City of Seattle

Climate Action Champions

Cost Effectiveness of Deep Green Alterations

Issue 2 | August 14, 2015

Job number 243463-00

Arup North America Ltd
12777 W Jefferson Blvd
Los Angeles
California 90066
www.arup.com

ARUP

Document Verification

ARUP

Job title	Climate Action Champions			**Job number** 243463-00
Document title	Cost Effectiveness of Deep Green Alterations			**File reference**
Document ref				

Revision	**Date**	**Filename**			
Draft 1	06/05/15	**Description**	Rough draft		
			Prepared by	Checked by	Approved by
		Name	Kevin Wan	Martin Howell	Douglas Nordham
		Signature			
Draft	06/22/15	**Filename**			
		Description	Draft		
			Prepared by	Checked by	Approved by
		Name	Kevin Wan	Martin Howell	Douglas Nordham
		Signature			
Issue	06/30/15	**Filename**			
		Description			
			Prepared by	Checked by	Approved by
		Name	Kevin Wan	Martin Howell	Douglas Nordham
		Signature			
Issue 2	08/14/15	**Filename**			
		Description			
			Prepared by	Checked by	Approved by
		Name	Kevin Wan	Martin Howell	Douglas Nordham
		Signature			

Issue Document Verification with Document ✓

Contents

		Page
	Document Verification	1
Contents		**1**
1	**Executive Summary**	**1**
2	**Introduction**	**3**
3	**Code and Market Landscape**	**4**
3.1	Seattle Energy Code	4
3.1.1	Prescriptive approach	4
3.1.2	Component performance building envelope option	4
3.1.3	Total Building Performance Path	4
3.1.4	Target Performance Path	5
3.2	Energy in Seattle	5
4	**Building Prototype Development**	**7**
4.1	Baseline - Boylston-Howell Apartment	7
4.2	Building Energy Modeling	7
4.3	Baseline Energy Use & Commentary	10
5	**Energy Conservation Measures**	**12**
5.1	Strategies	12
5.2	ECM 1- Lighting Upgrade & Control	14
5.3	ECM 2- Upgrade exhaust fan efficiency in common areas	16
5.4	ECM 3- Reduce common area corridor over ventilation	17
5.5	ECM 4- Setback control for heating set point and digital thermostat	17
5.6	ECM 5 - Humidity sensors for clothes dryer	18
5.7	ECM 6 - High efficiency boilers (condensing)	19
5.8	ECM 7 - Tankless hot water boilers (apartment by apartment)	19
5.9	ECM 8 - Seasonal boiler set-point temperature setback	20
5.10	ECM 9 - Air source heat pump water heaters	20
5.11	ECM 10- Heat recovery from shower drain	22
5.12	ECM 11 - Renewable photovoltaic	22
5.13	ECM 12 - Envelope upgrade	24
5.14	ECM 13 - Air source heat pump space heating	26

5.15 ECM 14- Heat recovery ventilation 27
5.16 ECM 15 – Solar hot water heating 28
5.17 ECM 16– Home battery storage and photovoltaic 29
5.18 ECM Suite Analysis and Net-Zero Potential 31

6 Costs & Payback Analysis 32
6.1 Baseline Energy Cost 32
6.2 ECM Energy Cost Savings & Recommendations 32
6.3 Life-Cycle Cost Analysis 34

7 Citywide adoption 36
7.1 Citywide viability of measures 36
7.2 Recommendations 40

8 Appendix 44

Table 1. Energy Utilization Index Comparisons 12
Table 2. Lighting Power Density (LPD) for baseline case 14
Table 3. LPD for proposed design 15
Table 4. Proposed lighting control strategies 15
Table 5 Hot water heating thermal efficiency in baseline and proposed designs 19
Table 6. Envelope thermal properties in baseline and proposed designs 24
Table 7. Baseline & proposed design for space heating 26
Table 8. Utility unit rate economic calculations 32
Table 9. Energy & energy cost saving summary 33
Table 10 ECM Costing Summary 34
Table 11 Life Cycle Cost Analysis Results 36
Table 12 - ECM Citywide applicability 38
Figure 1 - ECM Energy Savings 2
Figure 2. Seattle City Light Fuel Mix 6
Figure 3. Boylston-Howell apartment 7
Figure 4 - Energy bills for prototype building (2014) 8
Figure 5 Model calibration for gas consumption 10
Figure 6. Model calibration for electricity consumption 10
Figure 7. Energy distribution for prototype building 11
Figure 8. Benchmarking for developed building prototype 12
Figure 9. Energy and lighting audit 14
Figure 10. Energy performance for lighting upgrade 16
Figure 11 - Existing thermostat (Left) & "Smart" Thermostat (Right) 17

Figure 12 Energy performance for setback control of heating set point.............. 18
Figure 13 Energy performance for heat pump hot water heating 21
Figure 14 - Drain heat recovery (source: energy.gov) 22
Figure 15. Roof and usable PV areas estimation (Ref. NREL-PV Watts)............ 23
Figure 16. Energy performance for building envelope upgrade 25
Figure 17. Electricity performance for air source heat pumps (HSPF=6.8) 27
Figure 18. Principles of HRV and typical products 28
Figure 19 Electricity demands and photovoltaic energy generation profiles........ 29
Figure 20 Proposed TOU electricity tariff 30
Figure 21 Individual & cumulative energy use summary..................................... 31
Figure 22. Baseline energy cost summary 32

1 Executive Summary

The City of Seattle has set itself the bold goal of achieving zero net greenhouse gas emissions by 2050. In order to reach this target, a number of major obstacles will need to be overcome. One significant hurdle is related to the City's existing building stock energy usage. There are some existing programs that look to improve the energy efficiency of these buildings but the pace of change needs to be significantly increased in order to meet the 2050 goal.

This report focuses on the existing multi-family, residential buildings within the City which – according to Seattle's benchmarking program – account for 49% of all reporting buildings 20,000 sq. ft. or greater (i.e., residential, commercial, and institutional). Many are operating with energy use intensities that significantly exceed buildings that are designed and constructed to current energy standards and so, the potential to impact the City's greenhouse gas goals by targeting this building sector is significant.

The report uses a prototype building as the basis of study – a 30 unit, six level, 39,000 sqft building located in the Capitol Hills / Central District. A detailed physical survey was completed at the building to understand the major sources of energy use and to identify possible energy conservation measures (ECM's) and on-site generation approaches.

A computational energy model was then created and calibrated before ECM's and on-site generation were either quantitatively or qualitatively evaluated. The ECMs were also considered from the point of view of being more broadly applicable to the multi-family building stock in Seattle.

A total of 18 ECM's were identified ranging from lighting upgrades, building automation, heat recovery and making the switch to more efficient forms of heating. Renewable energy was also assessed, though this generates energy as opposed to reducing it. The ECM's analyzed and shortlisted were estimated to reduce the buildings energy consumption by 39% through improved efficiency. Renewable energy was estimated to supply 14% of the remaining load, leading to a total reduction of imported energy from conventional utilities nearing 53%. Although interactive effects between these ECM's were not accounted for due to the study's scope, it is estimated that this level of saving could still be achieved once some of the ECM's that were identified but not analyzed are accounted for.

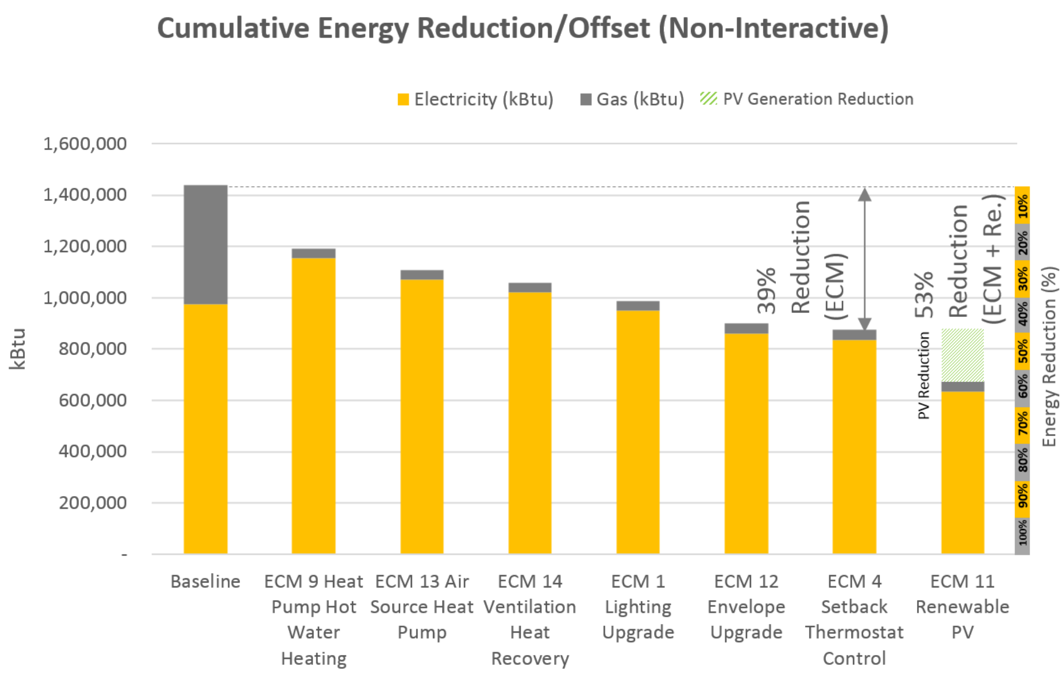


Figure 1 - ECM Energy Savings

The ECM's were then assessed to understand their applicability Citywide. It is estimated that the modeled ECM's could help reduce the energy consumption in multi-family homes Citywide by about 39%, as applied to approximately 651 million square feet of low, mid and high rise buildings.

In terms of carbon impact, this translates into a saving of approximately 245 MMtonsCO_2 / year, a reduction of 25% below current multi-family building sector emissions for buildings that are greater than 20,000 sqft.

This report also touches on potential approaches that could be considered to help gain adoption of the ECM's Citywide. This includes features or benefits that should be promoted for certain EMC's, suggested programs and tools and for ECM's that are likely to be viable in the future, methods that may help promote future adoption.

2 Introduction

The City of Seattle is committed to achieving community-wide carbon-neutral operations for all of its non-industrial functions by the year 2050, including not only Seattle's buildings, but also its transportation, and waste handling. Additionally, this goal is supported by intermediate building sector targets for 2030, The City mandates significant code requirements for new construction and tenant improvements. The City's 2012 energy code is estimated to result in buildings that use 11.3% less energy than buildings constructed in accordance with the 2010 edition of ASHRAE 90.1, making it one of the most advanced codes in the nation[1].

The State has also implemented a renewable portfolio standard requiring that all electric utilities serving more than 25,000 customers in the state of Washington, obtain 15% of their electricity from new renewable sources by 2020.

Until the 2012 energy code cycle, Seattle was not allowed to amend the residential portions of the energy code locally. Seattle now has the authority to amend these for multi-family buildings over three stories.

Existing multi-family buildings are considered especially difficult to address in terms of energy efficiency upgrades. This is because common areas and residences typically have separate utility meters, with different entities responsible for paying utility bills. This means that upgrades completed by a building owner may return savings only to a tenant, making capital investment economics difficult. Conversely, tenants are unlikely to make investments in energy efficient appliances and building fixtures without some long-term benefit or incentive.

The potential energy impacts from this building sector however are significant and worthy of pursuit. Based on data from Seattle's benchmarking program for buildings greater than or equal to 20,000 ft^2, 49% of these are multi-family and at least 25% of those operate with Energy Use Intensities (EUI's) of 45[2] to 120 kBtu/ft^2. Buildings constructed under current energy standards would operate at about 35 kBtu/ft^2, meaning the potential energy savings are between 22 and 71%.

This report aims to develop a roadmap for a transition of the existing Seattle multi-family housing stock in terms of potential energy upgrades and their benefit to Seattle's environmental and energy goals.

These upgrades may include:

1. A transition from fossil fuel heating, primarily natural gas, to high-efficiency electric heating, to take advantage of their predominantly carbon-neutral electricity grid.

---

[1] Mike D. Kennedy Inc. for Seattle Office of Sustainability & Environment. Comparison of the 2012 Seattle Energy Code with ASHRAE 90.1-2010. June 2014.

[2] Seattle Office of Sustainability & Environment. 2011/2012 Seattle Building Energy Benchmarking Analysis Report. January 2014.

2. Transition from inefficient electric resistance heating to more efficient heat pump electric heating and making use of heat recovery strategies.
3. Phasing out inefficient lighting and transform to energy efficient and advanced control lighting systems
4. Upgrade building electrical infrastructure and be future-ready ready for renewable power such as solar photovoltaic energy generation.

This report uses the energy audit of an existing multi-family building as a template to assess these goals through a real, case-study example. Findings are then assessed and leveraged Citywide, to understand the potential of these ECMs to provide residential market transformation.

3 Code and Market Landscape

3.1 Seattle Energy Code

The 2012 Seattle Energy Code is the standard currently enforced in the City. This standard is an amended version of the 2012 Washington State Energy Code which in turn is based on the International Energy Conservation Code. As is typical, the Energy code is revised following a three year improvement cycle. The Code offers a number of compliance paths.

3.1.1 Prescriptive approach

Under the prescriptive approach, building envelope components (walls, roofs, glazing etc.) and all other regulated systems need to meet the performance described in the Code on a component by component basis.

3.1.2 Component performance building envelope option

Should the prescriptive envelope approach not be met, a trade-off approach can be used. Here the total code maximum heat loss rate of the envelope should be met by the proposed building envelope. This effectively allows buildings to trade off, say, poorer performing glazing with higher performance wall insulation levels.

3.1.3 Total Building Performance Path

The Total Building Performance path in the Seattle code is an energy modeling approach similar to that in the 2012 IECC, allowing tradeoffs among building systems and building envelope components as compared with a code-minimum baseline building.

3.1.4 Target Performance Path

Certain building occupancy types are allowed to comply with the Target Performance Path and then just need to comply with defined mandatory measures, being exempt from the rest of the code. This includes type B office buildings and type R-2 multi-family buildings over three stories. To comply with the Target Performance Path, buildings need to verify though energy modeling that they can achieve energy use targets that are below prescribed values from the Code and then verify that this target has been achieved during building operation following award of the certificate of occupancy. As the City gears up for the 2015 version of the code, a series of interlocking changes are being proposed and seeking legislative approval including the following;

- Significant changes to mechanical system design and control requirements for commercial and residential buildings are being considered including the following.
    - Dedicated outdoor air systems (DOAS) required for office, retail, education, libraries and fire stations, complete with either energy recovery and / or demand control ventilation. Economizers no longer needed where these systems are provided.
    - Increased glazing areas over 30% where high performance mechanical systems – including DOAS – are provided.
    - Thermostatic controls configured such that perimeter system HVAC zone are not able to operate in a different heating or cooling mode than adjacent zones and hence prevents the occurrence of simultaneous heating and cooling in commercial buildings.

3.2 Energy in Seattle

Fuel sources for Seattle's multifamily building stock include electricity from Seattle City Light, a publically owned utility, natural gas from Puget Sound Energy, and some steam from Enwave. In the case of Seattle City Light, the current fuel mix relies mainly on hydroelectricity as well as some wind and landfill gas (see figure 2). With this fuel mix, and by purchasing offsets for remaining greenhouse gas emissions, Seattle City Light maintains carbon neutral status. Washington State has renewable portfolio standards (RPS) that require electricity retailers to acquire minimum percentages of electricity from the grid. Currently, these standards require that at least 15% of electricity is provided from eligible renewable sources by 2020. Hydroelectricity, though classified as renewable is not one of the eligible renewable sources required by the RPS. As Seattle City Light continues to add additional renewables, the percentage of the fuel mix supplied by lower carbon intensity sources will continue to grow.

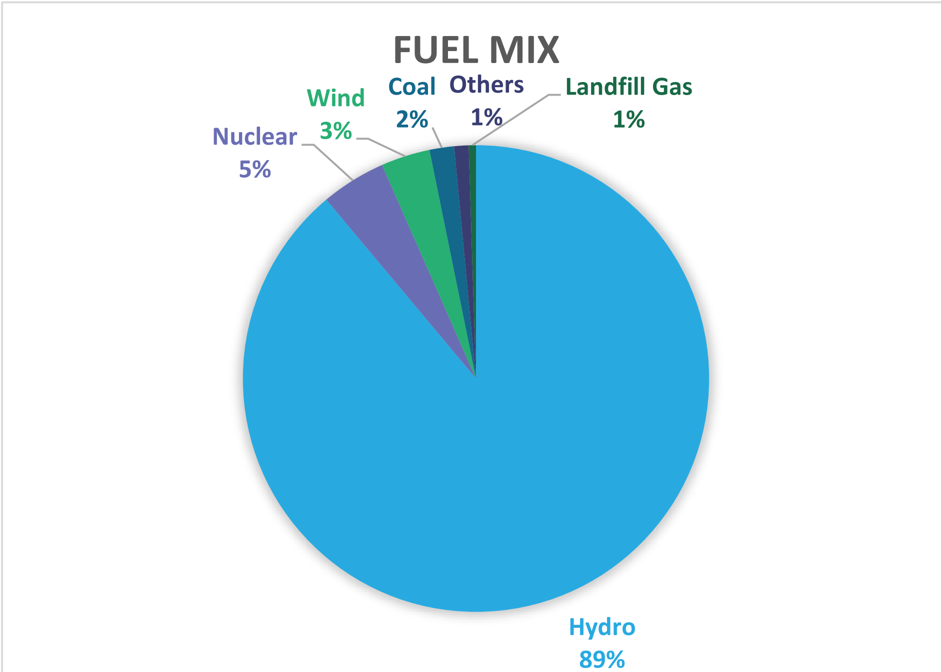


Figure 2. Seattle City Light Fuel Mix

Ref: 2013 revised fuel mix, Seattle City Light Website (http://www.seattle.gov/light/FuelMix/)

4 Building Prototype Development

To further understand viable energy efficiency and alternative energy strategies for multi-family housing, an existing building was identified to act as a prototype baseline case for this study.

