FINAL REPORT

BC Energy Step Code Development for Public Sector Buildings

Province of British Columbia

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SUMMARY OF CHANGES

Version 2.1:

- Corrected references to the Care Facility NECB Reference results in Tables 11 and D-6.
- Corrected all references to the Library NECB Reference results in Tables 2, 7, 14, 15, and D-2, and Figure 2.
- Corrected figure numbering in Appendix C.
- Corrected NECB Cost Savings (%) columns in Appendix D

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1. EXECUTIVE SUMMARY

Morrison Hershfield has been retained by the Building and Safety Standards Branch of the Province of British Columbia to develop and analyze public sector building archetypes for Step Code, with the goal of understanding the energy, emissions, and economic implications of energy efficiency improvements to these building archetypes.

The archetypes analyzed are:

1. School
2. Library
3. College
4. Recreation Centre
5. Care Facility
6. Hospital

In order to align with the BC Energy Step Code, energy use intensity (EUI) and thermal energy demand intensity (TEDI) are investigated for these building types, along with greenhouse gas emissions reductions and requirements for net zero or net zero ready design. The incremental capital cost increases and payback periods of energy saving measures are included in this report.

In general, it is possible to achieve net zero ready design with less than 5% additional incremental capital cost, with the exception of schools, libraries, and colleges with labs in colder climates, and hospitals in all climates. Net zero ready design refers to a low energy building that could potentially be made net zero through the addition of rooftop PV, though the design itself may or may not include PV.

Each archetype has unique considerations, summarized briefly below and described in more detail in the report. Possible Step Code targets are shown for each archetype, with methodology, details of design measures considered, associated capital costs and payback periods outlined further in the report.

The measures included in the report were chosen to be achievable with market-ready design and construction practices. Performance criteria was considered based on a starting point of current code (NECB 2011) and an end point of net zero ready, with two performance levels in between; one representative of current typical design practice (based on achieving LEED Gold), and one in between current practice and net zero ready. The models have been benchmarked against ASHRAE 100 2018, which uses CBECS data, a large sample of existing buildings in various climate zones in the United States.

<u>School</u>

Energy savings for schools are achieved through improvements in mechanical system efficiency with heat recovery, reduced air leakage, lighting system savings, and ground source heat pumps at higher steps. The incremental costs range from 1.7% to 3.6%, and in climate zone 4 are able to achieve net zero ready design. Climate zone 5 is very close to net zero ready (it would only need an extra 2% of additional roof area to place enough PV panels to achieve net zero), while climate zones 6 and 7 would require an additional 14% to 32% of additional roof area.

Savings are modest compared with an ASHRAE 100 benchmark, with savings ranging up to 26% better than the benchmark at the highest steps. The ASHRAE 100 data set uses schools that may or may not be used for additional community and summer use, which the archetype includes; this may reduce archetype savings compared with the benchmark.

To connect the modeled archetype results with a high performance building case study, Odyssey Elementary in Utah (climate zone 5) is a net zero energy building with 320 kW of PV installed, with an operating EUI of 54 kWh/m^2. Energy use is significantly reduced in the evenings and over the summer; it is not clear if the school is used at these times but differences in hours of operation may skew results compared with the EUI of the archetype. The building uses displacement ventilation, ground source heat pumps, evaporative cooling, LED lighting with daylight sensor control, and a highly thermally efficient envelope. This is a lower EUI than the archetype building, which allows for fan coils rather than displacement ventilation (increasing fan energy), and allows for some server energy in addition to ASHRAE default plug loads. The targets presented below appear to be achievable based on this comparative case study; the modelling for Step Code targets would be expected to be normalized to allow year round operation and evening use by community groups.

Table 1. Possible Step Targets for Schools

Climate Zone	Benchmark EUI (ASHRAE 100) (kWh/m^2)	Step	EUI (kWh/m^2)	TEDI (kWh/m^2)	GHGI (kgCO_2/m^2)
4	113.9	1	275	100	36
		2	150	45	16
		3	130	30	12
		4	100	12	8
5	116.1	1	335	120	45
		2	180	62	20
		3	150	40	15
		4	110	25	8
6	129.2	1	390	165	56
		2	200	90	25
		3	170	60	20
		4	110	30	8
7	154.4	1	450	200	67
		2	240	120	32
		3	200	85	25
		4	115	40	8

Library

Energy savings for the library are achieved through significant lighting savings, high efficiency heat recovery, improvements in envelope thermal performance and infiltration rate, and use of a ground source heat pump at higher steps. Incremental capital costs to achieve the highest steps below are up to 5.1%, with savings compared with code of almost 75%. The savings compared with the ASHRAE 100 benchmark are significant, up to 77% at the highest steps. Net zero ready design is achieved for all but the coldest climate zone.

Table 2. Possible Step Targets for Libraries

Climate Zone	Benchmark EUI (ASHRAE 100) (kWh/m²)	Step	EUI (kWh/m²)	TEDI (kWh/m²)	GHGI ($kgCO_2/m^2$)
4	193.9	1	155	45	14
		2	120	45	11
		3	92	35	9
		4	55	11	1
5	196.4	1	185	55	17
		2	140	55	14
		3	105	45	10
		4	60	15	1
6	229.2	1	200	72	21
		2	160	70	19
		3	125	65	14
		4	60	24	1
7	270.3	1	240	100	30
		2	200	100	25
		3	155	80	16
		4	65	32	2

College

The college building archetype includes lecture halls, classrooms, offices, lounges, computer rooms, and an atrium. The general archetype excludes lab spaces, as these can have a significant impact on energy use due to high ventilation air requirements and high process load requirements. Depending on lab programming, its EUI might be up to approximately four times that of the other spaces. We recommend separating the special case of labs out to consider separately as an additional energy use allowance in any targets set.

Energy savings are achieved through improvements in heat recovery and envelope thermal performance, reduced air leakage rates, lighting system savings, and use of a ground source heat pump at higher steps.

Net zero ready design is achievable for a single storey college building, with cost premiums of under 5%. Compared with the ASHRAE 100 benchmark, energy savings ranging from 37% to almost 60% are achievable.

Labs have additional considerations for setting energy targets. The energy use in labs is primarily governed by the programming and use of the lab, which will dictate the ventilation requirements and process loads within the lab in order to fulfill the required functions of the space. While energy savings can be achieved using design measures such as heat recovery and an efficient central heating and cooling plant, the ventilation and process loads have such a significant effect on the overall energy use that these must be taken into account when describing the energy use of these spaces.

It is difficult to define a single EUI target for labs; for example the EUI for a lab in climate zone 4 may range from approximately 200 kWh/m² to 700 kWh/m² depending on the ventilation rates required for the space use. We recommend that lab spaces be excluded from the EUI target, and that a prescriptive requirement that labs use demand controlled ventilation and heat recovery unless prohibitive be implemented.

Table 3. Possible Step Targets for Colleges

Climate Zone	Benchmark EUI (ASHRAE 100) (kWh/m^2)	Step	EUI (kWh/m^2)	TEDI (kWh/m^2)	GHGI ($kgCO_2/m^2$)	Labs
4	203.9	1	235	22	15	Excluded from EUI target, require heat recovery and DCV where possible based on space use requirements
		2	165	20	8	
		3	145	15	7	
		4	130	6	2	
5	205.6	1	250	33	17	
		2	180	28	10	
		3	165	20	8	
		4	130	11	2	
6	245	1	255	45	19	
		2	190	42	13	
		3	180	35	10	
		4	130	9	2	
7	312.5	1	275	70	22	
		2	215	65	18	
		3	185	46	12	
		4	130	15	2	

Recreation Centre

The recreation centre archetype includes a fitness facility, gym, change rooms, multipurpose space, and offices. Pools and arenas are considered separately, as these have high energy use and may be heavily dependent on programming and user needs.

Energy savings are achieved with improved heat recovery, reduced window areas, significant lighting savings, domestic hot water flow savings, and air source heat pumps at higher steps. Net zero ready design is achievable in all climates with under 4% incremental capital cost increase. Savings compared with ASHRAE 100 are modest, ranging from 3% to 18% savings, however, given the variation in spaces that may be considered part of a recreation centre, benchmarking is difficult as the benchmark programming may vary.

Pool energy use is both very large and is primarily dependent on the specific type of pool and intended end user, which will dictate pool water set point temperature, room air temperature and relative humidity setpoints, and hygiene related water turn-over rates. We recommend accounting for pool energy separately in any energy targets; a proposed additional EUI allowance for the pool area (pro-rated by the pool surface area) is shown in the table below.

Arena energy use is likewise very large and dependent on programming. We recommend applying prescriptive measures in ice rinks that follow the NECB, with improvements explored on a project by project basis.

Table 4. Possible Step Targets for Recreation Centres

Climate Zone	Benchmark EUI (ASHRAE 100) (kWh/m²)	Step	EUI (kWh/m²)	TEDI (kWh/m²)	GHGI ($kgCO_2$/m²)	Pool	Arena
4	83.6	1	240	55	25	EUI allowance of 2,900 kWh/m² of pool surface area, excluded from TEDI target	NECB prescr-iptive measures
		2	130	15	9		
		3	105	11	8		
		4	75	7	1		
5	87.5	1	270	70	29		
		2	150	25	11		
		3	120	20	10		
		4	90	10	1		
6	98.9	1	300	95	36		
		2	160	40	13		
		3	130	35	11		
		4	90	20	1		
7	116.7	1	335	120	43		
		2	180	62	15		
		3	145	48	12		
		4	100	30	1		

Care Facility

The care facility includes one storey of primarily common space, three storeys of single or double occupancy suites with higher levels of care, and five storeys of independent living suites. The loads and measures investigated are similar to those of typical multi-unit residential buildings, with minor differences in space types. Energy savings are achieved mainly through improvements in envelope thermal performance, reductions in air leakage, and reductions in window area. Improvements in mechanical systems were analyzed but provide less benefit than for some other building types.

Overall, our recommendation based on this analysis is to consider care facilities to fall under the residential building targets already established for the Step Code. The archetype building energy models in this report include heat pumps, which reduce the EUI compared with current residential Step Code targets, however the building energy use and energy savings achieved through various design measures mirror those of residential buildings already addressed in the Step Code.

Hospital

The hospital archetype is a patient care tower including client rooms, operating rooms, MDR, exam and clinical support, public areas, staff areas, corridors, and other support spaces. Other hospital archetypes and space type mixes were investigated and showed similar EUIs once normalized to the same mechanical system type, similar process loads, and 24/7 operating hours. A normalization method for process loads is discussed below.

Hospital energy use is driven primarily by high airflow rates (which are governed by a CSA standard) and heat recovery and mechanical efficiency. High internal loads and efficient massing leading to relatively low envelope losses mean that envelope measures tend to have little impact on energy use, sometimes even increasing the overall energy use by increasing the amount of cooling and reheat required. Accordingly, energy savings for the archetype are achieved by changing from a central VAV system that cools and reheats all the air in the system, to a 100% outdoor air system with heat recovery, with radiant heating and cooling in the zones, that supplies tempered air and cools or heats as required at the individual zone.

Energy savings compared with the ASHRAE 100 benchmark range from 33% to 42%, at an incremental capital cost of under 2%. Net zero is not achievable for any of the options analyzed; a minimum of an additional 53% of roof area worth of PV panel area would be needed to achieve net zero ready for a single storey building (without additional energy use of additional floor area).

Typical current hospitals in the US Pacific Northwest (climate zone 4), which are designed similarly to those in BC, have a median EUI of 785 kWh/m^2, higher than the code baseline in this study. Several case studies of existing hospitals in the Pacific Northwest, done by the University of Washington[1], showed EUIs ranging between 495 kWh/m^2 and 712 kWh/m^2, below the median but still above the code baseline (though approaching it for the lowest energy hospital.) This is as expected, as the code baseline for NECB requires a mechanical system that is not typically used in hospitals in current design but which reduces the energy use of the baseline. The same University of Washington report also looks at Scandinavian hospitals, focusing on four hospitals with an average EUI of 378 kWh/m^2. This is approximately in line with the archetype's Step 2 values, or equivalent to current typical construction practice. While our current archetype is based on actual design phase energy models for several hospitals, some inputs are standardized to NECB values to provide a reasonable baseline comparison, and it would be valuable to compile detailed case studies of operating high performance buildings locally to bridge the gap between code development and operations.

The higher steps presented below are achievable in the model based primarily on changes to the mechanical design that are not currently typically used in hospitals in BC, and a detailed feasibility study within the BC context may be required. It would be valuable to undertake a detailed feasibility study of a high performance option on a future healthcare project during the planning or schematic design phases to better understand potential barriers, actual costs, etc.

Internal loads vary based on the programming of the hospital. Diagnostic equipment, steam sterilization, laundry, and helipad or other snow melt loads, and other loads, may be required in some hospitals and not in others. These loads can be significant and may impact the space conditioning loads for the building overall, so must be taken into account in setting targets. We recommend a project-specific accounting method to adjust the EUI target for the

[1] Burpee, H., McDade, E. "Comparative Analysis of Hospital Energy Use: Pacific Northwest and Scandinavian", available at http://aahfoundation.org/pdfs/Burpee-%20%20FY2011-12-Comparative%20Analysis%20of%20Hospital%20Energy%20Use-%20Final%20Report.pdf

individual project up or down on a 1:1 basis for higher or lower project specific process loads, as shown in the table below.

Table 5. Possible Step Targets for Hospitals

Climate Zone	Benchmark EUI (ASHRAE 100) (kWh/m²)	Step	EUI (kWh/m²)	TEDI (kWh/m²)	GHGI ($kgCO_2/m^2$)	Process Loads
4		1	405	80	33	Targets were set using NECB defaults at 70 kWh/m2 EUI of process loads. Project EUI targets should be adjusted on a 1:1 basis up or down to account for differences in project specific process loads.
		2	365	75	24	
		3	300	20	10	
		4	265	10	9	
5		1	525	75	53	
		2	375	70	30	
		3	320	22	15	
		4	300	10	14	
6		1	565	100	61	
		2	375	90	30	
		3	320	35	20	
		4	305	15	15	
7		1	640	130	75	
		2	385	80	35	
		3	325	40	20	
		4	305	20	15	

Next Steps

Future research may be of value in order to provide further detail and understanding of the Step Code targets presented in this report and to identify potential barriers to implementation.

With respect to all Step Code targets and buildings, compile detailed case studies of operating high performance buildings locally and globally that compare the EUIs with the Step Code targets, including any program or code differentials that may lead to varying numbers. This is to help validate the performance level of the Step Code targets and to begin identifying the gaps and barriers for achieving even higher levels of performance if global examples of lower energy buildings emerge.

The Building and Safety Standards Branch should connect with ministries where recent LEED Gold buildings are operating to compile operating data, to bridge the gap between code development and operations.

A detailed feasibility study of healthcare high performance option should be undertaken on a future healthcare project during planning or schematic design, even if not pursued, to understand better potential barriers, actual costs, etc.

2. PROJECT OVERVIEW

2.1 Introduction

Morrison Hershfield has been contracted by the Province of BC to aid in updating its Energy Step Code framework for additional building types and to assess potential net zero energy ready performance targets for provincial buildings. An Energy Performance Cost Benefit Analysis has been completed for six archetypes for public sector buildings in order to make a recommendation on the most suitable performance targets, to move towards net-zero energy ready buildings in a cost effective manner. The six archetype buildings that have been analyzed include a school, library, college, recreation center, care facility, and hospital.

The building energy analysis in this report was completed using EnergyPlus, and costing information was provided by a sub consultant, BTY Group. The impact of a variety of parameters including envelope performance, HVAC system performance, building window-to-wall ratio, lighting and internal load savings was assessed. The range of conditions analyzed generated a large data set, which was then analyzed using Morrison Hershfield's interactive Building Energy Performance Map to determine trends in the data and derive conclusions. A detailed description of the methodology and analysis is provided in Section 3.

2.2 Scope of Analysis

The purpose of this study is to determine the range of performance feasible for these new public sector building types, and the financial implications of improving energy performance in order to inform the selection of new targets within the Energy Step Code Framework.

For each archetype and climate zone considered, energy results and financial impacts are outline for:

- The NECB baseline building scenario,
- A typical current practice design which meets LEED Gold by achieving a minimum 6 EA c1 points using the NECB alternate compliance path of LEED v4, with a low incremental capital cost,
- The lowest energy solution, which would be allow for a net zero design with the smallest on-site energy generation capacity,
- A middle case which balances improved performance between current practice and the lowest energy case and capital costs. The middle solution is shown with and without a low carbon HAVC plant system to demonstrate the extent of improvements which are made by a change in HVAC technology in reaching the lowest energy solution.

In performing the analysis several factors were identified which will require either a separate set of energy targets or a move to prescriptive or baseline building approach to adequately address the diversity in public sector buildings. These include a separation of pools and laboratories from the recreation center and college archetypes respectively, and a recommendation for a prescriptive approach for ice rinks.

In addition to the tables and charts provided in this report, the full data set generated for all building scenarios and climates zones, including the separate analysis of labs and pools will be provided to the Province.

2.3 Energy Performance Approaches and Metrics

2.3.1 Reference Building Approach

Targeting a performance level relative to an energy code, such as NECB, is known as a reference building approach. The key features of a reference building approach are:

- The “reference building” is a fictitious building that the design is compared to for assessing performance.
- The reference building predominantly has the same physical characteristics as the proposed design, such as program type, geometry, and orientation. Efficient massing of the design is not accounted for, since the reference building would have the same efficient massing.
- The reference building approach normalizes certain assumptions about the building, thereby eliminating any performance biases related to building characteristics that are not typically under the control of the design team. This typically includes characteristics such as occupancy, hours of operation, receptacle and process loads, among others.
- The reference building approach typically uses a strict ruleset that dictates how performance is to be assessed using energy modeling, and how credit is rewarded for energy efficiency measures.
- The reference building approach typically results in a moving target, in that the performance of the reference building changes based on certain characteristics of the design (see below for examples in the NECB). This can sometimes result in situations where better relative performance does not equal better absolute performance.
- The reference building approach does not typically reward innovative strategies that minimize absolute energy use, such as night setback of temperatures, reductions in receptacle and process loads, and other types of measures that would be considered standardized assumptions.

The reference building approach is common throughout North America, with most states in the US, British Columbia, and Ontario referencing some version of ASHRAE 90.1 – Energy Standard for Buildings except Low-Rise Residential Buildings. The NECB is currently referenced in British Columbia, Alberta, Manitoba, Ontario and Nova Scotia. However, the reference building approach is less common in other parts of the world, such as many countries in Europe, where a target based approach is used.

In generating the public building sector dataset, only the boiler/chiller based NECB reference building was modelled, and all NECB and LEED points are calculated based on this reference. Strictly by NECB, if the proposed model uses a heat pump system, the reference building also changes to heat pump, reducing some of the relative energy use benefits. In this study, the reference building was not changed to a heat pump. The rationale for keeping a consistent reference is to simplify the results and focus on the energy savings relative to a conventionally built code building. Reference building based metrics that were considered in this analysis:

Energy Savings over NECB

This metric looks at the relative energy savings of a particular design over an NECB reference building.

This metric has the same opportunities and challenges as discussed above for a reference building approach.

TEDI Savings over NECB

This metric looks at the relative thermal energy demand savings of a particular design over an NECB reference building. This metric has the same opportunities and challenges as discussed above for a reference building approach. Additionally, the NECB baseline what modelled using the NECB prescribed wall performance without accounting for thermal bridging effects. The proposed buildings are modelled including the effect of thermal bridging, and will therefore have a higher TEDI despite having the same or better clear wall performance when all other factors are equal.

GHG Savings over NECB

This metric looks at the relative GHG savings of a particular design over a gas-based NECB reference building (i.e. an NECB Reference Building that uses natural gas for space heating rather than electricity or heat pumps). Since the NECB Reference Building fuel sources vary depending on the design, it was deemed more appropriate to use a fixed fuel source for this metric, based on the most common heating systems used in BC.

This metric is similar to the Energy Savings over NECB metric, but the focus is on GHG emissions rather than energy savings. Focusing on GHG emissions emphasizes saving energy on fuel sources that have the largest GHG impact, rather than equally rewarding different fuel types. In BC, this pushes solutions to rely on electricity.

2.3.2 Target Based Approach

A target based approach sets absolute targets for energy efficiency. A range of metrics have been used in this approach, such as Energy Use Intensity, Thermal Energy Demand Intensity, and Greenhouse Gas Emissions Intensity. These are defined in more detail below. The key features of a target based approach are:

- It focuses on absolute values, rather than a comparative value. This tends to lead to more appropriate design solutions for reducing energy and/or carbon rather than solutions selected for the purpose of outperforming a fictitious reference building.

- A target based approach has been used successfully in high performance standards, such as Passive House, and has shown success in reducing actual energy use of operating buildings.

- Targets and metrics can be chosen to achieve the specific outcomes desired by a particular policy (ex. energy, carbon, etc.)

- Targets often have to be set for different building types that inherently have different energy use characteristics; this can make it challenging to implement in a policy intended to capture all buildings. This can be remedied by providing additional allowances for certain defined process-type loads, or weighting significantly difference space types in a mixed use building.

Target based metrics that were considered in this analysis:

Energy Use Intensity (EUI)

This metric looks at the absolute energy use of the building, and is typically varied depending on building type or climate. This metric has the same opportunities and challenges as discussed above for a target based approach.

GHG Emissions Intensity

This metric is similar to EUI, but instead of focusing on absolute energy use, it focuses on absolute GHG emissions, with the intent of maximizing GHG reductions by prioritizing savings for high GHG fuels.

Thermal Energy Demand Intensity

This metric represents the amount of heating a building needs to offset building envelope losses and temper ventilation air, prior to any mechanical interventions (with the exception of ventilation heat recovery equipment). The intent of this metric is to maximize passive or near passive systems before looking at heating delivery methods and technology. This metric has been made popular by Passive House, an international high performance building standard, which promotes highly insulated buildings with exceptional ventilation heat recovery and otherwise simple mechanical systems.

This metric is agnostic to fuel source, with the primary intention of imposing efficient building envelope solutions. According to the Pembina Institute's report on "Accelerating Market Transformation for High-Performance Building Enclosures", in addition to providing energy savings, prioritizing building envelope solutions are also important for the following reasons:

- Building envelope solutions "are long lasting and costly to refurbish, unlike other systems that can be more easily replaced as better technologies become available."
- Building envelope solutions are simpler, "their performance does not depend on complex energy management systems and they are more tolerant to delayed maintenance."
- Reducing heating and cooling demand early in the design process allows for reduction of the size of space conditioning systems, reducing construction cost and ongoing energy demand.
- Better building envelopes "also offer significant non-energy benefits, such as thermal comfort, acoustic isolation, durability, and increased resiliency to power outages and extreme temperature events."

One consideration in using a TEDI target is that for public sector buildings, which typically have high lighting loads, sometimes have high plug loads, and are usually mechanically cooled, the lowest TEDI building does not correlate to the lowest energy use building. The lowest TEDI buildings typical occur when no lighting savings are considered from the NECB values, and the envelope and heat recovery performance are so high that they cause a larger increase in cooling energy than reduction in heating energy. The internal heat gains provided by high internal loads such as lighting help heat the building, reducing the load on the mechanical heating system, but increasing the load on the cooling system as well as the overall energy use of the building. TEDI focusses only on heating loads, and does not account for increases in cooling loads or other energy use. These items are accounted for in the EUI target rather than the TEDI target.

3. ARCHTYPE BUILDING DESCRIPTIONS AND CURRENT TYPICAL LEED GOLD SOLUTION

Morrison Hershfield used existing energy models from MH's internal database that best reflected the six building types that were to be analyzed. The energy models were modified to form archetypes, where the key performance criteria, such as building envelope performance, mechanical systems and efficiency, and lighting efficiency, reflected typical strategies that are used in current practice and can be practically implemented in the near future. The six archetype models were then analyzed in EnergyPlus whole building energy simulation software with properties outlined below. Detailed input tables are found in Appendix A. Energy end use break downs are provided for each archetype and the corresponding NECB reference building for climate zones 4 and 7a.

3.1 School

The school archetype building is a 4,670 m^2 facility including classrooms, a gym, offices, and a library. The Heating Ventilation Air Conditioning (HVAC) system consists of a dedicated outdoor air system with heat recovery and demand control ventilation providing ventilation air to the main building, and fan coils which cycle to serve heating and cooling loads served by a high efficiency central boiler and chiller plant. The gym and a small server room are served by dedicated gas-fired roof top units.

Parameters varied include effective wall, roof, window thermal and air tightness performance, glazing ratio, heat recovery efficiency, lighting savings, and two central plant types. The typical LEED Gold building currently has:

- R-10 walls, R-20 roof
- 20% Window to Wall Ratio (WWR), double glazed windows with low-e coating (USI 2.5 except USI 2.0 in zone 7a)
- 80% efficiency heat recovery on the main building Dedicated Outdoor Air System (DOAS) with demand control ventilation
- Typical air infiltration levels
- 25% lighting savings from the reference building
- A central high efficiency boiler and chiller plant

Table 6 and Figure 1 summarize the energy use, cost, and GHG results for the NECB reference building compared to the current typical LEED Gold school for climate zones 4 and 7a. The LEED Gold school currently achieves 46% energy savings from the NECB reference building in climate zone 4 and 47% in zone 7a.

Table 6. School Archetype Energy, Cost and GHG Results

	NECB Reference		LEED Gold School		
	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Savings from Reference (%)
Climate Zone 4					
Heating + DHW	0.0	179.6	0.0	77.7	57%
Cooling	3.0	0.0	4.4	0.0	-48%
Lighting	43.8	0.0	35.5	0.0	19%
Equipment	14.7	0.0	14.7	0.0	0%
Fans	26.9	0.0	13.0	0.0	52%
Pumps	1.2	0.0	3.0	0.0	-142%
Humidification	0.0	5.7	0.0	0.6	89%
Total Energy (kWh/m²)	89.7	185.3	70.5	78.3	46%
Total Energy (kWh/m²)	275.0		148.9		46%
Thermal Energy Demand Intensity (TEDI) (kWh/m²)	100.4		43.8		56%
Total Annual Energy Cost ($/m²)	11.4		8.8		23%
Total GHG (kgCO₂e/m²)	35.3		15.3		57%
Climate Zone 7a					
Heating + DHW	0.0	312.5	0.0	156.2	50%
Cooling	1.9	0.0	3.8	0.0	-95%
Lighting	43.8	0.0	35.4	0.0	19%
Equipment	14.7	0.0	14.7	0.0	0%
Fans	27.8	0.0	13.4	0.0	52%
Pumps	1.8	0.0	4.8	0.0	-163%
Humidification	0.0	42.1	0.0	7.8	82%
Total Energy (kWh/m²)	90.1	354.6	72.2	164.0	47%
Total Energy (kWh/m²)	444.6		236.2		47%
Thermal Energy Demand Intensity (TEDI) (kWh/m²)	197.9		119.1		40%
Total Annual Energy Cost ($/m²)	16.6		13.5		19%
Total GHG (kgCO₂e/m²)	66.6		31.1		53%

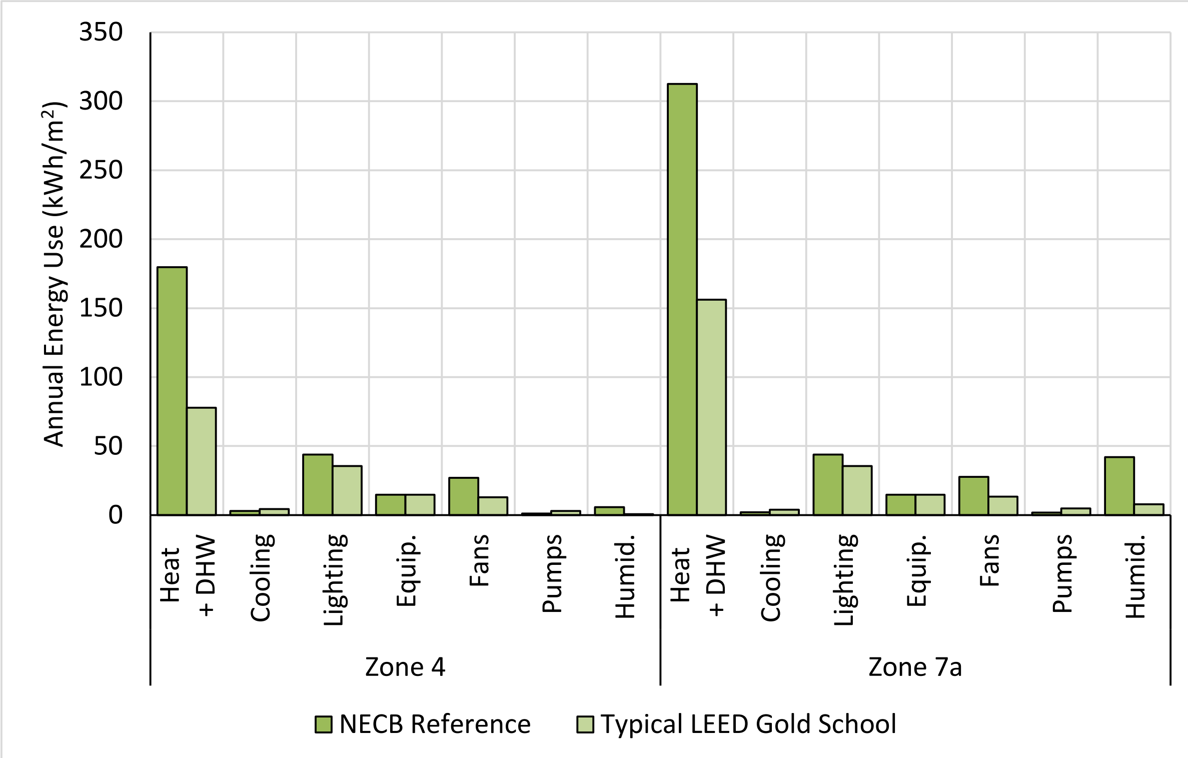

Figure 1. Annual Energy Use of NECB Reference and LEED Gold School

3.2 Library

The library archetype building is a 1,280 m^2 facility including shelf areas, study areas, office and meeting spaces. The HVAC system consists of a dedicated outdoor air system with heat recovery and humidification providing ventilation air, and fan coils which cycle to serve heating and cooling loads served by a high efficiency central boiler and chiller plant.

Parameters varied include effective wall, roof, window thermal and air tightness performance, glazing ratio, heat recovery efficiency, lighting savings, and two central plant types. The typical LEED Gold building currently has:

- R-10 walls, R-20 roof
- 30% WWR, double glazed windows with low-e coating (USI 2.0)
- 60% efficiency heat recovery on the main building DOAS
- Typical air infiltration levels
- 25% lighting savings from the reference building
- A central high efficiency boiler and chiller plant

Table 7 and Figure 2 summarize the energy use, cost, and GHG results for the NECB reference building compared to the current typical LEED Gold library for climate zones 4 and 7a. The LEED Gold library currently achieves 24% energy savings from the NECB reference building in climate zone 4 and 15% in zone 7a.

