UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Strategies for Reducing Energy & Carbon Intensity of a Vancouver Townhouse Complex

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A townhouse building in Vancouver, Canada was studied to see what energy and emissions savings were possible through implementation of practical energy improvement measures. It was found that a 60 – 65% reduction in energy consumption was possible through measures that have no impact on household comfort or function. These measures yield a levelized savings of roughly $650 per year and a simple payback of five years.

These measures have the potential to make these townhouses 5 times more efficient than the average Canadian residential building and 4 times more efficient than a typical British Columbia town-home.

The suggested measures will introduce a mix of improved efficiency, behaviour change and new energy supply. This comprehensive approach is required to achieve maximum potential savings.

All suggested improvement measures are recommended to be implemented at the unit level as opposed to the building level. This is because expectations vary significantly amongst the home owners, and energy use in this building is already separated by unit.

Energy and emissions savings may be eroded by the behaviour of the residents by up to 26%. Clear understanding of the available savings and disciplined behaviour will be key to maximizing the potential of the suggested measures.

These results are most relevant to other town-homes in British Columbia, particularly in the Metro Vancouver area and on Vancouver Island.

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1.0 Introduction

1.1 Purpose

Reducing conventional energy use and carbon intensity in residential buildings is important for several reasons. Energy costs are rising around the world, putting more emphasis on efficient energy use; concerns surrounding energy security are rising; escalating atmospheric carbon concentrations are expected to have severe and adverse effects on the global climate. Buildings are responsible for 30% of GHG emissions in North America[1], so addressing building performance is a very important part of the solution.

While there is a wealth of information about general building performance, detailed and quantified analysis of specific buildings is somewhat lacking. Analysis of specific buildings can also have significant value. First of all, individual case studies allow the residents and owners of buildings to make informed decisions about how to most effectively lower their energy consumption and associated carbon emissions. Secondly, the results have the potential to guide relevant government bodies in their development of new policies, budgets and programs.

1.2 Objectives

This study discusses both of these factors by investigating a townhouse complex in Vancouver, British Columbia. A variety of improvement measures are examined ranging from simple demand side management techniques to new alternative energy systems. Each measure is studied, quantified and ranked according to its overall effectiveness. Implementation of many of these measures in combination results in an overall strategy for significantly improved energy and carbon intensity of this complex.

To truly understand the value of each measure it is important to evaluate it on both technical ability as well as how it matches the values of the residents and owners in this building. While evaluating technical performance is fairly straightforward, quantifying behaviour and personal values is another matter. This study attempts to represent these factors in a measurable way.

Unfortunately there are some uncertainties in this study that cannot be eliminated. It is important to acknowledge this uncertainty and understand how sensitive the results are to these variations. The resultant sensitivity will affect overall confidence in the suggested improvements.

The information in this study will be used by the residents and owners of these townhouses to make decisions about how to invest in the future of their building. The results may also be of interest to the local, provincial and federal government when developing policies surrounding residential energy use.

1.3 Background

This study is a good example of using a university campus as a "living laboratory". A townhouse complex at the University of British Columbia approached the University Neighbourhoods Association (UNA) about using resources on campus to guide them though a significant building retrofit, specifically with the intention of reducing energy use and carbon emissions. The primary sponsor of this project (Ralph Wells) got in touch with the UBC Clean Energy Engineering program and posed this as a potential project. It was presented as something that could benefit the residents as well as demonstrate what clean energy solutions are possible for similar buildings in Vancouver. With the support of an enthusiastic group of home owners as well as considerable on campus resources (the UNA, UBC SEEDS and many academic experts) this study was worth pursuing.

1.4 Literature Review

A wealth of research and work has already been completed in the arena of residential energy use. Most available literature focuses on global or national trends as opposed to specific buildings, but these findings are generally applicable to this case study. Utilizing theory and results from previous work has both guided the organizational framework of this study and sharpened its focus on specific measures with high value. One of the main purposes of this project is to apply general knowledge to a specific building and to study the results.

The measures examined in this study can be generally placed in one of two groups: energy efficiency and conservation (demand side management) or energy supply. Of these two categories, DSM is currently much more common at the residential building level. Cullen[2] concludes that 73% of global energy use could be saved through practical DSM measures, and 83% of energy demand for buildings could be eliminated. This can theoretically be achieved through dramatically increased building insulation and increases in hot water, appliance and lighting efficiency. Although these passive saving techniques are quite realistic for new buildings, some are impractical in this study. Increased insulation is not possible in most of this building (however increased attic insulation and high efficiency windows are considered). Appliance upgrades will probably not be seriously considered until the current ones reach end of life. Other measures (such as hot water, lighting and behavioural improvements) are extremely relevant and explored in this study.

Similarly, Dietz[3] argues that 20% of US household emissions could be saved in the next 10 years with little or no effect on home function and comfort. This paper cites many of the same strategies that Cullen does, but focuses more on existing residential buildings (which may explain why estimated savings are considerably lower when compared to all buildings worldwide). Dietz does an excellent job of categorizing measures into five groups: weatherization, efficiency, maintenance, one time (or infrequent) behavioural change, and daily behavioural change. This framework will be used throughout this paper. He also attempts to quantify energy savings that are based largely on behavioural change. This is a very important element in this study and is discussed throughout this paper.

Although DSM is widely considered an effective way to curb energy use and emissions, how it is achieved can be debated. Jaccard[4] suggests that current spending on DSM measures by utilities in Canada is only marginally effective in reducing electricity use. He cites that free ridership and the rebound effect considerably weaken the usefulness of current subsidies, and implementation of mandatory policies would be more effective. The impact of provincial and federal DSM programs and how they change overall costs for both the homeowners and the government is explored in this project.

Jacobson and Delucchi [5] goes as far as claiming that global power needs can be met by 2050 exclusively using renewable energy sources while paying little or no attention to DSM measures. These technologies would be widely distributed and utilize local energy sources. They states that clean energy can be economically competitive with fossil fuels, but acknowledge that the current cost of alternative power much drop before this is possible. Comparing realities of current alternative energy costs to the lofty goals can show how far apart these two ideas are at present.

While Jacobson is confident that distributed power generation can solve the world's energy and emission problems, he does not go into much detail about the level of distribution that will be required. Alanne[6] talks in detail about the degree of decentralization possible and how effective this will be. Alanne believes that a diverse mix of decentralized power will be the best approach, including energy generation at the residential building level. He suggests increased reliability, affordability and environmental performance will result when compared to centralized power generation. Needless to say there are a variety of opinions on how to address global energy challenges. One of the goals of this study is to compare the effectiveness of DSM measures and new energy generation in this specific building.

Williams[7] believes that a balanced approach using both DSM measures and new energy supply will be critical to make significant emissions reductions in the future. He presents a convincing case, suggesting that the use of clean electricity will be almost as important as DSM measures to achieve deep emissions cuts by 2050 in California (Williams aims to reduce emissions to 80% below 1990 levels). He predicts that roughly 10% of these reductions will come from the residential sector, not only through DSM measures but also by utilizing solar thermal water heating and rooftop photovoltaic panels. These energy measures are not likely to be as effective in Vancouver as they are in California due to climate differences, but will be investigated in this study.

Another very important factor in the energy performance of residential buildings is the behaviour of the residents. Attari[8] explains that most people intend to be energy conscious in their homes but have a poor understanding of what behavioural changes are the most important. In general people believe that curtailment (turning off lights) is most important to overall energy use when in fact increasing efficiency (switching to CFL lights) makes a much bigger difference. He also shows that people are likely to underestimate energy use of high consuming technologies such as appliances. Common misconceptions are presented and discussed in more detail later in this paper.

Gardner and Stern[9] attempt to reduce this confusion by prioritizing what behavioural changes are most effective in typical US households. The recommendations on this list are a combination of low cost efficiency upgrades (upgraded lighting) and behavioural changes (change thermostat, washing machine settings). To maximize energy savings in this building, the information from the Attari and Gardner papers has been incorporated into this study.

2.0 Data and Methods

2.1 Data Sources

Acquiring accurate information for energy use in this building was essential to this study. Most of this information was obtained directly from the building owners. Utility bill history was provided by several of the owners in this complex, and the common area bills were made available as well. A walk through of one of the units and all common areas was completed to provide more detailed information about how energy is used. Access to the mechanical and architectural drawings provided important information about the construction of this building that was not obvious from the walk through.

Although the provided information was very important, in some cases it was not complete enough to completely characterize energy use. In these cases national and provincial trends were used to fill in the gaps. The primary resource for this data was Natural Resources Canada[10], who publishes a wide range of statistics on residential energy use.

Aside from building data, other information was required to complete this study. The budget and priorities of the homeowners were collected through a survey during the initial stages of this project. Provincial and federal subsidies for the residential energy sector are described in detail by Home Performance[11]. Historic pricing of electricity and natural gas is available from the Canadian National Energy Board[12] and US Energy Information Administration[13] as well as price forecasts. Information for specific measures examined in this study were collected from a wide variety of government, academic and commercial sources.

2.2 Methodology

An energy model was created to predict the outcome of several different retrofit scenarios for this townhouse complex. A block diagram depicting this model is shown below. The proposed scope of this study is to evaluate complete energy use and carbon emissions of this building (all privately owned units) over the next 20 years.

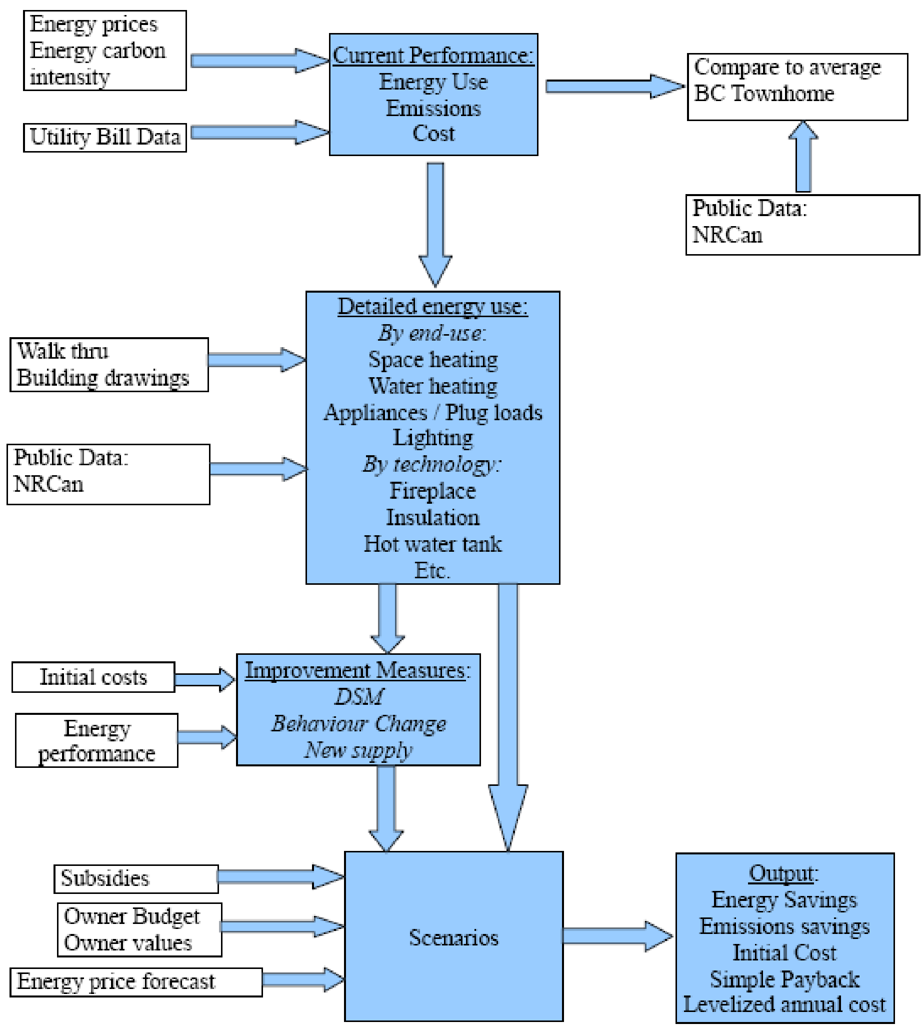


Exhibit 1: Energy Model Block Diagram

2.2.1 Improvement Measures

Many improvement measures were investigated in this study, ranging from relatively simple energy efficiency improvements to energy generation systems. These measures can be organized into two subcategories: energy by end-use, and implementation type. This information is summarized in the table below. These measures are recommended for implementation at the unit level as opposed to the building level.

	Space Heating	Water Heating	Appliances / plug loads	Lighting
Weatherization	-Attic Insulation -Window Upgrade			
Efficiency		-tankless water heater -drain water heat recovery	-appliance upgrades	
Equipment Change	-turn off pilot light in summer	-tank set points -washing machine settings	-washing machine settings -timers on electronics	
Daily behaviour change	-thermostat settings	-low flow shower head	-clothes line -cooking habits	-Change lights to CFL
New Energy Supply	-air source heat pump -ground source heat pump	-solar thermal -heat pump water heating	-photovoltaic panels -Micro CHP	-photovoltaic panels -Micro CHP

Exhibit 2: Improvement Measures included in study

2.2.2 Scenarios Investigated

Several scenarios were run in this model. Each of these scenarios was constructed to provide insight into a specific point of interest. Cases examined are:

1. Improved energy and carbon performance exclusively though demand side management (energy efficiency, conservation) technologies. This scenario will be constrained by the capital cost limitations of the owners in this building.

2. Improved performance exclusively through new energy generation. This will also be constrained by budget limits of the owners.

3. A combination of the best technologies from the first two cases, again limited by budget.

4. Direct comparison to option 3 without available provincial / federal subsidies. There are a

multitude of programs that home owners can take advantage of to improve energy use in their homes. Use of subsidies should allow additional improvements within the budget; it will also change the payback period of this project if measures are unchanged from case 3.

5. Best possible energy and carbon improvement with no budget constraints. This will show if a "net zero" solution is possible in this building, and if so at what cost.

Each scenario utilizes multiple improvement measures in combination to generate a significant overall impact on energy use and carbon emissions. It is important to realize that some measures can be combined (washing machine settings and tankless water heating), while others cannot (hot water tank set points and tankless water heating). It is also critical to aggregate savings and not double count improvements (improving attic insulation will reduce the impact of thermostat set points).

2.2.3 Output

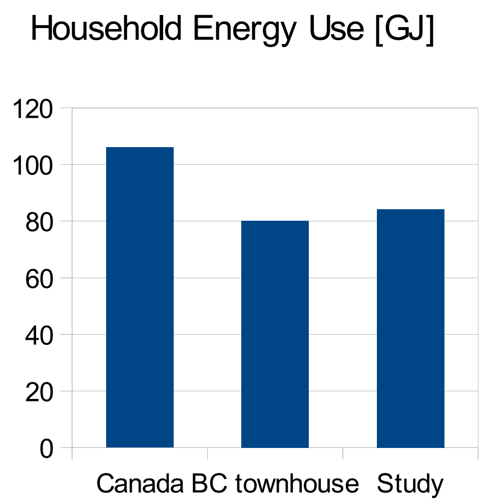
For each scenario the following output is generated.

1. Energy savings per year compared to business as usual (in GJ)
2. Carbon emission reductions per year compared to BAU (in Kg of CO_2)
3. Initial costs required (in CAD)
4. Simple payback period (in years)
5. Levelized annual savings (in CAD)

3 Results and Discussion

3.1 Present Building Performance

Energy use in this building is already considered low when compared to residential buildings in Canada as well as townhouses in British Columbia[10].



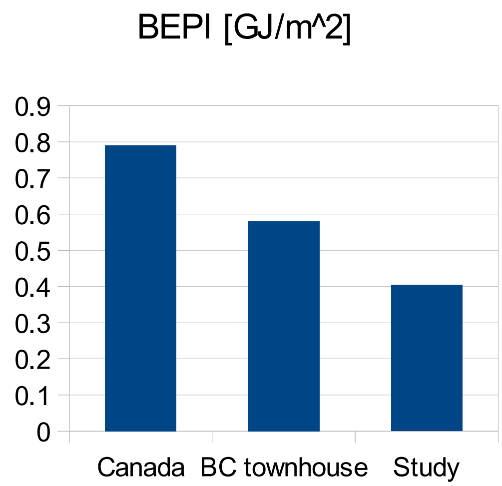


Exhibit 3: Energy use compared to BC and Canada averages

Total energy use is 20% better than the average Canadian residential building, and similar to typical town-homes in British Columbia. When energy use in normalized by household area (commonly known as the Building Energy Proficiency Index), this building shows significantly better performance in both cases; almost 50 % better than the national average and 35% better than BC townhouses.

