The Green Engineer
Sustainable Design Consulting

Conceptual Design Belmont Public Library
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CONCEPT PHASE - ZERO NET ENERGY ANALYSIS

BELMONT PUBLIC LIBRARY

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Contents

I. Executive Summary

The purpose of this study is to outline a set of performance goals for the Belmont Public Library project, both to identify potential options for optimizing energy performance and to identify a pathway for achieving a zero net energy (ZNE) building.

To get to ZNE, we must go beyond simply reducing energy consumption. No matter how efficient we make the systems, some energy must be consumed. Once we have reduced loads and consumption, we must generate enough renewable energy to offset the rest. Therefore, the first step to achieve a ZNE building is to design a highly efficient building that has a low site energy consumption and uses no fossil fuels. This makes it a ZNE "ready" building. Once a low site energy consumption target has been set, to get to ZNE, renewable energy generation is implemented either on site or off-site to get to the net zero goal.

The site energy consumption is typically measured as Energy Use Intensity (EUI) in kBTU/SF/year. The lower the EUI the closer the building is to being net zero. The preliminary analysis indicates that this project can achieve an EUI of 27 kBTU/SF by implementing industry standard energy conservation measures beyond those required by the new MA Energy Code (effective January 2020) and by eliminating the use of fossil fuels. If the project pursues aggressive energy conservation measures, the EUI of 23 kBTU/SF is achievable without any renewable energy for a high-performance building.

There is a potential to implement some on-site solar for the project. Based on the available roof area for solar, the building EUI can be reduced by 10.6 kBTU/SF. With an optimized on-site PV system the EUI for Option 2A can 16.4 kTBU/SF. To get to ZNE EUI of 0 kBTU/SF the project will then have to consider off-site PV generation or Renewable Energy Certificates (RECs) to offset net site energy consumption of 16.4 kBTU/SF.

We propose that the target performance goal for the project be between 23 kBTU/SF to 27 kBTU/SF, not including any on-site renewables.

Figure 1: Steps to Zero Net Energy Building

Step 1 Reduce Demand	☑ Improve Envelope ☑ Reduce lighting and plug loads ☑ Right-size HVAC
Step 2 Harvest Site Energy	☑ Daylighting Opportunities ☑ Passive Solar ☑ Harvest "waste" energy through heat recovery and other means
Step 3 Maximize Efficiency	☑ Efficient Equipment ☑ Elimimate Fossil Fuel use
Step 4 O&M	☑ Building Commissioning, staff training, maintenance ☑ Continuous Monitoring of on-going performance
Step 5 Renewable Energy	☑ Implement On-site Solar ☑ Buy RECs or implement off-site solar to get to NZE

This study is based on conceptual design options, preliminary energy analysis, and high level preliminary incremental cost estimates.

II. Preliminary Energy Analysis

A. Design Options

Energy Use Intensity (EUI) is a measure of how much energy a building uses. EUI is expressed as energy use per square foot per year. It is calculated by dividing the total energy consumed by the building in one year (often measured in kBtu) by the total gross floor area of the building. A lower EUI signifies better energy performance. EUI of 0 signifies a Net Zero building, often achieved through a combination of load reduction, energy efficient systems and renewable energy systems.

Discussions were held to identify the potential for improvements beyond a standard library building and to create a list of Energy Conservation Measures (ECMs) for the preliminary energy analysis. In addition, it was recognized that the project will potentially be built under the new MA energy code that goes into effect in January 2020. The new MA energy code is more stringent and requires several additional efficiency options to be included in the design. Based on these discussions, six different design options pertaining to envelope, lighting and HVAC improvements were shortlisted for further analysis. Figure 2 below summarizes the shortlisted ECMs.

- Option 1A: New MA energy code building with conventional HVAC - DX VAV and condensing boilers (VAV)
- Option 1B: Super-insulated envelope with conventional HVAC - DX VAV and condensing boilers (VAV)
- Option 2A: New MA energy code building with all electric HVAC - Variable Refrigerant Flow system (VRF)
- Option 2B: Super-insulated envelope with all electric HVAC - Variable Refrigerant Flow system (VRF)
- Option 3A: MA energy code building with all electric HVAC - Ground Source Heat Pump system (GSHP)
- Option 3B: Super-insulated envelope with all electric HVAC - Ground Source Heat Pump system (GSHP)