Table 7. Library Archetype Energy, Cost and GHG Results

	NECB Reference		LEED Gold Library		
	Electricity (kWh/m^2)	Natural Gas (kWh/m^2)	Electricity (kWh/m^2)	Natural Gas (kWh/m^2)	Savings from Reference (%)
Climate Zone 4					
Heating + DHW	0.0	67.5	0.0	55.5	18%
Cooling	2.7	0.0	6.2	0.0	-130%
Lighting	53.7	0.0	40.3	0.0	25%
Equipment	2.3	0.0	2.3	0.0	0%
Fans	28.2	0.0	12.5	0.0	56%
Pumps	0.0	0.0	0.7	0.0	N/A
Humidification	0.0	0.3	0.0	0.4	-32%
Total Energy (kWh/m^2)	86.9	67.8	62.0	55.8	24%
Total Energy (kWh/m^2)	154.7		117.8		24%
Thermal Energy Demand Intensity (TEDI) (kWh/m^2)	42.6		44.8		-5%
Total Annual Energy Cost ($\$/m^2$)	7.7		5.7		26%
Total GHG ($kgCO_2e/m^2$)	13.4		11.0		18%
Climate Zone 7a					
Heating + DHW	0.0	136.4	8.5	116.5	8%
Cooling	2.1	0.0	5.0	0.0	-143%
Lighting	53.7	0.0	40.3	0.0	25%
Equipment	2.3	0.0	2.3	0.0	0%
Fans	29.1	0.0	13.1	0.0	55%
Pumps	0.0	0.0	0.7	0.0	N/A
Humidification	0.0	11.6	0.0	14.2	-22%
Total Energy (kWh/m^2)	87.2	148.0	69.9	130.7	15%
Total Energy (kWh/m^2)	235.2		200.6		15%
Thermal Energy Demand Intensity (TEDI) (kWh/m^2)	95.9		109.4		-14%
Total Annual Energy Cost ($\$/m^2$)	10.1		8.5		16%
Total GHG ($kgCO_2e/m^2$)	28.0		25.0		11%

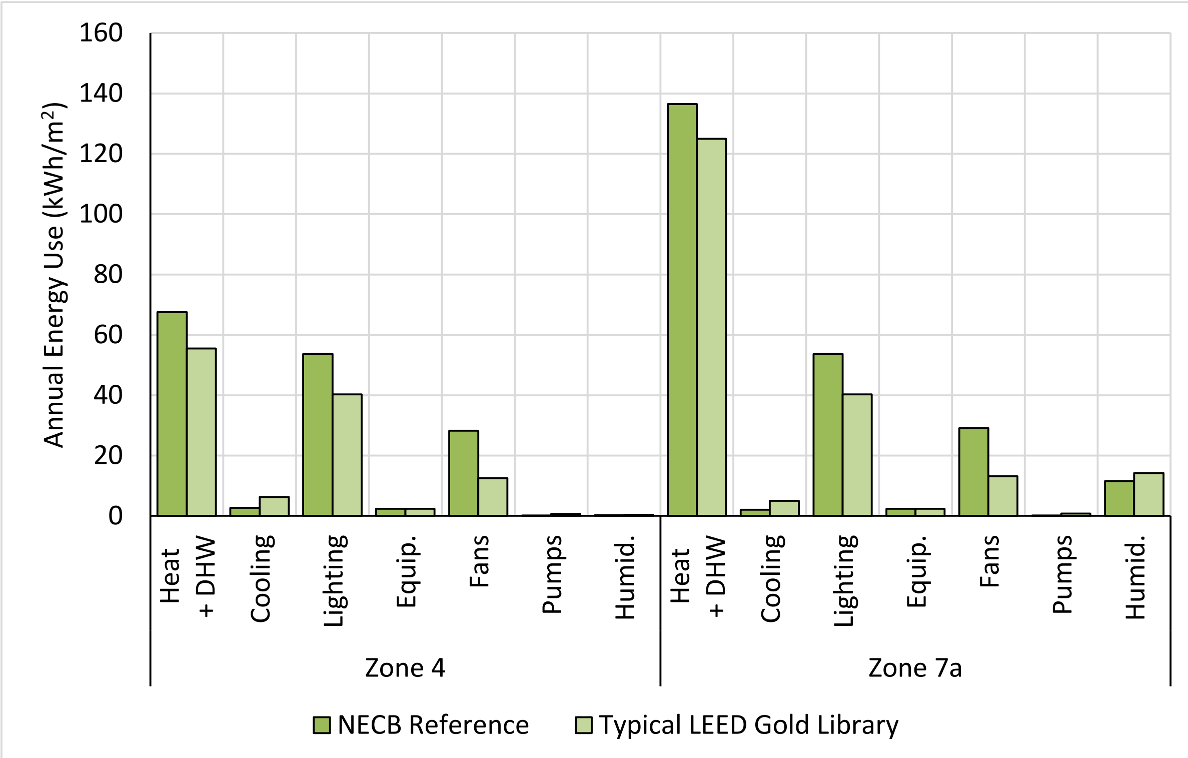

Figure 2. Annual Energy Use of NECB Reference and LEED Gold Library

3.3 College

The college archetype building is a 16,090 m^2 facility including lecture halls, classrooms, offices, lounges, computer rooms, and atrium. College buildings which include labs are considered as an alternative case, as outlined below. The HVAC system consists of dedicated outdoor air systems with heat recovery providing ventilation air, and fan coils which cycle to serve heating and cooling loads served by a high efficiency central boiler and chiller plant.

It is recommended that labs be separated from the remainder from the building for the purpose of setting energy targets as their energy use intensity, and possible energy conservation measures are highly dependent on the type of lab, which dictates ventilation requirements and feasibility of turn-downs along with plug and process loading. Lab energy use is further discussed below.

Parameters varied include effective wall, roof, window thermal and air tightness performance, glazing ratio, heat recovery efficiency, lighting savings, and two central plant types. The typical LEED Gold building currently has:

- R-10 walls, R-20 roof
- 40% WWR, double glazed windows with low-e coating (USI 2.0)
- 60% efficiency heat recovery on all DOAS when labs are included, heat recovery is not included for LEED Gold when labs are excluded
- Typical air infiltration levels

- 25% lighting savings from the reference building
- A central high efficiency boiler and chiller plant

Table 8 and Figure 3 summarize the energy use, cost, and GHG results for the NECB Reference building compared to the current typical LEED Gold college without labs for climate zones 4 and 7a. The LEED Gold college with labs currently achieves 56% energy savings from the NECB reference building in climate zone 4 and 52% in zone 7a.

Table 9 and Figure 4 summarize the energy use, cost, and GHG results for the NECB Reference building compared to the current typical LEED Gold college with labs for climate zones 4 and 7a. The LEED Gold college without labs currently achieves 28% energy savings from the NECB reference building in climate zone 4 and 22% in zone 7a.

Lab energy use is heavily dependent on the ventilation rates required for the labs, which is based on the programming and use of the lab. The results below assume the lab ventilation system is designed for 8 ACH, but operates at 5 ACH during weekdays, with one third of the labs requiring 2 ACH overnight and on weekends, and two thirds of the labs requiring no ventilation during unoccupied hours. The labs also include process chilled water load, lab equipment plug load, and a portion of the building IT load.

Further discussion of lab energy use is presented in Section 3.3.1 below.

Table 8. College Archetype Energy, Cost and GHG Results without Labs

	NECB Reference		LEED Gold College wo Labs		
	Electricity (kWh/m^2)	Natural Gas (kWh/m^2)	Electricity (kWh/m^2)	Natural Gas (kWh/m^2)	Savings from Reference (%)
Climate Zone 4					
Heating + DHW	0.0	67.2	0.0	34.2	49%
Cooling	10.3	0.0	8.9	0.0	14%
Lighting	64.9	0.0	48.8	0.0	25%
Equipment	58.5	0.0	58.5	0.0	0%
Fans	14.2	0.0	4.0	0.0	72%
Pumps	17.2	0.0	12.1	0.0	30%
Total Energy (kWh/m^2)	165.1	67.2	132.2	34.2	28%
Total Energy (kWh/m^2)	232.3		166.4		28%
Thermal Energy Demand Intensity (TEDI) (kWh/m^2)	21.2		18.8		11%
Total Annual Energy Cost ($\$/m^2$)	12.7		9.6		25%
Total GHG ($kgCO_2e/m^2$)	14.3		7.8		45%
Climate Zone 7a					
Heating + DHW	9.4	109.0	0.0	87.8	26%
Cooling	4.4	0.0	4.7	0.0	-6%
Lighting	64.9	0.0	48.8	0.0	25%
Equipment	58.5	0.0	58.5	0.0	0%
Fans	15.3	0.0	3.7	0.0	76%
Pumps	10.4	0.0	8.9	0.0	14%
Total Energy (kWh/m^2)	162.9	109.0	124.6	87.8	22%
Total Energy (kWh/m^2)	272.0		212.4		22%
Thermal Energy Demand Intensity (TEDI) (kWh/m^2)	59.8		70.8		-18%
Total Annual Energy Cost ($\$/m^2$)	13.8		10.7		23%
Total GHG ($kgCO_2e/m^2$)	22.0		17.6		20%

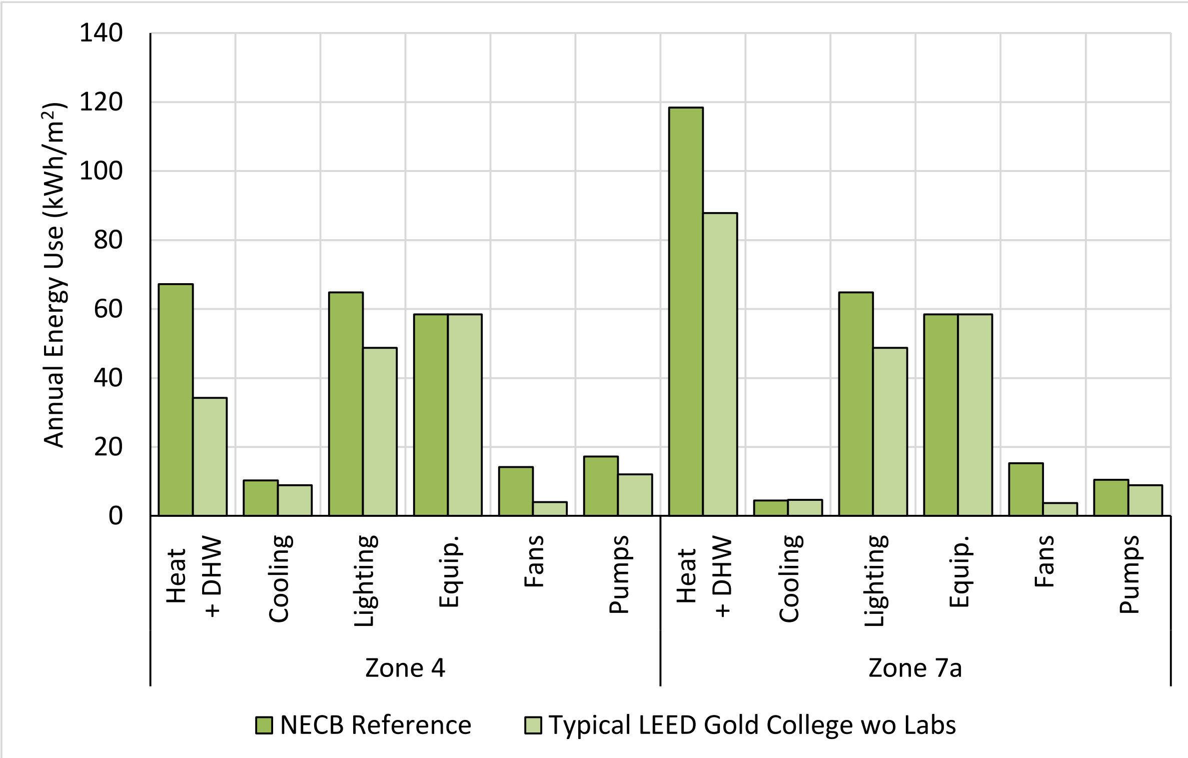

Figure 3. Annual Energy Use of NECB Reference and LEED Gold College without Labs

Table 9. College Archetype Energy, Cost and GHG Results with Labs

	NECB Reference		LEED Gold College w Labs		
	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Savings from Reference (%)
Climate Zone 4					
Heating + DHW	0.0	223.9	0.0	46.1	79%
Cooling	20.3	0.0	9.1	0.0	55%
Lighting	65.9	0.0	49.5	0.0	25%
Equipment	82.6	0.0	82.6	0.0	0%
Fans	75.1	0.0	16.9	0.0	77%
Pumps	21.5	0.0	10.5	0.0	51%
Total Energy (kWh/m²)	265.5	223.9	168.7	46.1	56%
Total Energy (kWh/m²)	489.4		214.7		56%

Thermal Energy Demand Intensity (TEDI) (kWh/m²)	141.9		34.8		75%
Total Annual Energy Cost ($/m²)	23.9		12.3		49%
Total GHG (kgCO₂e/m²)	44.3		10.4		77%
Climate Zone 7a					
Heating + DHW	80.7	291.9	32.6	102.2	64%
Cooling	9.4	0.0	4.9	0.0	48%
Lighting	65.9	0.0	49.5	0.0	25%
Equipment	82.6	0.0	82.6	0.0	0%
Fans	76.2	0.0	16.5	0.0	78%
Pumps	14.9	0.0	8.3	0.0	44%
Total Energy (kWh/m²)	329.8	291.9	194.5	102.2	52%
Total Energy (kWh/m²)	621.6		296.7		52%
Thermal Energy Demand Intensity (TEDI) (kWh/m²)	274.1		121.8		56%
Total Annual Energy Cost ($/m²)	30.1		15.6		48%
Total GHG (kgCO₂e/m²)	57.6		21.0		63%

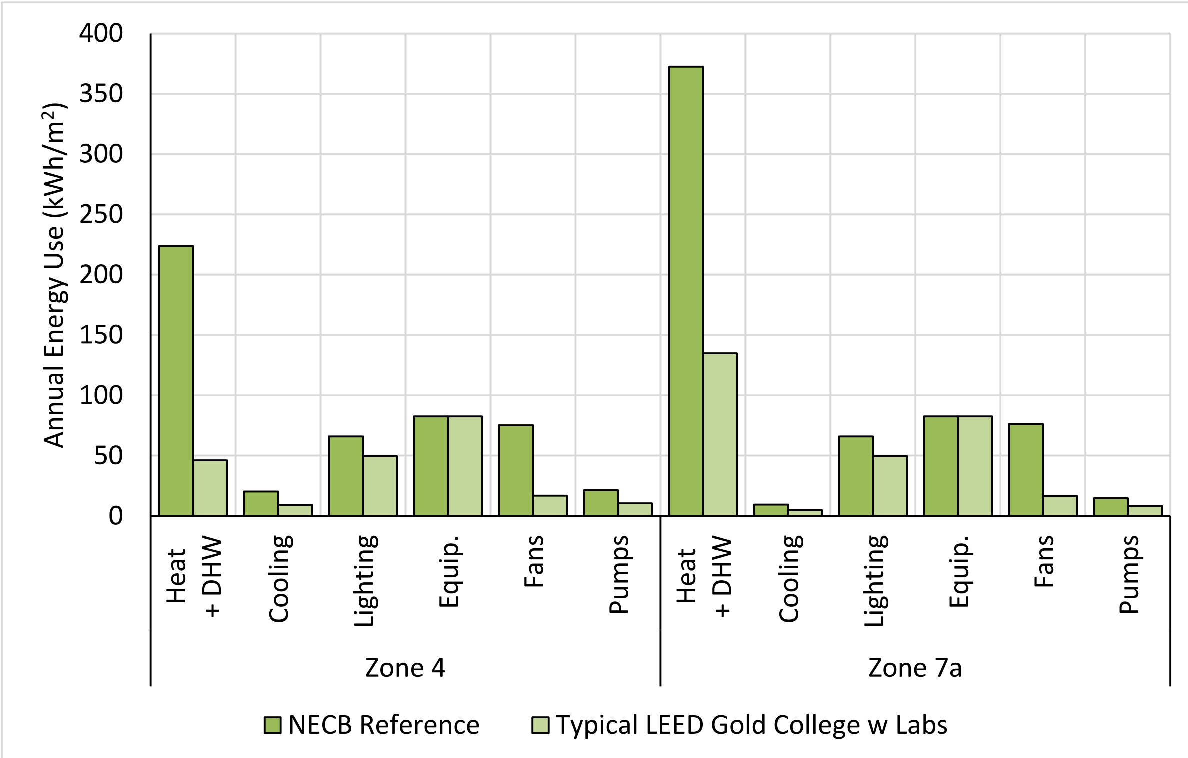

Figure 4. Annual Energy Use of NECB Reference and LEED Gold College with Labs

3.3.1 Labs

Laboratory energy use is variable depending of the type of laboratory. The two main factors affecting energy use are ventilation quantity and process loading. The activities in the lab can affect the ability of the HVAC system to reduce ventilation air both during occupied and unoccupied times, and more advanced air quality monitoring systems may be required to reduce supply air volumes optimally via demand control ventilation.

The major factors affecting lab energy use were found to be climate, ventilation quantity, heat recovery efficiency, and central plant HVAC system. Lighting loads have a minor effect on TEDI only, and building envelope has no effect. Figures 5 and 6 show the EUI and TEDI respectively for labs in all four climate zones based on the amount of ventilation air setback that can be achieved. Energy use can be three times higher for a lab constantly ventilated at 8 ACH vs a lab ventilated at 4 ACH during the day and turned off at night. The labs all have a 40% efficient run-around loop for air to air heat recovery, 50% lighting savings, and a high efficiency boiler and chiller. The air changes per hour required and whether ventilation air setback can be used will depend on program requirements and use.

The values shown include all typical NECB loads including the NECB recommended plug loads, lights, space conditioning, fans, and pumping energy, but do NOT include any process chilled water loads for equipment cooling, IT loads, or and other process loading. Additional energy allowance should be provided for these required loads.

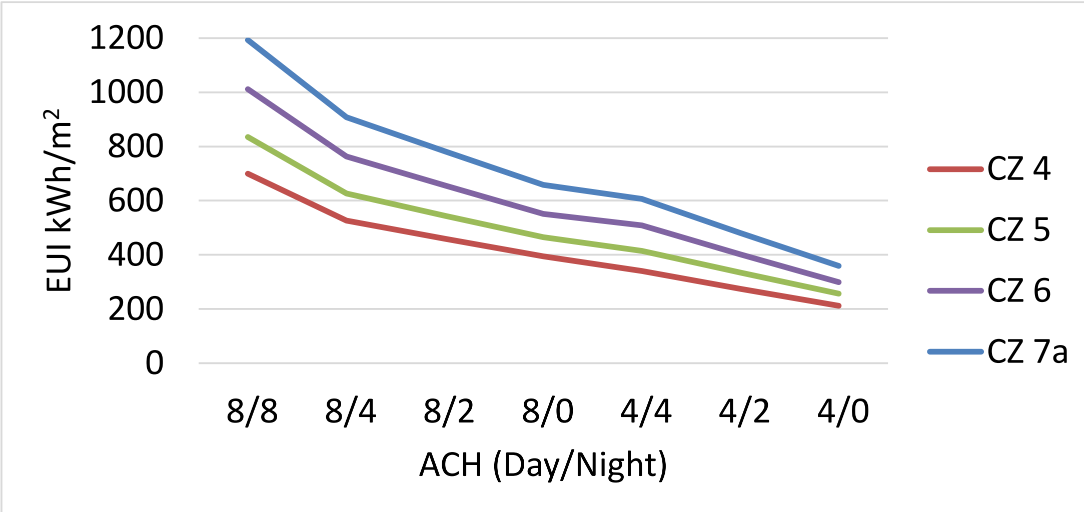

Figure 5. Annual Energy Use of Labs with varied Ventilation turn-down rates

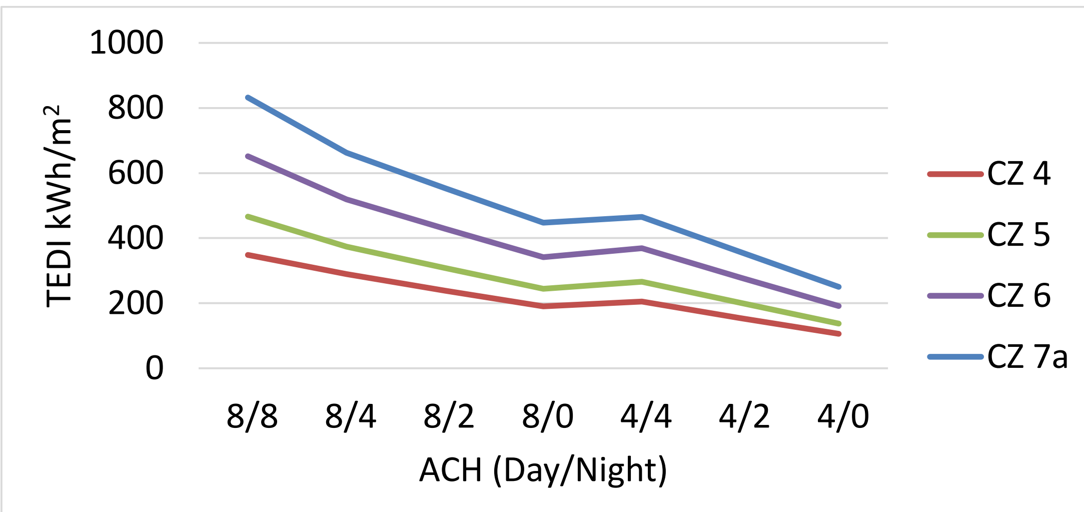

Figure 6. Annual Thermal Energy Demand of Labs with varied Ventilation turn-down rates

The quality of exhaust air can also affect the type of heat recovery that may be used to reduce ventilation heating. Typically, run-around loops can be used, where glycol is pumped between the intake and exhaust streams to transfer heat, but a lower efficiency than direct air-to-air heat exchangers. However, both run-around loop technology and direct air heat exchanger technology is improving to increase efficiency and reduce contamination of the intake stream.

Figures 7 and 8 show the EUI and TEDI outcomes for labs with progressively improving energy conservation measures. The first case demonstrates the NECB reference building, where the full design ventilation rate of 8 ACH is modelled all the time, but with 50% heat recovery efficiency. The second case shown a more typical design with a 40% efficient run-around loop, and the ventilation rate can be set back to 2 ACH overnight. The third case improves heat recovery efficiency and allows a ventilation set-back to 4 ACH during the day. The final case introduces a central plant ground-source heat pump instead of high efficiency boiler and chiller.

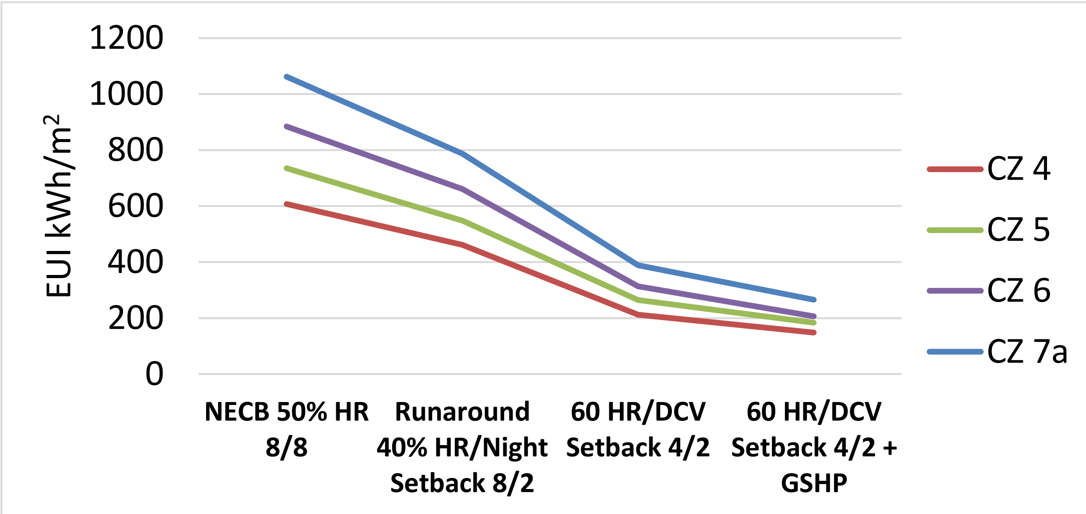

Figure 7. Annual Energy Use of Labs with improving systems

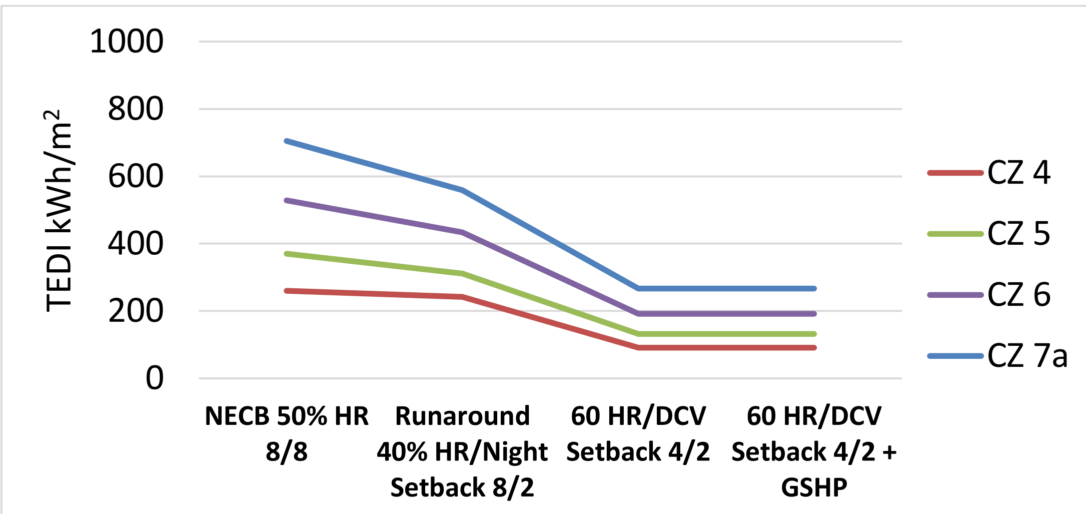

Figure 8. Annual Thermal Energy Demand of Labs with improving systems

3.4 Recreation Centre

The recreation centre archetype building is 8,420 m^2 facility excluding the pool. The facility includes a fitness facility, gym, change rooms, multipurpose space, and offices. The HVAC system consists of a dedicated outdoor air system with heat recovery providing ventilation air to the main building, and fan coils which cycle to serve heating and cooling loads served by a high efficiency central boiler and air cooled chiller plant. The fitness area, and gym areas have separate variable volume unitary systems, also served by the central plant.

The results are presented below are for the recreation centre excluding the pool. Pool energy use is both very large, and highly dependent on pool water set point temperature, room air temperature and relative humidity setpoints, and hygiene related water turn-over rates, which are dictated by the specific type of pool and intended end user. Pool energy use and energy conservation measures are discussed further in the following section

Parameters varied include effective wall, roof, and window thermal performance, glazing ratio, heat recovery efficiency, lighting savings, DHW savings, and two central plant types. The typical LEED Gold building currently has:

- R-10 walls, R-20 roof
- 30% WWR, double glazed windows with low-e coating (USI 2.0)
- 60% efficiency heat recovery on all systems
- Typical air infiltration levels
- 25% lighting savings from the reference building
- 20% DHW load Savings from the reference building
- A central high efficiency boiler and chiller plant

Table 10 and Figure 9 summarize the energy use, cost, and GHG results for the NECB reference building compared to the current typical LEED Gold recreation centre without pool for climate zones 4 and 7a. The LEED Gold recreation centre without pool currently achieves 45% energy savings from the NECB reference building in climate zone 4 and 46% in zone 7a.

Table 10. Recreation Centre Archetype Energy, Cost and GHG Results without Pool

	NECB Reference		LEED Gold Rec Centre wo Pool		
	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Savings from Reference (%)
Climate Zone 4					
Heating + DHW	0.0	128.5	0.0	42.5	67%
Cooling	2.7	0.0	4.7	0.0	-74%
Lighting	73.6	0.0	53.5	0.0	27%
Equipment	11.9	0.0	11.9	0.0	0%

Fans	20.8	0.0	17.7	0.0	15%
Pumps	0.7	0.0	1.0	0.0	-41%
Total Energy (kWh/m²)	109.6	128.5	88.7	42.5	45%
Total Energy (kWh/m²)	238.1		131.3		45%
Thermal Energy Demand Intensity (TEDI) (kWh/m²)	53.1		14.5		73%
Total Annual Energy Cost ($/m²)	11.0		7.0		36%
Total GHG (kgCO₂e/m²)	25.0		8.8		65%
Climate Zone 7a					
Heating + DHW	0.0	221.2	18.0	71.7	59%
Cooling	2.0	0.0	3.7	0.0	-86%
Lighting	73.6	0.0	53.5	0.0	27%
Equipment	11.9	0.0	11.9	0.0	0%
Fans	22.1	0.0	19.1	0.0	13%
Pumps	1.0	0.0	1.0	0.0	-5%
Total Energy (kWh/m²)	110.5	221.2	107.2	71.7	46%
Total Energy (kWh/m²)	331.7		178.9		46%
Thermal Energy Demand Intensity (TEDI) (kWh/m²)	119.5		60.9		49%
Total Annual Energy Cost ($/m²)	13.9		9.1		34%
Total GHG (kgCO₂e/m²)	42.1		14.4		66%

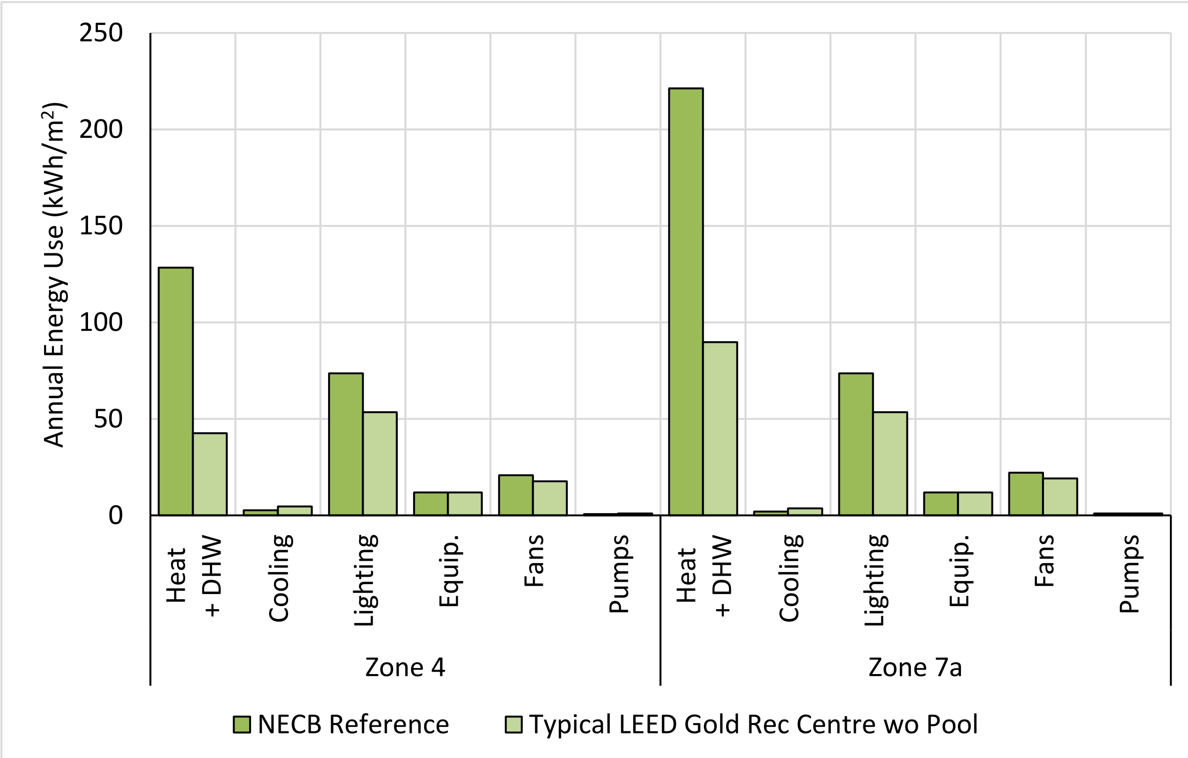

Figure 9. Annual Energy Use of NECB Reference and LEED Gold Recreation Centre without Pool

Ice rinks were not included in the energy model analysis and are therefore not reflected in the results above. The reason for excluding this program area is that most energy modeling software is not set up to model low-temperature spaces with low-temperature refrigeration systems that are found in ice rinks. As such, the experience and accuracy of modeling ice rinks in energy models is significantly less than other facility types. There would be little value in setting a performance requirement for these facilities since the confidence level in the results on a project by project basis would be low. Additionally, the specific temperature requirements in ice rinks result in thermal demand and envelope performance that is different than other space types, which the intended TEDI metric is not designed to capture, and the large rink-related process load will mask savings achieved in an otherwise well designed building.

