

Pursuing Portfolio-Wide, Zero Energy Existing Buildings on a Budget

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ABSTRACT

Most existing building portfolio owners approach renovations through the lens of financial metrics such as first cost and Net Present Value. However, due to the urgent needs for climate change mitigation, additional policy goals are being included to address existing building retrofits' energy consumption. If additional goals are being added, often it also means additional scope, which costs more money. If the sources of income are static, as is the case for most city governance, are portfolio owners able to transition existing buildings to meet aggressive climate change mitigation goals on the same budget? City of Alexandria is in this position.

It would be understandable to identify cost increases of higher efficiency materials and equipment and immediately downgrade goals to something less than the ultimate goal of Net Zero Energy. However, this paper finds that Net Zero Energy Buildings is possible for some buildings on the same existing buildings budget, or is the cheapest available option to meet the climate mitigation goals. Therefore, pursuing Net Zero Energy Buildings first and then downgrading only after failure of multiple options via the financials to Net Zero Emission Buildings opens the door to decarbonizing more buildings in a cost-effective manner at the portfolio level.

This paper shares energy modeling and financial analysis strategies used to come to those conclusions and shares City of Alexandria's pursuit of Net Zero Energy.

Introduction

Energy use in existing buildings is a major source of greenhouse gas emissions across the United States (MWCOG, 2018; WRI, 2106). As such, existing buildings are of critical importance in the efforts to reduce the consequences of climate change (Architecture2030, 2021). Many existing building portfolio owners are establishing energy efficiency, electrification, or Net Zero Energy Building (NZEB) targets to reduce greenhouse gas emissions by sometime between 2030 and 2050 (Peterson et al. 2016; National Academies 2021). Net Zero Energy Buildings are considered the optimum goal because they are: "An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" (Peterson et al. 2016). While this doesn't completely remove the building from the grid it does generate significant, clean energy use over the span of a year to make up for its energy consumption, which is a vast improvement over most buildings. If jurisdictions and other entities could increase the number of NZEB over the coming decades, the world would unarguably be closer to IPCC goals for reducing carbon emissions. Many entities are instead pursuing existing building goals shy of NZEB to focus on a zero emission targets by way of reliance on future "greening of the grid."

Zero Emission targets are defined as: "releasing no greenhouse gases to the atmosphere—that is, no carbon dioxide (CO₂), no methane, no nitrous oxide or other greenhouse gases" (National Academies, 2021). While Zero Emission Buildings are also commendable, there is additional societal and environmental benefit to having distributed energy production at the

location of the use. Also Net Zero Energy reduces the volume of upgrades required to the grid. Relying on renewable energy via RECs or “greening of the grid” alone without improving efficiency requires excess renewable energy that is in high demand and limited supply. When considering Net Zero Energy owners/ designers must consider the cost and surface area implications of needing too much photovoltaics, relative to a more efficient building that needs less solar power. Net Zero Energy is a way of internalizing some of the externalities associated with off-site decarbonized electricity.

City of Alexandria created the 2040 Environmental Action Plan which addresses both efficiency and electrification along with a suite of many other categories to reduce the city-controlled carbon emissions. Categories targeted include waste streams, vehicle transit, new and existing buildings, and other sources. Specifically for existing, city-owned buildings, a set of time-progressive goals were established on improving efficiency such as 25% energy reduction by 2030 and 50% energy reduction by 2040. Additionally, all fossil-fuel end use loads should be replaced with electric sources by 2040.

Some local governments have developed detailed plans to achieve official NZEB for existing buildings. For example, Fairfax City Public Schools studied net zero energy opportunities for their existing schools whose construction, number of stories, land-use, and occupancy are nearly identical (CMTA, 2019). Its analysis focused on overall cash-flow over the course of 30 years. Boise, ID studied 10 buildings in its portfolio to identify pathways to electrify the natural gas end-use loads of its buildings for 2030 electrification goal as part of pursuing net zero energy buildings (Maulin, 2021). However, this study was solely focused on lowering first costs and took no consideration for long-term cost-effectiveness. As a result, many more of its solutions resulted in electric resistance alternatives. Additionally, the study focused on primary building heating systems and did not take into consideration other building components such as roofs, walls, windows, and lighting to support a more comprehensive approach to improving efficiency of its buildings. Evanston, IL completed 3 “investment grade” energy audits of archetypal buildings within its portfolio: a fire station, a community center, and a service center. These audits focused on entirety of the buildings including envelope and other attributes for long-term options to achieve net zero emissions of its buildings. Evanston’s timeline appears to be on the near to medium term to achieve its 2030 goals, though hints at the benefits of the Zero Over Time (Jungclaus et al. 2018) and “Package Deals for Deep Energy Savings” (Matthew 2020), strategies which were not a focus of its efforts. Both documents indicate the relative capital cost-savings of upgrading equipment to high-efficiency options at the equipment end-of-life.