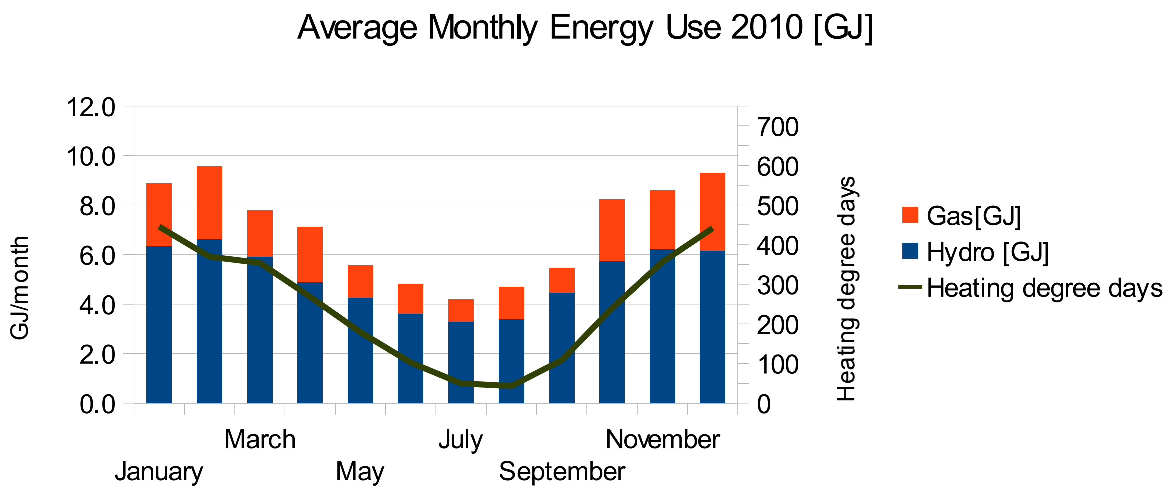
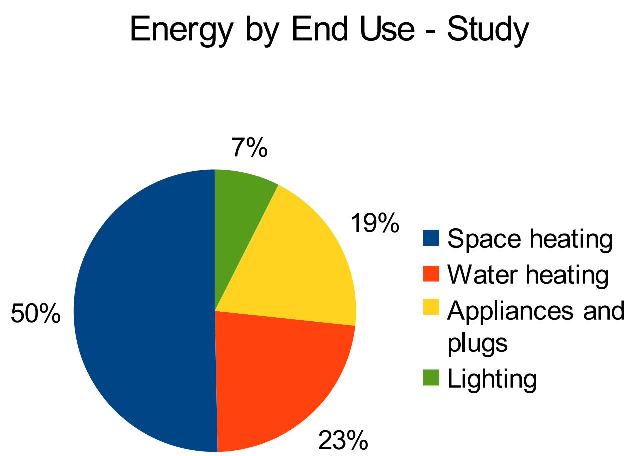


Exhibit 4: Average monthly energy use

Detailed energy consumption was provided by the homeowners. Three of the ten owners shared utility bills from 2011, and the average is shown here. Energy use varies throughout the year. This is mostly due to changing heating requirements. Electricity is the prominent source of energy, with natural gas providing some energy for heating and cooking. Determining energy consumption by end-use was done through utility bill analysis and use of statistics provided by Natural Resources Canada[10] (see supporting information for more detail). The breakdown of energy use is very similar to the BC average for town-homes.



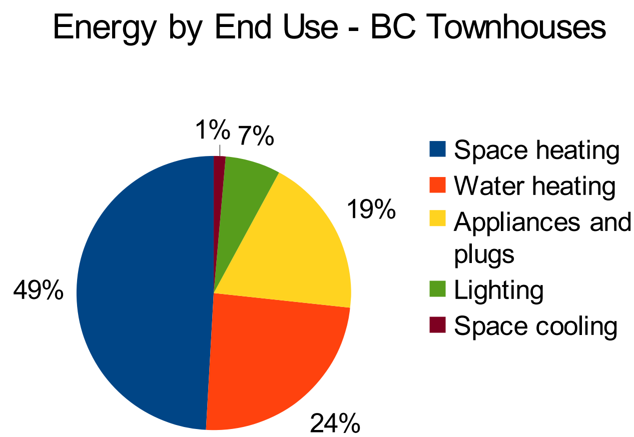


Exhibit 5: Energy by end use

Energy use in this complex is more efficient that the national and provincial averages because of building construction and installed energy technology. Key information is summarized below:

Space Heating	Insulation	R40 roof, R20 walls, double pane windows, excellent sealing
	Heating	2 gas fireplaces (58% efficient), baseboard heaters in every room
Water Heating		Electric hot water tank – Standby losses 91 Watts
Appliances & Plug loads		2x stove, dishwasher, 2x fridge, 2x freezer, washer/dryer, plug loads
Lighting		Mix of incandescent and compact fluorescent lights

Exhibit 6: Key information on current energy technologies

Features such as high insulation, an efficient hot water tank, and modern appliances help keep overall energy consumption low. There is room for improvement however; most notably the relatively inefficient heating technologies.

3.2 Survey Results

In order to make meaningful recommendations to the owners of these town-homes it was critical to understand their expectations and values. This information was acquired through a survey conducted in the early stages of this study. Owners were asked to rate the importance of different aspects of a major energy retrofit, provide approximate budget constraints, and suggest particular measures they wanted explored. All 10 owners participated in this survey. The scores show the average importance to the owners, and the standard deviation is a rough measure of the agreement between the owners (small standard deviation indicates high agreement).

	Score	Standard Deviation
Save money over time	8	1.5
Reduce greenhouse gas emissions	9	1.5
Statement about sustainability	7	3
Minimal disruption	6.5	2.5
Increase home value	7.5	2

Exhibit 7: Summary of values in survey results

The owners are in high agreement that reducing greenhouse gas emissions and saving money over time are the most important factors in an energy retrofit.

	Average	Standard Deviation
Minimum Budget	$6000	$5800
Maximum Budget	$10,000	$9000
Minimum Payback (years)	7	5
Maximum Payback (years)	10	7

Exhibit 8: Summary of budget in survey results

On average, the owners are willing to invest $6000 - $10,000 in this project, and are comfortable with a payback period of 7 – 10 years. The range in these answers was large however, suggesting that there is little agreement between the owners on how much to spend. This implies that implementing changes in individual units will be more feasible than something that requires agreement from most or all of the owners.

	# of responses
Photovoltaic Panels	4
Geothermal heating	4
Solar Thermal Water Heating	3
Insulation Upgrade	2

Exhibit 9: Summary of technologies in survey results

There is much more initial interest in new energy supply than energy efficiency and conservation amongst the owners in this building, and the only efficiency upgrade mentioned by more than one owner was insulation. All of the above measures are examined in this study.

3.3 Measures

Twenty five different improvement measures were considered for this project. Each measure was treated independently to show maximum potential performance. Detailed discussion on each measure can be found in the supporting information. A summary of this information can be seen in the below table. An explanation of the presented data can be found following this table.

Category	Measure	GJ/yr	Kg CO2/yr	$/yr	Initial Cost	L.A.S.	Rank
Space Heating	Roof Insulation (W)	1.5	53.2	$35	$660	-$20	15
	Window upgrade (W)	3.1	113.3	$75	$3,460	-$200	18
	Turn off pilot light (A)	3.6	180.0	$37	$0	$40	6
	Air Source Heat Pump (S)	24.6	1016.3	$481	$3,960	$60	11
	Program Thermostats (D)	0.8	18.9	$31	$70	$20	9
	Ground Source Heat Pump (S)	28.5	1107.4	$630	$8,130	-$70	12
Water Heating	Drainwater heat recovery (E)	7.2	167.2	$273	$780	$200	7
	Tankless water heater (E)	2.9	67.0	$110	$2,500	-$130	16
	Solar Thermal Heating (S)	8.7	203.2	$332	$2,750	$80	10
	Heat pump water heating (S)	4.8	112.8	$185	$840	$60	13
	Low Flow Shower Head (E)	1.8	42.3	$69	$60	$60	4
	Change Tank Setpoints (A)						
Appliances, lighting and plug loads	2x Stove (E)	1.1	25.2	$41	$1,400	-$110	21
	Dishwasher (E)	0.1	2.5	$4	$780	-$100	23
	1.5 x Fridge (E)	0.9	22.0	$36	$1,150	-$80	19
	2x Freezer (E)	0.6	14.3	$23	$900	-$60	20
	Washing Machine (E)	2.0	46.9	$77	$680	$0	14
	Dryer (E)	0.3	7.3	$12	$760	-$80	22
	Hang dry clothes (D)	1.0	23.6	$39	$130	$30	3
	Boil water with lid (D)	1.3	29.8	$49	$0	$50	2
	Washer Settings (A)	1.3	29.7	$49	$0	$50	1
	Photovoltaic Panels (S)	20.0	466.7	$763	$25,670	-$1,080	17
	Timers on computer, DVR (A)	0.6	14.3	$23	$50	$20	8
	Incandescent to CFL (D)	2.4	57.1	$93	$220	$60	5
	Micro Combined Heat & Power (S)						

Exhibit 10: Summary of Energy Measures Considered

Measures are categorized by type (following Deitz et al[3] as a model) into 5 groups:

W	Weatherization, an improvement to the building envelope
E	Efficiency upgrade of mechanical or electrical systems
A	Change in equipment setting, dependent on an infrequent behaviour change
D	Daily or very frequent behaviour change
S	New energy supply

Exhibit 11: Measure categories

GJ/yr is the projected energy savings per year, and Kg CO_2/yr estimates annual carbon dioxide abatement. For this study, the following carbon intensities are assumed.

	Grams CO_2/kWh	Kg CO_2/GJ
B.C. Electricity	84	23.3
B.C. Natural Gas	180	50

Exhibit 12: Carbon Intensity

Carbon intensity is discussed in detail in the supporting information. Measures that displace natural gas generally have higher carbon abatement than those that save electricity. $/yr is an estimation of annual energy cost savings. This figure is dependent on projected future energy costs (shown in supporting information).

	Current Cost [2012 $]	Projected Average Cost 2012-2032 [2012 $]
BC Hydro (Step 2)	$26.70 / GJ ($0.093/kWh)	$38.17 / GJ
Fortis	$8.90 / GJ	$10.39 / GJ

Exhibit 13: Projected energy cost

Initial cost is defined as capital cost plus installation cost minus any relevant subsidies. Levelized annual savings (L.A.S.) is calculated with a 7% discount rate (explained in detail in the supporting information).

Each measure was scored and subsequently ranked through a multi criteria decision making process. The purpose of this process is to rank these measures in an order that closely matches the values and expectations of the owners. The score for each measure was defined by the following equation:

$$Score = 9C_s + 8N_s + 6S_s - 3I_s - 2D_s$$

where:

$$C_s = \frac{Carbon\ abatement / GJ}{Best\ Carbon\ abatement / GJ} \qquad N_s = \frac{savings / GJ}{Best\ savings / GJ} \qquad S_s = \frac{Sutainable\ Statement}{Best\ sustainable\ statement}$$

$$I_s = \frac{Initial\ Cost}{Highest\ Initial\ Cost} \qquad D_s = \frac{Distruption}{Highest\ Distruption}$$

The weight of each factor in this equation is based largely on the survey results, and scaled slightly to produce more meaningful results. Carbon, energy and cost information are calculated in this study, while sustainability statement and disruption are scored subjectively. Monetary and carbon savings are normalized per GJ so each measure can be compared directly. A detailed discussion of this method can be found in the supporting information.

Two measures were not included in the ranking process. The micro CHP is projected to have negative carbon and energy savings because it displaces relatively clean electricity with electricity produced by natural gas at a low efficiency. Changing the hot water tank set points is not evaluated because lowering these would violate Canadian health regulations.

3.4 Scenarios

Several simulations were run in this study, each providing a useful piece of information about this project. For each case, the results are presented in an incremental energy savings graph with cost per GJ shown on the Y-axis and total energy savings shown on the X-axis. A negative cost per GJ indicates an economic savings. The measures are introduced in order of rank determined by the multi-criteria decision making process. This means that measures with the highest $/GJ savings are not necessarily located on the left side of the graph. All results in 2012 dollars. All improvement measures are for implementation in the individual units, not the townhouse complex as a whole.

Another important distinction is these graphs show maximum potential savings, not expected savings. Multiple barriers exist that will likely erode these savings. These barriers are discussed in section 3.5.

3.4.1 Savings Using only Energy Efficiency and Conservation Measures

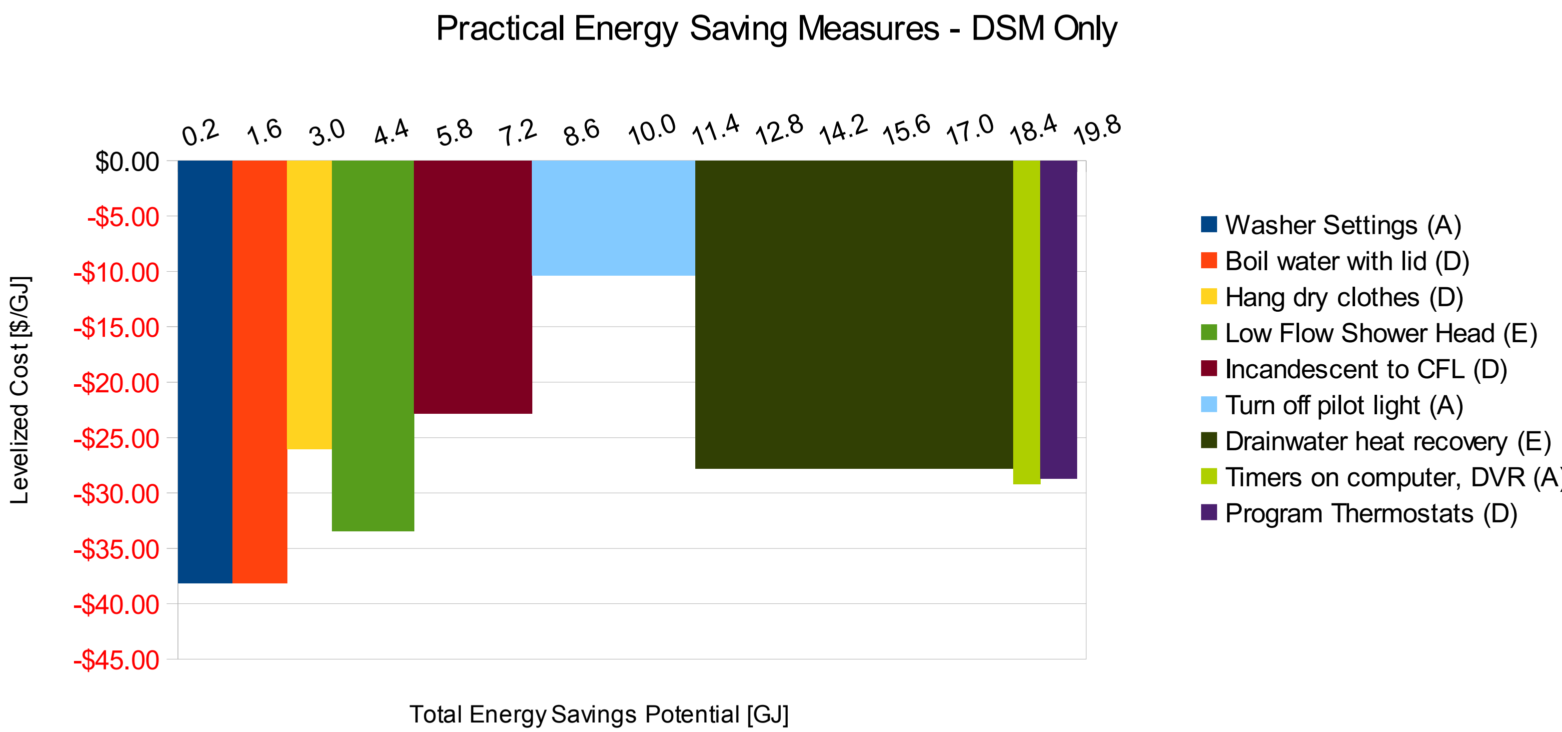


Exhibit 14: Energy savings graph for DSM measures

Annual Energy Savings	20 GJ
Annual Carbon Dioxide Abatement	560 Kg
Initial Cost	$1300
Average Annual Energy Savings	$630
Levelized Annual Savings (discount rate of 7%)	$500
Simple Payback	2 years

Exhibit 15: Summary of DSM measures

Practical DSM measures can reduce total household energy consumption by about 25%, abate about half a ton of carbon dioxide a year, and have a levelized annual savings of $500 per year. Many of the behavioural changes have the best savings ($/GJ) but contribute small overall energy savings. Drain water heat recovery provides the highest overall savings. Improved insulation, which was of interest to the owners in the survey, is not suggested as a viable DSM measure.

3.4.2 Savings Using only New Energy Supply

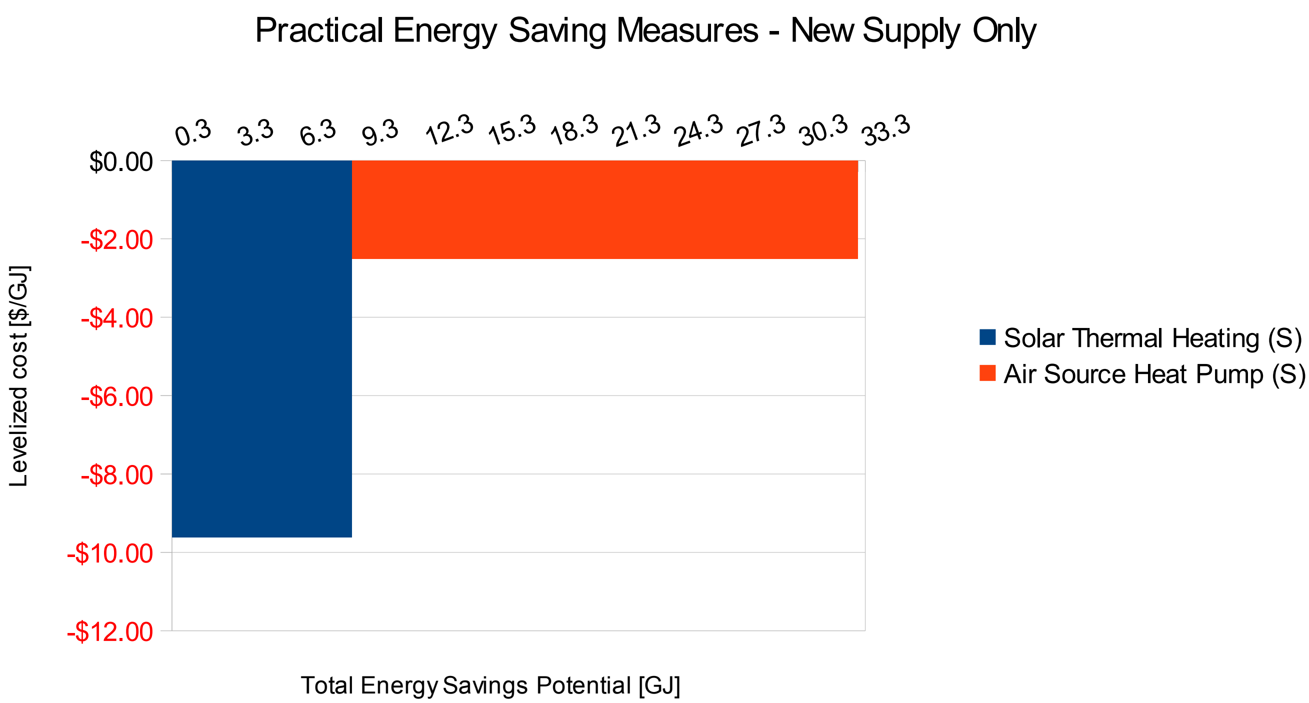


Exhibit 16: Energy savings graph for new energy supply measures

Annual Energy Savings	33 GJ
Annual Carbon Dioxide Abatement	1200 Kg
Initial Cost	$6700
Average Annual Energy Savings	$820
Levelized Annual Savings (discount rate of 7%)	$150
Simple Payback	8.3 years

Exhibit 17: Summary of new energy supply measures

Only two new energy supply options are suggested for this study. Geothermal heating also ranked very well but is not included because it becomes redundant with the inclusion of an air source heat pump. Due to high initial costs and an extremely long payback period, photovoltaic cells are not suggested.