We recommend applying prescriptive measures in ice rinks that follow the NECB, with improvements explored on a project by project basis. Note that NECB does require, as a prescriptive measure, that heat must be recovered from ice making equipment to serve hot water loads in the building.

3.4.1 Recreation Centre Pools

Several different design parameters were explored to determine EUI, TEDI, and GHG emissions for a recreation centre pool.

Fixed parameters affecting pool energy use included:

- A pool with a surface area of 397.5 m^2 was modelled, with an average depth of 2.7 m. All energy outcomes are reported as normalized values relative to pool surface area.
- Pool activity factor, set to 1 during the day for a public pool, and 0.6 when unoccupied
- Water filter regeneration, assuming regenerative filtration media is used and a 2.3 m^3 capacity filtration tank needs to be drained every 2 months, and refilled with warmed water
- Make-up water, assuming the total pool volume is gradually turned over every two months for hygiene related reasons, and replaced with warmed water
- Recirculation pumps, recirculate total pool volume once every 8 hours, with 310 $kW/m^3/s$ pumping power
- The air handler is sized for total air supply of 12.5 $L/s/m^2$ of room floor area, 2.5 $L/s/m^2$ of which is the minimum outdoor air ventilation rate. The pool is assumed to occupy 50% of the room floor area
- Room Air heating set point of 27.5°C, cooling set point of 28.5°C, dehumidification set point of 60% RH. While increasing the room air temperature or relative humidity set points does reduce evaporation, and therefore dehumidification loads, from the pool, the extent that set points can be raised is limited due to occupant comfort.
- When a pool cover is used, it is assumed to be 50% effective at reducing overnight evaporation and convection losses to the room. It is assumed that a physical pool cover cannot be used for a public pool due to safety concerns, but a liquid pool cover is used instead. Liquid pool covers reduce losses when water is still by providing a microscopic film which slows evaporation. As these products are fairly new, limited concrete data is available concerning their performance, so the 50% reduction is used assuming it is a conservative reduction.

Varied parameters include:

- Climate Zone
- Envelope performance and glazing ratio
- Lighting Savings
- Heat recovery efficiency
- Outdoor air economizing
- Presence of a pool cover, liquid
- Pool water setpoint, 27°C, 32°C, 40°C
- HVAC system,
    - DX Cooling Coil, HW Heating Coil and natural gas boiler, NECB type solution, no heat recovered from dehumidification
    - Dehumidification unit with recovered heat from dehumidification process to reheat supply air and Natural Gas Boiler, heat rejected from the cooling compressor can be recovered to reheat ventilation air
    - Dehumidification with recovered heat and electric boiler, as above, but with all loads shifted to electricity
    - Ground-source heat pump, heat pump can transfer heat directly between hot and chilled water loops, with back-up from the ground source, heat rejected from dehumidification loads can be recaptured and used to offset water

heating loads in addition to air heating loads. Additionally, a higher COP is applied to net heating loads relative to an electric boiler.

The main factors affecting energy use are pool water setpoint temperature, HVAC system, use of outdoor air economizing, and heat recovery efficiency. Building envelope and lighting have nearly no effect on overall energy use, and climate has a minor effect. The pool cover has a fixed effect, which becomes more significant once other methods are employed to reduce loads. Outdoor air economizing is usually beneficial, but in some cases depending on pool set point and climate, the economizer is a detriment because the heat recovered from dehumidification is more important in reducing overall energy use than the electricity used to dehumidify.

Heat recovery is effective in reducing EUI, but has a significant effect on TEDI, as heat recovery combined with an outdoor air economizer allows more warm, dry outdoor air to be supplied, reducing the need to cool and reheat recirculated air. The results for the Dehumidification with recovered heat/gas boiler scenario in climate zone 4 are shown in Figure 10 for different heat recovery efficiencies. The slight increase in energy use at 90% heat recovery indicate that the high heat recovery efficiency is actually causing excess cooling loads, though this does not typically occur in colder climates.

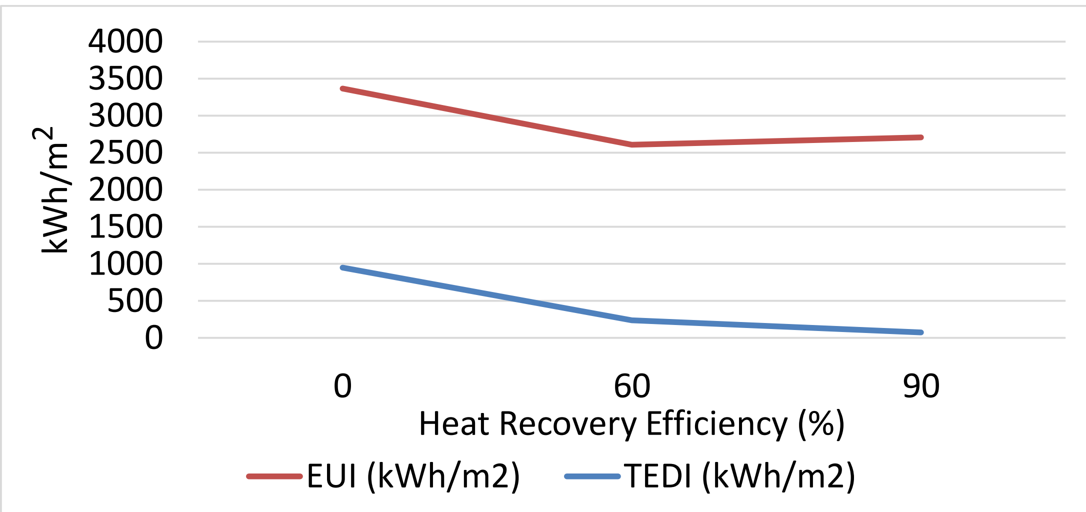

Figure 10. Annual EUI and TEDI of a Pool in CZ 4 with varied Heat Recovery Efficiency

Figure 11 demonstrates the impact of pool water set point temperature. The three temperatures represent at typical athletic pool, a leisure pool, and a whirlpool. High set point temperatures have moderate effects on heating demand for makeup water, but the principal effect is to increase the rate of evaporation and convective heat losses from the pool to the room.

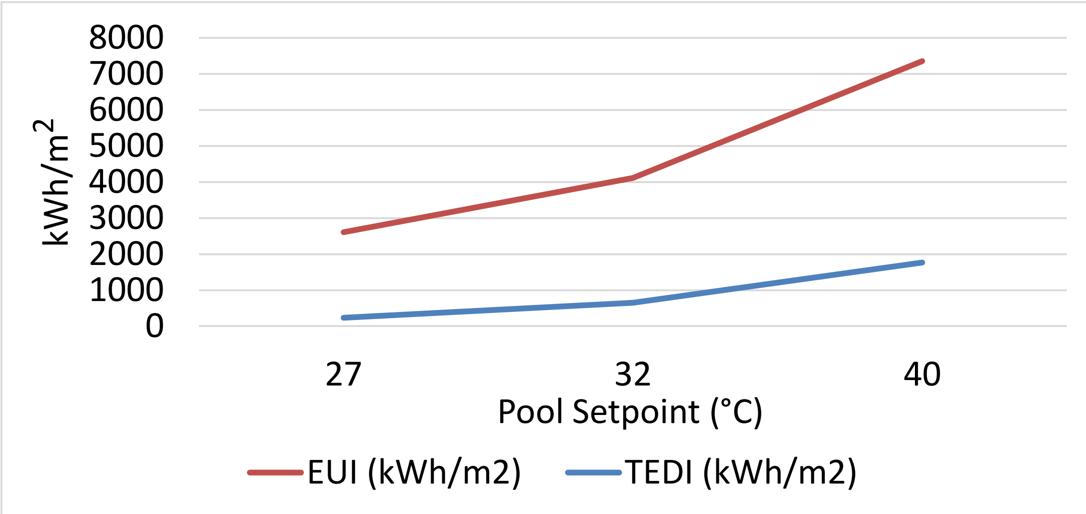

Figure 11. Annual Energy Use of a Pool in CZ 4 with varied Water Set Point Temperature

Figures 12 and 13 demonstrate that although there are many fixed loads associated with a pool, and energy use is very high, there are still avenues available to substantially reduce energy usage. Figure 12 shows a progression of reduced energy use and Figure 13 shows reduced TEDI for all four climate zones by moving from the NECB baseline model, to current typical practice with a dehumidification unit and 60% heat recovery, to a heat pump central plants with high efficiency heat recovery and a liquid pool cover. Pool energy use may be decreased by 50% from current typical practice, without accounting for additional savings which may be possible when the pool is integrated into a full building energy model, where heat may be recovered to serve all building loads, and not limited to pool loads.

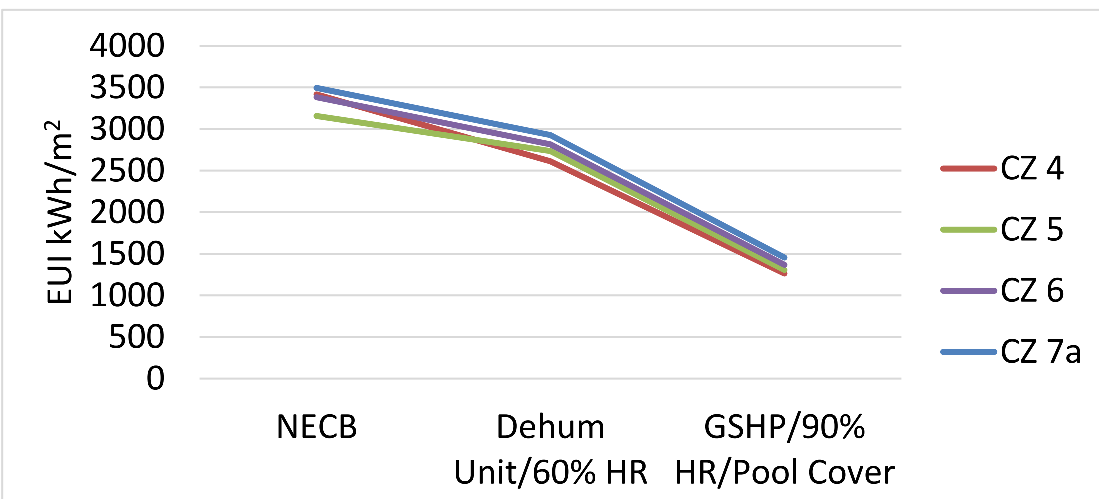

Figure 12. Annual Energy Use of Pool from NECB Baseline to Current Practice to Best Case

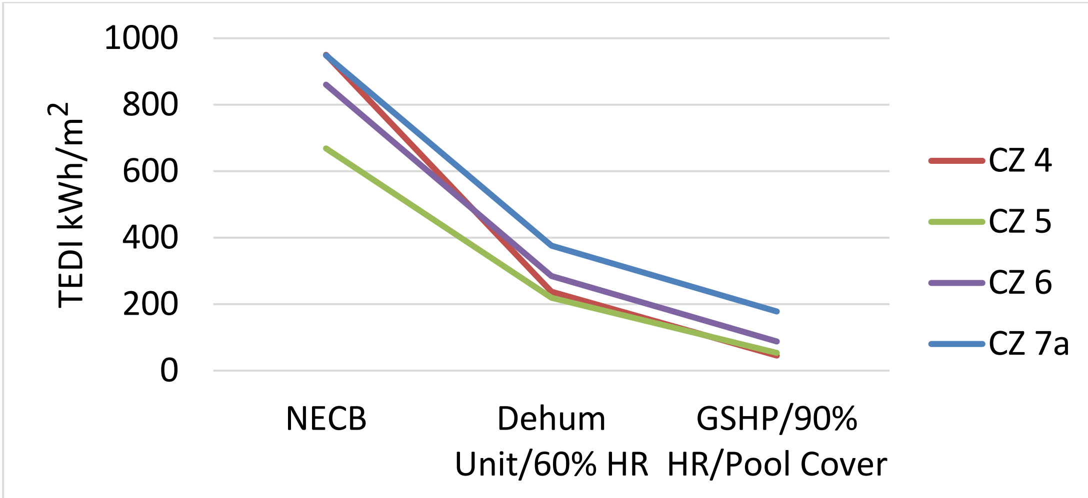

Figure 13. Annual Thermal Energy Demand of Pool NECB Baseline to Current Practice to Best Case

3.5 Care Facility

The care facility archetype building is 12,590 m^2 facility including one storey of primarily common space, three storeys of single or double occupancy suites with higher levels of care, and five storeys of independent living suites. The primary space types are suites, dining, lobby, lounge, kitchen, nurses' stations, and offices. The HVAC system consists of a dedicated outdoor air system with heat recovery providing ventilation air to common areas, which are heated and cooled using water-source heat pumps. All suites are served by suite HRVs, and fan coils which cycle to serve heating and cooling loads served by a high efficiency central boiler and chiller plant with a cooling tower. A small pool is served by a dedicated dehumidification unit, which recovers heat from dehumidification to reheat the supply air.

All results include the pool in the results presented as the pool is small relative to the size of the building. In the most energy efficient cases, where the effect of the pool is the greatest, eliminating the pool would decrease energy use by 8%, and GHG by 10%. At the LEED Gold level, eliminating the pool would decrease the EUI by 6%, and GHG by 4%. The full data set included results with and without pool.

Parameters varied include effective wall, roof, window thermal and air tightness performance, glazing ratio, heat recovery efficiency, lighting savings, and two central plant types. The typical LEED Gold building currently has:

- R-10 walls except R-20 in CZ 7a, R-20 roof
- 25% WWR, double glazed windows with low-e coating (USI 2.0 in CZ 4 and 7a, USI 2.5 in CZ 5 and 6)
- 60% efficiency heat recovery on all DOAS and suite HRVs
- Typical air infiltration levels
- 50% lighting savings in common areas from the reference building except 25% in CZ 4
- 40% DHW savings except 20% in CZ 6

- A central high efficiency boiler and chiller plant

Table 11 and Figure 14 summarize the energy use, cost, and GHG results for the NECB reference building compared to the current typical LEED Gold care facility for climate zones 4 and 7a. The LEED Gold care facility currently achieves 35% energy savings from the NECB reference building in climate zone 4 and 27% in zone 7a.

Table 11. Care Facility Archetype Energy, Cost and GHG Results

	NECB Reference		LEED Gold Care Facility		
	Electricity (kWh/m^2)	Natural Gas (kWh/m^2)	Electricity (kWh/m^2)	Natural Gas (kWh/m^2)	Savings from Reference (%)
Climate Zone 4					
Heating + DHW	0.2	100.4	5.3	35.8	59%
Cooling	3.5	0.0	7.3	0.0	-109%
Lighting	29.9	0.0	23.9	0.0	20%
Equipment	17.1	0.0	17.1	0.0	0%
Fans	9.5	0.0	17.3	0.0	-82%
Pumps	4.4	0.0	0.8	0.0	81%
Total Energy (kWh/m^2)	64.4	100.4	71.7	35.8	35%
Total Energy (kWh/m^2)	165.0		107.5		35%
Thermal Energy Demand Intensity (TEDI) (kWh/m^2)	45.6		24.7		46%
Total Annual Energy Cost ($\$/m^2$)	7.2		5.7		21%
Total GHG ($kgCO_2e/m^2$)	19.1		7.4		61%
Climate Zone 7a					
Heating + DHW	5.8	121.7	15.5	61.2	40%
Cooling	2.1	0.0	5.0	0.0	-142%
Lighting	29.9	0.0	17.9	0.0	40%
Equipment	17.1	0.0	17.1	0.0	0%
Fans	9.9	0.0	17.3	0.0	-74%
Pumps	3.9	0.0	0.7	0.0	82%
Total Energy (kWh/m^2)	62.8	121.7	73.4	61.2	27%
Total Energy (kWh/m^2)	190.3		134.6		29%
Thermal Energy Demand Intensity (TEDI) (kWh/m^2)	67.2		56.7		16%
Total Annual Energy Cost ($\$/m^2$)	8.1		6.6		19%
Total GHG ($kgCO_2e/m^2$)	23.0		12.1		47%

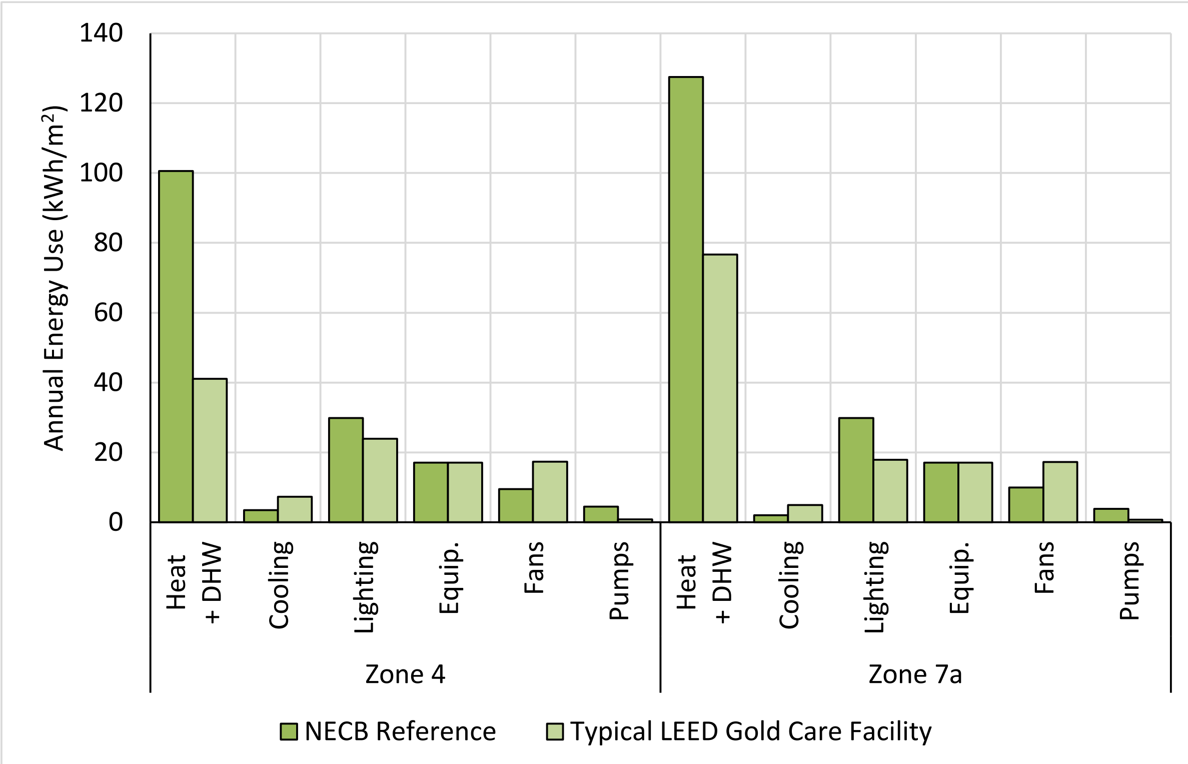

Figure 14. Annual Energy Use of NECB Reference and LEED Gold Care Facility

3.5.1 Suite Plug Load Distribution

Care facility suite plug load has unique considerations compared to typical residential suites. Occupants under more intensive care are not expected to cook, and may only be provided with a small fridge. Occupants in independent living have kitchenettes with a sink, fridge, and perhaps a small stove, but are likely to attend meals in the common dining rooms. All laundry is done in the common laundry facilities.

The overall suite plug load energy use was kept consistent with residential suites, 5 W/m^2 with the NECB G Receptacle Schedule, aside from a duplication of fridge energy. However, the load was divided into categories as shown in Table 12. The miscellaneous and stove energy use categories were chosen to align with the NECB dorm space type, and the existing guidance from the COV energy modelling guidelines for allotting natural gas use by gas stoves. The remainder of the load is divided between the four other principal appliances proportionally per the division provided by Energy Star, shown in Figure 15.

For suites containing just a fridge, the suite plug load was modelled as 2.9 W/m^2, accounting for the fridge and the miscellaneous load. The 0.95 W/m^2 of suites combined clothes washer and dryer energy was converted into a plug load in the laundry room to provide the equivalent annual energy use as if it were included in the suites, accounting for the difference in the laundry space type receptacle schedule and floor area. The stove, dishwasher, and a duplicate fridge load, 1.55 W/m^2 of suites total, were converted similarly to a plug load in the common kitchen facilities.

The fridge energy was duplicated between the suites and the commercial kitchen as fridge energy use is reasonably consistent regardless of degree of use. If the independent living suites had stoves, the stove energy use could be divided between the commercial kitchen and the suites proportionally to the expected level of utilization.

Table 12. Residential Suite Load Division

Category	W/m²	Source
Stove	1	from EMG, conversion for gas
Dishwasher	0.15	proportional from Energy Star
Fridge	0.4	proportional from Energy Star
Clothes washer	0.4	proportional from Energy Star
Dryer	0.55	proportional from Energy Star
Miscellaneous	2.5	NECB dorms
Total	5	NECB residential

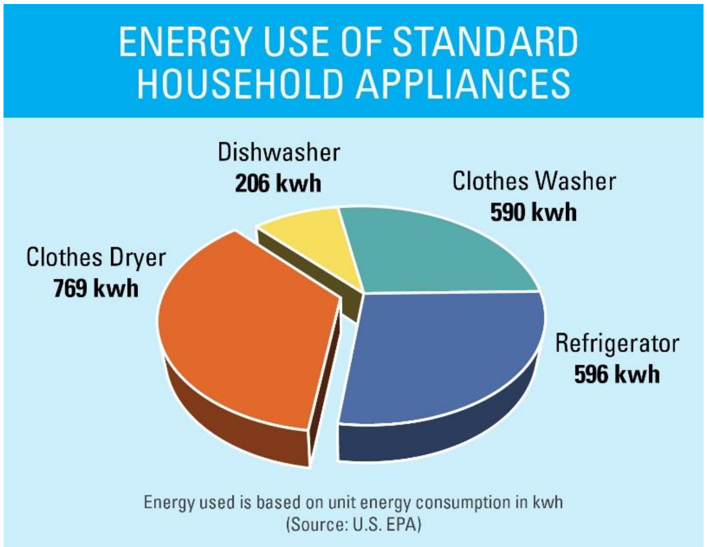

Figure 15. Energy Star Standard Household Appliance Energy Use[2]

3.6 Hospital

The hospital archetype building is a 26,450 m² patient care tower including client rooms, operating rooms, medical device reprocessing, exam and clinical support, public areas, staff areas, corridors, and other support spaces. The HVAC system type is varied between a dedicated outdoor air system with heat recovery and zone heating and cooling, and 100% outdoor air variable air volume systems with zone reheat.

[2] https://www.energystar.gov/products/appliances/clothes_dryers

Parameters varied include effective wall, roof, window thermal and air tightness performance, glazing ratio, heat recovery efficiency, lighting savings, and two central plant types. The typical LEED Gold building currently has:

- R-10 walls, R-20 roof
- 12% WWR, double glazed windows with low-e coating (USI 2.0)
- 80% efficiency heat recovery on the main building DOAS
- Typical air infiltration levels
- 30% lighting savings from the reference building
- A central high efficiency boiler and chiller plant
- 100% outdoor air VAV system with zone reheat

Table 13 and Figure 16 summarize the energy use, cost, and GHG results for the NECB reference building compared to the current typical LEED Gold hospital for climate zones 4 and 7a. The LEED Gold hospital currently achieves 10% energy savings from the NECB reference building in climate zone 4 and 40% in zone 7a.

Table 13. Hospital Archetype Energy, Cost and GHG Results

	NECB Reference		LEED Gold Hospital		
	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Electricity (kWh/m²)	Natural Gas (kWh/m²)	Savings from Reference (%)
Climate Zone 4					
Heating	0.0	68.3	0.0	86.2	-26%
Cooling	17.3	0.0	38.9	0.0	-124%
Lighting	81.5	0.0	59.9	0.0	26%
Equipment	69.7	0.0	69.7	0.0	0%
Fans	73.0	0.0	62.4	0.0	15%
Pumps	2.1	0.0	15.8	0.0	-662%
Humidification	0.0	79.8	0.0	16.6	79%
DHW	0.0	12.9	0.0	12.9	0%
Total Energy (kWh/m²)	243.6	160.9	246.6	115.7	10%
Total Energy (kWh/m²)	404.5		362.3		10%
Thermal Energy Demand Intensity (TEDI) (kWh/m²)	51.2		77.6		-52%
Total Annual Energy Cost ($/m²)	21.0		18.7		11%

Total GHG ($kgCO_2e/m^2$)	32.4		24.1		26%
Climate Zone 7a					
Heating	0.0	170.1	0.0	86.2	49%
Cooling	16.4	0.0	26.0	0.0	-58%
Lighting	81.5	0.0	59.9	0.0	26%
Equipment	69.7	0.0	69.7	0.0	0%
Fans	77.9	0.0	62.0	0.0	20%
Pumps	2.2	0.0	10.9	0.0	-398%
Humidification	0.0	209.1	0.0	55.5	73%
DHW	0.0	12.9	0.0	12.9	0%
Total Energy (kWh/m^2)	247.7	392.0	228.5	154.6	40%
Total Energy (kWh/m^2)	639.7		382.3		40%
Thermal Energy Demand Intensity (TEDI) (kWh/m^2)	127.6		77.0		40%
Total Annual Energy Cost ($\$/m^2$)	29.0		18.5		36%
Total GHG ($kgCO_2e/m^2$)	75.3		31.0		59%

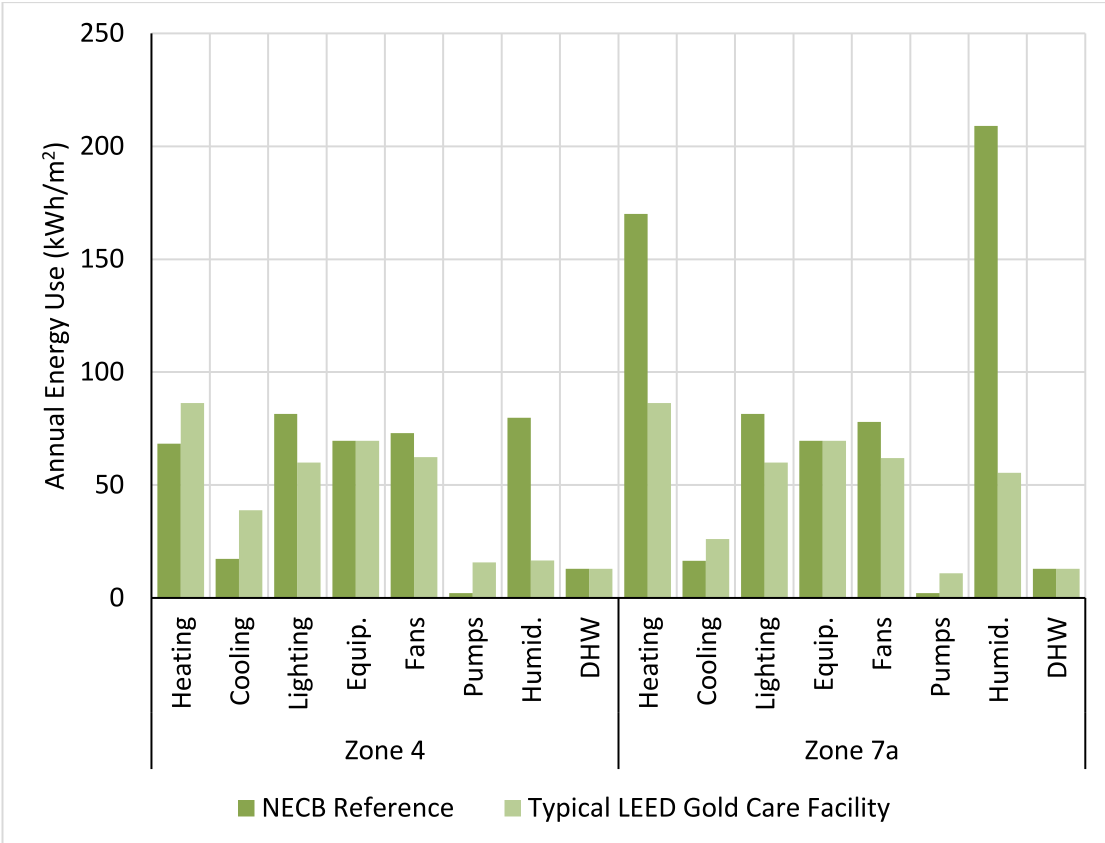

Figure 16. Annual Energy Use of NECB Reference and LEED Gold Hospital

3.6.1 Internal Loads

The results outlined in this report use NECB default plug loads, along with some data room IT loads and telecom loads, but do not account for significant additional loads that may be found in some healthcare facilities. In order to investigate the potential impacts of these plug loads, a set of simulations doubling the NECB default plug loads were run.

The default plug load has an EUI of approximately 70 kWh/m^2/year. Based on adding an additional 70 kWh/m^2/year, the difference in regulated loads appears to range between approximately an additional 20 – 35 kWh/m^2/year.

Due to the ranges of use within healthcare facilities, it may be preferable to develop a target formula or modification that allows for differences in non-regulated loads to influence the target, in order to allow for modelling of the building based on the design and anticipated use of the hospital.

3.6.2 HVAC Systems

Currently, most hospitals in BC are designed to use central VAV or constant volume systems, which operate by cooling all of the air entering the building at a central air handling unit or several central air handling units, then reheating the air supplied to any zones that require heating. In a hospital, which typically has significant simultaneous heating and cooling loads due to high internal heat gains, this leads to significant reheat energy. In addition, cooling a higher volume of air than that required by zones needing cooling typically leads to either increased mechanical cooling energy, or increased use of air-side economizer which results in more humidification energy being used.

The lower EUI and TEDI options use a dedicated outdoor air system (DOAS) with heat recovery to provide tempered outdoor air, and use radiant heating and cooling at the zone level to provide the heating and cooling required for each zone, minimizing reheat and central conditioning energy.

