UBC Social Ecological Economic Development Studies (SEEDS) Student Report

UBC transition from steam to hot water district energy: alternatives for addressing MacMillan's steam orphanage and UBC's absorption chillers

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Abstract

The current steam heating system will be replaced with a hot water distribution system that will reduce campus GHG emissions by 22%, energy use by 24%, and up to $4 million/year in operational and energy costs. Even though heating and domestic hot water are the main end uses of most buildings on campus, there are buildings that require steam for other processes; those buildings will become steam orphans. The purpose of this project is to identify alternatives for addressing the steam orphanage for MacMillan building's steam equipment, as well as for the three UBC's campus absorption chillers in three other buildings.

The main objectives for this project are: to outline the specifications, operating hours, steam consumption, O&M costs, GHG impacts and life expectancy of MacMillan's steam equipment and the three absorption chillers in CICSR, FSC, and Brimacombe. As well as to evaluate feasibility, costs and business case for different alternatives.

Three indicators were chosen to identify the best option for each building: capital cost, net present value and GHG impacts. However, from a simple environmental perspective, if the following options are implemented: MacMillan – New Autoclaves, CICSR – Heat Recovery Chiller, FSC – Electric Chiller, and Brimacombe – Electric Chiller. UBC can save up to 1,360 tonnes of GHG emissions, which is equal to 2.2% of total campus yearly emissions.

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1 Introduction

The university's Climate Action Plan (CAP) was born in 2010 as a result of UBC's commitment to reduce its direct and indirect greenhouse gas emissions. By the year 2015, the university would reduce its emissions 33% below 2007 levels, to 66% below by 2020, and finally the university would reduce its GHG emissions by 100% by 2050, and be a "net positive campus".

The CAP outlines six areas as the key sources of UBC's GHG emissions (UBC Campus Sustainability Office, 2010):

1) Campus Development and Infrastructure
2) Energy Supply and Management
3) Fleets and Fuel Use
4) Travel and Procurement
5) Food
6) Transportation

Various strategies were developed, but in general to achieve these goals, the university would focus on reducing the first 33% through energy efficiency and conservation, the next 33% by switching from natural gas to renewable energy sources, and finally become net GHG positive by exporting surplus renewable energy to the surrounding community.

To achieve its 2015 goal of reducing GHG emissions by 33% below 2007 levels, UBC has identified three main strategies. The first one is the Bioenergy Research and Demonstration Project. This plant was completed in September 2012 and is sized to reduce UBC's greenhouse gas emissions by 4,500 tonnes/year (Nexterra, 2012). The second strategy is participation in Power Smart's Continuous Optimization program for 72 buildings on campus. This program attempts to minimize building energy use by optimizing the systems within the building. Finally, the third strategy which UBC chose to adopt is to upgrade the campus' district energy system. The current steam heating system will be replaced with a hot water distribution system that will reduce campus GHG emissions by 22%, energy use by 24%, and up to $4 million/year in operational and energy costs; Phase 1 of this project has been completed (UBC Campus Sustainability Office, 2012).

The process of converting the district energy system from steam to hot water includes replacing the existing infrastructure (steam boilers, piping, and heat exchangers) with infrastructure for a hot water district energy system. Although heating and domestic hot water are the main end uses of most buildings on campus, there are buildings that require steam for other processes; for those buildings, onsite steam generation and other alternatives will need to be assessed. There are also three buildings on campus that use steam for cooling purposes through absorption chillers. For these buildings, replacement option will also need to be assessed.

The steam to hot water conversion project will be one of the largest hot water conversions in North America with 15 km of distribution piping, 131 energy transfer stations (ETS) in the buildings' mechanical rooms, and a 52MW hot water plant.

1.1 Purpose and Objectives

This project will focus on four buildings on campus: MacMillan, the Institute for Computing, Information and Cognitive Systems / Computer Science (also known as CICSR), the Forest

Sciences Centre (FSC), and the Brimacombe buildings. The purpose of this project is to identify alternatives for addressing the steam orphanage for MacMillan building's steam equipment, as well as for the three UBC's campus absorption chillers in the other three buildings.

Objectives:

- To outline the specifications, operating hours, steam consumption, O&M costs, GHG impacts and life expectancy of MacMillan's steam equipment and the three absorption chillers in CICSR, FSC, and Brimacombe.
- To evaluate feasibility, costs and business case for:
  - Providing an alternate source of steam (dedicated steam generators or steam boiler in mechanical room).
  - Replacing autoclaves with new autoclaves (electric or steam with built in steam generators).
- To evaluate feasibility, costs and business case for:
  - Converting chillers to hot water.
  - Replacing absorption chillers with electric chillers.
  - Replacing absorption chillers with heat recovery chillers, for CICSR

2 Project Background

Addressing steam orphanage is a priority for the UBC Project Services because the central steam plant is expected to be decommissioned in the near future. The four buildings that will be assessed in this report are described below.

2.1 MacMillan Building

Addressing the steam orphanage of MacMillan is a priority for Project Services since the building is part of the conversion phase that is being currently designed by the engineering consultants. Project Services has recognised that MacMillan's laboratories have equipment that is being serviced by the central steam plant. Table 1 shows additional information of the Macmillan Building.

Table 1. MacMillan's Building Information

Construction Year:	1967
Building Gross Area:	14,087m^2
Structure:	Concrete
Steam End Uses:	Heating Domestic Hot Water Lab processes
Steam Equipment:	4 autoclaves

Originally, the building had 15 pieces of equipment that would run on steam; seven autoclaves, two stills, two steam baths, one milk pasteurizer, one kettle, one retort, and one dishwasher. However, due to changes in the occupancy and technology, only four autoclaves remain in two different lab rooms in the building. Out of the four, only three are connected and only two are used on a regular basis. Table 2 shows information on each of these units.

Table 2 Autoclaves descrptions

LOCATION	SHAPE	STATUS	WIDTH	HEIGHT	DEPTH	VOLUME (FT^3)
ROOM 240	Cylindrical	Being repaired	16		24	2.5
ROOM 240	Rectangular	Active	20	20	30	7.0
ROOM 302D	Cylindrical	Active	15		24	2.5
ROOM 302D	Rectangular	Not connected	18	18	24	4.5

2.2 Absorption Chillers on Campus

The three absorption chillers on campus that currently run on steam (coming from the campus' central plant) will need to be addressed and feasible alternatives will need to be analysed. These chillers are located in three different buildings: Brimacombe, the Institute for Computing, Information and Cognitive Systems / Computer Science (CICSR), and the Forest Sciences Centre (FSC). Table 3 Building Information – CICSR, FSC, and Brimacombeshows information on each of the three buildings that will be analysed.

Table 3 Building Information – CICSR, FSC, and Brimacombe

	CICSR	FSC	BRIMACOMBE
CONSTRUCTION YEAR:	1993	1998	1995
BUILDING GROSS AREA:	10,204.19 m^2	22,717.94 m^2	8,550.62 m^2
STRUCTURE:	Concrete	Concrete	Concrete
STEAM END USES:	Heating Cooling Domestic Hot Water	Heating Cooling Domestic Hot Water	Heating Cooling Domestic Hot Water

STEAM EQUIPMENT:	365 Ton Absorption Chiller	580 Ton Absorption Chiller	300Ton Absorption Chiller

CICSR is hosts the Institute for Computing, Information and Cognitive Systems and it is primarily comprised of computer labs, data centres, and offices. FSC is home of the Faculty of Forest Sciences and is comprised of offices, class rooms, auditoriums, and labs. Lastly, the Brimacombe building consists of several materials and mechanical laboratories. All of these buildings were constructed from 1993 and 1998.

2.3 Chiller Technologies

2.3.1 Absorption Chillers

Absorption chillers technologies can be single- or double-effect, fired by steam or direct-fired by gas, oil, or waste heat. They use a lithium bromide/water cycle in which water is the refrigerant and lithium bromide is the absorbent. Absorption chillers differ from compression chillers in that they use a source of heat to provide the energy needed to drive the cooling process, rather than mechanical energy. The heat source is often low pressure steam or hot water.

Single-effect chillers have a typical coefficient of performance (COP) of 0.6-0.8. Table 4 lists the typical characteristics of a single stage absorption chiller (ASHRAE, 2011).

Table 4 Characteristics of Typical Single-Effect, Indirect-Fired, Water/Lithium Bromide Absorption Chiller

PERFORMANCE CHARACTERISTICS	
Steam input pressure	9 to 12 psig
Steam consumption	18.3 to 18.7 lb/ton · h

Hot-fluid input temp.	240 to 270°F, with as low as 190°F for for waste heat applications
Heat input rate	18,100 to 18,500 Btu/ton · h
Cooling water temp. in	85°F
Cooling water flow	3.6 gpm/ton, with up to 6.4 gpm/ton for some smaller machines
Chilled-water temp. off	44°F
Chilled-water flow	2.4 gpm/ton, with 2.6 gpm/ton for some smaller international machines

2.3.2 Electric Chillers

Liquid (usually water) is chilled by liquid refrigerant evaporating at a lower temperature. Then it's drawn into the compressor, which increases the pressure and temperature of the gas. Then enters the condenser where the cooling medium is warmed in the process. The condensed liquid refrigerant then flows through an expansion valve before returning to the evaporator where heat is removed from the cycle. Coefficient of performance for these chillers vary, but proven technologies have COP as high as 6 for chillers from 150 to 300 tonnes (ASHRAE, 2007).

3 Energy Analysis

Although steam consumption is the area of main focus of this study, electricity consumption is also important to understand the patterns of energy consumption of the buildings. Steam and electricity consumptions records for all four buildings were obtained from UBC Utilities. 2012 data was used to establish the baseline for the energy consumption. Due to lack of metered data from July to December 2012 for Brimacombe, data from July 2012 to June 2012 was used. All three buildings are equipped with PowerLogic ION 7330 meters that, according to UBC Utilities, are trending accurate data. Figure 1 shows the energy use intensities of all four buildings. This information allows us to compare the buildings among themselves and we can quickly identify that CICSR is a very energy intense building.

