8˚C (55˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Fan Type	Constant Air Volume	-	
Fan Schedule	On/Off	-	
Fan Power	0.3	W/cfm	

Lighting and Process Loads

Lighting	Baseline	Units	Reference/Description
Non-lab Space - Lighting Power Density	Office: 11.9 Classroom: 14.4 Corridor: 5.3	W/m²	ASHRAE 90.1-2013 Table 9.6.1 + User's Manual Schedules. 25% below ASHRAE 90.1-2013 Table 9.6.1 for corridors to account for LED and occupancy sensors
Non-lab Space - Schedule	Fractional	-	
Lab Space - Lighting Power Density	19.5	W/m²	ASHRAE 90.1-2013 Table 9.6.1.
Lab Space - Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 - Appendix A - A.1.1
Process Loads	**Baseline**	**Units**	**Reference/Description**
Non-lab Space - Plug Load	Office: 8.1 Classroom: 5.0	W/m²	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015
Non-lab Space - Schedule	Fractional	-	
Lab Space - Plug Load	20.0	W/m²	UBC Energy Modeling Guidelines v2.0
Lab Space - Plug Load Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 - Appendix A - A.1.1
Elevator	2 elevators @ 14.6 kW/each	-	BC Hydro Energy Modeling Guidelines Section 5.8
Occupancy	**Baseline**		
Non-lab Space - Occupant Density	Office: 0.039 Classroom: 0.133 Corridor: 0.01	Occupant/m²	Office: ASHRAE 90.1-2013 User's Manual Table G-D Classroom and Corridor: NECB 2015 Table A-8.4.3.3.(1)B
Non-lab Space - Schedule	Fractional	-	
Lab Space - Occupant Density	0.050	Occupant/m²	NECB 2015 Table A-8.4.3.3(1)B
Lab Space - Schedule	Fractional	-	ASHRAE 90.1-2013 User's Manual
Heating/Cooling Setpoint/Setback	**Baseline**		
Non-lab Space - Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
Non-lab Space - Cooling Setpoint/Setback	25 / no setback	˚C	UBC Energy Modeling Guidelines v2.0
Lab Space - Heating Setpoint/Setback	21	˚C	UBC Energy Modeling Guidelines v2.0
Lab Space - Cooling Setpoint/Setback	22	˚C	Based on 9639.000 project

GENERAL

Project Name	9639.010 UBCO Archetype Study
Archetype	Science/Lab Building (low fume hood density) - HVAC OPTION 2
Construction Year	New Construction (2020 Baseline)
Site Location	Kelowna, BC
Weather File	Kelowna CWEC 2016
Software	OpenStudio v.2.7.0

ARCHITECTURAL

Building Summary	**Baseline**	**Units**	**Reference/Description**
Storeys	5	-	Model geometry from UBC Net Positive Modelling Study (2016 06 27)
Breakdown of Space Type	28% Laboratory (low density fume hoods) 24% Office 8% Classroom 40% Circulation, amenity, etc.	-	
Conditioned Floor Area	13,760	m²	
Enclosure Performance	**Baseline**	**Units**	**Reference/Description**
Exterior Wall Above Grade	0.278	m^2-K/W	R-20. Concrete with exterior insulation
Suspended Slab	0.183	m^2-K/W	R-31. Slab on grade (NECB 2015)
Main Roof	0.183	m^2-K/W	R-31. Flat roof with rigid insulation (NECB 2015)
Fenestration		**Units**	**Reference/Description**
Window-to-Wall Ratio (WWR)	40%	%	
Windows Installed Overall U-value	2.20	W/m^2-K	NECB 2015
Window Installed Overall SHGC	0.38	-	
Infiltration		**Units**	**Reference/Description**
Infiltration Rate	2.0	L/s/m² @ 75Pa	UBC Modelling Guidelines v2.0
Infiltration Schedule	Fractional	-	Infiltration rate is reduced during occupied hours due to pressurization
Mechanical			
HVAC Summary	**Baseline**	**Units**	**Reference/Description**
Ventilation System Description	Non-lab Space: Dediacted outdoor air system with 4-pipe FCUs for heating and cooling. Lab Space: Individual AHU providing 100% outdoor air to lab spaces with 4-pipe FCUs for heating and cooling.		
Heating/Cooling System Description			
Heating/Cooling Plant	**Baseline**	**Units**	**Reference/Description**
System Description			
System Description	District energy system for heating and cooling	-	
Plant Efficiency	100%	%	
Hot Water Supply/Return Temperature	60˚C (140˚F) / 38˚C (100˚F)	˚C (˚F)	
Cold Water Supply/Return Temperature	6.7˚C (44˚F) / 13.3˚C (56˚F)	˚C (˚F)	
Pumps			
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	
Domestic Water Heating	**Baseline**	**Units**	**Reference/Description**
System Description	Central storage tank system, district energy connection with electric water heater for top-up.	-	
Plant Efficiency	100%	-	
Building Peak Load	Office: 0.032 l/s (52 W/person) Classroom: 0.045 l/s (65 W/person) Lab: 0.16 l/s (180 W/person)	l/s	Office: ASHRAE 90.1-2013 User's Manual Classroom and Lab: NECB 2015 Table A-8.4.3.3.(1)B per UBC Energy Modeling Guidelines v2.0
Schedule	Fractional	-	Office: ASHRAE 90.1-2013 User's Manual Classroom and Lab: NECB 2015
DHW Hot Water Supply Temperature	60˚C (140˚F)	˚C (˚F)	
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	

Airside System Description	Baseline	Units	Reference/Description
Non-Lab Space (Office, classrooms, circulation, amenity, etc.)			
System Description	Dedicated Outdoor Air System (DOAS)		
Design Air Flow	matches outdoor air		
Outdoor Air Rate	Office: 10 l/s/person Classroom: 8 l/s/person Corridors: 0.50 l/s/m2 CO2 sensors in meeting rooms & classrooms	l/s/person or l/s/m2	ASHRAE 62.1-2001 Table 2
Fan Type	Constant Air Volume	-	
Total Fan Power	1.1	W/cfm	Per ASHRAE 90.1-2013 Table 6.5.3.1-1
Fan Schedule	On/Off	-	AHU is turned off at night, space heating loads met by FCUs ASHRAE 90.1-2013 User's Manual
Heat Recovery Effectiveness	Sensible: 0.7 Latent: 0.6	%	
Heating Type	-	-	
Heating Efficiency	-	-	
Heating Supply Air Temperature	-	-	
Cooling Type	-	-	
Cooling Efficiency	-	-	
Cooling Supply Air Temperature	-	˚C (˚F)	
Lab Space			
System Description	AHU providing 100% outdoor air	-	No re-circulation
Design Air Flow	28,435 (60,256)	l/s (cfm)	Based on 8 ACH
Outdoor Air Rate	Occupied: 28,435 (60,256) Unoccupied: 14,217 (30,128)	l/s (cfm)	Based on 8 ACH occupied, 4 ACH unoccupied
Fan Type	Variable Air Volume	-	
Total Fan Power	0.9	W/cfm	MAU supply fan + fume hood
Rooftop Stack Discharge Exhaust Fan Type	Constant Air Volume	-	Sized for peak fume hood exhaust flow
Rooftop Stack Discharge Exhaust Fan Power	1.2	W/cfm	
Fan Schedule	On 24/7	-	
Heat Recovery Effectiveness	0.40	%	
Zone Heating / Cooling Devices	**Baseline**	**Units**	**Reference/Description**
Non-Lab Space (Office, classrooms, circulation, amenity, etc.)			
System Description	4-pipe FCUs	-	
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8˚C (55˚F)	˚C (˚F)	
Fan Type	Constant Air Volume	-	
Fan Schedule	On/Off	-	Cycling on at night to meet heating loads
Fan Power	0.3	W/cfm	
Lab Space			
System Description	4-pipe FCUs	-	
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8˚C (55˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Fan Type	Constant Air Volume	-	
Fan Schedule	24/7	-	Runs continuously to provide ventilation
Fan Power	0.3	W/cfm	