4.1 Baseline - Boylston-Howell Apartment

The building chosen is the Boylston-Howell apartment building, owned and managed by Capitol Hill Housing in Seattle and built in 1996. It is a 6-story building with 30 apartment units and the gross floor areas is about 38,600SF (24,500SF for apartments and 14,100SF for common spaces and garage areas). It maintains nearly full occupancy at all times including many people who have been in the building since it was built.

The building has no cooling system. Heating for apartments is served by electric resistance heaters. Exhaust ventilation is provided in bathrooms in each apartment as well as in kitchens, via a user operated exhaust hood. Common area corridors are also provided with exhaust air. Exhaust air is provided in the corridor areas. Corridor areas themselves have no space heating. Domestic hot water is served by a central natural gas fired boiler. Arup conducted an energy audit at the property on 15th May 2015.

Figure 3. Boylston-Howell apartment

4.2 Building Energy Modeling

A baseline eQuest energy model has been developed to estimate the building energy usage profiles for the Boylston-Howell building and to serve as a prototype for multi-family housing in Seattle (Figure 4). A Typical Meteorological Year (TMY) weather file which represents the long-term climatic condition of Seattle is employed. Input summaries for the energy model are provided in the appendices. Energy bills for the building from 2014 have been collected for analysis and model calibration. Both the electricity and gas consumption peak in the fall / winter period (Oct-Feb) due to the higher demand for space heating and domestic hot water use.

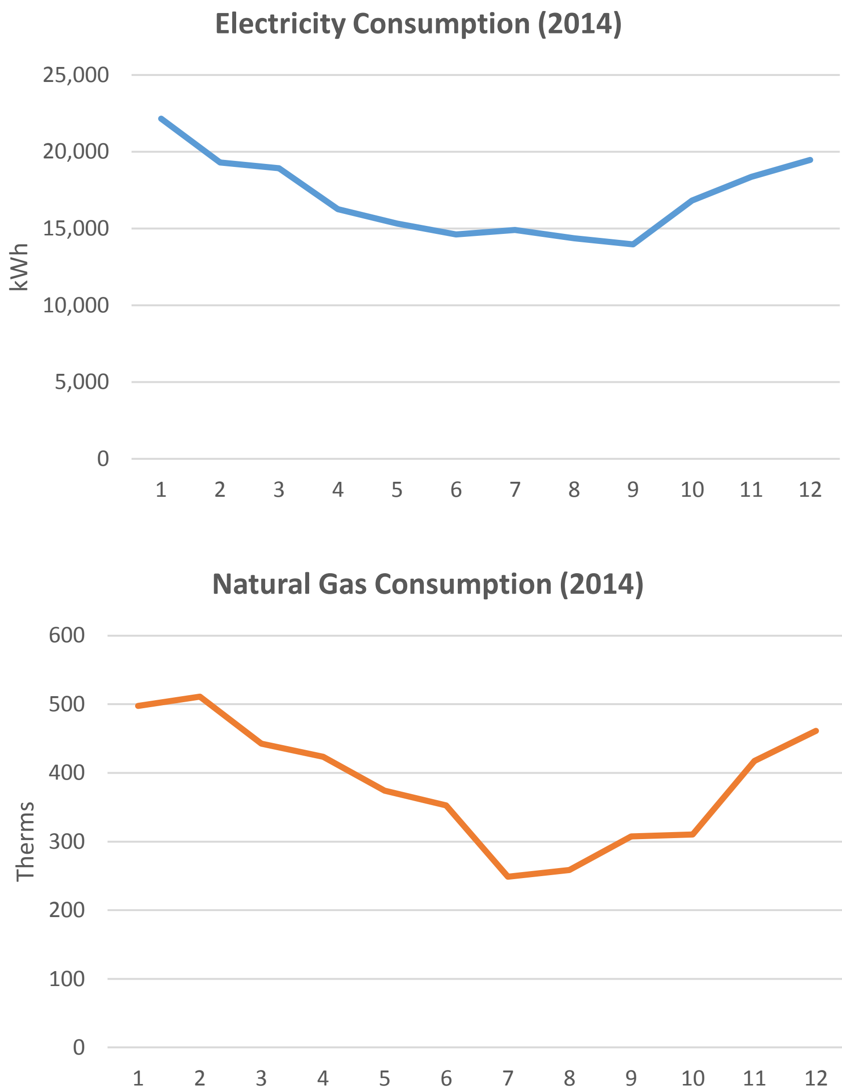


Figure 4 - Energy bills for prototype building (2014)

Monthly natural gas use is compared between the building energy model and the natural gas bills (Figure 5). More distinct seasonal profiles can be observed in the existing scenario are attributed to occupant behaviors and actual climatic conditions, especially the actual heating degree days each month. The overall annual gas use variation is +/-1% between the model and the actual utility bills.

As is typical with most multi-family residential buildings, each apartment is provided with its own electricity meter, and the bills are paid by the tenant. These bills were made available to the authors late in the study and are discussed below. An additional house meter that covers the common spaces of the building is also present and utility bills were provided.

Our electricity profile for the building is calibrated against a reference value made up of the common area utility bills combined with benchmark data provided by the City of Seattle for multi-family residential properties 20,000 sq. ft. and greater. As shown in (Figure 6), our energy model EUI_{elect} is 29.2 kBtu/ft^2 compared to the benchmark 28.3 kBtu/ft^2, which is about a 4% variation.

Late in the study period, we also gained access to apartment utility bills via the property's EPA Portfolio Manager website. From an assessment of this data, the electricity usage for 2014 was found to be lower than was modeled by approximately 25%. Natural gas usage was found to closely match the model estimates on an annual basis – within 1% - although the distinct seasonal variations in the actual billing data contrast strongly with the flatter curve in the modeled data. This may be worthy of further investigation. Total energy variation was approximately 15% between that used in our model and the data in Portfolio Manager. Variances in the data may be due the various sources being collected in different years, leading to differences is weather and occupancy patterns.

It was decided that since the model was more closely aligned with the City's average multi-family building, and since this studies focus was broader than a single building, these differences were acceptable.

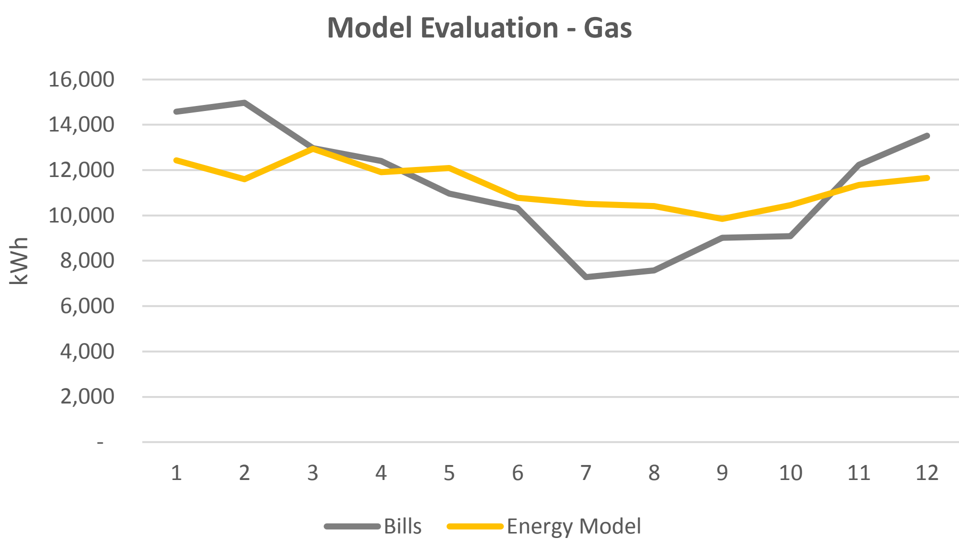


Figure 5 Model calibration for gas consumption

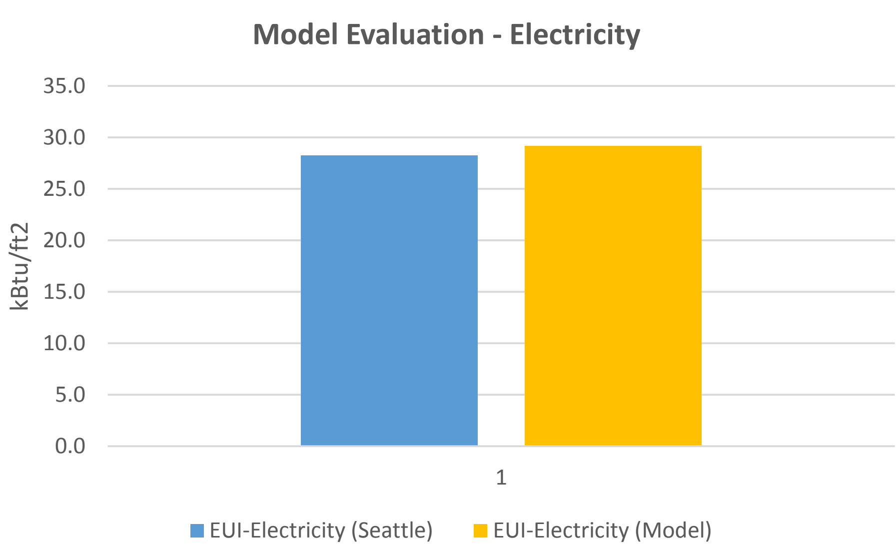
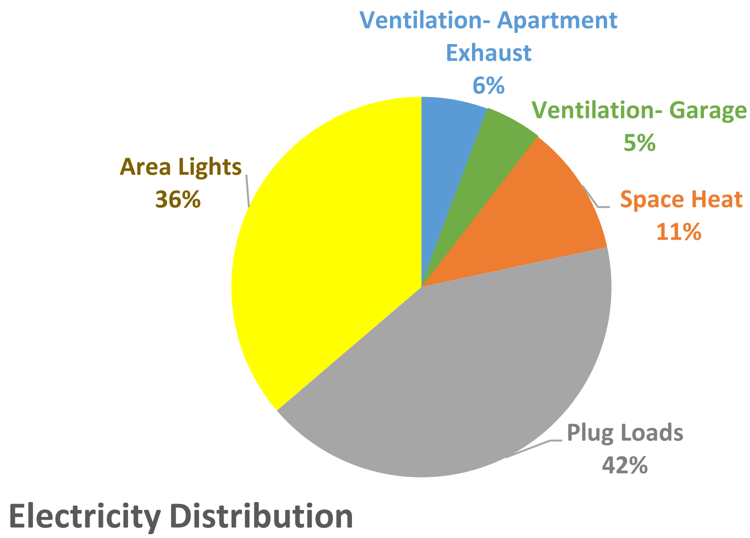


Figure 6. Model calibration for electricity consumption

4.3 Baseline Energy Use & Commentary

Total building energy consumption is estimated as 422,000 kWh (286,000 kWh for electricity and 136,000 kWh for natural gas). Electricity and gas distribution is summarized in Figure 7. It is seen that major electricity consumers were plug loads (42%), lighting (36%), space heating (11%) and ventilation (11%), as detailed in the energy model. Natural gas consumption is dominated by the domestic hot water heating (92%) and about 8% is used within the laundry clothes dryers.

The distribution of energy by end use was estimated via a computer simulation model and based on inputs gathered through a site visit to the facility.



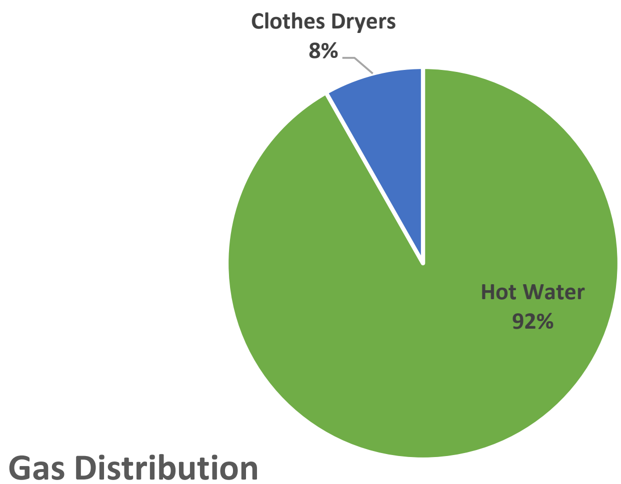


Figure 7. Energy distribution for prototype building

Total building energy use and EUI has been compared to Seattle benchmark data [3]and the energy estimates conducted by a previous consultant study (the Ecotope Audit[4]). It can be seen that the energy model results are very close to the Seattle benchmark, within 3.3%. The model is 6.2% higher than Ecotope report (Figure 8). This variation is small and likely due to differing assumptions between the two studies.

---

[3] Seattle Office of Sustainability & Environment. 2011/2012 Seattle Building Energy Benchmarking Analysis Report (Jan 2014)
[4] Ecotope – Audit and Billing Analysis Report for the Boylston-Howell Apartments (5 Feb 2012)

It is believed that following this modeling calibration effort, the energy model is able to be used as a representative model for City of Seattle multi-family housing stock. It is possible to apply energy conservation measures to the model to understand the energy conservation benefits to this building typology.

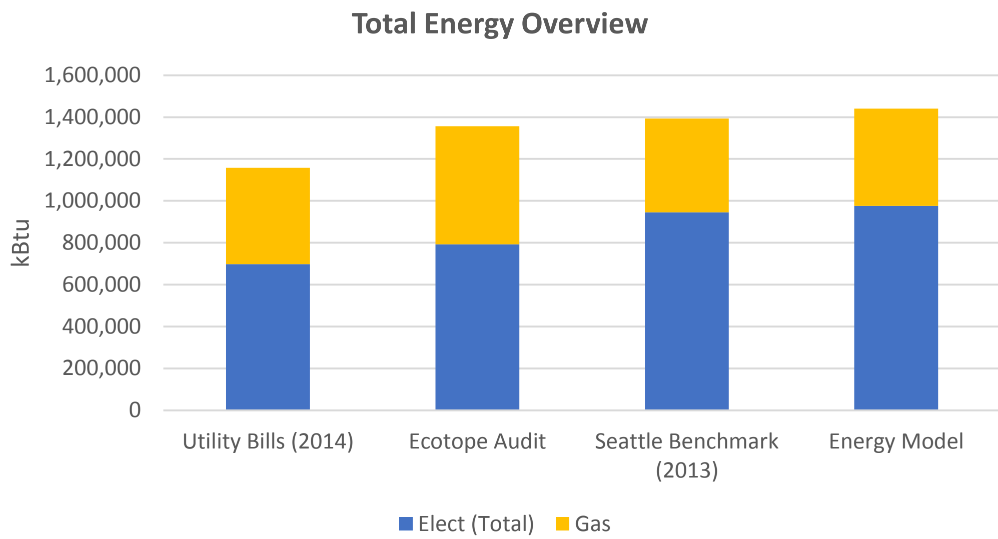


Figure 8. Benchmarking for developed building prototype

Table 1. Energy Utilization Index Comparisons

Benchmark	Electricity ($kBtu/ft^2$)	Natural Gas ($kBtu/ft^2$)	Total ($kBtu/ft^2$)
Utility Bills	22.3	13.8	37.1
Ecotope Report	23.7	16.9	40.5
Seattle Benchmark[5]	28.3	13.4	41.7
Prototype Model	29.2	13.9	43.0

5 Energy Conservation Measures

5.1 Strategies

The energy conservation measures (ECM's) identified for the prototype building, are representative of those that may be applicable to the rest of the existing Seattle multi-family housing stock. These ECM's are intended to be assessed and scaled Citywide.

[5] Average for mid-rise and high-rise multifamily median EUI of 2013

The ECM's are described as conventional or advanced. Conventional ECM's are those that are considered viable now, use current technology available on the market, and would be expected to be installed at equipment replacement or when remodeling. Prior to evaluation, the conventional ECM's were considered likely to pay back either with or without grants or incentives. Some conventional ECM's are considered "naturally occurring" due to support from existing energy efficiency programs or due to market factors.

Advanced ECM's are those that are considered to be outside of a conventional building upgrade/refresh or those that are based on a technology that may be currently available but not commonly installed. Prior to evaluation, these advanced ECM's were considered likely to need financial support to succeed or to be somehow tied in with a building's long-term capital improvement plan.

Quantitative analysis was undertaken only for select ECM's, as noted below by (QA). The remaining ECM's are described qualitatively.