While only two measure are suggested it is important to note that an air source heat pump can save more energy and abate more carbon than all the DSM measures combined (24 GJ/yr). This is due to a fundamental change to how each townhouse is heated, moving away from inefficient fireplaces and baseboard heaters to a considerably more efficient system (C.O.P of 2.9). Solar thermal water heating also provides more energy than any individual DSM measure (9 GJ/yr).

Higher capital costs drive the simple payback higher than the DSM measures, but is still quite affordable with a payback period of about 8 years.

3.4.3 Savings Using a Combined Approach

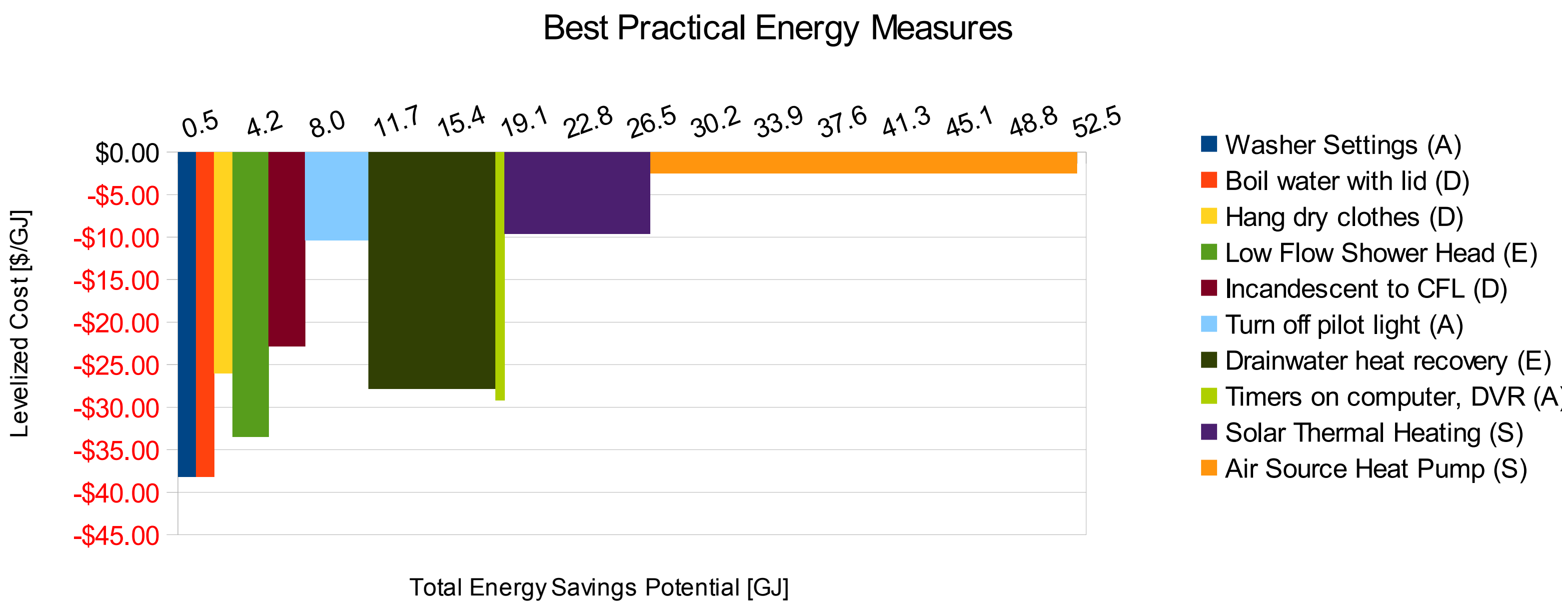


Exhibit 18: Energy savings graph for best combined measures

Annual Energy Savings	53 GJ
Annual Carbon Dioxide Abatement	1770 Kg
Initial Cost	$8000
Average Annual Energy Savings	$1450
Levelized annual savings (discount rate of 7%)	$640
Simple Payback	5.5 years

Exhibit 19: Summary of best combined measures

Combining the best energy supply and DSM measures can provide 53 GJ of annual savings to each owner, which is over 63% of current energy consumption. This investment would also abate about 2 tons of carbon dioxide per year, and provides levelized annual savings of about $650/year.

The capital cost required is in line with what homeowners are generally willing to invest in an energy retrofit (surveyed average of $6000 - $10,000), and the payback period is less than what is considered acceptable. This suggests that this combination of measures may be embraced by a majority of the owners in this complex.

Three acceptable DSM measures are omitted from this scenario due to functional conflicts. A tankless water heater is ruled out because solar thermal water heating requires a tank to function. Programmable thermostats for the baseboard heaters are also left out because the air source heat pump is assumed to displace this heating type of heating. Washing machine replacement is not recommended because once washing machine setting changes are in place, replacing this appliance is no longer economic.

3.4.4 Combined Approach without Subsidies

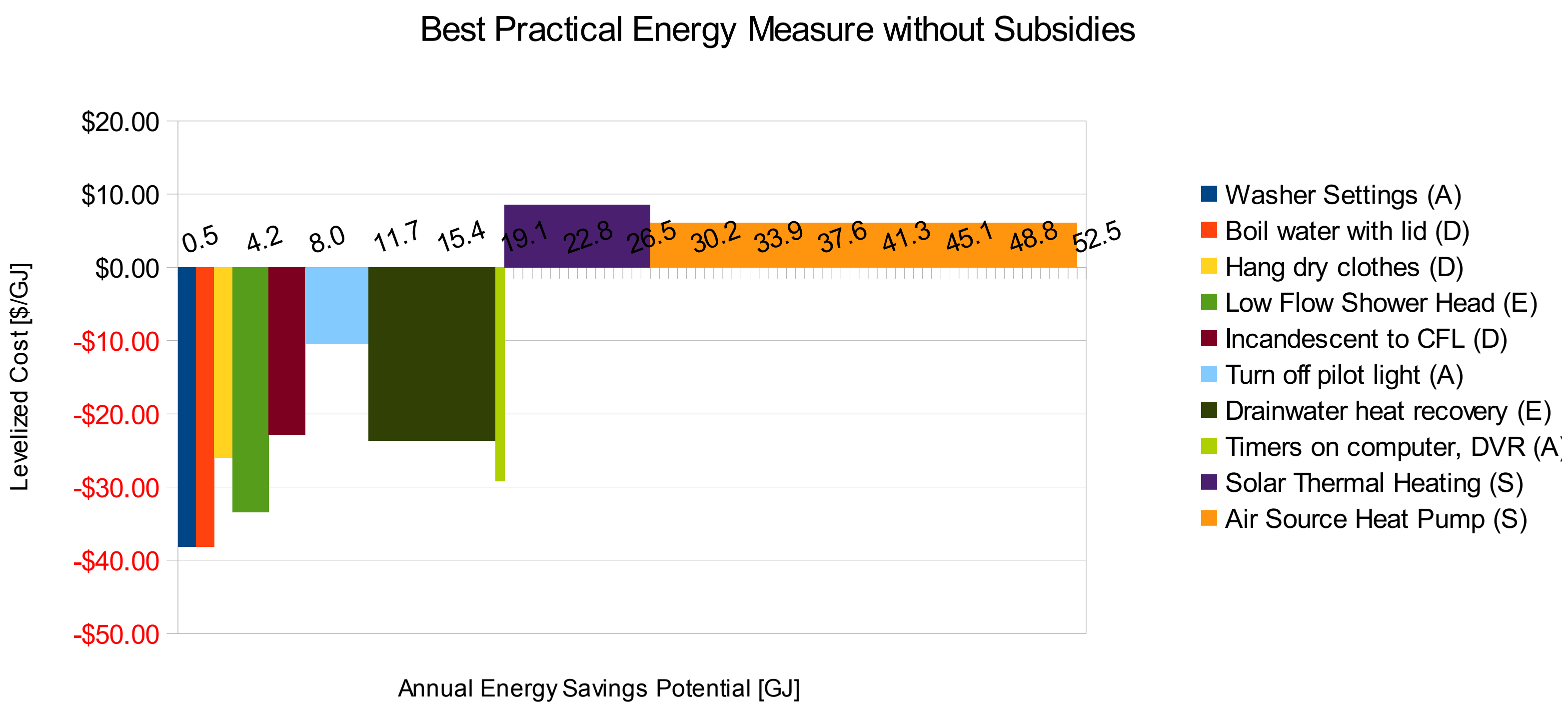


Exhibit 20: Energy savings graph for best combined measures without subsidies

Annual Energy Savings	53 GJ
Annual Carbon Dioxide Abatement	17700 Kg
Initial Cost	$12,000
Average Annual Energy savings	$1450
Levelized Annual Savings (discount rate of 7%)	$240
Simple Payback	8 years

Exhibit 21: Summary of best combined measures without subsidies

Removal of provincial and federal subsidies increases initial costs by roughly 50%. Removing subsidies clearly affects measures with high energy savings the most, particularly solar thermal water heating and the air source heat pump which become money losing investments. This case pushes initial costs higher than what is generally considered acceptable to the owners.

3.4.5 Net Zero Energy Solution

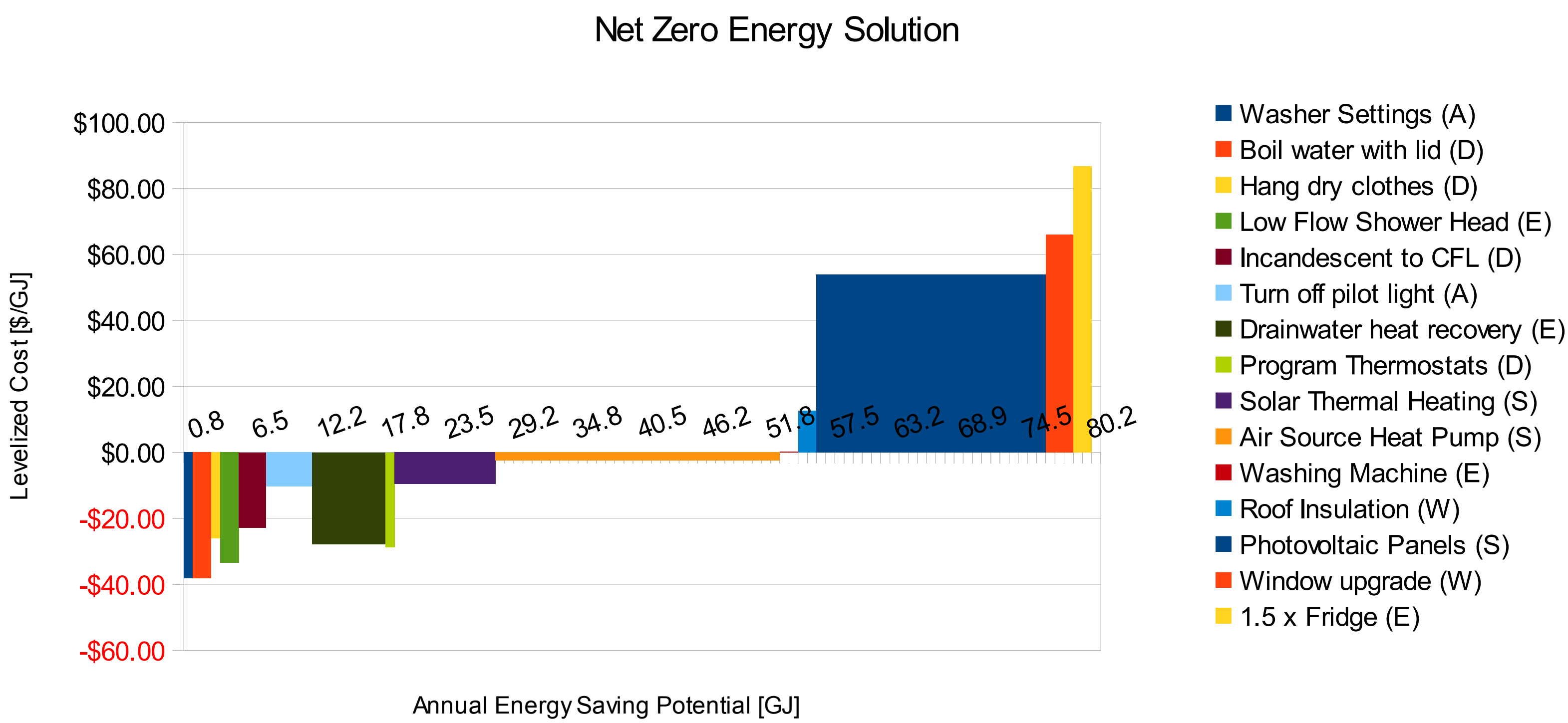


Exhibit 22: Energy savings graph for net zero solution

Annual Energy Savings	78 GJ
Annual Carbon Dioxide Abatement	2370 Kg
Initial Cost	$38,000
Average Annual Energy Savings	$2400
Levelized Annual Savings (discount rate of 7%)	-$650
Simple Payback	16 years

Exhibit 23: Summary of Net Zero Energy Solution

Reaching a net zero energy solution for the units in this building is not possible without significant initial investment and accepting an extremely long payback. The reason for this is photovoltaic panels are required to meet electricity requirements. Space heating and water heating needs can be largely met by more attractive measures, but no practical technologies exist to meet electricity demands. Photovoltaic systems are particularly expensive in Vancouver due to a lack of intense sunlight.

Based on the results from this section, the combination of measures suggested in section 3.4.3 will be considered the default solution going forward in this study.

3.5 Barriers

Although the options presented in the previous section are technically and economically feasible, there are several barriers that may prevent this project from reaching its potential.

The suggested technology and behaviour changes are expected to save the owners money and reduce carbon emissions, but this does not necessarily mean they will be adopted. Deitz[3] provides data on the rate of adoption of different energy measures in typical U.S. Households.

Measure	Percent adoption in U.S.
Weatherization	90
Low Flow Shower heads	80
Efficient Appliances	80
Laundry Temperature Settings	35
Low thermostat Settings	35
Line Drying Clothing	35

Exhibit 24: Typical adoption of various energy technologies

Adoption ranges from 90 to 35 percent depending on the measure. Low penetration is typical in measures that involve an equipment setting change (A) or a frequent behaviour change (D). If the residents in this building display typical adoption behaviour, roughly 11 GJ of annual savings will be lost on average (see supporting information).

When measures are implemented, savings can also be reduced by the rebound effect. The rebound effect is a natural response to implementation of more efficient technology, usually as a result of lower operating costs. In this study, increased use of appliances, hot water, heating and lighting may be a response to lower utility bills. Greening et al[14] shows typical rebound response for different residential energy end-uses.

Measure	Typical Rebound %
Space Heating	10 - 30
Water Heating	10 - 40
Major Appliances	0
Lighting	5 - 12

Exhibit 25: Typical rebound effect

The rebound effect has the largest impact on measures that involve efficiency (E), new energy supply (S), and weatherization (W). If the residents in this complex show a typical response to lower utility bills, approximately 9 GJ of annual savings will be lost to rebound (see supporting information). Water heating and space heating generally have the highest rebound. Greening sites behaviour changes such as raising indoor temperatures and increased shower length as behaviours that cause this to happen.

Many of the owners in this building have tenants in their basement suites, and these tenants are not billed separately for their utilities. This causes a disconnect between the tenants and the landlords that can inhibit energy savings. In this case an energy usage problem is anticipated[15].

Transactions from an end-user perspective

	End user can choose the technology	End user cannot choose the technology
End user pays the energy bill	Case 1: No PA problem (principal and agent same entity)	Case 2: Efficiency problem (agent selects end using technology, principal pays the energy use)
End user does not pay the energy bill	Case 3: Usage and efficiency problem	Case 4: Usage problem

Exhibit 26: Tenant / Landlord split incentive

While this effect is undesirable, it is unlikely that this will reduce energy savings beyond business as usual. This is because tenants are not expected to change their behaviour based on changes in energy technology.

Although the initial cost requirements of the recommended measures are within the budget constraints of the average homeowner in this building, it is above the budget of a few of the residents. This will undoubtedly reduce the savings potential in these units.

3.5.1 Overcoming Barriers

While most homeowners are interested in engaging in behaviour change that reduces energy use, it is well documented that people generally have a poor understanding of what are the most effective ways to achieve this. Attari's[8] research shows the magnitude of this misunderstanding.