Lighting and Process Loads

Lighting	Baseline	Units	Reference/Description
Non-lab Space - Lighting Power Density	Office: 11.9 Classroom: 14.4 Corridor: 5.3	W/m²	ASHRAE 90.1-2013 Table 9.6.1 + User's Manual Schedules. 25% below ASHRAE 90.1-2013 Table 9.6.1 for corridors to account for LED and occupancy sensors
Non-lab Space - Schedule	Fractional	-	
Lab Space - Lighting Power Density	19.5	W/m²	ASHRAE 90.1-2013 Table 9.6.1.
Lab Space - Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 - Appendix A - A.1.1
Process Loads	**Baseline**	**Units**	**Reference/Description**
Non-lab Space - Plug Load	Office: 8.1 Classroom: 5.0	W/m²	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015
Non-lab Space - Schedule	Fractional	-	
Lab Space - Plug Load	20.0	W/m²	UBC Energy Modeling Guidelines v2.0
Lab Space - Plug Load Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 - Appendix A - A.1.1
Elevator	2 elevators @ 14.6 kW/each	-	BC Hydro Energy Modeling Guidelines Section 5.8
Occupancy	**Baseline**		
Non-lab Space - Occupant Density	Office: 0.039 Classroom: 0.133 Corridor: 0.01	Occupant/m²	Office: ASHRAE 90.1-2013 User's Manual Table G-D Classroom and Corridor: NECB 2015 Table A-8.4.3.3.(1)B
Non-lab Space - Schedule	Fractional	-	
Lab Space - Occupant Density	0.050	Occupant/m²	NECB 2015 Table A-8.4.3.3(1)B
Lab Space - Schedule	Fractional	-	ASHRAE 90.1-2013 User's Manual
Heating/Cooling Setpoint/Setback	**Baseline**		
Non-lab Space - Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
Non-lab Space - Cooling Setpoint/Setback	25 / no setback	˚C	UBC Energy Modeling Guidelines v2.0
Lab Space - Heating Setpoint/Setback	21	˚C	UBC Energy Modeling Guidelines v2.0
Lab Space - Cooling Setpoint/Setback	22	˚C	Based on 9639.000 project

GENERAL

Project Name	9639.010 UBCO Archetype Study
Archetype	Lab Building (high fume hood density) - HVAC OPTION 1
Construction Year	New Construction (2020 Baseline)
Site Location	Kelowna, BC
Weather File	Kelowna CWEC 2016
Software	OpenStudio v.2.7.0

ARCHITECTURAL

Building Summary	**Baseline**	**Units**	**Reference/Description**
Storeys	4	-	Model geometry from UBC Net Positive Modelling Study (2016 06 27)
Breakdown of Space Type	49% Laboratory (high density fume hoods) 10% Office 13% Classroom 28% Circulation, amenity, etc.	-	
Conditioned Floor Area	13,760	m²	
Enclosure Performance	**Baseline**	**Units**	**Reference/Description**
Exterior Wall Above Grade	0.278	m^2-K/W	R-20. Concrete with exterior insulation
Suspended Slab	0.183	m^2-K/W	R-31. Slab on grade (NECB 2015)
Main Roof	0.183	m^2-K/W	R-31. Flat roof with rigid insulation (NECB 2015)
Fenestration		**Units**	**Reference/Description**
Window-to-Wall Ratio (WWR)	40%	%	
Windows Installed Overall U-value	2.20	W/m^2-K	NECB 2015
Window Installed Overall SHGC	0.38	-	
Infiltration		**Units**	**Reference/Description**
Infiltration Rate	2.0	L/s/m² @ 75Pa	UBC Modelling Guidelines v2.0
Infiltration Schedule	Fractional	-	Infiltration rate is reduced during occupied hours due to pressurization
Mechanical			
HVAC Summary	**Baseline**	**Units**	**Reference/Description**
Ventilation System Description	Non-lab Space: VAV system with central cooling, connected to district energy system. Hydronic heating in perimeter zones. Lab Space: Individual AHU providing 100% outdoor air to lab spaces, 4-pipe FCUs for heating and cooling.		
Heating/Cooling System Description			
Heating/Cooling Plant	**Baseline**	**Units**	**Reference/Description**
System Description			
System Description	District energy system for heating and cooling	-	
Plant Efficiency	100%	%	
Hot Water Supply/Return Temperature	60˚C (140˚F) / 38˚C (100˚F)	˚C (˚F)	
Cold Water Supply/Return Temperature	6.7˚C (44˚F) / 13.3˚C (56˚F)	˚C (˚F)	
Pumps			
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	
Domestic Water Heating	**Baseline**	**Units**	**Reference/Description**
System Description	Central storage tank system, district energy connection with electric water heater for top-up.	-	
Plant Efficiency	100%	-	
Building Peak Load	Office: 51 W/person Classroom: 65 W/person Lab: 180 W/person	l/s	Office: ASHRAE 90.1-2013 User's Manual Classroom and Lab: NECB 2015 Table A-8.4.3.3.(1)B per UBC Energy Modeling Guidelines v2.0
Schedule	Fractional	-	Office: ASHRAE 90.1-2013 User's Manual Classroom and Lab: NECB 2015
DHW Hot Water Supply Temperature	60˚C (140˚F)	˚C (˚F)	
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	

