UBC Social, Ecological Economic Development Studies (SEEDS) Student Reports

UBC Steam Plant

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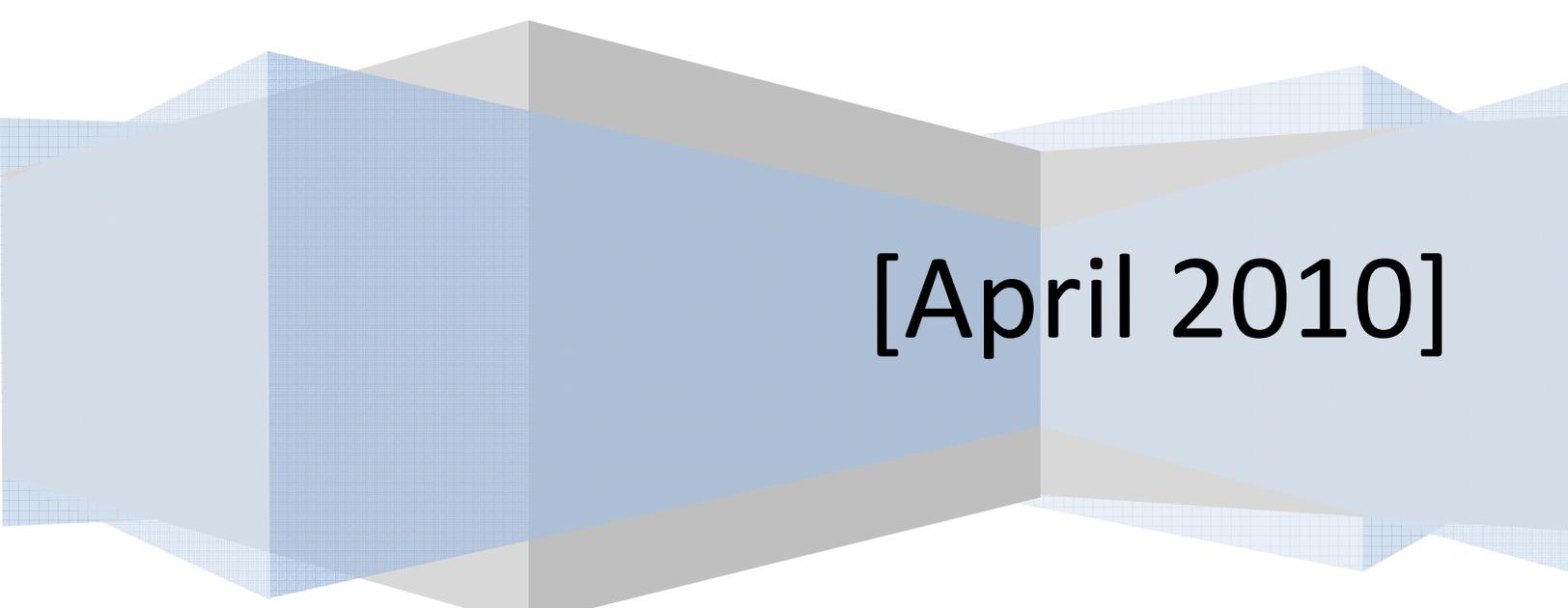University of British Columbia

CHBE 363

April 2010

CHBE 363 SEEDS PROJECT

UBC STEAM PLANT

An initial investigation

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Introduction to Project

The UBC steam plant is a branch of UBC utilities which supplies steam to heat all UBC buildings and domestic hot water. Recently, the steam plant took on a condensate initiative to recover more of the condensed water, returning it back to the steam plant to be sent through the system again. This initiative not only greatly decreased the amount of water used and lost by the campus, but it decreased the energy demand on the steam plant; the water is returned to the plant with residual heat and is thus above the temperature of city water. The steam plant also has an economizer at the bottom of each operational stack which further decreases the energy demand on the system, preheating the water before it is evaporated to form steam.

This SEEDS project is the next step to further improve UBC's steam plant, decreasing its environmental foot print while saving power and money. The initial proposal of this project was to take the heat remaining in the boiler stack flue gas and use it to heat the building directly adjacent to the steam plant (the Leonard S. Klinck building). With a winter natural gas consumption rate of 5 000 GJ/day, the estimated flue gas exhaust rate is 1.4 million m³/day which is primarily composed of nitrogen gas. At the top of the boiler stack, the temperature is consistent at approximately 90°C, which indicates that a total of 610KW of energy is exiting the boiler stack as heat.