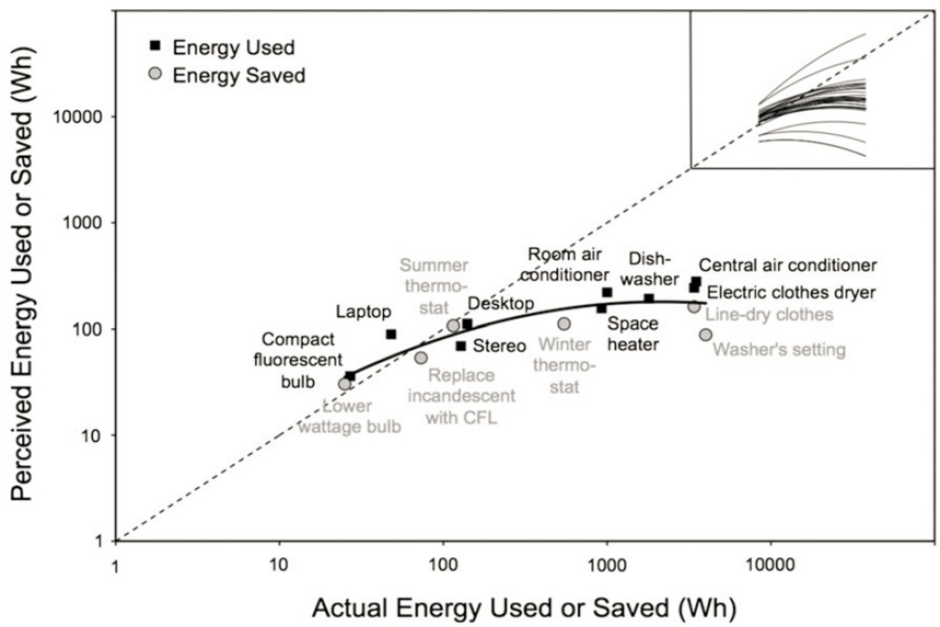


Exhibit 27: Typical understanding of household energy use

The above graph shows how people generally underestimate how much energy different household technologies use. This effect is quite small for low energy consumers like light bulbs and laptops, but is much larger for high energy consumers such as major appliances. This causes people underestimate savings from measures like line dying clothes or changing washing machine settings by a factor of 10 or more. Highlighting the actual savings potential of these measures will go a long way to ensuring they are adopted at a higher rate. This report will help with some of these misconceptions.

Besides clearly communicating information about potential energy savings, McKenzie-Mohr[16] suggests that creating a social culture of sustainability is the most effective way to maintain long term behavioural change. His research explains that social diffusion is often the best way to instill lasting energy savings. It appears this group of townhouses should have success developing this culture as the survey results show a strong interest in energy savings and emission reductions. Measures that are highly visible will be particularly important to increase social diffusion. Widespread adoption of these measures is much more likely if a few owners embrace these recommendations and share their experience with their neighbours.

3.6 Results from a Policy Perspective

This study can also be used to determine which subsidies are effective for this building from a policy perspective. This building is not completely representative of typical residential buildings in British Columbia, but the results are still worth examining.

Determining the effectiveness of a subsidy from a government perspective is not straightforward. There are many factors to consider when conducting such an analysis, and careful consideration of what should be included is important. In this study, two different approaches are explored: the first is a pure economic analysis, and the second includes a value for saved carbon dioxide emissions.

BC Hydro is not a net electricity producer. As a result, BC Hydro must purchase additional power to meet provincial needs. This power is purchased from a variety of sources, but the most expensive of these is from its Long Run Marginal Cost agreements. In 2009 BC Hydro was buying power through these contracts at a cost of 12.4 cents / kWh (scaled to 13.3 cents in 2012 CAD)[17]. This is 3.7 cents more than the tier 2 residential rate. If BC Hydro can lower their reliance on this power by reducing residential energy use they can save 3.7 cents for every kWh not used in the residential sector.

Saving natural gas can also be a financial benefit for the province. BC is currently planning to grow its liquid natural gas sector with the intent of exporting it to Asia at much higher prices. According to the provincial government the commodity price of natural gas in British Columbia is $4/GJ while the price in Asia is $16/GJ[18]. Natural gas saved domestically could potentially be sold abroad at a profit of $12/GJ. The province of British Columbia gets a 17% royalty[19] on all natural gas sales, meaning that selling this gas in Asia instead of BC can be interpreted as a $2/GJ profit for the province.

British Columbia is also planning to reduce its emissions, and has imposed a carbon tax of $30/tonne of carbon dioxide emitted[20]. In this study carbon dioxide abatement is also given a value of $30/tonne.

Electricity savings	$10.22	$/GJ
Natural Gas savings	$2.04	$/GJ
CO2 abatement value	$30.00	$/ton

Exhibit 28: Energy savings from a provincial perspective

Detailed analysis of these subsides can be found in the supporting information. Results of several notable measures are shown and discussed.

	Provincial results		**Homeowner results**	
	L.A.S.	L.A.S. + CO2 savings	L.A.S. W/ subsidies	L.A.S. W/o subsidies
Air Source Heat Pump (S)	-$66	-$35	$62	-$150
Drainwater heat recovery (E)	$39	$44	$199	$170
Solar Thermal Heating (S)	$22	$28	$84	-$75
Washing Machine (E)	$12	$13	-$1	-$9

Exhibit 29: Summary of measures from a provincial perspective

The levelized annual savings for the province is calculated with the method as before, but the initial costs are the value of the subsidy provided, and the annual savings are the incremental savings shown in Exhibit 28.

Drain water heat recovery is profitable for the homeowners with or without the subsidy. This suggests that some free-riding may happen some these measures. Solar thermal water heating and a the air source heat pump require a subsidy to be economically attractive to the residents.

Providing these subsides is profitable for British Columbia in every case except the air source heat pump (of course free-riding may diminish these savings). The heat pump is a unique case because about half the energy displaced is natural gas which is not economically attractive.

If the province values carbon dioxide abatement at $30/tonne, the loss to province is reduced by half. Again, this is due to a large reduction in natural gas use.

In general, subsidies that reduce residential electricity consumption are profitable for the province, while those that reduce natural gas use are only worth pursuing if abating carbon dioxide emissions is seen to have value.

It also appears that several of the suggested measures are profitable for the homeowners with or without subsidies, suggesting that some free-ridership will occur.

3.7 Uncertainty and Sensitivity Analysis

There are several uncertainties that may impact the effectiveness of the measures suggested. For this reason a sensitivity analysis was preformed on three key factors: how the price of energy will change over time, what the various owners consider an acceptable discount rate, and how strong the rebound effect will be.

For these analyses, the measures suggested in section 3.4.3 are all assumed to be implemented.

Measures
Hang dry clothes (D)
Washer Settings (A)
Boil water with lid (D)
Low Flow Shower Head (E)
Air Source Heat Pump (S)
Incandescent to CFL (D)
Timers on computer, DVR (A)
Solar Thermal Heating (S)
Drainwater heat recovery (E)
Turn off pilot light (A)

Exhibit 30: Measures included in sensitivity analysis

Energy prices for both electricity and natural gas are assumed to grow 3% annually. This is based on forecasts developed by the U.S. Department of Energy[13], and Canada's National Energy Board[12] (see supporting information). These sources both predict 2% - 4% annual growth as a range that energy prices are most likely to fall within until 2035. The below graph shows how changing energy prices affect levelized annual savings.

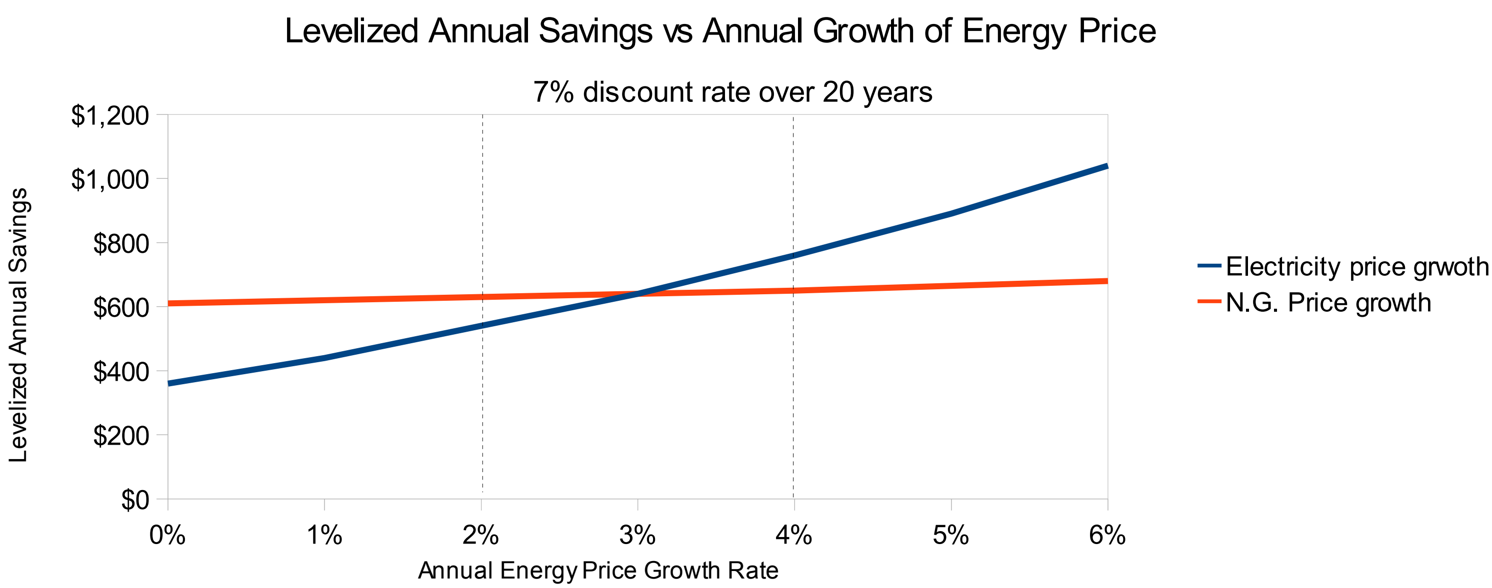


Exhibit 31: Sensitivity to changes in energy price growth

The suggested measures are much more sensitive to a change in electricity price. This is because once these measures are implemented there is very little natural gas use, and the price of electricity is much higher than the price of natural gas. Quicker escalation of energy prices means that savings will be higher as well (although utility costs will still rise in an absolute sense). It is important to note that even if energy prices do not change at all significant savings are still expected. Average annual savings are most likely to fall between $500 - $800 if energy prices increases within the expected bounds of 2 - 4% a year.

Another important factor in this study is the assumed discount rate. A rate of 7% was used throughout this study, but this may be unacceptably low for some of the owners. For this reason, levelized annual savings was graphed against changing discount rate.

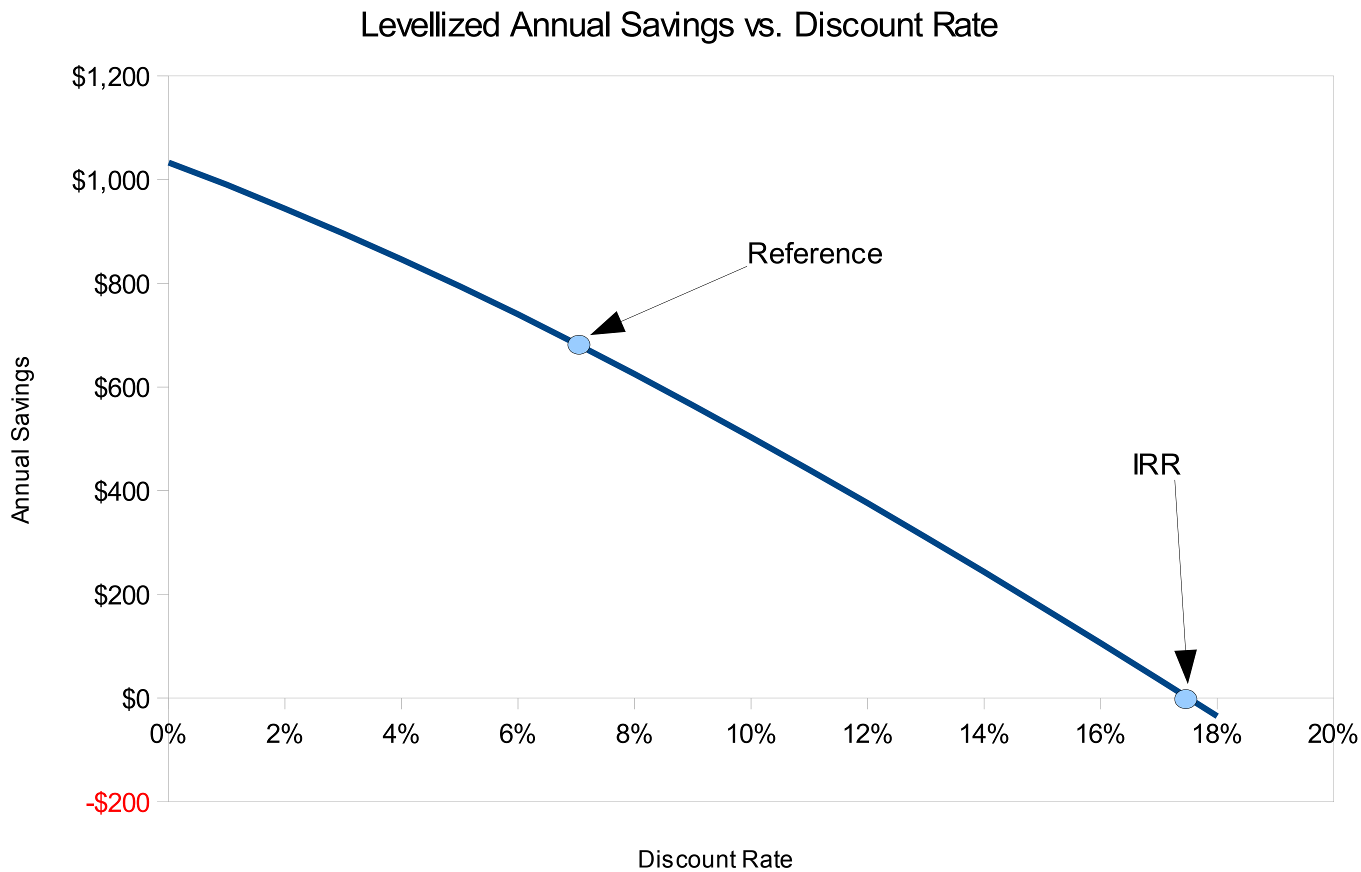


Exhibit 32: Sensitivity to varying discount rate

Annual savings are relatively insensitive to varying discount rate, and the internal rate of return for this project is 18%. This indicates that the suggested measures should be appealing to most or all of the owners, at least from a financial perspective.

Perhaps the most uncertain variable in this study is behaviour change. Assuming that all measures recommended are adopted, the primary behaviour risk is the rebound effect. Rebound occurs at different rates for different energy end-uses; the average rebound is plotted below (see supporting information for more details).

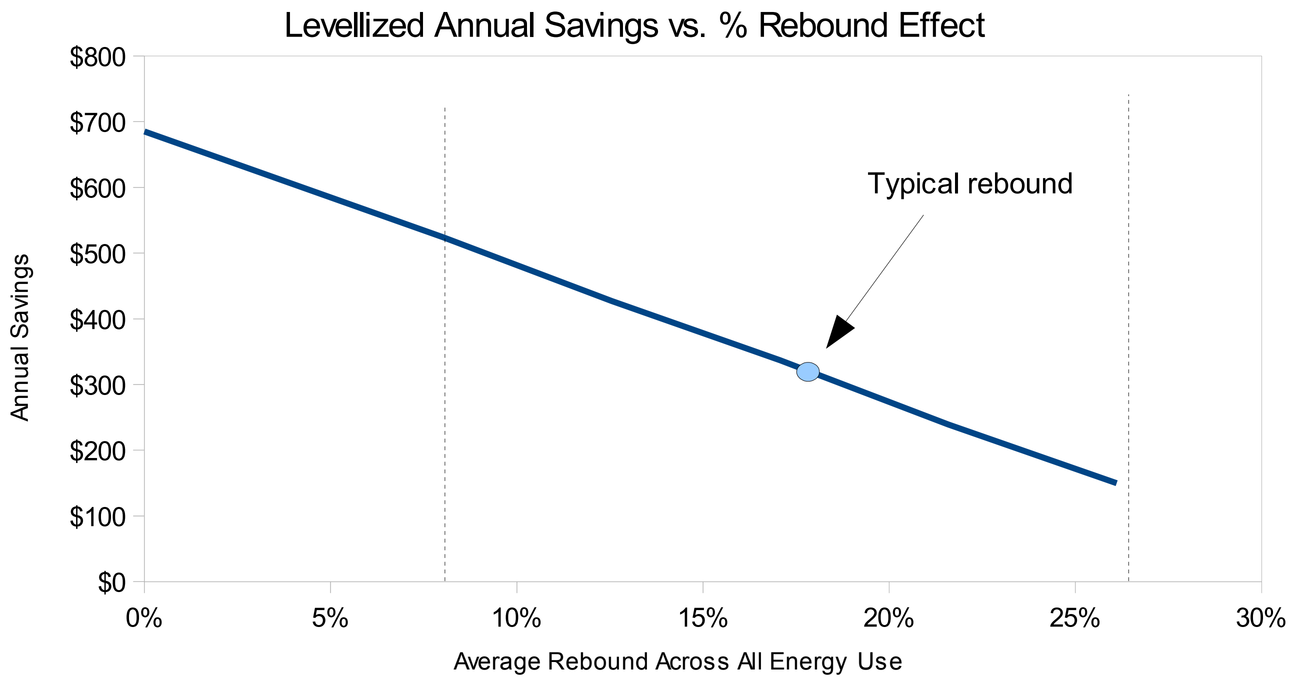


Exhibit 33: Sensitivity to rebound effect

Typical behaviour change predicts that roughly one third of annual savings will be eroded by rebound. What is considered a normal range of rebound suggests that savings will be reduced from $700 / year to somewhere between $550 - $150 / year. In the worst case this is over 75% of the maximum annual savings. For this reason, minimizing rebound is extremely important.