These studies are important because they confirm use of certain energy conservation measures important to electrifying buildings to achieve net zero energy building technologies to be cost effective over the long term, such as:

- use of inverter heat pumps for space heating
- use of heat pump hot water heating for domestic hot water
- air-sealing envelope
- LED lighting
- Insulation addition to the roof, as applicable
- High performance windows (Kiatreungwattana, 2021)

And these studies speak to the broader desire by cities throughout the country to do their part to blunt the impact of climate change within the bounds of their control and budgets. This could be useful from several angles such as: projected impact on the grid, potential demand signals to industry, potential “how-to” manuals for other cities that cannot go to the detailed

lengths incumbered by other cities, and where the policy goals of localities may be missing certain community-based externalities. Many studies have sought to better understand the most cost-effective timing of implementing energy efficiency in existing buildings (Jungclaus 2018; Matthew 2020). Consensus is that implementing energy efficiency at an equipment or system's end-of-useful-life is most cost-effective given the incremental costs are much less. However, the timing of the replacements does not necessarily line up with what most new-construction, NZEB practitioners would call ideal (Torcellini, 2019). For example, an HVAC system may need to be replaced before windows. And in this circumstance, the HVAC system may need be over-sized in the short term because the building's demand may be initially greater before energy efficient windows are installed. This adds expense to the capital costs and potentially requires additional modulation capacity of the HVAC be included. In another example, hydronic piping may have a typical BOMA lifetime of 40 years, but the fan coils connected to that piping may need to be replaced after 25 years. NZEB and general engineering design practice would dictate that if the existing fan coils were replaced with low supply water temperature versions, that the distribution piping diameter and pump size is also increased to counteract the increased head-pressure drop of the new, more-efficient fan coils.

Therefore, the fundamental question remains: Can these long-term building portfolio holders cost-effectively and realistically stretch their goals and achieve Net Zero Energy Buildings? The City of Alexandria is attempting to address answer this question for its own 160 building portfolio through the lens of 4 prototypical buildings and completing an evaluation of the potential energy efficiency packages, renewable energy options using existing budgets, equipment replacement schedules, energy modeling, and local utility rates.

This paper summarizes a process, analyses, and findings, challenges, and next steps for achieving NZEB instead of stopping short at Net Zero Emission Buildings. One could also see this as another case-study for steps to achieve Zero Over Time (Jungclaus et al. 2018) with specific analysis targeted towards a low utility cost (blended kWh and kW cost of ~\$0.082/kWh), and above-average capital cost situations. These are near worst-case financial conditions and therefore most portfolio owners will have better Net Present Value than what City of Alexandria experiences. In fact, the IEA indicates that the Virginia, 2022 commercial cost per kWh is the bottom 15% of states when ranked by cost (EIA, 2022) at \$0.0877/kWh.

Background

Organizations utilize budgets to allocate finite financial resources. Cities have capital budgets to set aside money to invest in infrastructure and buildings, facility including building system maintenance, replacement, and upgrades. The type and timing of building system investments are prioritized based on available funding in a city's capital budget. Once a dollar amount is set for facilities, then there is a process to determine what projects can and should be completed in the next year. At that level, choices are largely made to reduce deferred maintenance cost and reduce the financial risk from a building to the city such that buildings do not outright fall into a state of disrepair.

The City of Alexandria's capital asset management system – VFA by Accruent - serves as the foundation for managing the existing building portfolio's equipment inventory, end-of-life schedule, and supports the process to prioritize building investments. (See Figure 1). This capital asset management system includes an inventory of equipment and systems for each building such as, but not limited to foundation, walls, windows, doors, heating system, cooling systems, distribution systems, lighting, plumbing fixtures, plumbing distribution, major electric service

components, pumps, motors, ceiling tiles, carpet, interior paint, fixed furniture, etc. For each piece of equipment, the following information is stored: date installed, projected BOMA equipment life, specific number of years of life remaining prior to replacement or renewal, projected date of replacement/renewal, a picture, model number, description, RSMeans cost, and a total cost of replacement to include cost multipliers, design and construction contingencies. As of current, in the case of the City of Alexandria's capital asset management system, considerations for prioritizing building investments are based on maintaining buildings exactly as they are today. The City of Alexandria's capital budget is framed around using these costs to prioritize building investments over a 10-year time period. Despite the issue of prioritizing building investments according to maintaining buildings as they are today, this approach does provide the City of Alexandria predictable, logical method to track equipment based on average equipment life and provides estimates of future costs that fit within the City's capital budget. However, transitioning the City of Alexandria's existing buildings to Net Zero Energy Buildings or even the easier goal of Net Zero Emissions Buildings while fitting in with the capital budget requires a different approach. This study, similar to "Net Zero Energy" (CMTA, 2019), is based on the premise of cost-effective methods to efficient, electrified, existing buildings, and requires a 30-year time horizon (as compared to 10 years) to account for the timing of replacing systems/equipment at end-of-life.

