HOW-TO GUIDE: NET ZERO RETROFIT TECHNICAL AND COST BENCHMARK STUDIES

INTRODUCTION

Background

Desirability, convenience, and cost are the three greatest barriers to adoption of deep energy retrofits. A root cause is that suppliers (the architecture, engineering, construction and equipment manufacturing industry) are minimally coordinated. Simultaneously the demand for these solutions is perceived to be weak. Thus, no one is yet able to sell energy efficiency at scale as every upgrade is a custom project. This results in greater time, complexity, and cost.

In the Netherlands, Energiesprong is a program designed to overcome these barriers, and make net zero carbon housing available as a product where sales, manufacture, delivery, and performance assurance can be optimized. Energiesprong has retrofit social housing units, at scale, to net zero with no upfront capital cost to tenants. Energiesprong retrofits are now being completed in fewer than 10 days per unit, without displacing residents, and industrial processes have reduced costs 60% in the past three years, while improving the product from a 50% energy reduction to net zero site energy for a standardized threshold of thermal comfort and performance. A key goal for the Energiesprong organizing team was to facilitate a reduction in the cost of net zero retrofit solutions in order to support the offering of a comfortable, convenient, desirable, carbon free home.

While the approach is performing well in Europe, it has yet to be tried in the United States (US). In coordination with Energiesprong, and building off their experience, REAL**IZE,** a partnership amongst motivated US cities and states, Rocky Mountain Institute, Passive House Institute US, and Net Zero Energy Coalition, seeks to adapt this approach to the US market, starting in California and New York. With over 137 million existing homes, the US is a significant market opportunity.

One of the first steps in adapting this model to a market is to understand the current cost optimized set of deep energy retrofit solutions available in the market. By establishing this baseline, a roadmap for cost reductions and technological improvements can be set. This equates to establishing:

- A Baseline: Given off-the-shelf technology and typical construction costs, are net zero retrofit *projects* technically feasible for the targeted typology, and what is the benchmark financial case - costs and benefits?
- A Goal: A price-point for net zero retrofits as a *product* that is not merely cost-effective, but desirable and a compelling business proposition.

This document summarizes the process to characterize the financial costs and benefits, and the technical feasibility of net zero carbon retrofits for affordable multifamily buildings in San Francisco. This guide, supported by the Carbon Neutral Cities Alliance, intends to inform partner and observing cities how to perform a similar analysis for their own local building stock. San Francisco's analysis focused on retrofitting buildings to net zero operational carbon, but the more general term "net zero" will be used throughout this guide.

The authors underscore: although specific net zero retrofit packages are highlighted in the San Francisco analysis, the intention is not to prescribe a solution package. Rather, the goal is to develop benchmarks, foster familiarity with available technical solutions for the given typology, and identify the key technical and/or financial parameters that subsequent solutions must navigate. In addition, the results provide insight into which retrofit components currently account for the bulk of the cost, which are, in turn, likely targets for cost reduction.

Precedent and Findings

Prior modeling work has demonstrated net zero new construction in California is technically feasible and cost-effective for the most common residential typologies, across the state's diverse climates; from the mild coastal climate of San Francisco, to desert, to alpine, to temperate rainforest.[1] Industry leaders have successfully delivered more than 3,500 Zero Net Energy (ZNE) new construction units in 95 California projects as of 2015. While ZNE new construction is well documented,[2] retrofits have unique issues. Site conditions such as shading, form, orientation, assembly type, existing systems, maintenance issues, capital reserves, and encumbrances can each narrow the opportunity for ZNE. Nonetheless, discussions with leading retrofit organizations identified 656 units retrofitted to ZNE in 9 projects with another large project currently in the design phase. The common thread, all of the ZNE retrofits for existing multifamily identified are 100% affordable housing (Appendix E).

Given the budget for analysis, it was necessary to characterize the bulk of existing multifamily in the San Francisco Bay Area with the minimum number of prototypes. Three size bins: 5-9 units, 10-19 units, and 20+ units captured 97% of the affordable housing market in the San Francisco Metropolitan Statistical Area, so three building prototypes were developed to represent these three size bins. Appendix B summarizes the three prototype buildings selected, as well as the data sources and reasoning behind the characteristics of each building prototype.

The analysis found that net zero retrofits could be achieved for all three multifamily prototypes. With local and federal incentives included, the 6-unit and 15-unit prototypes were cost effective with many net zero retrofit package options and less than a 10-year payback period. The 65-unit prototype was not as cost effective and allowed less flexibility in the retrofit solution package as it had limited roof area for installation of a solar photovoltaic (PV) array. The analysis also determined the key areas for cost reductions were the envelope, heating, ventilation and air conditioning (HVAC), and PV. Finally, high labor rates in San Francisco increase the potential for off-site pre-fabrication to significantly reduce project costs.

[1] ARUP (2012) The Technical Feasibility of Zero Net Energy Buildings in California.
[2] Net Zero Energy Coalition (2015) To Zero and Beyond – Phase 1 Inventory.

CONDUCTING A BASELINE ANALYSIS

Below we outline the key considerations and steps involved for cities and states that wish to conduct a similar analysis for their own building stock.

Step 1: Determine Project Scope

Key parameters to define include:

a) Locational boundaries for analysis (i.e. city, county, greater metro area, state)
b) Target building type (i.e. multifamily affordable housing)
c) Definition of net zero (i.e. net zero carbon, net zero energy including source, net zero site energy, etc.)

This analysis focused on affordable multifamily housing in the San Francisco Metropolitan Statistical Area – based on climate conditions in the City of San Francisco. Net zero was defined in this analysis as net zero carbon – allowing both offsite renewables as well as “overgeneration” to compensate for carbon emissions from onsite natural gas combustion to enable a broad range of options to inform the baseline. San Francisco has a goal to reduce carbon emissions 80% below 1990 levels by 2050. For cities with similar carbon reduction goals, using net zero carbon is the most direct metric.

Step 2: Identify Appropriate Modeling Tools

Critical elements to select include:

a) Appropriate modeling tools
b) Available data sets for cost and building characteristics

Software

Building Energy Optimization (BEopt) and System Advisor Model (SAM) were the primary software tools used for this analysis, as both are relatively user friendly. However, for greatest accuracy a building scientist should be engaged to conduct the analysis.

BEopt is free energy performance optimization software developed by the National Renewable Energy Laboratory (NREL). It was used in San Francisco’s analysis as it is straightforward to use and can easily run an optimization for energy and carbon. The software has the ability to model large appliances as well as hourly energy data, and was created specifically for the residential sector with many assumptions embedded in the tool. BEopt was used to find the “optimal” retrofit package that offers the lowest cost at a given level of energy or carbon savings. Embedded in BEopt is a measure database that is set up to easily model certain envelope, lighting, large appliances, heating and cooling equipment, and hot water energy conservation measures (ECMs). The measure database has costs associated with each ECM that can be updated manually if better cost information is available. Additional ECMs can be built by the user and added to the database if it fits within the same framework of the ECMs in the database. For example, a measure could be added that includes more roof insulation, but a measure for water source heat pumps could not be created since that is not one of the supported HVAC systems in BEopt. BEopt is not able to optimize utility cost savings from water or wastewater conservation measures, so water and wastewater savings must be calculated separately.

Once research has determined all the desired parameters, the modeler builds their baseline building then selects the ECMs for analysis. This analysis is based on BEopt parametric and optimization runs. In a parametric modeling run, the user selects all ECMs for analysis, and BEopt calculates the costs and benefits of every possible combination of retrofit packages with the selected ECMs. The optimization run is essentially a smarter parametric run that considers all selected ECMs, but does not necessarily run every combination to save time. When running in optimization mode, the user needs to select whether they want to optimize for carbon savings, site energy savings, or source energy savings.