4. OPTIMIZATION ANALYSIS OF ENERGY, COST, AND CARBON OUTCOMES

The energy models described above and in Appendix A were run through an optimization process to identify the intersections of critical metrics so that a robust energy performance policy could be developed. The optimization process involves running a large-scale parametric analysis of each archetype, where various combinations of energy efficiency measures are run, with the number of options in the thousands or tens of thousands per building. For each option, energy, carbon and financial metrics are extracted. The variations in inputs vary by building, but typically involve the following:

- Wall and Roof Effective R-Values
- Window U-values and SHGC
- Window Area / Window to Wall Ratio (WWR)
- Infiltration (Code: 2.03 L/s/m^2 @ 75 Pa, Improved: 0.8 L/s/m^2 @ 75 Pa, PH: 0.08 L/s/m^2 @ 75 Pa)
- Ventilation Heat Recovery Efficiency
- Heating fuel source (condensing boiler or ground/air source heat pump)
- Lighting Savings
- Four Climate Zones (4-7a)

The measures required to attain the effective wall and window performance modelled is detailed in the capital cost data in Appendix B.

The metrics that were extracted for each run included:

- Energy Use, GHG emissions and TEDI (per m^2 of floor area)
- Energy, GHG, and TEDI savings over NECB
- Energy Cost (per m^2 of floor area)
- LEED v4 Points (for boiler/chiller plant buildings only, NECB alternate compliance path baseline)
- Incremental Capital Cost, expressed as a percentage of total construction cost
- Simple Payback
- NPV Savings Over NECB – This is the present value of the financial benefit over the 20 year study period. Account for the net effect of incremental capital costs and utility cost savings.

The EUI, TEDI, GHG and ICC outcomes for the typical current LEED Gold building, the lowest EUI scenario and a high NPV middle scenario are presented in the following sections for each archetype. A full table of scenario outcomes is provided in Appendix C.

A summary of the energy savings from the NECB baseline are shown in Table 14, GHG saving in Table 15, and incremental capital cost in Table 16.

Table 14. Summary of EUI savings from NECB

% NECB EUI Savings		CZ 4	CZ 5	CZ 6	CZ 7a
School	LEED Gold	45.9	46.8	48.0	46.9
	Mid Gas	52.4	54.4	56.7	55.8
	Mid Elec	59.6	62.9	68.0	69.8
	Best EUI	64.1	67.3	72.1	74.4
Care Facility	LEED Gold	34.9	32.1	30.2	29.3
	Mid Gas	41.9	42.0	40.5	39.1
	Mid Elec	57.3	57.4	60.9	59.3
	Best EUI	58.1	58.4	62.8	60.3
Rec Centre wo Pool	LEED Gold	44.9	44.9	47.3	46.1
	Mid Gas	55.7	55.3	56.8	56.7
	Mid Elec	68.5	67.1	70.8	69.4
	Best EUI	69.1	68.3	72.3	71.2
Library	LEED Gold	23.8	22.5	19.7	14.7
	Mid Gas	40.6	42.1	38.7	34.5
	Mid Elec	61.4	63.3	65.5	61.3
	Best EUI	65.0	67.4	71.2	73.8
College w Labs	LEED Gold	40.8	41.0	35.4	34.2
	Mid Gas	56.7	56.8	54.6	53.7
	Mid Elec	62.9	64.7	65.9	67.7
	Best EUI	66.9	69.0	70.6	72.6
College wo Labs	LEED Gold	28.4	29.0	24.4	21.9
	Mid Gas	37.3	35.0	29.8	31.8
	Mid Elec	43.8	40.8	40.7	44.2
	Best EUI	44.7	48.3	50.1	53.0

Table 15. Summary of GHG savings from NECB

% NECB GHG Savings		CZ 4	CZ 5	CZ 6	CZ 7a
School	LEED Gold	56.7	56.0	55.4	53.2
	Mid Gas	66.4	66.5	66.5	64.1
	Mid Elec	80.5	82.8	86.7	88.0
	Best EUI	80.9	83.6	87.3	88.7
Care Facility	LEED Gold	61.6	52.2	47.3	47.9
	Mid Gas	65.5	66.6	61.4	63.0
	Mid Elec	96.0	96.0	96.6	96.3
	Best EUI	96.1	96.1	96.8	96.4
	LEED Gold	64.6	64.4	65.6	65.7

Rec Centre wo Pool	Mid Gas	68.4	68.3	69.7	72.1
	Mid Elec	96.7	96.6	97.3	97.2
	Best EUI	96.7	96.8	97.4	97.5
Library	LEED Gold	18.4	13.5	13.8	12.0
	Mid Gas	35.1	36.3	34.4	42.4
	Mid Elec	95.1	94.2	95.9	94.2
	Best EUI	95.5	94.9	96.6	96.7
College w Labs	LEED Gold	45.1	40.6	28.4	17.5
	Mid Gas	77.8	74.3	69.7	66.4
	Mid Elec	95.5	95.8	96.1	96.2
	Best EUI	96.0	96.3	96.6	96.7
College wo Labs	LEED Gold	45.4	39.2	29.6	19.8
	Mid Gas	52.2	55.6	44.3	45.5
	Mid Elec	89.9	90.4	91.3	92.4
	Best EUI	90.1	91.6	92.7	93.6

Table 16. Summary of Incremental Capital Costs from NECB

% ICC		CZ 4	CZ 5	CZ 6	CZ 7a
School	LEED Gold	1.8	1.8	1.7	1.7
	Mid Gas	2.1	2.0	1.9	1.9
	Mid Elec	2.1	2.0	1.9	1.9
	Best EUI	3.4	3.2	3.4	3.6
Care Facility	LEED Gold	1.7	1.7	1.6	1.4
	Mid Gas	2.2	2.2	2.0	1.9
	Mid Elec	2.2	2.2	2.0	1.9
	Best EUI	2.7	2.9	2.8	2.4
Rec Centre wo Pool	LEED Gold	1.6	1.6	1.5	1.5
	Mid Gas	2.3	2.1	2.0	2.2
	Mid Elec	2.3	2.1	2.0	2.2
	Best EUI	3.0	3.7	3.7	3.9
Library	LEED Gold	2.0	1.9	1.8	1.8
	Mid Gas	2.9	3.0	2.9	2.6
	Mid Elec	2.9	3.0	2.9	2.6
	Best EUI	5.1	5.1	5.0	5.0
College w Labs	LEED Gold	1.6	1.6	1.3	1.3
	Mid Gas	2.5	2.6	2.1	2.1
	Mid Elec	2.5	2.6	2.1	2.1
	Best EUI	3.8	5.1	4.5	4.7

College wo Labs	LEED Gold	1.7	1.8	1.3	1.3
	Mid Gas	2.7	2.5	1.7	2.0
	Mid Elec	2.7	2.5	1.7	2.0
	Best EUI	4.3	4.9	4.7	4.7

4.1 Economic Information

Table 17 summarizes the economic parameters used in the energy cost benefit analysis, including utility and carbon rates, escalation rates, and GHG emission factors.

Table 17. Utility Rates, GHG Emissions Factors, and Financial Parameters

Parameter	Value
Electricity Utility Cost	**$0.064/kWh**
Electricity Utility Cost Escalation Rate	**2.1%**
Natural Gas Utility Cost	**$6.99/GJ ($0.025/kWh)**
Natural Gas Utility Cost Escalation Rate	**0.4%**
Carbon Tax Cost	**$30/tonCO2e (year 1-4) $50/tonCO2e (year 5-20)**
Carbon Tax Cost Escalation Rate	**0%**
Discount Rate	**3%**
Grid Electricity GHG Emissions Factor	**0.011 kgCO2/kWh**
Natural Gas GHG Emissions Factor	**0.185 kgCO2/kWh**
Capital Costs for Modeled Energy Efficiency Measures	**See Appendix B**

The economic analysis was performed using the same values and methodology as the Part 3 analysis in the BC Step Code Metrics Research Study

4.2 Optimization Analysis

The results of the options analysis was viewed through an interactive data visualization tool developed at Morrison Hershfield. The tool allows one to analyze the relationships between energy efficiency measures and the various energy, carbon and financial outputs, as well as identify any trends or patterns in the data that would point to obvious recommendations for the policy. The library archetype will be used as an example of how the trends in the data were assessed to derive a policy recommendation. The trends and conclusions are similar for all building types so the analysis is only presented once. However, the expected outcomes of the policy, when applied to each of the six archetypes is detailed below.

The data visualization tool is dynamic and is best viewed live. The tool was used in a workshop with the Province to demonstrate the methodology to find appropriate step targets. The screenshots that follow summarize the demonstration at that workshop in addition to follow-up analysis conducted by Morrison Hershfield. When viewing the screenshots, note that each vertical line or axis is either an energy model input (right side of screen) or an energy model output (left side of screen). Each wavy line is one, discrete energy simulation. Where the wavy line crosses a particular axis indicates that inputs and outputs that were used or have resulted from that particular simulation. A screenshot with only one wavy line is shown in Figure 17 to illustrate this concept. All screenshots in the body of the report are recreated in full, landscape pages, provided in Appendix C.

The results presented for each building's simulation results in the following sections are shown in table format, along with all outcomes in Appendix D.

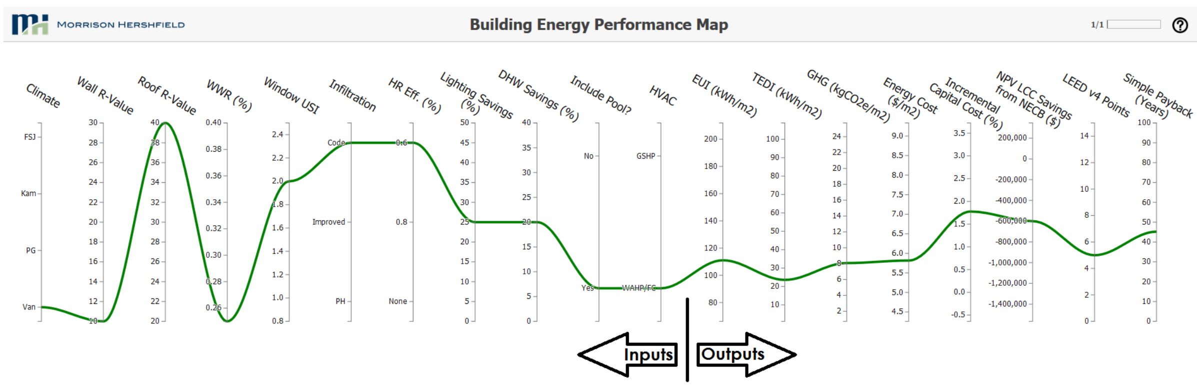

Figure 17. Data Visualization Example

The following series of images and captions are intended to show the methodology for choosing the LEED Gold Case, Best Case, and Middle cases for each archetype, using the care facility as an example

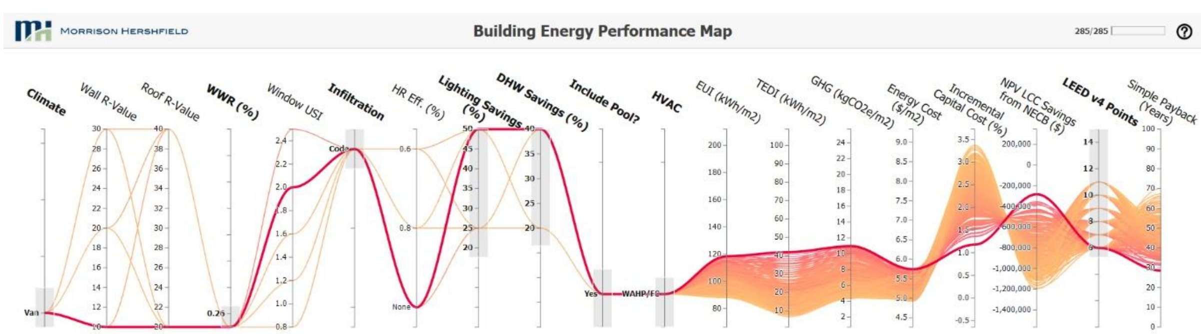

Figure 18. The LEED Gold solution for each climate was chosen by filtering for scenarios with 6 or more LEED v4 EAc1 points, with at least 25% lighting savings, a high efficiency boiler/chiller plant, and 20% DHW savings for buildings where DHW is significant. These measures are not always required to meet the LEED point criteria, but are typically found in all LEED certified buildings. Generally, the solution with the lowest incremental capital cost was selected. Occasionally, the solution with lowest incremental cost favored higher performance opaque walls, but the next lowest cost solution favoured heat recovery. In these cases, the heat recovery solution was

selected, as that is typically the first selected option.

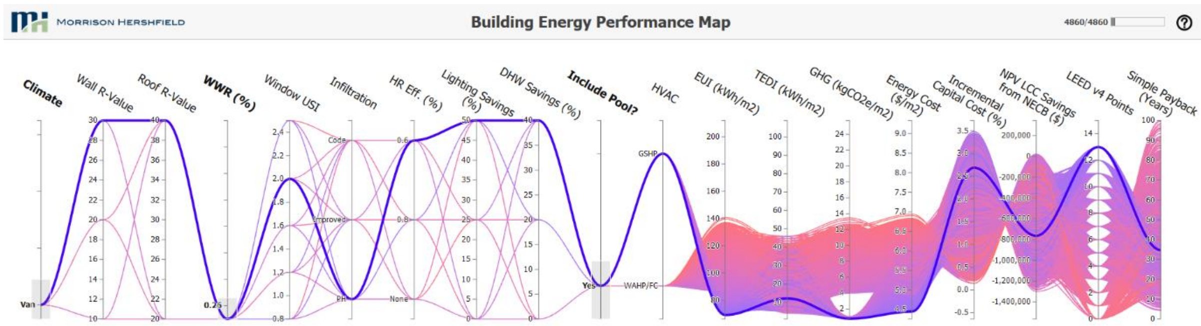

Figure 19. The best case was chosen for each climate as the case with the lowest EUI, which always corresponds with the lowest GHG emissions for electricity based HVAC systems. The best EUI case does not always correspond with the most effective option in each category, or with the lowest possible TEDI, since all the archetypes considered have mechanical cooling. For archetypes with higher internal heat gains from lighting or plug loads, solutions resulting in lower heating loads may cause higher cooling loads by trapping or recovering excess heat, which has a net effect of increasing energy use when combined with a mechanical system such as heat pumps with high efficiency heating. Additionally, high lighting savings is beneficial for electricity use, however always results in higher TEDI due to lower internal heat gains.

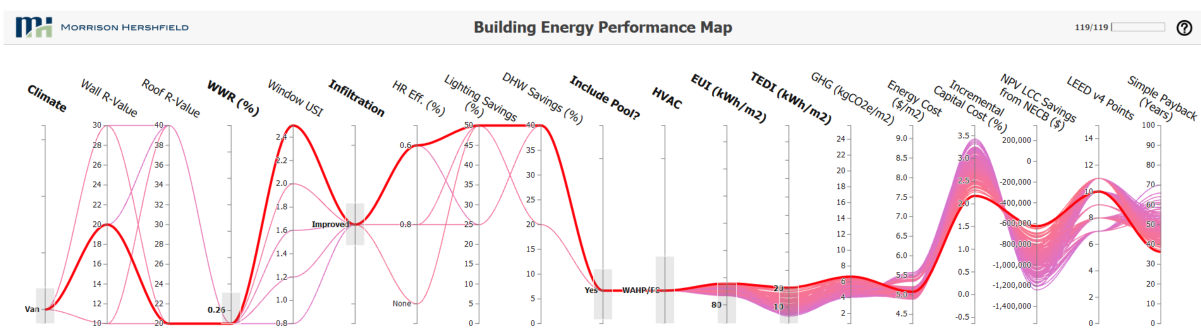

Figure 20. The middle case was chosen such that with the high efficiency boiler and chiller plant and improved air leakage, the EUI and TEDI were both reduced by at least 30% of the difference between the LEED Gold case scenario and the Best EUI Scenario. The highest Net Present Value scenario was selected. The corresponding scenario using the heat pump HAVC plant is shown to demonstrate the improvement provided between the middle and best case by the switch fuel source.

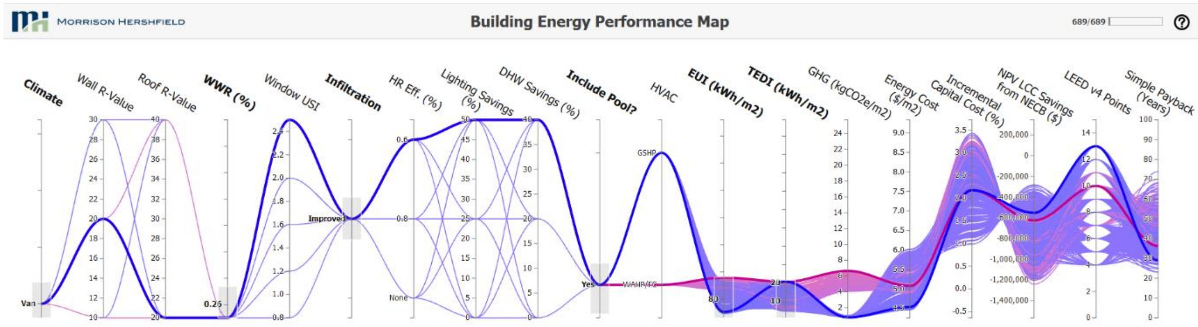

Figure 21. For the middle case, the corresponding scenario using the heat pump HVAC plant is shown to demonstrate the improvement provided between the middle and best case by the switch fuel source. Due to the heating COP and the low emissions factor for electricity, total energy use and GHG emissions decrease substantially. Energy costs decrease moderately since the increase in utility cost between natural gas and electricity is smaller than the expected electric heating COP. The LEED points shown for the heat pump HVAC plant should be disregarded since the baseline building HAVC type should change when using heat pump in the proposed building.

4.3 School Expected Outcomes

The best school scenario modelled would achieve 64% to 74% energy savings from current code requirements, and at least an 80% reduction in greenhouse gas emissions.

Schools have very high design outdoor air requirements and variable occupancy throughout the day with after school activities and community use year round. For schools demand control ventilation is critical to reduce and increase the outdoor air supply rate when necessary to control energy use, and is already present in nearly all new schools.

The typical energy conservation measures used at each stage of improvement are:

- 6 LEED points achieved with 25% lighting reduction and high efficiency heat recovery in addition to DCV
- The middle step increases roof performance
- The best energy case includes a ground-source heat pump system, highest wall performance, and full LED lighting. Glazing performance is only increased in colder climates due to low glazing ratios, and negative impacts on cooling in warmer climates

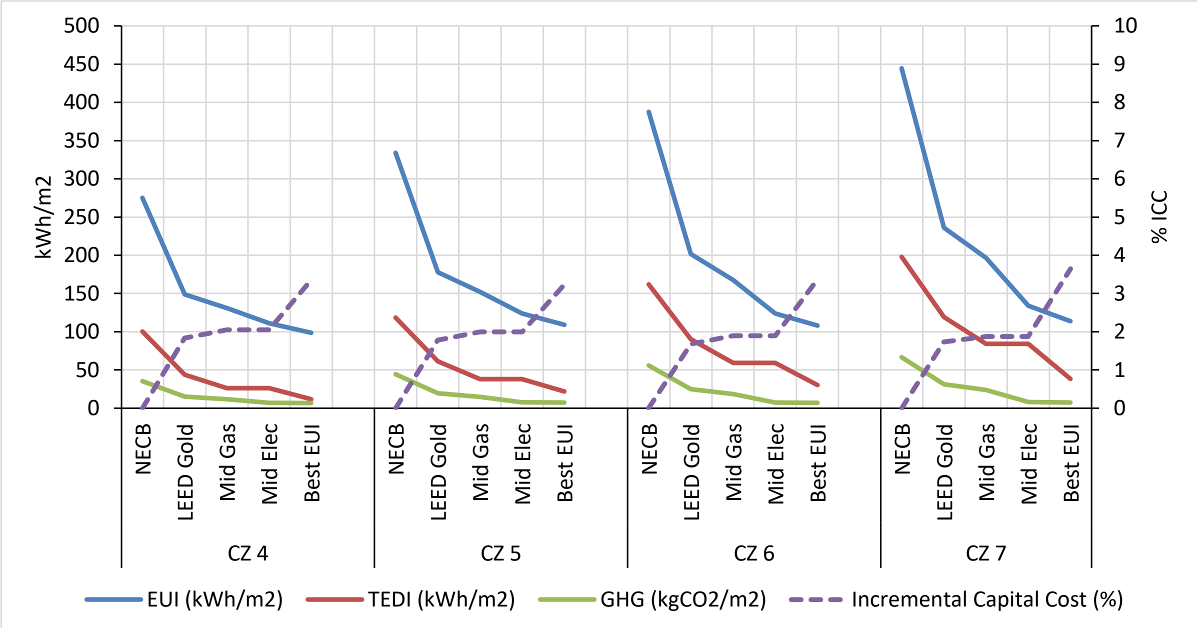

Figure 22. School Scenarios

4.4 Library Expected Outcomes

The best library scenario modelled would achieve 61% to 74% energy savings from current code requirements, and at least a 94% reduction in greenhouse gas emissions.

Libraries have high code lighting requirements, which provide significant opportunity for cost savings.

The typical energy conservation measures used at each stage of improvement are:

- 6 LEED points achieved with 25% lighting reduction and heat recovery
- The middle step increases roof and glazing performance in CZ 4 and wall performance in CZ 5-7a, in addition to 50% lighting savings in CZ 4-6 and higher efficiency heat recovery in all climates
- The best energy case includes a ground-source heat pump system, highest performance envelope, and full LED lighting

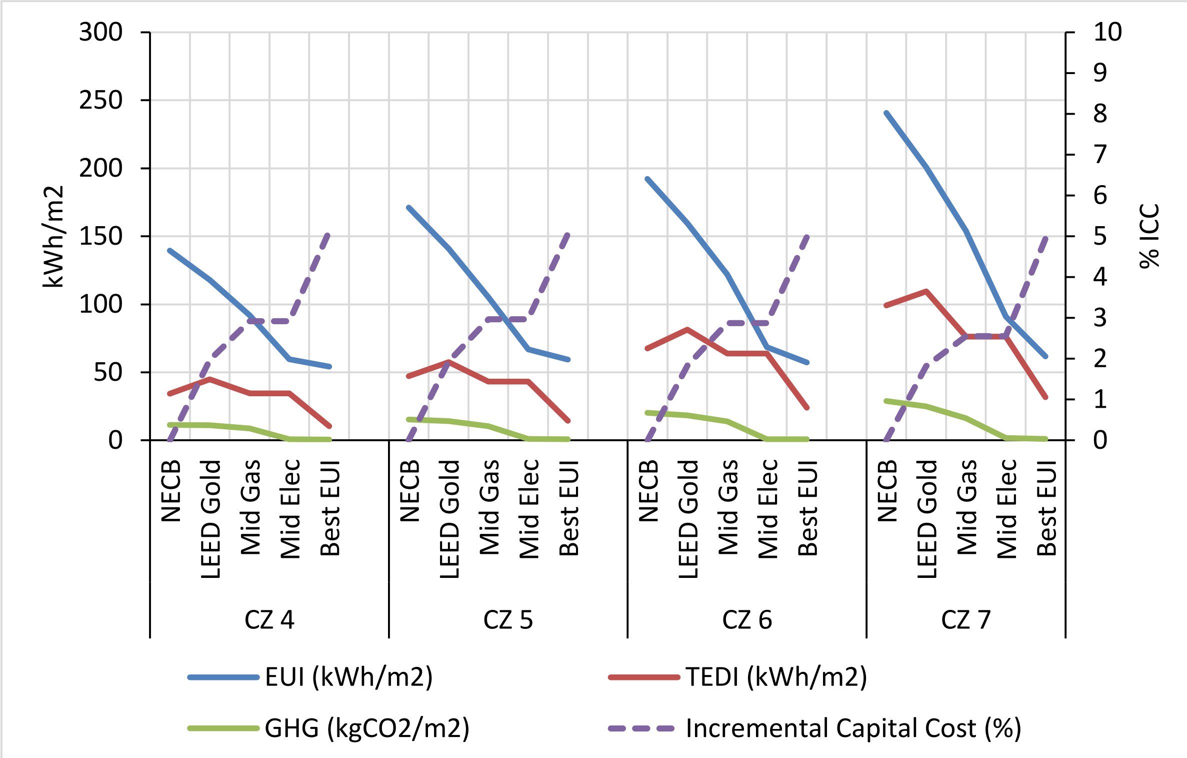

Figure 23. Library Scenarios

4.5 College Expected Outcomes

The best college scenario modelled with labs would achieve 66% to 72% energy savings from current code requirements, and at least a 92% reduction in greenhouse gas emissions.

The best college scenario modelled without labs would achieve 44% to 53% energy savings from current code requirements, and at least a 95% reduction in greenhouse gas emissions.

Like schools, college also have high outdoor air requirements in classrooms and lecture halls where high occupancy density is expected, and demand control ventilation is commonly employed. Laboratories have very high design flow rates, and methods to reduce out door air flow or recover heat from exhaust are dependent on the type of lab. In the data presented below, the labs have reduced flow compared to the reference building during the day and night. The non-lab areas also have demand control ventilation. These measures alone provide significant energy savings, and so fewer additional measure are required to meet LEED Gold.

The energy conservation measures used to meet energy targets with or without labs are very similar at each stage, but the resulting energy use is significantly higher with labs. The lowest energy scenarios include better envelope performance when labs are excluded than when they are included because there is less ventilation air removing internal heat gains, resulting in more cooling.

The typical energy conservation measures used at each stage of improvement are:

- 6 LEED points achieved with 25% lighting reduction, and demand control ventilation
- The middle step simply adds heat recovery is labs are included
- When labs are excluded, the middle step adds typical heat recovery in CZ 5-6 and high efficiency heat recovery in CZ 4. CZ 4 includes full LED lighting, and CZ 5 and 7a increase wall performance
- The best energy case includes a ground-source heat pump system, and typically the highest performance walls and roof, higher performance glazing in colder climates, high efficiency heat recovery, and full LED lighting

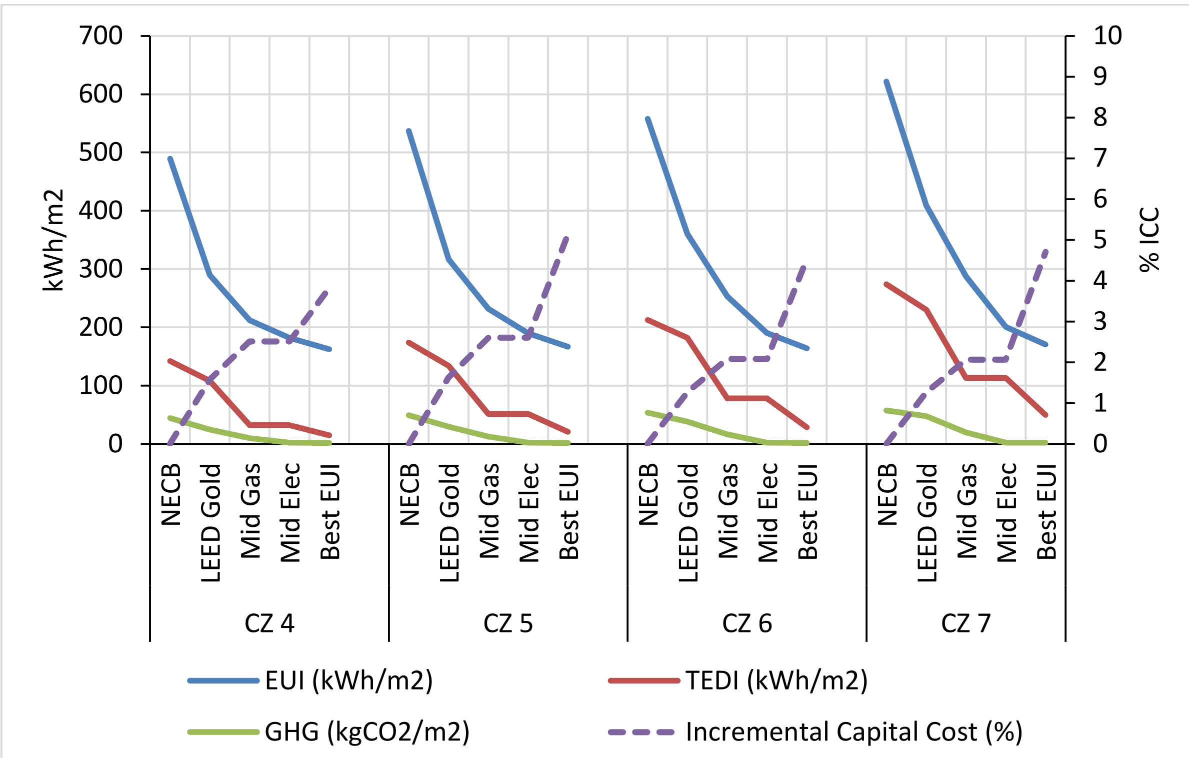

Figure 24. College Scenarios with Labs

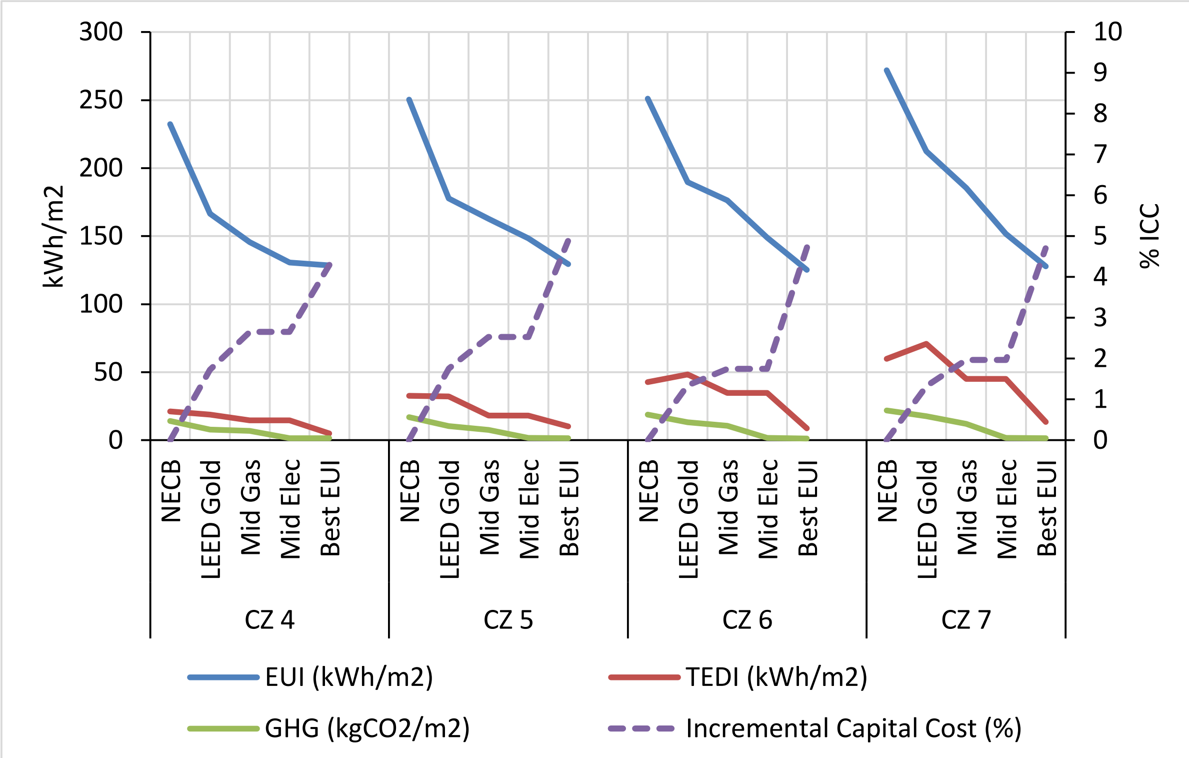

Figure 25. College Scenarios without Labs

4.6 Rec Centre Outcomes

The best rec centre scenario modelled without pool would achieve 68% to 72% energy savings from current code requirements, and at least a 96% reduction in greenhouse gas emissions.