Figure 2: Summary of ECMs discussed for preliminary energy analysis

		Envelope Options		LPD Options		HVAC Systems		Renewable Energy	
		New MA Code 20% Better Envelope (*Roofs R-39.2 Walls R-22.7 Glazing R-3.2*)	Super-insulated Envelope (*Roof R-60 Walls R-40 Glazing R-5*)	New MA Code Improved Lighting & Controls (*LPD - 0.62 W/SF*)	40% Better Than MA Code Lighting (*LPD - 0.47 W/SF*)	Conventional System DX VAV Condensing Boilers	All Electric HVAC Sytems	On-site PV on roof	Off-site PV
Convention System DX VAV unit w/ Condensing Boilers	Option 1A	X		X		X		X	
	Option 1B		X		X	X		X	
All Electric VRF Systems	Option 2A	X		X			X	X	X
	Option 2B		X		X		X	X	X
Ground Source Heat Pump	Option 3A	X		X			X	X	X
	Option 3B		X		X		X	X	X

B. Energy Use Analysis

Preliminary energy analysis was performed to estimate annual site energy use, source energy use, greenhouse gas (GHG) emissions, annual energy cost, and site EUI for the six options identified for the project. The results of the energy analysis indicate that:

- **Option 1A** uses fossil fuels, has the highest EUI, and high greenhouse gas emissions.
- **Option 2A** is an all electric design option. It reduces site energy use and greenhouse gas emissions significantly, both important descriptors for ZNE building. This option has an EUI at the upper limit of the target EUI range.
- **Option 2B** option is all electric and has a more stringent envelope and lower lighting power density. It reduces site energy use by 50% and GHG emissions by 41% when compared to option 1A.
- **Options 3B** (all electric GHSP) has the lowest site EUI, site energy use, annual energy cost, and greenhouse gas emissions. This option reduces site energy use by 53% and GHG emissions by 45% when compared to option 1A.
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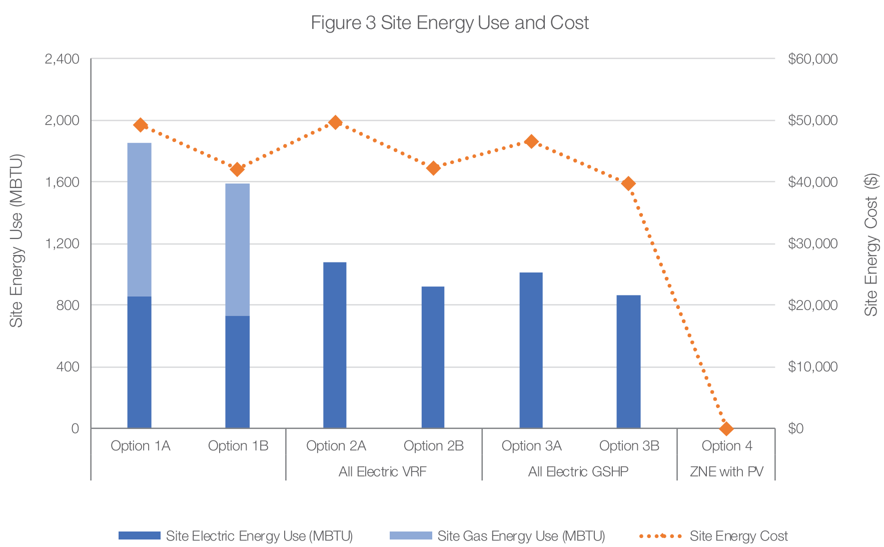