To capture this heat, a system similar to the economizer may be implemented, passing a pipe of water through the top of the boiler stack. This heater water would then be pumped over to the mechanical room in LSK at which point, the heat would be recovered through a heat exchanger to heat the building. This proposed solution would be a closed loop system; the water would be pumped in a circuit between the steam plant and LSK.

Upon further research, this initial proposal required some adjusting. First, if the heat from the flue gas is to be extracted, some of the gases will condense into liquid, running down the sides of the boiler stacks. Many greenhouse gases (GHGs) are highly acidic and corrosive when condensed and would damage the inside wall of the stacks. To solve this dilemma, the boiler stacks must be replaced with corrosion resistant material and the condensate must be collected and treated before disposal. Second, the method of heat transfer from the hot water to the LSK system must be considered. Currently, the LSK mechanical room is equipped with a very old shell-and-tube heat exchanger which is much in need of replacement. Third, the LSK building does not require additional heating from the steam plant; the computer servers in the building give off enough heat to comfortable heat the entire space with the current HVAC circulation system.

Given this last challenge, the proposal changed from heating LSK to heating the domestic hot water used in LSK. The health and safety requirements for domestic hot water in a building such as LSK state that the temperature of the water must be between 50 and 60°C to prevent the inhabitancy of Legionella (a water-borne disease). UBC Utilities requires the campus domestic hot water be at a temperature of 60°C. Because of these regulations, it is unlikely that the heat from the flue gases could meet the demand on the LSK hot water system. Therefore, an alternative system will be proposed in this paper: the heat from the UBC steam plant flue gas will be used to pre-heat the domestic hot water for the LSK building by means of a closed loop system heat recovery and transfer system between the two buildings.

UBC SEEDS

UBC Social, Ecological, Economic, Development Studies (SEEDS) is an academic program that gives the opportunity for undergraduate and graduate students with the help of professors to work on projects involving issues on the UBC campus. Originally started in 2000, over five hundred projects by over three thousand participants have been done that have saved the university over two hundred thousand dollars. All the projects researched are located online for future students to continue investigating and hopefully applying.

Projects are placed into eight major categories including air, water, energy, financial, food, human, land, and materials. These categories encompass the possible areas of research into convenient sections for organization. A great part about the program is that any student or faculty can start a SEEDS project whether there is an immediate need or not.

The SEEDS program has three criteria that need to be met. The first is collaboration between faculty, staff, and students at UBC. Indeed, the interdisciplinary nature of the projects requires help from many qualified individuals. The second requirement is that the project must be able to count towards academic credit for students. The SEEDS project is not a standalone course, but rather can be easily implemented to be part of the course assessment. Lastly, the projects need to involve operational sustainability issues at UBC that are applicable and useful.

Although there are no monetary benefits to students, faculty, or staff for their dedicated work, there are many benefits to pursuing a SEEDS project. UBC staff can work with talented students on great research that will develop intellectual resources for future use. UBC faculty can use SEEDS projects to integrate community service learning into their academic courses in order to contribute to campus sustainability. The students at UBC benefit most because they are able to use their knowledge and expertise to work on projects of importance and real applicability for academic credit. Overall, everyone benefits from SEEDS projects.

UBC Utilities

UBC Utilities is responsible for providing electrical, water and gas utilities to UBC at cost. Any profits that UBC Utilities earns from selling excess energy to non-university tenants (at market price) are reinvested into the utilities operations. The operation is staffed twenty four hours a day. Our focus for this SEEDS project is the steam plant operation.