Conventional ECM's:

- ECM 1 - Lighting upgrade and control (QA)
- ECM 2 - Upgrade exhaust fan efficiency in common areas
- ECM 3 - Reduce common area corridor over-ventilation
- ECM 4 - Setback control for heating set point and digital thermostat (QA)
- ECM 5 - Humidity sensors for clothes dryer
- ECM 6 - High efficiency boilers (condensing) (QA)
- ECM 7 - Tankless hot water boilers (apartment by apartment)
- ECM 8 - Seasonal boiler set-point temperature reset
- ECM 9 - Air source heat pump water heaters (QA)
- ECM 10 - Heat recovery from shower water

Advanced ECM's:

- ECM 11 - Photovoltaic array (QA)
- ECM 12 - Envelope upgrade (QA)
- ECM 13 - Air source heat pump space heating (QA)
- ECM 14 - Heat recovery ventilation (QA)
- ECM 15 - Solar hot water heating
- ECM 16 - Home battery storage and renewable photovoltaic (QA)

5.2 ECM 1- Lighting Upgrade & Control

An energy audit has been conducted to identify the potential areas for better lighting efficiency and control upgrades. T-8 fluorescent lighting is used in most of the corridor, stairway, laundry and mechanical spaces with manual on/off switches. T-12 fixtures can still be found in certain spaces like the trash room. Low pressure sodium lamps are used in the garage areas. Lights in the corridor, stairway, garage and trash room are operated 24/7 which is unnecessary and wastes a great deal of energy.

Upgrading the lighting control system with occupancy sensors for most of the common spaces areas and replacing the fixtures with efficient LED lighting technology is envisaged to provide measurable energy savings.

Figure 9. Energy and lighting audit

Table 2. Lighting Power Density (LPD) for baseline case

Spaces	Areas (ft^2)	Lighting Fixtures	Nos.	Watts	LPD (W/ft^2)
Garage	2356.0	LowPress Na	7	175	0.52
Boiler Rooms	48.3	T-8 Sylvania	2	32	1.33
Laundry Room	372.3	T-8 Sylvania	12	32	1.03
Trash Room/Storage	161.6	T-12 Ecolux	6	40	1.49
Corridor/Lobby	250.0	Light Bulbs	5	32	0.60

Table 3. LPD for proposed design

Spaces	Areas (ft^2)	Lighting Fixtures	Nos.	Watts	LPD (W/ft^2)
Garage	2356.0	LowPress Na to LED	40	17.5	0.29
Boiler Rooms	48.3	T-8 to LED	2	17.5	0.72
Laundry Room	372.3	T-8 to LED	12	17.5	0.56
Trash Room/Storage	161.6	T-12 to LED w/ballast upgrade	6	17.5	0.65
Corridor/Lobby	250.0	LED Light Bulbs	5	17.5	0.35

Table 4. Proposed lighting control strategies

Spaces	Lighting Control(s)	PAP
Corridor/Stairway	w/ Occupancy sensor	30%
Garage Parking	w/ Occupancy sensor& Bi-level control	25%
Mech./Elect. Room	w/ Occupancy sensor	40%
Laundry Room	w/ Occupancy sensor	20%
Trash Room/Storage	w/ Occupancy sensor	40%

Rated capacity of lighting fixtures and the numbers of the luminaires for different spaces are counted and the associated lighting power density (LPD in W/ft2) is determined. LPD for both baseline and proposed scenarios were determined with similar approaches. A power adjustment percentage (PAP) recognized by ASHRAE is adopted to account for the savings provided by the occupancy sensors and bi-level lighting controls for garage spaces.

Energy simulations have been conducted to determine the lighting efficiency and control upgrades in different spaces. Figure 10 shows the comparison of the electricity performance between the baseline and the proposed lighting upgrade. We found that the proposed lighting strategies reduced 23% of the lighting energy use and contributed 5% energy saving towards the overall building energy use. It was also found that the space heating load increased slightly due to the more efficiency fixtures emitting less heat.

Although not considered as part of this study, further lighting savings will be available within apartments through the replacement of inefficient fixed lighting technologies.

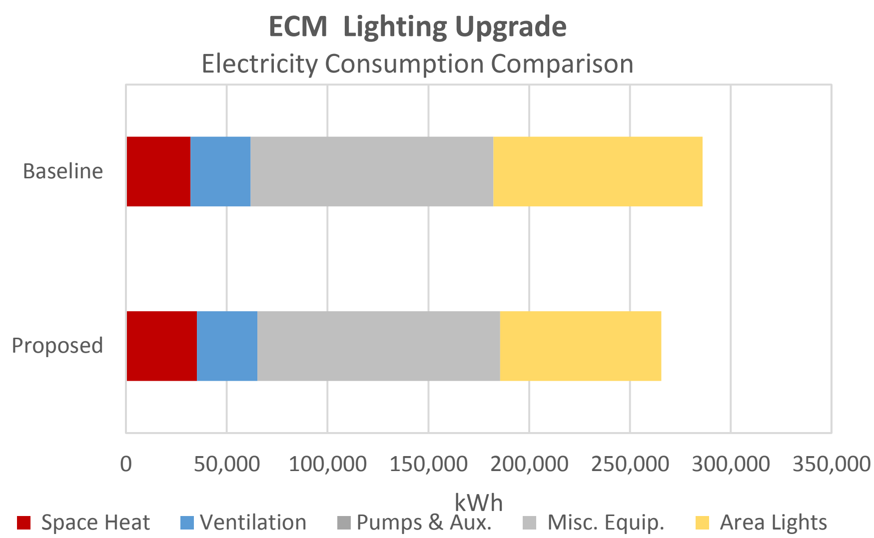


Figure 10. Energy performance for lighting upgrade

5.3 ECM 2- Upgrade exhaust fan efficiency in common areas

A single exhaust fan located on the roof was found to exhaust air from each common area corridor via a vertical shaft. The amount of air being exhausted on each floor is extremely small – 20 CFM was listed on the record drawings, which would indicate that the fan on the roof was only the size of a single residential bathroom fan – and this is then collected and exhausted out at roof level. Although no details were provided on exhaust fan performance, it is highly likely that newer and more efficient motors are now available that would provide common area energy savings.

The way this building ventilates common area corridors is considered fairly unique for multi-family residential buildings. The typical approach is to have a common area fan supplying air to corridors, which is then used as make-up air to apartments – entering via door undercuts. Current code does not allow use of the corridor as a means of ventilation for the dwelling units.

However the overarching ECM goal of improving common area ventilation fan motor efficiency is still expected to be broadly applicable. As shown in ECM-3 that follows, the amount of air exhausted from the Boylston-Howell corridors was extremely low. In typical multi-family buildings, corridor fans are expected to be larger and moving higher quantities of air, leading to even larger savings from changing motors.

5.4 ECM 3- Reduce common area corridor over ventilation

Although not applicable to the Boylston-Howell building, observations from previous studies of Seattle-area apartment buildings suggest that over ventilation in multi-family building corridors is a fairly common occurrence. The ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality, suggests an outdoor ventilation rate of 0.06 CFM/ft^2 or 0.4 ACH for corridors (based on 250 ft^2).

For this measure, it is assumed that corridors are over-ventilated to approximately four ACH – approximately 0.6 CFM/ft^2, 10 times the ASHRAE minimum. Reducing from 4 ACH to the ASHRAE minimum of 0.4 ACH would save around 3% of total building energy.

5.5 ECM 4- Setback control for heating set point and digital thermostat

Each apartment is currently provided with a simple thermostat to control heating temperature. This thermostat consists of a dial, pointing to set points with a range centered on about 70ºF indicating a comfort zone. These thermostats do not have a timeclock function, nor do they allow temperature set-backs or react dynamically to occupancy. During the audit, apartments were found with the heating running despite nobody being at home. We also found evidence of broken or non-calibrated thermostats where unoccupied apartments were extremely hot.

Figure 11 - Existing thermostat (Left) & "Smart" Thermostat (Right)

This ECM is intended to retrofit existing thermostats with more sophisticated programmable versions that allow for more aggressive user controllable setbacks during the day time (6am-6pm). The control logic for this ECM is assumed as follows;

- Typical space heating temperature: 71ºF (adjustable)

- If thermostat not interacted (including occupancy) with for two hours: set back temperature to 60ºF
- If thermostat not interacted (including occupancy) with for four hours: set back temperature to 50ºF

Some occupancy assumptions were made to represent this advanced form of setback control, starting at 6am. It is envisioned that the setback strategies could reduce 25% of the heating energy use and contribute 3 % energy savings to the total building energy use. The savings may be expected to be more significant in buildings where space heating energy use is larger.

With newer thermostats such as those sold by Nest or Honeywell, built in algorithms learn residents occupancy patterns and preferences, leading to energy savings without being significantly invasive.

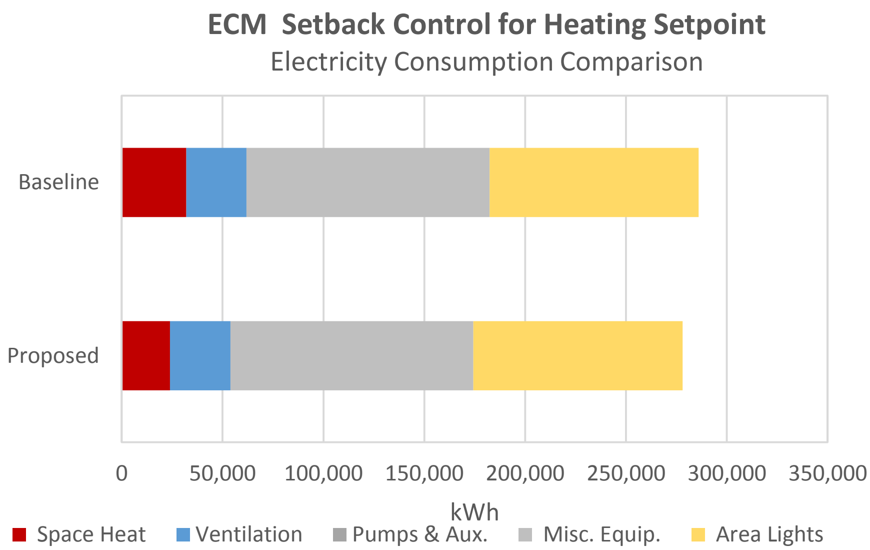


Figure 12 Energy performance for setback control of heating set point

5.6 ECM 5 - Humidity sensors for clothes dryer

The building laundry currently has four clothes dryers installed. Building staff were not aware of whether laundry machines were owned by the building or were provided by an outside contractor but it is expected that multi-family residential buildings in Seattle can follow either approach.

Newer residential laundry machines that are Energy Star compliant, offer greater efficiencies and smart functionality such as humidity sensing to turn off as soon as clothes are dry. It is expected that commercial laundry machines will eventually transition naturally over time to these more efficient products when they reach the end of their service life. However defining a timeline for replacement should also be considered to make sure that opportunities for economically viable replacement units are not being missed.

5.7 ECM 6 - High efficiency boilers (condensing)

This measure is intended to replace the existing central domestic hot water heater with a high efficiency condensing water heater. Condensing boilers are water heaters fueled by natural gas. They achieve high efficiency (typically greater than 90%) by capturing the latent heat of vaporization that occurs during gas combustion in flue gases, to pre-heat cold water entering the boiler. The water vapor that is condensed into liquid form leaves the exhaust system via a drain.

The building owners – Capitol Hill Housing – noted that they are now using condensing water heaters in their new properties and have started to use them in retro-fit applications, so this EMC appears be "naturally occurring."

Use of this measure could reduce building energy use by 4.2%.

Table 5 Hot water heating thermal efficiency in baseline and proposed designs

	Baseline	**Proposed**
	Designs & Eff.	Designs & Eff.
Domestic Hot Water Heating System	Natural Gas Boiler Heater Fuel: Natural Gas Thermal Eff.: 85% Input Rating: 500kBtu/h Hot Water Use: 70Gal/Person/Day Storage Tank: 200Gal Standby Loss 3%/hr (Insulation R=12) Supply Water: 150°F (Inlet=Equal Ground T)	Condensing Boiler Heater Fuel: Natural Gas Thermal Eff.: 95% Input Rating: 147kW (500kBtu/h) Hot Water Use: 70Gal/Person/Day Storage Tank: 200Gal Standby Loss 3%/hr (Insulation R=12) Supply Water: 150°F (Inlet=Equal Ground T)

5.8 ECM 7 - Tankless hot water boilers (apartment by apartment)

Although the current water heating system in the building indicates a heating efficiency of 85%. The efficiency of the complete system includes all losses in heating storage, piping transfer, set point of water heaters and the quantity of hot water consumed. System efficiencies may range from less than 50% to 85% – overall thermal efficiencies likely closer to 70% [6] or lower. Tankless water heaters could be considered to increase the overall system efficiency closer to 80% plus.

Tankless water heaters provide on-demand water local to the usage point, without storage. Due to these units needing to operate a much greater power levels, it is not feasible to provide these using a centralized approach per the existing condition, and instead they would need to be provided on an apartment by apartment basis.

Although it is expected that this EMC will provide energy savings, the following challenges would need to be overcome;

1. Space would need to be found for the units and associated exhaust flue at each apartment, along with make-up air needed for combustion.

[6] Domestic hot water system modeling for the design of energy efficient systems. NREL. 2002

2. Natural gas infrastructure would need to be installed. Currently, natural gas only serves common areas and does not run to each apartment. In retrofit applications, the incoming gas line to the building may also need to be made larger.
3. Decisions would need to be made about who pays for the natural gas bill given that the heater is now within each apartment. Currently, the natural gas bills are paid by the building owner. The same applies to maintaining and “owning” the unit.
4. Routine and call out maintenance costs would be an issue. It may also be difficult for maintenance personnel to gain access to apartments.

Although these considerations can be navigated in new construction, they are expected to be difficult to overcome in an existing building retro-fit application.

5.9 ECM 8 - Seasonal boiler set-point temperature setback

The current water heater feeds a hot water storage tank that in turn feeds the residential units, servicing showers and hot water faucets. The boiler maintains storage water set point 24/7. For multi-family buildings, this set point is typically around 150ºF.

This ECM focuses on the opportunity to reduce this set point during periods of low demand such as during week days or overnight. It is assumed that a temperature of 140ºF would still ensure that water is hot enough for showers etc. but offer energy savings due to reduce heat losses from the storage tank. This would have an additional benefit of reducing boiler run time, as well as ensuring the boiler runs more often at a higher output, enhancing its efficiency which tends to suffer at part load conditions.

5.10 ECM 9 - Air source heat pump water heaters

Heat pump water heaters operate by extracting heat from ambient air and using this to heat water. When ambient temperatures drop and the heat pump becomes less viable, a conventional electric secondary heater takes over water heating duties. These units operate at higher efficiencies than conventional water heaters – in some cases at about three times the efficiency or more.

The existing hot water boiler in the building is a Laars “Mighty Therm 2” and was installed around five years ago. This is a conventional natural gas fired water heater with heating capacity of 425,000Btu/hr and thermal efficiency 85%, feeding a hot water storage tank of 200gals. This measure investigates the potential for switching to an electric, high efficiency water heating system like air source heat pumps, to both reduce overall energy use and to reduce gas related GHG emissions. A similar capacity of air source heat pump is assumed to replace the existing boiler. An average heating COP 3.5 is assumed. The heat pump would be shut down if outdoor dry-bulb temperature drops below approximately 40ºF. Auxiliary heating by electric resistance would augment the heat pump during these periods. Another option might be to consider placing the evaporator unit in a below-grade parking garage, distant from the garage entrance, where ambient temperatures rarely drop below 40ºF.

Figure 13 shows the total energy use of the proposed heat pump water heating. Making use of the principle of refrigerant cycle, the heat pump technology is much more efficient than conventional hot water heating. This measure is estimated to save around 17% of the total building energy use. Because it also switches to lower carbon electricity, this measure will also provide significant carbon savings.

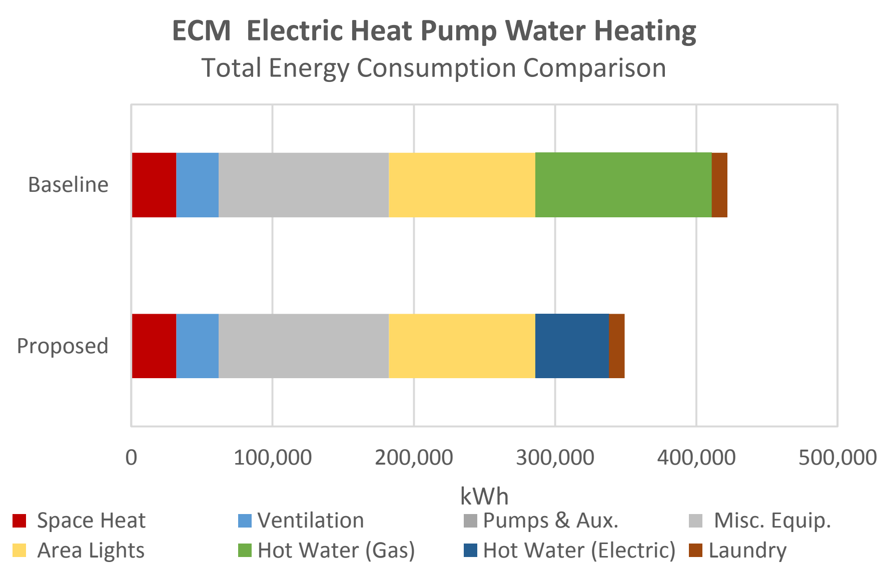


Figure 13 Energy performance for heat pump hot water heating

5.11 ECM 10- Heat recovery from shower drain

This ECM is intended to recover heat from water within the building drain, after it has been used by residents for showers. One method of heat recovery currently on the market involves the use of a copper pipe coil wrapped around the drain pipe. As hot water discharges down the drain, the coil circulates cold water around it to pick up waste heat. This heating of the cold water system results in reduced boiler energy requirements.