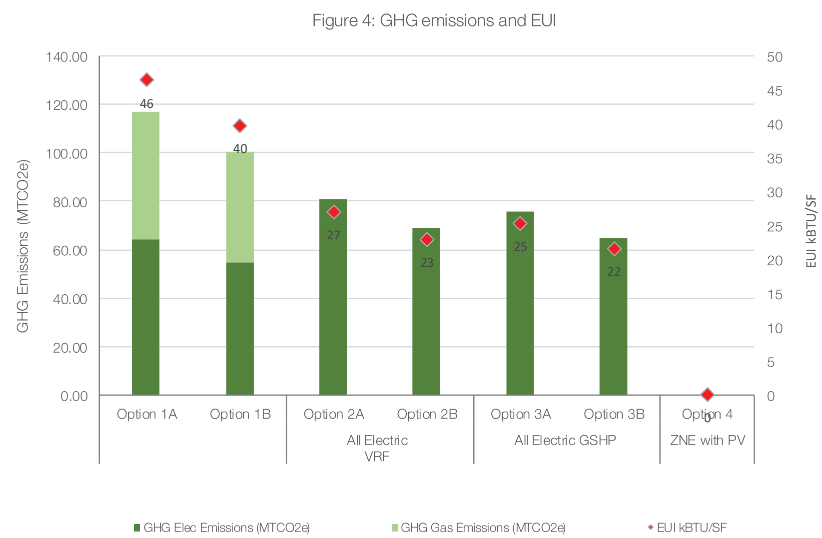


Figure 3 above presents the annual site energy use and annual energy costs for each of the options analyzed. Site energy consumption for Option 2A is 42% lower than Option 1A compliant option. Annual energy costs for Option 1A vs Option 2A are comparable. The annual energy costs are driven by changes to the utility pricing structure.

Figure 4 above presents the GHG emissions and site EUIs for each of the options analyzed. Site energy consumption for Option 2A has 31% lower GHG emissions when compared to Option 1A compliant option. Options 2A, 2B, 3A, and 3B can all enable the design to meet the target EUI but all have capital cost, utility pricing, and other implications.

C. Solar PV to achieve zero net energy building

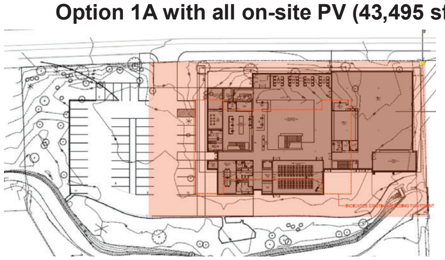
To get to ZNE building enough renewable energy must be generated to offset the site energy use. Preliminary calculations were performed to estimate the total PV array size that would be required to offset the total site energy consumption for each of the six options. Figure 5 below lists the estimated PV array size for each of the options and approximate installed PV cost.

Figure 5: Total PV Array Size for Zero Net Energy (ZNE) Building

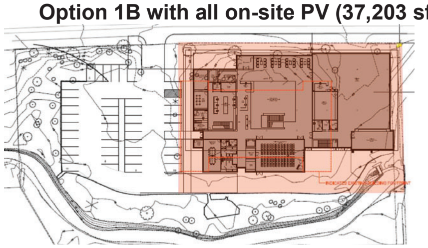
Scenario	Estimated PV Output to off-set site energy use (kWH)	Estimated installed PV Capacity (kWp)	Approximate Installed PV SF	Approximate Installed PV Cost per Watt ($)	Approximate Total PV Cost ($)
Option 1A	543,686	435	43,495	$3.00	$1,304,846
Option 1B	465,019	372	37,202	$3.00	$1,116,045
Option 2A	316,771	253	25,342	$3.00	$760,251
Option 2B	269,334	215	21,547	$3.00	$646,401
Option 3A	296,564	237	23,725	$3.00	$711,753
Option 3B	252,980	202	20,238	$3.00	$607,152

Figures below are diagrammatic representation of the extent of the PV array on the site to offset total energy use for each option. The PV arrays would span more than the roof area of the project for each of the options.

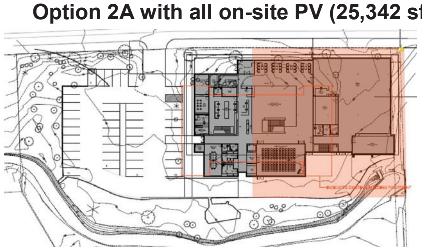
Option 1A with all on-site PV (43,495 sf)



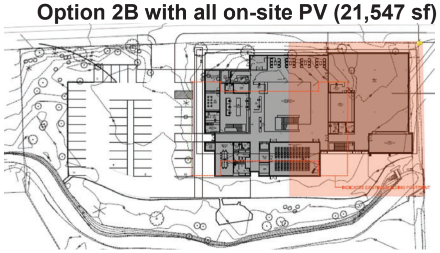
Option 1B with all on-site PV (37,203 sf)



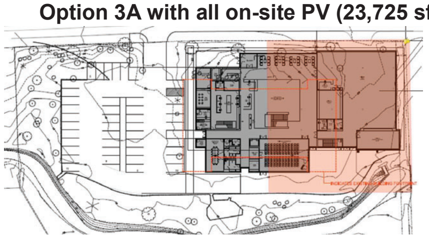
Option 2A with all on-site PV (25,342 sf)