Objective

The objective of our project is to use excess flue gas heat from a boiler stack in the UBC Steam Plant building to preheat water going to the nearby Leonard S. Klinck (LSK) building. This system will be closed loop and help supply preheated hot water to the LSK building washrooms and other hot water demands. The proposed project will involve replacing the boiler stacks, adding a closed loop piping system from the steam plant to LSK, installing a head exchanger in LSK, and transferring exhaust gas heat to warm LSK's water supply. An economic evaluation of the project, which includes pipes, pumps, heat exchangers, and other considerations, is included in this report. Figure 1 summarizes the objective with a simple schematic.
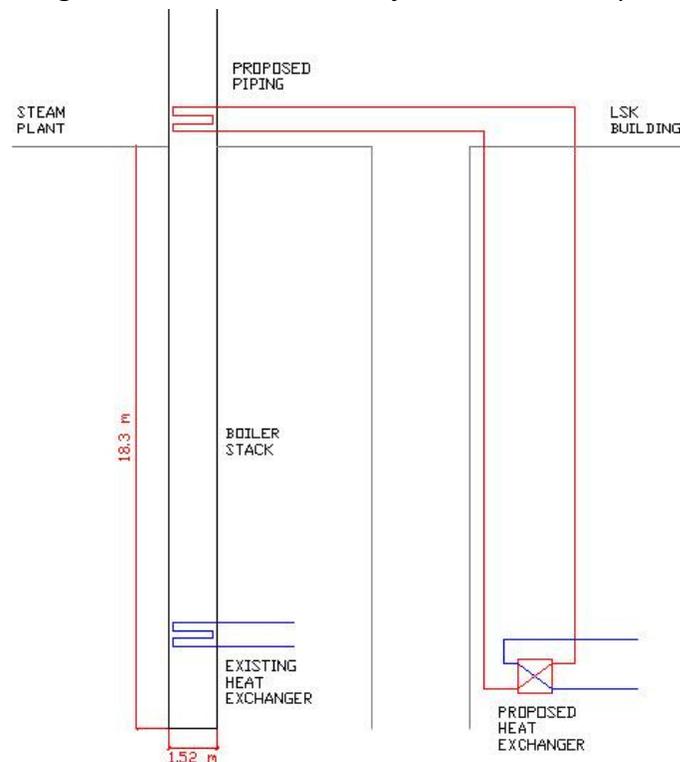

Figure 1: Schematic of the project proposal

Proposed Solution

To address the task of capturing heat from the flue gas, it is proposed to install a piping system inside the top of the boiler stack above the roof line of the steam plant which will act as a shell and tube heat exchanger. The piping system is a closed loop which extends to the Leonard S. Klinck (LSK) building which is adjacent to the steam plant, by routing over the alley and then to the boiler room. A plate heat exchanger is to be installed to replace the existing shell and tube heat exchanger in the boiler room which will capture the heat from the pipe to which it is fed. This heat is to be used for providing energy to the hot water system in the LSK building. Also, as the heat from the flue gas is captured, the flue gas will condense and cause corrosion to boiler stack. Therefore, it is proposed to replace the existing boiler stacks with 316 grade stainless steel.

Heat Availability and Water Flow Rate

In order to make a determination of the economic feasibility of the project and to estimate the project's design requirements, the amount of heat available for extraction from the flue gas must be estimated. The availability of heat depends on the volume, temperature and heat capacity of the flue gas exiting the boiler stack. Two estimates are made: a maximum estimate which is used for designing the system to handle the maximum expected load and calculate the financial benefits, and a more moderate estimate that is provided for information's sake.

Jason Cantas has provided data for the daily natural gas consumption of the steam plant, which is shown in Figure 2 below. The gas demand varies seasonally, with a maximum flow in the winter months of approximately 5000 GJ/day and an average flow over the year of about 3000 GJ/day.
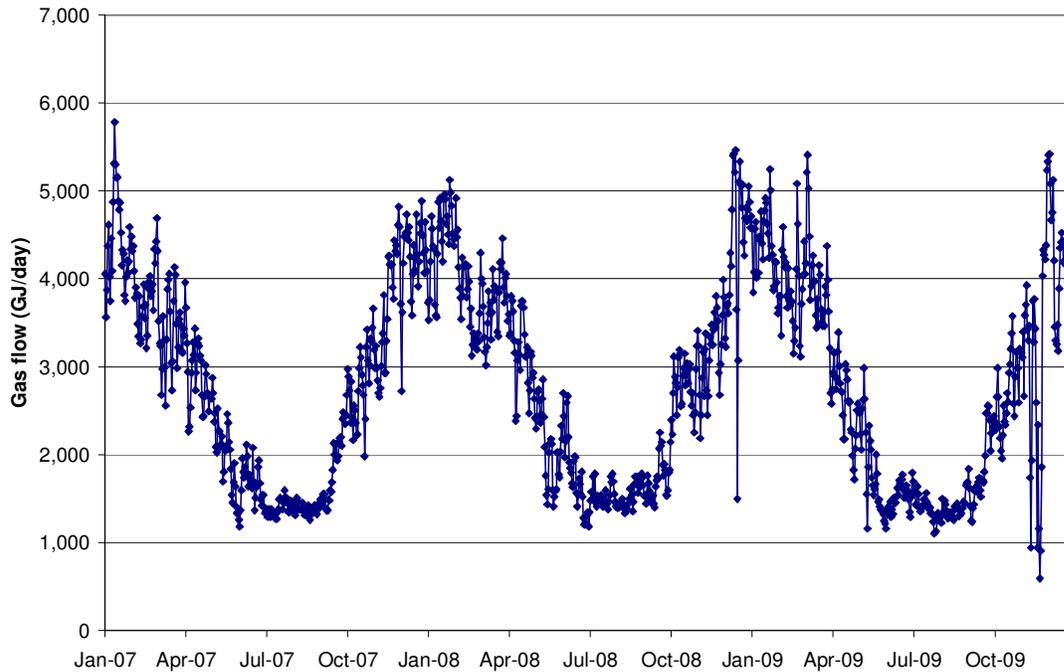
Figure 2: Steam Plant Daily Natural Gas Flow, 2007-2009