BEopt has limitations including an inability to model: central heating and cooling systems, central heat pump hot water systems, or common areas other than corridors and parking garages. BEopt was originally built for single-family homes and was recently upgraded for multifamily; it is likely that future versions will improve upon its multifamily modeling capabilities. BEopt is also time intensive. Depending on size of the model, number of parameters, and server speed, optimization run times could vary from 8 hours to 270 hours. BEopt cannot optimize across different heating and cooling systems, so multiple optimization runs were needed for each prototype. Multiple simultaneous BEopt runs cannot occur on the same server, so multiple cloud-based Amazon servers were used for the San Francisco analysis, to run three models at once.

Although BEopt has its limitations, it is the best software for a relatively economical analysis that considers the interactivity of a wide range of combinations of ECMs, so specific BEopt functionalities will be referenced throughout the remainder of the guide. BEopt has straightforward tutorials and a forum for questions on its website, so experienced building performance modelers can pick it up quickly. More detail about the BEopt analysis can be found in "Step 8."

Although BEopt can model rooftop PV, BEopt cannot model racking systems. To capture the benefits of racking, the solar analysis was performed with System Advisor Model (SAM), another free software package developed by NREL. SAM allows for complex solar analysis including racking, shading, and varying panel and inverter efficiencies. SAM will also size a PV array based on available roof area and ground cover ratio. More detail about the solar analysis can be found in "Step 5."

Water and sewer conservation and utility bill savings were modeled in Excel using available water conservation measures savings potential, costs, and water and sewer utility rates.

Data

The complete list of data sets used in the San Francisco analysis are listed in Appendix A, and the choice of which data was used to determine each building characteristic is discussed in greater detail in "Step 3". This section examines resources that are particularly powerful, and relevant for projects outside of San Francisco, such as RSMeans, National Residential Efficiency Measures Database, Building America Research Benchmark Definition, and Residential Energy Consumption Survey (RECS) data. Each of these data sets are available free to the public, with the exception of RSMeans.

Though RSMeans is proprietary, it is a widely used construction cost database. Because RSMeans data products are nearly continuously updated based upon, or indexed to, regional construction cost data, the database provides perspective on how material costs and labor rates vary based on project location. Although RSMeans includes all common building components, and most uncommon ones, it is not always granular enough to indicate either outlier costs based on the circumstances at a specific site, nor how efficiency of construction processes or volume may affect costs.

The National Residential Efficiency Measure Database was developed by NREL and is referenced by BEopt's measure database. This data set is granular and varies based on level of efficiency, but is somewhat of a black box. Using both data sets (RSMeans and BEopt's National Residential Efficiency Measures Database built-in assumptions) can improve the reliability of the range of estimated ECM costs.

Building America Research Benchmark Definition is a technical report also created by NREL that summarizes typical residential building's energy usage. Many of the default baseline assumptions in BEopt were determined based on this technical report, so it is a good way to have a more detailed understanding of those inputs.

RECS data is compiled by the US Energy Information Administration (EIA). Data is compiled using household surveys, data collection from household energy suppliers, and end use consumption and expenditures estimation. This data can be used to characterize typical building appliances and energy end use breakdowns. Both the Building America Research Benchmark Definition and RECS data are a good starting point in understanding existing buildings' energy usage.

Step 3: Select Prototypical Buildings

Key parameters to define include:

a) How many prototypical buildings offer the best balance between characterizing the range of buildings in the targeted market segment(s), and budget for analysis?
b) What is the typical end-use breakdown for local buildings in this segment?
c) What building characteristics impact the most significant end uses?

Data on typical building stock was collected from public data, RS Means, City and County of San Francisco agencies, and energy programs including the Association of Bay Area Government's Bay Area Regional Energy Network (BayREN). A local consultant provided monitored data for affordable multifamily buildings, which was used to determine energy end-use breakdowns. The largest end uses in the San Francisco analysis were domestic hot water, plug loads, and heating. Below is a comprehensive summary of building characteristics used in the analysis and the sources used to collect this information.

Key Building Characteristics that Impact End Uses

Domestic Hot Water:

- Domestic hot water heater type and configuration (central, individual, gas, electric) – Bay Area Regional Energy Network (BayREN) Multifamily program
- Showerhead and sink flow rates and typical usage – Unites States Green Building Council (USGBC) baseline water usage & Building America Research Benchmark Definition
- Washing machine type and setup (laundry room or in unit) – Residential Energy Consumption Survey (RECS)
- Domestic hot water typical use – Building America Research Benchmark Definition

Heating/Cooling:

- Wall insulation – City and County of San Francisco; local consultant feedback
- Roof insulation – City and County of San Francisco; local consultant feedback
- Air leakage – San Francisco Net Zero Energy Homes Project and consultant feedback
- Window type (single pane, double pane, frame type, etc.) – City and County of San Francisco feedback
- Window to wall ratio – Reviewed Mayor's Office of Housing affordable housing stock on Google Maps
- Building skin area to building area – Land Use 2016
- Number of stories – Planning Data 2015
- Heating system (furnace, baseboard, HP, radiators, etc.) – BayREN Multifamily program
- Cooling system (heat pump, PTAC, condensing unit, no cooling, etc.) – BayREN Multifamily program
- Thermostat type (programmable, manual, smart, etc.) – Engineering judgment
- Mechanical ventilation requirements – Local ventilation codes (ASHRAE 62.1)
- Climate zone – Energy modeling software will bring in energy data file

Plug Loads:

- Appliances in unit (washer/dryer and dishwasher in unit) – RECS data
- Stovetop type and usage (electric, induction, natural gas) – CASE Report: Plug Loads
- Miscellaneous other plug loads (TV, computer, cell phone charger, etc.) – Monitored data
- Number of units – City and County of San Francisco's Mayor's Office of Housing & the BayREN Multifamily program

Lighting:

- Typical lighting type and operation – Building America Research Benchmark
- Corridor with lights included in project – BayREN Multifamily
- Parking garage and/or exterior lights included in project – View City and County of San Francisco's Mayor's Office of Housing properties on Google Maps

Solar Capacity:

- Number of stories – Planning Data 2014
- Roof area to living unit area – View City and County of San Francisco's Mayor's Office of Housing properties on Google Maps
- Building area – Land Use 2016

Buildings were divided into six different categories to enable prototype building selection: 1 unit, 2-3 unit, 3-4 unit, 5-9 unit, 10-19 unit, and 20+ unit. The goal was to capture most of the market with the least number of prototypes possible. The 5-9 unit, 10-19 unit, and 20+ unit categories captured 97% of the affordable housing market in San Francisco, so those three categories were selected for building prototypes. In retrospect, the majority of multifamily units in the City of San Francisco are in 20+ unit buildings, and the form of these buildings varies more than for smaller buildings, and the number of stories plays a large role in the cost of the net zero retrofit packages, so it likely would have been valuable to develop additional 20+ unit prototypes.

In order to determine if these building typologies accurately reflect the physical reality of the relevant urban form, it is a good idea to talk with building owners with large portfolios of the identified building types your analysis seeks to model. This exercise should confirm assumptions made for the analysis accurately reflect the characteristics of their building stock.

