February 26, 2020

Bradford A. Bruno
Manager
Juno Enterprises
Juneau, AK, 99801

Dear Mr. Bruno,

Attached is a report summarizing the sizing and analysis of a heat exchanger for use in the Juno Enterprises factory in Juneau, AK. The heat recovery system design reduces factory expenses by heating the outside air with available heated ethylene glycol before entrance to the factory. Over a functional lifetime of 20 years and with 8% interest rate, it reduces factory heating expenses by \$236,000. This comprises the capital costs of installation and the pump, and the annual costs including powering the pump and the increased power needed for the ventilation fans.

The recommended recovery exchanger system is detailed in the following report, and contains information on piping the ethylene glycol to the T-Mag TM6L-123 pump and through the neat exchanger. The finned coil heat exchanger unit is sized to fit within the $1 \times 1 \times 3$ m^3 vent, and contains a system of pipes 24 tubes high by 22 tubes deep with each 1m long, with 364 fins spaced parallel to the airflow into the factory. The ethylene glycol heats the incoming 5 °C air to the desired interior temperature of 24 °C. The proposed system does not require factory renovation, and can be installed as soon as it is shipped and produced.

Any questions, or comments can be directed to the team leader, landretr@union.edu. Please review the attached documentation for specifics concerning the system heat transfer, fluid dynamics, economics, or environmental concerns.

Sincerely,

Roderick Landreth – Project Manager
Advanced Systems, Thermotopia Inc.

Adam Perterlein – Economist
Sam Veith – Heat Transfer Analyst
Jack Edson – Optimization Specialist

Project Summary

The proposed design comprises a pipe carrying 30 °C ethylene glycol 25.3 m (25m horizontally and 4m vertically) through a pipe, into a heat exchanger unit, and then returns through a similar pipe to the vat. The whole system saves \$255,000 over its 20 year lifespan including 8% interest rate and 25% tax, total savings being \$236,000 after the \$15,000 capital costs. The pump is T-Mag TM6L-123, providing 0.99 kW to pump the ethylene glycol through a heat exchanger warming the cold air to 24 °C upon entrance to the factory, the same as the desired temperature within the factory.

The heat exchanger is comprised of tubes stacked 24 high and 22 deep down the length of the 3 m vent with a 1 m^2 square cross-section, each tube 1 m long. The fins parallel to air flow are spaced 364 per meter, with the fan exerting 3.7 kW excess to compensate for the pressure drop the heat exchanger causes in the vent. The pipes contain ethylene glycol moving at a rate of 5.62 kg/s, and are spaced every 41 mm, being 16 mm in diameter with 1 mm thick walls. The electrical efficiency of the pump and fan is 60% and 75%, respectively.

The \$15,000 capital cost includes the \$4000 pump, heat exchanger installation and heat exchanger-pipe interface. Annuities include the price of power for the pump and the increased power draw of the vent fan. The heat recovery system is in the MACRS depreciation class of 20 years. The objective function for the heat exchanger optimization included exhaustively maximizing the present worth savings. The free variables include the mass flow rate of ethylene glycol, length of the pipes, number of tube rows, number of tubes deep, and the spacing of the fins parallel to the flow of the air.

Following this is an in-depth view of the system specifics, including the heat transfer method of analysis, the used approach for optimization, and economics analyses. Additionally, environmental and health considerations are included.

Contents

1 Background and Introduction

As energy prices rise, it becomes more and more advantageous to search for more efficient methods of satisfying common energy needs. The frequent target of these energy saving endeavors is the heating of buildings. It becomes more attractive, as heating prices rise, to attempt to repurpose so-called "low-grade" energy sources, such as waste heat from industrial processes, for the heating needs of the building in which that industrial process is housed. The low-grade energy source considered herein is ethylene glycol which has been heated by an industrial process to 30 °C. Through a heat exchanger placed into an existing duct system, a transportation system composed of about 50.6 m of pipe, and a pump to move the ethylene glycol, this heat is moved into the air of the factory where it will offset the heating costs of the facility.

Air must be continuously pumped into any enclosed building to avoid sick building syndrome, in which the buildup of contaminants within the air cause negative health impacts. This air is pumped in at the ambient outdoor temperature, and therefore must be heated to an appropriate indoor temperature. The average outdoor ambient temperature in Alaska is 5 °C and the air must be delivered at 24 °C.