An engineering correlation can be applied to estimate the daily volume of flue gas exiting the boiler stacks. The volume of flue gas resulting from the burning of each gigajoule of natural gas is approximately 294.8 Nm^3 (Beychok). The unit Nm^3 (normal cubic metres) refers to the volume of gas at 0°C and 101.325 kPa. Because air is used to combust the natural gas, approximately 80% of the flue gas consists of nitrogen (Beychok). Given the specific volume and specific heat capacity of nitrogen and the estimated temperature of the flue gas at the proposed site of the heat exchange piping of 90°C, the heat content of the flue gas can be estimated.

In addition to the above parameters, the rate of heat extraction also depends on the temperature and flow rate of water used to extract the heat. The maximum rate of heat extraction occurs when the exit temperature of the flue gas is as low as possible. For estimation purposes we can assume that the lowest possible temperature of water in the heat transfer loop entering the stacks is the temperature of cold tap water, approximately 10°C. By adjusting the flow rate of this cold water as it flows through the heat exchange piping in the boiler stack, we could cool the flue gas from its initial value of 90°C to any temperature desired between 10 and 90°C (with lower flue gas exit temperatures resulting in greater heat extraction). For estimation purposes we select 33°C as the lowest possible flue gas exit temperature, which would make the water exit temperature approximately 30°C (assuming the temperatures of the

hot and cold streams exiting the boiler stack differ by 3°C). With these temperatures we can estimate the maximum rate of heat transfer as approximately 610 kW, with a required water flow rate of water of 26 m³/h through the heat exchange piping. This flow rate is used to design the system to handle the maximum foreseeable demand.

A second more moderate estimation of the rate of heat transfer is calculated below. Over an entire year the average natural gas consumption is approximately 3000 GJ/day. We must also consider that the cold water coming from LSK will probably not be as cold as 10°C because this water exits from a heat exchanger on the LSK side. In addition, it may be beneficial to further increase the temperature of the hot water going to LSK while lowering the flow rate, because it may be the case that attaining higher temperatures is of greater importance than maximizing the total flow of heat. Estimating the temperature of the cold water entering the stack as 20°C and the water leaving the stack as 40°C, the average rate of heat transfer is estimated to be 305 kW (half of the maximum). These calculations are summarized in Table 1.

Table 1 : Calculation of Heat Transfer Rate and Water Flow Rate

|	Maximum design load	Average estimation
Natural gas usage per day, both boilers (GJ/day)	5000	3000
Natural gas usage per day per boiler (GJ/day)	2500	1500
Wet exhaust flue gas volume per GJ (Nm³/GJ)	294.8	294.8
Wet exhaust flue gas volume per day (Nm³/day)	737000	442200
Specific volume of nitrogen (Nm³/kg)	0.872	0.872
Wet exhaust flue gas mass per day (kg/day)	845183	507110
Wet exhaust flue gas mass per second (kg/s)	9.782	5.869
Specific heat capacity of nitrogen at 350 K (J/kg·K)	1040	1040
Heat capacity of water at 25 °C (J/kg·K)	4181	4181
Temperature of water incoming from LSK (°C)	10	20
Desired temperature of water sent to LSK (°C)	30	40
Flue gas initial temperature (°C)	93	93
Flue gas exit temperature (°C)	33	43
Heat transfer rate from flue gas (W)	610410	305205
Mass flow rate of water required (kg/s)	7.30	3.65
Volumetric flow rate of water required (m3/h)	26.28	13.14

Pump Selection

The pump that circulates water through the closed loop between LSK and the boiler stack must be selected to match the calculated design parameters. Given the maximum design flow rate of 26 m^3/h and the required head pressure of less than 30 m, the Iwaki MDM 2156 ANSI-certified 5HP Run Dry Mag Drive Pump (BPH Pump & Equipment, Inc.) appears to meet all the design requirements while providing maximum long-term reliability. With an estimated cost of $4700 this pump represents a small fraction of the total project expenses. The low power consumption of 2-3 kW means that the operating costs of the pump are insignificant compared to the potential energy savings of the project.