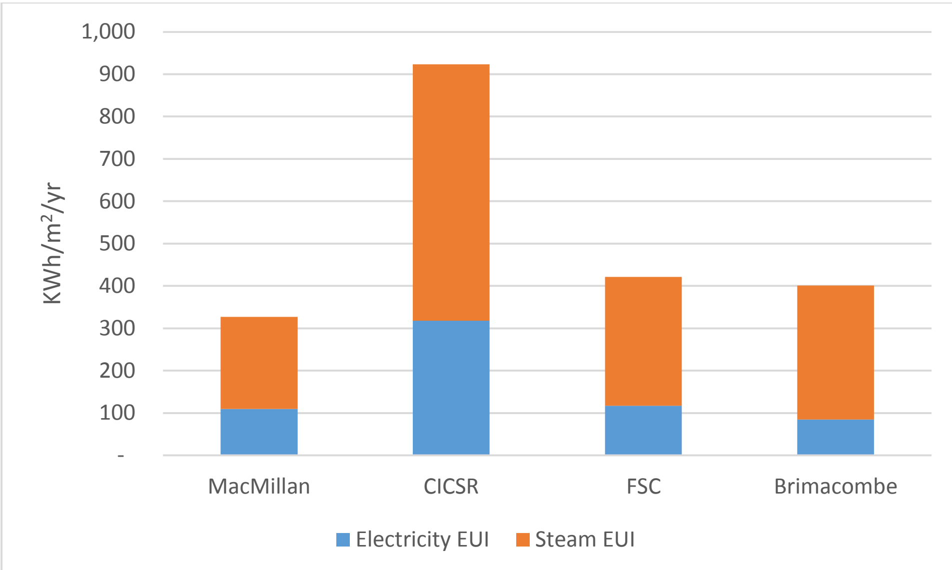


Figure 1 Energy Use Intensities for all four buildings

3.1 MacMillan

MacMillan is an academic building, home of the Faculty of Land and Food Systems, primarily comprised of research labs, class rooms and offices. Figure 2 shows MacMillan's monthly energy consumption for 2012. Electricity consumption is relatively constant throughout the year, while steam consumption is high during the coldest months, and decreases with warmer weather.

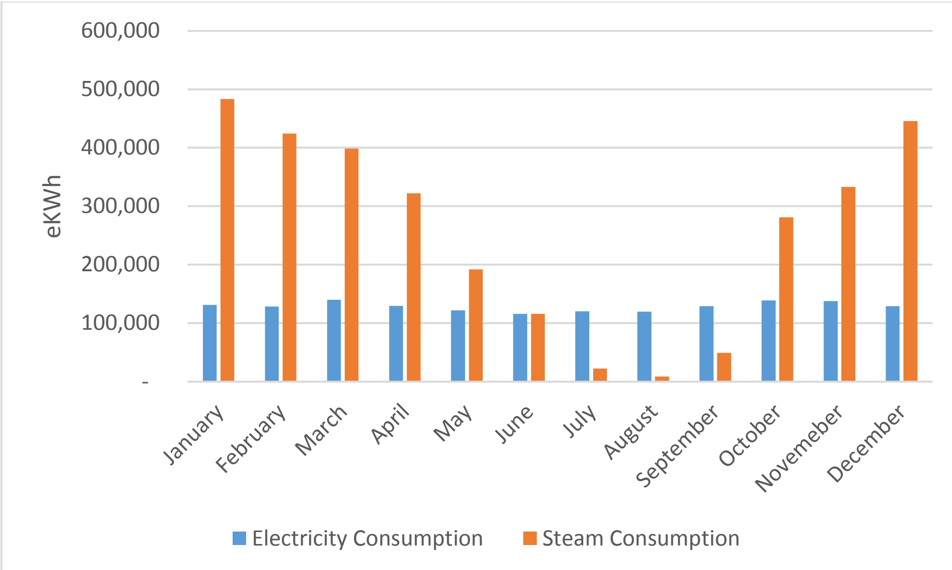


Figure 2 MacMillan energy consumption for 2012

MacMillan steam consumption consists of heating, domestic hot water (DHW) and process steam (autoclaves). Since there is no sub-metering in UBC's buildings, some assumption were done to isolate each of these steam end uses. DHW is considered a constant load it is assumed that it represents 7% of the total energy consumption (DOE, 2012).

The autoclaves' consumption was calculating doing some assumptions. According to the manufacturer, for a 25 minute cycle in a 200 l autoclave with a 17 lb instrument tray full of water tasks, a temperature difference of 200°F (from 70 to 270 °F), the steam consumption is 18 lb/cycle, which is equal to 55lb/hr and 7lbs/hr while on stand-by mode (STERIS, 2010). This consumption will be considered for the large autoclave in room 240. Assuming that the energy needed to fill up energy of steam used to purge and fill the free volume of autoclave is 4,028 BTU/ft^3, the consumption of the smaller autoclave in room 302D is 37 lb/hr (Martynenko, N/A). The consumption of the two autoclaves is then 92lb/hr plus 10 lbs/hr while on stand-by, assuming the smaller autoclaves uses 3 lbs/hr. According to the buildings Operations Manager, the large autoclave is used 6 hr/week, 8months/year which is equal to 210 hr. The smaller autoclave has a log where users write down the hours of use; during 2012 this autoclave operated for 113 hours. The total steam consumption of both autoclaves, including idle time, is 100,000lb/yr or 106 GJ/yr. Figure 3 shows the end use breakdown of the steam consumption of MacMillan building in GJ.

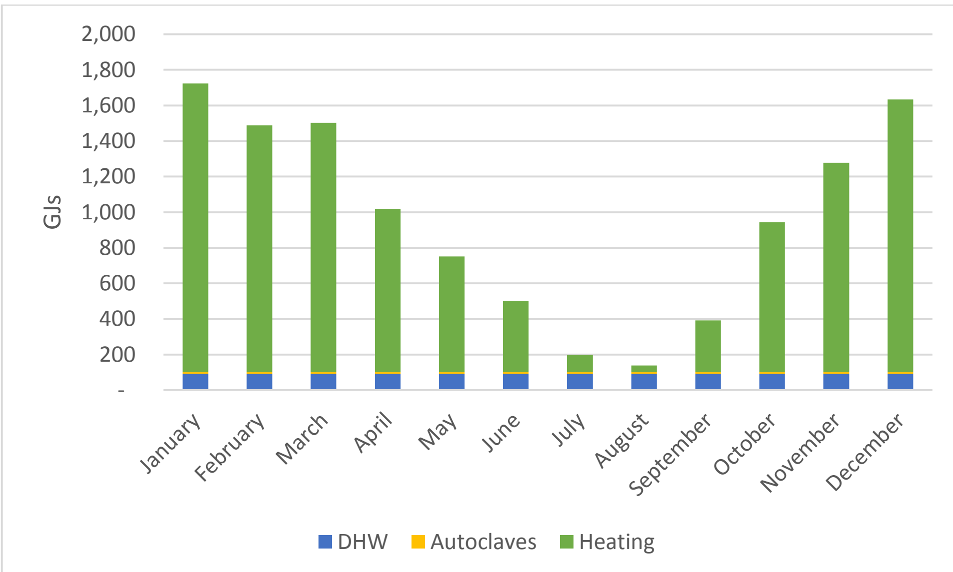


Figure 3 MacMillan steam end uses

3.2 Absorption Chillers

The first step that was taken in this project was to assess the capacities of the three chillers. Usually chillers are designed for peak loads and allow room for increased building occupancy. However, it was suspected that these absorption units were significantly oversized. The first exercise was to determine the buildings peak consumption on the hottest day over the past three years. Figure 4 shows the peak loads for the three absorption units using weather data and steam consumption from the three buildings. The cooling loads were calculated on the hottest day of the past three years, which is August 15, 2010. Even though these buildings are only partially occupied during august, these peak loads exceed September loads.

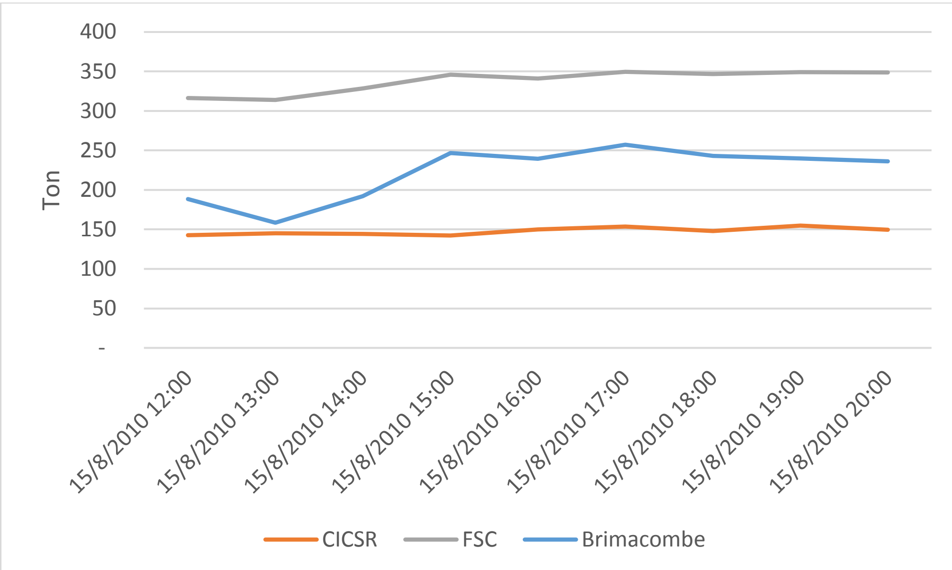


Figure 4 Peak cooling loads for absorption units during the hottest day over the past three years

The results show that the chillers are oversized. Brimacombe is only oversized by 15%, but CICSR is oversized by 58% and FSC by 40%.