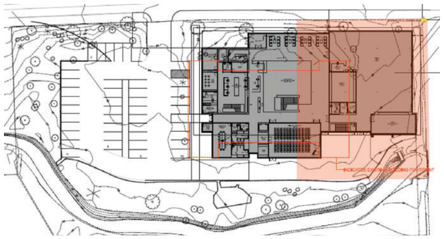
Option 2B with all on-site PV (21,547 sf)



Option 3A with all on-site PV (23,725 sf)



Option 3B with all on-site PV (20,238 sf)



D. On-site Solar PV Potential

Based on the early discussions with the design team, under current library design the available area for a rooftop PV installation is estimated to be approximately 10,000 SF (Figure 6). This would accommodate a 100 kW(p) PV system on-site. A 100 kW(p) system offsets between 23% to 49% of the project's energy use for the six design options. The remainder of the renewable energy required to achieve ZNE design would need to be procured through off-site PV, community solar, renewable energy credits (REC's) or carbon offsets.

Figure 7: Percentage of on-site PV vs net energy use for the available roof area

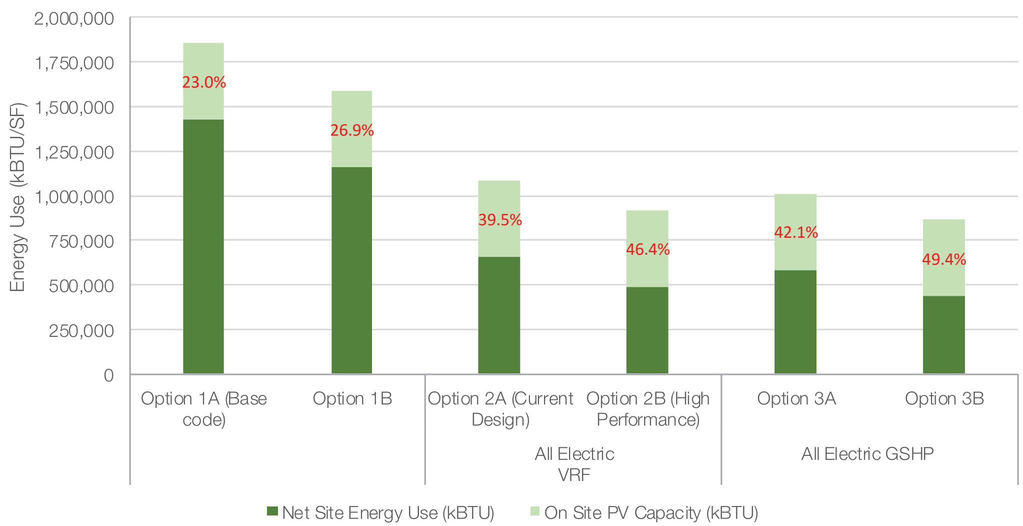
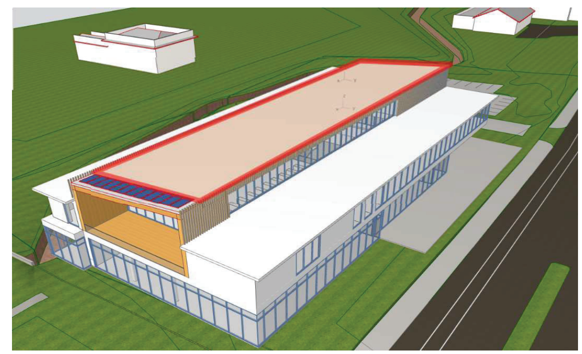


Figure 6: Potential available roof area for PV array



For a 100 kW(p) PV array system on-site, the maximum offset of site energy used is for Option 3B, where this system offsets about 49.4% of total site energy consumption. In comparison, for Option 1A, the on-site PV only offsets 23% of the site energy consumption.

As the design progresses there is an opportunity to alter the design to add potential roof area suitable for on-site solar PV system, thus increasing the overall capacity of on-site renewable energy generation. In addition, design team will also investigate high efficiency solar panels to maximize the solar generation within the available roof area.

E. VRF vs GSHP energy comparison and path to zero net energy

The four all electric options (Options 2A, 2B, 3A, and 3B) require significantly smaller renewable energy generation systems when compared to the fossil fuel options (Option 1A and 1B). Of these, the lowest EUI options are Option 2B and Option 3B. Option 3B requires the least amount of renewable energy generation to get to ZNE as it has the lowest site energy consumption (Figure 8 below). Option 2B and 3B can achieve a site EUI of 23 kBTU/SF and 22 kBTU/SF respectively, which meets the lower threshold for the target EUI range. Additionally, Option 3B saves about $2,568 in site energy cost per year over Option 2B since GSHPs are more efficient than the VRF systems.