Step 4: Energy Conservation Measures

Appendix C provides the full summary of ECMs considered in this analysis along with their costs

a) **Determine which energy conservation measures should be analyzed** using past deep energy retrofit projects, BEopt's built-in energy conservation measures, and engineering judgment. Ideally target measures that will reduce the largest energy end-uses.
b) **Determine the cost of energy conservation measures** using BEopt's built in costs, RSMeans, and, ideally, costs from real projects completed in the area.
c) **Determine how location factors into labor and material cost** using location factors that can be found using RSMeans. This will differ by ECM, so the most accurate approach is to change the location factor for each ECM.
d) **Determine what a typical contractor mark-up is for these types of projects.** This may be difficult to obtain and is highly dependent on the economy and size of a general contractor's business. If possible, speak with a few local general contractors to see if they are willing to share this information.
e) **Determine state and city sales tax to apply to material costs.**
f) **Determine incentives available for energy conservation measures.** Again, this can be complex to understand so speaking with the City's Department of the Environment/Office of Sustainability to help navigate various programs and how they interact is recommended.

The San Francisco analysis used RSMeans to determine location factors for each ECM and adjusted cost for each measure in BEopt. The local sales tax of 8.5% was applied to all materials. The contractor mark-up assumed was 31.5%. The contractor markup only applies if a general contractor is managing the subcontractor-performed work on any/all projects, which is more likely for projects with a wide range of ECMs. In some cases, the owner may instead provide internal construction management and divide up the scope by trade or ECM (e.g. a PV contractor installs the solar electric system, a plumbing contractor separately installs the new fixtures, etc.). The contractor mark-up includes labor and materials markup (5-15%), overhead (5-15%), contingency (3-5%), and profit (0-15%, highly dependent on the economy). BEopt costs already account for contractor mark-up, so this only needs to be included in RSMeans costs or costs provided by a manufacturer. A combination of BEopt, RSMeans, project case studies, and manufacturer provided costs were used to determine ECM costs.

Once costs were compiled, they were vetted by local consultants to confirm they aligned with their experience. Given that costs can be highly variable and difficult to accurately assess, if time and budget allow, a sensitivity analysis is useful to give a range of retrofit package costs.

Step 5: Solar Analysis

Appendix C includes solar cost information

a) **Set reasonable assumptions for solar installation.** Typically, only 75% of roof area can be covered with solar PV due to shading constraints, setback requirements and other factors. Module efficiency must also be balanced with the size of the array.
b) **Determine maximum solar production a given roof can support.**
c) **Determine cost of solar.** This can be difficult to determine since the cost of solar is continuously decreasing. For this reason, speaking with local consultants and/or solar power purchase agreement providers familiar with the most relevant installation costs is recommended rather than relying on data more than six months old. The State of California's Solar Initiative database was used to determine the cost of solar for this analysis. The solar cost used for this project was $3.28 per kilowatt (kW) for standard efficiency and $3.48/kW for premium efficiency modules. For taller buildings requiring cranes and locations with no off-street parking, costs can be greater – but materials costs continue to decline.
d) **Determine incentives for solar.** The Solar Investment Tax Credits (ITC) and Modified Accelerated Cost Recovery System (MACRS) are the most common federal incentives. For ITC and MACRS, it is important that the solar owner has a tax appetite to take advantage of these incentives. Local or state programs might provide additional incentives.

Step 6: Understand Utility Economics

Appendix D includes utility bill rate structures and escalation rates

a) **What are the utility bill rate structures that inform energy, water, and sewage costs?** Depending on whether the project is master metered or individually metered it may fall under different rate structures. Typically, a master meter serving common areas and central systems would receive a commercial tariff and individual meters would fall under residential. Understanding energy and demand charges, and any fixed rates is key. Fixed rates and demand charges are critical as they may persist even once the building has achieved net zero. Water and sewage bills are important to understand as some energy conservation measures will reduce water usage (i.e. low flow fixtures and ENERGY STAR clothes washer). As stated previously, BEopt is focused solely on energy savings, so does not account for water and sewage bill savings. While BEopt can automatically optimize for the lowest carbon production at the lowest cost, including savings from water and sewage bills would need to be added manually to the analysis using a spreadsheet calculation.
b) **What is the typical carbon production per unit of electricity and natural gas?** This has a large impact on the analysis when optimizing for zero carbon emissions. Carbon emission factors for electricity should be as up to date as possible and account for all generation sources. San Francisco's analysis used Pacific Gas & Electric's (PG&E) last verified emissions factors from 2013 for electricity (427 pounds (lbs) of carbon dioxide (CO_2)/megawatt hour (MWh)). For natural gas emissions, this analysis used BEopt's default value of 14.15 lbs CO_2/therm, which is based on American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 105.
c) **How is net metering set up for this utility?** This can have a large impact on cost effectiveness of net zero since typically solar production doesn't perfectly match up with building load demand. Understanding how much solar overproduction is allowed is also necessary to understand whether natural gas carbon emissions can be offset through overproduction of onsite renewables. Excess net metering credits may also change the economics of keeping natural gas or converting to an all-electric building.

d) **How are off-site renewable options structured for this utility?** The cost effectiveness of an off-site renewable option and/or how renewable energy credits are handled may change the approach for hitting net zero. It is also important to understand if the utility allows off-site renewables in conjunction with on-site renewables and net metering. San Francisco's investor owned utility, Pacific Gas and Electric currently does not allow a given meter to combine Net Energy Metering (NEM) of onsite generation to be supplemented with Community Solar off-site generation; however, the City's CleanPowerSF Community Choice Aggregation program NEM rules provide an option to couple onsite generation with 100% renewable electricity from the grid, including community solar. In the absence of the latter option, a project would need to either decide to hit net zero using on-site renewables or off-site renewables.
e) **Does the utility allow Power Purchase Agreements (PPA)?** PPAs can be used to reduce upfront cost and potentially share benefits from ITC and MACRS when the building owner doesn't have a tax appetite. However, utilities throughout the US have varying policies on third party ownership and sale of renewable energy generation to utility customers. If the analysis intends to include a PPA, understanding the local utility's policy is key.
f) **Determine utility escalation rates.** Gas and electric rate changes can typically be found on the EIA website. The escalation rates are not more granular than the state level. Utility websites with historical prices listed can also be used to calculate escalation rates. In San Francisco's analysis, EIA data was used for energy price escalation rates and water and sewage escalation rates were derived using historical price data. Engineering and professional judgment should be used when determining escalation rates since they can have a large impact on the economics of the retrofit package over the life of the package. For example, in San Francisco's analysis the water and sewage bills were averaging a 10% annual escalation rate over the last five years due to drought. This seemed unsustainable for the length of the analysis period, so a conservative 5% annual escalation rate was selected instead so it would not be larger than the discount rate.
g) **Consider adding storage to the analysis.** While the San Francisco analysis did not include storage, as the availability and cost of storage continues to improve it is an important tool to consider when optimizing the economics in difficult utility rate structure environments. Storage could be beneficial when the utility doesn't allow a combination of net metering and off-site renewables or to reduce demand and time of use charges.