3.2.1 CICSR Steam Consumption

The first of the three absorption chillers that will be analysed is the one in the Institute for Computing, Information and Cognitive Systems / Computer Science Information (also known as CICSR). As expected, electricity consumption is fairly constant throughout the year (Figure 5), with slightly less consumption over the summer months, which is consistent with the fact that cooling is provided by steam. Steam, on the other hand shows to trends; there’s an increase in steam consumption over the winter months that slightly decreases when the days start to get warmer. The second trend is in the summer months, the steam consumption increases again in May and it decreases again in November. This indicates that the chiller is operating in free cooling mode from November to May and the steam consumption is due to heating needs. Then, the chiller is turned on in May and the majority of the steam consumption is due to the building's cooling needs. Later on, a more in depth analysis on the steam consumption will be done.

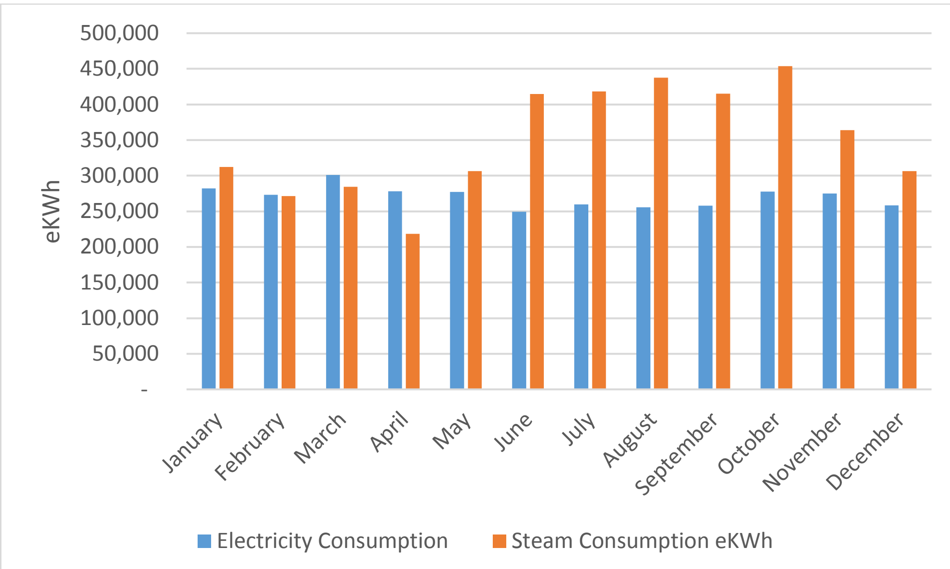


Figure 5 CICSR Monthly Energy Consumption

It is suspected that CICSR is a building with simultaneous cooling and heating needs due to the large computer science infrastructure consisting of consisting of core networking, common file servers, and shared computational resources. CICSR's steam consumption shows an interesting trend, as mentioned before. Figure 6 explains the daily steam consumption and heating degree days (HDD) for 2012. As the graph shows, during the winter months, there is a correlation between steam consumption and HDD. Right on May 16 the data shows that the absorption chiller was turned on. Then the steam load is fairly constant until November 15 that it was turned off again and free cooling is used to meet the building's cooling loads.

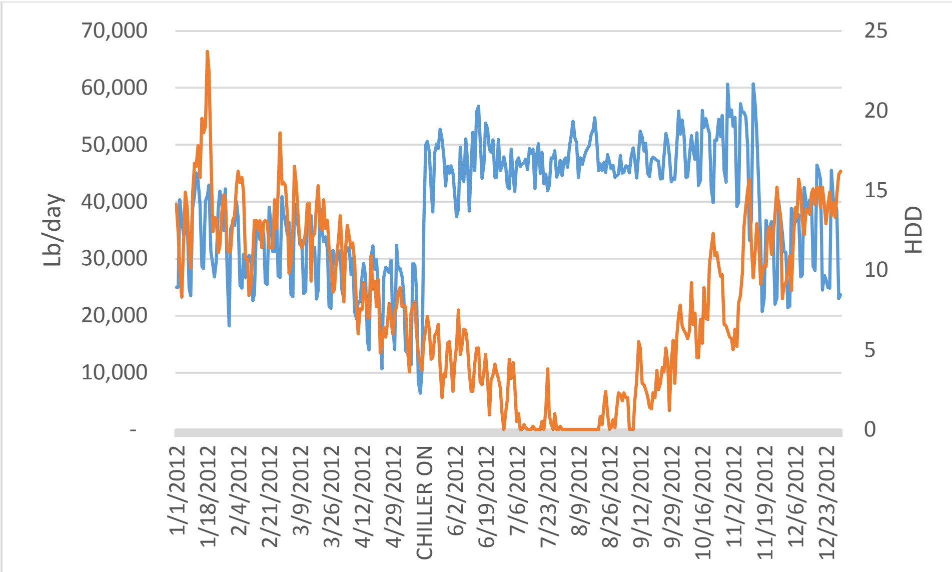


Figure 6 CICSR Daily steam consumption vs. HDDs

In order to calculate the steam end uses for CICSR, a linear regression analysis during the heating months was applied and assuming that DHW accounts for 7% of the building's energy consumption (Figure 7). According to the linear regression model, the steam consumption for a building is a function of the HDD and DHW is a constant load. Therefore, the following linear equation is used to calculate the steam consumption. Steam Consumption = 2,358.6(HDD) + DHW load, where DHW = 53,300 lb/month.

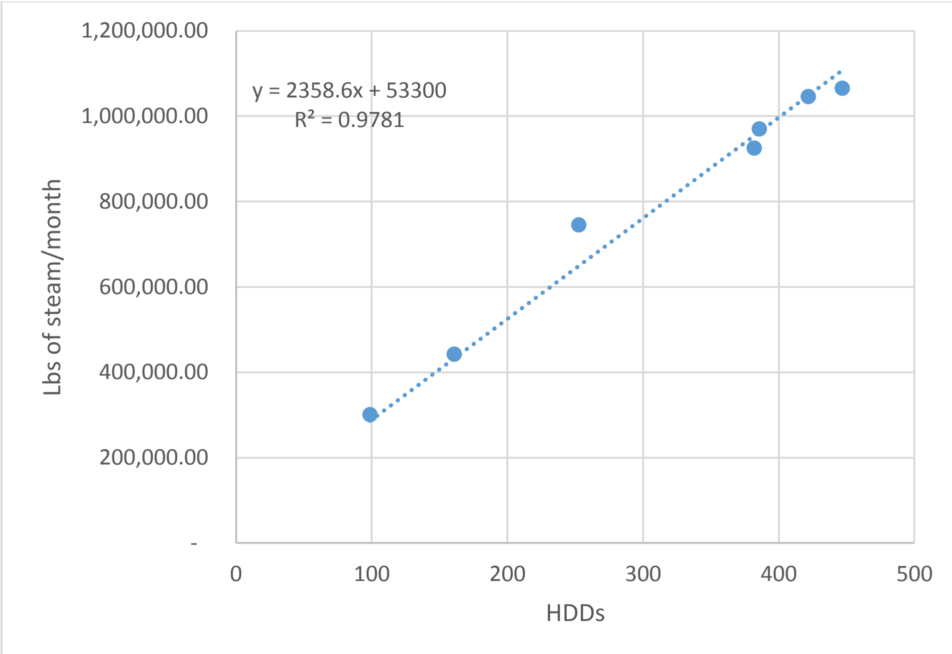


Figure 7 CICSR monthly consumption vs. HDD

This equation can be applied to calculate the steam consumption for heating and DHW in the winter months. During the summer months, the heating loads must obey the same equation while the cooling loads will be the difference between the heating + DHW loads and the total steam consumption, as Figure 8 illustrates. According to the model, cooling steam consumption is 6,990,000 lbs/year or 7,400 GJ, which is equal to $71,000/yr in fuel costs.

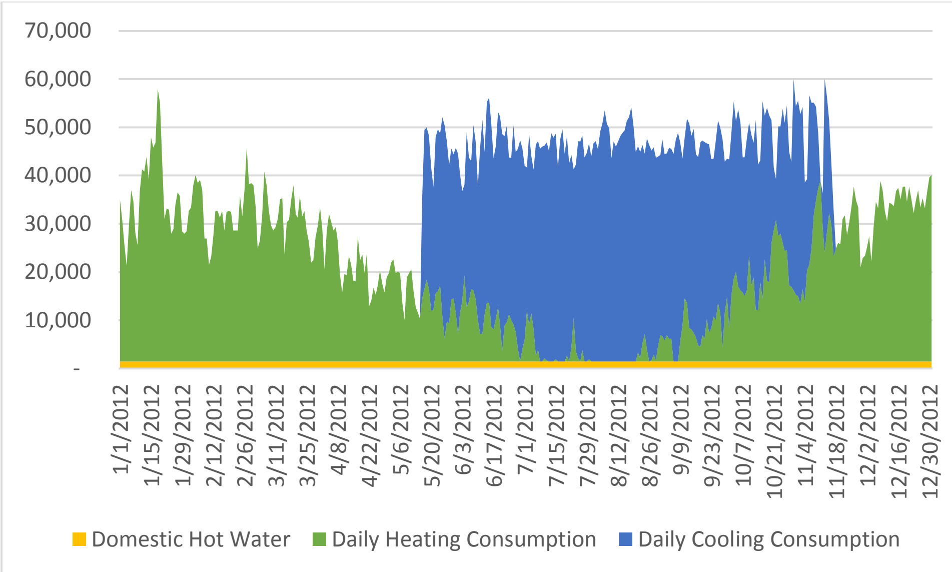


Figure 8 CICSR daily steam consumption by end use

According to the manufacturer, these absorption chillers use 19.6lb/hr to produce one ton of cooling, which is equal to 3.52MW. Now that the cooling steam consumption of the chiller is known, it is possible to calculate what the cooling load of the building is. Figure 9 shows the cooling load of CICSR for the summer of 2012.