Figure 8 : Summary - VRF vs GSHP options

Options	Site EUI (kBTU/SF)	Site Energy Use (kWh)	Site Energy Cost ($)	Energy Cost Savings ($)	Source Energy (MBTU)	GHG Emissions (MTCO2e)
Option 2B - All Electric VRF	23	269,334	$42,285		2,573	68.87
Option 3B - All Electric GSHP	22	252,980	$39,718	$2,568	2,417	64.69

As indicated above, all electric options require renewable energy generation to get to the goal of ZNE building. Figure 9 below compares the amount of installed PV that will be required to get to ZNE for Option 2B and Option 3B. The associated installed PV costs are lower for Option 3B since it requires smaller installed PV capacity. However, this option has additional cost associated with the ground wells that are required to implement the GSHP option. Adding the cost of ground wells to the installed PV cost to achieve ZNE, option 2B turns out to be a lower first cost option when comparing the two.

Figure 9 : Option 2B vs Option 3B - path to net zero

Options	Estimated PV Output to off-set site energy use (kWH)	Estimated installed PV Capacity (kWp)	Approximate Installed PV SF	Approximate Installed PV Cost per Watt ($)	Approximate Total PV Cost ($)	Total Cost to achieve Net Zero	Notes
Option 2B - All Electric VRF	269,334	215	21,547	$3	$646,401	$646,401	No additional well cost
Option 3B - All Electric GSHP	252,980	202	20,238	$3	$607,152	$847,152	Additional GSHP cost, @ $10,000 per well for 18 wells and $60,000 for the system.

III. Life Cycle Costing Analysis

In this analysis, method used for life cycle costing is called Total Equivalent Annual Cost (TEAC). It amortizes the upfront cost over the life span of the envelope, lighting, and equipment, and adds that to the operating cost. Another way to think of it is: operating cost + the bond payment on the capital cost. The IESNA (Illuminating Engineering Society) recommends this specifically for comparisons of lighting options, but it works well for comparing alternatives with different life spans.

Basic Formula used for LCCA is:

TEAC =
Annual Operating Cost + Initial Costs x $[(i\,(1+i)^n)/((1+i)^n-1)]$

where

i = discount rate
n = expected service life

Few things to note for the LCCA analysis

- Incremental costs for each of the options have been considered for calculating the TEAC for simplification purposes.
- Total Equivalent Annual Cost (TEAC) was determined for each option, based on preliminary energy analysis of the concept design options, high level preliminary incremental cost estimates, and rough estimates of maintenance costs for each of the six options.
- Typically, super-insulated buildings result in lower HVAC system sizing and therefore lower first costs for the HVAC options. The incremental cost estimates in this LCCA analysis do not includes such details.

The LCCA results show

- Options 1A and 2A have similar life cycle costs (TEAC), but Option 2A has much lower greenhouse gas emissions, site energy use, and EUI.
- Option 3A has a higher life cycle cost but provides comparable EUI and GHG emissions when compared to Option 2A.