The screenshot shows the VFA Capital Planning Software interface. The left sidebar contains navigation options: Regions, Areas, Assets, Systems, Rooms, Inventory, Requirements, Actions, Photo Browser, Cost Estimator, and System Template Library. The main area displays a table of building systems for the City of Alexandria, Area 4, Burke Library. The table has columns for System Group, System Name, Renewal action FY, Lifetime, Date Inspected, and Quantity. The table lists various systems such as Foundation Wall and Footings, Structural Slab on Grade, Multi-Story Steel, Precast Concrete Panels, Aluminum Windows, Automatic Openers, Door Assembly, and Single-Ply Membrane.

System Group	System Name	Renewal action FY	Lifetime	Date Inspected	Qu
A - Substructure	Foundation Wall and Footings - No Basement	2065	75	Oct 27, 2014	
A - Substructure	Structural Slab on Grade - Non-Industrial	2065	75	Oct 27, 2014	10,
B10 - Superstructure	Multi-Story - Steel	2065	75	Oct 27, 2014	20,
B2010 - Exterior Walls	Precast Concrete Panels - Low-Rise	2043	75	Oct 27, 2014	7,
B2020 - Exterior Windows	Aluminum Windows	2032	30	Oct 27, 2014	2,
B2030 - Exterior Doors	Automatic Openers - Pair	2027	12	Oct 27, 2014	
B2030 - Exterior Doors	Door Assembly - 3 x 7 HM	2032	30	Oct 27, 2014	
B2030 - Exterior Doors	Door Assembly - 6 x 7 Storefront	2032	30	Oct 27, 2014	
B2030 - Exterior Doors	Door Assembly - 3 x 7 Storefront	2032	30	Oct 27, 2014	
B2030 - Exterior Doors	Door Assembly - 6 x 7 HM	2032	30	Oct 27, 2014	
B2030 - Exterior Doors	Automatic Openers - Pair	2019	12	Oct 27, 2014	
B30 - Roofing	Single-Ply Membrane - Fully Adhered	2041	25		10,
B3021 - Glazed Roof Openings	Skylights	2032	30	Oct 27, 2014	

Figure 1: Screenshot of VFA Capital Planning Software

While not all municipalities may use VFA or other programs like it, for the City of Alexandria it does provide a predictive, logical method to track equipment based on average equipment life and provides estimates of future costs that are helpful while choosing projects. City of Alexandria's budget process revolves around a 10-year cycle of expenditure planning. But this study, similar in nature to "Net Zero Energy" (CMTA, 2019) is based on the premise of cost-effective methods to efficient, electrified, existing buildings, necessitates a 30-year time horizon to account for replacement of systems/ equipment at end-of-life. This procedural budget dissonance for the City of Alexandria has yet to be resolved, and it will require additional research, analysis, and discussion.

The difficulty in looking out 30 years in the future versus 10 years is the inherent inaccuracy associated with predicting the future needs of constituents. Imagine, for example being a commercial office building owner in 2015 and planning the building budget for 30 years in the future while in complete ignorance of the future 2020 pandemic. Many commercial building owners in urban locations are changing their commercial building occupancy to

residential because of the increase in work-from-home permissions. Such changes generally require huge adjustments to structure and mechanical systems. At the same time, most City of Alexandria buildings are over 30 years old with little change to intended use.

Methodology and Analysis

Our methodology is the following: complete an audit similar in scope to an ASHRAE Level 3 energy audit on multiple buildings, including review of utility bills, current equipment, use, etc. Then create a calibrated building energy model for each building relying on current equipment information stored in the City's capital asset management system, and by collecting information through the energy audit. Using this baseline energy model, model parameters are then changed to reflect what is required of a highly efficient and electrified equipment to achieve a Net Zero Energy Building. These are comparison energy models. Multiple models are created mimic building systems being replaced over time, in this case 30 years. In these models, the schedule of replacements in VFA was reviewed, and forecasting and experimenting with time-dependent improvements at the end-of-life that yield a cost-effective Net Zero Energy Building and Net Zero Emissions buildings in line with the Environmental Action Plan (50% energy reduction, and all end uses electrified).