Pipe Specifications

In order to build a closed loop system between LSK and the Steam Plant, approximately 150 m of pipe is needed. To prevent any corrosion, a stainless steel 316 material will be used. The pipe specification will be according to ASTM (American Standard Test Method) A312. This specification covers seamless and welded stainless steel pipes intended for high temperature and general corrosive service. It is commonly used in pulp and paper mills, refineries, and other industries where high pressure, high temperature and corrosion resistant are very important. The specific pipe that will be used is NPS 10" SCH 10S (Refer to appendix for details). This pipe will be build above ground along the sidewalk for the ease of maintenance. This design will significantly reduce the cost of construction. To minimize the heat loss, insulation will be used to cover the pipe. Styrofoam and cardboard are some materials that relatively inexpensive that can be used for insulation.

Table 2: Summary of piping dimensions

Figure 3: Pipe diagram
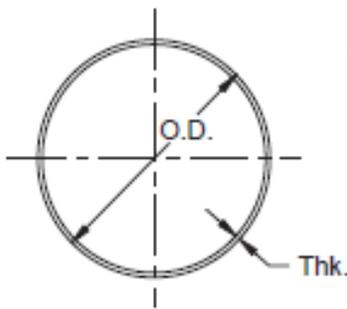
NPS 10" SCH 10S	
Material	Stainless Steel 316
Outside Diameter	273 mm
Burst Pressure	2149 PSI
Thickness	4.2 mm
Weight	28.5 kg/m

Stacks

As part of the solution to the project it is proposed to replace the boiler stacks in the steam plant. There are currently two stacks, which exhaust the flue gases produced from the combustion of natural gas in the boiler to the atmosphere. These stacks are beginning to show signs of corrosion and hence will need to be replaced in the near future. Furthermore, if the proposed heat exchanger design is implemented, greater amounts of condensate will return down the stacks, increasing the rate of corrosion. Therefore it makes financial and practical sense to include stack replacement in this proposal.

The stacks are currently fabricated from 304-grade stainless steel. It is proposed that any new stacks instead be fabricated from 316-grade stainless steel. 316 grade has significantly improved corrosion resistance in comparison to 304 grade hence would be more suitable for this application. However, it is significantly more expensive (material price approximately $5900 US per tonne), although the extra material costs involved would be outweighed by the increased lifespan of the stacks.

Each stack consists of two segments. The top section is of cylindrical shape and therefore can be fabricated from sheet metal with relative ease. However the lower segment, which adjoins the boilers, is of irregular shape and is custom designed for the UBC steam plant. This will therefore result in greater material and labour costs should replacement take place.

From calculations using the known dimensions of the upper segments of the stacks (see appendices), a total of 4.4 tonnes of 316-grade stainless steel will be required. This will lead to material costs of approximately $26,000 dollars excluding labour and any federal/provincial taxes which will be involved. Our estimate for the total cost of replacing the top segment of both stacks is in the region of $60,000.

As previously stated, the specific design of the bottom segments will result in greater expense. We estimate the extra cost to be in the region of $25,000 for both stacks leading to a cost of $85,000 for replacing the lower segment of each stack. This estimate includes both material and non-material costs. Using these estimates, the material and labour costs for replacing both stacks in their entirety will be approximately $145,000 at today's prices.

Stack Dimensions:
      Top Segment: Height = 30'
                                Internal Diameter = 5'
                                Wall Thickness = ¼"
      Bottom Segment: Height = 30'

      316 Stainless Steel: Price per tonne = $5916 (US)
                                      Density = 8000 kg/m^3

Heat Exchanger

Shell and Tube Heat Exchanger:

Shell and Tube heat exchangers are the most common heat exchangers found in industry. They consist of a series of small tubes inside a larger tube. In the larger tube, there is a series of baffles that ensure that the heat to be exchanged is properly contacted with each fluid. This is represented in the figure below:
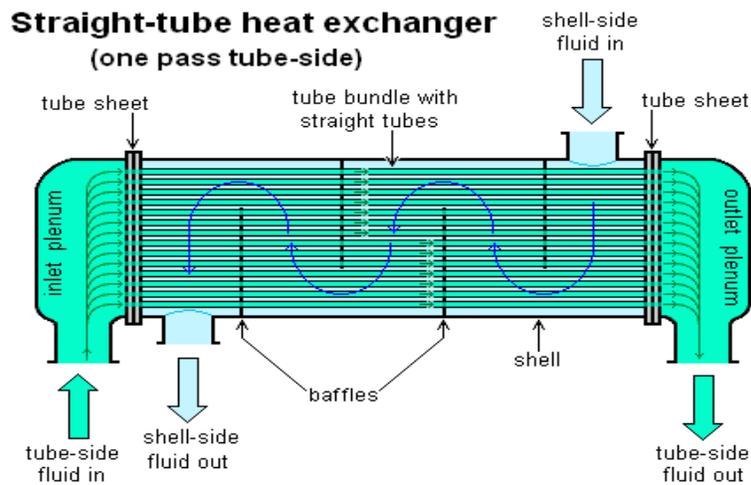