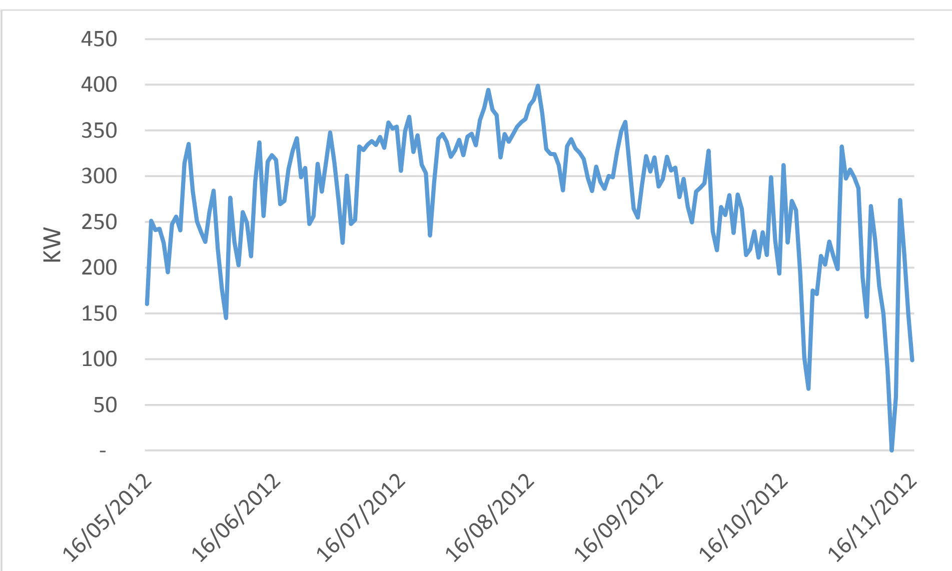


Figure 9 CICSR's Summer Cooling Load – KW

This information is useful to identify the average cooling load and also assess the heat recovery potential for this building. Figure 10 illustrates the heat recovery potential for this building. The area in red represents the cooling load, assuming there is a constant cooling need over the winter equal to 263 KW (which represents the average load over the summer). The line in blue represents the heating load and the area that falls under both loads represents the heat recovery potential, which is approximately 169 KW.

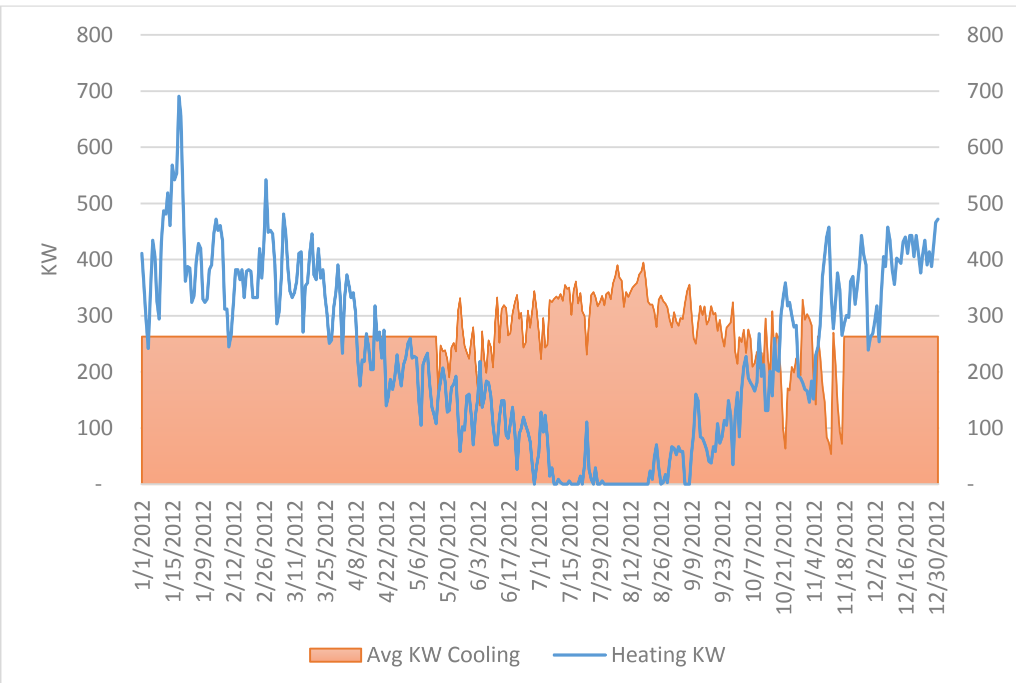


Figure 10 Heat Recovery Potential – Avg Cooling and Heating Load

3.2.2 FSC Steam Consumption

The second chiller is located in the Forest Sciences Centre. Again, electricity consumption is fairly constant throughout the year. Steam consumption, on the other hand, is high when heating needs are high but also when the cooling needs are high (see Figure 11). However, the cooling period is shorter than in CICSR.

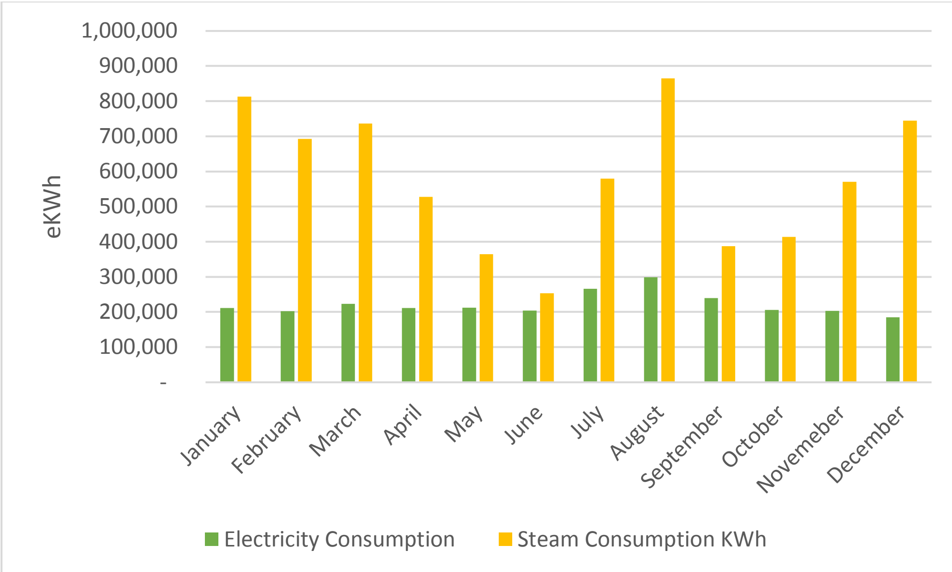


Figure 11 FSC Monthly Energy Consumption

Steam consumption in the Forest Sciences Centre (FSC) is different than CICSR. There is no simultaneous heating and cooling, instead, steam consumption is a function of HDDs during the winter, but also a function of CDD during the summer. Figure 12 illustrates how steam consumption decreases when HDDs decrease; this trend is sustained until July, when steam consumption increases as CDDs increase too.

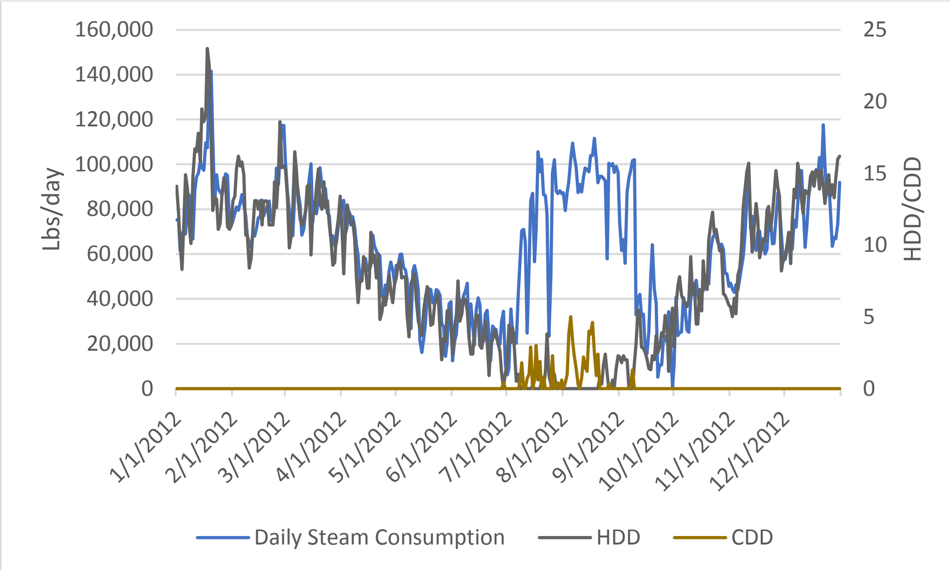


Figure 12 Daily Consumption vs HDD and CDD

A linear regression analysis with HDDs as a function of steam consumption (Figure 13) was done to identify the different steam end uses for FSC using the winter months. Assuming also a 7% for DHW load, the linear equation to determine steam consumption (during the winter months) is: Steam Consumption =5,684.1(HDD) + DHW load, where DHW = 196,960 lbs/month.

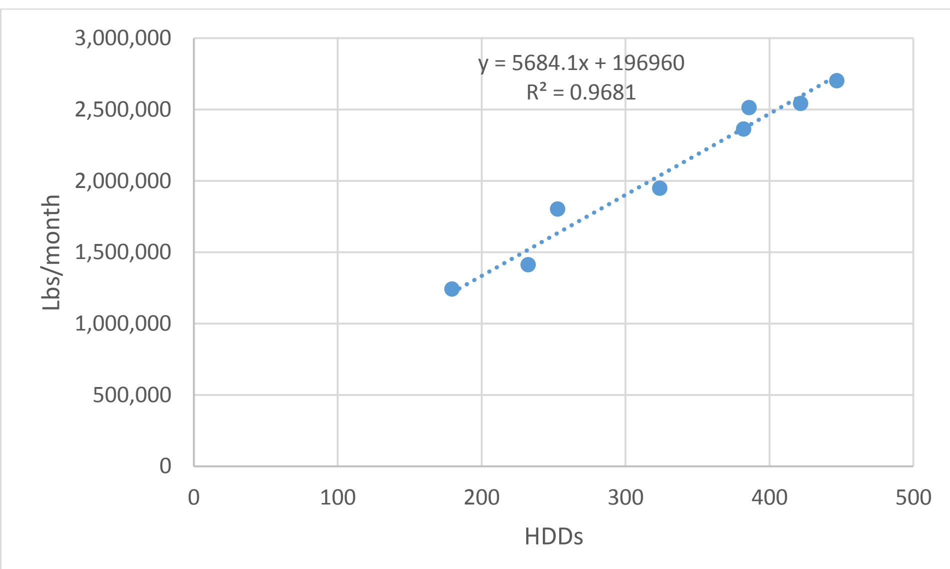


Figure 13 FSC monthly consumption vs. HDD

Using this linear model, the heating and DHW end uses can be calculated, while the cooling end use is equal to the difference between the predicted Heating + DHW and the real consumption. Figure 14 shows an approximation of the monthly steam consumption by end use. According to this model, cooling steam consumption accounts for 5,000,000 lbs/year or 5300 GJ of steam, which equals to $51,000/year in fuel costs.