Step 7: Financing

a) Property Assessed Clean Energy (PACE): PACE is a good financing tool when seeking to reduce upfront capital spend and obtain a long financing term (20 years) for energy-related improvements. Not all jurisdictions have active PACE programs, therefore understanding the rules of PACE for your region is necessary if you want to use this financing option.
b) Low Income Housing Tax Credit (LIHTC): This is one of the biggest sources for affordable multifamily project financing. The 4% tax credit pays for roughly 30% of construction costs; the 9% tax credit pays for roughly 70% of construction costs, but is typically fully subscribed in California communities. Although these are federal tax credits, states oversee and allocate them based on their own specific requirements.
c) Incentives: Local, state, and federal incentive programs can significantly improve the financial picture of your project, but each program has its own unique set of requirements. Understanding these requirements so projects can take full advantage of available incentives will be critical.
d) Discount Rate: Due to the time value of money, discount rates are used to derive the present value of all costs and savings realized over time. The discount rate selected can change the economic narrative of a project significantly depending on where costs and savings hit in time relative to one another. Therefore, the discount rate must be selected carefully. A 5% nominal discount rate was used for the San Francisco analysis. The nominal discount rate and fuel

escalation rates were used to calculate the real discount rate, which was 0% for water and wastewater, and 2-3% for electricity and gas.

e) Term: An analysis period of 15 years was used for the San Francisco analysis, which is the typical developer investment cycle for affordable housing as they can apply for LIHTC every 15 years. An analysis period of 25 years was also used, representing the useful life of solar PV, which made up much of the retrofit package cost. If the analysis period is longer than the life of the retrofit package, determine if the cost to replace ECMs that wear out and salvage costs should be included in the analysis.

Understanding how different financing options work together can be complex. Speak with local utility program providers and net zero practitioners to understand how they all work together. San Francisco's analysis looked at the cost of the retrofit package with and without incentives and assumed all retrofit package expenses were paid for upfront.

Step 8: Optimize Analysis to Hit Net Zero in the Most Cost-effective Way

a) **Determine whether you are optimizing for site energy, source energy, or carbon production.** BEopt can optimize the building to select which ECM package has the lowest cost for a given level of carbon or energy savings. San Francisco's analysis was focused on net zero carbon retrofits, and was optimized for carbon. The BEopt run was set to optimize until net zero carbon was achieved even though solar PV was not modeled in BEopt. This allowed for modeling of deeper energy efficiency solution packages.

a) **Check that BEopt cost outputs align with desired cost**. After running the analysis, check BEopt cost outputs against expected cost outputs. The San Francisco analysis found discrepancies for lighting and mini-split heat pump costs.

b) **Be careful to change ECM names if you change cost information in BEopt.** If you are running multiple analyses and have many models going at once, be careful when updating measures. During San Francisco's analysis, there were issues with BEopt crashing when the same ECM name had different costs in different models. Copy even the duplicate ECMs and rename them for their model to avoid running into this issue.

c) **Summarize cost baseline and goals.** Select the retrofit packages that achieve net zero carbon at the lowest cost using BEopt's optimization ability. The current cost of the retrofit package was the baseline for San Francisco's analysis. Next set a target that is desirable to building owners. The two targets selected for San Francisco's analysis were a 10-year simple payback period and the present value of utility bill savings over the life of the retrofit package – 25 years. Once the baseline cost and target cost are determined, the cost reduction needed for a desirable retrofit is known. See Appendix F for the San Francisco analysis cost baseline and targets for each prototype.

Note: If standards are in place, make sure the optimization only allows options that align with standards.

APPENDIX

APPENDIX A: RESOURCES

1. Building America Research Benchmark Definition: *http://www.nrel.gov/docs/fy10osti/47246.pdf*
2. USGBC Baseline Water Usage: *http://www.usgbc.org/credits/we2*
3. RECS Data: *https://www.eia.gov/consumption/residential/data/2009/*
4. San Francisco Zero Net Energy Homes Project: *https://sfenvironment.org/article/home/san-francisco-zero-net-energy-homes-project*
5. San Francisco Planning Department 2016: Land Use Database
6. San Francisco Planning Department 2015: Land Use Database
7. Bay Area Regional Energy Network (BayREN): Characterization of BayREN Multifamily Participant Buildings
8. San Francisco Mayor's Office Housing Properties: *https://data.sfgov.org/Housing-and-Buildings/Mayor-s-Office-of-Housing-and-Community-Developmen/9rdx-httc*
9. CASE Report Plug Loads: *http://www.bwilcox.com/BEES/docs/Rubin%20-%202016%20T24CASE%20Report%20-%20Plug%20Load%20and%20Ltg%20Modeling%20-%20June%202016.pdf*
10. ASHRAE 90.1 Code: *https://www.ashrae.org/resources--publications/bookstore/standard-90-1*
11. ASHRAE 90.2 Code: *https://www.ashrae.org/standards-research--technology/standards--guidelines/titles-purposes-and-scopes#90-2*
12. California Residential Compliance Manual: *http://energycodeace.com/site/custom/public/reference-ace-2016/#!Documents/91introduction.htm*
13. California Solar Database: *https://www.californiasolarstatistics.ca.gov/*
14. RSMeans: *https://www.rsmeans.com/info/contact/about-us.aspx*
15. National Residential Efficiency Measures Database (BEopt Cost): *http://www.nrel.gov/ap/retrofits/group_listing.cfm*

APPENDIX B: BASELINE PROTOTYPE INPUTS

After reviewing multifamily housing stock data provided by the City and County of San Francisco, three prototype buildings were selected to use as baseline models for the REAL**IZE** feasibility analysis. Table 1 shows inputs for all typologies. Table 2, 3, and 4 explain the assumptions made behind the inputs.

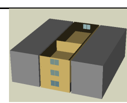
TABLE 1: SUMMARY OF PROPOSED TYPOLOGIES

	Typology 1	**Typology 2**	**Typology 3**	**Resource**
Number of Units	6	15	65	
Building Category	5-9 Units	10-19 Units	20+ Units	Mayor's Office of Housing & BayREN Multifamily
Number of Bedrooms	9 (three 2BR[3], three 1BR)	21 (six 2BR, nine 1BR)	90 (25 X 2BR, 40 X 1BR)	Mayor's Office of Housing
Size of Bedrooms (SF[4])	2 BR = 925; 1 BR = 650	2 BR = 850; 1 BR = 580	2 BR = 800; 1 BR = 500	Land Use 2016
Building Area (SF)	4,725	11,270	40,900	Land Use 2016
Number of Stories	3	3	5	Planning Data 2015
Aspect Ratio (North South/East West)	3.5	2.8	2.7	Land Use 2016
Decade Built	1900	1920	1920	Planning Data 2015
Wall	Wood frame, uninsulated	Wood frame, uninsulated	Masonry, uninsulated	SFE[5] feedback
Window	Single pane	Single pane	Single pane	SFE feedback
Window to Wall Ratio (WWR)	Narrow = 15% Long = 0%	Narrow = 15% Long = 10%	Narrow = 25% Long = 20%	Viewing Mayor's Office of Housing properties on Google Maps
Roof	Built up plywood, uninsulated	Built up plywood, uninsulated	Built up plywood, uninsulated	SFE feedback
Air Leakage	7 ACH50[6]	11 ACH50	7 ACH50	The SF Zero Net Energy Homes Project
Mechanical Ventilation	None	None	None	Not required in code
Heating	Individual furnace	Individual furnace	Central hot water boiler	BayREN Multifamily
Cooling	None	None	None	SFE feedback

[3] BR – bedroom
[4] SF – square feet
[5] SFE – San Francisco Department of Environment
[6] ACH50 – air changes per hour at 50 Pascals