Figure 4 : Shell and Tube Heat Exchanger

These heat exchangers can be run in four different configurations to contact the fluid, co-current, counter-current, double up and double down. The counter-current configuration is the most common set up used. These heat exchangers are fairly efficient. Their efficiency increases as the flow rate of the hot fluid increases. These models are also very cost effective. The drawback to these heat exchangers is that they can be quite large for an industrial process as it is hard to find space for a large tube or length of piping.

The shell and tube heat exchanger is the model used currently in LSK. These are used for the hot water system in the building. Steam is run from the steam plant and sent to two heat exchangers and contacted with the cold tap water. This use of the heat exchangers is inefficient as it is better to contact a fluid to be heated with hot water instead of steam. These heat exchangers are also old and the insulation is falling apart. We propose to replace these heat exchangers with a plate heat exchanger.

Plate Heat Exchangers:

Plate heat exchangers are very compact. These exchangers are a lot more efficient than shell and tube heat exchangers because they have a larger surface area to contact the two fluids. Like the name suggests, they exchange the heat by using a series of plates shown in Figure 6 below:
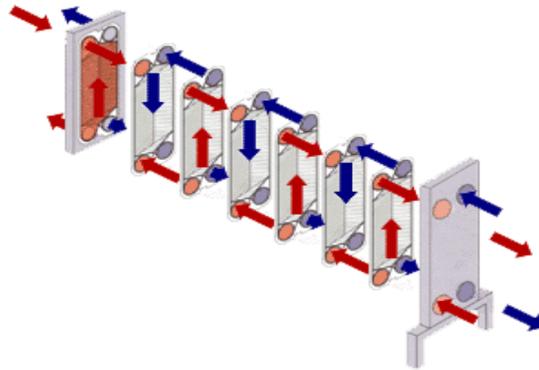

Figure 5: Plate Heat Exchanger

These heat exchangers have many advantages. They are much more compact than shell and tube heat exchangers and because the plates are all fastened together in series, it is easier to take the heat exchanger apart for maintenance. Finally, there is less cross contamination between the two contact fluids. There have been some reports of this type of heat exchanger leaking, but to account for that our group has selected a rubber gasketed plate heat exchanger.

Brazed Plate Heat Exchanger

According to the calculated flow rate of the flue gas condensate, it was determined that the best heat exchanger for this design was a brazed plate heat exchanger with the following design specs: SEC Heat Exchangers Model: M100-100

Height: 30.71"
Width:12.36"
Number of plates: 100
316L stainless
EPDM rubber gaskets
Weight: 223.52 lb
Price: $5,934 (U.S.)

This heat exchanger operates with the following conditions:

Max temperature: 170°C
Max pressure: 21 bar
Max flow rate: 40 m³/h
Cold stream
    Inlet: 10°C
    Outlet: 30°C
Hot stream
    Inlet: 33°C

These specifications are well within the calculated values of the flows and temperatures determined. Below is a schematic of the Brazed plate heat exchanger:
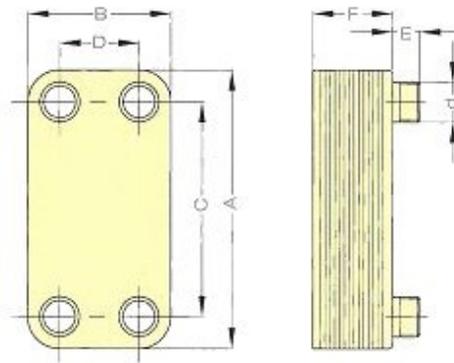

Figure 6: Brazed Plate Heat Exchanger

Impacts

The financial, environmental, and social implications of the recommended improvements to the UBC steam plant are considered in this section. All are determined to be net positive, with further investigations into the exact environmental impacts suggested.

Financials

Costs

The costs for refitting the UBC steam plant are for materials, installation, and general project expenses, as summarized in the below table.