3.8 Study Limitations

Discussing the limits of this study is important because it helps clearly define how the results were generated and what value they have.

Due to the small number of owners who shared their utility data, it was not possible to develop any trends about differences in energy use within this building. This means that the impact of factors like the number of residents, working from home, and having a tenant cannot be commented on. A much bigger sample size is required to develop these trends. For this reason all the results in this study pertain to average energy use.

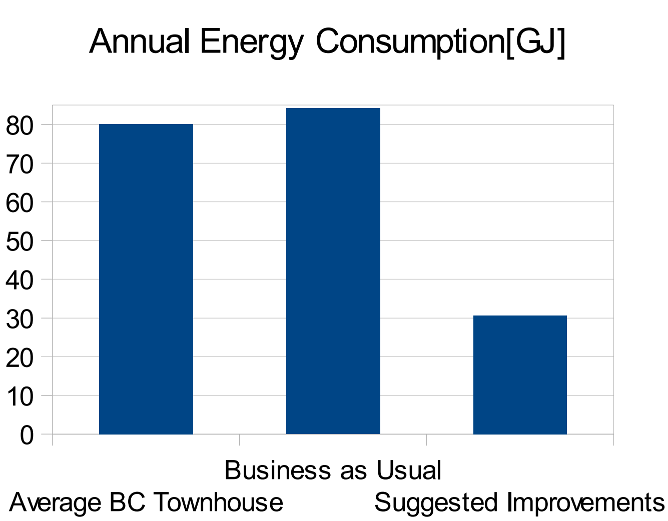
All energy savings and associated carbon dioxide abatement in this study are strictly limited to direct use of energy in this building. Any energy consumption and emissions embodied in the production of the various technologies are not included. Including these factors may change the results, particularly by making some of the more expensive technologies such as photovoltaic panels and ground source heat pumps look less attractive. Conversely this would have little or no impact on most behaviour change because new equipment is often not required.

The value of current energy technologies in this building is not incorporated into this study. This could make some measures look more appealing than they really are. This limitation is best described by examining appliance replacement. If an appliance currently installed in this building is near the end of its life, purchasing a replacement will be required anyway. This means that compared to the business-as-usual case the only additional cost is the incremental price difference between a typical and high efficiency appliance. Conversely, if a current appliance is relatively new it can likely be sold to recover some of the cost of an energy efficient appliance. This value is left out because it is extremely difficult to determine the present value and expected remaining life of the current technologies installed in this building. It is recommended that owners take the estimated value and remaining lifetime of current technologies into account when considering the improvement measures in this study.

Applying the results from this study to other residential buildings in Canada may be misleading. This building has significantly different energy use than typical Canadian residential buildings, both in total energy consumption and in energy consumption by end-use. This building is already quite energy efficient so measures (such as attic insulation) that look unnecessary in this particular building may still be very important in other buildings. Energy prices and associated carbon intensities will be significantly different in other areas of Canada and the world. Many of the subsidies included in this study are only available in British Columbia as well. All these factors make British Columbia unique, and different initial costs, energy costs and carbon intensities should be expected in other areas of Canada and around the globe. The results from this study are probably most relevant to other town-homes in British Columbia, particularly those in the lower mainland and on Vancouver Island where environmental conditions are similar.

4.0 Conclusions

A combination of practical measures presented in this study can significantly reduce energy consumption in these townhouses while staying within budget constraints and a delivering simple payback period of 5.5 years. All improvement measures are implemented at the unit level.



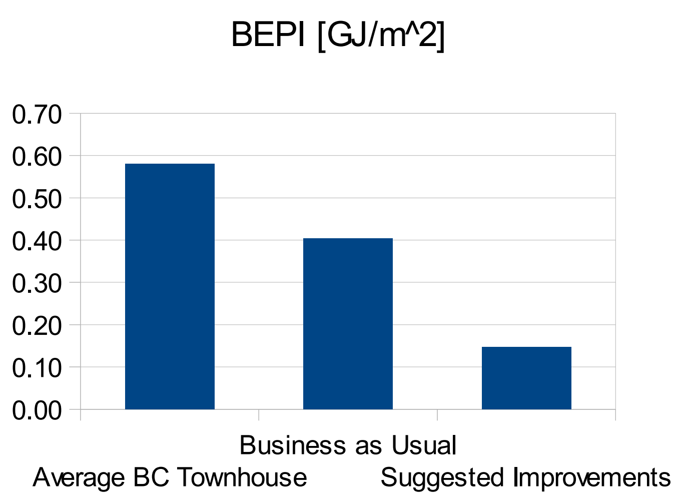


Exhibit 34: Summary of energy use

Energy use per household can be reduced by 63% to roughly 30 GJ per year. The Building Energy Proficiency Index becomes roughly 3 times better than business as usual, 4 times better than a typical BC town-home, and 5 times better than the average Canadian residential building (BEPI of 0.15 GJ/m$^{2)}$. The suggested measures also reduce CO_2 emissions by 1800 Kg per year.

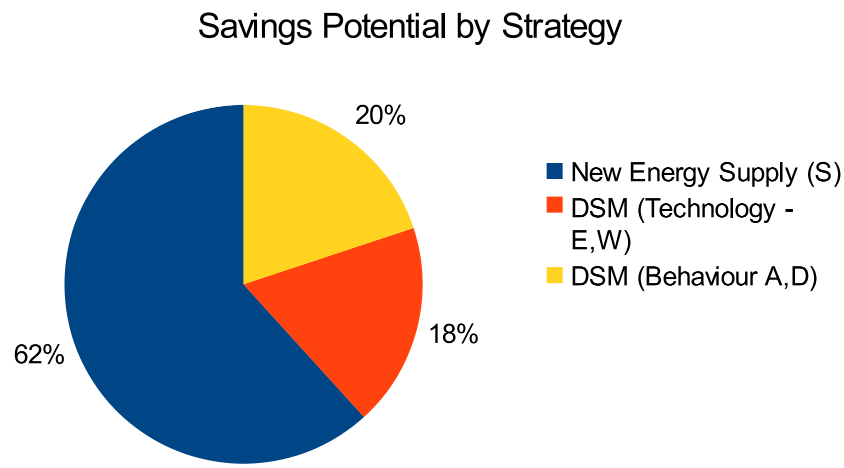


Exhibit 35: Savings Potential by Strategy

Demand side management technology, new energy supply, and behavioural change all make important contributions in this comprehensive strategy to lower energy consumption. Removing any one of these three pillars would significantly impact energy savings. New energy supply provides the most savings because fundamental changes are recommended to the way the building is heated, which is 50% of current energy use.

The full potential of these savings may not be realized because resident behaviour may counteract some of the suggested savings. If the residents follow typical behaviour patterns, up to one third of the potential energy savings will be eroded by low adoption of some measures as well as the rebound effect.

Creating a net zero energy building is not realistic unless the owners are can tolerate very high initial costs and are comfortable with an investment that has a very long payback period. This is mostly because production of clean electricity is not practical or economic at this time.

The results of this study are fairly insensitive to energy prices changing over time. This means the suggested measures should not be seen as particularly risky investments. The recommended improvements also have a predicted internal rate of return of 18%, which is anticipated to be acceptable to most or all of the homeowners.

4.1 Conclusions for homeowners

There are several barriers that may prevent maximum potential savings from being realized, and most of these are related to the behaviour of the residents. Residents need to have a clear understanding of what savings potential there is and what needs to be done to make them realize this potential. Adopting all suggested measures is strongly encouraged, and resisting behaviour change from lower utility bills such as higher indoor temperatures or longer showers is very important.

McKenzie-Mohr[21] shows that implementing meaningful behaviour change is most effective when it happens through social diffusion. Discussion about energy saving amongst the residents and visible behaviour change will go a long way to ensuring savings will be as high as possible.

4.2 Conclusions for policy makers

It appears that most available provincial subsidies are not particularly effective in this specific building. Many subsidies are too small to catalyse penetration of certain energy efficient technologies, while others are too high, which means that some free-ridership will likely take place. Others that do increase the adoption of new technologies do not end up delivering a net benefit to the province of British Columbia because the value of the subsidy outweighs the benefits. A couple subsidies, most notably the subsidy solar thermal water heating appears to benefit both the residents in this building and BC.

This does not necessarily mean these subsidies are ineffective in general. This building has excellent weatherization compared to the average residential unit in BC, which may skew the results of any subsidy involving space heating. The same can be said for appliances. Conducting a similar study on a building with characteristics that are closer to what is typical in British Columbia may be a useful exercise.

There may be other factors that prevent British Columbians from using available subsidies, such as lack of knowledge or restrictions on the use of the subsidy. Better understanding of these barriers is important as well.

5.0 Recommendations

It is recommended that the residents in this building implement the measures suggested in section 3.4.3. Once this is done, actual energy savings should be compared to the savings predicted in this study. Continued discussion and sharing of information is strongly encouraged amongst the owners of this building. This will highlight which measures are most effective and also help to minimize erosion of savings due to behaviour change over time.

It may be useful to do a similar analysis of common area energy consumption. This consists of parking-garage lighting, outdoor lighting and a few other miscellaneous uses. One specific measure that should be explored is putting a portion of the garage lights on motion sensor control.

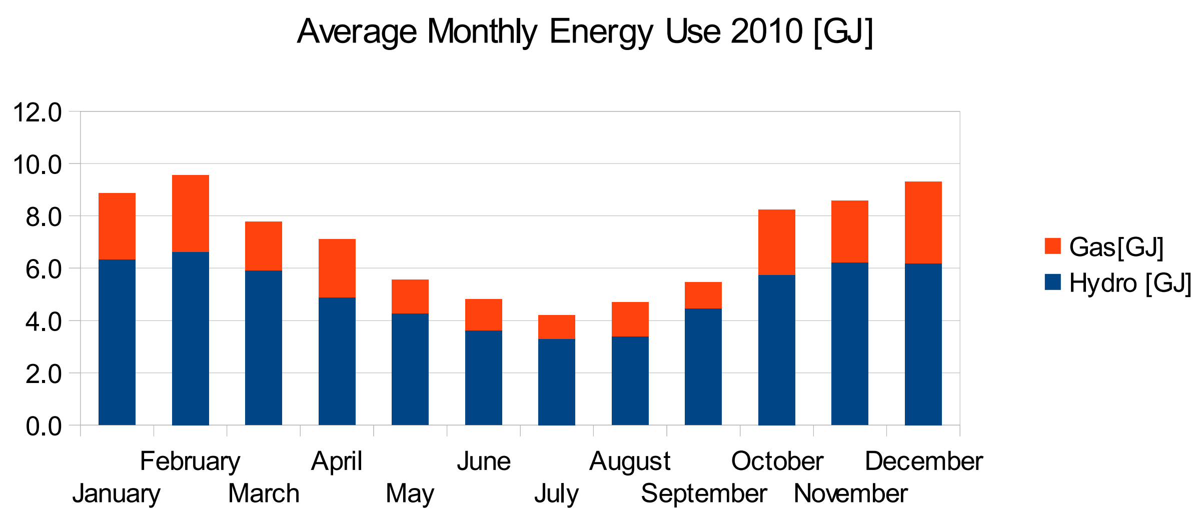
A similar analysis of more typical British Columbia residential buildings may give more insight into current subsidies and other residential energy policy. Results from this particular study suggest that improvements can be made to current incentive programs.

Supporting Information

S1 Detailed Energy breakdown

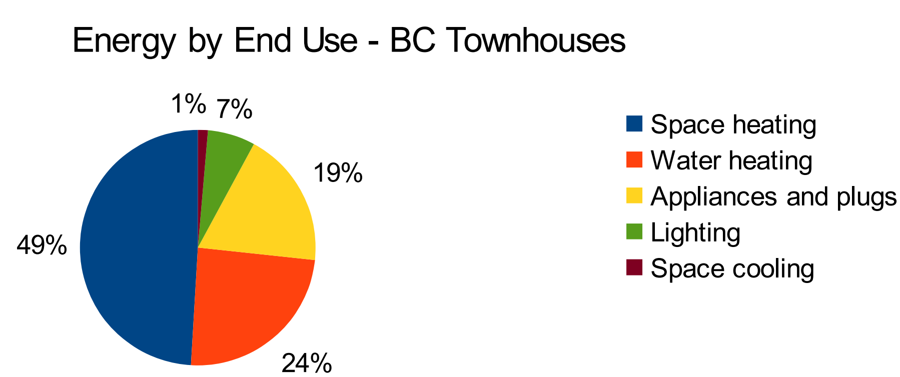
Determining the energy by end-use in these town-homes involved a combination of direct data analysis and use of provincial townhouse trends.

The first step was to analyze the average utility data from 2010. Several years of utility data provides a more robust analysis, however data was available for only one year.



	Base Load[GJ]	Seasonal [GJ]
Electricity	39.6	21.4
Natural Gas	1.2	22.1

The provincial average for energy use in townhouses[10] was used when there was not enough



resolution in the utility data to completely define energy by end use. This resulted in the following assumptions about energy use in this building.

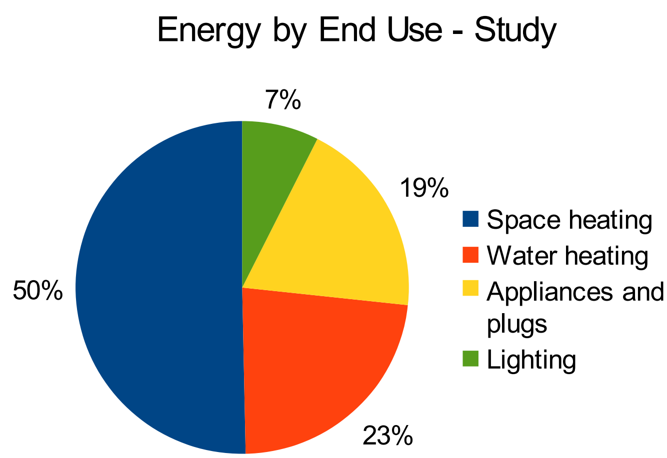
Energy End Use	Assumptions
Space Heating	95% of seasonal electricity + 100% of seasonal natural gas
Water Heating	25% of base electricity
Appliances and Plug Load	18% of base electricity + base natural gas (stove)
Lighting	7% of base electricity + 5% of seasonal electricity

The appliances and plug load energy use was double checked by calculating expected appliances and plug load energy use, provided by a Natural Resources Canada database[22][23]. Detailed appliance information was provided by the owners. 1.5x fridge indicates a half size fridge in the rental unit.

Appliance	Current Model	Energy use [kWh]	Energy [GJ]
2x Stove (E)	Frigidaire 2003	1200	4.3
Dishwasher (E)	Bosch SHE68E15uc	180	0.6
1.5 x Fridge (E)	Electrolux FRT21	612	2.2
2x Freezer (E)	Danby DCF401W	430	1.5
Washing Machine (E)	2003 Ave	708	2.5
Dryer (E)	Kenmore 970	937	3.4
DVR (E)	Motorola DCX-400-M		0.4
Computer (E)	Apple 2008		0.4
OTHER Plugs	estimate		1.0
Modem	Cisco DPC3825		0.2
TOTAL			16.7

The two estimates of appliance and plug load energy consumption come within 1 GJ of each other.

This analysis produced the following estimate of energy by end use in this complex.



S2 Energy Price Projections

Forecasting electricity and natural gas prices over the next 20 years will be important to understand the real financial value of each measure. Higher future energy costs generally increase the economic value of measures suggested in this study.

Natural gas prices:

The Canadian National Energy Board[12] and the U.S. Department of Energy[13] have both published predictions for the commodity price of natural gas out to 2035 (adjusted for inflation).

	Price in 2035 (2012 $/GJ)	Low	High
U.S. DOE	8	7	9
Canada NEB	8	6.5	10.5

For this study a constant growth rate in the commodity price from 2012 to 2035 is assumed, reaching a final price of $8/GJ. Residential customers pay a higher rate than this due to delivery charges.

Electricity Prices:

Increases in the price of electricity is very hard to predict in British Columbia because the price of electricity is often entangled in political decision making processes.

BC Hydro is expected to increase their residential electricity rates by 3.9% each year for the next two years[24]. There are no published increases beyond 2014. For this study, a rate increase of 3.9% will be followed by an average increase of 3% per year (adjusted for inflation). All costs are shown in $/GJ.

Price Forecasts [$/GJ]

	Hydro		Fortis	
	Step 1	Step 2	Commodity	Total
2012	$18.53	$26.72	$4.00	$8.90
2013	$19.82	$28.59	$4.12	$9.02
2014	$20.60	$29.71	$4.25	$9.15
2015	$21.22	$30.60	$4.38	$9.28
2016	$21.85	$31.52	$4.51	$9.41
2017	$22.51	$32.46	$4.65	$9.55
2018	$23.18	$33.44	$4.79	$9.69
2019	$23.88	$34.44	$4.94	$9.84
2020	$24.59	$35.47	$5.09	$9.99
2021	$25.33	$36.54	$5.24	$10.14
2022	$26.09	$37.63	$5.40	$10.30
2023	$26.88	$38.76	$5.57	$10.47
2024	$27.68	$39.92	$5.74	$10.64
2025	$28.51	$41.12	$5.91	$10.81
2026	$29.37	$42.36	$6.09	$10.99
2027	$30.25	$43.63	$6.28	$11.18
2028	$31.16	$44.94	$6.47	$11.37
2029	$32.09	$46.28	$6.67	$11.57
2030	$33.05	$47.67	$6.87	$11.77
2031	$34.05	$49.10	$7.08	$11.98
2032	$35.07	$50.58	$7.29	$12.19
2033	$36.12	$52.09	$7.52	$12.42
2034	$37.20	$53.66	$7.75	$12.65
2035	$38.32	$55.27	$7.98	$12.88
20 YEAR AVERAGE	$26.46	$38.17	$5.49	$10.39

For this study the average energy price from the next 20 years is used in all calculations.