Domestic Hot Water (DHW) Heater	Individual gas	Central gas	Central gas	BayREN Multifamily
Miscellaneous Plug Loads	842 kWh[7]/1BR annually 1,111 kWh/2BR annually	842 kWh/1BR annually 1,111 kWh/2BR annually	842 kWh/1BR annually 1,111 kWh/2BR annually	Metered data for affordable housing from Redwood Energy
Laundry	Common laundry room, top-loaded washer, electric dryer	Common laundry room, top-loaded washer, electric dryer	Common laundry room, top-loaded washer, electric dryer	CASE Report: Plug Loads, RECS
Appliances	No dishwasher, conventional refrigerator, gas cooking range	No dishwasher, conventional refrigerator, gas cooking range	No dishwasher, conventional refrigerator, gas cooking range	CASE Report: Plug Loads, RECS
Corridor Lighting	No	Yes, LPD[8] 0.7 W/sf, 24/7	Yes, LPD 0.7 W/sf, 24/7	BayREN Multifamily; ASHRAE 90.1 1999
Living Unit Lighting	LPD 0.93 W[9]/sf, 3 hr[10]/day	LPD 0.93 W/sf, 3 hr/day	LPD 0.93 W/sf, 3 hr/day	Building America Research Benchmark
Exterior Lighting	No exterior light	No exterior light	No exterior light	Viewing Mayor's Office of Housing properties on Google Maps

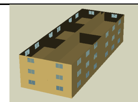
TABLE 2: EXPLANATION OF INPUTS FOR TYPOLOGY 1

	Typology 1	**Comments**
Number of Units	6	Selected this number of units since it allowed for an even number of units per floor.
Building Category	5-9 Units	5-9 unit buildings are the 2nd most prevalent (27%) residential building type in San Francisco's building stock. 8.9% of all San Francisco units are in 5-9 unit buildings.
Geometry		The typical 5-9 unit building in San Francisco is a row home. After reviewing affordable housing stock in San Francisco on Google Maps, it was determined that the longer walls typically share most wall area with their neighboring buildings. These walls were modeled as 100% adiabatic with no windows.
Number of Bedrooms	9 (three 2BR, three 1BR)	Typical 5-9 unit building units have 1.5 bedrooms, so used an even split between one and two bedroom units.
Size of Bedrooms (SF)	2 BR = 925; 1 BR = 650	Typical 5-9 unit building units are 793 sf, so one and two bedroom sizes were selected so the average unit in this building is 793 sf.

7 kWh – kilowatt-hour
8 LPD – Lighting Power Density
9 W - Watt
10 HR - Hour

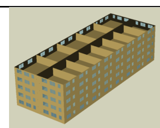
Building Area (SF)	4,725	The building area was calculated by adding the area of all the units together.
Number of Stories	3	57% of 5-9 unit residential buildings are three stories.
Aspect Ratio (North South/East West)	3.5	Average aspect ratio of 5-9 unit buildings found in planning data excluding outliers.
Decade Built	1900	1900 was the most common (36%) decade of 5-9 unit building construction. Older buildings typically have worse performance, which is beneficial for economic purposes.
Wall	Wood frame, uninsulated	Used feedback from SFE that most walls have no insulation if built prior to 1978.
Window	Single pane	Used feedback from SFE that most windows are single pane if built before 1950s.
Window to Wall Ratio (WWR)	Narrow = 15% Long = 0%	Reviewed affordable housing stock in Google Maps to determine typical WWR. Since the WWR on left and right walls was approximately 3%, a 0% WWR was used for modeling simplicity.
Roof	Built up plywood, uninsulated	Used feedback from SFE that most roofs have no insulation.
Air Leakage	7 ACH50	Took average (14 ACH50) from 12 blower door tests conducted for the SF Zero Net Energy Homes Project. Because row homes' exterior wall area to floor area ratio is low, it was assumed only 50% came from outside, which was the lower end of the ratio provided by experienced blower door testers.
Mechanical Ventilation	None	ASHRAE 62.2 does not require mechanical ventilation, so especially for older buildings they are getting their outdoor air from infiltration and natural ventilation.
Heating	Individual furnace	Majority of heating system for 5-9 unit buildings.
Cooling	None	Used feedback from SFE that most residential buildings don't have cooling if built before 2000.
Domestic Hot Water (DHW) Heater	Individual gas	Although BayREN Multifamily was split between central and individual gas DHW heaters, individual DHW heaters were selected for diversity across prototype scenarios.
Miscellaneous Plug Loads	842 kWh/1BR annually 1,111 kWh/2BR annually	Used metered data of affordable housing projects from local consultant Redwood Energy. This excludes major appliances.
Appliances	Conventional appliances	Includes conventional refrigerator. Per RECS data, 67% of buildings have central laundry units. Dishwashers are not included in the analysis, per RECS data.
Corridor Lighting	No	Majority of homes in BayREN Multifamily have external entrances for each unit.
Living Unit Lighting	LPD 0.93 W/sf, 3 hr/day	Used engineering judgment and Building America Benchmark Study to determine baseline LPD and hours of operation.
Exterior Lighting	No exterior lights	Used Google Maps of affordable housing stock. They typically have no lighting associated with balconies or street parking. The light at the entrance is a minor energy draw; these were excluded from this analysis.

TABLE 3: EXPLANATION OF INPUTS FOR TYPOLOGY 2

	Typology 2	Notes
Number of Units	15	Selected this number of units since it allowed for an even number of units per floor.
Building Category	10-19 Units	10-19 unit buildings are the most prevalent (32%) residential building type in San Francisco's affordable building stock. 22.5% of all San Francisco units are in 10-19 unit buildings.
Geometry		A typical 10-19 unit building is a split between a row home with about 50% of the left and right walls shared or a standalone building with no shared walls. A standalone building was modeled with other buildings nearby. This will yield more universal results since row buildings aren't as common outside of San Francisco.
Number of Bedrooms	21 (six 2BR, nine 1BR)	Typical 10-19 unit building units have 1.4 bedrooms, so two and one bedroom units were modeled so the average unit would be approximately 1.4 bedrooms in this building.
Size of Bedrooms (SF)	2 BR = 850; 1 BR = 580	Typical 10-19 unit building units are 690 sf, so one and two bedroom units were sized so average unit is 690 sf.
Building Area (SF)	11,270	Area was calculated by adding the area of the units and corridor together.
Number of Stories	3	69% of 10-19 unit residential buildings are three stories.
Aspect Ratio (North South/East West)	2.8	Took average of all aspect ratios for 10-19 unit buildings excluding outliers.
Decade Built	1920	1920 was the most common (30%) decade that 10-19 unit buildings were built. Older buildings typically have worse performance, in line with the type of buildings that has favorable retrofit economics.
Wall	Wood frame, uninsulated	Used feedback from San Francisco that most walls have no insulation if built prior to 1978.
Window	Single pane	Used feedback from SFE that most windows are single pane if built before 1950s.
Window to Wall Ratio (WWR)	Narrow = 15%, Long = 10%	Reviewed affordable housing stock in Google Maps to determine typical window to wall ratio.
Roof	Built up plywood, uninsulated	Used feedback from SFE that most roofs have no insulation.
Air Leakage	11 ACH50	Took average (14 ACH50) from 12 blower door tests conducted for the SF Zero Net Energy Homes Project. This prototype had the highest exterior wall area to floor area ratio, so it was assumed 75% came from outside, which was a higher end ratio provided by experienced blower door testers.
Mechanical Ventilation	None	ASHRAE 62.2 does not require mechanical ventilation for residential units, so older buildings are predominantly getting outdoor air from infiltration and natural ventilation.
Heating	Individual furnace	There was a split between individual electric heaters and individual furnaces in BayREN Multifamily. Since natural gas heating was most typical in San Francisco, the individual gas furnace was selected for this prototype.