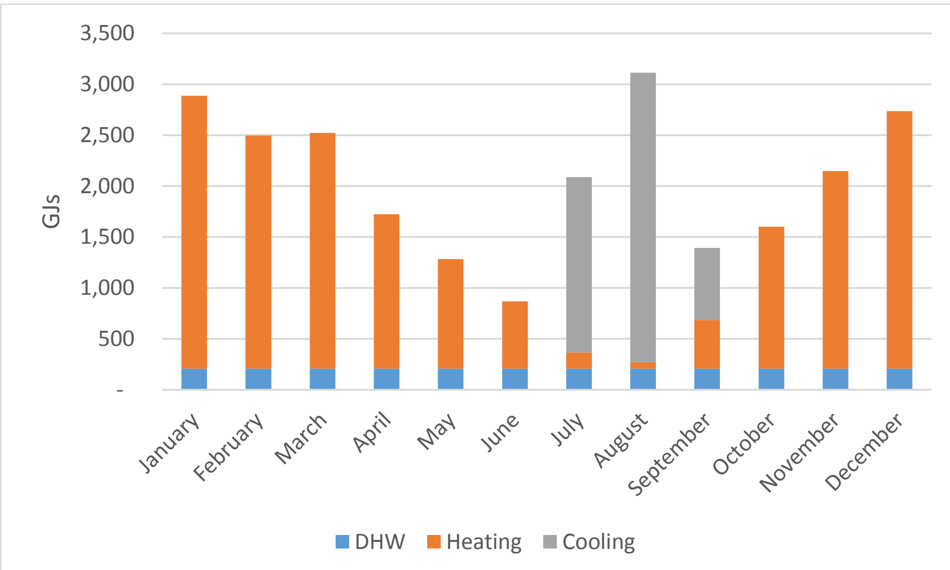


Figure 14 FSC monthly steam consumption by end use

3.2.3 Brimacombe Steam Consumption

The third and last chiller is the one located in Brimacombe; the smallest of the three. Again, electricity consumption is constant throughout the year and the steam consumption varies with outdoor temperature (Figure 15). The bulk of the steam consumption occurs in the winter months too, and it goes down as the warmer days arrive. It reaches its lowest point in June, and we see an increase again in July.

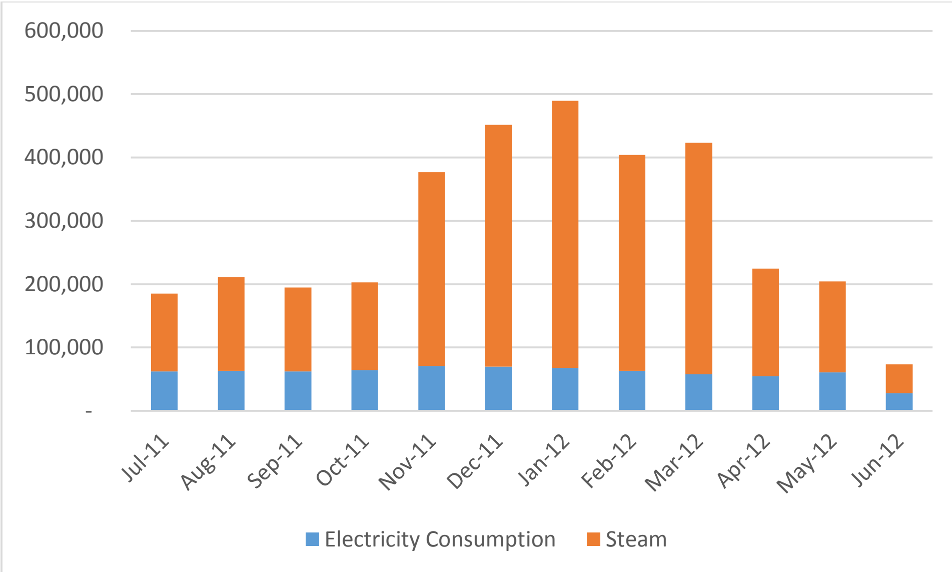


Figure 15 Brimacombe monthly energy consumption

Although, monthly energy consumption useful, these electricity and steam consumptions can tell a more detailed story if deeper analysis is done. Figure 16 shows the building's daily energy consumption in orange; at the same time, on the secondary axis, HDDs and CDDs are plotted. Again, steam consumption correlates with HDDs during the winter months, and to a lower degree, it correlates with CDDs.

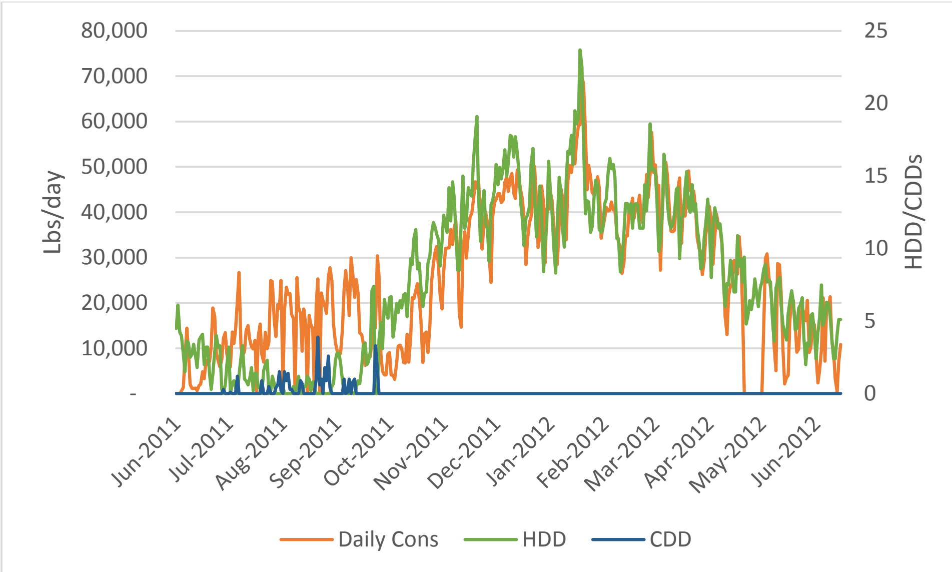


Figure 16 Brimacombe daily steam consumption vs. HDDs and CDDs

Again, a linear regression analysis is done with HDDs as a function of steam consumption for the winter months to identify the different steam end uses for Brimacombe; see Figure 17. Assuming also a 7% for DHW load, the linear equation to determine steam consumption (during the winter months) is: Steam Consumption =2,765.3(HDD) + DHW load, where DHW = 77,250 lbs/month.

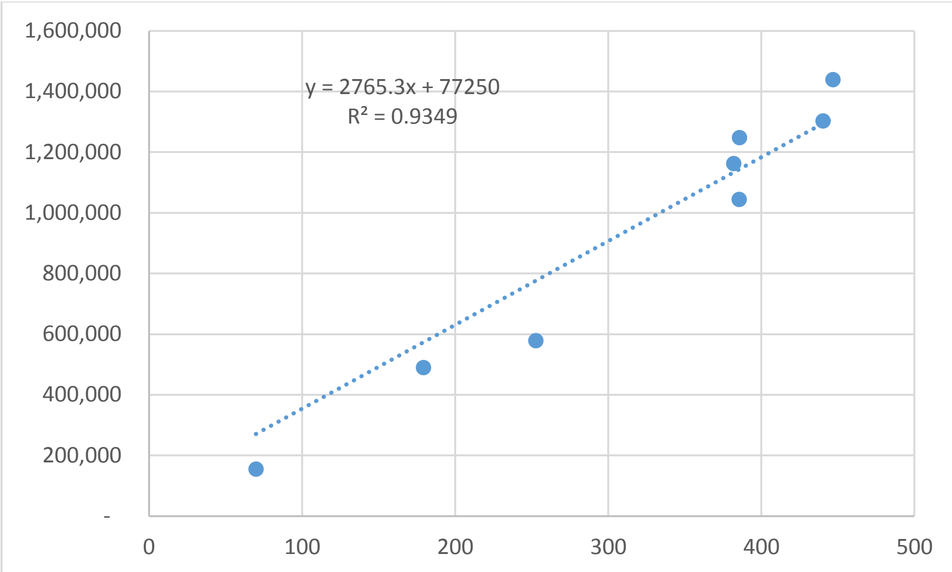


Figure 17 Brimacombe monthly steam consumption vs. HDDs

Using this linear equation we can isolate the different steam end uses: heating, DHW and cooling. Figure 18 shows the steam consumption from July 2011 to June 2012 by end use. Even though the majority of the steam consumption goes to heating, there is a substantial amount that goes to the absorption chiller. The chiller consumes 840,000 lbs/year or 884GJ of steam that is equal to $8,500/year in fuel costs.