Methodology

Evaluating the cost-effectiveness Net Zero Energy Existing Buildings utilized common energy modeling and energy analysis methods, including energy reduction potential, and cost-effectiveness based on Net Present Value (NPV) of the resulting building. The following sub-sections including "Energy Modeling," "Energy Efficiency Measures," and "Financial Analysis" describe the methodology in greater detail.

Energy Modeling

Baseline and comparison energy models were developed using eQuest due to its ease of use and robustness. Energy models were developed using available building information and calibrated using multiple years of actual monthly utility electricity and natural gas billing data. Adjustments were made to accommodate year-over-year deviations of modeled energy use to that of actual energy use, including adjustments to accommodate for COVID-19 impacts on building occupancy and operations. An example of a calibrated building energy model is shown in Figure 2.

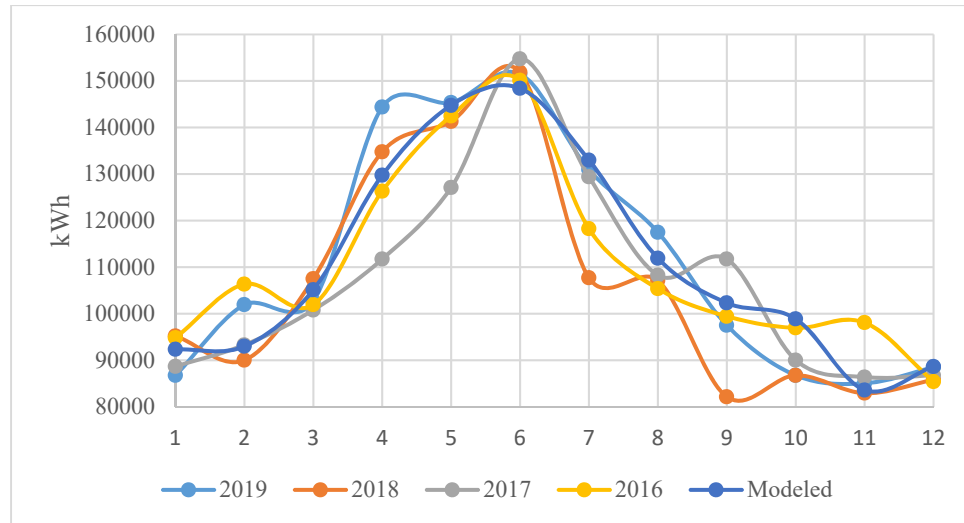


Figure 2. Example of Calibrated Energy Use by Month, Several Years Data

The calibrated baseline energy models served as the foundation for evaluating the opportunity to achieve Net-Zero Energy on a budget for each building within the City’s portfolio. Where energy modeling inputs were unknown, realistic assumptions were made, and the energy models were calibrated to within 20% of monthly energy use as compared to actual usage, albeit not ASHRAE calibration standards. Calibrations of energy models were accomplished by varying the air infiltration rates (actual measurement of infiltration is an expensive and non-standard diagnostic for existing, commercial buildings), derating insulation and window performance relative to age and construction practices, and equipment run-time and process loads to match the energy bills.

Energy Efficiency Measures (EEM)

A suite of energy efficiency and electrification measures were evaluated attempting to achieve NZEB portfolio wide. Table 1 provides a summary of energy efficiency measures considered. Each energy efficiency measure is defined by the system/equipment it seeks to retrofit, the necessary energy performance specification, and the strategy for which it may be most applicable.

The individual strategies were identified by what was possible within constructs of VFA equipment specified (roof, walls, windows, lighting, boiler, furnace, RTU, etc.), possibility of reducing the largest end-use loads within our control (typically: cooling, heating, lighting; excluding most plug loads), commercially available equipment, and experience in implementing some retrofits such as lighting and achievable limits (watts/ square foot). What EEM’s could be included in a cost-effective manner became clear through the modeling process. For example, if R-40 roof insulation was not cost effective, then R-70 is not likely to be either as it would be even more costly with less incremental benefit. However, some items like air-sealing or wall insulation did not generally exist in VFA as a line item, because air-sealing is a method applied to many pieces of equipment (doors, windows, walls, dampers, ceilings, structure etc.) or in the case of insulation is effectively integrated into the generic line-item of “exterior walls.” In such cases, City of Alexandria added this strategy as a line item to be included in the modeling strategy and eventually into VFA.