Figure 10: Life Cycle Costing Analysis

Description	Conventional Fossil Fuel System VAV AHUs + Condensing Boilers (VAV)		All Electric Variable Refrigerant Flow (VRFs)		All Electric Ground Source Heat Pumps (GSHP)	
	Option 1A	Option 1B	Option 2A	Option 2B	Option 3A	Option 3B
	VAV	VAV	VRF	VRF	GSHP	GSHP
	20% Improved Envelope	Super insulated envelope	20% Improved Envelope	Super insulated envelope	20% Improved Envelope	Super insulated envelope
	20% reduction in lighting	40% reduction in lighting	20% reduction in lighting	40% reduction in lighting	20% reduction in lighting	40% reduction in lighting
Project Area	40,000	40,000	40,000	40,000	40,000	40,000
Discount Rate (i)	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Expected Service Life (n) -Envelope	50	50	50	50	50	50
Expected Service Life (n) - Lighting	10	10	10	10	10	10
Expected Service Life (n) - HVAC	20	20	15	15	20	20
Expected Service Life (n) - Ground Well					40	40
Annual Maintenance Costs ($)	$ 9,200	$ 9,200	$ 9,200	$ 9,200	$ 9,200	$ 9,200
Annual Maintenance Costs ($/SF)	$0.23	$0.23	$0.23	$0.23	$0.23	0.23
Initial Cost Envelope ($) (Incremental)*	$ 480,000	$ 1,400,000	$ 480,000	$ 1,400,000	$ 480,000	$ 1,400,000
Initial Cost Lighting ($) (Incremental)*	$ 40,000	$ 120,000	$ 40,000	$ 120,000	$ 40,000	$ 120,000
Initial Cost HVAC ($) (Incremental)*	$ -	$ -	$ -	$ -	$ 60,000	$ 60,000
Initial Cost Ground Wells ($) (Incremental)*					$ 260,000	$ 180,000
Initial Costs ($) (Incremental)*	$ 520,000	$ 1,520,000	$ 520,000	$ 1,520,000	$ 840,000	$ 1,760,000
Energy Cost ($) *From Preliminary Energy Analysis*	$ 49,273	$ 42,024	$ 49,733	$ 42,285	$ 46,561	$ 39,718
Annual Operating Cost ($)	$ 58,473	$ 51,224	$ 58,933	$ 51,485	$ 55,761	$ 48,918
Total Equivalent Annual Cost ($)	$ 79,967	$ 114,296	$ 80,427	$ 114,558	$ 91,461	$ 123,010
TEAC (Incremental Cost/SF)	$ 2.00	$ 2.86	$ 2.01	$ 2.86	$ 2.29	$ 3.08
GHG Emissions (MTCO2e)	117.21	100.18	81.00	68.87	75.83	64.69
Site Energy Use Intesity (kBTU/SF)	46	40	27	23	25	22

** Initial costs are based on incremental costs for each option.*
Discount rate of 2.5% is used

Cost estimate assumptions for the LCCA analysis are listed below:

- 20% better than ASHRAE 90.1-2016 envelope - incremental cost of $12/SF, when compared to 90.1-2016 compliant envelope
- 20% better than ASHRAE 90.1-2016 lighting - incremental cost of $1/SF, when compared to 90.1-2016 compliant lighting
- Super-insulated envelope - Incremental cost of $35/SF, when compared to 90.1-2016 compliant envelope
- 40% better than ASHRAE 90.1-2016 lighting - incremental cost of $3/SF, when compared to 90.1-2016 compliant lighting
- VAV HVAC option - capital cost of $45/SF, no incremental cost.
- All Electric VRF option - capital cost of $45/SF, no incremental cost, when compared to VAV HVAC option
- All Electric GSHP option - capital cost of $46.5/SF, incremental cost of $1.5/SF, when compared to VAV HVAC option.
- Ground wells - capital cost of $10,000 per well.

IV. Further Considerations as the Design Progresses

It is important to keep in mind that this ZNE analysis is performed as part of the high level concept study for the project and to understand different pathways to get to zero net energy building design. There are attributes that are critical to achieving high levels of energy efficiency which have not been studied in detail because of the nature of this analysis which is based on other similar high efficiency library projects.

- Glazing percentage: Amount of glazing, orientation (north vs. south, etc.), and glazing specifications (U-Values, Solar Heat Gain Coefficient, Visible Light Transmittance, etc.) all contribute to optimized design that maintains a good balance between aesthetics, functionality, and energy efficiency, all important to a successful building. As the project moves into schematic design phase and beyond, glazing percentages and orientation will be refined to optimize envelope loads and in turn impact mechanical system sizing. ASHRAE 90.1-2016, Appendix G limits the glazing percentage for a school building type to 22%. Library type has no specific threshold and defaults to 40%.These thresholds could serve as a guide while studying different options. Analysis of detailed envelope designs and refining incremental costs for each design option which takes into account reduced mechanical equipment sizing will be done when there are more concrete design details available during schematic design.

- Utility Incentives: Massachusetts utilities offer incentives to projects implementing high levels of energy efficiency and clean energy design options through MassSave and the MassCEC programs. However, this project will be served by Belmont Light, which is a municipal electricity company and is not eligible for the MassSave and MassCEC Incentives program. However, there may be other available incentives through Belmont Light which the project should investigate as the design systems are selected.

- GHG Emissions Rate: The current GHG emissions calculated in the analysis are based on the EIA's eGrid rates for the New England region electric emissions and national Natural Gas emissions. However, this project is served by Belmont Electric which predicts 30% lower electric GHG emissions rate due to its renewable energy generation portfolio by the year 2020 when compared to the New England region rates. As the project moves forward most recent GHG emissions rate available for the Belmont Light electric are proposed to be used in the next phases of the analysis.

END OF REPORT