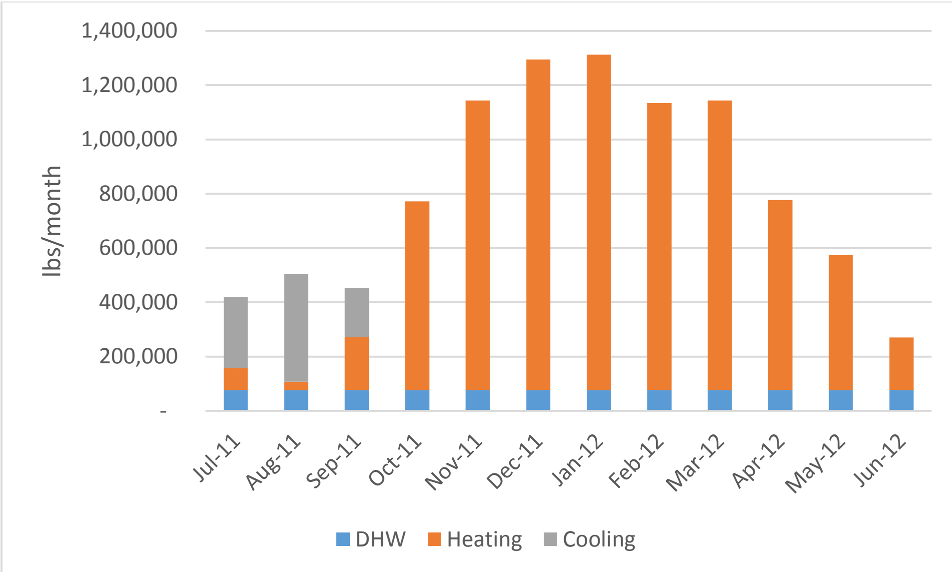


Figure 18 Brimacombe monthly steam consumption by end use

4 Replacement Alternatives

Different alternatives were evaluated for each of the buildings. Table 5 shows the different options analysed for each of the buildings

Table 5 Replacement alternatives for all four buildings

	MACMILLAN	CICSR	FSC	BRIMACOMBE
OPTION 1	Dedicated Steam Generators	Conversion to Hot Water	Conversion to Hot Water	Conversion to Hot Water
OPTION 2	Electric Steam Boiler	Replacing with Electric Chiller	Replacing with Electric Chiller	Replacing with Electric Chiller
OPTION 3	New Autoclaves	Replacing with Heat Recovery		

4.1 MacMillan

The different alternatives for MacMillan's autoclaves were evaluated. Two of the options consider providing on-site steam to the existing autoclaves and one option evaluates buying new autoclaves due to the advanced age of the existing equipment. The business cases are presented below.

4.1.1 Option 1: Distributed Electric-Steam Generators

Option one for MacMillan's autoclaves is to leave the existing equipment and installing dedicated steam generators. A Field Service Representative from Steris conducted a site visit to the building and assessed the existing autoclaves and the requirements to install three new steam generators. The steam generators quoted for each of the autoclaves have a rating of 30KW, and a max steam output of 95 lb/hr with 140 °F feed water. The steam generators lose up to 10 lbs/hr when fed with cool water. Table 6 shows the economic analysis for the purchase of three steam generators in the initial year. 5 years of remaining life was considered for the existing autoclaves. Also, the manufacturer could not warranty the work to be done for the installation of the steam generators due to the advanced age of the equipment.

Table 6 MacMillan Option 1 business case

ELECTRICITY USE (BASED ON TWO AUTOCLAVES)		
Rating	KW	30
Annual hours of operation	Hours/year	323
Electricity consumption	kWh/year	9,690
UBC Electrical cost	$/year	514
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	2,500
TOTAL OPERATING COST	$/yr	3,014
SUMMARY		
CAPITAL COSTS		

Steam Generators	$/yr	39,954
Installation costs		3,280
TOTAL COSTS	**$/yr**	**46,248**
	5.75%	
	15 Year NPV	**-$116,734**

4.1.2 Option 2: Central Electric-Steam Generator

Option 2 is installing a new electric boiler in the mechanical room. A quotation was provided by Fulton for boiler model FB-L-75. It is a 75KW electric boiler with a steam output rating of 255 lb/hr, which allows for autoclaves peak consumption. Table 7 shows the economic analysis for the purchase of one electric steam boiler, at a 15 Net Present Value and a 5 year remaining life of the equipment.

Table 7 MacMillan Option 2 business case

ELECTRICITY USE (BASED ON TWO AUTOCLAVES)		
Rating	kW	75
Annual hours of operation	Hours/yr	323
Electricity consumption	kWh/year	24,225
UBC Electrical cost	$/year	1,284
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	5,000
TOTAL OPERATING COST PER YEAR INCL. WOOD FUEL	$/yr	6,284
SUMMARY		
CAPITAL EXPENSES		
Electric Steam Boiler	$	17,000
VT-10 feed water/ condensate return system	$	3,000
Pre heat kit	$	2,500
Cooling kit	$	1,600
Installation costs	$	10,000
TOTAL COSTS	$/yr	40,384
	5.75%	
	15 Year NPV	**-$143,581**

4.1.3 Option 3: New Autoclaves

The third option for MacMillan is to purchase two new electric autoclaves to replace the existing four autoclaves, since only two run on a regular basis. A large 250L Steris autoclave for room 240 and a smaller bench top Tuttnauer autoclave for room 302D were quoted. The Steris LAB250 is a 250L steam sterilizer that comes with a 30KW steam generator; it is the same model that many labs in life science have. The smaller Tuttnauer 3870 is a manual sterilizer with capacity of 85L. It has 3KW electric elements that heat up a small water reservoir (Tuttnauer, N/A). Table 8 shows the economic analysis for the purchase of one electric steam boiler, at a 15 Net Present Value. Since they are not used all day long, additional sterilization services can be covered by these two autoclaves.

Table 8 MacMillan Option 3 business case

ELECTRICITY USE		
System Load Factor (average)	%	100%
Rating	kWe	33
Annual hours of operation	Hours/yr	323
Electricity consumption	Kwh/yr	10,659
UBC Electrical cost	$/year	565
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	2,500
TOTAL OPERATING COST PER YEAR INCL. WOOD FUEL	$/yr	3,065
SUMMARY		
CAPITAL EXPENSES		
AMSCO LAB 110 w/installation		46,682
Tuttnauer 3870M		14,307
TOTAL COSTS	**$/yr**	**64,054**
	5.75%	
	15 Year NPV	**-$91,959**

4.2 Absorption Chillers

Because running those chillers on steam is no longer an option, three different alternatives were assessed for each chiller. For all three buildings three options were assessed: converting chillers to hot water, replacing chillers with water cooled centrifugal chillers, and replacing chillers with modular heat recovery chillers.

Based on the chillers peak loads and considering there is a 20% decrease in capacity when the supply temperature is below 112°C, according to the manufacturer. This assumption is backed up by Figure 19 Typical Lithium Bromide Absorption Chiller Performance Versus Temperature which shows that a supply water temperature of 112°C equals to a capacity drop of 15% (ASHRAE, 2011). To be conservative, the 20% decrease in capacity will be considered and only CICSR and FSC are oversized enough to allow that drop in capacity. Brimacombe, on the other hand is already maxed out (peak load equals to 85% of chiller's capacity) the chiller would not be able to provide enough cooling capacity. The maximum capacity that this 365 ton chiller could provide is 240 ton running on 115°C water from the steam plant, while the peak load registered in the warmest day of the past three years is 257 ton. Therefore, this option will not be considered for the Brimacombe building.

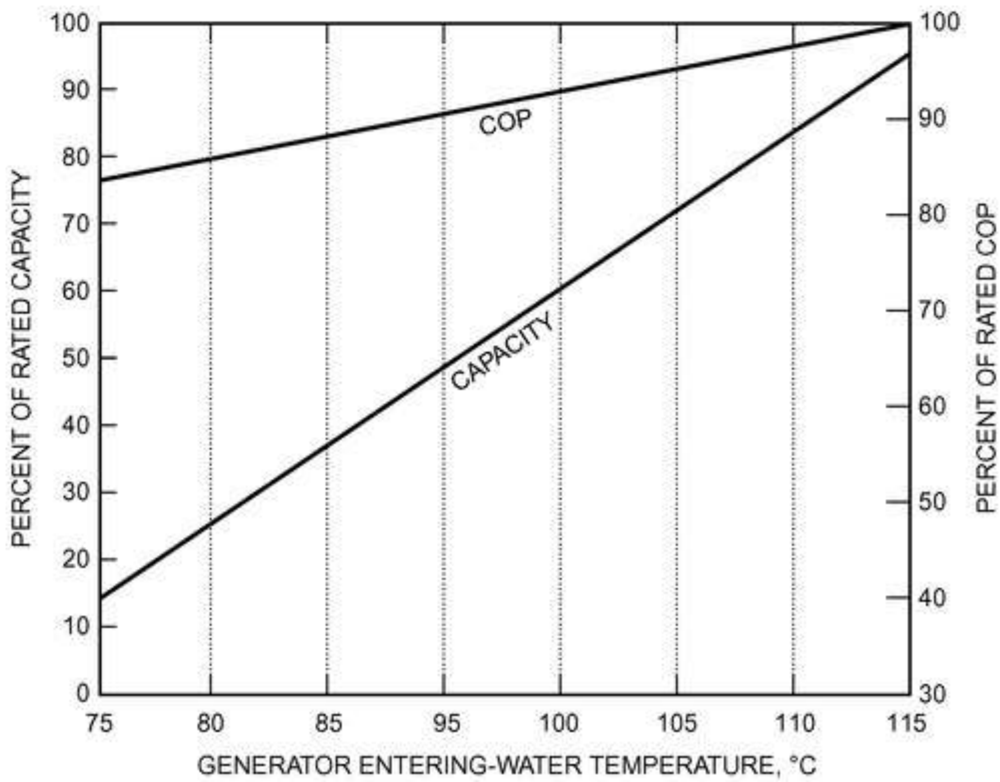


Figure 19 Typical Lithium Bromide Absorption Chiller Performance Versus Temperature (ASHRAE, 2011)

Only CICSR shows a representative year-round cooling load, therefore, it is the only chiller for which heat recovery will be assessed. Table 9 shows the feasible alternatives when addressing steam orphanage for each one of the chillers.