Rec centres, excluding the pool have high domestic hot water loads and ventilation requirements as a result of the fitness facilities, in addition to high lighting levels.

The typical energy conservation measures used at each stage of improvement are:

- 6 LEED points achieved with 25% lighting reduction, 20% domestic hot water savings, and heat recovery
- The middle step has full LED lighting, and high efficiency heat recovery, with triple glazing in CZ 4 and 7a
- The best energy case includes a ground-source heat pump system, and typically the highest performance walls and roof except CZ 4, and 40% DHW savings, but no further glazing improvements

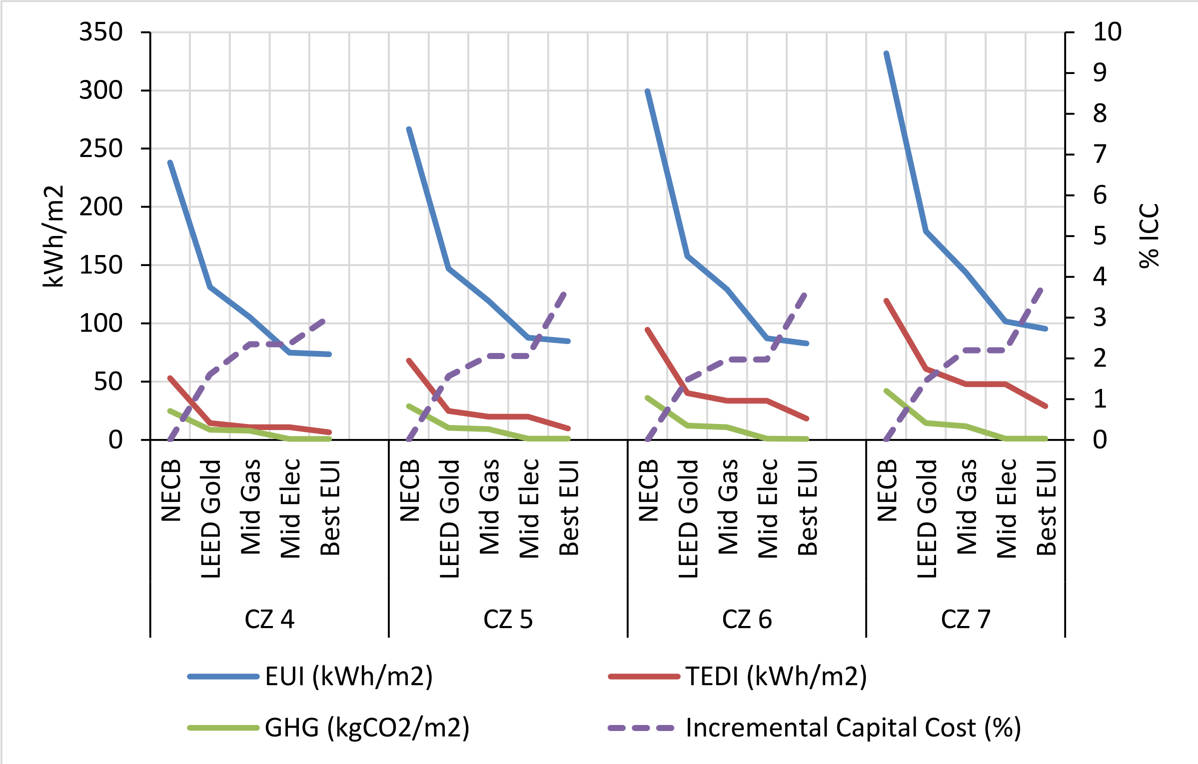

Figure 26. Rec Centre Scenarios without Pool

4.7 Care Facility Expected Outcomes

The best care facility scenario modelled would achieve 58% to 62% energy savings from current code requirements, and at least a 96% reduction in greenhouse gas emissions.

Care facilities are similar to MURBs, however the significant common areas have higher lighting loads, and mechanical cooling is more commonly found. More envelope focused energy conservations measure are employed compared to other public sector building, and the NECB reference building does not result in automatic energy savings due to a change to more efficient HVAC system type.

The typical energy conservation measures used at each stage of improvement are:

- 6 LEED points achieved with full LED lighting (except 25% savings in CZ 4), 40% domestic hot water savings (except CZ 6), heat recovery, and higher performance walls in CZ 7

- The middle step has full LED lighting, increased wall performance in all zones, and triple glazing in CZ 7a

- The best energy case includes a ground-source heat pump system, and the highest performance walls and roof, high efficiency heat recovery

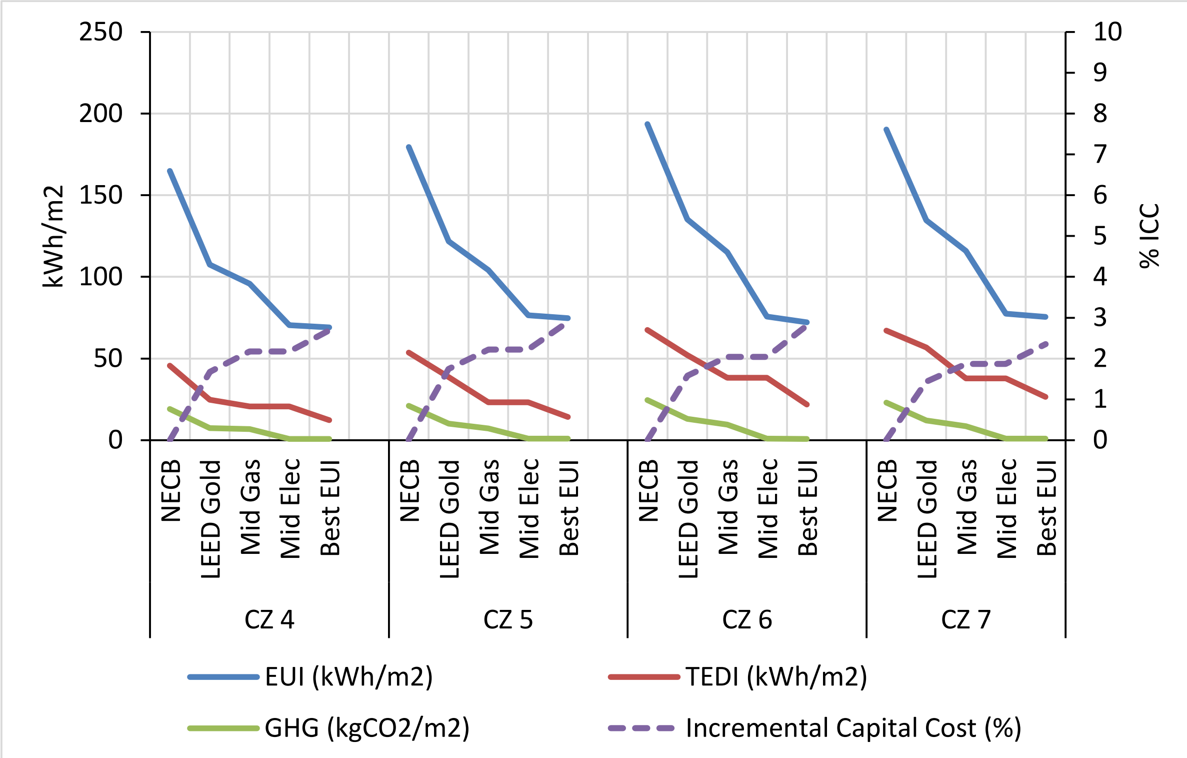

Figure 27. Care Facility Scenarios

4.8 Hospitals Expected Outcomes

The best hospital scenarios modelled would achieve 33% to 50% energy savings from current code requirements, and a 68% to 85% reduction in greenhouse gas emissions.

Due to the high internal loads present in hospitals, as well as the high ventilation rates and humidification requirements, mechanical systems are a key element of energy efficiency for hospitals. Cooling and reheat account for a significant portion of the energy use, as does humidification, with envelope losses representing a smaller portion of heating loads. For these reasons, a best case scenario is shown minimizing reheat using a DOAS system with highly efficient enthalpy heat recovery supplying preheated ventilation air to the zones to be heated and cooled via radiant heating and cooling systems within the zones. This is compared to the current typical design using a VAV system with hydronic reheat at the zone level, where all of the air must be cooled to meet the needs of the warmest zones, and then much of the air volume is reheated to supply to the zones.

The typical energy conservation measures used at each stage of improvement are:

- 6 LEED points achieved with 30% lighting reduction and high efficiency enthalpy heat recovery with 100% outdoor air VAV system with condensing boiler

- The middle step substitutes an air source heat pump for the boiler to provide heating

- The best energy case includes a dedicated outdoor air system with high efficiency enthalpy heat recovery, with radiant heating and cooling in the zones

The incremental capital cost increases when an air-source heat pump is used rather than a natural gas condensing boiler to serve the multi-zone VAV system. The DOAS with zone heating and cooling scenario then changes back to a central natural gas boiler system, reducing costs. This was done to minimize capital costs, as the heating energy use is already minimized by the elimination of reheat energy based on air system type selection. The "best EUI" scenario then increases in capital costs because of the reduction in air leakage and improvement in envelope.

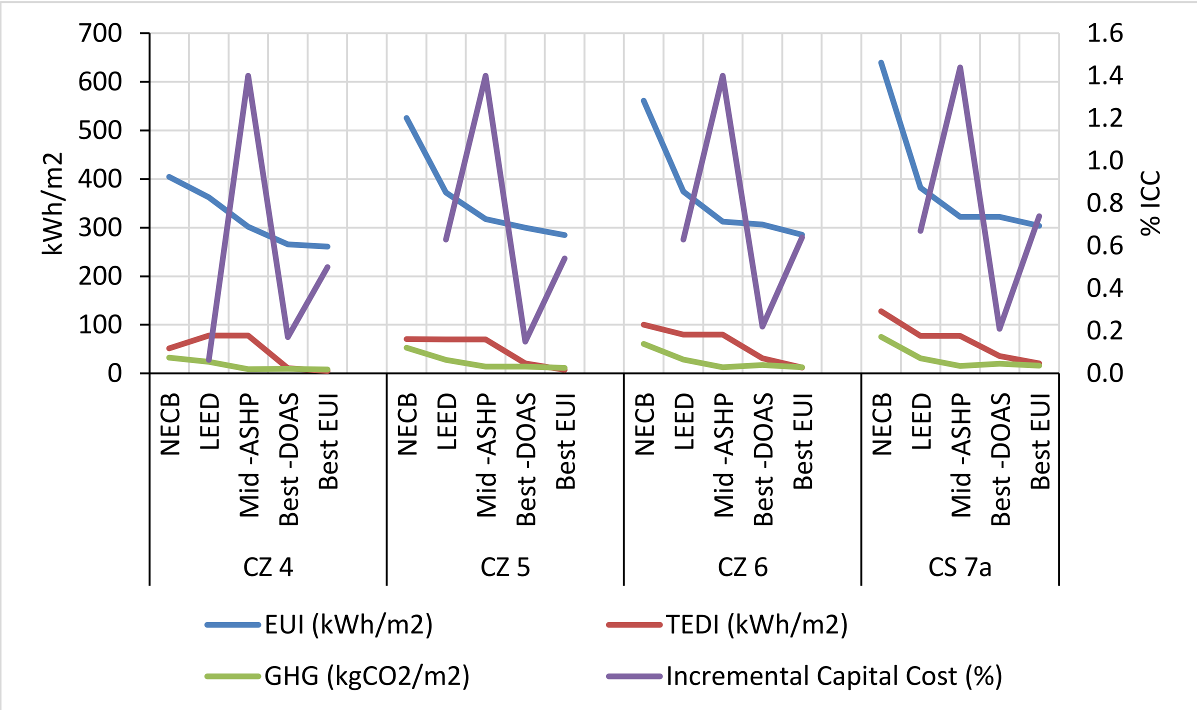

Figure 28. Hospital Scenarios

4.9 Net Zero and Solar PV

In British Columbia, the low carbon emissions factor for electricity means that the most effective method of attaining net zero energy or emissions is to build a building with an electric based HVAC system, and low enough internal loading that the on-site solar PV can provide all the energy needs of the building. Since many sites may be limited to roof-top PV, for the multi-storey archetypes studied net zero energy may not be feasible. Table 18 shows the maximum possible PV capacity on the roof for each archetype building, along with the capacity required for the scenarios with the lowest EUI, the number of storeys where net-zero energy building is feasible with rooftop PV alone, and the quantity of ground-mounted PV required as a percent of the roof area for an additional storey.

All archetypes except hospitals can meet net zero with roof top PV alone for single storey buildings in climate zone 4. Most buildings can also meet net zero with rooftop PV in climate zone 5 to 7a, except schools above climate zone 4 which require up to 32% additional roof area equivalent in ground-mounted PV, college with labs which requires 12% additional roof area in zone 7a, and hospitals which requires between 53% and 142% additional roof area in order to meet net zero.

Table 18. Net Zero Feasibility

Archetype	Climate	Roof Area (m2)	# storeys in archetype	Roof PV Capacity (kW)	Roof PV Generation (kWh/m2 floor)	Lowest EUI (kWh/m2 floor)	# storeys NZ possible	% additional roof area for additional storey
School	CZ 4	4451	1	465	117.2	98.7	1	69%
	CZ 5			364	106.7	109.2	0	2%
	CZ 6			364	94.3	108.0	0	14%
	CZ 7a			269	86.3	113.9	0	32%
Care Facility	CZ 4	2249	9	235	21.9	69.1	2	5%
	CZ 5			184	20.0	74.6	2	25%
	CZ 6			184	17.7	72.1	2	36%
	CZ 7a			136	16.2	75.6	1	4%
Rec Centre wo Pool	CZ 4	4817	2	503	70.2	73.6	1	5%
	CZ 5			394	63.9	84.6	1	32%
	CZ 6			394	56.5	82.9	1	47%
	CZ 7a			291	51.7	95.4	1	84%
Library	CZ 4	814	2	85	78.0	54.1	2	4%
	CZ 5			67	71.0	59.4	2	25%
	CZ 6			67	62.8	57.2	2	37%
	CZ 7a			49	57.4	61.6	1	7%
College w Labs	CZ 4	4731	6	494	34.5	54.1	1	57%
	CZ 5			387	31.4	59.4	1	77%
	CZ 6			387	27.8	57.2	1	97%
	CZ 7a			286	25.4	61.6	0	12%
College wo Labs	CZ 4	3263	6	341	34.5	162.2	1	24%
	CZ 5			267	31.4	166.5	1	37%
	CZ 6			267	27.8	164.0	1	50%
	CZ 7a			197	25.4	170.3	1	67%
Hospital	CZ 4	6116	6	639	28.4	260.6	0	53%
	CZ 5			500	25.8	284.6	0	84%
	CZ 6			500	22.8	285.0	0	108%
	CZ 7a			369	20.9	304.0	0	142%

5. IMPLEMENTATION CONSIDERATIONS

In order to ensure that the proposed performance metrics translate to the real diversity in public sector buildings, some considerations should be made:

- Some space types within a building have drastically higher energy use than the rest of the building, and have very project-specific design parameters. These include laboratories and pools. An energy target system must simultaneously allow for energy use which is necessary for a building to serve its purpose, but also encourage the use of energy reduction measure when possible.

  Laboratories must have the capacity to provide high ventilation rates for occupant safety at times, but every effort must be made to both reduce operational flow rates, and recover heat from the ventilation air. Labs also have varied and potentially high process loads depending on lab activities. Lab energy use may be addressed by applying prescriptive requirements to heat recovery and demand control ventilation as much as possible, then to allow for the additional remaining ventilation energy use and process load energy in the overall building energy target.

  Recreation centre pools are a valuable public resource which consume high quantities of energy, but there are avenues for improving performance in the pool HVAC systems, and possibilities to design the systems to synergistically share loads with the remainder of the building, such as with an ice rink, reducing overall energy demand. Pool prescriptive requirements may require heat recovery within the pool HVAC systems.

- Hospitals can have significant variations in process loads based on the programming of the hospital and the types of equipment required. Diagnostic equipment, steam sterilization, laundry, and helipad or other snow melt loads, and other loads, may be required in some hospitals and not in others. Hospital energy targets should be adjusted to take into account variations in process loads and their impacts on regulated loads.

- The distributions of suite plug loads should be address in the energy modelling guidelines for buildings where some of the typical suite energy use is expected to occur outside of the suite. A method has been described for care facilities with dedicated laundry and common dining facilities, and the same method should likely be considered for multi-unit residential buildings which have common laundry facilities in lieu of in-suite laundry.

APPENDIX A: ENERGY SIMULATION DETAILS

Table A-1. School Building Simulation Input Summary

Characteristic	School
Weather	Vancouver CWEC, Kamloops CWEC, Prince George CWEC, Fort St John CWEC
Software	EnergyPlus v8.6
Climate Zone	4,5,6,7A
Building Area	4,665 m^2
Operating Hours	NECB Schedule D occupancy, lighting and plug loads.
Occupancy	Default Occupancies taken from ASHRAE 62.1-2010, as NECB defaults are unrealistically low. 3.3 m^2/person Classrooms, Gym 4 m^2/person Staffroom 10 m^2/person Change Rooms, Library 20 m^2/person Office 30 m^2/person Washrooms 100 m^2/person Corridors 200 m^2/person Mech/Elec
Plug & Process Loads	10 W/m^2 Food Classroom 7.5 W/m^2 Offices 5 W/m^2 Classrooms 2.5 W/m^2 Change Rooms 1 W/m^2 Gym, Library, Mech/Elec, Staffroom, Storage, Washrooms Server Load: 4 kW, continuous Exhaust Fans: 2.9 kW, continuous when occupied
Outdoor Air	Per ASHRAE 62.1-2001 8 to 10 L/s/person or 0.25 to 2.5 L/s/m^2
Infiltration	0.25 L/s/m^2 Exterior Wall Area, Code DOE-2 Coefficients Options: 0.1 L/s/m^2 Exterior Area, Improved 0.01 L/s/m^2 Exterior Area, Passive house
Wall R-Value	Options: R-10 to R-40
Roof R-Value	Options: R-20 to R-40
Window U-Value	Options: USI-2.5 to USI-0.8
Window SHGC	0.4
Window Area %	Options: 10% to 40%
Lighting	13.4 W/m^2 Mech/Elec 13.3 W/m^2 Classrooms 11.9 W/m^2 Offices

	10.7 W/m² Food Classroom 10.5 W/m² Washrooms 10 W/m² Library 9.8 W/m² Gym, Change Rooms 9.4 W/m² Staffroom 7.1 W/m² Corridors 6.8 W/m² Storage 11 kW Exterior Lights, Astronomical Clock Options: Up to 50% reduction in lighting
HVAC Systems	Hydronic Fan Coils and DOAS Roof-top Units in Gym and Server Room Options: Boiler/Chiller Plant Air-source Heat Pump Plant
Baseline Building HVAC Systems	NECB Baseline building with Unitary Gas Roof-top Units
Supply and Ventilation Air	Ventilation air supplied directly to zones through DOAS. Fan coil fans cycle to meet heating and cooling loads.
Heat Recovery	Options: Up to 80% Heat Recovery efficiency, Electric Preheat Coil to -5°C All scenarios (except baseline) have demand control ventilation implemented
Fans	DOAS: 1 W/cfm Gym, Server RTU: 0.5 W/cfm Fan Coils: 0.3 W/cfm
Cooling	RTU: DX Cooling, COP 3.8 Options Boiler: Water-cooled Centrifugal Chiller, COP 5.2 ASHP Plant: ASHP, COP 3.15
Heating	Options Boiler Plant: Condensing Boiler, 96% eff. ASHP Plant: ASHP, COP 4.15, condensing boiler top-up
Pumps	72 ft head, variable speed HW, DHW, ChW Secondary, and CndW 72 ft head, constant speed ChW Primary
DHW	60 W/person Condensing gas boiler

Table A-2. Library Simulation Input Summary

Characteristic	Library
Weather	Vancouver CWEC, Kamloops CWEC, Prince George CWEC, Fort St John CWEC
Software	EnergyPlus v8.6
Climate Zone	4,5,6,7A
Building Area	1,283 m²
Operating Hours	NECB Schedule C occupancy, lighting and plug loads.

Characteristic	Library
Occupancy	200 m^2/person Stairs, Mechanical 100 m^2/person Corridor, Storage 30 m^2/person Washroom 20 m^2/person Office, Shelf Area, Cataloguing 10 m^2/person Lounge 5 m^2/person Conference
Plug & Process Loads	7.5 W/m^2 Office 1 W/m^2 Lounge, Conference, Mechanical, Washroom, Storage 2.5 W/m^2 Cataloguing
Outdoor Air	As per Design: DOAS: 1,570 cfm
Infiltration	0.25 L/s/m^2 Exterior Wall Area, Code DOE-2 Coefficients Options: 0.1 L/s/m^2 Exterior Area, Improved 0.01 L/s/m^2 Exterior Area, Passive house
Wall R-Value	Varied R-10 to R-30
Roof R-Value	Varied R-20 to R-60
Window U-Value	Varied 2.0 USI to 0.8 USI
Window SHGC	0.3
Window Area %	30%
Interior Lighting	18 W/m^2 Shelf Area 13.4 W/m^2 Mechanical 13.2 W/m^2 Conference 11.9 W/m^2 Office 11 W/m^2 Cataloguing 10.5 W/m^2 Washrooms 9.4 W/m^2 Lounge 7.4 W/m^2 Stairs 7.1 W/m^2 Corridor 6.8 W/m^2 Storage Varied 0% to 50% Savings
HVAC Systems	Hydronic Fan Coils and Dedicated Outdoor Air System (DOAS)
Supply and Ventilation Air	Constant ventilation air supplied directly to zones through DOAS. Fan coil fans cycle to meet heating and cooling loads.
Heat Recovery	Varied: 60% to 90% HR
Fans	1 W/cfm DOAS 0.3 W/cfm Fan Coils
Cooling	FC Option: Chiller, 3.72 seasonal COP GSHP Option: Ground-source Heat Pump, 5 seasonal COP Serves 100% of load

Characteristic	Library
Heating	FC Option: Condensing Boiler, 96% seasonal eff. GSHP Option: Ground-source Heat Pump, 3 seasonal COP Serves 100% of load
Pumps	60 ft head, variable speed
Humidification	Gas Steam Humidification to 20% RH
DHW	4650 W Peak Load Same source as heating

Table A-3. College Simulation Input Summary

Characteristic	College
Weather	Vancouver CWEC, Kamloops CWEC, Prince George CWEC, Fort St John CWEC
Software	EnergyPlus v8.6
Climate Zone	4,5,6,7A
Building Area	16,833 m^2 plus 4000 m^2 parkade
Operating Hours	NECB Schedule D profiles for occupancy, lighting and plug loads Research Labs ventilation setback at night, Teaching and Office Labs air terminals, and remainder of building VAV systems off/cycling at night
Occupancy	Default values from the NECB Appendix A were used: Classrooms, Computer Labs: 7.5 m^2/person Lobby, Lounge, Atrium, Café: 10 m^2/person Teaching, Research, and Office Labs, Office, Kitchen, Library: 20 m^2/person Washrooms: 30 m^2/person Corridor, Storage: 100 m^2/person Electrical, Mechanical: 200 m^2/person
Plug loads	Default values from the NECB Appendix A were used: Computer Labs: 12.8 W/m^2 (based on 250W/computer, at 40% cycling/diversity) Teaching, Research, and Office Lab, Kitchens: 10 W/m^2 Office: 7.5 W/m^2 Classrooms: 5 W/m^2 Atrium: 2.5 W/m^2 Lobby, Lounge, Café, Library, Storage, Electrical, Mechanical: 1 W/m^2 Plus Process Loads: 98.5 kW Total Electrical/Communication Rooms (40% cycling/diversity from given design load), continuous 24/7 70.3 kW Lab Process Cooling Load (40% cycling/diversity from given design load), NECB D Schedule

Characteristic	College
	8.3 kW Parkade Exhaust Fans, 0.5 W/cfm, 4 h/day
Infiltration	0.25 L/s/m^2 Exterior Wall Area, Code DOE-2 Coefficients Options: 0.1 L/s/m^2 Exterior Area, Improved 0.01 L/s/m^2 Exterior Area, Passive house
Wall R-Value	Options: R-10 to R-30
Roof R-Value	Options: R-20 to R-60
Window U-Value	Options: USI-2.0 to USI-0.8
SHGC	0.3
WWR	34.5%, 0.92% Skylight-Roof Ratio
Interior Lighting	Library: 22.9 W/m^2 Electrical, Mechanical: 13.4 W/m^2 Teaching, Research, and Office Lab: 23.6 W/m^2 Café: 14.1 W/m^2 Classrooms, Computer Labs: 13.3 W/m^2 Lobby: 9.7 W/m^2 Lounge, Kitchen: 9.4 W/m^2 Office: 11.9 W/m^2 Washrooms: 10.5 W/m^2 Storage: 6.8 W/m^2 Atrium: 24.36 W/m^2 Corridor: 7.1 W/m^2 Parking: 2 W/m^2 Options: Up to 50% reduction in lighting
HVAC System Type	Atrium: DOAS with DCV and perimeter heating Lecture Halls: DOAS with DCV, reheat and perimeter heating Labs: DOAS with DCV reheat and perimeter heating General Building: DOAS with reheat, DCV and perimeter heating Electrical Rooms: Fan Coils Mechanical Rooms: HW Baseboards/Unit Heaters
Supply and Ventilation Air	Proposed Lab VAV System sized for 8 ACH, but limit to a maximum 5 ACH, with setback to 0 or 2 ACH at night. Total Building OA: 123,440 cfm DOAS Lab: 99,000 cfm OA, 1.6 W/cfm DOAS General: 15,530 cfm OA, 0.6 W/cfm

Characteristic	College
	DOAS Atrium: 3,350 cfm OA, 1.1 W/cfm DOAS Lecture: 5,550 cfm OA, 0.6 W/cfm FC: 0.3 W/cfm
Heat Recovery	Options: Up to 80% Heat Recovery efficiency, Electric Preheat Coil to -5°C
Cooling	Chiller Option: 1 X Screw Chiller, 4.8 COP when plant load < 40 tons 2 x Mag Bearing Chiller, 6.2 COP when plant load > 40 tons 2 x Variable Cooling Towers GSHP Option: Ground-source Heat Pump, 5 seasonal COP Serves 100% of load
Heating	Boiler Option: Condensing Boiler, 97% seasonal eff. GSHP Option: Ground-source Heat Pump, 3 seasonal COP Serves 100% of load
Pumps	13.8 W/gpm variable speed secondary chilled water 16.8 W/gpm condenser water 34.6 W/gpm hot water pumps 10.4 W/gpm constant speed primary chilled water pump
DHW	Storage: 300 W/person Labs: 180 W/person Kitchen: 120 W/person Café, Library, Office: 90 W/person Classrooms, Computer Labs: 65 W/person Lounge: 60 W/person Same source as Heating Plant

Table A-4. Rec Centre Building Simulation Input Summary

Characteristic	Rec Centre
Weather	Vancouver CWEC, Kamloops CWEC, Prince George CWEC, Fort St John CWEC
Software	EnergyPlus v8.6
Climate Zone	4,5,6,7A
Building Area	9,794 m^2
Operating Hours	Based on ASHRAE 90-2007 User's Manual for Assembly spaces, customized for expanded operation hours for occupancy, lighting and plug loads. DHW

Characteristic	Rec Centre
	schedule customized to be representative for buildings with pool and fitness facilities.
Occupancy	20 m^2/person Office 10 m^2/person Lobby, Change Rooms 5 m^2/person Gym, Meeting, Multipurpose, Pool 4 m^2/person Gym
Plug & Process Loads	7.5 W/m^2 Office 1 W/m^2 Gym, Fitness, Meeting, Multipurpose, Lobby 2.5 W/m^2 Change Rooms plus 80 kW Pool Filtration and Makeup Water pumps 109.4 kW peak Pool Latent Load 132.7 kW peak Pool Heating Load
Outdoor Air	As per Design: DOAS: 10,420 cfm Pool: 12,460 cfm Fitness: 4,030 cfm Gym: 6,290 cfm
Infiltration	0.25 L/s/m^2 Exterior Wall Area, Code DOE-2 Coefficients Options: 0.1 L/s/m^2 Exterior Area, Improved 0.01 L/s/m^2 Exterior Area, Passive house
Wall R-Value	Varied R-10 to R-30
Roof R-Value	Varied R-20 to R-60
Window U-Value	Varied 2.0 USI to 0.8 USI
Window SHGC	Typical: SHGC 0.3 Varied 0.3 to 0.5
Window Area %	Typical: 30% Varied 15% to 30%
Interior Lighting	13.4 W/m^2 Mechanical 13.2 W/m^2 Meeting, Multipurpose 11.9 W/m^2 Office 9.8 W/m^2 Pool, Change Rooms, Fitness, Gym 9.7 W/m^2 Lobby 7.1 W/m^2 Corridor Varied 0% to 50% Savings
Exterior Lighting	11.54 kW
HVAC Systems	Hydronic Fan Coils and Dedicated Outdoor Air System (DOAS) Plus Three Single-Zone Variable Volume Unitary Systems for Pool, Fitness, and Gym
Supply and Ventilation Air	Constant ventilation air supplied directly to zones through DOAS. Fan coil fans cycle to meet heating and cooling loads. Unitary Systems provide constant ventilation when occupied and variable volume for conditioning
Heat Recovery	Typical: 60% DOAS and Unitary Heat Recovery

Characteristic	Rec Centre
	Varied: 60% to 80% HR
Fans	0.93 W/cfm Pool Unitary 0.6 W/cfm Gym Unitary 0.5 W/cfm Fitness Unitary 0.9 W/cfm DOAS 0.2 W/cfm Fan Coils
Cooling	Boiler/Chiller Option: Chiller, 5 seasonal COP Pool DX Coil, 3 seasonal COP ASHP Option: Air-source HP, 3.15 nominal COP
Heating	Boiler/Chiller Option: Condensing Boiler, 97% seasonal eff. ASHP Option: Air-source HP, 4.15 nominal COP Condensing Back-up Boiler, 97% seasonal eff.
Pumps	60 ft head, variable speed
DHW	96.7 kW Peak Load 90 W/person Fitness, Gym, Pool, Office, Meeting 45 W/person Multipurpose Same source as heating plant