Cooling	None	Used feedback from SFE that most buildings don't have cooling if built before 2000.
DHW Heater	Central gas	Most common DHW heater type in BayREN Multifamily for 10-19 unit buildings
Miscellaneous Plug Loads	842 kWh/1BR, 1,111 kWh/2BR	Used metered data of affordable housing projects from Redwood Energy; this excludes major appliances.
Appliances	Conventional Appliances	Includes conventional refrigerator. Per RECS data, 67% of buildings have central laundry units. Dishwashers are not included in the analysis, per RECS data.
Corridor Lighting	Yes, LPD 0.7 W/sf, 24/7	Most 10-19 unit buildings have a common corridor. The LPD comes from ASHRAE 90.11999 corridor lighting requirement. This was the oldest 90.1 corridor lighting requirement found.
Living Unit Lighting	LPD 0.93 W/sf, 3 hr/day	Assumption based on RMI experience and building America Benchmark Study to determine baseline LPD and hours of operation.
Exterior Lighting	No exterior lights	Used Google Maps of affordable housing stock. They typically have no lighting associated with balconies or street parking. The light at the entrance is a minor energy draw and was excluded from this analysis.

TABLE 4: EXPLANATION OF INPUTS FOR TYPOLOGY 3

	Typology 3	**Notes**
Number of Units	65	Selected this number of units as it allowed for an even number of units per floor.
Building Category	20+ Units	20+ unit buildings are the third most prevalent (20%) residential building type in San Francisco affordable building stock. 66.2% of all San Francisco units are 20+ unit buildings.
Geometry		A typical 20+ unit building is a split between a row home with about 40% of the left and right walls shared or a standalone building. This will yield more universal results, as row buildings aren't as common elsewhere. The more units the less likely the building was to be a row building. Therefore, a standalone building was modeled with other buildings nearby given the number of units (65).
Number of Bedrooms	90 (25 X 2BR, 40 X 1BR)	Typical 20+ unit building units have 1.4 bedrooms, so two and one bedroom units were modeled so the average unit would be approximately 1.4 bedrooms.
Size of Bedrooms (SF)	2 BR = 800; 1 BR = 500	Typical 20+ unit building units are 620 sf, so one and two-bedroom units were sized so average unit is 620 sf.
Building Area (SF)	40,900	This was calculated by adding the area of the units and corridor together.
Number of Stories	5	Although three-story buildings are the most common for this typology, a five-story prototype was selected to represent a building in the commercial energy code category.
Aspect Ratio (North South/East West)	2.7	This is the average aspect ratio for 20+ unit buildings.
Decade Built	1920	1920 was the most common (19%) decade that 20+ unit buildings were built.
Wall	Masonry, uninsulated	Used feedback from SFE that most walls have no insulation if built prior to 1978.

Window	Single pane	Used feedback from SFE that most windows are single pane if built before 1950s.
Window to Wall Ratio (WWR)	Narrow = 25%; Long = 20%	Reviewed Mayor's Office of Housing affordable housing stock in Google Maps to determine typical WWR.
Roof	Built up plywood, uninsulated	Used feedback from SFE that most roofs have no insulation.
Air Leakage	7 ACH50	Took average (14 ACH50) from 12 blower door tests completed in San Francisco. Due to low skin to floor area ratio, it was assumed only 50% came from outside, the lower end of ratios provided by experienced blower door testers.
Mechanical Ventilation	None	ASHRAE 62.2 does not require mechanical ventilation for residential units, so older buildings are predominantly getting outdoor air from infiltration and natural ventilation.
Heating	Central Hot Water Boiler	BayREN Multifamily listed many different heating systems for this type of building. A central hot water boiler was selected for diversity as all other typologies used individual heating systems.
Cooling	None	Used feedback from SFE that most buildings don't have cooling if built before 2000.
DHW Heater	Central gas	Most common DHW heater type in BayREN Multifamily for 20+ unit buildings.
Miscellaneous Plug Loads	842 kWh/1BR, 1,111 kWh/2BR	Used metered data of affordable housing projects from local consultant, Redwood Energy. This excludes major appliances.
Appliances	Conventional Appliances	Includes conventional refrigerator. Clothes washer/dryer energy will be reduced to approximate central laundry per RECS data that 67% of buildings have central units. Dishwashers are not included in the analysis, as RECS data showed they are not common in these buildings.
Corridor Lighting	Yes, LPD 0.7 W/sf, 24/7	Most of this building type category has common corridors. The LPD comes from ASHRAE 90.11999 corridor lighting requirement. This was the oldest 90.1 corridor lighting requirement found.
Living Unit Lighting	LPD 0.93 W/sf, 3 hr/day	Used engineering judgment and benchmark study to determine baseline LPD and hours of operation.
Exterior Lighting	No exterior lights	Used Google Maps of affordable housing stock. They typically have no lighting associated with balconies or street parking. The light at the entrance is a minor energy draw and was excluded from this analysis.

APPENDIX C: ENERGY CONSERVATION MEASURE COST

6 UNIT PROTOTYPE COSTS

Wall Insulation	ECM Name	Material Cost ($/SF Exterior Wall)	Labor Cost ($/SF Exterior Wall)	Corridor Factor	Notes
BEopt does not include corridor exterior wall in wall area, so cost must be adjusted by corridor factor (total exterior wall/living unit exterior wall).	Wood Stud R-13 Fiberglass	$2.55	$2.55	N/A	Material cost and location factor comes from RSMeans. Added sales tax (8.5%) and contractor markup (31.5%) to material cost. Labor rate comes from BEopt with RSMeans location factor included.
	Wood Stud R-23 Closed Cell Spray Foam	$2.90	$3.49		
	R-6 Polyisocyanurate Continuous Insulation	$0.91	$4.334		
	R-12 Polyisocyanurate Continuous Insulation	$1.31	$4.334		Material cost and labor cost come from BEopt. Location factor comes from RSMeans. Added sales tax (8.5%) to material cost.
	R-15 XPS[11] Continuous Insulation	$2.10	$4.334		

[11] XPS- Extruded Polystyrene

Roof Insulation	ECM Name	Material Cost ($/SF Roof)	Labor Cost ($/SF Roof)	Corridor Factor	Notes
Note: BEopt does not include corridor roof area, so cost must be adjusted by corridor factor (total roof area/living unit roof area).	R-15 XPS Continuous Insulation	$3.70	$4.69	N/A	Material cost and location factor comes from RSMeans. Added sales tax (8.5%) and contractor markup (31.5%). Labor rate comes from BEopt with RSMeans location factor included.
	R-25 XPS Continuous Insulation	$5.89	$4.69		
	R-35 XPS Continuous Insulation	$8.39	$4.69		

High Performance Windows	ECM Name	Material Cost ($/SF Window)	Labor Cost ($/SF Window)	Notes
	U-0.49, SHGC[12]-0.56 (clear, double, non-metal, air)	$14.27	$32.88	Material cost and labor cost come from BEopt. Location factor comes from RSMeans. Added sales tax (8.5%) to material cost.
	U-0.39, SGHC-0.53 (low-E[13], double, non-metal, air)	$15.35	$32.88	
	U-0.37, SHGC-0.3 (Low-E, double, non-metal, air)	$15.99	$32.88	
	U-0.35, SHGC-0.44 (Low-E, double, non-metal, argon)	$16.76	$32.88	
	U-0.32, SHGC-0.56 (Low-E, double, insulated, air)	$18.76	$32.88	