Airside System Description	Baseline	Units	Reference/Description
Non-Lab Space (Office, classrooms, circulation, amenity, etc.)			
System Description	VAV with central cooling		
Design Air Flow	Autosize		
Outdoor Air Rate	Office: 10 l/s/person Classroom: 8 l/s/person Corridors: 0.50 l/s/m2 CO2 sensors in meeting rooms & classrooms	l/s/person or l/s/m2	ASHRAE 62.1-2001 Table 2
Fan Type	Variable Speed	-	
Total Fan Power	1.4	W/cfm	Per ASHRAE 90.1-2013 Table 6.5.3.1-1
Economizer	yes	-	
Fan Schedule	On/Off	-	AHU is turned off at night, space heating and loads met by re-heat coil and baseboards. ASHRAE 90.1-2013 User's Manual
Heat Recovery Effectiveness	Sensible: 0.7 Latent: 0.6	%	
Heating Type	-	-	
Heating Efficiency	-	-	
Heating Supply Air Temperature	-	-	
Cooling Type	Central cooling coil connected to district energy system	-	
Cooling Efficiency	n/a	-	
Cooling Supply Air Temperature	12.8˚C (55˚F), reset to 15.6˚C (60˚F) under minimum cooling load condition	˚C (˚F)	ASHRAE 90.1-2013 G3.1.3.12
Lab Space			
System Description	AHU providing 100% outdoor air	-	No re-circulation
Design Air Flow	83,243 (176,400)	l/s (cfm)	Based on 50% "set-up open" and 50% "open", 1200 cfm and 900 cfm respectively
Outdoor Air Rate	Occupied: 52,324 (110,880) Unoccupied: 23,784 (50,400)	l/s (cfm)	Occupied: 20% of fume hoods are "set-up open" (1,200 cfm), 30% are "open" (900 cfm), and 50% closed (300 cfm)
Fan Type	Variable Air Volume	-	
Total Fan Power	0.9	W/cfm	MAU supply fan + fume hood (@ design airflow)
Rooftop Stack Discharge Exhaust Fan Type	Constant Air Volume	-	Sized for peak fume hood exhaust flow
Rooftop Stack Discharge Exhaust Fan Power	1.2	W/cfm	
Fan Schedule	On 24/7	-	
Heat Recovery Effectiveness	0.40	%	
Zone Heating / Cooling Devices	**Baseline**	**Units**	**Reference/Description**
Non-Lab Space (Office, classrooms, circulation, amenity, etc.)			
Heating Type	Hydronic re-heat coil + Hydronic baseboard convector in perimeter zones	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	-	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	-	˚C (˚F)	
Lab Space			
System Description	4-pipe FCUs	-	
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8˚C (55˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Fan Type	Constant Air Volume	-	
Fan Schedule	24/7	-	Runs continuously to provide ventilation
Fan Power	0.3	W/cfm	

Lighting and Process Loads

Lighting	Baseline	Units	Reference/Description
Non-lab Space - Lighting Power Density	Office: 11.9 Classroom: 14.4 Corridor: 5.3	W/m²	ASHRAE 90.1-2013 Table 9.6.1 + User's Manual Schedules. 25% below ASHRAE 90.1-2013 Table 9.6.1 for corridors to account for LED and occupancy sensors
Non-lab Space - Schedule	Fractional	-	
Lab Space - Lighting Power Density	19.5	W/m²	ASHRAE 90.1-2013 Table 9.6.1.
Lab Space - Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 - Appendix A - A.1.1
Process Loads	**Baseline**	**Units**	**Reference/Description**
Non-lab Space - Plug Load	Office: 8.1 Classroom: 5.0	W/m²	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015
Non-lab Space - Schedule	Fractional	-	
Lab Space - Plug Load	20.0	W/m²	UBC Energy Modeling Guidelines v2.0
Lab Space - Plug Load Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 - Appendix A - A.1.1
Elevator	2 elevators @ 14.6 kW/each	-	BC Hydro Energy Modeling Guidelines Section 5.8
Occupancy	**Baseline**		
Non-lab Space - Occupant Density	Office: 0.039 Classroom: 0.133 Corridor: 0.01	Occupant/m²	Office: ASHRAE 90.1-2013 User's Manual Table G-D Classroom and Corridor: NECB 2015 Table A-8.4.3.3.(1)B
Non-lab Space - Schedule	Fractional	-	
Lab Space - Occupant Density	0.050	Occupant/m²	NECB 2015 Table A-8.4.3.3(1)B
Lab Space - Schedule	Fractional	-	ASHRAE 90.1-2013 User's Manual
Heating/Cooling Setpoint/Setback	**Baseline**		
Non-lab Space - Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
Non-lab Space - Cooling Setpoint/Setback	25 / no setback	˚C	UBC Energy Modeling Guidelines v2.0
Lab Space - Heating Setpoint/Setback	21	˚C	UBC Energy Modeling Guidelines v2.0
Lab Space - Cooling Setpoint/Setback	22	˚C	Based on 9639.000 project

GENERAL

Project Name	9639.010 UBCO Archetype Study
Archetype	Lab Building (high fume hood density) - HVAC OPTION 2
Construction Year	New Construction (2020 Baseline)
Site Location	Kelowna, BC
Weather File	Kelowna CWEC 2016
Software	OpenStudio v.2.7.0

ARCHITECTURAL

Building Summary	**Baseline**	**Units**	**Reference/Description**
Storeys	4	-	Model geometry from UBC Net Positive Modelling Study (2016 06 27)
Breakdown of Space Type	49% Laboratory (high density fume hoods) 10% Office 13% Classroom 28% Circulation, amenity, etc.	-	
Conditioned Floor Area	13,760	m²	
Enclosure Performance	**Baseline**	**Units**	**Reference/Description**
Exterior Wall Above Grade	0.278	m^2-K/W	R-20. Concrete with exterior insulation
Suspended Slab	0.183	m^2-K/W	R-31. Slab on grade (NECB 2015)
Main Roof	0.183	m^2-K/W	R-31. Flat roof with rigid insulation (NECB 2015)
Fenestration		**Units**	**Reference/Description**
Window-to-Wall Ratio (WWR)	40%	%	
Windows Installed Overall U-value	2.20	W/m^2-K	NECB 2015
Window Installed Overall SHGC	0.38	-	
Infiltration		**Units**	**Reference/Description**
Infiltration Rate	2.0	L/s/m² @ 75Pa	UBC Modelling Guidelines v2.0
Infiltration Schedule	Fractional	-	Infiltration rate is reduced during occupied hours due to pressurization
Mechanical			
HVAC Summary	**Baseline**	**Units**	**Reference/Description**
Ventilation System Description	Non-lab Space: Dediacted outdoor air system with 4-pipe FCUs for heating and cooling. Lab Space: Individual AHU providing 100% outdoor air to lab spaces with 4-pipe FCUs for heating and cooling.		
Heating/Cooling System Description			
Heating/Cooling Plant	**Baseline**	**Units**	**Reference/Description**
System Description			
System Description	District energy system for heating and cooling	-	
Plant Efficiency	100%	%	
Hot Water Supply/Return Temperature	60˚C (140˚F) / 38˚C (100˚F)	˚C (˚F)	
Cold Water Supply/Return Temperature	6.7˚C (44˚F) / 13.3˚C (56˚F)	˚C (˚F)	
Pumps			
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	
Domestic Water Heating	**Baseline**	**Units**	**Reference/Description**
System Description	Central storage tank system, district energy connection with electric water heater for top-up.	-	
Plant Efficiency	100%	-	
Building Peak Load	Office: 51 W/person Classroom: 65 W/person Lab: 180 W/person	l/s	Office: ASHRAE 90.1-2013 User's Manual Classroom and Lab: NECB 2015 Table A-8.4.3.3.(1)B per UBC Energy Modeling Guidelines v2.0
Schedule	Fractional	-	Office: ASHRAE 90.1-2013 User's Manual Classroom and Lab: NECB 2015
DHW Hot Water Supply Temperature	60˚C (140˚F)	˚C (˚F)	
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	