Table 3 – Costs by Item

Item	Cost
Heat Exchanger	$6,000
Pump	$4,700
Piping	$18,000
Piping Insulation	$5,000
Top Stacks Material Costs	$26,000
Top Stacks Installation Costs	$35,000
Bottom Stacks Material + Installation Costs	$85,000
Heat Exchanger, Pump, and Piping Installation Costs	$40,000
Additional Construction and Project Costs	$50,000
Subtotal	$269,700
Project Buffer (5%)	$13,485
Taxes (13%)	$35,061
Total	**$318,246**

The unit costs are sourced from the suppliers of the chosen items or are based on calculated cost of materials for the given dimensions. The cost for the stacks installations was estimated by Jason Cantas, UBC Utilities Chief Engineer. The installation costs for the heat exchanger, pump, and pipes are estimated by assuming that the ratio of materials:installation costs for these units is the same as that of the stacks. The additional construction and project costs are miscellaneous costs associated with obtaining approval for the project and the construction between the steam plant and LSK associated with the piping. A 5% project buffer is built into the budget, as is 13% tax (as whether or not this could be classified as one of UBC's PST-exempt projects is unclear).

Thus, the total cost for this project is estimated at approximately $320k. The pie chart (Figure 1) to the right shows the breakdown of costs per item, lumping material and installation costs together. It can be seen that replacing the stacks comprises the most significant portion of project costs.

Figure 7 – Costs by Percentage
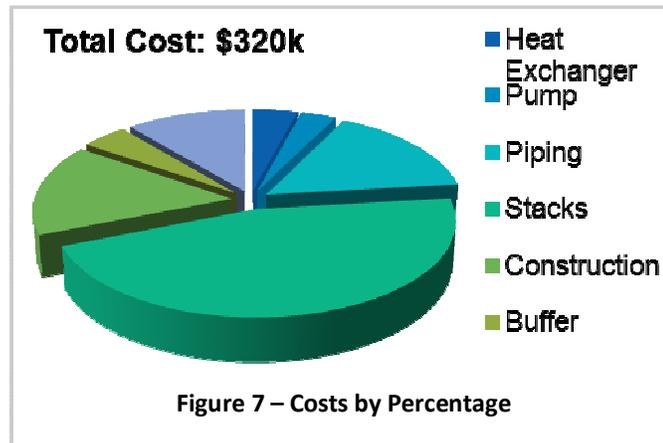
It is important to note that these cost estimates are based on the design point that it is possible and best to run the piping from the steam plant to LSK outside and above ground. Should it be found that this is not in fact the best option, the costs of this project would change significantly. The $5000 associated with additional pipe insulation would disappear, and an estimated $375k in additional construction costs would be incurred. This extra construction cost is based on a midpoint of the $1000-$5000/m cost for excavation on campus that was cited from an alternative energy campus study conducted at UBC by Stantec and quoted by Ron Loewen, Applied Science Capital Projects Manager. The length of 150 m for excavation was taken from the estimates for pipes. 150 m of pipe at $2500/m gives $375k.

Benefits

For the purpose of our analysis, the benefits to UBC Utilities are specified in terms of revenue that UBC Utilities could gain by selling the extra energy our system would produce. In other words, our system recaptures energy that would otherwise be lost in the exhaust and provides it to LSK in the form of heat for their water system. Thus, the steam plant would no longer have to supply LSK with energy for heating their water system, freeing up that previously allocated energy to be sold to the tenants and other non-UBC groups on campus at a profit.

Table 4 - Benefits Summary

Benefits	
Maximum Available Heat	610 kW
Energy Saved (75% System Efficiency)	458 kW
Market Value of **Energy Saved** (based on BC Hydro Residential Energy Prices)	**$261K/year**
Time to Recoup Capital Investment	*1.2 years*

As the above table summarizes, the financial benefits to implementing the proposed UBC Steam Plant upgrades are significant. The maximum available heat is given as 610 kW (see Introduction to Problem). Assuming a 75% system efficiency of actually translating that heat to usable energy at LSK, that results in 458 kW of energy that UBC Utilities could sell. UBC Utilities sells energy at cost to UBC, but it is noted on their website that they also sell at market cost to tenants and other non-UBC occupants of the University Endowment Lands (UEL). This analysis

assumes that all 458 kW of energy could be sold, which is justified based on the fact that it is also noted on the UBC Utilities website that BC Hydro offers electricity to some of the new south campus developments. Using a lower bound of the BC Hydro residential electricity rates (6.5¢/kWh), this would result in $261k/year of additional revenue for UBC Utilities.