It is expected that this ECM will be challenging to implement in a multi-family building because of the centralized approach to water heating. The boiler and domestic cold water line is remote from the entry point into the drain where waste water is at its hottest (within the apartments). Because the heat recovered is low grade, the distribution losses that would occur between the apartment and the basement incoming cold water line would likely offset any benefit.

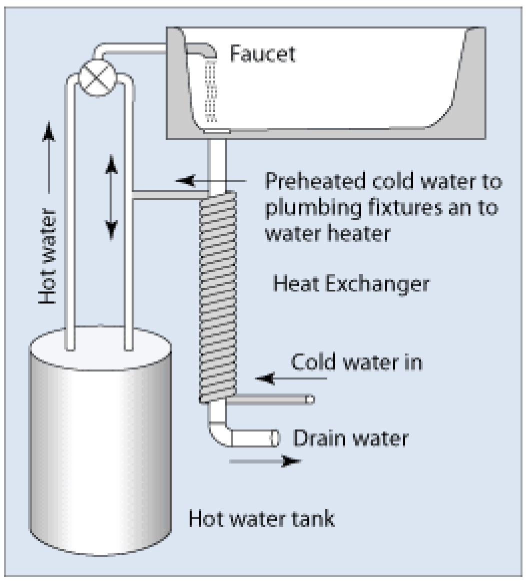


Figure 14 - Drain heat recovery (source: energy.gov)

5.12 ECM 11 - Renewable photovoltaic

A total roof area (4,800ft^2) for the prototype building was identified and 75% of the area (3600ft^2) was considered to be usable space for a photovoltaic system. This de-rating was due to potential shading and code required clearances for vents and other rooftop fixtures. A rated system size of 64 kW dc was identified with a rated capacity of about 18 W dc/ft^2 and assuming a more aggressive PV efficiency of 19%. Annual energy per 1 kW-DC PV of 1,081 kWh or 19.1 kWh/ft2 was estimated for the project location.

Figure 15. Roof and usable PV areas estimation (Ref. NREL-PV Watts)

Approximately 69,000 kWh per year of energy could be generated from a roof mounted PV system for the building which represents a net energy reduction of approximately 16.3%.

Common space areas consume about 36% of the total building energy and this PV system could offset about 60% of the common space energy usage.

PV systems have traditionally been difficult to include in multifamily buildings due to the division of electricity meters. The most likely scenario currently is as described above where the building owner installs the system and gets a benefit due to net metering for the common area utility bills.

For buildings that are able to install a larger PV system that can more than offset the common area energy cost (likely either multi-family building with two floors or with large surface parking lots able to be covered with shade canopy PV) or buildings where tenants would like to get the benefit of installing a PV system, a policy change would be required. Some states are now allowing various forms of “virtual net metering”, “wheeling”, or “solar garden” arrangements for certain eligible multi-family homes. This is a utility tariff arrangement that allows the financial benefit from a single PV system to be virtually apportioned to the utility bills of the buildings tenants or other “shareholders” of the PV system.

The City of Seattle could consider investigating this approach as another mechanism to help facilitate the widespread adoption and implementation of renewable energy. Since the PV system is not currently cost-effective in Seattle, but PV costs are falling rapidly, any work on the roof or electrical service should be used as an opportunity to make the building "solar-ready," to hasten the time when such an installation becomes economically attractive for the owner and tenants.

5.13 ECM 12 - Envelope upgrade

The facade of the prototype building is nearing the end of its service life due to water damage, and requires replacement. The fenestration in the current building is double glazed 1/4in. clear glass with a vinyl frame. Thermal properties are described in Table 6.

Wall construction in the baseline is 6in. wood frame assembly with 6in. insulation. Thermal conductivity is estimated at, U-value = 0.079 Btu/h-ft^{2o}F.

For this ECM, two iterations of the envelope upgrade analysis were studied –

i. Upgrade to latest code minimum requirement

ii. Exceed code by 10%

The code minimum façade design is assumed to meet current code requirements for thermal conduction as shown in Table 6. No specific shading coefficient is required for glazing in the code, however this was kept relatively high as it was found that lowering the shading coefficient too much negatively impacted energy savings due to lost useful solar heat gain during winter.

The proposed "exceed code by 10%" iteration assumes more efficiency wall and fenestration thermal performance. It also assumes that the upgrade will improve the air tightness of the façade using an air barrier. Air leakage is assumed to reduce from 1 CFM/sqft of envelope surface area to 0.4 CFM/sqft of envelope surface area.

Energy performance of the envelope upgrade is summarized in Figure 16. Upgrading the current fenestration to exceed code minimum by 10% would provide 17% space heating and 5% ventilation energy savings. Considering that the window-to-wall (WWR) ratio of the building examined is only 15%, the contribution of the fenestration upgrade is likely to be more significant on buildings with larger glazed areas.

Table 6. Envelope thermal properties in baseline and proposed designs

Construction components	Baseline			Proposed	
	Description	Thermal properties		Description	Thermal properties
Seattle Energy Code Minimum(2012)					
Fenestration	Double Glazing-Air-Clean 1/4in. Frame Vinyl	U=0.483 Btu/h-ft^{2}°F SC=0.84		Double Glazing-Low-E 1/4in, 1/4in Air Frame Vinyl	U=0.3 Btu/h-ft^{2}°F SC=0.75
Walls	6in. Cellulose insulation	U=0.079 Btu/h-ft^{2}°F		Insulation - (R-4)	U=0.058 BTU/h-ft^{2o}F

10% Exceed Code Minimum					
Fenestration	Double Glazing-Air-Clean 1/4in. Frame Vinyl	U=0.483 Btu/h-ft²°F SC=0.84		Triple Glazing-Low-E 1/4in, 1/4in Air Frame Vinyl	U=0.27 Btu/h-ft²°F SC=0.75
Walls	6in. Cellulose insulation	U=0.079 Btu/h-ft²°F		Insulation - (R-7)	U=0.053 BTU/h-ft²oF

It was also found that reducing the glass shading coefficient too much ends up canceling out any winter heating savings due to lost useful solar gain. Although not seen in the energy model due to the lack of cooling in this building, the summer impact of glazing shading coefficient also needs to be considered to ensure this does not negatively impact occupant comfort. Generally, direct solar heat gain is not significant in the summer months due to a higher sun angle, except for west-facing facades, and passive solar heat would become a beneficial component for heat load particularly in winter time. Shading designs have not typically been included as a design consideration in Seattle and were not considered in this study.

Upgrading the wall conduction performance to 10% better than the code minimum could save 26% and 7%, respectively, in space heating and ventilation energy use (reduction of heating demand and hence the corresponding fan power of ventilation).

A combined analysis has also been conducted to investigate the interactive effects of fenestration, wall and envelope air tightness upgrade. Overall space heating energy could reduce by 62% and ventilation by 22%. This results a contribution of 6.3% energy savings to the total building energy use.

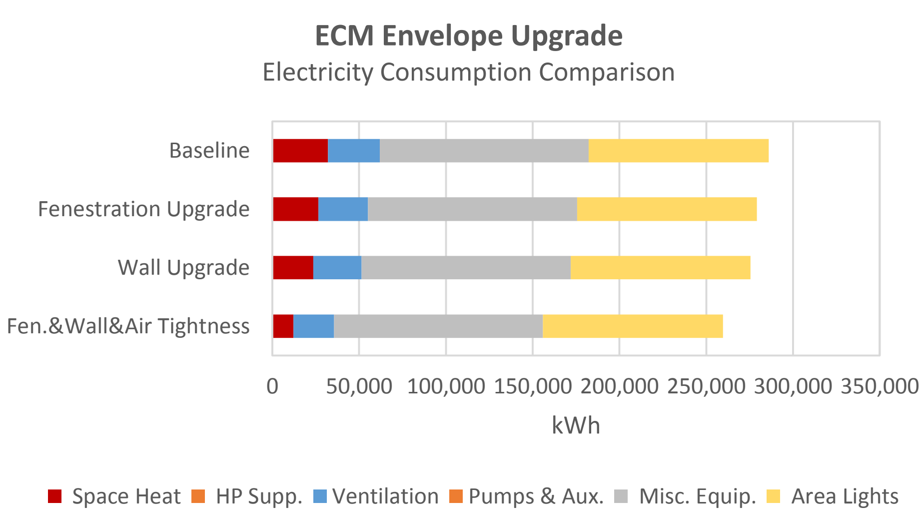


Figure 16. Energy performance for building envelope upgrade

5.14 ECM 13 - Air source heat pump space heating

The existing building uses electric resistance heating as the primary source of space heating though a combination of baseboard heating and convective “Cadet” type units. This ECM investigates the viability of in-unit air source heat pumps which are considered to be a more efficient approach for space heating. Heat pumps are designed to move thermal energy opposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer space. When it is in heating mode, it basically employs the refrigeration cycle that is used by an air conditioner or a refrigerator but in the opposite direction, drawing heat into the occupied space.

A Heating Season Performance Factor (HSPF) is usually used as a measure of the overall heating efficiency of a heat pump during a whole season.

Seattle Energy Code 2012 requires a minimum HSPF 6.8 for heat pumps with capacities <65,000 Btu/h. The efficiency of air source heat pumps on the market achieve HSPF’s of 10 for a similar capacity range.

Table 7. Baseline & proposed design for space heating

System	Baseline	Proposed
	System & Efficiency	System & Efficiency
Air-side heating system	Electric Resistance Heat Efficiency: 100%	Air-source Heat Pumps Heating Efficiency: Seattle Code min.: HSPF=6.8

Analysis has been undertaken to investigate the energy performance of changing the electric resistance heating to air source heat pumps. Figure 17 shows the breakdown of the electricity consumption between the baseline and the proposed scenario (there is no variation in gas consumption therefore gas is omitted).

It is found that changing from electric resistance heating to air source heat pumps (meeting the current code minimum requirement with HSPF = 6.8) would lead to a 55% reduction in space heat electricity use and a total building energy use saving of 4.3%.

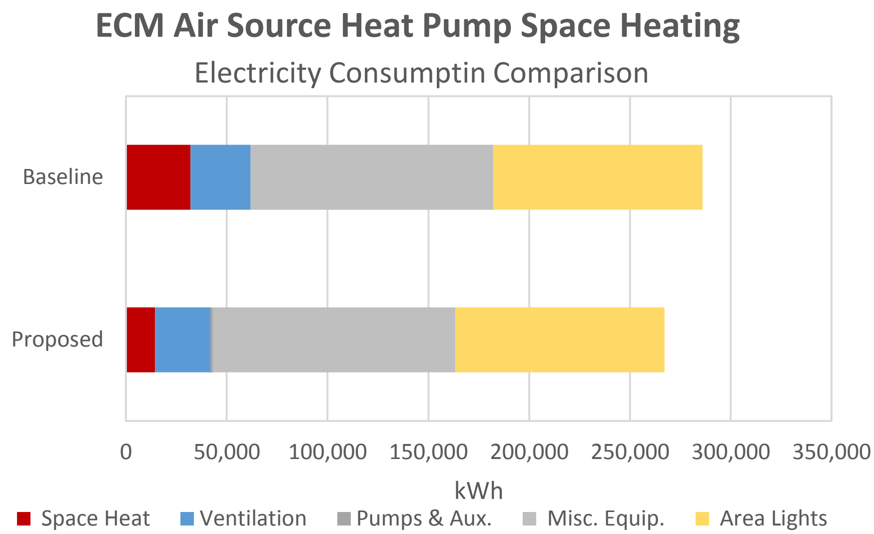


Figure 17. Electricity performance for air source heat pumps (HSPF=6.8)

5.15 ECM 14- Heat recovery ventilation

Currently, ventilation air for the apartments enters through trickle vents mounted in the windows or via infiltration. This is common design practice for the multi-family market. For locations with heating dominated climates such as Seattle's, untreated outdoor (i.e., intentional infiltration) air during the winter time would contribute to the heating load.

Heat recovery ventilators (HRV) recover the heat or "coolth" from exhaust air streams and transfer this to outside air being brought into the building for ventilation purposes. Heat exchange efficiencies of around 65% to 70% are typical.

Exhaust ventilation between 50-80cfm is provided for the residential units of the building between 8am-4pm per record drawings. To be viable for heat recovery ventilation, a centralized fresh air ducted will need to be designed and connected to the HRV with the exhaust air stream. Heat exchange between the two air streams is assumed to occur when outdoor air is below 65ºF. Hourly temperature data was analyzed and the frequency of occurrence of the potential saving hours was calculated. It was found that about 30% of the time that the exhaust system is scheduled to run in the building would be viable for HRV usage.

The HRV was found to save approximately 3% of the total building energy use after factoring in losses due to the HRV fan.

The HRV could have additional benefits besides energy savings that are more difficult to quantify. It was found that many trickle vents in the property were closed during the site visit. Not having a valid pathway for ventilation air can cause the circulation of poor quality air from occupied spaces or even through the building façade, causing moisture ingress. It could also cause mold. An HRV can help provide continuous clean ventilation air with a reduced burden on the buildings energy usage.

Figure 18. Principles of HRV and typical products

5.16 ECM 15 – Solar hot water heating

Given that heating domestic water accounts for around 30% of the total energy consumption of the study building, the use of solar hot water should be a viable strategy in multi-family homes. Though it won't be able to completely offset the domestic hot water load, it should be able to offer a significant reduction – perhaps as much as 50% of the domestic water heating load. Solar water heating complements multi-family buildings which typically have a central hot water system.

As the price of solar photovoltaic has dropped in recent years, there is now some anecdotal data to suggest that it is less costly to heat water using electric resistance heating powered by PV than it is through the use of solar thermal. Additional market research is suggested and economic assessments should be made on a case by case basis.

5.17 ECM 16– Home battery storage and photovoltaic

Home battery storage systems soon to be arriving on the market consist of rechargeable lithium-ion batteries (e.g. Tesla Powerwall). This measure is intended to pair up batteries with renewable photovoltaic installations so that surplus electricity generated during the peak output hours will be stored in the battery and help with peak demand reduction or other load shifting. The electricity demand profiles for most residences fluctuate and typically peak in the morning and evening periods with a reduced demand around mid-day when many residents are gone. Electric energy generated by photovoltaic depends on the solar array orientation but will generally maximize output around noon which is at odds with the peak residential demand (Figure 19).

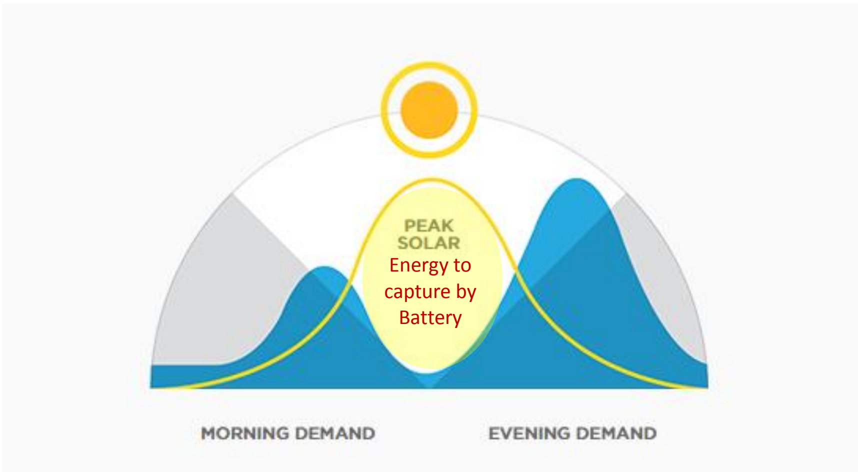


Figure 19 Electricity demands and photovoltaic energy generation profiles

Based on Seattle City Light's utility rates, a flat electricity tariff rate ($0.0716/kWh) has been used in the current multifamily building prototype calculations. It is envisaged that moving to more efficient forms of heating using electricity instead of natural gas would create higher electricity demands in the morning hours. Generally a time of use (TOU) tariff design could be considered to manage this impact. This rate design would also provide an economic incentive for energy storage technologies and related investments and business models.