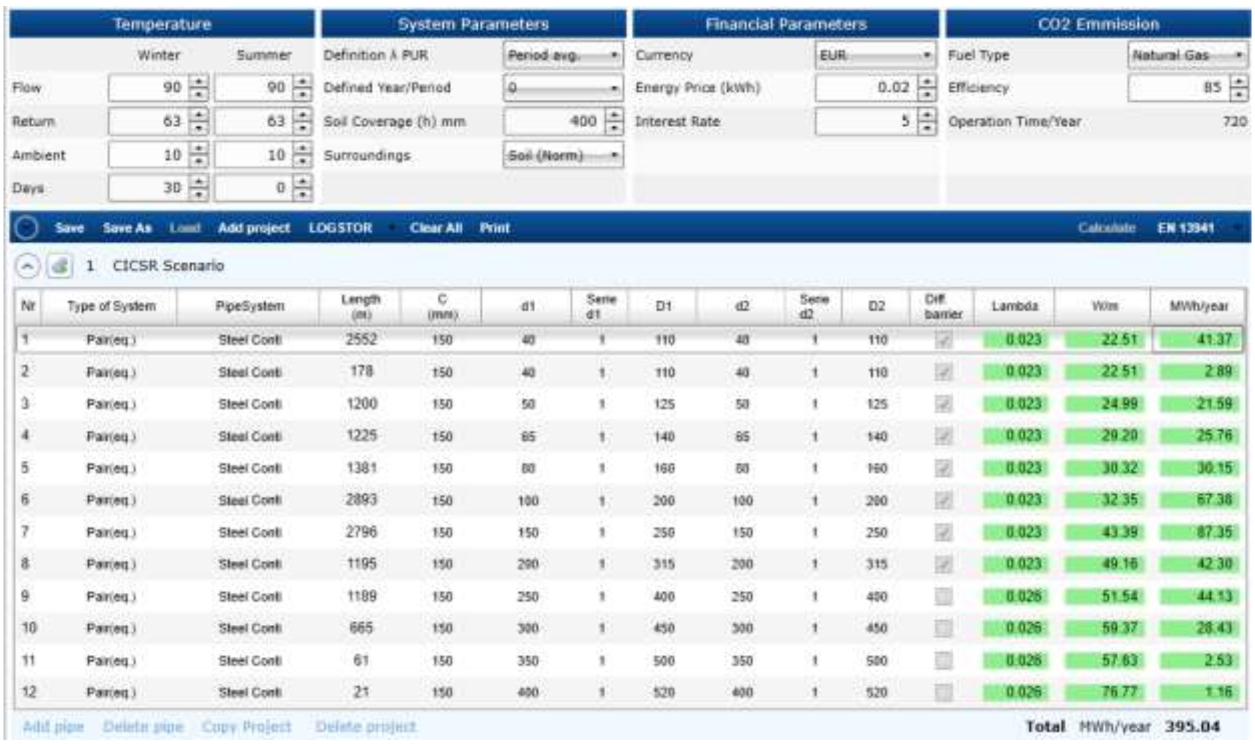
Table 9 Absorption chillers replacement alternatives

	CICSR	**FSC**	**Brimacombe**
Option 1	Conversion to Hot Water	Conversion to Hot Water	~~Conversion to Hot Water~~
Option 2	Replace with Electric Chiller	Replacing with Electric Chiller	Replacing with Electric Chiller
Option 3	Replace with Heat Recovery Chiller	~~Replace with Heat Recovery Chiller~~	~~Replace with Heat Recovery Chiller~~

4.2.1 CICSR

4.2.1.1 Option1: Convert Existing Chiller from Steam to Hot Water

As discussed above, it is technically feasible to convert CICSR's chiller to hot water. However, the capacity drops proportionally to the temperature of the water. In order to meet peak cooling loads, it is necessary to increase the temperature of the district energy from the average 75° to 90°C. This will result in distribution losses that are calculated by the Logstor Calculator 2.1. Figure 20 shows a screenshot of the calculator. Assuming the 90°C will be sustained for 30 days a year (to meet peak consumption during the warmest days of the year), the thermal losses account for 395,000 kWh.



Nr	Type of System	PipeSystem	Length (m)	C (mm)	d1	Serie d1	D1	d2	Serie d2	D2	Diff barrier	Lambda	W/m	MWh/year
1	Pair(eq.)	Steel Conti	2552	150	40	1	110	40	1	110	✓	0.023	22.51	41.37
2	Pair(eq.)	Steel Conti	178	150	40	1	110	40	1	110	✓	0.023	22.51	2.89
3	Pair(eq.)	Steel Conti	1200	150	50	1	125	50	1	125	✓	0.023	24.99	21.59
4	Pair(eq.)	Steel Conti	1225	150	65	1	140	65	1	140	✓	0.023	29.20	25.76
5	Pair(eq.)	Steel Conti	1381	150	80	1	160	80	1	160	✓	0.023	30.32	30.15
6	Pair(eq.)	Steel Conti	2893	150	100	1	200	100	1	200	✓	0.023	32.35	67.38
7	Pair(eq.)	Steel Conti	2796	150	150	1	250	150	1	250	✓	0.023	43.39	87.35
8	Pair(eq.)	Steel Conti	1195	150	200	1	315	200	1	315	✓	0.023	49.16	42.30
9	Pair(eq.)	Steel Conti	1189	150	250	1	400	250	1	400		0.026	51.54	44.13
10	Pair(eq.)	Steel Conti	665	150	300	1	450	300	1	450		0.026	59.37	28.43
11	Pair(eq.)	Steel Conti	61	150	350	1	500	350	1	500		0.026	57.63	2.53
12	Pair(eq.)	Steel Conti	21	150	400	1	520	400	1	520		0.026	76.77	1.16

Figure 20 Distribution losses for running DES at 90°C

Table 10 shows the business case for converting the CICSR chiller to how water. The performance of the absorption chiller will be affected by the reduced supply water temperature, with a 10% decrease in rated COP, according to Figure 19.

The calculations include annual energy consumption, a COP of 0.58, Logstor Calculator thermal losses, maintenance costs of $10,000/year, and $100,000 of capital costs of modifying the chiller. Over a period of 15 years, the net present value for this option is $-1,130,750.

Table 10 CICSR Option 1 business case

THERMAL ENERGY USE		
Annual Energy Consumption	MMBTU/yr	7,859
Total Annual Energy Consumption	GJ's/yr	8,291
Thermal losses due to 90°C summer time DES	GJ's/yr	1,677
Thermal Energy Costs	$/year	88,682
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	10,000
TOTAL OPERATING COSTS	$/yr	98,682
SUMMARY		
CAPITOL EXPENSES		100,000
TOTAL COSTS	$/yr	198,682
	5.75%	
	15 Year NPV	**-$1,130,750**

4.2.1.2 Option 2: Replace Existing Chiller with new Electric Chillers

Option 2 consists of replacing the absorption chiller with a new 200 ton SMARDT Water Cooled Chiller (oil-free magnetic bearing, centrifugal), considering that the current chiller is considerably oversized (as shown in Figure 4). Table 11 shows the business case for replacing the CICSR chiller with the electric chiller. The calculations include annual energy consumption, assuming conservative chiller COP of 4.5 (manufacturer's data claims COPs higher than 6). It also includes maintenance costs of $10,000/year, and $431,501 of capital costs for replacing the chiller. Over a period of 15 years, the net present value for this option is -$686,041.

Table 11 CICSR Option 2 business case

ELECTRICITY USE		
Electricity consumption	kWh/year	276,591
UBC Electrical cost	$/year	14,659
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	10,000
TOTAL OPERATING COST PER YEAR	$/yr	24,659
SUMMARY		
CAPITAL EXPENSES		431,501
TOTAL COSTS	$/yr	456,409
	5.75%	
	15 Year NPV	**-$686,041**

4.2.1.3 Option 3: Replace Chiller with new Heat Recovery Chiller

Option 3 consists of replacing the absorption chiller with a new 200 ton Water Cooled Modular Chiller with condenser return water temperature as high as 135°F, while simultaneously producing chilled water for the chiller system. Table 12 shows the business case for replacing the CICSR chiller with the simultaneous heating and cooling chiller. The calculations include annual energy consumption, assuming chiller COP of 4. It also includes maintenance costs of $10,000/year, and a capital cost of $462,000. Considering that CICSR has a heat recovery potential of 275 KW all year round, the heat recovery chiller can save up to 5,700 GJ in thermal energy equal to $50,280/year. Over a period of 15 years, the net present value for this option is -$207,009.

Table 12 CICSR Option 3 business case

ELECTRICITY USE

Electricity consumption	kWh/year	304,250
UBC Electrical cost	$/year	16,125
THERMAL ENERGY SAVINGS		
Total Annual Thermal Energy saved	GJ's/yr	5,652
Thermal Energy Savings	$/year	50,280
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	10,000
TOTAL OPERATING COST/SAVINGS	$/yr	(24,155)
SUMMARY		
CAPITAL EXPENSES		462,000
COSTS LESS SAVINGS	$/yr	437,845
	5.75%	
	15 Year NPV	**-$207,009**

4.2.2 Forest Sciences Centre (FSC)

4.2.2.1 Option 1: Convert Existing Chiller from Steam to Hot Water

Option 1 for FSC also consists on converting the absorption chiller to run on hot water. According to the manufacturer, it is technically possible to make do so. However, as the capacity drops proportionally to the temperature of the water, it is necessary to increase the temperature of the district energy from the average 75° to 115°C. This will result in distribution losses also calculated by the Logstor Calculator 2.1. Figure 21 shows a screenshot of the calculator. Assuming the 115°C will be sustained for 30 days a year (to meet peak consumption during the warmest days of the year), the thermal losses account for 505,000 kWh.