This waste heat is recovered within a designed heat exchanger. The heat exchanger moves thermal energy from a high temperature fluid, in this case ethylene glycol, to a low temperature fluid, in this case the intake air. The proposed heat exchanger design is based on a fin and tube construction where the ethlyene glycol flows through tubes surrounded by fins over which the air passes. The designed heat exchanger should have minimal head loss within both the tubes and fins to decrease the required pump work, but have enough surface area to transfer the required heat from the ethylene glycol to the air.

The increase in taxable income due to lowered heating cost is slightly offset by the depreciation of the capital costs over the twenty year lifetime of the proposed system. The effective tax rate, before depreciation is taken into account, is assumed to be 25%. The total tax burden increase is $78,000 present worth over twenty years, including a present worth $1,900 deduction based upon depreciation. The present worth of all costs and savings is based upon an interest rate of 8% and no inflation.

2 Problem Definition

The heat recovery system must offset the electricity spent warming the 5 °C cold Alaskan air to room temperature, 24 °C, as efficiently and safely as possible. The main goal is to design a finned coil heat exchanger unit and the piping system that produces the highest present worth savings. This report functions to recommend a heat recovery system that recycles heat in ethylene glycol used to cool machinery in the factory. The inflow of cold air is through ventilation ducts of dimensions 1x1x3 m^3, and is 25 meters horizontally and 4 meters above a vat of 30 °C ethylene glycol that can be used to preheat the air. A design of piping is also necessary to convey the working fluid between the vat to the heat exchanger.

The heat exchanger system's present value cost compared to that of heating the air with electrical heaters corresponds to overall heat savings, and is a function of the mass flow rate of the ethylene glycol, number of rows and layers of pipes carrying ethylene glycol, the spacing of the fins parallel to the flow, and the length of each tube down the width of the vent. This can be optimized exhaustively within the system limitations, using the overall heat transfer coefficient method to determine the total present worth of savings. The system limitations prevent the length of a tube from being longer than the vent, 1 m, have enough layers to be taller than the vent, 1 m, and having enough rows of tubes in the direction of flow to surpass the length of the vent, 3 m. The total savings also can not exceed the total possible taxable price of heating the air without the heat recovery system, $263,000.

Major costs include purchasing the pump to transfer the liquid to the heat exchanger, powering the pump, installing the heat exchanger and accessories, and the increase in power to the vent fans pushing the air through the heat exchanger. The main cost overall is that of electricity, specifically the power increase of the fan. The system has a lifespan of 20 years and is evaluated for total present value cost with an interest rate of 8% and a tax rate of 25%, falling into the 20 year depreciation class in the MACRS governmental depreciation standard.

Following this description of the required system is the proposed solution and system specifications.

Quantity	Value
Delivery temperature	24 °C
Inlet temperature	5 °C
Glycol temperature	30 °C
Flow rate of air	3 m^3/s
Maximum heat exchanger volume	$1 \times 1 \times 3$ m^3
Annual operation time	5520 hours
Interest rate	8%
Tax rate	25%
Lifetime of system	20 years
Electricity costs	9 cents/kW hr

Table 1: A table of the design constraints for the design task.