[12] SHGC – Solar Heat Gain Coefficient
[13] LOW-E – Low-emittance

	U-0.3, SHGC-0.46 (Low-E, double, insulated, air)	$20.59	$32.88	
	U-0.26, SHGC-0.31 (Low-E, double, insulated, argon)	$29.50	$32.88	
Air Leakage	ECM Name	Material Cost ($/SF Building)	Labor Cost ($/SF Building)	Notes
	7 ACH50 --> 6 ACH50	$0.07	$0.38	Costs were multiplied by exterior wall and roof area to living unit area ratio so cost is per exterior surface area and not building square foot like BEopt requires as an input. Based on feedback with air sealing specialists they suggested that each ACH50 reduction was not created equal, so cost increases the more stringent the air sealing.
	7 ACH50 --> 4 ACH50	$0.09	$0.95	
	7 ACH50 --> 2 ACH50	$0.11	$1.69	
	7 ACH50 --> 1 ACH50	$0.12	$2.13	
HVAC	ECM Name	Material Cost ($/Unit)	Labor Cost ($/Unit)	Notes
	Gas Furnace, 80% efficient	$967.00	$2,045.30	Used labor rates from BEOpt. Used material cost from HP manufacturer and supplemented with BEopt. Added sales tax (8.5%) and contractor mark-up to heat pump manufacturer cost. Used location factors from RSMeans.
	Electric Furnace	$949.38	$2,045.30	
	Mini-split 12 kBtu[14]/unit, SEER[15] 14.5, 8.2 HSPF[16]	$1,298.37	$3,263.43	
	Mini-split 12 kBtu/Unit, SEER 23, 10.5 HSPF	$1,391.11	$3,263.43	
	Mini-split 12 kBtu/unit, SEER 26, 12.5 HSPF	$1,483.85	$3,263.43	
	Mini-split 12 kBtu/unit, SEER 29.3, 14 HSPF	$1,713.22	$3,263.43	
	Electric Baseboards	$23.17	$39.75	

[14] KBTU – Thousand British Thermal Units
[15] SEER – Seasonal Energy Efficiency Ratio
[16] HSPF – Heating Seasonal Performance Factor

Air Quality	ECM Name	Material Cost ($/Unit)	Labor Cost ($/Unit)	Add Cost ($/CFM)	Notes
	Supply ASHRAE 62.2 2013	$380	$905	-	Material cost and labor cost come from BEopt. Location factor comes from RSMeans. Added sales tax (8.5%) to material cost.
	HRV[17], 60% 2013 ASHRAE 62.2	$322	$1,857	$4.15	
Air quality addition only required when air leakage was below 4 ACH50. This will result in energy penalty, but is necessary once air leakage is reduced.	ERV[18], 72% 2013 ASHRAE 62.2	$283	$1,857	$5.50	
DHW Heaters	ECM Name	Material Cost ($/Unit)	Labor Cost ($/Unit)	Notes	
	Gas, standard, 30 gallons (individual, baseline)	$362.39	$1122.17	Used labor rates from BEopt. Used DHW cost from RSMeans. Added sales tax (8.5%) and contractor markup (31.5%). Used location factors from RSMeans.	
	Gas, condensing, 30 gallons (individual)	$1,458.24	$1,086.34		
	Electric premium, 25 gallons (individual)	$334.72	$1,122.17		
	HPWH[19], 50 gallons (individual)	$1,277.05	$1,122.17		
LED[20] Lights	ECM Name	Material Cost ($/SF Living Unit)	Labor Cost ($/SF Living Unit)	Notes	
Corridor lighting cost is included in cost/sf living unit, so costs are adjusted depending on corridor size.	100% LED Lights	$0.09	$0.34	Light bulb cost came from research into wholesale cost and included sales tax. Labor time was assumed 10 minutes per fixture and rate was adjusted for San Francisco using RSMeans.	
Solar	ECM Name	Total Cost ($/W)		Notes	

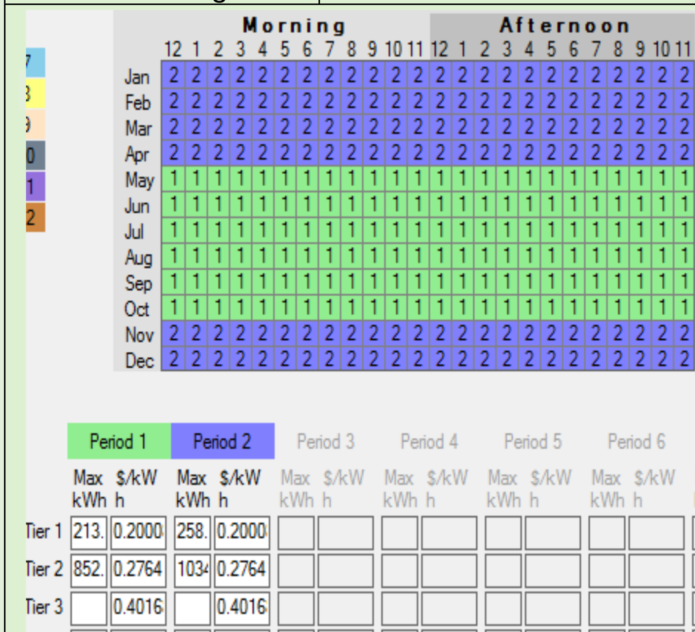
[17] HRV – Heat Recovery Ventilator
[18] ERV – Energy Recovery Ventilator
[19] HPWH – Heat Pump Water Heater
[20] LED – Light-Emitting Diode

	Solar	$3.28/W standard efficiency $3.48/W premium efficiency	Solar cost came from average of lowest 10% of San Francisco solar projects in December 2016.

Other	ECM Name	Material Cost ($/Unit)	Labor Cost ($/Unit)	Adjustment Factor	Notes
A few adjustment factors are included to fix some BEopt modeling assumptions. BEopt models a clothes washer and clothes dryer per unit. Most (66%) multifamily buildings have central laundry rooms. These adjustment factors effectively reduce the quantity of appliances accordingly.	Refrigerator (top mounted, no ice machine), 15.9 EF[21]	$576	$339	N/A	Material cost and labor cost come from BEopt. Location factor comes from RSMeans. Added sales tax (8.5%) to material cost. Some appliances were compared to retail price to confirm price seemed accurate.
	ENERGY STAR refrigerator (top mounted, no ice machine), 21.9 EF	$971	$339	N/A	
	Cooking range - electric	$ 899	$260	N/A	
	Cooking range - electric, Induction	$1,937	$260	N/A	
	Conventional clothes washer, top loaded	$791	$285	0.33	
	ENERGY STAR clothes washer, front loaded	$956	$285	0.33	
	ENERGY STAR clothes dryer (electric)	$803	$397	0.33	
	Heat pump clothes dryer (electric)	$1,519	$397	0.33	
	Low flow showerhead, 1.8 gpm[22]	$68	$51	N/A	
	Low flow faucet aerator, 1.5 gpm	$6	$31	N/A	
	Smart thermostat	$270	$250	N/A	

[21] EF – Energy Factor
[22] GPM – Gallons Per Minute

APPENDIX D: ECONOMIC INPUTS

Incentives	Program Name	Incentive Available	Requirement
	PG&E Multifamily Upgrade Program	$400/unit + $25/unit per additional percent improvement above 10%	10%-18% improvement, PV and air sealing do not qualify
		$675/unit + $75/unit per additional percent improvement above 19%	19%-50% improvement, PV and air sealing do not qualify
	ITC	30% cost of installation	Must have tax appetite; can still benefit from using a PPA but may not realize full benefits
	MACRS	Not included in this analysis	Must have tax appetite; can still benefit from using a PPA but may not realize full benefits
Electricity Cost	Minimum Charge:	$9.9999/month	Notes
			BEopt only allows a monthly tiered structure, so since PG&E uses a daily tiered use structure, the maximum cost was multiplied by 30.4375 (average number of days in the month). PG&E Also charges an additional $0.00029/kWh to fund the California energy commission. This will be added to the rate structure. Rates come from baseline territory T, March 2017 values: http://www.pge.com/nots/rates/tariffs/tm2/pdf/ELEC_SCHEDS_E-1.pdf