S3 Carbon Intensity of Energy Sources

Carbon emissions are very important to this study. According to the homeowner survey results, reducing carbon emissions is the most important factor to them in a major home energy retrofit. For government, understanding carbon emissions are increasingly important as British Columbia makes major efforts to reduce province wide emissions.

According to the BC Ministry of Environment, residential natural gas use in BC emits 50 Kg of carbon dioxide per GJ consumed[25]. This number is used throughout this study.

Defining carbon dioxide emissions associated with BC electricity consumption is less clear. BC Hydro states that the average emissions associated with BC produced electricity is 6.9 Kg of CO_2 per GJ[25]. This figure does not take into account the emission intensity of imported electricity, which is typically much higher than this. BC Hydro estimates that imported electricity has a carbon intensity of 150 Kg/GJ[26]. When electricity use in British Columbia is adjusted for imports, Havona calculates emissions to be 23 Kg of CO_2 per GJ[27]. For the purposes of this study the figure of 23 Kg/GJ is deemed to be more realistic and is used throughout.

Carbon Intensity

	g CO2/kWh	Kg CO2/GJ
BC Electricity	84	23.3
BC Natural Gas	180	50.0

S4 Analysis of Individual Measures

A detailed analysis of every improvement measure in this study was required. This varied from measure to measure, but generally involved a technical analysis to determine the level of energy and emissions savings possible, and a series of financial calculations to show economic feasibility. Occasionally a separate set of calculations was required before a group of measures could be studied properly (for example, calculating technical requirements for a new space heating system).

Measure End use	Capital cost	Install cost	Subsidies Federal	Provincial	Net Cost	Life yrs	Saved Energy [GJ]/year Hydro	N.G.	CO2/yr Kg	L.A.S. w/ subsidy
Roof Insulation (W) *a*	$663	$0	$0	$0	$663	30	0.7	0.7	53.2	-$18
Window upgrade (W) *g,j,l,**	$4,160	$0	$420	$280	$3,460	30	1.5	1.5	113.3	-$204
Turn off pilot light (A)	$0	$0	$0	$0	$0	5	0.0	3.6	180.0	$37
Air Source Heat Pump (S) *a,h,j,l*	$2,958	$3,000	$500	$1,500	$3,958	16	8.1	16.6	1020.0	$61
Program Thermostats (D) *b*	$160	$0	$40	$50	$70	15	0.8	0.0	18.9	$23
Ground Source Heat Pump (S) *c,j,l,**	$15,000	$0	$2,500	$4,375	$8,125	25	12.0	16.6	1107.4	-$68
Drainwater heat recovery (E) *e,j,i,l*	$999	$100	$150	$165	$784	20	7.2	0.0	167.2	$199
Tankless water heater (E) *a,h,j,l,**	$2,500	$0	$0	$0	$2,500	20	2.9	0.0	67.0	-$126
Solar Thermal Heating (S) *m,j,l,**	$4,500	$0	$1,250	$500	$2,750	22	8.7	0.0	203.2	$84
Heat pump water heating (S) *a,h,j,l*	$990	$100	$250	$0	$840	10	4.8	0.0	112.8	$65
Low Flow Shower Head (E) *b,l*	$60	$0	$0	$0	$60	10	1.8	0.0	42.3	$61
2x Stove (E) *b,l*	$1,400	$0	$0	$0	$1,400	15	1.1	0.0	25.2	-$112
Dishwasher (E) *b,k,l*	$800	$0	$0	$25	$775	11	0.1	0.0	2.5	-$99
1.5 x Fridge (E) *b,k,l*	$1,200	$0	$0	$50	$1,150	17	0.9	0.0	22.0	-$82
2x Freezer (E) *b,k,l*	$920	$0	$0	$25	$895	22	0.6	0.0	14.3	-$58
Washing Machine (E) *b,k,l*	$750	$0	$0	$75	$675	14	2.0	0.0	46.9	-$1
Dryer (E) *b,l*	$760	$0	$0	$0	$760	13	0.3	0.0	7.3	-$79
Hang dry clothes (D) *b*	$130	$0	$0	$0	$130	20	1.0	0.0	23.6	$26
Boil water with lid (D)	$0	$0	$0	$0	$0	10	1.3	0.0	29.8	$49
Washer Settings (A)	$0	$0	$0	$0	$0	13	1.3	0.0	29.7	$49
Photovoltaic Panels (S) *f,j,l,**	$27,074	$0	$0	$1,408	$25,666	55	20.0	0.0	466.7	-$1,078
Timers on computer, DVR (A) *b*	$50	$0	$0	$0	$50	15	0.6	0.0	14.3	$18

Capital cost references: a: NREL database[28] b: Home Depot[29] c: EESC[30] d:Stiebel Eltron[31] e:RenewABILITY[32] f:Solar Buzz[33] g: CMHC[34] m:Solar BC[35]
Install cost references: h: Fraser Plumbing[36] i: BC Hydro[37]
Subsidy references: j: Home Performance[11] k: BC Hydro[37]
Technology lifetime references: l: NREL[28]
** indicates install cost included in capital cost estimate*
All other data not referenced is estimated

Financial factors such as capital cost, installation cost, subsidies and projected product life are best compared directly. All measures can be treated the same way in an economic analysis. For this reason a financial summary of all measures is shown above.

Because the technical analysis for each measure is unique they are discussed individually in the following sub-sections.

S4.1 Space Heating Measures

The measures examined for improving space heating performance can be grouped into three categories: weatherization, behaviour change, and new energy supply.

Weatherization:

This building is already extremely well insulated. The attic has R-40 insulation and the exterior walls have R-20 insulation. There are modern double pane windows. For this reason the potential energy savings through increased insulation are small.

Heat loss through walls and windows is calculated by the following formula:

$Q=\sum UA\Delta T$ where Q is heat transfer, U is the inverse of the R value, A is the area and ΔT is the difference between the indoor and outdoor temperatures.

ATTIC INSULATION

Area	Length [ft]	Width [ft]	Area [ft^2]	Area [m^2]
Basement	48	16	768	71.424

Insulation	R	RSI	U [W/m^2K]
Base Case (est.)	40	7.04	0.14
Improvement	68	11.968	0.08

Heat Transfer	Watts
Base case	111.7
Upgrade	65.7
Improvement	46.0

Energy Savings / yr	403.1	kWh
Energy Savings / yr	1.5	GJ

WINDOW UPGRADE

Type	U value [W/m^2K]
clear double pane	2
double, low-e argon	1.08

Area	Width [ft]	Height [ft]	Area [ft^2]	Area [m^2]
Basement	3	4	12	1.116
Main Floor	12	4	48	4.464
Top Floor	11	4	44	4.092
			104	**9.672**

Heat Transfer	Watts
Base case	212.9
Upgrade	115.0
Improvement	98.0

Energy Savings / yr	858.7	kWh
INDEPENDENT	3.1	GJ

U values from CMHC

The potential energy savings are quite low, and the initial costs for these measures are high. To make matters worse, other measures which increase the efficiency of space heating further diminish these already low savings. For this reason, weatherization for this building is not recommended.

Behaviour Change:

Two low cost measures were studied to lower space heating energy use. Installing thermostats for the baseboard heaters and then making sure they are set to lower the indoor temperature to 18° C overnight is estimated to save up to 8% of space heating requirements annually[9].

Install thermostats

Electric Heat [GJ]	Percent savings	Electric Heat [GJ]
20.3	8.00%	1.6

Installed cost of $80 for 5 thermostats makes this measure economic over time.

Turning off the pilot lights in the months when the natural gas fireplaces are not in use is a no-cost way to reduce greenhouse gas emissions and energy costs. This measure is expected to save 0.9 GJ / month of natural gas. This figure is calculated by subtracting the natural gas use from a unit that does not turn its pilot light off in the summer from one that does.

Turn off Pilot Light		
Consumption/month [GJ]	Summer Months	Total [GJ]
0.9	4	3.6

New Energy Supply:

Although this building has energy performance that is significantly better than average, one area where obvious improvements can be made is in space heating technology. The units in this building space heat almost equally with baseboard heaters and fireplaces. Electric baseboard heaters have an efficiency of 100%. The fireplaces in these buildings are quite efficient at 58%[22], but this efficiency is quite low when compared to other space heating technologies.

Before examining new energy supply measures for space heating, it is important to calculate the size requirements of a new system. A space heating system must be able to not only heat these units in average winter conditions, but temperatures that are much lower than normal as well. For Vancouver a typical design temperature is -8°C[38].

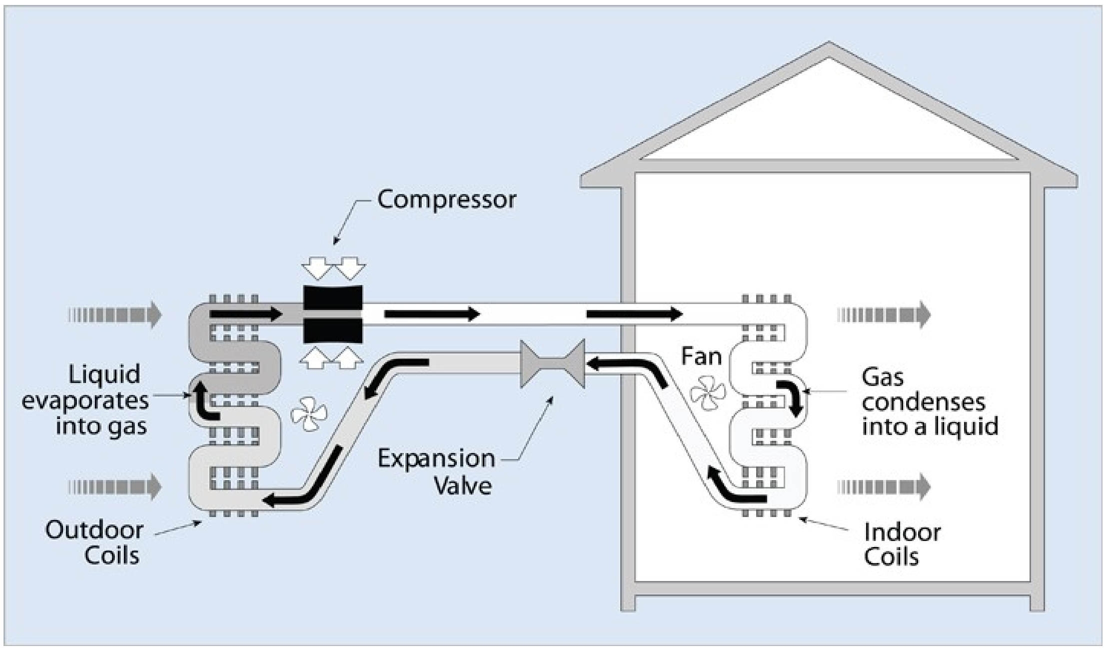
By taking data from the four coldest months of the year, heating requirements per degree Celsius can be estimated. This figure can then be extrapolated to show heating requirements at the design temperature.

Sizing heat system					
	Average T	GJ Useful Heat	MJ/hr	ΔT	MJ/hr/degree
January	3.6	7.1	9.6	17.4	0.55
February	4.9	7.6	10.3	16.1	0.64
November	6.1	7.0	9.3	14.9	0.63
December	3.8	7.3	9.9	17.2	0.57
AVERAGE					0.60

Design Temp [C]	ΔT	MJ/Hr	BTU/hr	kW	Tons
-8	29.0	17.3	16430.6	4.8	1.4

Sizing each new space heating system is important; it helps predict realistic initial costs and ensures that heating demands can be met in all conditions.

Two heat pump systems were studied: an air source system and a ground source system. Both systems work on the same basic principle, heat is pumped from an outdoor source (either the air or the ground) into the indoor space through a refrigeration cycle. To make the system work, electricity is required to power a pump and a compressor. As the outdoor temperature decreases the system efficiency decreases as well. A basic diagram showing the critical components of a heat pump system is shown below.



A common measure of efficiency for heat pumps is the coefficient of performance.

$$C.O.P. = \frac{Useful\ thermal\ energy}{Required\ electrical\ energy}$$

The C.O.P. for the air source heat pump is assumed to be 2.9 and ground source heat pump is assumed to be 4.0.[39]

Air Source Heat Pump

Base case	Energy [GJ]	Efficiency	Useful heat
Fireplace (N.G.)	22.1	57.00%	12.6
Baseboard heaters (Elec)	20.3	100.00%	20.3
TOTAL			32.9
Cooling penalty	1.5		

Upgrade	Useful heat	C.O.P.	HSPF	Energy [GJ]
Air Source Heat Pump	32.9	2.9	10.0	11.2

Savings /yr		
Natural Gas	16.6	GJ
Electricity	9.1	GJ
Cooling use	1.0	GJ
Electricity	8.1	GJ

Ground Source Heat Pump

Upgrade	Useful heat	C.O.P.	HSPF	Energy [GJ]
Ground Source Heat Pump	32.9	4.0	13.5	8.3

Savings /yr		
Natural Gas	16.6	GJ
Electricity	12.0	GJ
Cooling use	1.0	GJ
Electricity	11.0	GJ

In both cases the heat pump is assumed to displace 100% of the base board heating and 75% of the fireplace heating. The fireplaces will likely be used from time to time in the winter regardless of energy savings. An additional cooling load of 1 GJ per year is added for summer cooling.

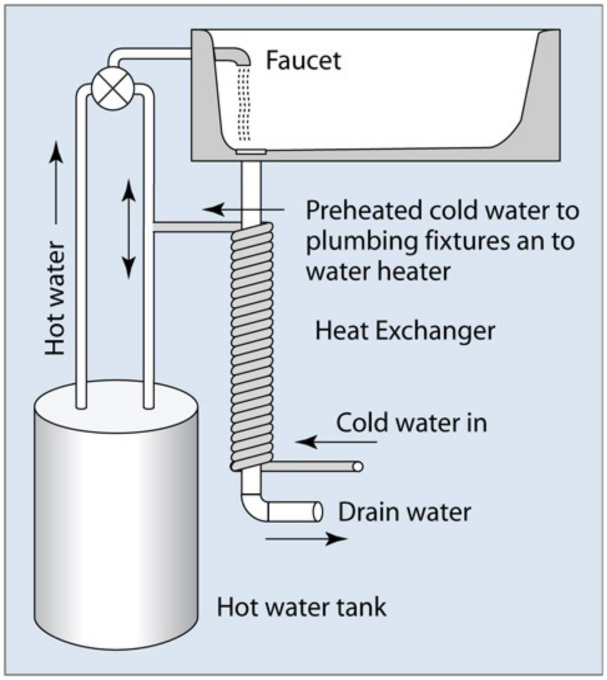
The air source heat pump is recommended instead of the ground source system. This is because the air source system is a fraction of the price while only sacrificing a small loss in overall efficiency.

S4.2 Water Heating Measures

The water heating measures studied can be split into two categories: efficiency and new energy supply.

Efficiency:

Several simple measures can be implemented to increase the efficiency of a domestic hot water system. Drain water heat recovery uses a simple heat exchanger to capture energy from hot drain water and return it to the hot water tank. These units can be over 50% efficient[31].



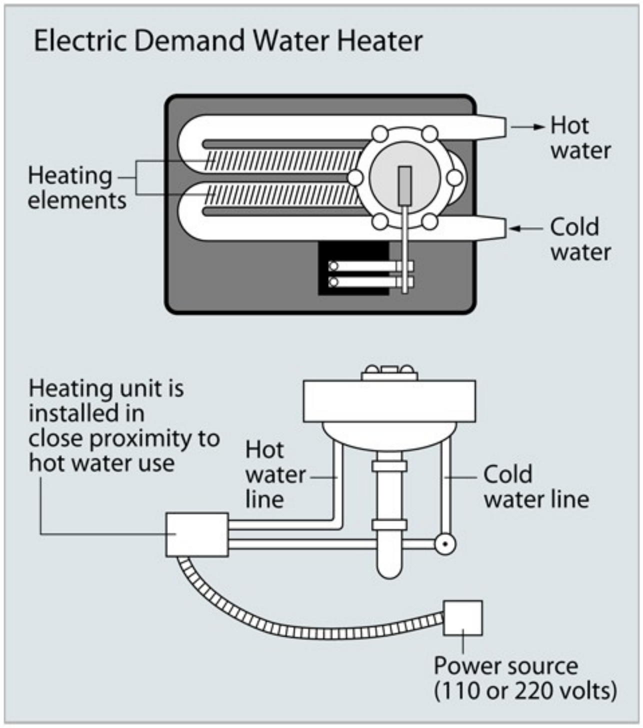
In this building it feasible to position the heat exchanger around a 4” drain pipe which sees all drain water flow in these units, giving it a chance to recover heat from all hot water use. The recommended heat exchanger for this measure is theoretically 58% efficient[31]. However, this efficiency requires a continuous flow rate of 9.5 L per minute, which not realistic. For this reason a 25% reduction in efficiency is assumed.

It is important to remember that not all electricity consumed for hot water heating is useful energy. The current hot water tank has a continuous standby loss of 91 watts[22], and this energy cannot be considered recoverable.

Drainwater heat recovery

Energy [GJ]	Standby Loss [W]	Losses [GJ]	Useful heat	Ideal recovery	Practical losses	Recovered GJ
19.3	91.0	2.9	16.5	58%	25%	7.2

Another way to increase hot water efficiency is to use a tankless water heater. Tankless water heaters eliminate standby losses and provide hot water on demand.



In this case an electric water heater is suggested, so the savings are simply the standby losses of the current hot water tank. One drawback of tankless water heating is it requires a significant initial cost.