Table 1: Energy Efficiency Measures by Generic Package

System/ Equipment	Efficiency Details	Option 1: Max Ins.	Option 2: Cost Opt.
Heat Pump Hot Water	3 COP (Unitary or Split)	X	X
Lighting Efficiency	0.5 Watts/sqft	X	X
Windows and Door.	Min Code U-value/ SHGC (0.32/0.40)		X
Windows and Doors.	U-value/ SHGC (0.15/0.25)	X	
OA Min flow & Infilt.	70% reduction	X	X
Roof Insulation	R-32		X
Roof Insulation	R-50	X	
Roof Insulation	R-90	X	
Wall Insulation	R-20 EFIS	X	
Wall Insulation	R-40 EFIS	X	
Exhaust Fans	ECM, w/ Controls	X	X
Variable Speed Drives		X	X
Ultra-high Eff. Motors		X	X
Heat Pumps (split systems)	3 COP/ 10 EER		X
Variable Refrigerant Volume	3.8/12 EER		X
Ground Source Heat Pumps	3.8/12 EER	X	
Geothermal Radiant Floor		X	

There are a few things to note about these set of EEMs. First, there are several instances where different equipment values are applicable to the same generic package. This is because the different buildings had unique baselines such as the differences in insulation levels, internal loads, and occupancy schedules. Different levels of performance were cost effective at different levels. Secondly, this list of measures is applicable to the City of Alexandria's climate zone (4A) and limited sample set of low-lying buildings. Care should be taken in extrapolating package summaries to other cities due to differences in baseline construction, weather, utility rates, and construction costs.

Additionally, these EEMs and costs included changes to the equipment system sizing. For example: the packages that added insulation to the exterior or reduced interior lighting load, had an impact on the resulting heating and cooling capacity needed for the building. If the mechanical system replacement occurred after such upgrades in VFA, the mechanical system could be downsized to accommodate smaller loads (as indicated by the energy model) and thus reduce the capital costs because mechanical system EEM cost was calculated on a \$/ton basis.

It should also be noted that this list does not include retro-commissioning as a basic EEM, even though many other researchers include it (Sanborn, 2022; Winter, 2022) as part of the standard pathway to achieving a high efficiency, electrified building. There are two reasons for this. First, most of the buildings in the City of Alexandria's portfolio will need extensive replacement of the mechanical systems to meet efficiency and electrification goals. This includes new pumps, pipes, plants, fan coils, AHUs, sometimes new ducts etc. Essentially, the equipment normally in standard retro-commissioning scopes needs to be replaced with an entirely new system to achieve Net Zero Energy. Therefore, the effectiveness of retro-

commissioning is limited to the time prior to MEP system replacement. That time could still be valuable considering some buildings may not get retrofit for a decade or more. However, because of the time-variability to cost-effectively replace whole MEP systems, it is not guaranteed long-term savings. Second, while our buildings have all shown the opportunity for improvement through the retro-commissioning process, there is no standard amount of savings or costs could be applied. In essence, it is a guess until the process can be completed.

Examples of these Energy Efficiency Measure Packages are as follows:

1. Option 1 (Opt1) – Max Insulation - focuses on envelope improvements, much the way that new construction NZEBs are designed. A heavy emphasis was placed on Exterior Insulation Façade Systems, low U-value roof systems, and high-performance windows. One of the many benefits of this package was that it reduced HVAC system sizing, which reduced first cost, and could occasionally make cheaper options like preferred technology, ground-source heat pumps more viable.
2. Option 2 (Opt2) - Cost Optimum – or cost optimized, evaluated various iterations, and identified energy efficiency measures which had the most energy savings for each dollar invested. These measures were then applied to a single package and run through an energy model. The goal on this EEM package was to create the most cost-optimized outcome while also meeting the Net Zero Energy goal.

Either Option 1 or Option 2 could produce a Net Zero Energy Building or a Net Zero Emission building, with the primary difference related to how zero-emission or renewable energy is used at the building. Net Zero Energy Buildings require photovoltaics be installed on the roof to the maximum amount, with any extra applied as ground mounted solar as available space allows. Photovoltaics could be included by direct ownership, Power Purchase Agreement (PPA)/ Energy Savings Performance Contracting (ESPC). Net Zero Emissions Buildings relied on “clean” energy supplied from the grid at a current, local price premium of \$0.012/kWh.

Financial Analysis

The financial analysis was performed using a custom-based spreadsheet that took inputs from the previously described components – mainly the schedule of equipment replacement from VFA, projected costs from VFA, and energy modeling outputs. Over-arching assumptions as related to financial inputs were included in each calculation such as electricity cost escalation rate, discount rate, construction cost inflation rate, solar cost per watt installed, year of solar installation, area of building, and maximum allowable solar size as is available to be installed on the roof.