Gas Cost	Rate		Notes
	$1.28967/therm		BEopt does not allow tiered rates for natural gas, so the baseline rate ($1.28967/therm) was assumed in the model. For baseline energy consumption, the tiered structure was manually added. After reviewing the baseline natural gas use, the average day does not exceed 0.69 therms/unit/day, so it should be in the lower tier the majority of the time. When natural gas exceeds 0.69 therms/unit/day in April 1st - October 31st or 1.79 therms/unit/day during November 1st - March 31st the rate increases to $1.82246/therm. BEopt also does not allow a minimum charge for natural gas (would be $3.00/month), it only allows a fixed charge. No fixed cost was included in BEopt, but was added manually if needed. Rates come from baseline territory T, March 2017 values: http://www.pge.com/tariffs/tm2/pdf/GAS_SCHEDS_G-1.pdf
Water and Sewer Cost	Rate		Notes
	Water Charge:	$6.14/Unit/DU[23]/Month	1 Unit = 1 ccf[24] of water = 749 gallons *Source: http://www.sfwater.org/index.aspx?page=169*
	Wastewater Charge:	$10.91/Unit/DU/Month	
Economic Assumptions	Inputs	Value	Notes
	Project analysis period	15 years, 25 years	15 years is typical investment cycle for affordable multifamily developers and 25 years is the life of a solar PV array, which makes up majority of cost for retrofit package.
	Natural gas escalation rate	0.8%	Average escalation of natural gas prices over last 10 years from EIA for California.
	Electricity escalation rate	3.2%	Average escalation over last 10 years from EIA for California.
	Water escalation rate	5.0%	Sewage and water both escalated at 10% over the last five years. To be conservative, an escalation rate equal to the discount rate of 5%.
	Discount rate	5.0%	Conservative discount rate.
	Efficiency material cost multiplier	Varies by ECM	Already accounted for in ECM costs since accounted for per measure instead of an averaged material cost multiplier.

[23] DU – Dwelling Unit
[24] CCF – 100 Cubic Feet

APPENDIX E: PARTIAL LIST OF CALIFORNIA AFFORDABLE HOUSING RETROFITS DESIGNED FOR ZNE

The following retrofit projects are designed for site ZNE, and have not yet verified at least one year of demonstrated net-zero or near-zero energy performance. This is not exhaustive; it merely documents that ZNE multifamily retrofits are indeed a segment of ZNE buildings. In addition to the net zero projects below, the research found a number of projects with zero net electricity use and gas thermal appliances, as well as all-electric sites with up to 80% energy cost reduction.

Building Name	**City**	**ZNE Status**	**Units**	**Project Completed**	**Program or Designer**
Unknown	Eureka	ZNE design (measurement data not public)	52	Under construction	Redwood Energy
William Penn Hotel	San Francisco	ZNE design	94	In design	Integral Group, RMW Architects
Corona Del Rey	Corona	ZNE design	160	Under construction	Association for Energy Affordability (LIWP)
Pleasant View Apartments	Fresno	ZNE design	60	Under construction	
Season at Ontario	Ontario	ZNE design	80	Under construction	
Solinas Village (Self-Help Enterprises)	McFarland	ZNE design (95%+ modeled reduction in energy cost, measurement data not yet public)	304	2016	
Casas de la Vina (Self-Help Enterprises)	Madera			2016	
Self-Help Enterprises	Wasco			2016	
Self-Help Enterprises	Goshen			2016	
Self-Help Enterprises	Oildale			2016	
Total	100% affordable	Designed for ZNE	750	10	2 organizations polled

Sources:

Association for Energy Affordability (2017)

- https://camultifamilyenergyefficiencydotorg.files.wordpress.com/2017/05/liwp-property-profile-shev8.pdf
- http://www.bigconference.green/pdfs/Low-Rise-Multifamily-Case-Studies-A-Shotgun-Approach-to-Net-Zero-ish_John-Neal-and-Stephen-Gribble.pdf

Redwood Energy (2017) personal communication. Redwood Energy was polled because of track record with ZNE new construction affordable housing.

APPENDIX F: SAN FRANCISCO ANALYSIS COST BASELINE AND TARGETS

	6 Unit Prototype	15 Unit Prototype	65 Unit Prototype
Current Net Zero Carbon Retrofit Cost ($/Unit)	$19,013	$22,255	$22,296
Cost With Current Incentives ($/Unit)	$7,527	$8,985	$11,329
Price Point Using 25 Year Present Value* Utility Bill Savings ($/Unit)	$17,997	$22,053	$12,189
Cost Reduction Required to be Paid for Through 25YR Utility Bill Savings (Without Incentives/With Incentives)	5.34% / 0%	0.9% / 0%	45.3% / 0%
Price Point for 10 Year Simple Payback Period	$9,045	$11,371	$5,867
Cost Reduction Required for 10 Year Simple Payback Period (Without Incentives/With Incentives)	52.4% / 0%	48.9% / 0%	73.7% / 48.2%

*The energy savings present value was calculated using a 5% discount rate and an escalation rate of 2.28-2.48%, which is a blended average rate based on last 10 years of gas and electric escalation in California from the EIA. 25 years selected as life of retrofit package. The water and sewage savings were calculated assuming 5% discount rate and 5% escalation rate.

APPENDIX G: ACRONYM KEY

- ACH50 – Air Changes Per Hour at 50 Pascals
- ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers
- BayREN – Bay Area Regional Energy Network
- BEopt – Building Energy Optimization
- BR – Bedroom
- ECM – Energy Conservation Measure
- CASE – Codes and Standards Enhancement Initiative
- CCF – 100 Cubic Feet
- CO_2 – Carbon Dioxide
- DHW – Domestic Hot Water
- DU – Dwelling Unit
- EF – Energy Factor
- EIA – United States Energy Information Administration
- GPM – Gallons Per Minute
- HR – Hour
- HPWH – Heat Pump Water Heater
- HRV – Heat Recovery Ventilator
- HSPF – Heating Seasonal Performance Factor
- HVAC – Heating, Ventilation, and Air Conditioning
- ITC – Solar Investment Tax Credit
- kBtu – Thousand British Thermal Units
- kWh – Kilowatt-hour
- LBS – Pounds
- LED – Light-Emitting Diode
- LIHTC – Low Income Housing Tax Credit
- Low-E – Low-emittance
- LPD – Lighting Power Density
- MACRS – Modified Accelerated Cost Recovery System
- MWH – Megawatt hour
- NREL – National Renewable Energy Laboratory
- PACE – Property Assessed Clean Energy
- PG&E – Pacific Gas and Electric
- PPA – Power Purchase Agreement
- REC – Renewable Energy Credits
- RECS – Residential Energy Consumption Survey
- SAM – System Advisor Model
- SEER – Seasonal Energy Efficiency Ratio
- SF – Square Foot
- SFE – San Francisco Department of Environment
- SHGC – Solar Heat Gain Coefficient
- SOLAR PV – Solar Photovoltaic
- US – United States
- W – Watt
- WWR – Window to Wall Ratio
- XPS- Extruded Polystyrene
- ZNE – Zero Net Energy