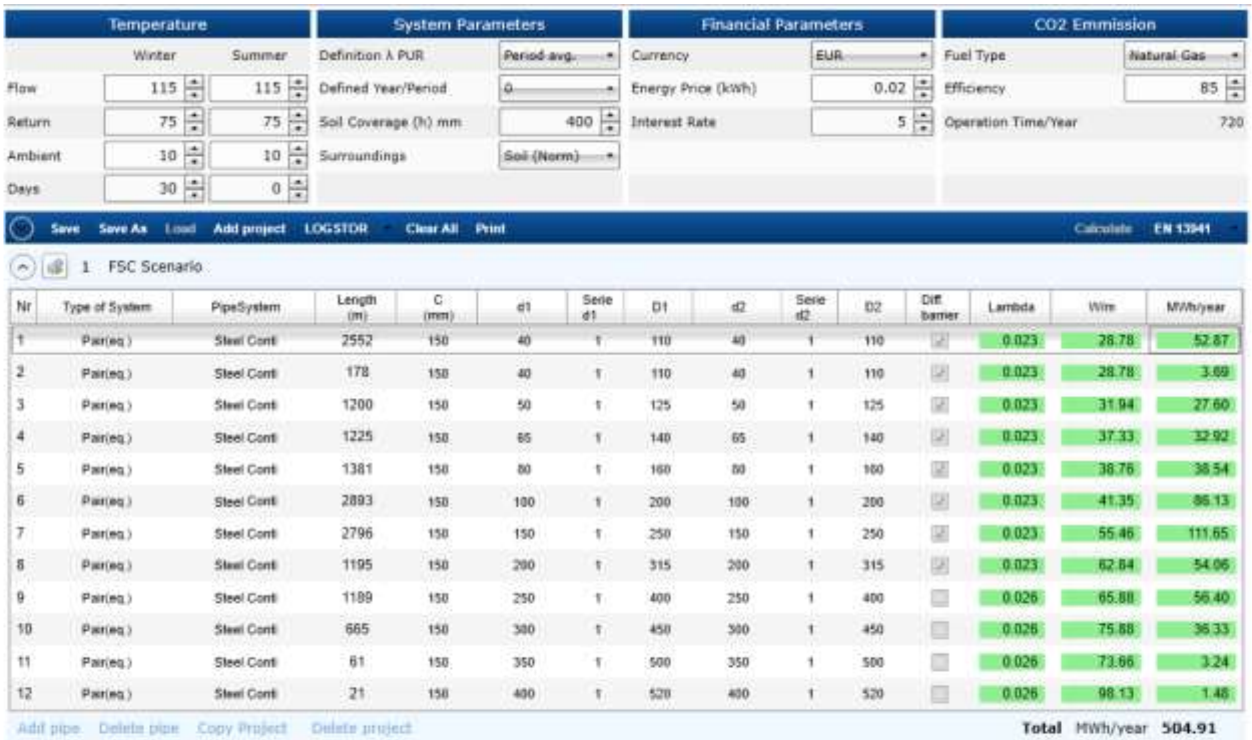


Figure 21 Distribution losses for running DES at 115°C

Table 13 shows the business case for converting the FSC chiller to hot water. The calculations include annual energy consumption, assuming the COP of the absorption chiller drops from 0.64 to 0.58. It also includes the Logstor Calculator thermal losses, maintenance costs of $10,000/year, and $100,000 of capital costs for modifying the chiller. Over a period of 15 years, the net present value for this option is -$924,278.

Table 13 FSC Option 1 business case

THERMAL ENERGY USE		
Annual Energy Consumption	MMBTU/year Hot Water	5,311
Total Annual Energy Consumption	GJ's/yr	5,604
Thermal losses due to 115°C summer time DES temps	GJ's/yr	2,139
Thermal Energy Costs	$/year	68,880
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	10,000

TOTAL OPERATING COSTS	$/yr	78,880
SUMMARY		
CAPITAL EXPENSES		100,000
TOTAL COSTS	$/yr	178,880
	5.75%	
	15 Year NPV	**-$924,278**

4.2.2.2 Option2: Replace Existing Chiller with new Electric Chillers

Option 2 consists of replacing the absorption chiller with a new 387 ton SMARDT Water Cooled Chiller, considering that the FSC chiller is also considerably oversized (as shown in Figure 4). Table 14Table 11 shows the business case for replacing the CICSR chiller with the electric chiller. The calculations include annual energy consumption, assuming chiller COP of 4.5. It also includes maintenance costs of $10,000/year, and $580,250 of capital costs for replacing the chiller. Over a period of 15 years, the net present value for this option is -$783,908.

Table 14 FSC Option 1 business case

ELECTRICITY USE		
Electricity consumption	kWh/year	205,756
UBC Electrical cost	$/year	10,907
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	10,000
TOTAL OPERATING COSTS	$/yr	20,907
SUMMARY		
CAPITAL EXPENSES		580,250
TOTAL COSTS	$/yr	601,157
	5.75%	
	15 Year NPV	**-$783,908**

4.2.3 Brimacombe

4.2.3.1 Option 2: Replace Existing Chiller with new Electric Chillers

Option 2 consists of replacing the absorption chiller with a new 300 ton SMARDT Water Cooled Chiller, which is the same capacity of the current absorption chiller. Table 15 shows the business case for replacing the Brimacombe chiller with the electric chiller. The calculations include annual energy consumption, assuming chiller COP of 4.5. It also includes maintenance costs of $10,000/year, and $522,500 of capital costs for replacing the chiller. Over a period of 15 years, the net present value for this option is -$744,723.

Table 15 Brimacombe Option 1 business case

ELECTRICITY USE		
Electricity consumption	kWh/year	46,049
UBC Electrical cost	$/year	2,345
OTHER O&M COSTS		
Maintenance Costs (internal and contractor)	$/yr	10,000
TOTAL OPERATING COSTS	$/yr	22,345
SUMMARY		
CAPITOL EXPENSES		522,500
TOTAL COSTS	$/yr	534,845
		5.75%
	15 Year NPV	**-$632,200**

5 Recommendations

By evaluating all the different alternatives for all four buildings, several conclusions can be drawn. Table 16 summarizes the results for each of the scenarios that were analysed. Three indicators were chosen to identify the best option for each building: Capital cost, Net Present Value, and GHG emissions. For MacMillan, the option with the lower initial capital cost is Option 2 – Installing an electric boiler in the mechanical room. However, existing autoclaves will require to be replaced in the near term. Assuming a 5-year remaining life for the existing equipment, the NPV for these two options ends up being less attractive than investing in new autoclaves in the present term.

For CICSR, Option 1 – Converting chiller to hot water has the lowest capital cost, but Option 3 – Replacing chiller with SHC chiller is the one with the best NPV, as well as a positive GHG impact, saving 925 tonnes of GHG emissions when compared to the business as usual scenario.

FSC circumstance is similar to CICSR, Option 1 – Converting the chiller to hot water represents the best alternative in terms of capital cost. However, the NPV and GHG impacts are better in Option 2 – Replacing chiller with a water cooled chiller; this alternative will reduce GHG emissions by 393 ton when compared to current operations.

Brimacombe does not have multiple options to choose from. The only feasible alternative is to replace the absorption chiller with a water cooled chiller.

Table 16 Summary of the evaluated options

		Initial Capital Cost	NPV	Tonnes eCO2
MacMillan	Steam Generators	$43,234	-$116,734	0.2
	Electric Boiler	**$34,100**	-$143,581	0.6
	New Autoclaves	$60,989	**-$91,959**	**0.2**
CICSR	Hot Water	**$100,000**	$(1,095,978)	652
	Electric Chiller	$431,750	$(795,762)	7
	Heat Recovery Chiller	$462,000	**$(391,205)**	**(362)**
FSC	Hot Water	**$100,000**	$(1,158,447)	506
	Electric Chiller	$580,250	**$(863,646)**	**5**
Brimacombe	Hot Water	N/A	N/A	N/A
	Electric Chiller	**$522,500**	**$(632,200)**	**1**

6 Conclusions

The academic exercise done in this project is very useful to screen the different options to address the steam orphanage in different buildings at UBC. Even though the results presented in terms of capital cost, NPV, and GHG impact, there are other factors that may be taken into account. In the case of MacMillan, the three autoclaves that are currently operating in the building are 35+ years old, which means they are way past their useful life. Right now, one of these autoclaves is out of service. In this case, it is advised to consider the option of replacing the autoclaves with new electric autoclaves. The operation of these units is more efficient and the lifespan will be longer. As in for the absorption chillers scenarios, even though the options with the lowest capital cost seems attractive, it is worth looking at the long term scenario. Going for electric chillers saves 60% of operational costs per year, while lowering the GHG impacts by 99%. The simultaneous heating and cooling chiller seems a great candidate for CICSR, a building with large cooling loads all year round due to the large number of computer servers. From a mere environmental perspective, if the following options are implemented: MacMillan – Option 3: New Autoclaves, CICSR –Option 3: Replace Chiller with new Heat Recovery Chiller, FSC – Option2: Replace Existing Chiller with new Electric Chillers, and Brimacombe – Option 2: Replace Existing Chiller with new Electric Chillers. UBC can save 1,360 tonnes of GHG emissions.

7 Recommendations for Future Work

More detailed engineering calculations or measurements must be conducted to refine most of the assumptions that were made for this project. Likewise, capital costs should also be refined;

due to lack of time, installation costs for most of the systems were also based on assumptions. Capital costs were provided by the manufacturers, meaning they should be accurate.

Still, this project is a helpful first step in the assessment of the different alternatives for addressing steam orphanage in these four buildings. It serves as an idea of what paths to follow.

8 References

ASHRAE. (2007). *Interpretation IC 90.1-2004-6 of ASHRAE standard 90.1-2004.*

ASHRAE. (2011). *ASHRAE handbook: HVAC Applications.* Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers.

DOE. (2012). *2011 Buildings Energy Data Book.* D&R International, Ltd. .

Martynenko, V. (N/A). *The influence of aerated concrete products technology on the energy consumption during autoclaving.*

Nexterra. (2012). *Nexterra, UBC and GE Celebrate the Opening of Groundbreaking Renewable Biomass CHP System – A First in North America.* Vancouver, BC.

STERIS. (2010). *Amsco Lab 250 and Amsco Lab 110 Small Sterilizers Data Sheet.*

Tuttnauer. (N/A). *Autoclaves and Accessories for Healthcare Professionals Product Catalog.*

UBC Campus Sustainability Office. (2010). *Case Studies Series / Planning for Climate Action.*

UBC Campus Sustainability Office. (2012). *UBC Annual Operational Sustainability Report | 2011/2012.* Vancouver, BC.