Table A-5. Care Facility Building Simulation Input Summary

Characteristic	Care Facility
Weather	Vancouver CWEC, Kamloops CWEC, Prince George CWEC, Fort St John CWEC
Software	EnergyPlus v8.6
Climate Zone	4,5,6,7A
Building Area	12,588 m^2 plus 1,548 m^2 parkade
Operating Hours	NECB profiles for occupancy, lighting and plug loads Schedule A: Office, Salon Schedule B: Dining, Kitchen, Lockers, Lounge/Recreation, Pool Schedule C: Laundry, Mech/Elec, Physical Therapy, Storage, Tub, Washrooms Schedule G: Corridors, Lobby, Suites Schedule H: Nurses, Parking Corridor, Lobby and Parkade Lights are Always On Kitchen Exhaust operates 6h/day Parkade Exhaust operates 4h/day Miscellaneous Exhausts operate 2 h/day Parkade and Mechanical Spaces conditioned to 10°C

Characteristic	Care Facility
	Pool conditioned to 27.8/28.9°C Cooler/Freezer conditioned to -10°C Main Building conditioned to 22/24°C, two-pipe change over fan coils switch on May 10 and October 11
Occupancy	Default values from the NECB Appendix A were used: Pool: 5 m^2/person Dining, Lockers, Lounge/Rec, Lobby: 10 m^2/person Office, Salon, Kitchen, Laundry, Physical Therapy, Nurses: 20 m^2/person Washrooms, Tub: 30 m^2/person Corridor, Storage: 100 m^2/person Mech/Elec: 200 m^2/person Parking: 1000 m^2/person Suites: 22.58 m^2/person Suite Density based on 2 people/first bedroom, 1 person/additional bedroom
Plug loads	Default values from the NECB Appendix A were used except Suite, Kitchen, and Laundry plug load distributed as described in Section 3.5.1: Laundry: 76.3 W/m^2 Kitchen: 40.5 W/m^2 Physical Therapy: 10 W/m^2 Office, Salon: 7.5 W/m^2 Lockers, Nurses: 2.5 W/m^2 Suites: 2.9 W/m^2 Mech/Elec, Storage, Washrooms, Tub, Lobby, Lounge/Rec, Dining, Pool: 1 W/m^2 Plus Process Loads: 5 kW Parkade Exhaust Fans, 4 h/day 24.9 kW Miscellaneous Exhaust Fans, 2 h/day 6 kW Elevators 1 kW Pool Pumps Kitchen Walk-in Cooler/Freezer included in building cooling loads, modelled as seasonal 3.5 COP PTAC with average -10°C setpoint in R-20 insulated room Pool Latent Load of 2.01 kW Pool Water Heating Load of 2.85 kW, assuming 10% make-up water/week
Zoning	Zoning methodology used for the energy model is in line with the methodology outlined in Section 2 of the EE4 Software Version 1.7 Modelling Guide. In general, a zone includes areas in the building that are served by the same HVAC system, have similar operation and function, and have similar heating/cooling loads
Infiltration	0.25 L/s/m^2 Exterior Wall Area, Code DOE-2 Coefficients

Characteristic	Care Facility
	Options: 0.1 L/s/m² Exterior Area, Improved 0.01 L/s/m² Exterior Area, Passive house
Wall R-Value	Options: R-10 to R-20
Roof R-Value	Options: R-10 to R-20
Window U-Value	Options: USI-2.0 to USI-0.8
C-factor	1.1
WWR	24.3%
Interior Lighting	Suite, office, Salon: 11.9 W/m² Kitchen: 10.7 W/m² Washroom, Tub: 10.5 W/m² Mech/Elec: 10.2 W/m² Physical Therapy: 9.8 W/m² Lobby: 9.675 W/m² Nurses: 9.4 W/m² Lockers: 8.1 W/m² Lounge/Rec: 7.9 W/m² Pool: 7.8 W/m² Corridors: 7.1 W/m² Dining: 7.0 W/m² Storage: 6.8 W/m² Laundry: 6.5 W/m² Parking: 2 W/m² Options: Up to 50% reduction in lighting
HVAC System Type	Option: WAHP/FC Common Areas: DOAS and Water-source Heat Pumps Suites: Cycling Fan Coils and ERVs Pool: Unitary System Option: GSHP Common Areas: DOAS and Fan Coils Suites: Cycling Fan Coils and ERVs Pool:

Characteristic	Care Facility
	Unitary System with Water Coils
Baseline Building HVAC System Type	Common Areas: VAV with HW Baseboards Suites: Cycling Fan Coils and Unit Ventilators or ERVs Pool: Unitary System
Supply and Ventilation Air	Mai MUA: 4,960 cfm OA, 1.4 W/cfm Kitchen MUA: 2,800 cfm OA, 1.4 W/cfm WAHPs: 0.5 W/cfm Suite HRVs: 5,170 cfm OA, 1.7 W/cfm Suite Fan Coils: 0.3 W/cfm Pool Unitary: 0.9 W/cfm Parking Exhaust: 18,000 cfm OA, 0.3 W/cfm Miscellaneous Exhaust (additional intake): 3,644 cfm OA, 0.4 W/cfm
Heat Recovery	Options: Up to 80% Heat Recovery efficiency, Electric Preheat Coil to -5°C
Cooling	Options Chiller Plant: Air-cooled Screw Chiller, COP 3 Cooling Tower for WAHP GSHP Plant: GSHP, COP 5
Heating	Options Boiler Plant: Condensing Boiler, 96% eff. GSHP Plant: GSHP, COP 3, condensing boiler top-up
Pumps	20.1 W/gpm variable hot water 24.2 W/gpm variable chilled water 10.7 W/gpm variable heat pump water
DHW	Suites, Storage: 300 W/person Kitchen, Dining: 120 W/person Pool, Salon, Office: 90 W/person Laundry, Lounge/Rec: 60 W/person Nurses, Physical Therapy: 45 W/person Same as Heating Plant Options: Up to 40% load savings

Table A-6. Hospital Building Simulation Input Summary

Characteristic	Hospital
Weather	Vancouver CWEC, Kamloops CWEC, Prince George CWEC, Fort St John CWEC
Software	EnergyPlus v8.9
Climate Zone	4,5,6,7A
Building Area	26,456 m^2
Operating Hours	NECB profiles for occupancy, lighting and plug loads Care Station NECB H Clinical Core Zone NECB H Corridor NECB H Electrical/telecom NECB H Elevator NECB H Exam NECB C Lockers NECB C Lounge NECB B Mechanical/Service NECB H Medical Device Processing NECB H Meeting/Conference NECB C Office NECB A Operating Room NECB H Patient Room NECB H Pharmacy NECB C Reception/Lobby NECB C Retail NECB C Stair NECB H Storage/Utility NECB H WR NECB H Waiting NECB B Thermostat schedules follow MNECB B, C, and H (22-24°C, with night setback to 18°C)
Occupancy	Default values from the NECB Appendix A were used: Care Station 20 m^2/person Clinical Core Zone 20 m^2/person Corridor 100 m^2/person Electrical/telecom 200 m^2/person Elevator 200 m^2/person Exam 20 m^2/person Lockers 10 m^2/person Lounge 10 m^2/person Mechanical/Service 200 m^2/person Medical Device Processing 20 m^2/person Meeting/Conference 5 m^2/person

Characteristic	Hospital
	Office 20 m²/person Operating Room 20 m²/person Patient Room 20 m²/person Pharmacy 20 m²/person Reception/Lobby 10 m²/person Retail 30 m²/person Stair 200 m²/person Storage/Utility 100 m²/person WR 30 m²/person Waiting 10 m²/person
Plug loads	Default values from the NECB Appendix A were used: Care Station: 10 W/m² Clinical Core Zone: 2.5 W/m² Corridor: 0 W/m² Electrical/telecom: 1 W/m² Elevator: 0 W/m² Exam: 10 W/m² Lockers: 2.5 W/m² Lounge: 1 W/m² Mechanical/Service: 1 W/m² Medical Device Processing: 10 W/m² Meeting/Conference: 1 W/m² Office: 7.5 W/m² Operating Room: 10 W/m² Patient Room: 10 W/m² Pharmacy: 2.5 W/m² Reception/Lobby: 1 W/m² Retail: 2.5 W/m² Stair: 0 W/m² Storage/Utility: 1 W/m² WR: 1 W/m² Waiting: 1 W/m² Plus Process Loads: 130 kW Elevators 1 kW Server loads 267 W/m² Telecom No sterilization steam equipment, helipad or other snow melt, helipad lighting, etc.
Zoning	Zoning methodology used for the energy model is in line with the methodology outlined in Section 2 of the EE4 Software Version 1.7 Modelling Guide. In general, a zone includes areas in the building that are served by the same

Characteristic	Hospital
	HVAC system, have similar operation and function, and have similar heating/cooling loads
Infiltration	0.25 L/s/m² Exterior Wall Area, Code DOE-2 Coefficients Options: 0.1 L/s/m² Exterior Area, Improved 0.01 L/s/m² Exterior Area, Passive house
Wall R-Value	Options: R-10 to R-30
Roof R-Value	Options: R-20 to R-40
Window U-Value	Options: USI-2.0 to USI-0.8
C-factor	0.11 W/m²K
WWR	12%
Interior Lighting	Care Station 9.4 W/m² Clinical Core Zone 9.4 W/m² Corridor 9.6 W/m² Electrical/telecom 13.4 W/m² Elevator 6 W/m² Exam 17.9 W/m² Lockers 9.8 W/m² Lounge 11.5 W/m² Mechanical/Service 13.4 W/m² Medical Device Processing 13.7 W/m² Meeting/Conference 13.2 W/m² Office 11.9 W/m² Operating Room 20.3 W/m² Patient Room 6.7 W/m² Pharmacy 12.3 W/m² Reception/Lobby 9.7 W/m² Retail 18.1 W/m² Stair 7.4 W/m² Storage/Utility 6.8 W/m² WR 10.5 W/m² Waiting 11.5 W/m² Options: Up to 30% reduction in lighting
HVAC System Type	Baseline: DOAS with fan coil and standard boiler, 50% sensible heat recovery Option 2: VAV with condensing boiler, 80% enthalpy heat recovery Option 3: VAV with ASHP, 80% enthalpy heat recovery Option 4: DOAS with condensing boiler, radiant heating and cooling, 80% enthalpy heat recovery

Characteristic	Hospital
Supply and Ventilation Air	66,000 L/s outside air at 100% OA (2.5 L/s/m^2) Fans: Supply fan 4" TSP @ 55% combined efficiency Return fan 1" TSP @ 30% combined efficiency
Heat Recovery	Baseline: 50% sensible only heat recovery All other: 80% enthalpy heat recovery
Cooling	Chiller plant seasonal COP 4.5
Heating	Options Baseline boiler: Standard boiler, 75% seasonal eff. Boiler Plant: Condensing Boiler, 90% seasonal eff. ASHP Plant: GSHP, COP 3
Pumps	41.6 W/gpm variable hot water 90.3 W/gpm variable chilled water
DHW	Care Station 45 W/person Clinical Core Zone 45 W/person Corridor 0 W/person Electrical/telecom 0 W/person Elevator 0 W/person Exam 90 W/person Lockers 0 W/person Lounge 60 W/person Mechanical/Service 0 W/person Medical Device Processing 90 W/person Meeting/Conference 45 W/person Office 90 W/person Operating Room 300 W/person Patient Room 90 W/person Pharmacy 45 W/person Reception/Lobby 0 W/person Retail 40 W/person Stair 0 W/person Storage/Utility 300 W/person WR 0 W/person Waiting 60 W/person 90% efficient natural gas heating

APPENDIX B: CAPITAL COST DETAILS

Effective wall performance is calculated assuming thermal bridging from typical construction details for lower performing walls and introducing improvements in thermal bridging in addition to clear wall performance as effective performance increases. Many thermal bridges may be reduced by using low cost, but non-typical methods such as aligning windows with the wall insulation by using plywood liner in window opening. Or designing a building to minimize the quantity of window to wall transitions. High performance wall assemblies typically require exterior insulation with thermally broken clips or clips made of less thermally conductive materials supporting exterior cladding, and glazing that is aligned with the wall insulation plane.

Wall performance premiums are calculated based on the cost of the clear wall required to attain the effective performance after thermal bridging is accounted for. Clip performance can vary widely between manufacturers, and alternate insulation configurations can be used to obtain similar effective performance results.

The construction assembly costs are subjective and are order of magnitude estimates. There are many variables and constraints on real projects that will overshadow some of the estimated cost differences between assemblies. The main point to remember is that construction costs vary quite widely in practice. This variability is part of the reason that construction projects typically have a bid process, where there can be a big difference between the highest and lowest bid. Consideration of the nature of this analysis and the fluidity of construction costs is required to reach meaningful conclusions. The construction cost estimates utilized in this analysis are broad cost estimates with more uncertainty than a Class D estimate, because the estimates were not arrived for a specific building, nor is there a comprehensive list of requirements to base assumptions. Accordingly, order of magnitude means that the construction cost estimates are +/- 50%.

Table B-1. **School Cost Summary**

<table>
<tr><th>Category</th><th colspan="5">Premium</th></tr>
<tr><td>Air Leakage</td><td colspan="5">Cost per building, dependent on air infiltration level attained
Code: $50,000
Improved: $75,000
Passive House: $100,000</td></tr>
<tr><td rowspan="10">Wall Performance</td><td>Climate Zone</td><td>4</td><td>5</td><td>6</td><td>7A</td></tr>
<tr><td>Baseline Assembly</td><td colspan="4">Exterior insulated steel stud wall assembly, with typical bridging details</td></tr>
<tr><td></td><td>R-18.9 ext ins.</td><td>R-21 ext. ins.</td><td>R-25.2 ext. ins.</td><td>R-25.2 ext. ins. plus R-12 batt</td></tr>
<tr><td>Baseline Clear Wall R-Value (modelled)</td><td>18</td><td>20.4</td><td>23</td><td>27</td></tr>
<tr><td>Baseline Effective Wall R-Value (with typical thermal bridging)</td><td>9.5</td><td>10.1</td><td>10.7</td><td>11.54</td></tr>
<tr><td>Effective R-10</td><td>$2.50/m² wall</td><td>-$2.16/m² wall</td><td>-$11.50/m² wall</td><td>-$13.39/m² wall</td></tr>
<tr><td>R-20 Assembly</td><td colspan="4">R-32 ext. ins. plus R-12 batt, improved grade, parapet, and window transitions</td></tr>
<tr><td>Effective R-20 Premium</td><td>$33.48/m² wall</td><td>$28.82/m² wall</td><td>$19.48/m² wall</td><td>$17.59/m² wall</td></tr>
<tr><td>R-40 Assembly</td><td colspan="4">R-61 ext. ins. plus R-19 batt, further improved grade transition</td></tr>
<tr><td>Effective R-40 Premium</td><td>$99.8/m² wall</td><td>$95.14/m² wall</td><td>$85.80/m² wall</td><td>$83.91/m² wall</td></tr>
<tr><td>Roof Performance</td><td colspan="5">R-20: $0/m² roof
R-40: $35/m² roof</td></tr>
<tr><td>Glazing Performance</td><td colspan="5">USI-2.5: $-10/m² window
Baseline, USI 2.4 to 2.2
USI-2.0: $17/m² window
USI-1.6: $76/m² window
USI-1.2: $173/m² window
USI-0.8: $184/m² window</td></tr>
<tr><td>Heat Recovery</td><td colspan="5">60% efficient HRV: $5/cfm
80% efficient HRV: $8/cfm
Demand Control Ventilation $35,000</td></tr>
<tr><td>Lighting Power Reductions</td><td colspan="5">25% reduction, controls, some LED: $57.5/m² floor
50% reduction, full LED: $72/m² floor</td></tr>
<tr><td>Maintenance</td><td colspan="5">Base line is RTU
FC/DOAS vs. RTU – $2.312/m² floor ($0.2148/ft²)
Boiler/Chiller vs No Central Plant – $4.327/m² floor ($0.402/ft²)
ASHP vs No Central Plant – $3.229/m² floor ($0.300/ft²)</td></tr>
<tr><td>Base Costs</td><td colspan="5">$4,122/m² floor($383/ft²)</td></tr>
</table>

Location Factors	Base and incremental capital costs are multiplied by location factors for each climate zone Zone 4 – 1 Zone 5 – 0.95 Zone 6 – 1.15 Zone 7 – 1.15

Table B-2. Library Capital Cost Data

Category	**Premium**				
Air Leakage	Cost per building, dependent on air infiltration level attained Code: $50,000 Improved: $75,000 Passive House: $100,000				
Wall Performance	Climate Zone	4	5	6	7A
	Baseline Assembly	Exterior insulated steel stud wall assembly, with typical bridging details			
		R-18.9 ext ins.	R-21 ext. ins.	R-25.2 ext. ins.	R-25.2 ext. ins. plus R-12 batt
	Baseline Clear Wall R-Value (modelled)	18	20.4	23	27
	Baseline Effective Wall R-Value (with typical thermal bridging)	8.4	8.9	9.4	10
	Effective R-10 or less Premium	$15.9/$m^2$ wall	$11.3/$m^2$ wall	$1.9/$m^2$ wall	$0/$m^2$ wall
	R-20 Assembly	R-40 ext. ins. plus R-19 batt, improved grade, parapet, and window transitions			
	Effective R-20 Premium	$49.9/$m^2$ wall	$45.3/$m^2$ wall	$35.9/$m^2$ wall	$34/$m^2$ wall
	R-30 Assembly	R-53 ext. ins. plus R-19 batt, improved grade, parapet, and window transitions			
	Effective R-30 Premium	$78.9/$m^2$ wall	$74.3/$m^2$ wall	$64.9/$m^2$ wall	$63/$m^2$ wall
Roof Performance	R-20: $0/$m^2$ roof R-40: $35/$m^2$ roof R-60: $70/$m^2$ roof				
Glazing Performance	Baseline, USI 2.4 to 2.2 USI-2.0: $17/$m^2$ window USI-1.6: $76/$m^2$ window USI-1.2: $173/$m^2$ window USI-0.8: $184/$m^2$ window				
Heat Recovery	60% efficient HRV: $5/cfm 80% efficient HRV: $8/cfm				
Lighting Power Reductions	25% reduction, controls, some LED: $52.5/$m^2$ floor 50% reduction, full LED: $72/ m^2 floor				
Maintenance	Base line is RTU FC/DOAS vs. RTU – $2.312/$m^2$ floor ($0.2148/$ft^2$) Boiler/Chiller vs No Central Plant – $4.327/$m^2$ floor ($0.402/$ft^2$) GSHP vs No Central Plant – $3.229/$m^2$ floor ($0.300/$ft^2$)				
Base Costs	$5,890/$m^2$ ($547/$ft^2$)				

Location Factors	Base and incremental capital costs are multiplied by location factors for each climate zone Zone 4 – 1 Zone 5 – 0.95 Zone 6 – 1.15 Zone 7 – 1.15

Table B-3. College Cost Summary

Category	Premium				
Air Leakage	Cost per building, dependent on air infiltration level attained Code: \$50,000 Improved: \$75,000 Passive House: \$100,000				
Wall Performance	Climate Zone	4	5	6	7A
	Baseline Assembly	Exterior insulated steel stud wall assembly, with typical bridging details			
		R-18.9 ext ins.	R-21 ext. ins.	R-25.2 ext. ins.	R-25.2 ext. ins. plus R-12 batt
	Baseline Clear Wall R-Value (modelled)	18	20.4	23	27
	Baseline Effective Wall R-Value (with typical thermal bridging)	12.7	14.0	14.9	16.5
	Effective R-10 or less Premium	\$15.9/m^2 wall	\$11.3/m^2 wall	\$1.9/m^2 wall	\$0/m^2 wall
	R-20 Assembly	R-40 ext. ins. plus R-19 batt, improved grade, parapet, and window transitions			
	Effective R-20 Premium	\$49.9/m^2 wall	\$45.3/m^2 wall	\$35.9/m^2 wall	\$34/m^2 wall
	R-30 Assembly	R-53 ext. ins. plus R-19 batt, improved grade, parapet, and window transitions			
	Effective R-30 Premium	\$78.9/m^2 wall	\$74.3/m^2 wall	\$64.9/m^2 wall	\$63/m^2 wall
Roof Performance	R-20: \$0/m^2 roof R-40: \$35/m^2 roof				
Glazing Performance	Baseline, USI 2.4 to 2.2 USI-2.0: \$17/m^2 window USI-1.6: \$76/m^2 window USI-1.2: \$173/m^2 window USI-0.8: \$184/m^2 window				
Heat Recovery	60% efficient HRV: \$5/cfm 80% efficient HRV: \$8/cfm				
Lighting Power Reductions	25% reduction, controls, some LED: \$52.5/m^2 floor 50% reduction, full LED: \$72/ m^2 floor				
Maintenance	Base line is VAV with Hydronic Boiler FC/DOAS vs. VAV – \$0.5339/m^2 floor (\$0.0496/ft^2) ASHP vs Hydronic Boiler – -\$1.098/m^2 floor (-\$0.102/ft^2)				
Base Costs	\$4,733/m^2 floor(\$440/ft^2)				
Location Factors	Base and incremental capital costs are multiplied by location factors for each climate zone Zone 4 – 1				

<table>
<tr><td></td><td>Zone 5 – 0.95
Zone 6 – 1.15
Zone 7 – 1.15</td></tr>
</table>

Table B-4. Recreation Centre Capital Cost Data

<table>
<tr><th>Category</th><th colspan="5">Premium</th></tr>
<tr><td>Air Leakage</td><td colspan="5">Cost per building, dependent on air infiltration level attained
Code: $50,000
Improved: $75,000
Passive House: $100,000</td></tr>
<tr><td rowspan="11">Wall Performance</td><td>Climate Zone</td><td>4</td><td>5</td><td>6</td><td>7A</td></tr>
<tr><td rowspan="2">Baseline Assembly</td><td colspan="4">Exterior insulated steel stud wall assembly, with typical bridging details</td></tr>
<tr><td>R-18.9 ext ins.</td><td>R-21 ext. ins.</td><td>R-25.2 ext. ins.</td><td>R-25.2 ext. ins. plus R-12 batt</td></tr>
<tr><td>Baseline Clear Wall R-Value (modelled)</td><td>18</td><td>20.4</td><td>23</td><td>27</td></tr>
<tr><td>Baseline Effective Wall R-Value (with typical thermal bridging)</td><td>8.4</td><td>8.9</td><td>9.4</td><td>10</td></tr>
<tr><td>Effective R-10 or less Premium</td><td>$15.9/m² wall</td><td>$11.3/m² wall</td><td>$1.9/m² wall</td><td>$0/m² wall</td></tr>
<tr><td>R-20 Assembly</td><td colspan="4">R-40 ext. ins. plus R-19 batt, improved grade, parapet, and window transitions</td></tr>
<tr><td>Effective R-20 Premium</td><td>$49.9/m² wall</td><td>$45.3/m² wall</td><td>$35.9/m² wall</td><td>$34/m² wall</td></tr>
<tr><td>R-30 Assembly</td><td colspan="4">R-53 ext. ins. plus R-19 batt, improved grade, parapet, and window transitions</td></tr>
<tr><td>Effective R-30 Premium</td><td>$78.9/m² wall</td><td>$74.3/m² wall</td><td>$64.9/m² wall</td><td>$63/m² wall</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Roof Performance</td><td colspan="5">R-20: $0/m² roof
R-40: $35/m² roof
R-60: $70/m² roof</td></tr>
<tr><td>Glazing Performance</td><td colspan="5">Baseline, USI 2.4 to 2.2
USI-2.0: $17/m² window
USI-1.6: $76/m² window
USI-1.2: $173/m² window
USI-0.8: $184/m² window</td></tr>
<tr><td>Heat Recovery</td><td colspan="5">60% efficient HRV: $5/cfm
80% efficient HRV: $8/cfm</td></tr>
<tr><td>Lighting Power Reductions</td><td colspan="5">25% reduction, controls, some LED: $52.5/m² floor
50% reduction, full LED: $72/ m² floor</td></tr>
<tr><td>Maintenance</td><td colspan="5">Base line is RTU
FC/DOAS vs. RTU – $2.312/m² floor ($0.2148/ft²)
Boiler/Chiller vs No Central Plant – $4.327/m² floor ($0.402/ft²)
ASHP vs No Central Plant – $3.229/m² floor ($0.300/ft²)</td></tr>
<tr><td>Base Costs</td><td colspan="5">$5,293/m² ($492/ft²)</td></tr>
<tr><td>Location Factors</td><td colspan="5">Base and incremental capital costs are multiplied by location factors for each climate zone
Zone 4 – 1
Zone 5 – 0.95</td></tr>
</table>

	Zone 6 – 1.15 Zone 7 – 1.15

Table B-5. Care Facility Cost Summary

<table>
<tr><th>Category</th><th colspan="5">Premium</th></tr>
<tr><td>Air Leakage</td><td colspan="5">Cost per building, dependent on air infiltration level attained
Code: $50,000
Improved: $75,000
Passive House: $100,000</td></tr>
<tr><td rowspan="10">Wall Performance</td><td>Climate Zone</td><td>4</td><td>5</td><td>6</td><td>7A</td></tr>
<tr><td rowspan="2">Baseline Assembly</td><td colspan="4">Exterior insulated steel stud wall assembly, with thermally unbroken balconies and strip windows</td></tr>
<tr><td>R-18.9 ext ins.</td><td>R-21 ext. ins.</td><td>R-25.2 ext. ins.</td><td>R-25.2 ext. ins. plus R-12 batt</td></tr>
<tr><td>Baseline Clear Wall R-Value (modelled)</td><td>18</td><td>20.4</td><td>23</td><td>27</td></tr>
<tr><td>Baseline Effective Wall R-Value (with typical thermal bridging)</td><td>9.4</td><td>9.7</td><td>10.2</td><td>10.9</td></tr>
<tr><td>Effective R-10 or less Premium</td><td>$6.9/m² wall</td><td>$2.3/m² wall</td><td>$-7.1/m² wall</td><td>$-9/m² wall</td></tr>
<tr><td>R-20 Assembly</td><td colspan="4">R-40 ext. ins. plus R-19 batt, reduced balcony area and thermally broken balconies, reduced glazing transition area</td></tr>
<tr><td>Effective R-20 Premium</td><td>$40.9 /m² wall</td><td>$36.3/m² wall</td><td>$26.9/m² wall</td><td>$25/m² wall</td></tr>
<tr><td>R-30 Assembly</td><td colspan="4">R-49 ext. ins. plus R-19 batt, No Balconies, optimized thermal bridging details</td></tr>
<tr><td>Effective R-30 Premium</td><td>$60.9/m² wall</td><td>$56.3/m² wall</td><td>$46.9/m² wall</td><td>$45/m² wall</td></tr>
<tr><td>Roof Performance</td><td colspan="5">R-20: $0/m² roof
R-40: $35/m² roof</td></tr>
<tr><td>Glazing Performance</td><td colspan="5">USI-2.5: $-10/m² window
Baseline, USI 2.4 to 2.2
USI-2.0: $17/m² window
USI-1.6: $76/m² window
USI-1.2: $173/m² window
USI-0.8: $184/m² window</td></tr>
<tr><td>Heat Recovery</td><td colspan="5">60% efficient Suite ERV: $1,800/unit
80% efficient Suite ERV: $2,400/unit
60% efficient HRV: $5/cfm
80% efficient HRV: $8/cfm</td></tr>
<tr><td>DHW Reductions</td><td colspan="5">20% load savings: 0$
40% load savings via Drain Water Heat Recovery: $2.5/m2 floor</td></tr>
<tr><td>Lighting Power Reductions</td><td colspan="5">25% reduction, controls, some LED: $52.5/m² floor
50% reduction, full LED: $72/ m² floor</td></tr>
<tr><td>Maintenance</td><td colspan="5">GSHP vs Boiler/Chiller – -$1.098/m² floor (-$0.102/ft²)</td></tr>
<tr><td>Base Costs</td><td colspan="5">$3,582/m² floor ($333/ft²)</td></tr>
<tr><td>Location Factors</td><td colspan="5">Base and incremental capital costs are multiplied by location factors for each climate zone
Zone 4 – 1
Zone 5 – 0.95
Zone 6 – 1.15</td></tr>
</table>

<table>
<tr><td></td><td>Zone 7 – 1.15</td></tr>
</table>

Table B-6. Hospital Cost Summary

<table>
<tr><th>Category</th><th colspan="5">Premium</th></tr>
<tr><td>Air Leakage</td><td colspan="5">Cost per building, dependent on air infiltration level attained
Code: \$50,000
Improved: \$75,000
Passive House: \$100,000</td></tr>
<tr><td rowspan="10">Wall Performance</td><td>Climate Zone</td><td>4</td><td>5</td><td>6</td><td>7A</td></tr>
<tr><td rowspan="2">Baseline Assembly</td><td colspan="4">Exterior insulated steel stud wall assembly</td></tr>
<tr><td>R-18.9 ext ins.</td><td>R-21 ext. ins.</td><td>R-25.2 ext. ins.</td><td>R-25.2 ext. ins. plus R-12 batt</td></tr>
<tr><td>Baseline Clear Wall R-Value (modelled)</td><td>18</td><td>20.4</td><td>23</td><td>27</td></tr>
<tr><td>Baseline Effective Wall R-Value (with typical thermal bridging)</td><td>14.5</td><td>16.0</td><td>17.6</td><td>19.8</td></tr>
<tr><td>Effective R-10 or less Premium</td><td>\$0/m^2 wall</td><td>\$0/m^2 wall</td><td>\$0/m^2 wall</td><td>\$0/m^2 wall</td></tr>
<tr><td>R-20 Assembly</td><td colspan="4">R-18 ext. ins. plus R-19 batt</td></tr>
<tr><td>Effective R-20 Premium</td><td>\$1.0 /m^2 wall</td><td>\$-2.3/m^2 wall</td><td>-12.8/m^2 wall</td><td>\$-14.7/m^2 wall</td></tr>
<tr><td>R-30 Assembly</td><td colspan="4">R-40 ext. ins. plus R-19 batt</td></tr>
<tr><td>Effective R-30 Premium</td><td>49.4/m^2 wall</td><td>\$46.1/m^2 wall</td><td>\$35.6/m^2 wall</td><td>\$33.7/m^2 wall</td></tr>
<tr><td>Roof Performance</td><td colspan="5">R-20: \$0/m^2 roof
R-40: \$35/m^2 roof
R-60: \$70/m^2 roof</td></tr>
<tr><td>Glazing Performance</td><td colspan="5">Baseline, USI 2.4 to 2.2
USI-2.0: \$17/m^2 window
USI-1.6: \$76/m^2 window
USI-0.8: \$184/m^2 window</td></tr>
<tr><td>Lighting Power Reductions</td><td colspan="5">30% reduction, full LED: \$10/m^2 floor</td></tr>
<tr><td>Mechanical System Type</td><td colspan="5">Baseline: DOAS with fan coil and standard boiler, 50% sensible heat recovery
Option 2: VAV with condensing boiler, 80% enthalpy heat recovery: +\$30/m^2
Option 3: VAV with ASHP, 80% enthalpy heat recovery: + \$80/m^2
Option 4: DOAS with condensing boiler, radiant heating and cooling, 80% enthalpy heat recovery: +\$0/m^2</td></tr>
<tr><td>Base Costs</td><td colspan="5">\$6,000/m^2 floor (\$333/ft^2)</td></tr>
<tr><td>Location Factors</td><td colspan="5">Base and incremental capital costs are multiplied by location factors for each climate zone
Zone 4 – 1
Zone 5 – 0.95
Zone 6 – 1.15
Zone 7 – 1.15</td></tr>
</table>

APPENDIX C: BUILDING ENERGY PERFORMANCE MAP IMAGES

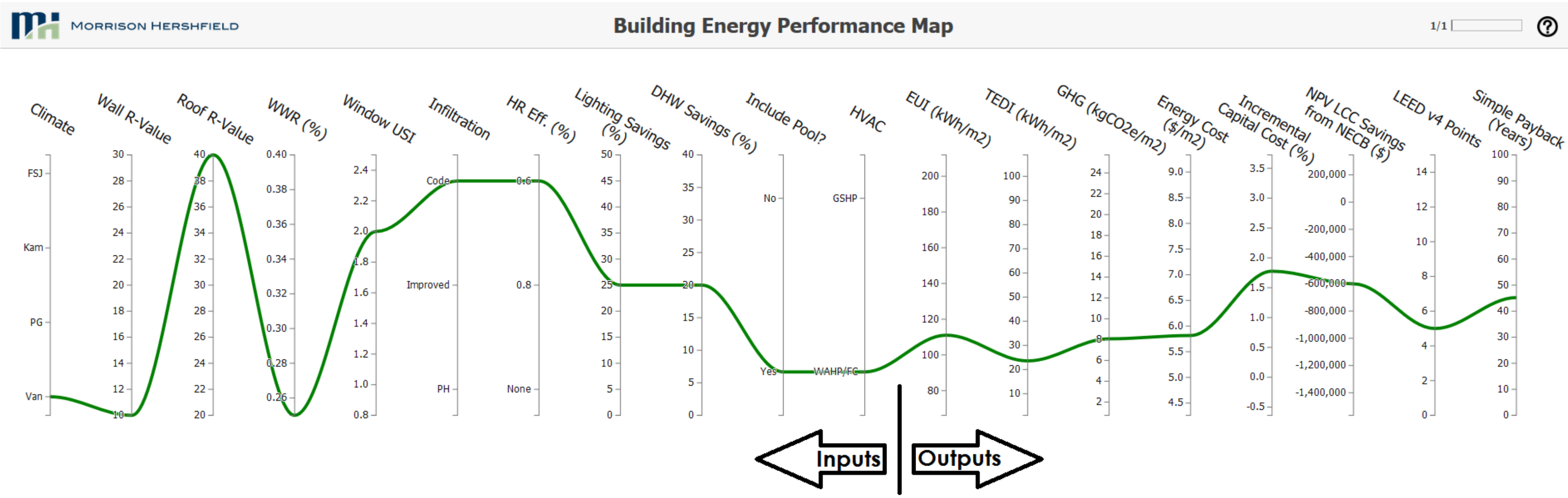

Figure 17.