There are three main areas on the package summary tabs, including equipment replacement by year, background calculations of the financials by year, and the results summary for the individual package.

The building results were the major outputs from the different package summaries, and allow for comparison of the primary energy and financial outputs, and include:

- Total capital cost of selected equipment over 30 years
- 30 years of energy cost
- Delta Net Present Value (EEM NPV minus Baseline NPV). Positive numbers are good.

- Annual Energy Use (kBtu)
- Energy Use Index (kBtu of electricity and gas used divided by square feet)

Notably, where an equipment item would be replaced more than once during the 30-year time frame (such as a hot water heater), it was repeated with the corresponding date of intended replacement. Additionally, the cost in current dollars (the value in VFA) and future dollars (multiplied by the annual construction inflation rate), would be associated with equipment item. A net present value (NPV) was calculated based on the repeated, annual energy costs and selected equipment replacement/renewal costs.

There are considerable uncertainties in the results due to the number of variables in VFA, energy models, and financial analyses. However, steps were taken to mitigate the uncertainty such as, using conservative (high) costs associated with energy efficiency measures. Where a range of costs were found for a high-efficiency measure, the highest cost was selected to best account for needed, yet unforeseen scope increases and the high cost of materials and labor Alexandria experiences.

One apparent paradox in the results section as related to the financial metrics is the difference in projected costs provided by the VFA equipment accounting software baselines and the more accurate costs used in the proposed EEM packages that are reflective of current experience and vendor scope. The differences between the two sets of costs arise when the VFA costs use industry-standard multipliers on top of the RSMeans costs to account for externalities like demolition of existing equipment, potential design, permitting, scope, schedule, and budget over-runs due to the nature of retrofitting an existing building. While this may sound like an “apples-to-oranges” comparison, this is the reality the building owners and project managers experience. VFA, and other software like it, can slightly inflate the replacement costs to be sure that enough funding is available to cover the entire project regardless of additional changes and soft-costs. Furthermore, hydronic heating and cooling systems include many expensive pieces of equipment including boilers, chillers, cooling towers, pumps, pipes, valves etc. which can sum to millions of dollars. When eliminating such systems entirely and changing over to technologies like air-source heat pumps that have none of those systems, this can result in ZEB capital costs that are less than the baseline. It is a rare opportunity for organizations to achieve NZEBs when using capital planning software.

This analysis also assumes static rates of construction cost inflation (7%), discount rates (5%), and utility rate inflation (1.2%) with an initial step increase of 25% to reflect recent energy market shocks. These numbers fluctuate greatly every month and year, sometimes in opposing directions. Therefore, with a study that is forecasting financials over the course of 30 years, one must look at the results through a non-definite lens. The trends of the analysis may be more reliable than the accuracy of the individual financial costs and savings.

Results

Results for four (4) archetypal buildings within the City of Alexandria’s existing building portfolio – a 20,000 square foot library, a 10,000 square foot historic building, 75,000 square foot storage facility/office, and a 15,000 square foot fire station – are shown in Tables 2 – 5. There are considerable uncertainties in the results due to the number of variables in VFA, energy models, and financial analyses. However, steps were taken to mitigate the uncertainty such as, using conservative (high) costs associated with energy efficiency measures. Where a range of

costs were found for a high-efficiency measure, the highest cost was selected to best account for potential cost externalities and the high cost of materials and labor Alexandria experiences. Where energy modeling inputs were unknown, realistic assumptions were made, and the energy models were calibrated to within 20% of monthly energy use as compared to actual usage.

Table 2. 20,000 Square Foot Library, Net Zero Energy Results

	Baseline	Net Zero Energy				Net Zero Emission	
		Opt1 + Own PV	Opt1 + ESPC PV	Opt2 + Own PV	Opt2 + ESPC PV	Opt1	Opt2
Select Equip. Cost (VFA + Incremental)	\$8.3M	\$7.4M	\$7.1M	\$6.4M	\$6.4M	\$7.1M	\$6.4M
Energy Cost, 30 Yrs	\$1.1M	\$428k	\$710k	\$444k	\$698k	\$724k	\$915k
Delta NPV	\$0	-\$422k	-\$267k	\$520k	\$415k	-\$267k	\$327k
Final, Annual EUI	75	0	0	0	0	18	30
Peak Demand (kW)	97	34	34	196	196	34	196

Table 3. 10,000 Square Foot Historic Building, Efficient and Electrified Package Results