For an economic analysis of this ECM, an example TOU tariff is assumed as shown in (Figure 20). The electricity tariff rate is assumed as follows:-

- Off Peak (9pm-6am): 0.0512$/kWh
- Part Peak (10am-12pm & 7pm-8pm): 0.0716/kWh
- Peak (7am-9am & 1pm-6pm): 0.111/kWh

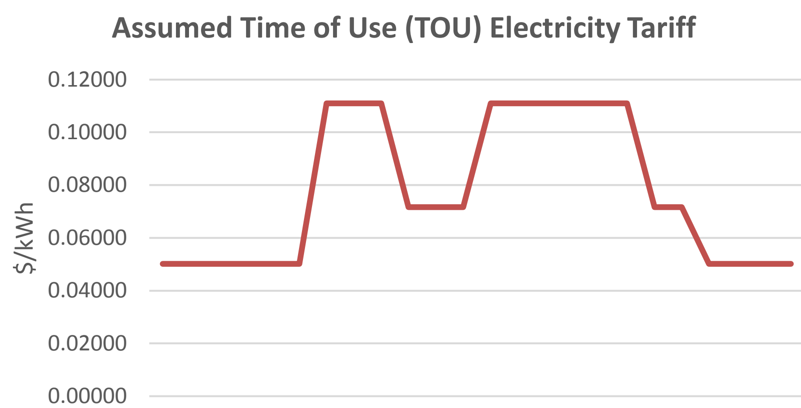


Figure 20 Proposed TOU electricity tariff

Under the TOU tariff scenario, surplus electricity generated (e.g. during the mid-day) will be captured and stored into the home battery system, held and consumed during the peak morning tariff periods (e.g. 7am-9am).

An adjusted baseline based on the TOU tariff was developed and a comparison was complete between the following scenarios

i. without home battery (i.e. surplus of electricity generation will be feedback to grids with a flat tariff like the current tariff)

ii. With home battery for load shifting whilst on the assumed TOU tariff.

It is envisaged that the photovoltaic systems plus home battery storage under the TOU tariff would generate 25.9% overall energy cost savings, in which employing the demand shifting home battery system could produce about 2% more of the energy cost saving due to the shifting of the electricity demands. A more aggressive assumed tariff would generate higher savings.

This measure has the added macro benefit that it may help limit peak electrical demand amplified by switching to more efficient forms of heating.

5.18 ECM Suite Analysis and Net-Zero Potential

An analysis has been conducted to investigate the cumulative energy reduction and the net-zero energy potential through packaged ECM strategies. Figure 20 shows the cumulative energy use for the seven analyzed ECMs. It should be noted that these estimates do not take into account the interactive effects between ECM's.

It is estimated that a 39% energy reduction could be achieved through the combination of the (6) packaged ECM strategies. Renewable energy was estimated to supply 14% of the remaining load. A total of 53% of energy was offset.

Only the heat pump hot water heating involved the fuel switching from natural gas to electricity and thus the energy use due to gas reduced significantly afterwards.

Since this ECM suite analysis is conducted without interactions, a reduction of approximately 5% should be accounted for in the ultimate energy use reduction. Therefore, it is believed that the ECM suite could produce a net energy use reduction of about 48%. This figure is believed to be conservative because other EMC's, though not quantitatively evaluated (e.g. ECM -2 and 3), would likely increase this estimate energy use reduction.

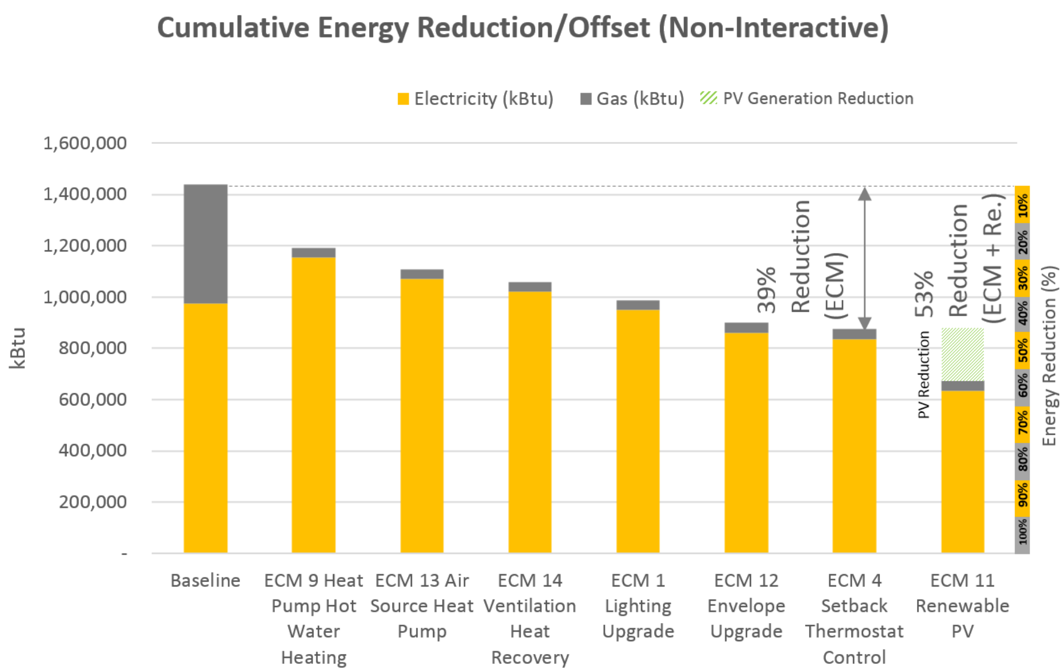


Figure 21 Individual & cumulative energy use summary

6 Costs & Payback Analysis

6.1 Baseline Energy Cost

The cost of residential utilities was obtained from electricity and natural gas bills provided by building management. The utility rate is calculated on an annual basis and unit costs equal $0.0716 / kWh for electricity and $1.0886 / therm for natural gas.

Table 8. Utility unit rate economic calculations

Energy Sources	Unit Rate	
Electricity Rate	0.0716	$/kWh
Gas Rate	1.0886	$/Therms

The baseline energy cost for the building prototype is identified in Figure 22. A total of approximately $25,500 in annual energy cost ($20,478 for electricity and $5,051 for natural gas) is estimated for both common areas and apartments.

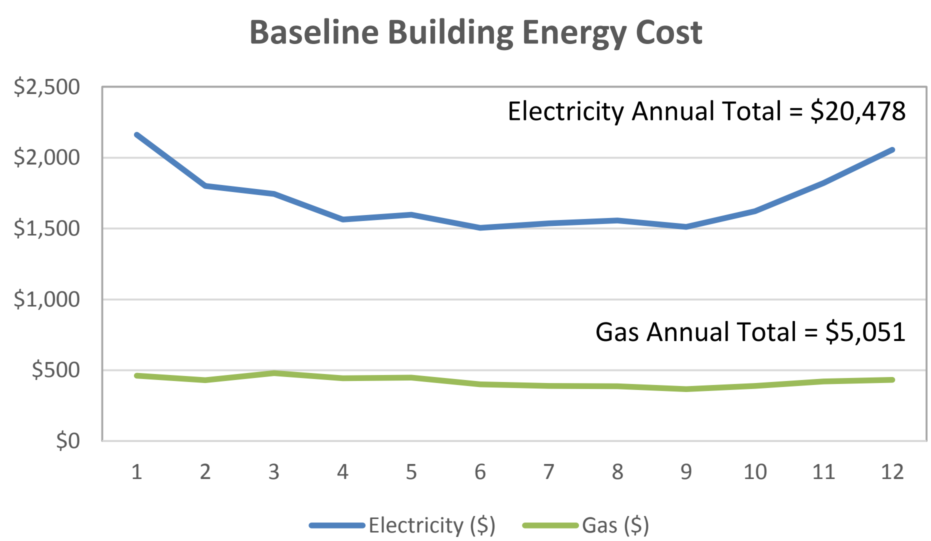


Figure 22. Baseline energy cost summary

6.2 ECM Energy Cost Savings & Recommendations

An overview of the individual ECM energy cost and energy cost savings are summarized in

Table 9. The energy costs and savings of the qualitative ECM's are estimated using the unit rates for electricity and natural gas as discussed in section 6.1. It can be seen that the total energy cost savings varied from 2.2% to 19.3% (including energy cost benefits due to on-site energy generation).

Table 9. Energy & energy cost saving summary

ECMs Strategies	Energy Cost ($)	Energy Cost Saving (%)	Recommended ECM
Baseline	$25,529	-	-
ECM 1 Lighting Upgrade	$24,062	5.7%	Yes
ECM 2 Upgrade exhaust fan efficiency in common areas	Not analyzed		Yes
ECM 3 Reduce common area corridor over ventilation	Not analyzed		Yes
ECM 4 Setback Control	$24,956	2.2%	Yes
ECM 5 Humidity sensors for clothes dryer	Not analyzed		Yes
ECM 6 Condensing Boilers	$24,872	2.6%	No
ECM 7 Tankless hot water boilers	Not analyzed		No
ECM 8 - Seasonal boiler set-point temperature reset	Not analyzed		No
ECM 9 Air source heat pump water heaters	$24,616	3.6%	Yes
ECM 10 Heat recovery from shower drain	Not analyzed		No
ECM 11 Renewable PV	$20,601	19.3%	Yes
ECM 12 Envelope Upgrade	$23,639	7.4%	Yes
ECM 13 Air Source Heat Pump	$24,042	5.8%	Yes
ECM 14 Ventilation Heat Recovery	$24,616	3.6%	Yes
ECM 15 Solar hot water heating	Not analyzed		Yes[7]
ECM 16 Home Battery Storage	Depends	25.9%	No

Also noted in Table 9 is whether an ECM is "recommended" or not for citywide consideration. As can be seen in the following section, some of the recommended ECM's do not have an economic justification to them when applied to the Boyston-Howell Apartment building, however they may still be recommended. This is because they are considered to be economically applicable to a large number of other buildings in the City or because they have some other strategic value or quality to the City.

[7] Solar hot water recommended at sites where photovoltaics are not implemented.

6.3 Life-Cycle Cost Analysis

To assess the viability of the identified ECMs, life-cycle cost payback analysis has been undertaken. Costing data for the proposed ECM's and the baseline were estimated and are summarized in Figure 10. These include the first cost, annual maintenance cost and major repair estimates.

Table 10 ECM Costing Summary

ECMs	Baseline					Proposed			
	First Cost	Main Cost[8]	Repair Cost[9]	Replace Cost[10]		First Cost	Main Cost	Repair Cost	Replace Cost
ECM 1 Lighting	$-	$-	$5,659	$7,138		$11,444	$413	$4,931	$17,458
ECM 4 Setback Control	$6,270	$594	$3,300	$-		$6,270	$594	$6,270	$-
ECM 6 Condensing Boiler	$-	$264	$1,825	$9,800		$9,700	$160	$134	$9,700
ECM 9 Heat Pump Water Heater	$-	$264	$1,825	$9,800		$10,600	$20	$240	$10,600
ECM 11 Renewable PV	$-	$-	$-	$-		$159,250	$1,401	$51,160	318,550
ECM 12 Envelope Upgrade	$534,887	$-	$29,196	$75,481		$570,298	$-	$29,196	$75,481
ECM 13 Heat Pump Space Heating	$20,296	$1,657	$-	$-		$120,000	$1,110	$18,366	$86,580
ECM 14 Ventilation Recovery	$-	$1,749	$-	11,520		$50,400	$1,749	$-	$42,000
ECM 16 Home Battery	$-	$-	$-	$-		$46,680	$480	$-	$57,920
Total	$561,453	$4,528	41,806	$113,739		$952,962	5,448	$110,297	$560,368

Maintenance costs cover minor regular maintenance items such as equipment inspection or filter changes and typically occur annually.

[8] Maintenance cost – Every year
[9] Repair cost – Every 10 years
[10] Replacement cost – Every 20 years (Not considered if it is end of the life-cycle analysis)

Repair costs occur less frequently and cover major repairs and replacement of defective equipment.

Since ECM-12 and ECM-13 are considered major upgrades that would occur at the end of life of the systems they are replacing, it has been assumed that there is a replacement cost associated with the baseline in each case as follows;

- ECM-12 assumes that the baseline installs a minimally code compliant envelope.
- ECM-13 assumes that the baseline replaces the existing electric resistance heating.

Each of these upgrade measures becomes significantly more cost-effective when it is implemented at the time of a scheduled replacement. Under such conditions, the cost burden for the owner is only the incremental difference between the high-performance version and the code-minimum version of the replacement.

A 20-year life-cycle payback analysis was conducted for each of the quantitatively evaluated ECM's using the following economic assumptions as provided by the City of Seattle:

- Escalation rate for maintenance: 2.87% per annum
- Electricity escalation: 5% per annum
- Natural gas escalation: 5% per annum
- Discount rate for net present value: 2.07%

An overview of the lifecycle payback analysis is summarized in Table 11. Detailed calculations are included within the appendices.

Table 11 Life Cycle Cost Analysis Results

ECMs	Net Capital Cost	Annual Net Energy Cost Saving	Simple Payback	LCC Payback	IRR	Net Present Value
ECM 1 Lighting Upgrade	($11,444)	$1,467	7.8	8.7	12.4%	$18,743
ECM4 Setback Control	($6,270)	$573	10.9	13.1	6%	$1,946
ECM 6 Condensing Boiler Heating	($9,700)	$658	14.7	9.4	10.8%	$13,399
ECM 9 Heat Pump Hot Water Heating	($10,600)	$1,590	6.7	5.2	21.7%	$38,533
ECM 11 Renewable PV	($159,250)	$4,929	32.3	>20	-6.0%	-$116,112
ECM 12 Envelope Upgrade	($35,411)	$982	36.1	>20	-0.7%	-$9,891
ECM 13 Heat Pumps	($93,824)	$1,289	72.8	>20	-6.8%	-$68,643
ECM 14 Ventilation Heat Recovery	($50,400)	$913	55.2	>20	-3.9%	-$26,675
ECM 16 Home Battery Storage[11]	($46,680)	$0	Never	Never	0%	$0

7 Citywide adoption

This study focused on a specific multi-family building, assumed to be representative of the sector. The greater intent however is to understand how the findings for the prototype building can be applied to the broader City, as well as understanding how their adoption can be promoted.

7.1 Citywide viability of measures

The energy conservation measures were identified from an audit of a specific multi-family building. Their applicability to other multi-family homes in the City will depend on how typical the situation at Boylston-Howell building is. A second consideration is that though an ECM may be applicable to other multi-family homes, it may be difficult to implement due to space constraints, tenant requirements, or other factors.

These considerations are discussed in this section and a percentage is considered for each of the measures that have undergone quantitative analysis. This percentage will be applied to each measure as they are scaled up to a citywide level. So a factor

[11] There are no economic benefits from using battery storage based on current utility rates. It is estimated that should a time of use tariff structure be used, this system will have a simple payback of 6.5 years and a net present value of $68,208.

of 100% means that the savings found in section 5 of this report for a given ECM will be applied to 100% of the citywide residential building stock. A factor of 50% means that the savings will be applied to just 50% of the multi-family building stock.

The following Table 12 is our estimate of the viability of each ECM across approximately 651 million square feet of low, mid, and high rise multi-family residential building stock.

The viability factors are based on engineering judgment, assuming the following general attributes for each multi-family building classification:

Low-rise: Easier to distribute services vertically throughout the building. Larger roof area as a percentage of total building area. Simpler HVAC systems.

Mid-rise: Similar to low-rise but reduced roof area and space for renewable energy. Higher likelihood of more complex and efficient HVAC systems such as water source heat pumps.

High-rise: Least roof space for renewable energy and outdoor HVAC systems. Difficult to distribute vertically. Most likely to have more efficient HVAC systems such as water source heat pumps.

Table 12 - ECM Citywide applicability

ECM	Considerations	Applicability Factor (based on building type)		
	Multi-family Building Type	Low	Mid	High
ECM 1 – Lighting Upgrade	Findings are expected to be fairly representative of the majority of multi-family buildings in Seattle. Though limited numbers may have undergone lighting technology changes, it is expected that the majority have not implemented the listed control measures. This ECM is simple to implement and so it is expected to be viable at most buildings.	90%	90%	90%
ECM 4 – Setback Thermostat Control	Heating control systems in multi-family buildings are typically less sophisticated than those found in commercial buildings. Whether using gas fired heating or electric resistance heating, it is expected that this type of aggressive set back control is not common in the market place. Although this measure needs a more sophisticated thermostat, it would be replacing existing thermostats and is considered viable for most buildings.	100%	100%	100%
ECM 9 – Heat Pump Hot Water Heating	Most multi-family buildings are provided with gas fired boilers for domestic water heating and so this ECM is likely viable. One of the challenges in implementing this ECM will be finding space outdoors or in a well-ventilated area, such that the heat pump can efficiently extract heat from the air. Remote corners of underground garages might be ideal.	80%	70%	40%

	There may therefore also be challenges in routing infrastructure to the unit.			
ECM 11 – Rooftop PV	Many multifamily buildings of this scale do not have cooling and hence have roofs that are clear of equipment and have the real estate for photovoltaic systems. It is also expected that most buildings will have a vertical chase either inside or outside the building for routing of power lines, as well as space either within the building or externally for inverter placement. Some buildings however may not have acceptable levels of solar access due to adjacent buildings or trees. Some roof areas may also be used as common space for residents.	90%	70%	40%
ECM 12 – Envelope	The envelope upgrade ECM is expected to be valid for most multi-family buildings, but primarily at the time of a significant façade replacement. This is expected to be occur rarely, with façade components lasting between 15 and 30 years.	80%	80%	80%
ECM 13 – Air source heat pump space heating	This measure is expected to be applicable to most buildings in Seattle since most use conventional space heating systems such as electric baseboard heating. It is expected that the condenser unit associated with this system would be located either a roof level or at grade level, necessitating a vertical chase for refrigerant pipework. Both indoor and outdoor units will also require electrical connections. The space and infrastructure requirements may mean that this systems is not viable for all buildings.	70%	70%	50%

ECM 14 – Ventilation heat recovery	This measure could benefit most residential buildings however compatibility will depend on having the space to locate the unit within each apartment, perhaps in a soffit above the kitchen, bath or entry, and having the pathways to route the necessary ductwork.	50%	50%	20%

As the City of Seattle heads towards its 2050 zero net greenhouse gas emissions target, promoting the adoption of the ECMs identified and recommended in this report will be an important element of achieving those results. Our comments, observations, and suggestions are intended to provide helpful guidance to the City on some of the potential direct and collateral issues related to the implementation of the ECMs being considered.