Tankless water heater
Losses savings [GJ]
2.9

Tankless hot water heaters can be used in combination with drain water heat recovery.

Another low cost efficiency measure that can be implemented is the use of low flow shower heads. The savings potential in this building is not very high, because the standard shower heads in this building are already classified as low flow at 8 litres per second. This can be reduced further however, as common low flow shower heads currently available provide a flow rate of 5 litres / second without compromising shower pressure. CBEEDAC[40] estimates that shower use typically consumes about 25% of total household hot water use.

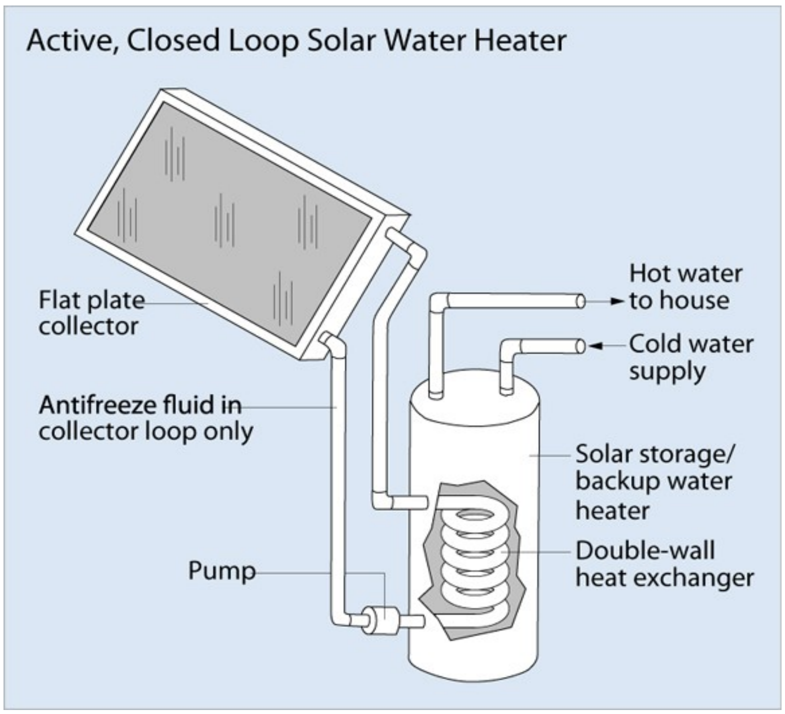
Low flow shower heads

Total Hot water Demand [GJ]	Shower Energy [GJ]	Current Flow [L/min]	Low Flow [L/min]	Savings [GJ]
19.3	4.8	8.0	5.0	1.8

The use of low flow shower heads reduces the energy savings of hot water heat recovery by approximately 1 GJ.

New Energy Supply:

Two new energy supply options are explored as well. Solar thermal water heating is a realistic possibility due to low initial costs and high efficiency when compared to photovoltaic panels.



Performance of any solar energy system is highly dependent on the amount and intensity of sunlight available. Vancouver has a distinct disadvantage in this respect. Natural Resources Canada reports that average solar energy availability in Vancouver is about 4.5 GJ / m^2 / year[38]. A realistic estimate of system efficiency is 65%[41].

A typical size for a rooftop solar thermal system is 3 m^2, and this appears to be a well sized unit for these town-homes[35].

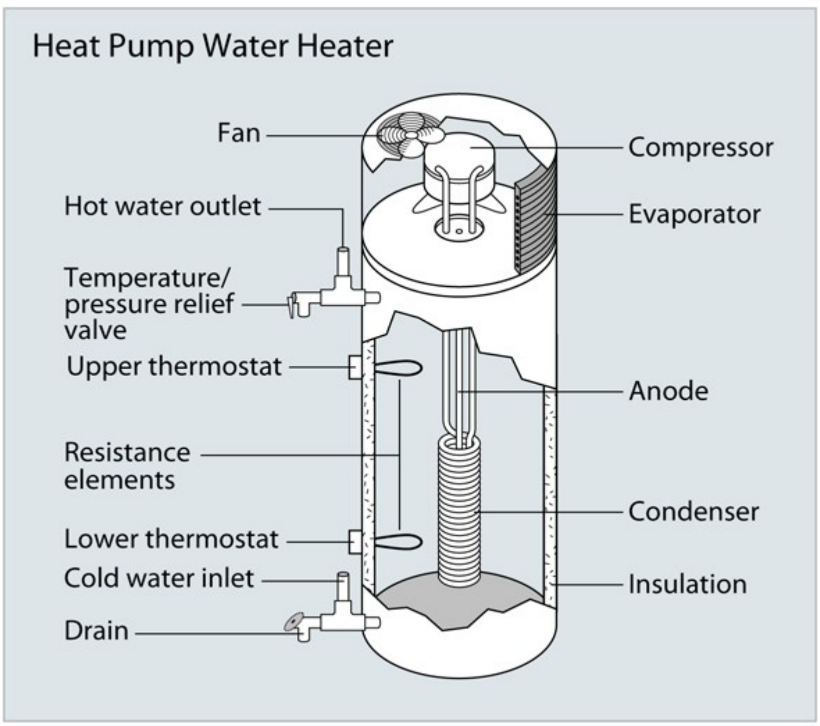
Solar thermal water heating

Annual solar energy [GJ/m^2]	Peak day [GJ/m^2]	Area [m^2]	Efficiency	Energy [GJ]
4.465	0.033	3.0	65.00%	8.7

It is important that to note that this hot water energy will not be generated evenly over the year, as available sunlight changes significantly throughout the seasons. The majority of these savings will come in the summer, and electricity will still be needed to provide hot water heating in the winter.

Because solar thermal water heating requires a hot water tank, it is not considered compatible with tankless water heaters.

Another energy supply option for hot water heating is an add-on heat pump. These heat pumps are attached to an existing hot water tank, and typically have a coefficient of performance of 2[28].



These systems are seen as particularly useful in hot climates because the heat pump extracts heat from the surrounding air and uses this energy to heat the water in the tank, providing space cooling and hot water at the same time. These are not as practical in this building because there are no space cooling requirements in the summer, and additional space heating will be required in the winter to make up for the heat removed. For this study it is assumed that space heating will be need to be made up 50% of the year.

Heat Pump Water Heating – add on

Total hot water demand [GJ]	Energy Factor	New Energy [GJ]	Savings	Heat make up	Adjust Savings
19.3	2.0	9.7	9.7	50.00%	4.8

Even with the make up heating requirements, an add-on hot water heat pump is still a viable measure. The reason it is not considered in the final recommendations is that once other more favourable measures are included in a major retrofit, the effectiveness of this system is greatly reduced.

Another hot water savings measure considered but not recommended is changing the set points on the hot water tank. While this measure is technically capable of reducing energy consumption, changing these would violate the minimum temperature set point recommended by Health Canada[42]. For this reason it is not considered a viable option.

S4.3 Appliances, Plug Loads and Lighting

All energy use in these units that is not directly related to space heating and water heating fall into this category. All of this is electricity consumption except stove top cooking which uses natural gas. A wide variety of measures were considered to reduce this demand.

Efficiency:

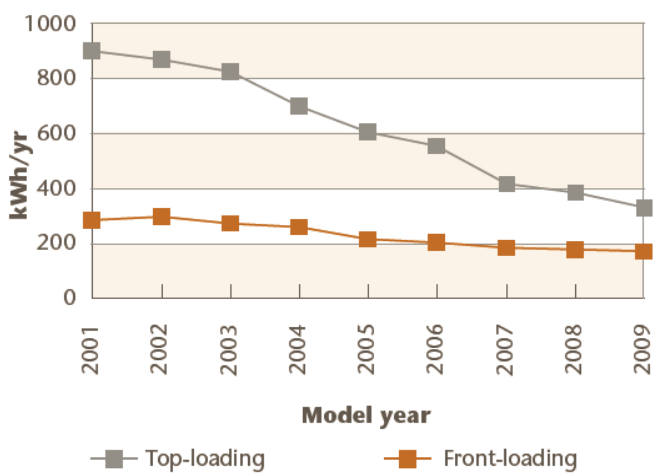
Replacement of all major appliances was considered. Appliances were compared against current energy star models with similar specifications. Typical energy use information is provided my Natural Resources Canada[22].

Major Appliances

Appliance	Current Model	Energy use [kWh]	Energy [GJ]	New	Energy [kWh]	Energy [GJ]	Savings
2x Stove (E)	Frigidaire 2003	1200	4.3	Energy Star, 2012	900	3.2	1.1
Dishwasher (E)	Bosch SHE68E15uc	180	0.6	Energy Star, 2012	150	0.5	0.1
1.5 x Fridge (E)	Electrolux FRT21	612	2.2	Energy Star, 2012	350	1.3	0.9
2x Freezer (E)	Danby DCF401W	430	1.5	Energy Star, 2012	260	0.9	0.6
Washing Machine (E)	2003 Ave	708	2.5	Energy Star, 2012	150	0.5	2.0
Dryer (E)	Kenmore 970	937	3.4	Energy Star, 2012	850	3.1	0.3

In general, the efficiency of major appliances has not improved significantly since 2003 when the original appliances in these townhouses were purchased. One exception is top loading washing machines.

Figure 9 Average annual UEC of clothes washers by type, 2001–2009



Top loading washing machines have improved steadily in efficiency over the last 10 years[43]. This makes replacing a typical 2003 washing machine economically viable. All other major appliances are recommended to be upgraded at end of life. If washing machine settings are changed, buying a new washing machine may not be viable.

<u>Behaviour Change</u>:

Although major appliance upgrades are not generally recommended at this time, there are several behaviour changes that can be implemented that will reduce appliance energy consumption.

Line drying clothes is a low cost way to reduce dryer energy consumption. It is assumed that 30% of year-round clothes drying can be done on a clothes line.

Line Dry Clothes

Current use [GJ]	Line dry rate	Savings [GJ]
3.4	30.00%	1.0

Another behavioural change that can reduce energy use is to cook and boil water with a lid as much as possible. Cullen explains that 80% of stove top cooking energy can be saved by keeping a lid on a pot while boiling water. Cullen also states that 75% of cooking is typically done on the stove top[2]. For this study it is assumed that 50% of stove-top cooking is already done with a lid in place, and a 50% improvement is available.

Boil water with lid

Current use [GJ]	Lid reduction	Savings
4.3	30%	1.3

Washing machine energy consumption can be reduced by simply changing the wash cycle settings, and in many cases the available savings are larger than line drying clothes. This is accomplished by changing all hot water cycles to use warm water, and change all rinse cycles to cold water. The US Department of Energy estimate this can cut energy consumption of washing machines in half[44].

Washer settings

% savings from washing	Savings
50.0%	1.3

It is also possible to save energy by reducing plug loads. Through discussion with some of the residents in this building it was discovered that loads such as computers, DVRs, and modems are plugged in and drawing standby electricity 24 hours a day. An example of the loads from one of the units is shown.

Electronics	Current Model	Energy use [GJ]
DVR (E)	Motorola DCX-400-M	0.4
Computer (E)	Apple 2008	0.4
OTHER Plugs	estimate	1.0
Modem	Cisco DPC3825	0.2

In this study it is assumed that timers can turn these electronics off overnight, which is assumed to be 30% of the time.

Timers on standby electronics

Standby Energy [GJ]	Turn off time at night	Savings
2.0	30.00%	0.6

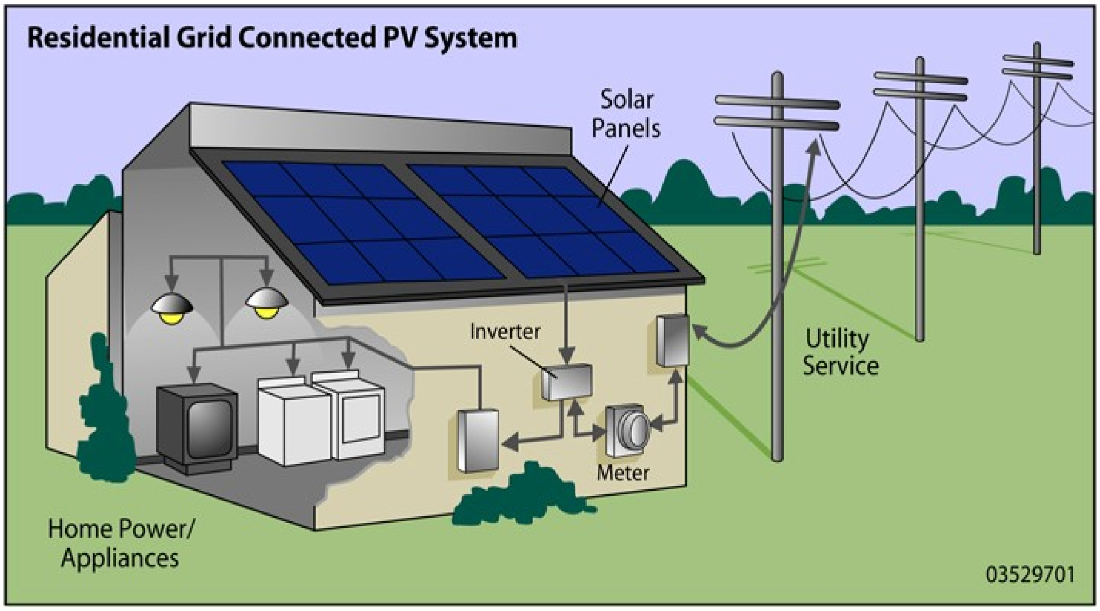
Lighting can be made significantly more efficient by switching incandescent light bulbs to compact fluorescent bulbs. Gardener and Stern suggest that a typical household can save 7% of their entire energy use through this change[9]. After talking with some of the residents in this building, it is estimated that it is possible to change about 40% of all lighting. This is because compact fluorescent bulbs are already used at some level, and it is not realistic to switch all lighting to this style.

Change incandescent to CFL

Total energy [GJ]	Max saving	Lights changed	Savings
84.2	7.27%	40.00%	2.4

New Energy Supply:

In this building it is feasible to use new energy supply to offset space and water heating requirements. Generating new electricity is not as attractive, as current technologies are expensive (solar panels) or not realistic for use in residential areas (wind turbines).



Despite high initial costs, photovoltaic panels are considered for this study because of the significant interest expressed in the survey. Vancouver is far from an ideal location for photovoltaic panels because of the lack of intense sunlight. The CMHC provides a comparison of different cities and the relative effectiveness of solar panels[45].

City	Kwh produced annually / kW installed capacity
Cairo, Egypt	1635
Los Angeles, U.S.A.	1485
Regina, Canada	1361
Vancouver	1009
London, England	728

Vancouver has significantly less solar potential than most cities that are currently considered candidates for residential photovoltaic panels.

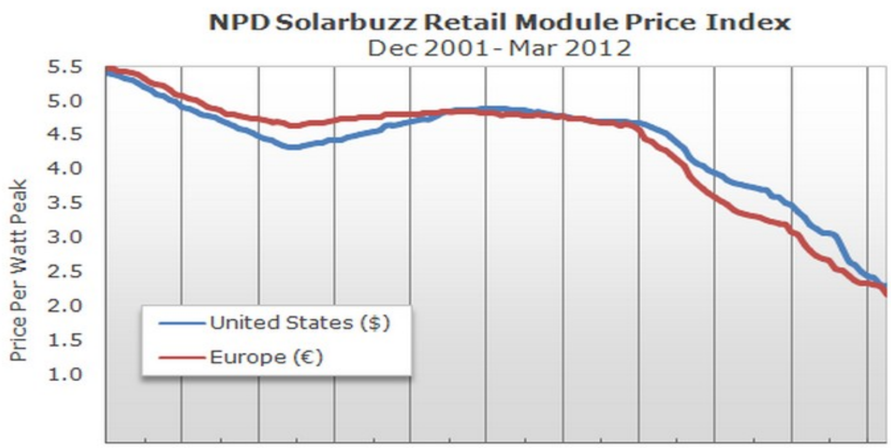
Because this building has plentiful south-facing roof area, the efficiency of solar panels can be increased slightly by tilting them 15 degrees towards the south, increasing from 1009 kWh/kW to 1026 kWh/kW[45].

For the purposes of this study, adding 20 GJ of annual energy from the installation of solar panels is considered. This is the amount that is approximately needed to approach a net zero home.

PV Panels

Desired Energy [GJ]	kWh/kW Installed / yr	GJ/ kW installed	Panels needed [kW]
20.0	1026.0	3.7	5.4

Cost is still the primary reason photovoltaic panels are not recommended in this study; however, these systems are getting closer to becoming economic.



Prices has dropped significantly over the last several years to $2.30 / Watt of installed capacity in March of 2012. Solar panel prices are typically 35 – 40% of total installed system cost, meaning that photovoltaic systems currently cost $6 - $6.50 / watt installed[33]. If these prices continue to drop, they may become economically attractive in Vancouver in the future.

At this time a solar panel system is not recommended, but continued monitoring of initial costs may be worthwhile.

Another new energy supply system that was examined but not recommended is micro combined heat and power (Micro CHP). Combined heat and power is a way of generating electricity at the point of use, which allows waste heat from the electricity production process to be used for space and water heating. A typical comparison of combined heat and power to conventional energy generation is shown below[46].