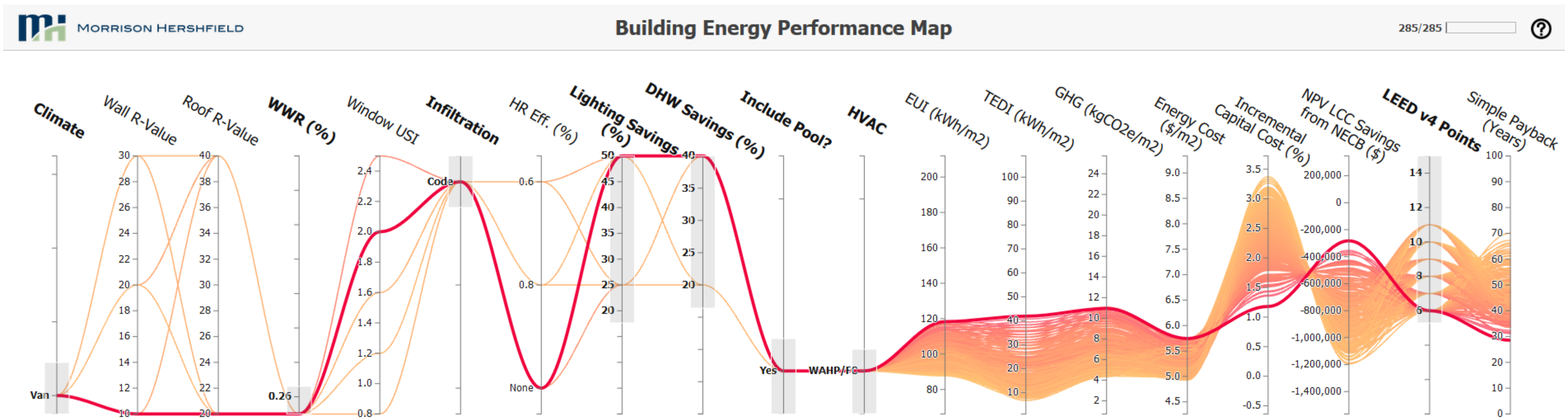

Figure 18.

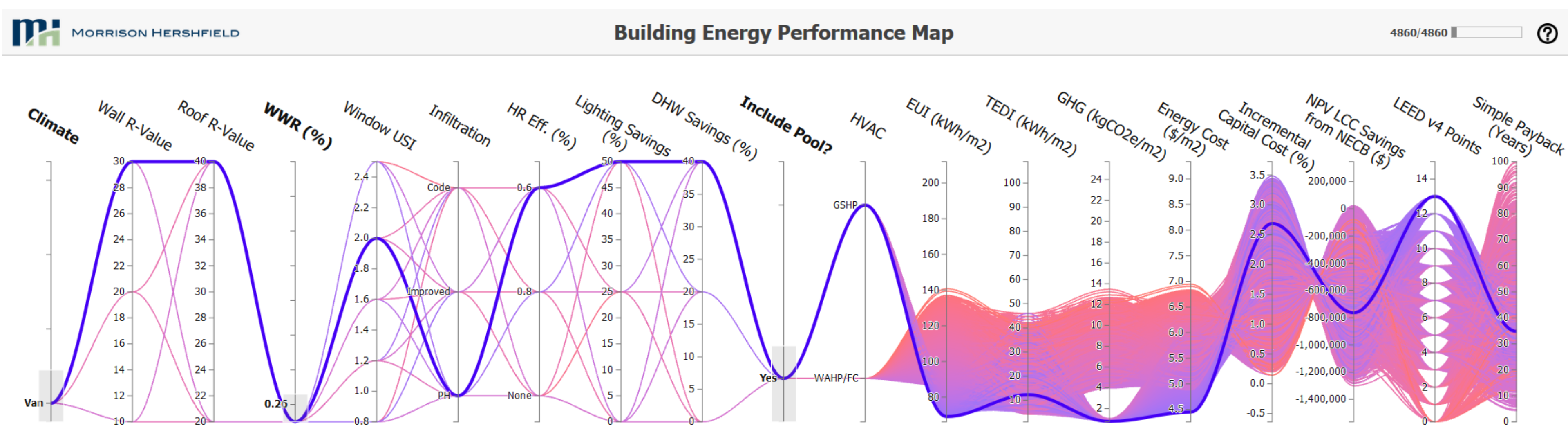

Figure 19.

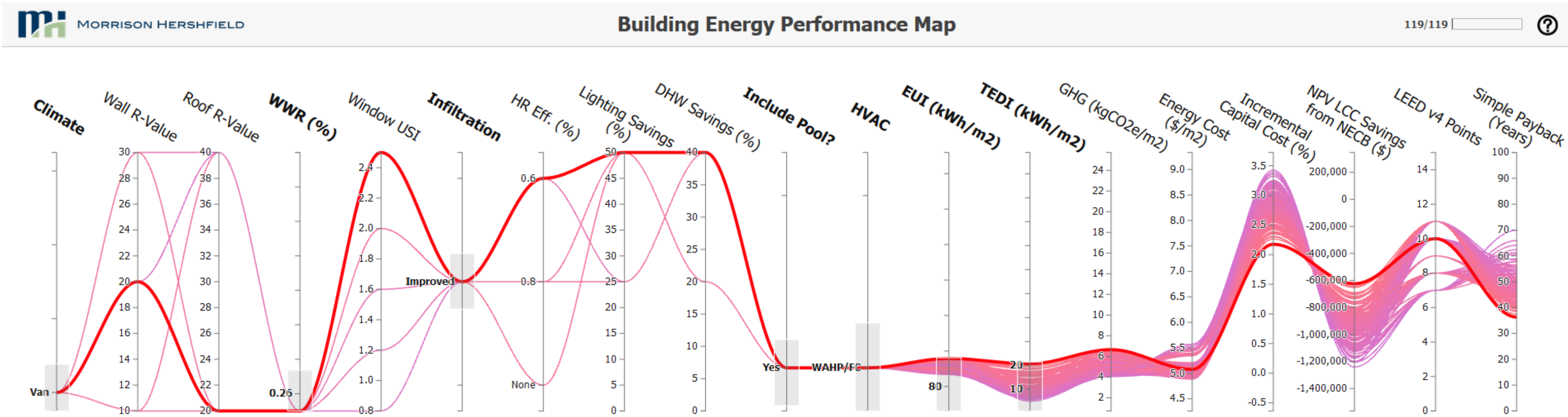

Figure 20.

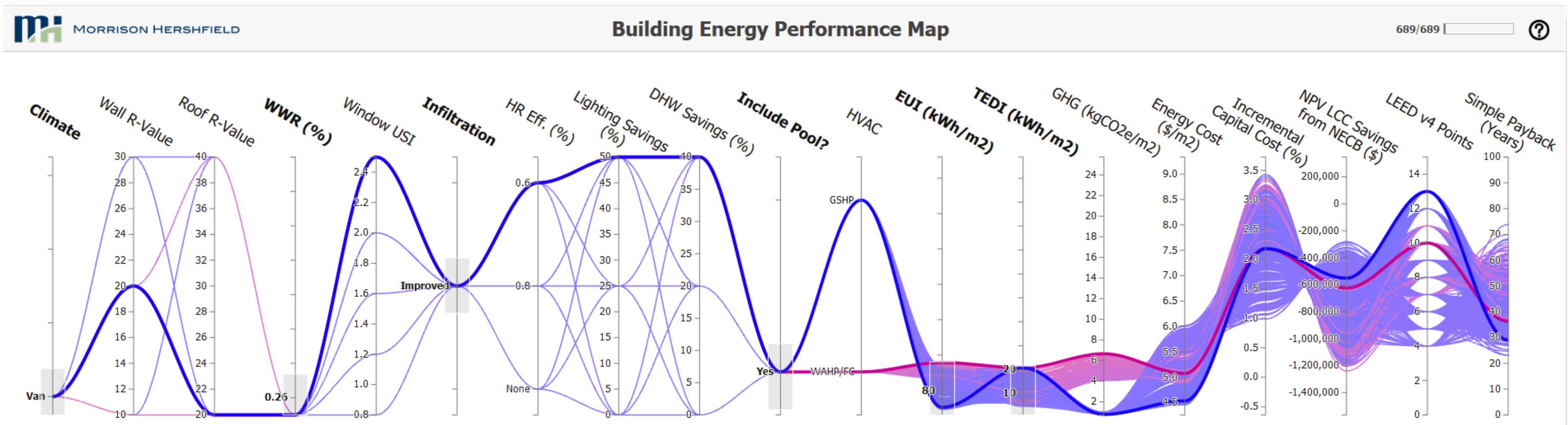

Figure 21.

APPENDIX D: ARCHETYPE OUTCOMES

Table D-1. School Step Outcomes

Climate	Step	HVAC	WWR	Wall R-Value	Roof R-Value	Window USI	Infiltration	Ventilation Savings	Lighting Savings (%)	EUI (kWh/m²)	TEDI (kWh/m²)	GHG ($kgCO_2/m^2$)	Roof PV (kWh/m2)	Electricity (kWh/m2)	Gas (kWh/m2)	Peak Electricity (kW)	NECB Energy Savings (%)	NECB Cost Savings (%)	NECB GHG Savings (%)	Energy Cost ($/m2)	Incremental Capital Cost (%)	NPV LCC Savings from NECB ($)	LEED Cost Savings (%)	LEED v4 Points	Simple Payback (Years)	Savings from ASHRAE 100 (%)
CZ 4	NECB	NECB	40	18	25	2.4	Code	None	0	275.0	100.4	35.3	117.2	89.7	185.3					11.4						-141.5
	LEED	FC	20	10	20	2.5	Code	80% HR with DCV	25	148.9	43.8	15.3	117.2	70.5	78.3	125.3	45.9	23.3	56.7	8.8	1.8	-$61,772	19.9	7.0	28.6	-30.7
	Mid	FC	20	10	40	2.5	Improved	80% HR with DCV	25	130.9	26.1	11.8	117.2	59.8	71.1	124.4	52.4	31.8	66.4	7.8	2.1	-$68,351	28.8	11.0	23.4	-14.9
	Mid	ASHP	20	10	40	2.5	Improved	80% HR with DCV	25	111.0	26.1	6.9	117.2	32.6	78.4	116.9	59.6	40.6	80.5	6.8	2.1	-$28,440	37.9	14.0	18.4	2.5
	Best EUI	ASHP	20	40	40	2	PH	80% HR with DCV	50	98.7	11.8	6.7	117.2	32.5	66.3	98.8	64.1	47.5	80.9	6.0	3.4	-$212,758	45.1	16.0	26.8	13.3
	Best TEDI	ASHP	20	40	40	0.8	PH	80% HR with DCV	0	118.9	6.1	7.0	117.2	32.8	86.2	127.9	56.7	36.2	80.1	7.3	2.1	-$77,032	33.3	13.0	22.4	-4.4
CZ 5	NECB	NECB	40	20.4	31	2.2	Code	None	0	334.1	118.6	44.3	106.7	100.4	233.7					13.6						-187.8
	LEED	FC	20	10	20	2.5	Code	80% HR with DCV	25	177.7	61.4	19.5	106.7	76.9	100.8	145.1	46.8	23.6	56.0	10.4	1.8	$41,941	19.4	7.0	22.0	-53.0
	Mid	FC	20	10	40	2.5	Improved	80% HR with DCV	25	152.3	38.1	14.9	106.7	75.7	76.6	139.1	54.4	33.7	66.5	9.0	2.0	$55,014	30.1	12.0	17.2	-31.2
	Mid	ASHP	20	10	40	2.5	Improved	80% HR with DCV	25	123.8	38.1	7.6	106.7	36.0	87.8	148.6	62.9	44.3	82.8	7.6	2.0	$99,150	41.2	15.0	13.1	-6.7
	Best EUI	ASHP	20	40	40	2.5	PH	80% HR with DCV	50	109.2	22.0	7.3	106.7	35.0	74.2	128.6	67.3	51.1	83.6	6.7	3.2	-$49,032	48.4	17.0	19.1	6.0
	Best TEDI	ASHP	20	40	40	0.8	PH	80% HR with DCV	0	130.8	10.3	7.8	106.7	36.7	94.1	158.1	60.9	41.1	82.4	8.0	2.0	$58,058	37.8	14.0	15.4	-12.6
CZ 6	NECB	NECB	35.2	23	31	2.2	Code	None	0	387.6	161.9	55.8	94.3	91.6	296.0					14.9						-200.1
	LEED	FC	20	10	20	2.5	Code	80% HR with DCV	25	201.6	90.2	24.9	94.3	71.4	130.2	145.9	48.0	22.1	55.4	11.6	1.7	$44,890	19.0	7.0	25.0	-56.1
	Mid	FC	20	10	40	2.5	Improved	80% HR with DCV	25	167.8	59.3	18.7	94.3	96.6	71.2	139.3	56.7	34.4	66.5	9.8	1.9	$66,548	31.8	12.0	18.1	-29.9
	Mid	ASHP	20	10	40	2.5	Improved	80% HR with DCV	25	123.9	59.3	7.4	94.3	34.9	89.0	187.8	68.0	49.2	86.7	7.6	1.9	$119,447	47.2	17.0	12.7	4.1
	Best EUI	ASHP	20	40	40	1.6	PH	80% HR with DCV	50	108.0	30.3	7.1	94.3	33.9	74.1	150.1	72.1	55.9	87.3	6.6	3.4	-$122,554	54.2	18.0	20.3	16.4
	Best TEDI	ASHP	20	40	40	0.8	PH	80% HR with DCV	0	126.6	19.6	7.4	94.3	34.7	91.9	160.1	67.3	48.0	86.7	7.8	1.9	$97,370	45.9	16.0	14.2	2.0
CZ 7a	NECB	NECB	28.3	27	35	2.2	Code	None	0	444.6	197.9	66.6	86.3	90.1	354.6					16.6						-187.9
	LEED	FC	20	10	20	2	Code	80% HR with DCV	25	236.2	119.1	31.1	86.3	72.2	164.0	154.4	46.9	18.7	53.2	13.5	1.7	$70,748	16.9	6.0	26.4	-52.9
	Mid	FC	20	10	40	2.5	Improved	80% HR with DCV	25	196.7	84.1	23.9	86.3	124.9	71.8	149.0	55.8	31.6	64.1	11.4	1.9	$121,364	30.1	12.0	16.9	-27.3
	Mid	ASHP	20	10	40	2.5	Improved	80% HR with DCV	25	134.2	84.1	8.0	86.3	37.3	96.9	206.4	69.8	50.5	88.0	8.2	1.9	$186,776	49.4	17.0	10.6	13.1
	Best EUI	ASHP	20	40	40	0.8	PH	80% HR with DCV	50	113.9	38.3	7.5	86.3	35.9	77.9	157.7	74.4	58.2	88.7	6.9	3.6	-$99,953	57.3	18.0	18.6	26.3
	Best TEDI	ASHP	20	40	40	0.8	PH	80% HR with DCV	0	132.3	32.8	7.8	86.3	36.7	95.5	173.1	70.3	51.2	88.2	8.1	1.9	$188,471	50.1	18.0	11.4	14.4

Table D-2. Library Step Outcomes

Climate	Step	Wall R-Value	Roof R-Value	WWR (%)	Window USI	SHGC	HR Eff. (%)	Infiltration	Lighting Savings (%)	HVAC	EUI (kWh/m2)	TEDI (kWh/m2)	GHG (kgCO2e/m2)	Roof PV (kWh/m²)	Electricity (kWh/m²)	Gas (kWh/m²)	Building Peak Heating (W/m²)	Building Peak Cooling (W/m²)	NECB Energy Savings (%)	NECB Cost Savings (%)	NECB GHG Savings (%)	Energy Cost ($/m²)	Incremental Capital Cost (%)	NPV LCC Savings from NECB ($)	LEED Cost Savings (%)	LEED v4 Points	Simple Payback (Years)	Savings from ASHRAE 100 (%)
CZ 4	NECB	18.0	25.0	40.0	2.4	0.3	None	Code	0.0	NECB	154.7	42.6	13.4	78.0	86.9	67.8						7.7	0.0					20.2
	LEED	10.0	20.0	30	2.0	0.3	0.6	Code	25.0	FC	117.8	44.8	11.0	78.0	62.0	55.8	77.8	51.5	23.8	25.7	18.4	5.7	2.0	-$113,921	22.1	9.0	59.1	39.2
	Mid	10.0	20.0	30	1.6	0.3	0.9	Improved	50.0	FC	91.9	34.5	8.8	78.0	47.4	44.5	70.1	46.7	40.6	42.4	35.1	4.4	2.9	-$157,675	39.6	15.0	52.9	52.6
	Mid	10.0	20.0	30	1.6	0.3	0.9	Improved	50.0	GSHP	59.7	34.5	0.7	78.0	59.6	0.0	70.1	46.7	61.4	49.9	95.1	3.8	2.9	-$151,973	47.5	17.0	45.0	69.2
	Best EUI	30.0	60.0	30	0.8	0.3	0.9	PH	50.0	GSHP	54.1	10.3	0.6	78.0	54.1	0.0	33.2	46.8	65.0	54.5	95.5	3.5	5.1	-$308,926	52.4	18.0	72.0	72.1
	Best TEDI	30.0	60.0	30	0.8	0.3	0.9	PH	0.0	GSHP	85.0	7.2	1.0	78.0	84.9	0.1	28.7	56.9	45.0	28.6	92.9	5.5	3.8	-$259,159	25.2	10.0	100.0	56.1
CZ 5	NECB	20.4	31.0	40.0	2.2	0.3	None	Code	0.0	NECB	181.9	51.1	16.3	71.0	98.9	83.0						8.9	0.0					7.4
	LEED	10.0	20.0	30	2.0	0.3	0.6	Code	25.0	FC	141.0	57.6	14.2	71.0	68.1	72.9	130.3	68.4	22.5	25.7	13.5	6.6	1.9	-$95,281	21.9	8.0	47.2	28.2
	Mid	20.0	20.0	30	2.0	0.3	0.9	Improved	50.0	FC	105.3	43.1	10.5	71.0	51.8	53.6	113.9	58.5	42.1	44.2	36.3	5.0	3.0	-$134,988	41.3	15.0	42.2	46.4
	Mid	20.0	20.0	30	2.0	0.3	0.9	Improved	50.0	GSHP	66.8	43.1	1.0	71.0	65.5	1.3	113.9	58.5	63.3	52.2	94.2	4.3	3.0	-$127,590	49.7	17.0	35.7	66.0
	Best EUI	30.0	60.0	30	0.8	0.3	0.9	PH	50.0	GSHP	59.4	14.3	0.8	71.0	58.4	1.0	73.7	53.1	67.4	57.4	94.9	3.8	5.1	-$267,428	55.3	18.0	55.4	69.8
	Best TEDI	30.0	60.0	30	0.8	0.3	0.9	PH	0.0	GSHP	90.9	10.6	1.3	71.0	89.1	1.8	68.1	63.1	50.0	34.9	92.0	5.8	3.8	-$222,724	31.6	12.0	68.2	53.7
CZ 6	NECB	23.0	31.0	35.2	2.2	0.3	None	Code	0.0	NECB	199.0	71.2	21.1	62.8	89.1	109.8						9.1	0.0					13.2
	LEED	10.0	20.0	30	2.0	0.3	0.6	Code	25.0	FC	159.6	81.3	18.4	62.8	64.2	95.4	149.2	54.0	19.7	22.5	13.8	7.0	1.8	-$122,840	20.4	8.0	60.9	30.3
	Mid	20.0	20.0	30	2.0	0.3	0.9	Improved	50.0	FC	122.0	63.7	14.0	62.8	49.4	72.6	138.0	46.9	38.7	40.6	34.4	5.4	2.9	-$178,670	39.0	15.0	52.6	46.8
	Mid	20.0	20.0	30	2.0	0.3	0.9	Improved	50.0	GSHP	68.6	63.7	0.9	62.8	68.0	0.6	138.0	46.9	65.5	51.6	95.9	4.4	2.9	-$168,546	50.3	18.0	41.4	70.1
	Best EUI	30.0	60.0	30	0.8	0.3	0.9	PH	50.0	GSHP	57.2	24.0	0.7	62.8	56.6	0.6	90.1	47.0	71.2	59.7	96.6	3.7	5.0	-$333,870	58.6	18.0	62.0	75.0
	Best TEDI	30.0	60.0	30	0.8	0.3	0.9	PH	0.0	GSHP	87.5	18.9	1.3	62.8	85.6	1.9	83.2	57.2	56.0	38.7	93.9	5.6	3.7	-$267,627	37.0	14.0	71.2	61.8
CZ 7a	NECB	27.0	35.0	28.3	2.2	0.3	None	Code	0.0	NECB	235.2	95.9	28.0	57.4	87.2	148.0						10.1	0.0					13.0
	LEED	10.0	20.0	30	2.0	0.3	0.6	Code	25.0	FC	200.6	109.4	25.0	57.4	69.9	130.7	178.3	60.9	14.7	16.1	12.0	8.5	1.8	-$131,171	16.1	6.0	75.0	25.8
	Mid	20.0	20.0	30	2.0	0.3	0.9	Improved	25.0	FC	154.0	76.2	16.3	57.4	69.9	84.0	144.7	57.9	34.5	30.2	42.4	7.1	2.6	-$171,314	30.2	12.0	56.4	43.0
	Mid	20.0	20.0	30	2.0	0.3	0.9	Improved	25.0	GSHP	91.1	76.2	1.6	57.4	87.3	3.7	144.7	57.9	61.3	43.3	94.2	5.7	2.6	-$155,152	43.3	16.0	39.3	66.3
	Best EUI	30.0	60.0	30	0.8	0.3	0.9	PH	50.0	GSHP	61.6	31.8	0.9	57.4	60.1	1.5	100.6	51.5	73.8	61.3	96.7	3.9	5.0	-$321,278	61.3	18.0	53.9	77.2
	Best TEDI	30.0	60.0	30	0.8	0.3	0.9	PH	0.0	GSHP	92.4	25.8	1.6	57.4	89.0	3.4	94.1	61.4	60.7	42.4	94.3	5.8	3.7	-$255,158	42.4	16.0	57.9	65.8

Table D-3. College Step Outcomes with Labs

Climate	Step	Wall R-Value	Roof R-Value	WWR (%)	Window USI	HR Eff. (%)	Infiltration	Lighting Savings (%)	HVAC	Include Labs?	EUI (kWh/m2)	TEDI (kWh/m2)	GHG (kgCO2e/m2)	Roof PV (kWh/m²)	Electricity (kWh/m²)	Gas (kWh/m²)	Building Peak Heating (W/m²)	Building Peak Cooling (W/m²)	NECB Energy Savings (%)	NECB Cost Savings (%)	NECB GHG Savings (%)	Energy Cost ($/m²)	Incremental Capital Cost (%)	NPV LCC Savings from NECB ($)	LEED Cost Savings (%)	LEED v4 Points	Simple Payback (Years)
CZ 4	NECB	18.0	25.0	40.0	2.4	50 Lab, General	Code	0.0	NECB	Yes	489.4	141.9	44.3	34.5	265.5	223.9						23.9	0.0				
	LEED w HR	10.0	20.0	40.0	2.0	0.6	Code	25.0	Boiler/Chiller	Yes	214.7	34.8	10.4	34.5	168.7	46.1	52.3	32.2	56.1	48.7	76.6	12.3	2.5	$1,036,289	45.0	16.0	10.0
	LEED	10.0	20.0	40.0	2.0	None	Code	25.0	Boiler/Chiller	Yes	289.5	108.1	24.4	34.5	167.8	121.7	87.5	32.8	40.8	39.3	45.1	14.5	1.6	$1,255,654	34.9	13.0	8.0
	Mid	10.0	20.0	40.0	2.0	0.6	Improved	25.0	Boiler/Chiller	Yes	211.9	32.0	9.8	34.5	168.7	43.2	50.4	32.4	56.7	49.1	77.8	12.2	2.5	$1,025,170	45.4	16.0	10.1
	Mid	10.0	20.0	40.0	2.0	0.6	Improved	25.0	GSHP	Yes	181.8	32.0	2.0	34.5	181.8	0.0	50.4	32.4	62.9	51.1	95.5	11.7	2.5	$1,057,056	47.5	17.0	9.7
	Best EUI	20.0	20.0	40.0	2.0	0.8	Improved	50.0	GSHP	Yes	162.2	14.8	1.8	34.5	162.2	0.0	39.4	29.7	66.9	56.4	96.0	10.4	3.8	$403,805	53.2	18.0	13.4
	Best TEDI	30.0	60.0	40.0	0.8	0.8	PH	0.0	GSHP	Yes	201.8	1.1	2.2	34.5	201.8	0.0	18.2	40.9	58.8	45.7	95.0	13.0	3.8	-$370,049	41.7	15.0	16.5
CZ 5	NECB	20.4	31.0	40.0	2.2	50 Lab, General	Code	0.0	NECB	Yes	536.9	173.9	49.3	31.4	287.7	249.2						26.1	0.0				
	LEED w HR	10.0	20.0	40.0	2.0	0.6	Code	25.0	Boiler/Chiller	Yes	235.6	55.2	13.4	31.4	173.7	61.9	113.5	49.4	56.1	50.0	72.9	13.1	2.6	$1,470,167	46.3	17.0	8.8
	LEED	10.0	20.0	40.0	2.0	None	Code	25.0	Boiler/Chiller	Yes	316.8	133.9	29.3	31.4	168.5	148.3	175.0	68.6	41.0	41.2	40.6	15.4	1.6	$1,704,766	36.9	14.0	6.8
	Mid	10.0	20.0	40.0	2.0	0.6	Improved	25.0	Boiler/Chiller	Yes	231.8	51.4	12.6	31.4	173.8	58.0	111.7	48.9	56.8	50.4	74.3	13.0	2.6	$1,465,928	46.8	17.0	8.9
	Mid	10.0	20.0	40.0	2.0	0.6	Improved	25.0	GSHP	Yes	189.7	51.4	2.1	31.4	189.7	0.0	111.7	48.9	64.7	53.3	95.8	12.2	2.6	$1,539,743	49.8	17.0	8.4
	Best EUI	30.0	60.0	40.0	1.6	0.8	PH	50.0	GSHP	Yes	166.5	20.5	1.8	31.4	166.5	0.0	85.6	38.4	69.0	59.0	96.3	10.7	5.1	$74,324	56.0	18.0	15.0
	Best TEDI	30.0	60.0	40.0	0.8	0.8	PH	0.0	GSHP	Yes	203.5	8.9	2.2	31.4	203.5	0.0	72.0	47.2	62.1	49.9	95.5	13.1	4.0	$236,553	46.2	17.0	13.7
CZ 6	NECB	23.0	31.0	35.2	2.2	50 Lab, General, Lecture	Code	0.0	NECB	Yes	557.5	212.5	53.6	27.8	284.5	273.0						26.6	0.0				
	LEED w HR	10.0	20.0	40.0	2.0	0.6	Code	25.0	Boiler/Chiller	Yes	256.9	81.8	16.9	27.8	176.1	80.9	131.5	34.2	53.9	48.2	68.5	13.8	2.0	$1,458,162	46.9	17.0	8.7
	LEED	10.0	20.0	40.0	2.0	None	Code	25.0	Boiler/Chiller	Yes	360.1	182.1	38.4	27.8	162.2	197.9	190.7	38.6	35.4	38.1	28.4	16.5	1.3	$1,657,987	36.5	14.0	6.8
	Mid	10.0	20.0	40.0	2.0	0.6	Improved	25.0	Boiler/Chiller	Yes	253.3	78.3	16.2	27.8	176.1	77.2	131.3	34.3	54.6	48.6	69.7	13.7	2.1	$1,453,477	47.3	17.0	8.7
	Mid	10.0	20.0	40.0	2.0	0.6	Improved	25.0	GSHP	Yes	190.1	78.3	2.1	27.8	190.1	0.0	131.3	34.3	65.9	54.1	96.1	12.2	2.1	$1,694,043	52.9	18.0	7.8
	Best EUI	30.0	40.0	40.0	0.8	0.8	PH	50.0	GSHP	Yes	164.0	28.2	1.8	27.8	164.0	0.0	99.2	33.6	70.6	60.4	96.6	10.6	4.5	-$24,653	59.4	18.0	15.3
	Best TEDI	30.0	60.0	40.0	0.8	0.8	PH	0.0	GSHP	Yes	198.9	19.9	2.2	27.8	198.9	0.0	92.7	39.9	64.3	52.0	95.9	12.8	3.2	$489,486	50.7	18.0	12.6
CZ 7a	NECB	27.0	35.0	28.3	2.2	50 Lab, General, Lecture	Code	0.0	NECB	Yes	621.6	274.1	57.6	25.4	329.8	291.9						30.1	0.0				
	LEED w HR	10.0	20.0	40.0	2.0	0.6	Code	25.0	Boiler/Chiller	Yes	296.7	121.8	21.0	25.4	194.5	102.2	144.9	38.1	52.3	48.1	63.5	15.6	2.0	$1,984,884	46.9	17.0	7.6
	LEED	10.0	20.0	40.0	2.0	None	Code	25.0	Boiler/Chiller	Yes	408.9	230.0	47.5	25.4	161.6	247.3	201.3	41.6	34.2	40.4	17.5	18.0	1.3	$2,372,586	39.1	15.0	5.6
	Mid	10.0	20.0	40.0	2.0	0.6	Improved	25.0	Boiler/Chiller	Yes	287.7	112.9	19.4	25.4	194.6	93.1	134.7	38.2	53.7	49.0	66.4	15.4	2.1	$2,015,205	47.9	17.0	7.6
	Mid	10.0	20.0	40.0	2.0	0.6	Improved	25.0	GSHP	Yes	200.8	112.9	2.2	25.4	200.8	0.0	134.7	38.2	67.7	57.1	96.2	12.9	2.1	$2,517,209	56.2	18.0	6.5
	Best EUI	30.0	60.0	40.0	0.8	0.8	PH	50.0	GSHP	Yes	170.3	49.6	1.9	25.4	170.3	0.0	95.8	36.8	72.6	63.6	96.7	11.0	4.7	$693,588	62.8	18.0	13.4
	Best TEDI	30.0	60.0	40.0	0.8	0.8	PH	0.0	GSHP	Yes	204.6	42.7	2.3	25.4	204.6	0.0	89.4	42.9	67.1	56.3	96.1	13.2	3.2	$1,409,768	55.3	18.0	10.2