7.2 Recommendations

Outreach approach: The approach to achieve deep green retrofit savings may vary depending on the type of multi-family building and there may not be a one size fits all approach.

Low income properties that are government owned or funded could be marketed to though the following types of benefits that come from implementing the energy conservation measures described in this report;

- Becoming a role model in the field of sustainability
- Savings
- Impact of the measures
- Occupant health and well being
- Maintenance cost savings

For buildings that are privately owned and at market rate, the following benefits could be promoted;

- Economics
- Cost effectiveness
- Branding opportunities around living sustainably
- Occupant health and well being
- Maintenance cost savings

There is also the potential to incentivize private owners for implementing deep green retrofits. One example might be to offer a development bonus on the next multi-family home they build, should they retrofit an existing property.

Upgrade Frequency: Although the focus of this study is deep green retrofits, “low hanging fruit” items should not be discounted in this building type, especially within the residential units. Where tenants are living in an apartment for many years without a major refurbishment being undertaken, quick energy saving wins are being lost. This is likely amplified in some apartment buildings by the fact that the tenant is responsible to pay the electricity bills but doesn’t necessarily own or have the right to replace energy using equipment. The City of Seattle could consider the following;

- Outside of major building refurbishments, requiring timed upgrades within residences where lighting, fans and appliances get replaced. These could be heavily incentivized or even – taking advantage of existing programs – free to building owners and residents.
- Consider encouraging the retirement of dated laundry equipment, as well as promoting switching to electric powered dryers. There are two complications here that will need to be overcome;
    - Firstly, laundry machines may be owned by a third party company and these companies will need to be the focus of outreach efforts.
    - Secondly, for dryers, electric dryers are typically slightly less efficient than gas fired dryers.

Air Source Heat Pump Space Heating: Although up to three times more efficient than electric resistance space heating on an annual basis, in purely economic terms, switching to air source heat pumps may be difficult to justify in all buildings and a focus should be on the following;

- Energy cost savings
- Better durability than electric resistance heating – moves system away from occupied areas and potential impact damage
- Easier metering than gas fired heating systems
- Possibly more control over bringing outside air into space when combined with a DOAS system – avoiding the need for trickle vents. This may have other benefits including reducing smells and odors and – longer term – reducing the opportunity for mold to develop within the building wall assemblies

There should also be a focus on providing training to technicians and installers for this technology as well as promoting the creation of accurate energy modeling approaches (it is understood that an industry consortium may be doing this already with a view to releasing simulation tools by the end of 2015). “Quick check” online tools comparing this system against other typical HVAC systems may also help promote heat pumps (such as those found at https://www.sba.gov/content/energy-saving-calculators-energy-star).

The technology could also be more readily adopted through the use of more aggressive minimum energy efficiency compliance standards.

Battery Storage: The use of batteries within buildings to store electrical energy could offer Seattle benefits in the near future, including reducing electrical demand increases that may be seen due to the move from lower efficiency natural gas systems to higher efficiency heat pump systems for space or water heating. In order to help

- Potential resiliency benefits if able to operate during power outage (e.g. microgrid)

Encouraging adoption of ECM's: As the market continues to grow for some of the ECM's discussed within this study, costs will continue to drop and they will become more viable in the future. The City of Seattle could consider commissioning preliminary surveys of multi-family buildings to assess them for some of the higher cost measures. This could include – for example – designating if a building is "technology ready" by answering a few simple questions;

- Solar Ready: Is there enough unshaded roof space to accommodate a solar system? Is there a route for feeders? Is there space for inverters?
- Heat Pump Space Heating Ready: Are there vertical chases for refrigerant pipework? If switching from gas heating, is the electrical infrastructure able to accommodate the system? Is there space for the condensing units? Is there the ability to bring in ventilation air from the outside? Are there fire safety issues to consider?
- Battery Ready: Is there space for the batteries? Will the electrical infrastructure allow their integration? Can it operate in "islanded mode" separate from the utility?

Similar to an energy benchmark, this "technology ready" designation could then stay with the building as it changes ownership.

1. Establish incentive programs to reward the phasing out natural gas use for domestic hot water or space heating

2. Support rebate and incentive programs for upgrading space heating efficiency, particular heat pumps and heat recovery ventilation

3. Support rebate and incentive programs to reward electrical system upgrade for PV ready and on-site renewable energy generation (e.g. Solar hot water and photovoltaic)

4. Provide quick savings online calculation tools

5. Provide training / design guidelines for more innovative systems such as retrofitting heat pumps in multi-family buildings or installing ventilation heat recovery systems

6. Develop pilot program for battery storage coupled with PV to understand benefits and challenges. Also consider microgrid demonstration which could examine how this technology could benefit the resiliency of the utility grid as the penetration of intermittent renewable resources increases.

7. Continue to support energy benchmarking and associated measurement programs.

    a. Seek and report additional benchmarking data on heating and gas use specifically

    b. Explore ongoing retro-commissioning and retrofit programs in conjunction with benchmarking

    c. Explore mandating City benchmarking targets for existing buildings, e.g. Energy Star Target Finder

8 Appendix

The following appendices are included;

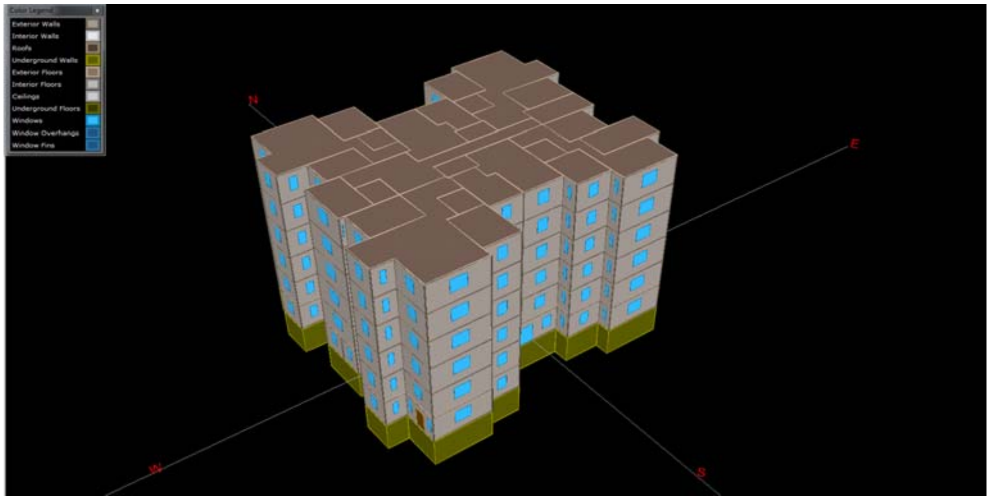
I. Energy model input assumptions

II. ECM Economic & Payback Analysis

III. Energy Audit File-Note for Boylston-Howell

Appendix I

Baseline Energy Model Summary - Seattle Boylston-Howell



Weather File:

Climate Zone:	USA_WA_Seattle-Tacoma.Intl.AP.727930_TMY3.bin

Building Envelope

Thermal Properities - Wall

External Wall	0.046	U-value, Btu/h-ft2-F
Roof	0.028	U-value, Btu/h-ft2-F

Thermal Properities - Windows

Fenestration (Inc Frame)	0.43	U-value, Btu/h-ft2-F
Glazing SC	0.72	Double plane, Clear Glass
Glazing Visible Trans	0.73	
Solar Tran	0.52	
Window-to-wall Ratio	15% for all N,E,S,W	

Air-side

No Cooling

Heating Type: Electric Resistence

Heating System: Electric Furance, No Ventilation

Thermal Set-point	Cooling	75F
	Heating	71F

Domestic Hot Water Heating

Heater Fuel:	Natural Gas	
Heater Type:	Storage	
Thrmal Efficiency	85%	
Storage Tank	200	Gal
Standby Loss	3	%/hr
Supply Water Temp	150	F

Lighting

Residential (General Living Space)	0.9	W/ft2
Residential (Bedroom)	0.4	W/ft2
Bathrooms	1.0	W/ft2
Corridor	0.7	W/ft2
Garage Parking	0.5	W/ft2
Mech/Elect Room	1.0	W/ft2
Office	1.5	W/ft2
Laundry Room	1.3	W/ft2
Storage/Trash Room	1.2	W/ft2
Lobby	0.9	W/ft2

Equipment/Misc Load

Refrigerator	1.2	W/ft2
Cooking	0.8	W/ft2
Residential (General Living Space)	0.3	W/ft2
Residential (Bedroom)	0.3	W/ft2
Restroom	0.05	W/ft2

People Sensible Load	250	Btu/hr
People Latent Load	200	Btu/hr

Appendix II

LBNL-CAC: LCC & Payback Analysis

ECM Lighting Upgrade

Annual Resource Cost Summary

Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings
Electricity			$ 1,467.10
Natural Gas			$ -
Total			$1,467

Capital Costs Savings Summary

ECM Incremental Cost	$11,444
Baseline First Cost	$0
Total Incremental Cost	$11,444
Net Capital Cost:	($11,444)

Annual Maintennace Cost Summary

Annual Recurring OM&R Cost **Savings:**	$ (413)
Includes:	

Repairment Life and Cost Summary

Estimated Useful Life (yrs)	10
Percent repaired	100%
Repairment Cost **Savings:**	$ 728.65
Includes:	

Replacement Life and Cost Summary

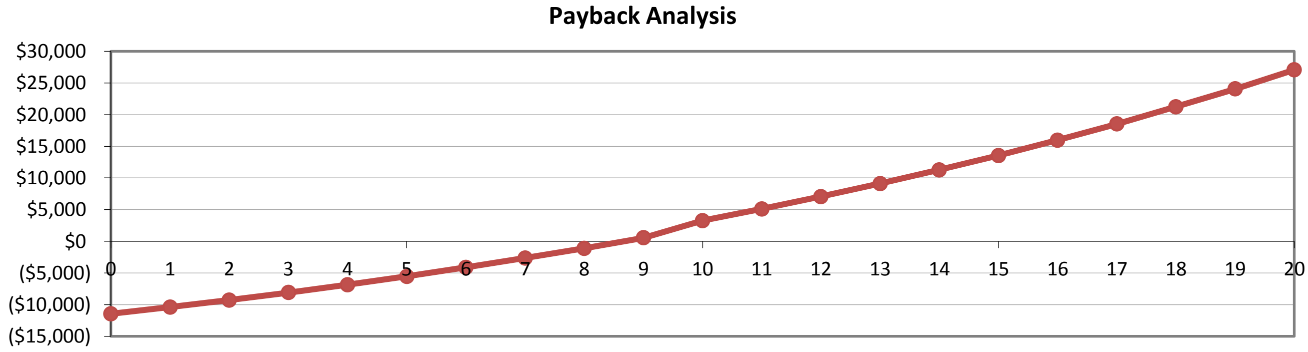
Estimated Useful Life (yrs)	20
Percent replaced	100%
Replacement Cost **Savings:**	$ -
Includes:	

Net Present Value Analysis

Base year for analysis	2015
Study period (yrs)	20
Maintenance escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(11,444)				(11,444)
1	0	1,467	0	(413)	(10,390)
2	0	1,540	0	(425)	(9,275)
3	0	1,617	0	(437)	(8,095)
4	0	1,698	0	(450)	(6,846)
5	0	1,783	0	(463)	(5,526)
6	0	1,872	0	(476)	(4,130)
7	0	1,966	0	(490)	(2,654)
8	0	2,064	0	(504)	(1,093)
9	0	2,168	0	(518)	556
10	967	2,276	0	(533)	3,265
11	0	2,390	0	(549)	5,106
12	0	2,509	0	(564)	7,051
13	0	2,635	0	(581)	9,106
14	0	2,766	0	(597)	11,275
15	0	2,905	0	(614)	13,565
16	0	3,050	0	(632)	15,983
17	0	3,202	0	(650)	18,536
18	0	3,363	0	(669)	21,229
19	0	3,531	0	(688)	24,072
20	0	3,707	0	(708)	27,072

Payback Analysis



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($11,444)	$1,467	8.7 yrs	12.4%	$18,743

LBNL-CAC: LCC & Payback Analysis | **ECM Setback Control**

Annual Resource Cost Summary

Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings
Electricity			$ 573.43
Natural Gas			$ -
Total			$573

Capital Costs Savings Summary

ECM Incremental Cost	$6,270
Baseline First Cost	$0
Total Incremental Cost	$6,270
Net Capital Cost:	($6,270)

Annual Maintennace Cost Summary

Annual Recurring OM&R Cost **Savings:** $ -

Includes:

Repairment Life and Cost Summary

Estimated Useful Life (yrs)	10
Percent repaired	100%
Repairment Cost **Savings:**	$ (2,970.00)

Includes:

Replacement Life and Cost Summary

Estimated Useful Life (yrs)	20
Percent replaced	100%
Replacement Cost **Savings:**	$ -

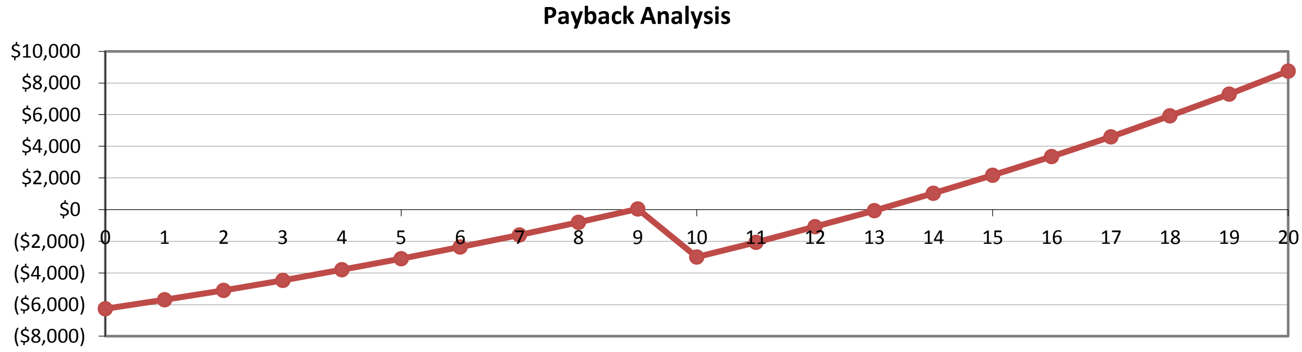
Includes:

Net Present Value Analysis

Base year for analysis	2015
Study period (yrs)	20
Maintenance escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(6,270)				(6,270)
1	0	573	0	0	(5,697)
2	0	602	0	0	(5,094)
3	0	632	0	0	(4,462)
4	0	664	0	0	(3,798)
5	0	697	0	0	(3,101)
6	0	732	0	0	(2,370)
7	0	768	0	0	(1,601)
8	0	807	0	0	(794)
9	0	847	0	0	53
10	(3,941)	890	0	0	(2,999)
11	0	934	0	0	(2,065)
12	0	981	0	0	(1,084)
13	0	1,030	0	0	(54)
14	0	1,081	0	0	1,027
15	0	1,135	0	0	2,163
16	0	1,192	0	0	3,355
17	0	1,252	0	0	4,606
18	0	1,314	0	0	5,921
19	0	1,380	0	0	7,301
20	0	1,449	0	0	8,750

Payback Analysis



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($6,270)	$573	13.1 yrs	8.3%	$5,418

LBNL-CAC: LCC & Payback Analysis

ECM Condensing Boiler Heating

Annual Resource Cost Summary			
Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings
Electricity			$ -
Natural Gas			$ 658.26
Total			$658

Capital Costs Savings Summary	
ECM Incremental Cost	$9,700
Baseline First Cost	$0
Total Incremental Cost	$9,700
Net Capital Cost:	($9,700)