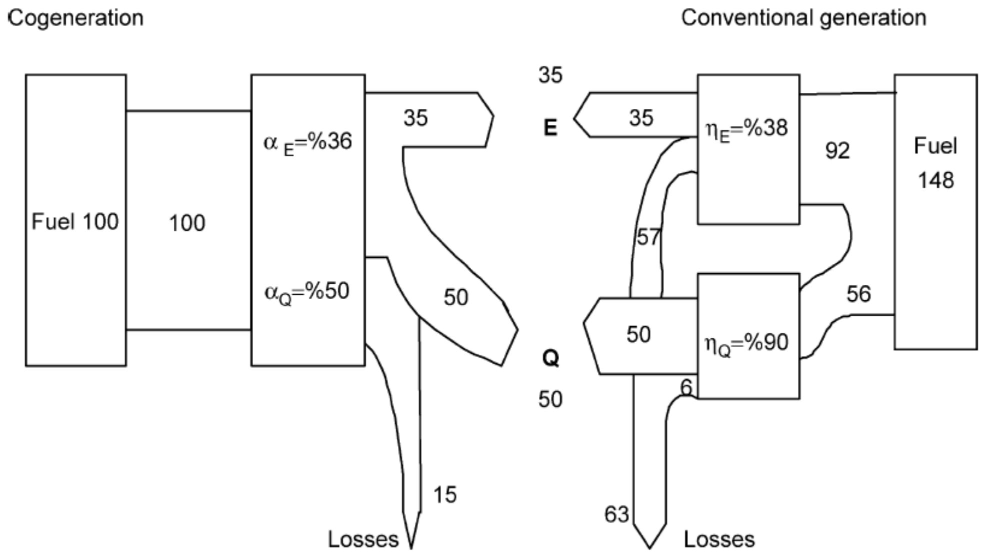


Fig. 1. Cogeneration versus conventional generation [4], where α_E, part of the energy transformed into electricity in a cogeneration unit, α_Q, part of the energy transformed into usable in a cogeneration unit, η_E, electrical yield of an electrical power plant (production of electricity only), η_Q, yield of a boiler (production of heat only), E, electricity demand, Q, heat demand.

Two Micro CHP systems were considered for this study. A brief overview of these systems is given below[46].

Honda – 1 kW

Input [GJ]	4.7
Out Elec [GJ]	1
Out Heat [GJ]	3
Capital $	$3,000
Technology	I.C. Engine

SOLO – 1kW

Input [GJ]	4.7
Out Elec [GJ]	1.034
Out Heat [GJ]	3.196
Capital $	$4,000
Technology	Stirling Engine

There are several reasons that a Mirco CHP system is not recommended in this study.

- Initial costs are high
- Lack of availability of systems at the correct capacity
- Summer heating load (hot water demand only) is much lower that summer electricity load. This

means that the system will generate significant excess heat during the warm part of the year, or alternatively, the system can only be used intermittently this time of year, generating very little electricity (see below table).

- The domestic hot water system must be completely changed to utilize heat generated by the Micro CHP system
- The recommended Micro CHP systems run on natural gas, drastically increasing household greenhouse gas emissions
- Because these systems produce electricity at an efficiency of 20 – 25%, the cost of the natural gas required is quite high.
- Floorspace required for this type of system is not available

Meet Space Heating Demand Scenario

Heating / yr [GJ]	32.9
Electriciy / yr [GJ]	11.0
N.G. / yr [GJ]	51.5
Electricity needed	41.8
Purchased Elec	30.9
CO2 / yr [Kg]	2575.6
Fuel Cost / yr	535.3

Meet Electricity Demand Scenario

Heating / yr in	52.2
Electriciy need	22.5
Heat Produced	67.5
Wasted Heat	15.2
N.G. / yr [GJ]	105.7
CO2 / yr [Kg]	5284.3
Fuel Cost / yr	1098.3

For these reason Micro CHP systems are not recommended for use in this energy retrofit.

S5 Levelized Annual Cost

All economic value in this study is presented as levelized annual savings. This was done for two reasons. First of all, it is hard to predict what the owners in this building will consider a realistic life time for this investment. Perhaps most importantly, it is hard to compare technologies directly when they have different expected lifetimes. This is commonly handled by transforming initial costs into into an equivalent annual cost through the following equation[47]:

$$L.A.C. = I_c \frac{i}{1-(1+i)^{-n}} \quad \text{where} \quad L.A.C. = levelized\ annual\ cost \qquad I_c = initial\ cost$$

$$i = discount\ rate \qquad n = expected\ lifetime\ of\ technology$$

Savings due to reduced energy consumption more than offset the levelized annual cost in the suggested measures. Levelized annual savings is then defined by the following expression:

$$L.A.S. = \frac{\$\ energy\ savings}{year} - L.A.C.$$

This number is positive for all suggested measures, but can be negative for unattractive measures.

S6 Multi Criteria Decision Making

The survey completed by the owners in this building revealed that several values are important to them when considering a major energy retrofit in their homes. In order to make recommendations that match these ideals, several criteria had to be considered simultaneously to determine a net overall value for each measure.

As shown in the survey results, saving money over time and reducing carbon emissions are the most important factors to the homeowners. Other factors such as home disruption, making a sustainable statement and capital cost were valued at some level as well.

Developing a rating system that incorporates all these values is somewhat challenging. Factors as such as cost savings, initial costs and greenhouse gas reductions are easy to quantify, but assigning a value to statement or perceived disruption is far less concrete. For these factors, a rating ranging from zero to five was assigned in an attempt to measure these factors. A value of five indicates a very high statement or high disruption.

Measure	Statement	Distruption
Roof Insulation (W)	1	1
Window upgrade (W)	2	4
Turn off pilot light (A)	0	0
Air Source Heat Pump (S)	3	4
Program Thermostats (D)	1	1
Ground Source Heat Pump (S)	4	5
Drainwater heat recovery (E)	2	3
Tankless water heater (E)	2	3
Solar Thermal Heating (S)	5	4
Heat pump water heating (S)	2	3
Low Flow Shower Head (E)	1	1
2x Stove (E)	1	1
Dishwasher (E)	1	1
1.5 x Fridge (E)	1	1
2x Freezer (E)	1	1
Washing Machine (E)	1	1
Dryer (E)	1	1
Hang dry clothes (D)	2	0
Boil water with lid (D)	0	0
Washer Settings (A)	0	0
Photovoltaic Panels (S)	5	3
Timers on computer, DVR (A)	1	1

These ratings are highly subjective and may influence the results in a way that is misleading to the homeowners; however, it was deemed more important to attempt including these values in an overall rating than to ignore them altogether.

Another difficult step in this type of analysis is assigning an appropriate weight to each factor. These weightings were guided largely by the owner survey results.

	Score	Standard Deviation
Save money over time	8	1.5
Reduce greenhouse gas emissions	9	1.5
Statement about sustainability	7	3
Minimal disruption	6.5	2.5
Increase home value	7.5	2

Reducing greenhouse gas emissions was given a weight of 9, based on the above results. Saving money and increasing home value had survey values of 8 and 7.5 respectively. For this reason saving money over time was give a weight of 8. Statement about sustainability was given an average score of

7 on the survey, but was given a weight of 6 in this study. Statement was downgraded for two reasons: there is higher disagreement about whether or not this is important amongst the owners, and the scoring of what made a sustainable statement was highly subjective. The average score of 6.5 for minimal disruption was deemed to be unrealistically high; while disruptions may last hours or perhaps days, energy and carbon savings will last many years. For this reason disruption was downgraded to a weight of -2. Finally, capital costs are a concern of the owners as shown in the budget section of the survey. For this reason initial cost was given a subjective weight of -3, valuing it slightly more important than disruption.

This resulted in the final equation:

$$Score = 9C_s + 8N_s + 6S_s - 3I_s - 2D_s$$

where:

$$C_s = \frac{Carbon\ abatement/GJ}{Best\ Carbon\ abatement/GJ} \qquad N_s = \frac{\$/GJ}{Best\ \$/GJ} \qquad S_s = \frac{Sutainable\ Statement}{Best\ sustainable\ statement}$$

$$I_s = \frac{Initial\ Cost}{Highest\ Initial\ Cost} \qquad D_s = \frac{Distruption}{Highest\ Distruption}$$

These scores were then ranked to determine in what order these measures should be suggested to the homeowners.

Because this process is somewhat subjective, a sensitivity analysis was preformed to determine if and how the rankings would change in different situations. Four additional cases were examined:

- High importance of saving money
- High importance on making a sustainable statement

- High importance on reducing carbon emissions

- Ignore the impact of home disruption and initial costs

Measure	Base Case	High N	High S	High C	No D,I
Roof Insulation (W)	15	15	15	14	15
Window upgrade (W)	18	18	18	18	18
Turn off pilot light (A)	**6**	**10**	12	**1**	12
Air Source Heat Pump (S)	11	11	**10**	11	**7**
Program Thermostats (D)	**9**	**8**	**9**	**8**	**9**
Ground Source Heat Pump (S)	12	13	11	12	11
Drainwater heat recovery (E)	**7**	**7**	**5**	**9**	**1**
Tankless water heater (E)	16	16	17	16	17
Solar Thermal Heating (S)	**10**	**9**	**1**	**10**	**4**
Heat pump water heating (S)	13	12	13	13	13
Low Flow Shower Head (E)	**4**	**3**	**4**	**5**	**2**
2x Stove (E)	21	21	21	21	21
Dishwasher (E)	23	23	23	23	23
1.5 x Fridge (E)	19	19	19	19	19
2x Freezer (E)	20	20	20	20	20
Washing Machine (E)	14	14	14	15	14
Dryer (E)	22	22	22	22	22
Hang dry clothes (D)	**3**	**4**	**2**	**3**	**6**
Boil water with lid (D)	**2**	**2**	**7**	**4**	**5**
Washer Settings (A)	**1**	**1**	**6**	**2**	**3**
Photovoltaic Panels (S)	17	17	16	17	16
Timers on computer, DVR (A)	**8**	**6**	**8**	**7**	**8**
Incandescent to CFL (D)	**5**	**5**	**3**	**6**	**10**
Weight					
Cost	8	9	7	6	8
GHG	9	7	7	9	9
Disruption	-2	-2	-2	-2	0
Statement	6	6	9	5	6
Capital cost	-3	-3	-3	-3	0

Changing the weight of the factors in the analysis can cause rankings of various measures to change, particularly measures with high rankings. Making cost saving important raises the rank of measures that have a low initial cost and save electricity. High statement importance pushes visible outdoor measures to a higher score. Raising the value of lowered carbon emissions tends to give measures that reduce natural gas consumption a high ranking. Ignoring capital costs and home disruption make big impact measures more attractive.

Although the measures are rearranged slightly in the different scenarios, it is interesting to note that these changes never cause an recommended measure to become unattractive or vise versa. This suggests that these measures do not have much sensitivity when it comes to their overall viability.

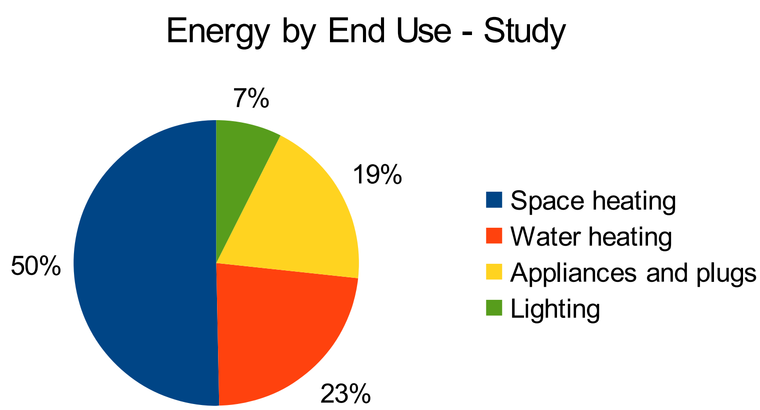
S7 Behavioural Impacts

Natural behaviour of the residents in this building has the potential to offset energy savings. The biggest expected contributors are the rebound effect and low adoption of certain technologies. Typical rebound is presented by Greening[14], who presents a summary of many different studies on this phenomenon. Deitz[3] presents typical adoption rates of various technologies. The assumed impact of typical behaviour is shown below. Suggested measures are shown in bold.

	Rebound	Rebound Losses [GJ]	Adoption	Adoption Losses [GJ]
Roof Insulation (W)	20%	0.1	90%	0.0
Window upgrade (W)	20%	0.2	90%	0.1
Turn off pilot light (A)	**0%**	**0.0**	**50%**	**1.8**
Air Source Heat Pump (S)	**20%**	**5.1**	**90%**	**2.6**
Program Thermostats (D)	0%	0.0	35%	0.5
Ground Source Heat Pump (S)	20%	5.7	90%	2.9
Drainwater heat recovery (E)	**25%**	**1.6**	**90%**	**0.6**
Tankless water heater (E)	25%	0.7	90%	0.3
Solar Thermal Heating (S)	**25%**	**2.2**	**90%**	**0.9**
Heat pump water heating (S)	25%	1.2	90%	0.5
Low Flow Shower Head (E)	**0%**	**0.0**	**80%**	**0.4**
2x Stove (E)	0%	0.0	80%	0.2
Dishwasher (E)	0%	0.0	80%	0.0
1.5 x Fridge (E)	0%	0.0	80%	0.2
2x Freezer (E)	0%	0.0	80%	0.1
Washing Machine (E)	0%	0.0	80%	0.2
Dryer (E)	0%	0.0	80%	0.1
Hang dry clothes (D)	**0%**	**0.0**	**35%**	**0.7**
Boil water with lid (D)	**0%**	**0.0**	**35%**	**0.8**
Washer Settings (A)	**0%**	**0.0**	**35%**	**0.8**
Photovoltaic Panels (S)	4%	0.8	90%	2.0
Timers on computer, DVR (A)	**0%**	**0.0**	**35%**	**0.4**
Incandescent to CFL (D)	**8%**	**0.2**	**35%**	**1.6**
TOTAL SUGGESTED		**9.1**		**10.5**

Typical rebound behaviour would result in an erosion of 9 GJ/yr of energy savings. Average adoption losses are predicted to be 10.5 GJ/yr. Adoption losses are harder to predict because they are mostly a function of parametric decision making (either a technology is adopted or it is not).

A sensitivity analysis of how the rebound affect influences levelized annual savings was conducted. To do this correctly, each energy end-use needed to be weighted according to end-use of these town homes. Minimum and maximum expected rebound were taken from Greening et al[14].



Data from this analysis is summarized below.

Case	Reference	Minimum		Typical		Maximum
Space heating Rebound	0%	10%	15%	20%	25%	30%
Water heating Rebound	0%	10%	18%	25%	33%	40%
Electricity Rebound	0%	2%	3%	4%	5%	6%
Lighting rebound	0%	5%	7%	8%	10%	11%
Weighted average rebound	**0%**	**8%**	**13%**	**17%**	**22%**	**26%**
ADJUSTED L.A.S.	**$685**	**$524**	**$427**	**$337**	**$239**	**$150**

S8 Policy Analysis

To make conclusions for policy makers, an analysis of how effective various subsidies are was conducted. This analysis mimics the economic analysis done for the homeowners; levelized annual savings was calculated for every measure. Since this was done from the perspective of the provincial government, the initial cost is assumed to be the provided subsidy, and the annual savings were set to be the incremental value of saving electricity and natural gas (discussed in section 3.6). All energy savings are assumed to be reduced by typical rebound behaviour. Two cases were examined: the first is a pure economic analysis, the second puts a value $30/tonne on abated carbon emissions (in line with

BC's carbon tax).

These results can be compared to the levelized annual savings of the homeowners. Rows that are blacked out indicates no available provincial subsidy.

	Policy Perspective		**Homeowner Perspective**	
	L.A.S. w/ rebound	L.A.S. + carbon price	L.A.S. w/ subsidy	L.A.S. w/o subsidy
Roof Insulation (W)				
Window upgrade (W)	-$7.40	-$4.00	-$203.82	-$260.23
Turn off pilot light (A)				
Air Source Heat Pump (S)	-$65.62	-$35.13	$61.32	-$150.40
Program Thermostats (D)	$2.81	$3.38	$23.31	$13.43
Ground Source Heat Pump (S)	-$250.31	-$217.08	-$67.86	-$657.80
Drainwater heat recovery (E)	$39.35	$44.36	$199.42	$169.69
Tankless water heater (E)				
Solar Thermal Heating (S)	$21.55	$27.65	$83.70	-$74.51
Heat pump water heating (S)				
Low Flow Shower Head (E)				
2x Stove (E)				
Dishwasher (E)	-$2.23	-$2.15	-$99.23	-$102.56
1.5 x Fridge (E)	$4.52	$5.18	-$81.79	-$86.91
2x Freezer (E)	$4.00	$4.42	-$57.56	-$59.82
Washing Machine (E)	$11.96	$13.36	-$0.52	-$9.09
Dryer (E)				
Hang dry clothes (D)				
Boil water with lid (D)				
Washer Settings (A)				
Photovoltaic Panels (S)	$95.27	$109.27	-$1,077.87	-$1,178.86
Timers on computer, DVR (A)				
Incandescent to CFL (D)				
Micro CHP – Heating (S)				
Micro CHP – Electricity (S)				

Ideally a subsidy should encourage British Columbians to invest in energy technologies they otherwise would not have been interested in, while also providing value to the province. In the study of this specific building this is rarely the case. Many subsidies such as weatherization, appliance upgrades and photovoltaic panels are not high enough to make installing these technologies profitable for the homeowners. This may be because these home already have high quality windows and relatively efficient appliances. If these units had extremely inefficient appliances or low quality windows, these incentives might make more sense for both parties involved.

The heat pump incentive appears to be too high to yield a net benefit to BC; however, the subsidy is required to make this technology attractive to the homeowners in this building. Again, this incentive might perform better in a building with lower insulation.

The incentive for drain water heat recovery and programmable thermostats is estimated to provide a benefit for both homeowners and the province. Since these measures are attractive to the residents with or without the subsidy, lowering them may be an option.

The incentives that perform the best with this particular building are solar thermal heating and a new washing machine. In both cases these subsidies push the technologies to become attractive to the homeowners while still generating net value for the province.

It is hard to determine how much relevance these results have for the province in general. Judging the effectiveness of any subsidies involving weatherization, space heating or appliance use is not realistic because this building already performs at a much higher level than the average residential building in BC. The most relevant results are any measures involving hot water use. Hot water use is independent of building envelope, environment, and year of construction.

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