Airside System Description	**Baseline**	**Units**	**Reference/Description**
Non-Lab Space (Office, classrooms, circulation, amenity, etc.)			
System Description	Dedicated Outdoor Air System (DOAS)		
Design Air Flow	matches outdoor air		
Outdoor Air Rate	Office: 10 l/s/person Classroom: 8 l/s/person Corridors: 0.50 l/s/m2 CO2 sensors in meeting rooms & classrooms	l/s/person or l/s/m2	ASHRAE 62.1-2001 Table 2
Fan Type	Constant Air Volume	-	
Total Fan Power	1.1	W/cfm	Per ASHRAE 90.1-2013 Table 6.5.3.1-1
Fan Schedule	On/Off	-	AHU is turned off at night, space heating and loads met by FCUs ASHRAE 90.1-2013 User's Manual
Heat Recovery Effectiveness	Sensible: 0.7 Latent: 0.6	%	
Heating Type	-	-	
Heating Efficiency	-	-	
Heating Supply Air Temperature	-	-	
Cooling Type	-	-	
Cooling Efficiency	-	-	
Cooling Supply Air Temperature	-	°C (°F)	
Lab Space			
System Description	AHU providing 100% outdoor air	-	No re-circulation
Design Air Flow	83,243 (176,400)	l/s (cfm)	Based on 50% "set-up open" and 50% "open", 1200 cfm and 900 cfm respectively
Outdoor Air Rate	Occupied: 52,324 (110,880) Unoccupied: 23,784 (50,400)	l/s (cfm)	Occupied: 20% of fume hoods are "set-up open" (1,200 cfm), 30% are "open" (900 cfm), and 50% closed (300 cfm)
Fan Type	Variable Air Volume	-	
Total Fan Power	0.9	W/cfm	MAU supply fan + fume hood (@ design airflow)
Rooftop Stack Discharge Exhaust Fan Type	Constant Air Volume	-	Sized for peak fume hood exhaust flow
Rooftop Stack Discharge Exhaust Fan Power	1.2	W/cfm	
Fan Schedule	On 24/7	-	
Heat Recovery Effectiveness	0.40	%	
Zone Heating / Cooling Devices	**Baseline**	**Units**	**Reference/Description**
Non-Lab Space (Office, classrooms, circulation, amenity, etc.)			
System Description	4-pipe FCUs	-	
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95°F)	°C (°F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8°C (55°F)	°C (°F)	
Fan Type	Constant Air Volume	-	
Fan Schedule	On/Off	-	Cycling on at night to meet heating loads
Fan Power	0.3	W/cfm	
Lab Space			
System Description	4-pipe FCUs	-	
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95°F)	°C (°F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8°C (55°F)	°C (°F)	Supply air temperature controlled via local thermostats
Fan Type	Constant Air Volume	-	
Fan Schedule	24/7	-	Runs continuously to provide ventilation
Fan Power	0.3	W/cfm	

Lighting and Process Loads

Lighting	Baseline	Units	Reference/Description
Non-lab Space - Lighting Power Density	Office: 11.9 Classroom: 14.4 Corridor: 5.3	W/m²	ASHRAE 90.1-2013 Table 9.6.1 + User's Manual Schedules. 25% below ASHRAE 90.1-2013 Table 9.6.1 for corridors to account for LED and occupancy sensors
Non-lab Space - Schedule	Fractional	-	
Lab Space - Lighting Power Density	19.5	W/m²	ASHRAE 90.1-2013 Table 9.6.1.
Lab Space - Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 - Appendix A - A.1.1
Process Loads	**Baseline**	**Units**	**Reference/Description**
Non-lab Space - Plug Load	Office: 8.1 Classroom: 5.0	W/m²	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015
Non-lab Space - Schedule	Fractional	-	
Lab Space - Plug Load	20.0	W/m²	UBC Energy Modeling Guidelines v2.0
Lab Space - Plug Load Schedule	Fractional	-	UBC Energy Modeling Guidelines v2.0 - Appendix A - A.1.1
Elevator	2 elevators @ 14.6 kW/each	-	BC Hydro Energy Modeling Guidelines Section 5.8
Occupancy	**Baseline**		
Non-lab Space - Occupant Density	Office: 0.039 Classroom: 0.133 Corridor: 0.01	Occupant/m²	Office: ASHRAE 90.1-2013 User's Manual Table G-D Classroom and Corridor: NECB 2015 Table A-8.4.3.3.(1)B
Non-lab Space - Schedule	Fractional	-	
Lab Space - Occupant Density	0.050	Occupant/m²	NECB 2015 Table A-8.4.3.3(1)B
Lab Space - Schedule	Fractional	-	ASHRAE 90.1-2013 User's Manual
Heating/Cooling Setpoint/Setback	**Baseline**		
Non-lab Space - Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
Non-lab Space - Cooling Setpoint/Setback	25 / no setback	˚C	UBC Energy Modeling Guidelines v2.0
Lab Space - Heating Setpoint/Setback	21	˚C	UBC Energy Modeling Guidelines v2.0
Lab Space - Cooling Setpoint/Setback	22	˚C	Based on 9639.000 project

GENERAL

Project Name	9639.010 UBCO Archetype Study
Archetype	Classroom / Office Building - HVAC OPTION 1
Construction Year	New Construction (2020 Baseline)
Site Location	Kelowna, BC
Weather File	Kelowna CWEC 2016
Software	OpenStudio v.2.7.0

ARCHITECTURAL

Building Summary	**Baseline**	**Units**	**Reference/Description**
Storeys	6	-	Model geometry from UBC Net Positive Modelling Study (2016 06 27)
Breakdown of Space Type	48% Classroom/Lecture Hall 20% Office 34% Circulation, amenity, etc.	-	
Conditioned Floor Area	9,300	m²	
Enclosure Performance	**Baseline**	**Units**	**Reference/Description**
Exterior Wall Above Grade	0.278	m^2-K/W	R-20. Concrete with exterior insulation
Suspended Slab	0.183	m^2-K/W	R-31. Slab on grade (NECB 2015)
Main Roof	0.183	m^2-K/W	R-31. Flat roof with rigid insulation (NECB 2015)
Fenestration		**Units**	**Reference/Description**
Window-to-Wall Ratio (WWR)	40%	%	
Windows Installed Overall U-value	2.20	W/m^2-K	NECB 2015
Window Installed Overall SHGC	0.38	-	
Infiltration		**Units**	**Reference/Description**
Infiltration Rate	2.0	L/s/m² @ 75Pa	UBC Modelling Guidelines v2.0
Infiltration Schedule	Fractional	-	Infiltration rate is reduced during occupied hours due to pressurization
Mechanical			
HVAC Summary	**Baseline**	**Units**	**Reference/Description**
Ventilation System Description	VAV system with central cooling and re-heat coils at zone level. Hydronic baseboards in perimeter zones. District energy connection.		
Heating/Cooling System Description			
Heating/Cooling Plant	**Baseline**	**Units**	**Reference/Description**
System Description			
System Description	District energy system for heating and cooling	-	
Plant Efficiency	100%	%	
Hot Water Supply/Return Temperature	60˚C (140˚F) / 38˚C (100˚F)	˚C (˚F)	
Cold Water Supply/Return Temperature	6.7˚C (44˚F) / 13.3˚C (56˚F)	˚C (˚F)	
Pumps			
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	
Domestic Water Heating	**Baseline**	**Units**	**Reference/Description**
System Description	Central storage tank system, district energy connection with electric water heater for top-up.	-	
Plant Efficiency	100%	-	
Building Peak Load	Office: 51 W/person Classroom: 65 W/person	l/s	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015 Table A-8.4.3.3.(1)B per UBC Energy Modeling Guidelines v2.0
Schedule	Fractional	-	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015
DHW Hot Water Supply Temperature	60˚C (140˚F)	˚C (˚F)	
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	