3 Design Description

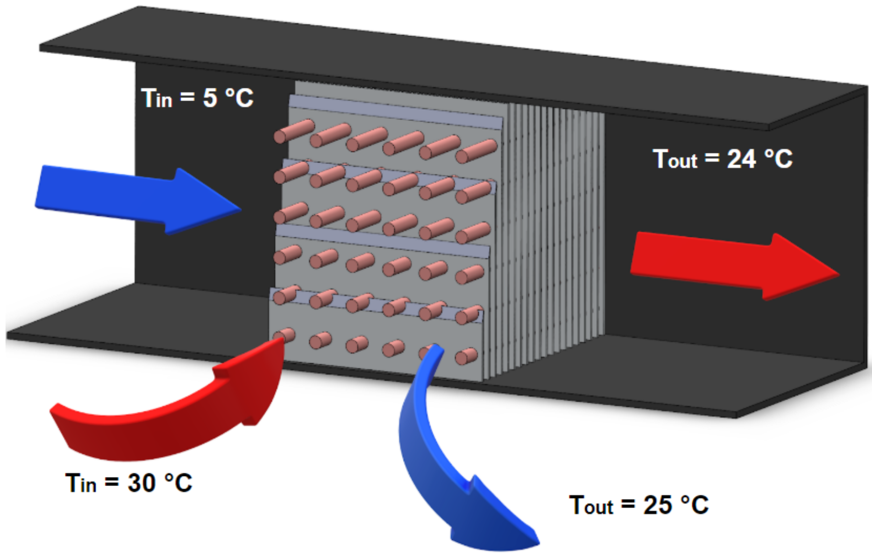

Figure 1: An illustration of a heat exchanger similar to the one designed for this proposal showing both the airside and glycol-side flows and temperatures.

Ethylene glycol is pumped from a storage vat to the air intake vent to heat the air. The ethylene glycol is available at 30 °C and heats the 5 °C air to 24 °C. A 1.5 kW T-Mag TM6L-123 pump moves the ethylene glycol at 81 gallons per minute across the 25.3 meter distance to the air intake. The pump has an attached motor, contributing to an efficiency of 60% and has a capability to deliver 13 meters of head as shown in the pump curve in figure 3. The copper delivery pipe is 25.3 meters long with an inner diameter of 3 inches. The inlet piping opens into a header coupler that

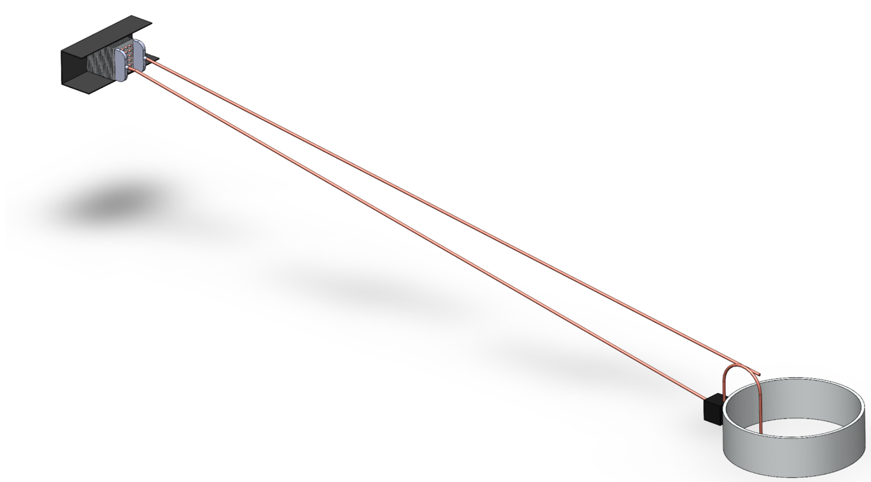

Figure 2: The piping diagram of the proposed system. The ethlyene glycol is transported from the reservoir to the heat exchanger and then back to the reservoir.