	Baseline	Net Zero Energy				Net Zero Emission	
		Opt1 + Own PV	Opt1 + ESPC PV	Opt2 + Own PV	Opt2 + ESPC PV	Opt1	Opt2
Select Equip. Cost (VFA + Incremental)	\$14M	NA*	NA*	NA*	NA*	\$15.8M	\$11.8M
Energy Cost, 30 Yrs	\$1.9M	NA	NA	NA	NA	\$1.7k	\$1.8k
Delta NPV	\$0	NA	NA	NA	NA	-\$379k	\$832k
Final Year EUI	212	NA	NA	NA	NA	115	89
Peak Demand (kW)	121	NA	NA	NA	NA	140	155

*NA = Not Applicable due to limitations of the Historic Building designation and available land/ roof area.

Table 4. 75,000 Square Foot Storage Facility/Office, Efficient and Electrified Package Results

	Baseline	Net Zero Energy				Net Zero Emission	
		Opt1 + Own PV	Opt1 + ESPC PV	Opt2 + Own PV	Opt2 + ESPC PV	Opt1	Opt2
Select Equip. Cost (VFA + Incremental)	\$16M	\$33M	\$27M	\$22M	\$16.4M	\$27M	\$16.4M
Energy Cost, 30 Yrs	\$3.4M	\$2.6M	\$2.6M	\$1.6M	\$1.6M	\$4.2M	\$3.5M
Delta NPV	\$0	-\$9.7M	-\$6.4M	-\$4.3M	-\$993k	-\$7.2M	-\$2.1M
Final Year EUI	59	0	0	0	0	47	36
Peak Demand (kW)	202	255	255	310	310	255	310

Table 5. New, 15,000 Square Foot Fire Station Efficient and Electrified Package Results

	Baseline	Net Zero Energy				Net Zero Emission	
		Opt1 + Own PV	Opt1 + ESPC PV	Opt2 + Own PV	Opt2 + ESPC PV	Opt1	Opt2
Select Equip. Cost (VFA + Incremental)	\$7.5M	\$9.1M	\$8.1M	\$13.9M	\$12.8M	\$8.1M	\$12.8M
Energy Cost, 30 Yrs	\$1.6M	\$209k	\$1.5M	\$271k	\$892k	\$1.7M	\$1.7M
Delta NPV	\$0	-\$29k	\$315k	\$72k	\$691k	\$161k	\$298k
Final Year EUI	135	0	0	0	0	79	76
Peak Demand (kW)	82	78	78	82	82	78	82

During evaluation of sampled results, achieving fully Net Zero Energy within the budget by standard definitions (Peterson 2016) may be available for a quarter of the portfolio. Another half of the buildings will be able to meet Net Zero Emissions criteria in a cost-effective manner. The last quarter of buildings, or maybe those involved with commercial storage or those buildings relying on radiant gas heaters, are going to have a difficult time to cost-effectively meet a Net Zero Energy or Net Zero Emission goal by themselves. However, of the available options to achieve Net Zero Energy or Net Zero Emission, Net Zero Energy with the use of ESPC-funded PV panels proved to be the least costly option on that building. Furthermore, combining costs and saving for all buildings shows that even with this building that needed excess funds to achieve NZEB, that the other buildings were able to more than compensate for the financial loss. See Table 6. Unfortunately, clearly identifying what goal is going to have the most positive environmental improvement at the least price and with the most resulting value is not a clear answer, as it is building specific. Positive improvements that meet IPCC and other climate change goals can be made to greatly improve the environmental performance but do not necessarily meet Net Zero Energy or Net Zero Emission goals. However, the fact that some buildings can achieve either of those goals with positive financial metrics re-enforces the need for owners to continue to try to meet those optimum outcomes as a first step, rather than assuming it costs too much or will not be a viable outcome.

Cost Optimal vs. Grid Impact

Some Zero Energy/ Emission packages that are the most cost-effective in the short and long term may also have the worst impact on the electric grid due to a) increased demand relative to the baseline b) inverted demand from summer afternoon to winter morning when renewable energy generation may be low. Writers of the building energy codes and utilities should consider adding requirements/ incentives to existing buildings that are fuel-switching between fossil fuel to electric heating to have some on-site storage that negates short periods of excess winter electric demand.

Actions

In most instances, the capital cost of the cost-optimum, efficient, electric retrofits is less than the baseline, due to a reduction in the actual equipment that needs to be installed as well as the contingency funding baked into VFA cost projections. This is somewhat surprising given that higher efficiency technology tends to use more and different materials/processes to achieve their efficient outcome and therefore costs more money. However, by pursuing Net Zero Energy first and identifying if any options are financially viable from a first cost and Net Present Value perspective, creates better outcomes for the portfolio at large even if some buildings need to downgrade their goal to Net Zero Emission instead. In fact, with this method, the first costs are projected to decrease relative to the VFA cost projections over the course of 30 years.