Airside System Description	Baseline	Units	Reference/Description
System Description	VAV with central cooling		
Design Air Flow	Autosized		
Outdoor Air Rate	Office: 10 l/s/person Classroom: 8 l/s/person Corridors: 0.50 l/s/m2 CO2 sensors in meeting rooms & classrooms	l/s/person or l/s/m2	ASHRAE 62.1-2001 Table 2
Fan Type	Variable Speed	-	
Total Fan Power	1.4	W/cfm	Per ASHRAE 90.1-2013 Table 6.5.3.1-1
Economizer	yes	-	ASHRAE 90.1-2013
Fan Schedule	On/Off	-	
Heat Recovery Effectiveness	Sensible: 0.7 Latent: 0.6	%	
Heating Type	-	-	
Heating Efficiency	-	-	
Heating Supply Air Temperature	-	-	
Cooling Type	Central cooling coil connected to district energy system	-	
Cooling Efficiency	n/a	-	
Cooling Supply Air Temperature	12.8˚C (55˚F), reset to 15.6˚C (60˚F) under minimum cooling load condition	˚C (˚F)	ASHRAE 90.1-2013 G3.1.3.12
Zone Heating / Cooling Devices	**Baseline**	**Units**	**Reference/Description**
Heating Type	Hydronic re-heat coil + Hydronic baseboard convector in perimeter zones	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	-	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	-	˚C (˚F)	

Lighting and Process Loads

Lighting	Baseline	Units	Reference/Description
Lighting Power Density	Office: 11.9 Classroom: 14.4 Corridor: 5.3	W/m²	ASHRAE 90.1-2013 Table 9.6.1 + User's Manual Schedules. 25% below ASHRAE 90.1-2013 Table 9.6.1 for corridors to account for LED and occupancy sensors
Schedule	Fractional	-	
Process Loads	**Baseline**	**Units**	**Reference/Description**
Plug Load	Office: 8.1 Classroom: 5.0	W/m²	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015
Schedule	Fractional	-	
Elevator	2 elevators @ 14.6 kW/each	-	BC Hydro Energy Modeling Guidelines Section 5.8
Occupancy	**Baseline**		
Occupant Density	Office: 0.039 Classroom: 0.133 Corridor: 0.01	Occupant/m²	Office: ASHRAE 90.1-2013 User's Manual Table G-D Classroom and Corridor: NECB 2015 Table A-8.4.3.3.(1)B
Schedule	Fractional	-	
Heating/Cooling Setpoint/Setback	**Baseline**		
Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
Cooling Setpoint/Setback	25 / no setback	˚C	UBC Energy Modeling Guidelines v2.0

GENERAL

Project Name	9639.010 UBCO Archetype Study
Archetype	Classroom / Office Building - HVAC OPTION 2
Construction Year	New Construction (2020 Baseline)
Site Location	Kelowna, BC
Weather File	Kelowna CWEC 2016
Software	OpenStudio v.2.7.0

ARCHITECTURAL

Building Summary	**Baseline**	**Units**	**Reference/Description**
Storeys	6	-	Model geometry from UBC Net Positive Modelling Study (2016 06 27)
Breakdown of Space Type	48% Classroom/Lecture Hall 20% Office 34% Circulation, amenity, etc.	-	
Conditioned Floor Area	9,300	m²	
Enclosure Performance	**Baseline**	**Units**	**Reference/Description**
Exterior Wall Above Grade	0.278	m^2-K/W	R-20. Concrete with exterior insulation
Suspended Slab	0.183	m^2-K/W	R-31. Slab on grade (NECB 2015)
Main Roof	0.183	m^2-K/W	R-31. Flat roof with rigid insulation (NECB 2015)
Fenestration		**Units**	**Reference/Description**
Window-to-Wall Ratio (WWR)	40%	%	
Windows Installed Overall U-value	2.20	W/m^2-K	NECB 2015
Window Installed Overall SHGC	0.38	-	
Infiltration		**Units**	**Reference/Description**
Infiltration Rate	2.0	L/s/m² @ 75Pa	UBC Modelling Guidelines v2.0
Infiltration Schedule	Fractional	-	Infiltration rate is reduced during occupied hours due to pressurization
Mechanical			
HVAC Summary	**Baseline**	**Units**	**Reference/Description**
Ventilation System Description	Dedicated outdoor air system with 4-pipe FCUs for heating and cooling.		
Heating/Cooling System Description			
Heating/Cooling Plant	**Baseline**	**Units**	**Reference/Description**
System Description			
System Description	District energy system for heating and cooling	-	
Plant Efficiency	-	%	
Hot Water Supply/Return Temperature	60˚C (140˚F) / 38˚C (100˚F)	˚C (˚F)	
Cold Water Supply/Return Temperature	6.7˚C (44˚F) / 13.3˚C (56˚F)	˚C (˚F)	
Pumps			
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	
Domestic Water Heating	**Baseline**	**Units**	**Reference/Description**
System Description	Central storage tank system, district energy connection with electric water heater for top-up.	-	
Plant Efficiency	-	-	
Building Peak Load	Office: 51 W/person Classroom: 65 W/person	l/s	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015 Table A-8.4.3.3.(1)B per UBC Energy Modeling Guidelines v2.0
Schedule	Fractional	-	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015
DHW Hot Water Supply Temperature	60˚C (140˚F)	˚C (˚F)	
Pump Type	Variable Speed	-	
Power	16.0	W/gpm	