Cost-Benefit Analysis

At total project costs of $320k and benefits of $261k/year, the payback period for the UBC Steam Plant upgrades would be only 1.2 years. Even using the more conservative cost estimates (including underground pipes), the payback period is still a reasonable 2.7 years.

Table 5 - Financial Comparison to UBC ecotrek

	UBC ecotrek	Our Proposal
Capital Costs	$35 000 000	$320 000
Annual Value of Energy Savings	$2 600 000	$261 000
Annual GHG Emission Reductions	15 000 tonnes CO2	unknown
Payback Period	13.5 years	1.2 years

UBC ecotrek, completed in 2006, was a $35M, three year project to retrofit over 300 buildings across campus to make them more energy efficient and reduce their greenhouse gas emissions. As the above table shows, the proposed UBC steam plant renovations compare well. The costs of $320k are 100x less than UBC's ecotrek project, and although the annual value of energy saving is 10x less, the payback period for the steam plant retrofits is only 1.2 years as compared to ecotrek's 13.5 year payback period. The environmental implications of the ecotrek project are known: 15 000 tonnes of CO2 less a year is produced as a result of ecotrek. The environmental implications of our proposal are not known, and should be assessed (see below Environmental Impacts section).

Overall, the proposed UBC steam plant retrofits present significant costs of $320k, but the benefits of $261k/year in revenue indicate a payback period of 1.2 years, which is extremely favourable when compared to the UBC's similar ecotrek project. The financial analysis demonstrates that the proposed renovations are financially viable and desirable.

Environmental

The environmental impacts of the UBC steam plant refit are not known quantitatively; however, by recapturing heat that would otherwise exit the system UBC steam plant will need to burn less gas in order to achieve the same output of energy. This will reduce greenhouse gas emissions and contribute to UBC reaching its target of reducing greenhouse gasses an additional 33 per cent from 2007 levels by 2015, reducing to 67 per cent below 2007 levels by 2020, and completely eliminating 100 per cent of GHGs by 2050.

No negative environmental impacts from the refit of the UBC steam plant are expected. Nonetheless, it is recommended that a full environmental assessment of the impacts of the proposed refits be carried out in a further extension to this project so that the GHG reductions can be quantified and any detrimental environmental effects are identified prior to the project's implementation.

Social

With the projected construction of UBC's innovative new biomass-fuelled combined heat and power generator; the growth of supported sustainability programs such as SEEDs, the Sustainability Ambassadors, and the UBC Sustainability Office; and the consistent identification of sustainability as a key pillar and strategic target of the university, UBC has become a world leader in institutionalizing sustainability. The push from all levels—student, staff, and faculty—for increased awareness and responsibility for all impacts and the long-term sustainability of activities, has created a social dynamic on campus of social activism. The proposed UBC Steam Plant refit is an example of this dynamic: it is a fundamental university operation that is being voluntarily reviewed by students with the support of staff from the SEEDs program as part of an academic program. The implications of this project would be further reinforcing the message that students' input is valuable, that students can improve the campus, and that we as an entire community value sustainability.

Recommendations for UBC Steam Plant and Future Groups

For the UBC Steam Plant, it is highly recommended that this heat recovery system be implemented. Energy conservation is a significant issue, and it is important for a leading university such as UBC to take the initiative. Although the heat recovered may not be enough to produce hot water to standard temperature, pre-heating water with waste heat will still save significant money and resources for UBC.

It is also recommended that UBC consider external piping system for the ease of maintenance. In addition, if UBC decides to expand this system to supply heat for other buildings, external systems will be much easier to modify than underground systems.

Further investigation should also be carried out by UBC or future CHBE groups into the quantitative environmental impacts of the proposed refit, especially in terms of GHG reductions. Determining the feasibility of the proposed above ground external pipe system is imperative. Assessing the demand for energy by tenants, the water usage and demand of LSK, and projecting the University Endowment Land's future demands would also be strongly recommended next steps before implementing the proposed changes to the UBC Steam Plant.

For future CHBE 363 groups, it is essential to expand on our current proposal and explore how it would be best to incorporate this design into the water heating systems of LSK and other neighbouring buildings. With both the waste heat supply and hot water demand varying heavily at different times of the year, it is important for the system to be able to supply heat to a different building once LSK's demand has been met. This will require the addition of more pipes, more valves and various feedback and feed-forward controllers. If a relatively cheap system can be designed, it will further increase the energy efficiency of the UBC Steam Plant, and save even more money and electricity. It is also recommended that a better estimate for the heat exchanger system efficiency within LSK be determined so that more precise financial projections could be carried out. This will definitely be a great group project for CHBE students in the future.

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