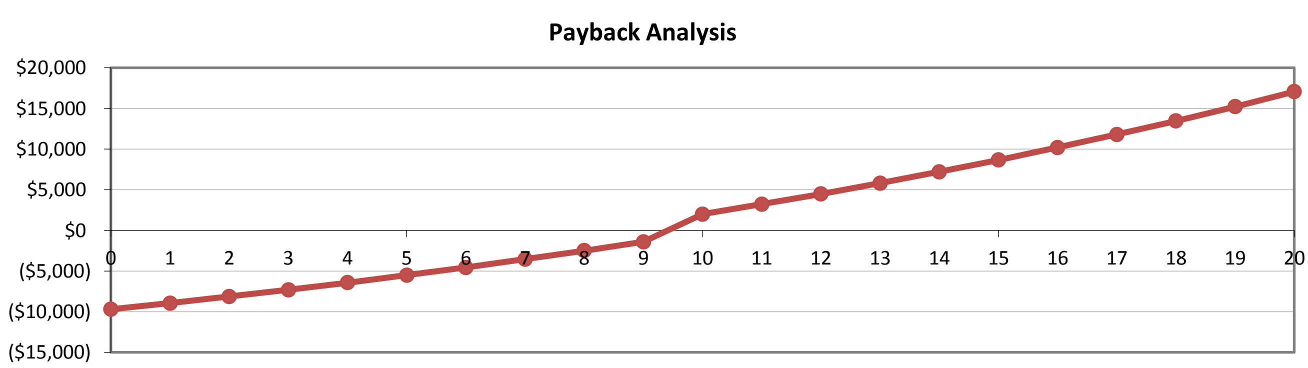
Annual Maintennace Cost Summary	
Annual Recurring OM&R Cost Savings:	$ 104
Includes:	

Repairment Life and Cost Summary	
Estimated Useful Life (yrs)	10
Percent repaired	100%
Repairment Cost Savings:	$ 1,690.63
Includes:	

Replacement Life and Cost Summary	
Estimated Useful Life (yrs)	20
Percent replaced	100%
Replacement Cost Savings:	$ -
Includes:	

Net Present Value Analysis	
Base year for analysis	2015
Study period (yrs)	20
Maintenance escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(9,700)				(9,700)
1	0	0	658	104	(8,938)
2	0	0	691	107	(8,140)
3	0	0	726	110	(7,304)
4	0	0	762	113	(6,429)
5	0	0	800	116	(5,513)
6	0	0	840	120	(4,553)
7	0	0	882	123	(3,548)
8	0	0	926	127	(2,495)
9	0	0	973	130	(1,393)
10	2,244	0	1,021	134	2,006
11	0	0	1,072	138	3,216
12	0	0	1,126	142	4,483
13	0	0	1,182	146	5,811
14	0	0	1,241	150	7,202
15	0	0	1,303	154	8,660
16	0	0	1,368	159	10,187
17	0	0	1,437	163	11,787
18	0	0	1,509	168	13,464
19	0	0	1,584	173	15,221
20	0	0	1,663	178	17,062



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($9,700)	$658	9.4 yrs	10.3%	$11,423

LBNL-CAC: LCC & Payback Analysis

ECM Heat Pump Hot Water Heating

Annual Resource Cost Summary			
Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings
Electricity			$ (3,045.64)
Natural Gas			$ 4,636.05
Total			$1,590

Capital Costs Savings Summary	
ECM Incremental Cost	$10,600
Baseline First Cost	$0
Total Incremental Cost	$10,600
Net Capital Cost:	($10,600)

Annual Maintennace Cost Summary	
Annual Recurring OM&R Cost Savings:	$ 244
Includes:	

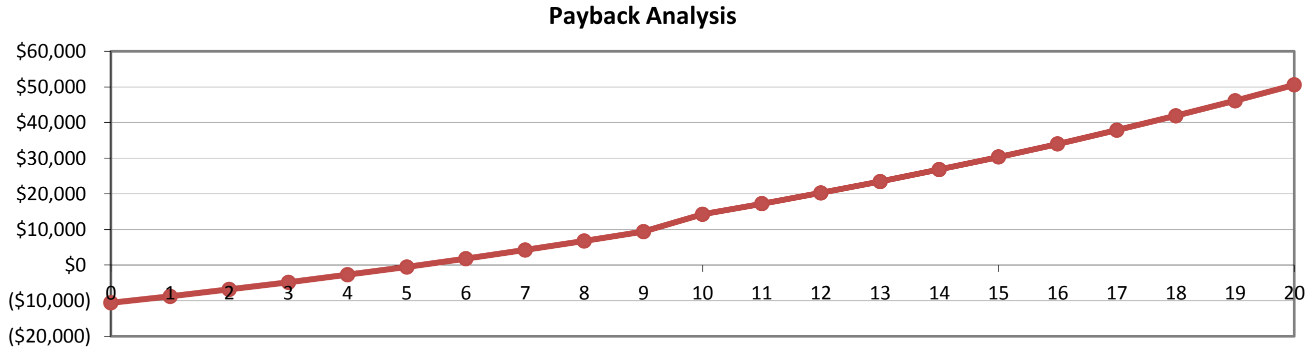
Repairment Life and Cost Summary	
Estimated Useful Life (yrs)	10
Percent repaired	100%
Repairment Cost Savings:	$ 1,585.00
Includes:	

Replacement Life and Cost Summary	
Estimated Useful Life (yrs)	20
Percent replaced	100%
Replacement Cost Savings:	$ (800.00)
Includes:	

Net Present Value Analysis	
Base year for analysis	2015
Study period (yrs)	20
Maintenance escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(10,600)				(10,600)
1	0	(3,046)	4,636	244	(8,765)
2	0	(3,198)	4,868	251	(6,844)
3	0	(3,358)	5,111	258	(4,832)
4	0	(3,526)	5,367	266	(2,725)
5	0	(3,702)	5,635	273	(519)
6	0	(3,887)	5,917	281	1,792
7	0	(4,081)	6,213	289	4,213
8	0	(4,286)	6,523	298	6,748
9	0	(4,500)	6,850	306	9,404
10	2,103	(4,725)	7,192	315	14,290
11	0	(4,961)	7,552	324	17,205
12	0	(5,209)	7,929	333	20,258
13	0	(5,470)	8,326	343	23,457
14	0	(5,743)	8,742	353	26,809
15	0	(6,030)	9,179	363	30,321
16	0	(6,332)	9,638	373	34,001
17	0	(6,648)	10,120	384	37,856
18	0	(6,981)	10,626	395	41,897
19	0	(7,330)	11,157	406	46,130
20	0	(7,696)	11,715	418	50,567

Payback Analysis



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($10,600)	$1,590	5.2 yrs	21.7%	$37,615

LBNL-CAC: LCC & Payback Analysis

ECM Renewable PV

Annual Resource Cost Summary				
Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings	
Electricity			$	4,928.70
Natural Gas			$	-
Total				$4,929

Capital Costs Savings Summary	
ECM Incremental Cost	$159,250
Baseline First Cost	$0
Total Incremental Cost	$159,250
Net Capital Cost:	($159,250)

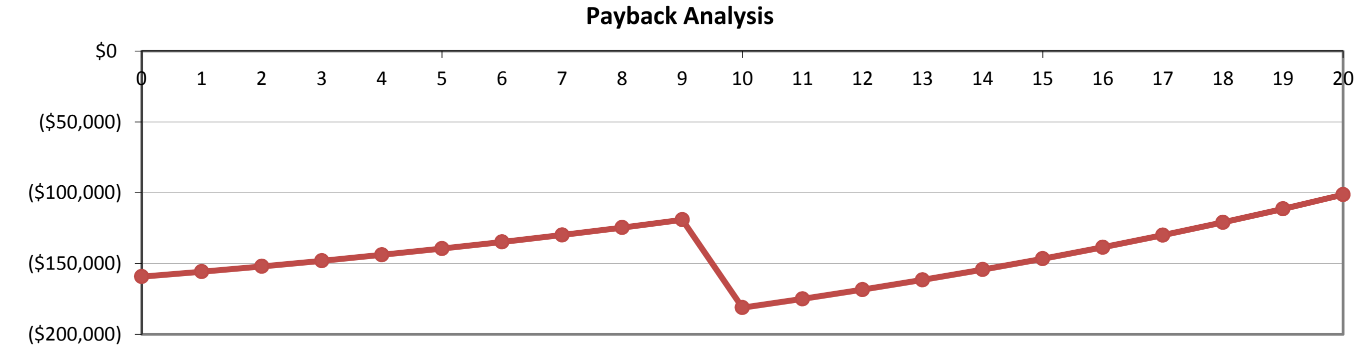
Annual Maintennace Cost Summary		
Annual Recurring OM&R Cost Savings:	$	(1,401)
Includes:		

Repairment Life and Cost Summary		
Estimated Useful Life (yrs)		10
Percent repaired		100%
Repairment Cost Savings:	$	(51,160.00)
Includes:		

Replacement Life and Cost Summary		
Estimated Useful Life (yrs)		20
Percent replaced		0%
Replacement Cost Savings:	$	-
Includes:		

Net Present Value Analysis	
Base year for analysis	2015
Study period (yrs)	20
Maintenance/Repair/Replace escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(159,250)				(159,250)
1	0	4,929	0	(1,401)	(155,723)
2	0	5,175	0	(1,442)	(151,989)
3	0	5,434	0	(1,483)	(148,038)
4	0	5,706	0	(1,526)	(143,858)
5	0	5,991	0	(1,569)	(139,437)
6	0	6,290	0	(1,614)	(134,761)
7	0	6,605	0	(1,661)	(129,817)
8	0	6,935	0	(1,708)	(124,590)
9	0	7,282	0	(1,757)	(119,065)
10	(67,892)	7,646	0	(1,808)	(181,119)
11	0	8,028	0	(1,860)	(174,950)
12	0	8,430	0	(1,913)	(168,434)
13	0	8,851	0	(1,968)	(161,550)
14	0	9,294	0	(2,024)	(154,281)
15	0	9,758	0	(2,083)	(146,605)
16	0	10,246	0	(2,142)	(138,501)
17	0	10,759	0	(2,204)	(129,946)
18	0	11,297	0	(2,267)	(120,917)
19	0	11,861	0	(2,332)	(111,387)
20	0	12,455	0	(2,399)	(101,332)



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($159,250)	$4,929	>20 yrs	-6.0%	-$116,112

LBNL-CAC: LCC & Payback Analysis | **10% Above Code ECM Envelope Upgrade**

Annual Resource Cost Summary			
Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings
Electricity			$ 981.64
Natural Gas			$ 0.12
Total			$982

Capital Costs Savings Summary	
ECM Incremental Cost	$35,411
Baseline First Cost	$0
Total Incremental Cost	$35,411
Net Capital Cost:	($35,411)

Annual Maintennace Cost Summary		
Annual Recurring OM&R Cost **Savings:**	$	-
Includes:		

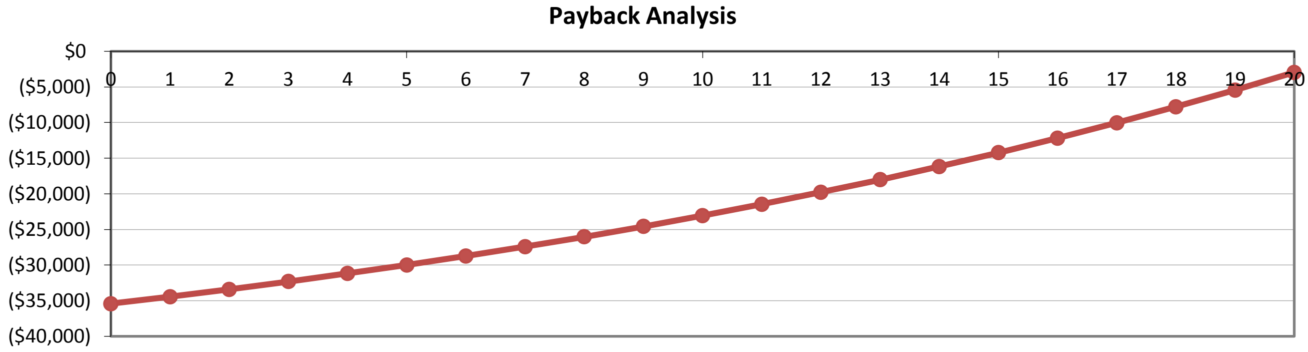
Repairment Life and Cost Summary		
Estimated Useful Life (yrs)		10
Percent repaired		100%
Repairment Cost **Savings:**	$	-
Includes:		

Replacement Life and Cost Summary		
Estimated Useful Life (yrs)		25
Percent replaced		100%
Replacement Cost **Savings:**	$	-
Includes:		

Net Present Value Analysis	
Base year for analysis	2015
Study period (yrs)	20
Maintenance escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(35,411)				(35,411)
1	0	982	0	0	(34,429)
2	0	1,031	0	0	(33,398)
3	0	1,082	0	0	(32,316)
4	0	1,136	0	0	(31,179)
5	0	1,193	0	0	(29,986)
6	0	1,253	0	0	(28,733)
7	0	1,315	0	0	(27,417)
8	0	1,381	0	0	(26,036)
9	0	1,450	0	0	(24,585)
10	0	1,523	0	0	(23,062)
11	0	1,599	0	0	(21,463)
12	0	1,679	0	0	(19,784)
13	0	1,763	0	0	(18,021)
14	0	1,851	0	0	(16,169)
15	0	1,944	0	0	(14,226)
16	0	2,041	0	0	(12,185)
17	0	2,143	0	0	(10,041)
18	0	2,250	0	0	(7,791)
19	0	2,362	0	0	(5,428)
20	0	2,481	0	0	(2,948)

Payback Analysis



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($35,411)	$982	>20 yrs	-0.7%	-$9,891

LBNL-CAC: LCC & Payback Analysis

ECM Heat Pump Replacement

Annual Resource Cost Summary			
Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings
Electricity			$ 1,288.81
Natural Gas			$ 0.11
Total			$1,289

Capital Costs Savings Summary	
ECM Incremental Cost	$93,824
Baseline First Cost	$0
Total Incremental Cost	$93,824
Net Capital Cost:	($93,824)

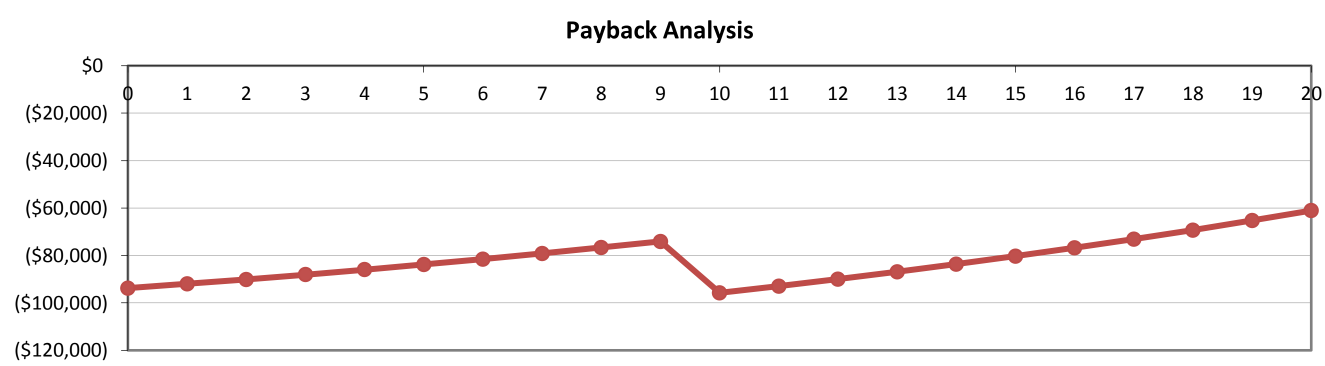
Annual Maintennace Cost Summary		
Annual Recurring OM&R Cost Savings:	$	547
Includes:		

Repairment Life and Cost Summary		
Estimated Useful Life (yrs)		10
Percent repaired		100%
Repairment Cost Savings:	$	(18,366.15)
Includes:		

Replacement Life and Cost Summary	
Estimated Useful Life (yrs)	20
Percent replaced	100%
Replacement Cost Savings:	-
Includes:	

Net Present Value Analysis	
Base year for analysis	2015
Study period (yrs)	20
Maintenance/Repair/Replace escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(93,824)				(93,824)
1	0	1,289	0	547	(91,988)
2	0	1,353	0	562	(90,072)
3	0	1,421	0	579	(88,073)
4	0	1,492	0	595	(85,985)
5	0	1,567	0	612	(83,806)
6	0	1,645	0	630	(81,531)
7	0	1,727	0	648	(79,156)
8	0	1,813	0	667	(76,676)
9	0	1,904	0	686	(74,086)
10	(24,373)	1,999	0	705	(95,754)
11	0	2,099	0	726	(92,929)
12	0	2,204	0	746	(89,978)
13	0	2,315	0	768	(86,895)
14	0	2,430	0	790	(83,675)
15	0	2,552	0	813	(80,310)
16	0	2,679	0	836	(76,795)
17	0	2,813	0	860	(73,121)
18	0	2,954	0	885	(69,283)
19	0	3,102	0	910	(65,271)
20	0	3,257	0	936	(61,077)



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($93,824)	$1,289	>20 yrs	-6.8%	-$68,643

LBNL-CAC: LCC & Payback Analysis

ECM Ventilation Heat Recovery

Annual Resource Cost Summary

Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings
Electricity			$ 913.16
Natural Gas			$ -
Total			$913

Capital Costs Savings Summary

ECM Incremental Cost	$50,400
Baseline First Cost	$0
Total Incremental Cost	$50,400
Net Capital Cost:	($50,400)

Annual Maintennace Cost Summary

Annual Recurring OM&R Cost **Savings:** $ -

Includes:

Repairment Life and Cost Summary

Estimated Useful Life (yrs)	10
Percent repaired	100%
Repairment Cost **Savings:**	$ -

Includes:

Replacement Life and Cost Summary

Estimated Useful Life (yrs)	20
Percent replaced	100%
Replacement Cost **Savings:**	-