Airside System Description	Baseline	Units	Reference/Description
System Description	Dedicated Outdoor Air System (DOAS)		
Design Air Flow	matches outdoor air		
Outdoor Air Rate	Office: 10 l/s/person Classroom: 8 l/s/person Corridors: 0.50 l/s/m2 CO2 sensors in meeting rooms & classrooms	l/s/person or l/s/m2	ASHRAE 62.1-2001 Table 2
Fan Type	Constant Air Volume	-	
Total Fan Power	1.1	W/cfm	Per ASHRAE 90.1-2013 Table 6.5.3.1-1
Fan Schedule	On/Off	-	AHU is turned off at night, space heating and loads met by FCUs. ASHRAE 90.1-2013 User's Manual
Heat Recovery Effectiveness	Sensible: 0.7 Latent: 0.6	%	
Heating Type	-	-	
Heating Efficiency	-	-	
Heating Supply Air Temperature	-	-	
Cooling Type	-	-	
Cooling Efficiency	-	-	
Cooling Supply Air Temperature	-	˚C (˚F)	
Zone Heating / Cooling Devices	**Baseline**	**Units**	**Reference/Description**
System Description	4-pipe FCUs	-	
Heating Type	Hydronic heating coil connected to district energy system	-	
Heating Efficiency	-	%	
Heating Supply Air Temperature	35°C (95˚F)	˚C (˚F)	Supply air temperature controlled via local thermostats
Cooling Type	Hydronic cooling coil connected to district energy system	-	
Cooling Efficiency	-	%	
Cooling Supply Air Temperature	12.8˚C (55˚F)	˚C (˚F)	
Fan Type	Constant Air Volume	-	
Fan Schedule	On/Off	-	Cycling on at night to meet heating loads
Fan Power	0.3	W/cfm	

Lighting and Process Loads

Lighting	Baseline	Units	Reference/Description
Lighting Power Density	Office: 11.9 Classroom: 14.4 Corridor: 5.3	W/m²	ASHRAE 90.1-2013 Table 9.6.1 + User's Manual Schedules. 25% below ASHRAE 90.1-2013 Table 9.6.1 for corridors to account for LED and occupancy sensors
Schedule	Fractional	-	
Process Loads	**Baseline**	**Units**	**Reference/Description**
Plug Load	Office: 8.1 Classroom: 5.0	W/m²	Office: ASHRAE 90.1-2013 User's Manual Classroom: NECB 2015
Schedule	Fractional	-	
Elevator	2 elevators @ 14.6 kW/each	-	BC Hydro Energy Modeling Guidelines Section 5.8
Occupancy	**Baseline**		
Occupant Density	Office: 0.039 Classroom: 0.133 Corridor: 0.01	Occupant/m²	Office: ASHRAE 90.1-2013 User's Manual Table G-D Classroom and Corridor: NECB 2015 Table A-8.4.3.3.(1)B
Schedule	Fractional	-	
Heating/Cooling Setpoint/Setback	**Baseline**		
Heating Setpoint/Setback	21 / 17	˚C	UBC Energy Modeling Guidelines v2.0
Cooling Setpoint/Setback	25 / no setback	˚C	UBC Energy Modeling Guidelines v2.0

Appendix B

Equipment Lifetimes for Energy Conservation Measures

Equipment Lifetimes for Energy Conservation Measures

The table below provides a summary of the lifetimes assumed for the lifecycle cost analysis of energy conservation measures (ECMs). Enclosure measures are assumed to not require replacement during the 40-year timespan of the financial analysis.

The nighttime free cooling and corridor supply air temperature nighttime setback are assumed to be no additional cost over baseline, and therefore equipment lifetimes were not required for the analysis. The lifetimes of the variable speed rooftop fans included in the Enclosure + Mechanical bundles of some archetypes have also not been included. The equipment supplier, Eco Supply, was unable to provide a cost without detailed design information and therefore this measure was excluded from the financial analysis.

SUMMARY OF EQUIPMENT LIFETIMES		
Energy Conservation Measure	**Lifetime**	**Source**
Centralized HRV Ventilation	15 years	2015 AHSRAE Handbook – HVAC Applications
Fan Coil Units	20 years	2015 AHSRAE Handbook – HVAC Applications
Electric Boiler	15 years	2015 AHSRAE Handbook – HVAC Applications
Water Source Heat Pump	20 years	2015 AHSRAE Handbook – HVAC Applications
DHW Heat Recovery	20 years	2015 AHSRAE Handbook – HVAC Applications
Aircuity System	20 years	Aqua Air (Supplier)

Appendix C

Utility Rate Input Details

Utility Rate Input Details

The table below outlines the assumptions provided by UBCO regarding the utility rates used in the financial analysis.

Notes:

→ The district energy system utility rates include a $250/tCO_2e$ carbon cost.

→ Chillers and water-source heat pumps are considered to be part of the district energy system and both hot and chilled water are purchased from the district energy system.

→ Demand charges are annual and based on annual peak load.

→ Heating and cooling are considered to be purchased on an hourly basis based on the net value for that hour. For example, during heating dominated periods, cooling will not be charged and the value of heating minus cooling will be charged at the heating rate. The reverse will be true during cooling periods.

UTILITY RATE INPUT DETAILS		
Utility Rates from FortisBC	**Value**	
Grid Electricity Cost	0.059 $/kWh	
Grid Electricity Demand Charge	89.54 $/kW/yr (assumes a 75% rachet is not exceeded throughout the year)	
Natural Gas Cost	0.029 $/kWh (carbon tax excluded)	
Greenhouse Gas Input Factors	**Value**	
Electricity	0.000040 tCO_2e/kWh	
Natural Gas	0.000180 tCO_2e/kWh	
District Energy System Carbon Input Factors	**Value**	
District Energy - Heating	147.2 g/kWh	
District Energy - Cooling	15.8 g/kWh	
Net Energy – District Energy System	**Value**	
Net Energy Cost – District Energy (Heating)	Electricity Gas Carbon Total	0.020 $/kWh 0.022 $/kWh 0.037 $/kWh 0.079 $/kWh
Net Energy Cost – District Energy (Cooling)	Electricity Water Carbon Total	0.023 $/kWh 0.002 $/kWh 0.004 $/kWh 0.029 $/kWh
Net Energy Demand – District Energy System	**Value**	
Net Energy Demand Charge – District Energy (Heating)	Electrical Demand Capital Amortization Operating Labour Total	30.99 $/kWh/yr 49.92 $/kWh/yr 40.00 $/kWh/yr 120.90 $/kWh/yr

UTILITY RATE INPUT DETAILS		
Net Energy Demand Charge – District Energy (Cooling)	Electrical Demand Capital Amortization Operating Labour Total	35.28 $/kWh/yr 101.59 $/kWh/yr 40.00 $/kWh/yr 176.88 $/kWh/yr

Appendix D

Space Type Breakdown Results

TABLE D.1 ENERGY AND GREENHOUSE GAS RESULTS PER SPACE TYPE – CAMPUS HOUSING									
	Baseline			Enclosure Bundle			Enclosure + Mechanical Bundle		
	Residential	CRU	Whole Bldg	Residential	CRU	Whole Bldg	Residential	CRU	Whole Bldg
TEUI, kWh/m²/yr	179	161	176	163	143	160	138	132	137
GHGI, kgCO2e/m²/yr	13	8	12	11	6	10	10	6	9
TEDI, kWh/m²/yr	26	20	25	17	8	15	15	5	13
DHW – Elec, kWh/m²/yr	10	1	9	10	1	9	4	0	3
DHW – DE, kWh/m²/yr	35	5	30	35	5	30	32	5	27
Peak Heating Demand, W/m²	30	47	33	10	30	13	8	20	10
Peak Cooling Demand, W/m²	26	39	28	18	32	21	18	32	21
Peak Total Demand, W/m²	11	20	12	11	19	12	11	19	11