Table 6. Key Results for Cost-Effective Net Zero Energy or Net Zero Emission Buildings

Building	% Capital Cost Increase for High Eff. and Electrification	Final Yr. % MBTU Savings	30 Yr Site Carbon Savings	Delta NPV Savings
Library – ZN Energy	-4%	57%	59%	\$230,000
Historic- NZ Emission	-14%	46%	21%	\$832,000
Storage/Office–NZ Energy	2%	21%	54%	(\$993,000)
Fire Station –NZ Emission	20%	41%	41%	\$161,000
Totals	-7%	38%	43%	\$230,000

Most portfolio owners will choose the series of packages whose combined sum of NPV yields the cost-neutral or cost-positive value and has the least initial cost. In this case, the selected packages yield a combined NPV improvement of \$230,000, which is close to being cost-neutral when compared to the many millions of dollars being required to maintain the buildings over the next 30 years. This projection of -7% cost decrease is a result of being flexible in the end goal to be either Net Zero Energy or Net Zero Emissions, with the financial metrics of first cost and NPV being the deciding factor.

Next Steps

Specific to City of Alexandria, one of the primary procedural hurdles is to create a method to preserve the left-over money generated either by postponing replacement while waiting for more optimal, cost-efficient timing, or any installation costing less than the VFA budget estimate. This analysis assumes that such “left-overs” can be dedicated solely to efficiency and electrification efforts. More broadly, opportunities to improve capital planning methods have revealed themselves during this process, including, but not limited to:

- allowing for completely different scope rather than merely replacement-in-kind,
- describing upgrades in greater detail for future project managers.
- applying the ZEEB findings and generalizations to the existing scopes
- during building evaluation, creating a rubric of questions to answer for possible implementation of future upgrades, such as, but not limited to, current breaker space and amperage available.

- Documenting the collection of left-over money until it is needed for a larger, more energy efficient improvements with the possibility to move funding between buildings

It should also be noted that while this strategy of flexible goals will reach some of the final outcomes of the City of Alexandria's 2040 EAP such as the electrification of end use loads and significant progress towards overall decarbonization, it did not meet the intent for 50% energy use reduction via MBTUs. Part of this failure could have been from using default efficiencies of split system heat-pumps in eQuest rather than upgrading to higher, generic, inverter-compressor efficiencies which the costs reflected. These efficiencies can be variable depending on the manufacturer and thus were kept at default eQuest settings. Furthermore, no changes to process loads such as office equipment or scheduling were made between the baselines and EEM packages to be conservative in approach. If such process loads could be tackled at the policy level either at replacement, or with new controls such as automatic computer shut-off during unoccupancy etc., then additional progress could be made outside of the scope of normal building energy modeling and this paper.

This analysis has highlighted opportunities for additional exploration and research including updating capital asset management systems and software to coordinate replacements of multiple pieces of equipment at the same time, consistent with how many of the Energy Efficiency Measure Packages were constructed. In this way the opportunities to sustainably upgrade systems create more options to decarbonize in a cost-effective manner. For example, such effort would ensure that hydronic piping, pumping, and fan coils/ AHUs are replaced as part of the same scope of work rather than being replaced in different years which would in turn allow for a wider variety of space heating, heat pump systems including air-to-water heat pump and heat pumps using R-410a or similar.

Conclusion

This paper shares efforts and results that support the City of Alexandria's efforts to plan building-level strategies and prioritize Net Zero Energy goals to transition its existing portfolio of buildings to be greatly decarbonized through efficiency, electrification, and installation or purchase of renewable energy. Having flexible, but none-the-less rigorous goals (first Net Zero Energy and then Net Zero Emission) allows the ownership to prioritize efficiency first, and then pick between the most cost-effective options.

The analysis used energy modeling on four actual buildings that are archetypal for the City of Alexandria's existing building portfolio, and then with the application of current cost data from asset-management software, utility rates, inflation, discount rates, estimated the total costs and net present value of each building over the course of the next 30 years of operation. It does not fully resolve many of the challenges that exist as of current: prioritizing building investments over a 10-year time period as compared to 30 years and prioritizing building investments according to maintaining buildings as they are today. That said, upgrading existing buildings to be Net Zero Energy or Net Zero Emission while improving financial outcomes relative to cost projections is possible especially when considered across a portfolio of existing buildings.

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