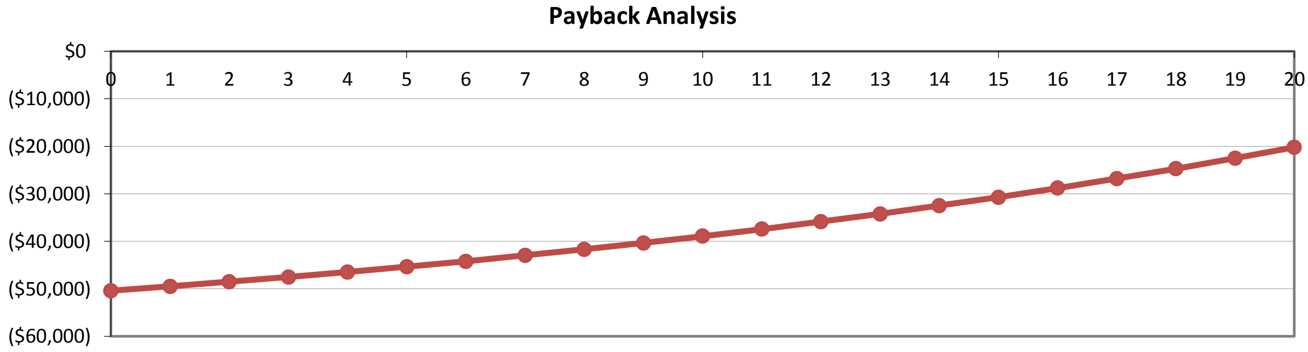
Includes:

Net Present Value Analysis

Base year for analysis	2015
Study period (yrs)	20
Maintenance escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(50,400)				(50,400)
1	0	913	0	0	(49,487)
2	0	959	0	0	(48,528)
3	0	1,007	0	0	(47,521)
4	0	1,057	0	0	(46,464)
5	0	1,110	0	0	(45,354)
6	0	1,165	0	0	(44,189)
7	0	1,224	0	0	(42,965)
8	0	1,285	0	0	(41,680)
9	0	1,349	0	0	(40,331)
10	0	1,417	0	0	(38,914)
11	0	1,487	0	0	(37,427)
12	0	1,562	0	0	(35,865)
13	0	1,640	0	0	(34,225)
14	0	1,722	0	0	(32,503)
15	0	1,808	0	0	(30,695)
16	0	1,898	0	0	(28,797)
17	0	1,993	0	0	(26,804)
18	0	2,093	0	0	(24,711)
19	0	2,198	0	0	(22,513)
20	0	2,308	0	0	(20,206)

Payback Analysis



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($50,400)	$913	>20 yrs	-3.9%	-$26,675

LBNL-CAC: LCC & Payback Analysis

ECM Home Battery Storage

Annual Resource Cost Summary			
Resource	Annual Resource Cosnumption Savings	Unit Cost	Annual Savings
Electricity			$ 7,222.45
Natural Gas			$ 0.01
Total			$7,222

Capital Costs Savings Summary	
ECM Incremental Cost	$46,680
Baseline First Cost	$0
Total Incremental Cost	$46,680
Net Capital Cost:	($46,680)

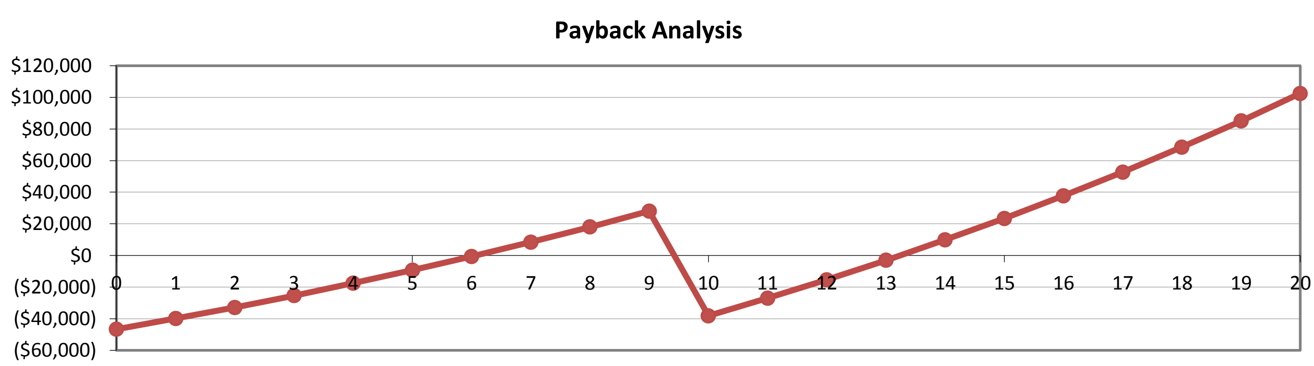
Annual Maintennace Cost Summary	
Annual Recurring OM&R Cost Savings:	$ (480)
Includes:	

Replacement Life and Cost Summary	
Estimated Useful Life (yrs)	10
Percent repaired	100%
Repairment Cost Savings:	$ (57,920.00)
Includes:	

Replacement Life and Cost Summary	
Estimated Useful Life (yrs)	20
Percent replaced	100%
Replacement Cost Savings:	$ -
Includes:	

Net Present Value Analysis	
Base year for analysis	2015
Study period (yrs)	20
Maintenance escalation rate	2.87%
Electricity escalation rate (First 10 years)	5.00%
Electricity escalation rate (Beyond)	5.00%
Natural gas escalation rate	5.00%
Discount rate for NPV	2.07%

Yr	Cost	Electricity	Gas	Maint.	Net
0	(46,680)				(46,680)
1	0	7,222	0	(480)	(39,938)
2	0	7,584	0	(494)	(32,848)
3	0	7,963	0	(508)	(25,393)
4	0	8,361	0	(523)	(17,555)
5	0	8,779	0	(538)	(9,313)
6	0	9,218	0	(553)	(648)
7	0	9,679	0	(569)	8,462
8	0	10,163	0	(585)	18,039
9	0	10,671	0	(602)	28,108
10	(76,863)	11,204	0	(619)	(38,169)
11	0	11,765	0	(637)	(27,042)
12	0	12,353	0	(655)	(15,344)
13	0	12,970	0	(674)	(3,048)
14	0	13,619	0	(693)	9,878
15	0	14,300	0	(713)	23,465
16	0	15,015	0	(734)	37,746
17	0	15,766	0	(755)	52,757
18	0	16,554	0	(777)	68,534
19	0	17,382	0	(799)	85,117
20	0	18,251	0	(822)	102,546



Economic Results Summary	Net Capital Cost	Annual Savings	Payback	IRR	Net Present Value
	($46,680)	$7,222	13.2 yrs	11.7%	$68,208

Appendix III

File Note

ARUP

12777 West Jefferson Boulevard
Building D
Los Angeles
California 90066
United States of America
www.arup.com

t +1 310 578 4400
f +1 310 861 9029
d +1 310 578 4469

Project title	Seattle City Deep Green Alternations	Job number	243463-00
cc		File reference	
Prepared by	Kevin Wan/Martin Howell	Date	June 30, 2015
Subject	Boylston-Howell Apartments Energy Audit Report		

This memo has been written to provide a summary of audit findings to Capitol Hill Housing for the Boylston-Howell Apartment building.

1 Energy Audit Summary

An energy audit was conducted at Boylston-Howell Apartments in Seattle on 15th May 2015 by Arup, as part of a broader project for the City of Seattle under the Climate Action Champions program. The building is owned and managed by Capitol Hill Housing and was built in 1996. It is a 6-storey building with 30 apartment units and the gross floor areas is about 38,600SF (24,500SF for apartments and 14,100SF for common spaces and garage areas). It maintains nearly full occupancy at all times including many people who have been in the building since it was built. The building is classified as low income housing.

The building has no cooling system. Heating for apartments is served by electric resistance heaters. Exhaust ventilation is provided in bathrooms in each apartment as well as in kitchens, via a user operated exhaust hood. Common area corridors are also provided with exhaust air. Exhaust air is provided in the corridor areas with no heating. Domestic hot water is served by a central natural gas fired boiler.

A total of 16 energy conservation measures (ECMs) were identified through the audit process. The ECM's are described as "conventional" or "advanced". Conventional ECM's are those that are considered viable now using current technology available on the market. Prior to evaluation, the conventional ECM's were considered likely to pay back either with or without support. Some conventional ECM's are considered naturally occurring due to support from existing energy efficiency programs or due to market factors. Advanced EMS's are those that were considered higher cost or not yet market ready. These ECM's would likely need support from incentives or grants or to be wrapped into a more holistic building upgrade project to be viable.

Conventional ECM's:

- ECM 1 - Lighting upgrade and control
- ECM 2 - Upgrade exhaust fan efficiency in common areas
- ECM 3 - Reduce common area corridor over-ventilation
- ECM 4 - Setback control for heating set point and digital thermostat
- ECM 5 - Humidity sensors for clothes dryer
- ECM 6 - High efficiency boilers (condensing)
- ECM 7 - Tankless hot water boilers (apartment by apartment)
- ECM 8 - Seasonal boiler set-point temperature reset
- ECM 9 - Air source heat pump water heaters
- ECM 10 - Heat recovery from shower water

Advanced ECM's:

- ECM 11 - Photovoltaic array
- ECM 12 - Envelope upgrade
- ECM 13 - Air source heat pump space heating
- ECM 14 - Heat recovery ventilation
- ECM 15 - Solar hot water heating
- ECM 16 - Home battery storage and renewable photovoltaic

2 Energy Conversation Measures

An analysis has been conducted to investigate the cumulative energy reduction for the different ECM strategies. Detailed analysis was not possible or desired for all ECM's and so a focus was made on quantitatively assessing nine key measures as shown in the following table.

Table 1. Energy & energy cost saving summary

ECMs Strategies	Energy Cost ($)	Energy Cost Saving (%)	Recommended ECM
Baseline	$25,529	-	-
ECM 1 Lighting Upgrade	$24,062	5.7%	Yes
ECM 2 Upgrade exhaust fan efficiency in common areas	Not analyzed		Yes
ECM 3 Reduce common area corridor over ventilation	Not analyzed		Yes
ECM 4 Setback Control	$24,956	2.2%	Yes
ECM 5 Humidity sensors for clothes dryer	Not analyzed		Yes
ECM 6 Condensing Boilers	$24,872	2.6%	No
ECM 7 Tankless hot water boilers	Not analyzed		No
ECM 8 - Seasonal boiler set-point temperature reset	Not analyzed		No
ECM 9 Air source heat pump water heaters	$24,616	3.6%	Yes
ECM 10 Heat recovery from shower drain	Not analyzed		No
ECM 11 Renewable PV	$20,601	19.3%	Yes
ECM 12 Envelope Upgrade	$23,639	7.4%	Yes
ECM 13 Air Source Heat Pump	$24,042	5.8%	Yes
ECM 14 Ventilation Heat Recovery	$24,616	3.6%	Yes
ECM 15 Solar hot water heating	Not analyzed		Yes[1]
ECM 16 Home Battery Storage	Depends	25.9%	No

To have an idea about the possible energy reduction for the packaged ECMs. Seven recommended ECMs are combined to investigate the cumulative energy reduction and the net-zero energy potential. Figure 1 shows the cumulative energy use for the seven analyzed ECMs. It should be noted that these estimates do not take into account the interactive effects between ECM's.

[1] Solar hot water recommended at sites where photovoltaics are not implemented.

It is estimated that a 39% energy reduction could be achieved through the combination of the (6) packaged ECM strategies. Renewable energy was estimated to supply 14% of the remaining load. A total of 53% of energy was offset.

Only the heat pump hot water heating involved a move from natural gas to electricity and thus the energy use due to natural gas reduced significantly after considering this measure.

Since this ECM suite analysis is conducted without interactions, a reduction of approximately 5% should be accounted for in the ultimate energy use reduction. Therefore, it is believed that the ECM suite could produce a net energy use reduction of about 48%. This figure is believed to be conservative because other EMC's, though not quantitatively evaluated (e.g. ECM's 2 and 3), would likely increase these estimates.

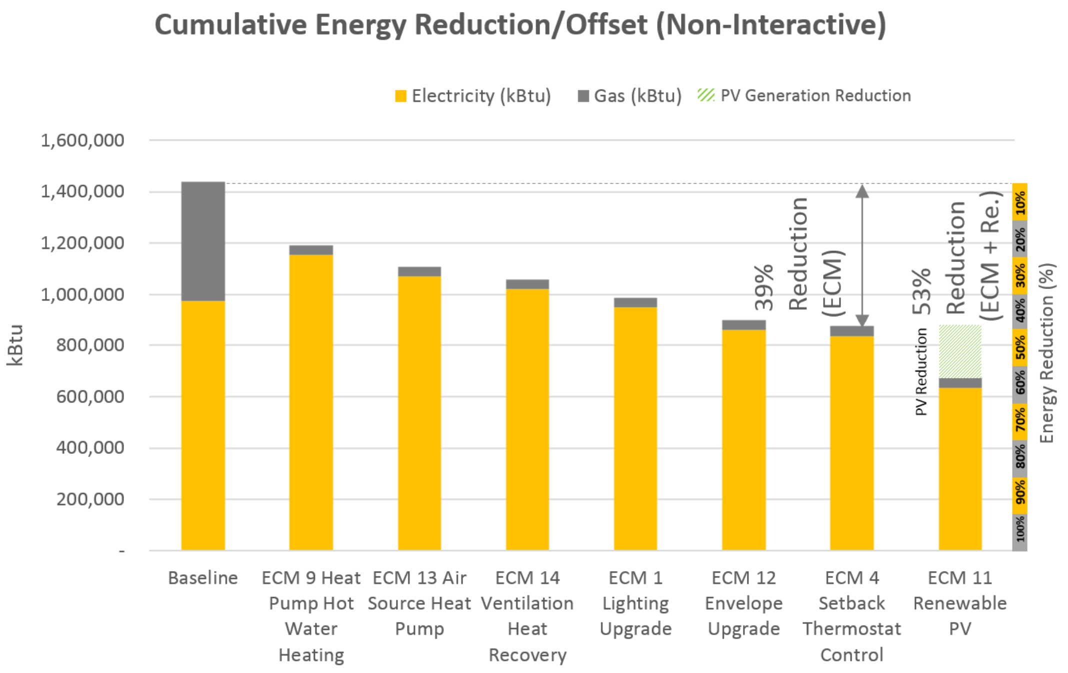


Figure 1 Individual & cumulative energy cost summary

3 Cost Benefits

To assess the economic viability of the identified ECMs, a life-cycle cost payback analysis was conducted. Costing data for the proposed ECM's and the baseline were estimated. Generally, these included first costs, annual maintenance cost and repair cost.

It is assumed there is no first cost in the baseline case except the ECM for space heating and the envelope upgrade. A 20-year life-cycle payback analysis was conducted for each of the recommended and quantitatively evaluated ECMs with escalation rates assumed as follows:

- Escalation rate for maintenance: 2.87% per annum
- Electricity: 5% per annum
- Natural gas: 5% per annum
- Discount rate for net present value: 2.07%

Table 2 Life Cycle Cost Analysis Results

ECMs	Net Capital Cost	Annual Net Energy Cost Saving	Simple Payback	LCC Payback	IRR	Net Present Value
ECM 1 Lighting Upgrade	($11,444)	$1,467	7.8	8.7	12.4%	$18,743
ECM4 Setback Control	($6,270)	$573	10.9	13.1	6%	$1,946
ECM 6 Condensing Boiler Heating	($9,700)	$658	14.7	9.4	10.8%	$13,399
ECM 9 Heat Pump Hot Water Heating	($10,600)	$1,590	6.7	5.2	21.7%	$38,533
ECM 11 Renewable PV	($159,250)	$4,929	32.3	>20	-6.0%	-$116,112
ECM 12 Envelope Upgrade	($35,411)	$982	36.1	>20	-0.7%	-$9,891
ECM 13 Heat Pumps	($93,824)	$1,289	72.8	>20	-6.8%	-$68,643
ECM 14 Ventilation Heat Recovery	($50,400)	$913	55.2	>20	-3.9%	-$26,675
ECM 16 Home Battery Storage[2]	($46,680)	$0	Never	Never	0%	$0

[2] There are no economic benefits from using battery storage based on current utility rates. It is estimated that should a time of use tariff structure be used, this system will have a simple payback of 6.5 years and a net present value of $68,208.

Out of these measures, the following are more likely to be economically viable for Capital Hill Housing to consider implementing at the property. It should be noted that rebates and incentive programs were not factored into these economics and so it is recommended that the local utility companies be contacted prior to funding any modifications since they will likely have programs that can provide assistance.

ECM-1 Lighting Upgrade – including technology change to LED and occupancy sensors for common areas / bi-level switching
ECM-2 Upgrade exhaust fan efficiency in common areas
ECM-4 Setback Control
ECM-5 Humidity sensors for clothes dryers (and generally updating other appliances)
ECM-6 Condensing Boiler Heating
ECM-9 Air source heat pump water heaters
ECM-11 Renewable PV

DOCUMENT CHECKING (not mandatory for File Note)

	Prepared by	Checked by	Approved by
Name	Kevin Wan/Martin Howell	Martin Howell	Martin Howell
Signature			