TABLE D.2 ENERGY AND GREENHOUSE GAS RESULTS PER SPACE TYPE – SCIENCE LAB												
	Baseline				Enclosure Bundle				Enclosure + Mechanical Bundle			
	Lab	Class	Office	Whole Bldg	Lab	Class	Office	Whole Bldg	Lab	Class	Office	Whole Bldg
TEUI, kWh/m²/yr	566	155	119	335	544	144	104	321	334	159	112	217
GHGI, kgCO2e/m²/yr	34	8	6	19	32	7	5	17	20	12	8	13
TEDI, kWh/m²/yr	117	14	16	63	106	7	8	53	66	44	35	43
DHW – Elec, kWh/m²/yr	4	4	1	3	4	4	1	3	4	4	1	3
DHW – DE, kWh/m²/yr	13	12	3	9	13	12	3	9	13	12	3	9
Peak Heating Demand, W/m²	65	30	30	48	58	22	21	39	46	37	33	28
Peak Cooling Demand, W/m²	114	41	36	79	99	33	28	71	62	37	29	40
Peak Total Demand, W/m²	42	18	18	30	41	18	17	30	37	16	16	23

TABLE D.3 ENERGY AND GREENHOUSE GAS RESULTS PER SPACE TYPE – LAB BUILDING												
	Baseline				Enclosure Bundle				Enclosure + Mechanical Bundle			
	Lab	Class	Office	Whole Bldg	Lab	Class	Office	Whole Bldg	Lab	Class	Office	Whole Bldg
TEUI, kWh/m²/yr	570	168	130	431	547	153	113	414	381	177	138	290
GHGI, kgCO2e/m²/yr	35	8	7	25	33	7	5	24	22	12	9	16
TEDI, kWh/m²/yr	118	14	16	85	108	7	8	76	72	45	39	50
DHW – Elec, kWh/m²/yr	4	4	1	3	4	4	1	3	4	4	1	3
DHW – DE, kWh/m²/yr	13	12	3	11	13	12	3	11	13	12	3	11
Peak Heating Demand, W/m²	71	32	32	56	59	22	22	45	49	38	33	31
Peak Cooling Demand, W/m²	92	52	50	82	84	33	31	72	68	41	29	53
Peak Total Demand, W/m²	47	21	21	39	46	20	20	38	39	19	19	31

TABLE D.4 ENERGY AND GREENHOUSE GAS RESULTS PER SPACE TYPE – CLASSROOM OFFICE									
	Baseline			Enclosure Bundle			Enclosure + Mechanical Bundle		
	Classroom	Office	Whole Bldg	Classroom	Office	Whole Bldg	Classroom	Office	Whole Bldg
TEUI, kWh/m²/yr	166	131	157	149	113	139	138	98	127
GHGI, kgCO2e/m²/yr	9	8	8	7	5	6	7	5	6
TEDI, kWh/m²/yr	19	24	21	8	11	9	7	10	8
DHW – Elec, kWh/m²/yr	4	1	3	4	1	3	2	0	1
DHW – DE, kWh/m²/yr	12	3	10	12	3	10	12	3	10
Peak Heating Demand, W/m²	41	46	42	31	37	32	26	33	29
Peak Cooling Demand, W/m²	53	45	51	42	33	39	42	33	39
Peak Total Demand, W/m²	21	21	21	20	20	20	19	19	19

Appendix E

Incremental Capital Costs – Individual Measures

Incremental Capital Costs

The tables below provide the incremental capital cost estimates for individual measures that were used to build each bundle for the five archetypes assessed in this study.

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES - STUDENT RESIDENCE BUILDING			
Bundle	**Individual Measure**	**Total Incremental Capital Cost**	
		Best Case	**Worst Case**
Exterior Wall			
Enclosure Bundle	Wood frame with exterior insulation, R-30 (USI-0.189), WWR 20%	$258,400	$387,600
Enclosure + Mechanical Bundle	Wood frame with exterior insulation, R-30 (USI-0.189), WWR 20%	$258,400	$387,600
Roof			
Enclosure Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$33,600	$38,100
Enclosure + Mechanical Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$33,600	$38,100
Window			
Enclosure Bundle	U-0.17 (USI-0.97), WWR 20%	($581,500)	($395,900)
Enclosure + Mechanical Bundle	U-0.17 (USI-0.97), WWR 20%	($581,500)	($395,900)
Fixed Exterior Shading			
Enclosure Bundle	Fixed exterior shades	$21,600	$43,300
Enclosure + Mechanical Bundle	Fixed exterior shades	$21,600	$43,300
Infiltration rate			
Enclosure Bundle	0.6 ACH50 + airtightness test	$9,500	$14,300
Enclosure + Mechanical Bundle	0.6 ACH50 + airtightness test	$9,500	$14,300
Ventilation			
Enclosure Bundle	Centralized HRV (70% effective)	$0	$0
Enclosure + Mechanical Bundle	Centralized HRV (90% effective)	$23,600	$35,400
Fan Coil Units (FCU)			
Enclosure Bundle	In-suite 4-pipe constant speed FCUs	$0	$0
Enclosure + Mechanical Bundle	In-suite 4-pipe variable speed FCUs	$11,500	$17,300
Domestic Hot Water (DHW)			
Enclosure Bundle	Electric boilers for top-up from 120˚F to 140˚F	$0	$0

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES - STUDENT RESIDENCE BUILDING			
Enclosure + Mechanical Bundle	Water source heat pump for DHW top-up	$40,500	$60,800
DHW Heat Recovery			
Enclosure Bundle	None	$0	$0
Enclosure + Mechanical Bundle	Added heat recovery	$17,000	$25,700

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES – CAMPUS RENTAL HOUSING			
Bundle	**Individual Measure**	**Total Incremental Capital Cost ($/building)**	
		Best Case	**Worst Case**
Exterior Wall: L1			
Enclosure Bundle	Concrete with exterior insulation, R-30 (USI-0.189), WWR 25%	$32,800	$46,500
Enclosure + Mechanical Bundle	Concrete with exterior insulation, R-30 (USI-0.189), WWR 25%	$32,800	$46,500
Exterior Wall: L2 - L6			
Enclosure Bundle	Wood frame with exterior insulation, R-30 (USI-0.189), WWR 40%	$167,900	$251,900
Enclosure + Mechanical Bundle	Wood frame with exterior insulation, R-30 (USI-0.189), WWR 40%	$167,900	$251,900
Roof			
Enclosure Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$33,600	$38,100
Enclosure + Mechanical Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$33,600	$38,100
Window: L1			
Enclosure Bundle	U-0.17 (USI-0.97), WWR 25%	($66,800)	($46,300)
Enclosure + Mechanical Bundle	U-0.17 (USI-0.97), WWR 25%	($66,800)	($46,300)
Window: L2 – L6			
Enclosure Bundle	U-0.14 (USI-0.79), WWR 40%	($308,500)	($205,700)
Enclosure + Mechanical Bundle	U-0.14 (USI-0.79), WWR 40%	($308,500)	($205,700)
Fixed Exterior Shading			
Enclosure Bundle	Fixed exterior shades	$33,000	$66,000
Enclosure + Mechanical Bundle	Fixed exterior shades	$33,000	$66,000
Infiltration rate			
Enclosure Bundle	0.6 ACH50 + airtightness test	$9,500	$14,300