Table D-4. College Step Outcomes without Labs

Climate	Step	Wall R-Value	Roof R-Value	WWR (%)	Window USI	HR Eff. (%)	Infiltration	Lighting Savings (%)	HVAC	Include Labs?	EUI (kWh/m2)	TEDI (kWh/m2)	GHG (kgCO2e/m2)	Roof PV (kWh/m²)	Electricity (kWh/m²)	Gas (kWh/m²)	Building Peak Heating (W/m²)	Building Peak Cooling (W/m²)	NECB Energy Savings (%)	NECB Cost Savings (%)	NECB GHG Savings (%)	Energy Cost ($/m²)	Incremental Capital Cost (%)	NPV LCC Savings from NECB ($)	LEED Cost Savings (%)	LEED v4 Points	Simple Payback (Years)	Savings from ASHRAE 100 (%)
CZ 4	NECB	18.0	25.0	40.0	2.4	50 Lab, General	Code	0.0	NECB	No	232.3	21.2	14.3	34.5	165.1	67.2						12.7	0.0					
	LEED w HR	10.0	20.0	40.0	2.0	0.6	Code	25.0	Boiler/Chiller	No	161.4	13.9	6.8	34.5	132.2	29.1	25.5	23.3	30.5	25.8	52.0	9.4	2.0	-$529,738	23.5	9.0	28.6	20.9
	LEED	10.0	20.0	40.0	2.0	None	Code	25.0	Boiler/Chiller	No	166.4	18.8	7.8	34.5	132.2	34.2	26.3	23.3	28.4	24.6	45.4	9.6	1.7	-$412,053	22.3	9.0	26.1	18.4
	Mid	10.0	20.0	40.0	2.0	0.8	Improved	50.0	Boiler/Chiller	No	145.6	14.7	6.8	34.5	115.6	30.0	26.3	21.9	37.3	34.1	52.2	8.4	2.7	-$680,613	32.0	12.0	29.1	28.6
	Mid	10.0	20.0	40.0	2.0	0.8	Improved	50.0	GSHP	No	130.6	14.7	1.4	34.5	130.6	0.0	26.3	21.9	43.8	33.7	89.9	8.4	2.7	-$746,512	31.6	12.0	29.5	35.9
	Best EUI	30.0	40.0	40.0	1.6	0.8	Improved	50.0	GSHP	No	128.4	5.1	1.4	34.5	128.4	0.0	17.7	26.2	44.7	34.8	90.1	8.3	4.3	-$1,618,400	32.7	13.0	46.1	37.0
	Best TEDI	30.0	60.0	40.0	0.8	0.8	PH	25.0	GSHP	No	148.0	0.1	1.6	34.5	148.0	0.0	5.3	32.1	36.3	24.9	88.6	9.5	5.1	-$2,344,495	22.5	9.0	77.1	27.4
CZ 5	NECB	20.4	31.0	40.0	2.2	50 Lab, General	Code	0.0	NECB	No	250.4	32.7	17.0	31.4	168.8	81.7						13.4	0.0					-21.8
	LEED w HR	10.0	20.0	40.0	2.0	0.6	Code	25.0	Boiler/Chiller	No	171.8	26.5	9.1	31.4	130.1	41.7	44.0	26.8	31.4	27.8	46.1	9.6	2.0	-$409,428	27.2	11.0	24.5	16.4
	LEED	10.0	20.0	40.0	2.0	None	Code	25.0	Boiler/Chiller	No	177.8	32.3	10.3	31.4	129.7	48.1	45.2	30.3	29.0	26.5	39.2	9.8	1.8	-$292,378	25.9	10.0	22.2	13.5
	Mid	20.0	20.0	40.0	2.0	0.6	Improved	25.0	Boiler/Chiller	No	162.8	18.3	7.5	31.4	129.7	33.1	36.5	27.5	35.0	29.9	55.6	9.4	2.5	-$629,521	29.4	12.0	28.5	20.8
	Mid	20.0	20.0	40.0	2.0	0.6	Improved	25.0	GSHP	No	148.4	18.3	1.6	31.4	148.4	0.0	36.5	27.5	40.8	28.5	90.4	9.6	2.5	-$730,490	27.9	11.0	29.9	27.8
	Best EUI	30.0	60.0	40.0	1.6	0.8	PH	50.0	GSHP	No	129.4	10.3	1.4	31.4	129.4	0.0	27.9	27.6	48.3	37.6	91.6	8.3	4.9	-$1,701,803	37.1	14.0	43.7	37.0
	Best TEDI	30.0	60.0	40.0	0.8	0.8	PH	0.0	GSHP	No	164.8	1.1	1.8	31.4	164.8	0.0	16.8	33.0	34.2	20.6	89.3	10.6	4.0	-$1,723,853	19.9	7.0	65.5	19.8
CZ 6	NECB	23.0	31.0	35.2	35.2	50 Lab, General, Lecture	Code	0.0	NECB	No	251.0	42.8	18.9	27.8	158.2	92.9	41.5	24.0				13.0	0.0					-2.5
	LEED w HR	10.0	20.0	40.0	2.0	0.6	Code	25.0	Boiler/Chiller	No	182.1	40.7	11.6	27.8	126.7	55.4	46.3	19.0	27.5	24.3	38.5	9.8	1.6	-$453,856	24.4	10.0	26.9	25.7
	LEED	10.0	20.0	40.0	2.0	None	Code	25.0	Boiler/Chiller	No	189.7	48.3	13.3	27.8	125.2	64.6	48.5	20.0	24.4	22.9	29.6	10.0	1.3	-$334,791	23.0	9.0	24.5	22.6
	Mid	10.0	20.0	40.0	2.0	0.8	Improved	25.0	GSHP	No	148.9	34.9	1.6	27.8	148.9	0.0	44.8	19.2	40.7	26.3	91.3	9.6	1.7	-$613,577	26.4	11.0	27.7	39.2
	Mid	10.0	20.0	40.0	2.0	0.8	Improved	25.0	Boiler/Chiller	No	176.3	34.9	10.5	27.8	126.8	49.4	44.8	19.2	29.8	25.7	44.3	9.7	1.7	-$540,772	25.7	10.0	28.4	28.1
	Best EUI	30.0	60.0	40.0	0.8	0.8	PH	50.0	GSHP	No	125.2	8.7	1.4	27.8	125.2	0.0	23.9	24.4	50.1	38.1	92.7	8.1	4.7	-$2,172,939	38.1	15.0	51.9	48.9
	Best TEDI	30.0	60.0	40.0	0.8	0.8	PH	0.0	GSHP	No	159.1	4.0	1.8	27.8	159.1	0.0	20.3	26.9	36.6	21.3	90.7	10.2	3.2	-$1,673,300	21.3	8.0	62.8	35.0
CZ 7a	NECB	27.0	35.0	28.3	2.2	50 Lab, General, Lecture	Code	0.0	NECB	No	272.0	59.8	22.0	25.4	162.9	109.0	47.0	33.0				13.8	0.0					13.0
	LEED w HR	10.0	20.0	40.0	2.0	0.6	Code	25.0	Boiler/Chiller	No	203.7	62.3	15.4	25.4	128.2	75.5	63.6	22.6	25.1	23.6	30.0	10.6	1.5	-$414,855	23.1	9.0	25.8	34.8
	LEED	10.0	20.0	40.0	2.0	None	Code	25.0	Boiler/Chiller	No	212.4	70.8	17.6	25.4	124.6	87.8	71.5	23.4	21.9	22.6	19.8	10.7	1.3	-$282,005	22.1	9.0	23.1	32.0
	Mid	20.0	20.0	40.0	2.0	0.6	Improved	25.0	Boiler/Chiller	No	185.4	45.1	12.0	25.4	128.3	57.1	51.3	22.6	31.8	27.6	45.5	10.0	2.0	-$597,308	27.1	11.0	28.1	40.7
	Mid	20.0	20.0	40.0	2.0	0.6	Improved	25.0	GSHP	No	151.7	45.1	1.7	25.4	151.7	0.0	51.3	22.6	44.2	29.3	92.4	9.8	2.0	-$651,293	28.9	11.0	26.4	51.5
	Best EUI	30.0	60.0	40.0	0.8	0.8	PH	50.0	GSHP	No	127.7	13.4	1.4	25.4	127.7	0.0	24.5	25.5	53.0	40.5	93.6	8.2	4.7	-$2,055,494	40.1	15.0	45.8	59.1
	Best TEDI	30.0	60.0	40.0	0.8	0.8	PH	0.0	GSHP	No	161.2	8.3	1.8	25.4	161.2	0.0	20.8	28.3	40.7	24.9	91.9	10.4	3.2	-$1,549,536	24.4	10.0	50.4	48.4

Table D-5. Rec Centre Step Outcomes without Pools

Climate	Step	Wall R-Value	Roof R-Value	WWR (%)	Window USI	SHGC	Infiltration	HR Eff. (%)	Lighting Savings (%)	DHW Savings	Plant	EUI (kWh/m2)	TEDI (kWh/m2)	GHG (kgCO2e/m2)	Roof PV (kWh/m²)	Electricity (kWh/m²)	Gas (kWh/m²)	Building Peak Heating (W/m²)	Building Peak Cooling (W/m²)	NECB Energy Savings (%)	NECB Cost Savings (%)	NECB GHG Savings (%)	Energy Cost ($/m²)	Incremental Capital Cost (%)	NPV LCC Savings from NECB ($)	LEED Cost Savings (%)	LEED v4 Points	Simple Payback (Years)	Savings from ASHRAE 100 (%)
CZ 4	NECB	18.0	25.0	40.0	2.4	0.3	Code	None	0.0	0.0	NECB	238.1	53.1	25.0	70.2	109.6	128.5						11.0	0.0					-184.7
	LEED	10.0	20.0	0.3	2.0	0.3	Code	0.6	25.0	20.0	Boiler/Chiller	131.3	14.5	8.8	70.2	88.7	42.5	89.3	42.8	44.9	36.2	64.6	7.0	1.6	-$276,641	35.2	14.0	21.4	-57.0
	Mid	10.0	20.0	0.3	1.6	0.3	Improved	0.9	50.0	20.0	Boiler/Chiller	105.4	10.8	7.9	70.2	66.8	38.7	84.1	41.9	55.7	50.1	68.4	5.5	2.3	-$377,626	49.4	17.0	22.6	-26.1
	Mid	10.0	20.0	0.3	1.6	0.3	Improved	0.9	50.0	20.0	ASHP	75.0	10.8	0.8	70.2	74.9	0.0	84.1	41.9	68.5	56.1	96.7	4.8	2.3	-$319,823	55.4	18.0	20.2	10.3
	Best EUI	20.0	40.0	0.3	2.0	0.3	PH	0.9	50.0	40.0	ASHP	73.6	6.6	0.8	70.2	73.5	0.0	76.4	41.7	69.1	56.9	96.7	4.7	3.0	-$606,319	56.2	18.0	25.6	12.0
	Best TEDI	30.0	60.0	0.3	0.8	0.3	PH	0.9	25.0	40.0	ASHP	101.9	0.7	1.1	70.2	101.7	0.1	56.9	41.1	57.2	40.3	95.4	6.6	4.1	-$1,387,146	39.4	15.0	49.6	-21.8
CZ 5	NECB	20.4	31.0	40.0	2.2	0.3	Code	None	0.0	0.0	NECB	266.9	68.1	28.9	63.9	117.4	149.4						12.1	0.0					-205.0
	LEED	10.0	20.0	0.3	2.0	0.3	Code	0.6	25.0	20.0	Boiler/Chiller	146.9	24.7	10.3	63.9	97.0	50.0	110.7	59.1	44.9	35.9	64.4	7.8	1.6	-$181,339	34.9	13.0	18.1	-67.9
	Mid	10.0	20.0	0.3	2.0	0.3	Improved	0.9	50.0	20.0	Boiler/Chiller	119.4	20.0	9.2	63.9	74.3	45.1	95.9	47.4	55.3	49.2	68.3	6.2	2.1	-$151,616	48.4	17.0	17.4	-36.4
	Mid	10.0	20.0	0.3	2.0	0.3	Improved	0.9	50.0	20.0	ASHP	87.8	20.0	1.0	63.9	87.8	0.0	95.9	47.4	67.1	53.4	96.6	5.7	2.1	-$125,260	52.6	18.0	16.0	-0.4
	Best EUI	30.0	60.0	0.3	2.0	0.3	PH	0.9	50.0	40.0	ASHP	84.6	9.8	0.9	63.9	84.5	0.1	78.3	46.3	68.3	55.1	96.8	5.4	3.7	-$806,002	54.4	18.0	28.2	3.3
	Best TEDI	30.0	60.0	0.3	0.8	0.3	PH	0.9	25.0	40.0	ASHP	112.4	4.1	1.3	63.9	112.3	0.1	59.6	50.1	57.9	40.4	95.7	7.2	4.1	-$1,232,705	39.4	15.0	42.2	-28.4
CZ 6	NECB	23.0	31.0	35.2	2.2	0.3	Code	None	0.0	0.0	NECB	299.2	94.7	36.0	56.5	111.3	187.9						12.9	0.0					-202.6
	LEED	10.0	20.0	0.3	2.0	0.3	Code	0.6	25.0	20.0	Boiler/Chiller	157.8	40.2	12.4	56.5	96.6	61.2	118.2	43.7	47.3	37.3	65.6	8.1	1.5	-$239,077	36.7	14.0	18.6	-59.5
	Mid	10.0	20.0	0.3	2.0	0.3	Improved	0.9	50.0	20.0	Boiler/Chiller	129.2	33.7	10.9	56.5	74.7	54.5	109.5	40.3	56.8	49.8	69.7	6.5	2.0	-$256,210	49.3	17.0	18.7	-30.7
	Mid	10.0	20.0	0.3	2.0	0.3	Improved	0.9	50.0	20.0	ASHP	87.3	33.7	1.0	56.5	87.2	0.1	109.5	40.3	70.8	56.5	97.3	5.6	2.0	-$187,969	56.1	18.0	16.5	11.7
	Best EUI	30.0	60.0	0.3	2.0	0.3	PH	0.9	50.0	40.0	ASHP	82.9	18.4	0.9	56.5	82.9	0.0	81.1	40.0	72.3	58.6	97.4	5.3	3.7	-$1,008,199	58.2	18.0	29.4	16.1
	Best TEDI	30.0	60.0	0.3	0.8	0.3	PH	0.9	25.0	40.0	ASHP	108.6	9.7	1.2	56.5	108.5	0.1	65.3	40.9	63.7	45.9	96.6	7.0	4.0	-$1,445,926	45.3	16.0	41.3	-9.8
CZ 7a	NECB	27.0	35.0	28.3	2.2	0.3	Code	None	0.0	0.0	NECB	331.7	119.5	42.1	51.7	110.5	221.2						13.9	0.0					-184.3
	LEED	10.0	20.0	0.3	2.0	0.3	Code	0.6	25.0	20.0	Boiler/Chiller	178.9	60.9	14.4	51.7	107.2	71.7	121.3	49.4	46.1	34.4	65.7	9.1	1.5	-$266,311	34.5	13.0	18.5	-53.4
	Mid	10.0	20.0	0.3	1.6	0.3	Improved	0.9	50.0	20.0	Boiler/Chiller	143.7	47.9	11.7	51.7	85.4	58.4	110.7	45.5	56.7	47.5	72.1	7.3	2.2	-$386,289	47.5	17.0	20.3	-23.2
	Mid	10.0	20.0	0.3	1.6	0.3	Improved	0.9	50.0	20.0	ASHP	101.6	47.9	1.2	51.7	101.2	0.4	110.7	45.5	69.4	53.0	97.2	6.5	2.2	-$339,069	53.0	18.0	18.2	12.9
	Best EUI	30.0	60.0	0.3	1.6	0.3	PH	0.9	50.0	40.0	ASHP	95.4	29.0	1.1	51.7	95.3	0.1	81.2	44.5	71.2	55.7	97.5	6.1	3.9	-$1,143,420	55.7	18.0	30.6	18.2
	Best TEDI	30.0	60.0	0.3	0.8	0.3	PH	0.9	25.0	40.0	ASHP	120.3	21.1	1.3	51.7	120.2	0.1	68.3	50.0	63.7	44.2	96.8	7.7	4.0	-$1,448,856	44.2	16.0	39.7	-3.1

Table D-6. Care Facility Step Outcomes

Climate		Wall R-Value	Roof R-Value	WWR (%)	Window USI	SHGC	Infiltration	HR Eff. (%)	Lighting Savings (%)	DHW Savings (%)	Include Pool?	HVAC	EUI (kWh/m2)	TEDI (kWh/m2)	GHG (kgCO2e/m2)	Roof PV (kWh/m²)	Electricity (kWh/m²)	Gas (kWh/m²)	NECB Energy Savings (%)	NECB Cost Savings (%)	NECB GHG Savings (%)	Energy Cost ($/m²)	Incremental Capital Cost (%)	NPV LCC Savings from NECB ($)	LEED Cost Savings (%)	LEED v4 Points	Simple Payback (Years)	Savings from ASHRAE 100 (%)
CZ 4	NECB	18.0	25.0	40.0	2.4	0.3	Code	None	0.0	0.0	Yes	NECB	165.0	45.6	19.1	21.9	64.6	100.4				7.2	0.0					38.0
	LEED	10.0	20.0	0.3	2.0	0.3	Code	0.6	25.0	40.0	Yes	WAHP/FC	107.5	24.7	7.4	21.9	71.7	35.8	34.9	45.9	61.6	5.7	1.7	-$535,615	16.5	6.0	39.5	59.6
	Mid	20.0	20.0	0.3	2.5	0.3	Improved	0.6	50.0	40.0	Yes	WAHP/FC	95.8	20.7	6.7	21.9	63.6	32.2	41.9	54.7	65.5	5.1	2.2	-$625,156	25.8	10.0	36.3	64.0
	Mid	20.0	20.0	0.3	2.5	0.3	Improved	0.6	50.0	40.0	Yes	GSHP	70.5	20.7	0.8	21.9	70.5	0.0	57.3	54.7	96.0	4.5	2.2	-$552,100	33.7	13.0	29.0	73.5
	Best EUI	30.0	40.0	0.3	2.0	0.3	PH	0.6	50.0	40.0	Yes	GSHP	69.1	12.3	0.8	21.9	69.1	0.0	58.1	73.1	96.1	4.5	2.7	-$764,045	34.9	13.0	34.8	74.0
	Best TEDI	30.0	40.0	0.3	0.8	0.3	PH	0.8	25.0	40.0	Yes	GSHP	82.8	4.6	0.9	21.9	82.8	0.0	49.8	89.9	95.3	5.3	3.3	-$1,232,563	22.0	9.0	62.1	68.9
CZ 5	NECB	20.4	31.0	40.0	2.2	0.3	Code	None	0.0	0.0	Yes	NECB	179.5	53.5	21.0	20.0	68.7	110.8				7.8	0.0					35.5
	LEED	10.0	20.0	0.3	2.5	0.3	Code	0.6	50.0	40.0	Yes	WAHP/FC	121.8	38.6	10.2	20.0	71.1	50.7	32.1	27.8	52.2	6.1	1.7	-$482,052	16.8	6.0	35.4	56.2
	Mid	20.0	20.0	0.3	2.0	0.3	Improved	0.6	50.0	40.0	Yes	WAHP/FC	104.1	23.2	7.1	20.0	69.9	34.3	42.0	56.6	66.6	5.5	2.2	-$585,108	24.7	10.0	33.4	62.6
	Mid	20.0	20.0	0.3	2.0	0.3	Improved	0.6	50.0	40.0	Yes	GSHP	76.5	23.2	0.8	20.0	76.5	0.0	57.4	56.6	96.0	4.9	2.2	-$498,363	33.1	13.0	26.2	72.5
	Best EUI	30.0	40.0	0.3	2.0	0.3	PH	0.8	50.0	40.0	Yes	GSHP	74.6	14.2	0.8	20.0	74.6	0.0	58.4	73.5	96.1	4.8	2.9	-$760,050	34.7	13.0	32.8	73.2
	Best TEDI	30.0	40.0	0.3	0.8	0.3	PH	0.8	0.0	40.0	Yes	GSHP	95.6	6.2	1.1	20.0	95.6	0.0	46.8	88.5	95.1	6.2	2.6	-$926,800	16.4	6.0	52.8	65.7
CZ 6	NECB	23.0	31.0	35.2	2.2	0.3	Code	None	0.0	0.0	Yes	NECB	193.6	67.5	24.4	17.7	63.8	129.8				8.1	0.0					38.4
	LEED	10.0	20.0	0.3	2.5	0.3	Code	0.6	50.0	20.0	Yes	WAHP/FC	135.2	52.1	13.0	17.7	68.8	66.4	30.2	22.8	47.3	6.5	1.6	-$576,973	16.3	6.0	40.4	57.0
	Mid	20.0	20.0	0.3	2.5	0.3	Improved	0.6	50.0	40.0	Yes	WAHP/FC	115.1	38.2	9.5	17.7	67.5	47.6	40.5	43.5	61.4	5.8	2.0	-$701,028	24.8	10.0	37.0	63.4
	Mid	20.0	20.0	0.3	2.5	0.3	Improved	0.6	50.0	40.0	Yes	GSHP	75.6	38.2	0.8	17.7	75.6	0.0	60.9	43.5	96.6	4.9	2.0	-$569,190	36.9	14.0	26.3	75.9
	Best EUI	30.0	40.0	0.3	2.0	0.3	PH	0.8	50.0	40.0	Yes	GSHP	72.1	21.8	0.8	17.7	72.1	0.0	62.8	67.7	96.8	4.6	2.8	-$913,249	39.8	15.0	33.7	77.1
	Best TEDI	30.0	40.0	0.3	0.8	0.3	PH	0.8	0.0	40.0	Yes	GSHP	92.0	10.2	1.0	17.7	92.0	0.0	52.5	84.8	95.9	5.9	2.5	-$1,035,190	23.2	9.0	47.4	70.7
CZ 7a	NECB	27.0	35.0	28.3	2.2	0.3	Code	50 Suites	0.0	0.0	Yes	NECB	190.3	67.2	23.0	16.2	68.6	121.7				8.1	0.0					48.7
	LEED	20.0	20.0	0.3	2.0	0.3	Code	0.6	50.0	40.0	Yes	WAHP/FC	134.6	56.7	12.1	16.2	73.4	61.2	29.3	15.6	47.9	6.6	1.4	-$508,611	17.6	6.0	38.3	63.7
	Mid	30.0	20.0	0.3	1.6	0.3	Improved	0.6	50.0	40.0	Yes	WAHP/FC	115.8	37.9	8.6	16.2	73.7	42.1	39.1	43.7	63.0	6.0	1.9	-$647,076	24.6	10.0	36.7	68.8
	Mid	30.0	20.0	0.3	1.6	0.3	Improved	0.6	50.0	40.0	Yes	GSHP	77.4	37.9	0.9	16.2	77.4	0.0	59.3	43.7	96.3	5.0	1.9	-$476,803	37.7	14.0	24.5	79.1
	Best EUI	30.0	40.0	0.3	1.6	0.3	PH	0.8	50.0	40.0	Yes	GSHP	75.6	26.5	0.8	16.2	75.6	0.0	60.3	60.5	96.4	4.9	2.4	-$699,395	39.2	15.0	29.6	79.6
	Best TEDI	30.0	40.0	0.3	0.8	0.3	PH	0.8	0.0	40.0	Yes	GSHP	95.1	16.6	1.0	16.2	95.1	0.0	50.0	75.3	95.5	6.1	1.8	-$715,109	23.5	9.0	37.4	74.4

Table D-7. Hospital Step Outcomes

Climate		Wall R-Value	Roof R-Value	Window USI	HR Eff. (%)	Lighting Savings (%)	Plant	ACH	HVAC	Infiltration	EUI (kWh/m2)	TEDI (kWh/m2)	GHG (kgCO2e/m2)	Roof PV (kWh/m2)	Electricity (kWh/m2)	Gas (kWh/m2)	Energy Savings NECB (%)	TEDI Savings NECB (%)	GHG Savings from NECB (%)	Energy Cost ($/m2)	Incremental Capital Cost (%)	NPV LCC Savings from Typ. ($)	LEED Cost Savings (%)	LEED v4 Points	Simple Payback (Years)	Savings from ASHRAE 100 (%)
CZ4	NECB	18	25	2.4	50% Sensible	0	NECB Boiler	4 / 4	SZ	Code	404.5	51.2	32.4	28.4	243.6	160.9	0	0	0	21	0	0	0	0	0	10.6
	LEED	10	20	2	80% Enthalpy	30	Cond Boiler	4 / 4	MZ VAV w/ Hydronic Reheat	Code	362.3	77.6	24.1	28.4	246.6	115.7	10.4	-51.6	25.7	18.7	0.1	-4.8	11	5	17.7	19.9
	Mid - ASHP	10	20	2	80% Enthalpy	30	ASHP	4 / 4	MZ VAV w/ Hydronic Reheat	Code	301.9	77.6	8.4	28.4	272.5	29.4	25.4	-51.6	74	18.2	1.4	-51.3	13.4	6	32.4	33.2
	Best - DOAS	20	20	2	80% Enthalpy	30	Cond Boiler	4 / 4	DOAS + Zone Heat & Cool	Code	265.3	10.3	9.2	28.4	229.4	36	34.4	79.8	71.7	15.9	0.2	74	24.3	12	2.1	41.3
	Best EUI	30	20	2	80% Enthalpy	30	Cond Boiler	4 / 4	DOAS + Zone Heat & Cool	PH	260.6	4.9	7.8	28.4	232.4	28.2	35.6	90.5	76.1	15.8	0.5	54.8	24.6	12	5.9	42.4
CZ5	NECB	20.4	31	2.2	50% Sensible	0	NECB Boiler	4 / 4	SZ	Code	525.9	70.8	52.8	25.8	255.8	270.1	0	0	0	25.4	0	0	0	0	0	-20
	LEED	10	20	2	80% Enthalpy	30	Cond Boiler	4 / 4	MZ VAV w/ Hydronic Reheat	Code	372.2	69.9	27.7	25.8	236.3	135.9	29.2	1.3	47.4	18.5	0.6	75.4	27.1	13	5.6	15.1
	Mid - ASHP	10	20	2	80% Enthalpy	30	ASHP	4 / 4	MZ VAV w/ Hydronic Reheat	Code	317.9	69.9	13.6	25.8	259.6	58.3	39.6	1.3	74.2	18.1	1.4	31.1	28.9	13	11.7	27.5
	Best - DOAS	20	20	2	80% Enthalpy	30	Cond Boiler	4 / 4	DOAS + Zone Heat & Cool	Code	299.8	20.2	14.2	25.8	237	62.8	43	71.5	73	17.3	0.2	124.6	32.1	15	1.3	31.6
	Best EUI	30	60	0.8	80% Enthalpy	30	Cond Boiler	4 / 4	DOAS + Zone Heat & Cool	PH	284.6	7.6	11	25.8	239.3	45.3	45.9	89.2	79.1	16.8	0.5	91.4	33.8	15	5.8	35.1
CZ6	NECB	23	31	2.2	50% Sensible	0	NECB Boiler	4 / 4	SZ	Code	561.4	100	61	22.8	246.3	315.1	0	0	0	26.3	0	0	0	0	0	-25.1
	LEED	10	20	2	80% Enthalpy	30	Cond Boiler	4 / 4	MZ VAV w/ Hydronic Reheat	Code	374.4	80	28.5	22.8	234.3	140	33.3	19.9	53.3	18.5	0.6	80.6	29.7	14	6	16.5
	Mid - ASHP	10	20	2	80% Enthalpy	30	ASHP	4 / 4	MZ VAV w/ Hydronic Reheat	Code	312.1	80	12.3	22.8	261	51.1	44.4	19.9	79.8	18	1.4	26.8	31.7	14	12.5	30.4
	Best - DOAS	20	40	2	80% Enthalpy	30	Cond Boiler	4 / 4	DOAS + Zone Heat & Cool	Code	306.5	31.4	17	22.8	228.5	78.1	45.4	68.6	72.2	17.2	0.2	137.3	34.5	15	1.4	31.7
	Best EUI	30	60	0.8	80% Enthalpy	30	Cond Boiler	4 / 4	DOAS + Zone Heat & Cool	PH	285	11.9	12.3	22.8	232.5	52.5	49.2	88.1	79.9	16.6	0.6	102.4	36.8	16	5.8	36.5
CZ7a	NECB	27	35	2.2	50% Sensible	0	NECB Boiler	4 / 4	SZ	Code	639.7	127.6	75.3	20.9	247.7	392	0	0	0	29	0	0	0	0	0	-41.2
	LEED	20	40	2	80% Enthalpy	30	Cond Boiler	4 / 4	MZ VAV w/ Hydronic Reheat	Code	382.3	77	31	20.9	228.5	153.8	40.2	39.7	58.8	18.5	0.7	122.3	36.3	16	4.8	15.6
	Mid - ASHP	20	40	2	80% Enthalpy	30	ASHP	4 / 4	MZ VAV w/ Hydronic Reheat	Code	322.4	77	15.4	20.9	254.1	68.3	49.6	39.7	79.5	18	1.4	68.3	38	17	9.8	28.8
	Best - DOAS	20	40	2	80% Enthalpy	30	Cond Boiler	4 / 4	DOAS + Zone Heat & Cool	Code	322.5	35.9	19.7	20.9	229.6	92.9	49.6	71.9	73.8	17.8	0.2	168	38.6	17	1.4	28.8
	Best EUI	30	60	0.8	80% Enthalpy	30	Cond Boiler	4 / 4	DOAS + Zone Heat & Cool	PH	304	20.6	15.7	20.9	232.9	71.1	52.5	83.8	79.1	17.3	0.7	135.9	40.4	17	4.7	32.9