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES – CAMPUS RENTAL HOUSING			
Enclosure + Mechanical Bundle	0.6 ACH50 + airtightness test	$9,500	$14,300
Ventilation			
Enclosure Bundle	Centralized HRV (70% effective)	$0	$0
Enclosure + Mechanical Bundle	Centralized HRV (90% effective)	$35,900	$53,900
Fan Coil Units (FCU)			
Enclosure Bundle	In-suite 4-pipe constant speed FCUs	$0	$0
Enclosure + Mechanical Bundle	In-suite 4-pipe variable speed FCUs	$9,600	$14,400
Domestic Hot Water (DHW)			
Enclosure Bundle	Electric boilers for top-up from 120˚F to 140˚F	$0	$0
Enclosure + Mechanical Bundle	Water source heat pump for DHW top-up	$39,100	$58,700
DHW Heat Recovery			
Enclosure Bundle	None	$0	$0
Enclosure + Mechanical Bundle	Added heat recovery	$14,300	$21,400

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES – SCIENCE LAB			
Bundle	**Individual Measure**	**Total Incremental Capital Cost ($/building)**	
		Best Case	**Worst Case**
Exterior Wall			
Enclosure Bundle	Concrete with exterior insulation, R-30 (USI-0.189), WWR 25%	$367,200	$520,800
Enclosure + Mechanical Bundle	Concrete with exterior insulation, R-30 (USI-0.189), WWR 25%	$367,200	$520,800
Roof			
Enclosure Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$128,400	$145,700
Enclosure + Mechanical Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$128,400	$145,700
Window			
Enclosure Bundle	U-0.14 (USI-0.79), WWR 25%	($691,600)	($461,100)
Enclosure + Mechanical Bundle	U-0.14 (USI-0.79), WWR 25%	($691,600)	($461,100)
Fixed Exterior Shading			
Enclosure Bundle	Fixed exterior shades	$56,400	$112,800
Enclosure + Mechanical Bundle	Fixed exterior shades	$56,400	$112,800

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES – SCIENCE LAB			
Infiltration rate			
Enclosure Bundle	0.6 ACH50 + airtightness test	$12,900	$19,300
Enclosure + Mechanical Bundle	0.6 ACH50 + airtightness test	$12,900	$19,300
Ventilation			
Enclosure Bundle	Centralized HRV (70% effective)	$0	$0
Enclosure + Mechanical Bundle	Makeup air unit and exhaust fan	$33,300	$49,400
Fan Coil Units (FCU)			
Enclosure Bundle	In-suite 4-pipe constant speed FCUs	$0	$0
Enclosure + Mechanical Bundle	In-suite 4-pipe variable speed FCUs	$12,200	$18,400
Aircuity Sensors			
Enclosure Bundle	None	$0	$0
Enclosure + Mechanical Bundle	Aircuity sensors	$350,000	$350,000

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES – LAB BUILDING			
Bundle	**Individual Measure**	**Total Incremental Capital Cost ($/building)**	
		Best Case	**Worst Case**
Exterior Wall			
Enclosure Bundle	Concrete with exterior insulation, R-30 (USI-0.189), WWR 25%	$367,200	$520,800
Enclosure + Mechanical Bundle	Concrete with exterior insulation, R-30 (USI-0.189), WWR 25%	$367,200	$520,800
Roof			
Enclosure Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$128,400	$145,700
Enclosure + Mechanical Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$128,400	$145,700
Window			
Enclosure Bundle	U-0.14 (USI-0.79), WWR 25%	($691,600)	($461,100)
Enclosure + Mechanical Bundle	U-0.14 (USI-0.79), WWR 25%	($691,600)	($461,100)
Fixed Exterior Shading			
Enclosure Bundle	Fixed exterior shades	$56,400	$112,800
Enclosure + Mechanical Bundle	Fixed exterior shades	$56,400	$112,800
Infiltration rate			

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES – LAB BUILDING			
Enclosure Bundle	0.6 ACH50 + airtightness test	$12,900	$19,300
Enclosure + Mechanical Bundle	0.6 ACH50 + airtightness test	$12,900	$19,300
Ventilation			
Enclosure Bundle	Centralized HRV (70% effective)	$0	$0
Enclosure + Mechanical Bundle	Makeup air unit and exhaust fan	$23,000	$34,000
Fan Coil Units (FCU)			
Enclosure Bundle	In-suite 4-pipe constant speed FCUs	$0	$0
Enclosure + Mechanical Bundle	In-suite 4-pipe variable speed FCUs	$12,200	$18,400
Aircuity Sensors			
Enclosure Bundle	None	$0	$0
Enclosure + Mechanical Bundle	Aircuity sensors	$525,000	$525,000

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES – CLASSROOM OFFICE			
Bundle	**Individual Measure**	**Total Incremental Capital Cost ($/building)**	
		Best Case	**Worst Case**
Exterior Wall			
Enclosure Bundle	Concrete with exterior insulation, R-30 (USI-0.189), WWR 25%	$333,800	$473,400
Enclosure + Mechanical Bundle	Concrete with exterior insulation, R-30 (USI-0.189), WWR 25%	$333,800	$473,400
Roof			
Enclosure Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$144,800	$164,200
Enclosure + Mechanical Bundle	Flat roof with XPS insulation, R-45 (USI-0.126)	$144,800	$164,200
Window			
Enclosure Bundle	U-0.14 (USI-0.79), WWR 25%	($628,700)	($419,100)
Enclosure + Mechanical Bundle	U-0.14 (USI-0.79), WWR 25%	($628,700)	($419,100)
Fixed Exterior Shading			
Enclosure Bundle	Fixed exterior shades	$58,200	$116,400
Enclosure + Mechanical Bundle	Fixed exterior shades	$58,200	$116,400
Infiltration rate			
Enclosure Bundle	0.6 ACH50 + airtightness test	$12,200	$18,300

INCREMENTAL CAPITAL COST OF INDIVIDUAL MEASURES – CLASSROOM OFFICE			
Enclosure + Mechanical Bundle	0.6 ACH50 + airtightness test	$12,200	$18,300
Ventilation			
Enclosure Bundle	Centralized HRV (70% effective)	$0	$0
Enclosure + Mechanical Bundle	Centralized HRV (90% effective)	$76,600	$114,900
Fan Coil Units (FCU)			
Enclosure Bundle	In-suite 4-pipe constant speed FCUs	$0	$0
Enclosure + Mechanical Bundle	In-suite 4-pipe variable speed FCUs	$11,800	$17,600
Domestic Hot Water (DHW)			
Enclosure Bundle	Electric boilers for top-up from 120˚F to 140˚F	$0	$0
Enclosure + Mechanical Bundle	Water source heat pump for DHW top-up	$39,100	$58,700