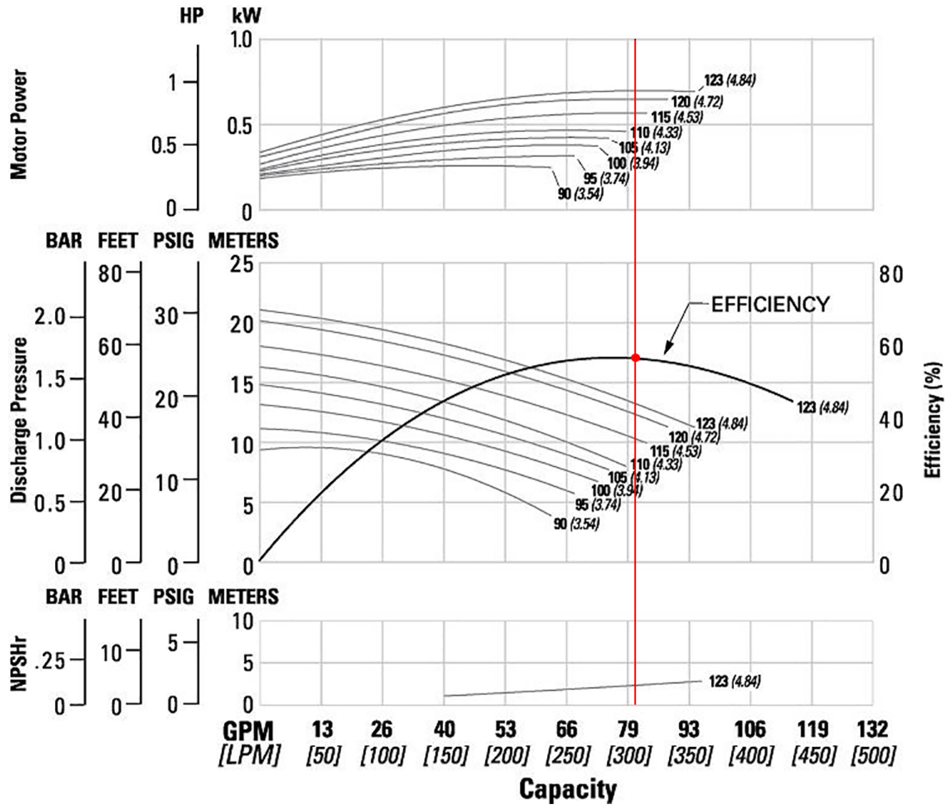

Figure 3: The pump curves for the line of pumps of which the selected pump is a member. The $NPSH$ is shown at the bottom, the efficiency and provided head is shown in the center, and the motor power required is shown at the top. The flow rate of the proposed system (81 GPM) is shown with a vertical red line. The red dot along the flow rate line represents the operating point.

connects to the heat exchanger. A piping diagram is shown in figure 1. A pipe of the same length returns the ethlyene glycol to the vat. The total head of the system is 6.5 meters.

The custom-designed heat exchanger is a finned coil, single pass, cross flow heat exchanger. This heat exchanger runs the air and ethylene glycol in perpendicular directions as seen in figure 2. The ethylene glycol is diverted into 24 pipes that are 1.0 meters long and stretch across the entire 1 meter length of the air duct. The heat exchanger is 24 tubes high and 22 rows deep. The pipes are spaced 41 mm on center from each other and have an inside diameter of 15 mm. There are 364 fins per meter to increase heat transfer area and make the air flow unmixed.

The air flows through the heat exchanger at 3 meters^3 per second and heats from 5 °C to 24 °C. This system is designed to operate 5,520 hours per year with an average ambient temperature of 5 °C. The output temperature is equal to the 24 °C output temperature to the building; therefore, the heat exchanger can operate without the electric heater for weather as low as 5 °C. The fan supplying the air will need to increase it's power by 3.7 kW to supply the required air supply. This will save an average of $11,800 dollars in heating costs annually. A tabulation of the design parameters and outputs are shown in table 2.

Quantity	Value
Pipe length	1.00 m
Number of layers (N_R)	24
Number of rows (N_W)	22
Fin density (N_F)	364 fins/m
$\dot{m}_g$	5.62 kg/s
Pump work	0.99 kW
Fan work	3.68 kW
Delivered temperature	24.0 °C
Capital costs	\$15,000
Total savings before taxes	\$314,000

Table 2: A table of the design variables and outputs used for the proposed design, including the five optimized variables.

4 Analysis

The system analysis is focused across four categories: Heat Transfer, Optimization, Economics, and Environmental and Regulations. These categories walk through the steps taken to achieve the proposed design.

4.1 Heat Transfer

The goal of the heat transfer analysis is to model the quantity of heat transferred across the heat exchanger and calculate the electricity required to power this heat exchanger. The process of transferring heat from the ethylene glycol to the air will decrease the current required electricity to heat the facility. The NTU-Effectiveness method (1) models the and quantifies the heat transfer. This is the current best method for approximating performance of a heat transfer unit. This analysis assumes a steady state / steady flow condition and that the material properties are constant. These material properties are most concerned with the specific heats of air and ethylene gylcol and the overall heat transfer coefficient. The heat provided by the ethylene glycol, Q_{actual}, is calculated with

$$Q_{actual} = \epsilon C_{min}(T_{eg} - T_{amb}) \tag{1}$$

where *epsilon* is the non-dimensional effectiveness of the heat exchanger, C_{min} is the maximum fluid heat capacity rate, T_{eg} is the temperature of the ethylene glycol, and T_{amb} is the ambient temperature outside the plant. T_{eg} is a given value of 30 °C for the vat and it is assumed to be a constant temperature even though the heat exchanger discharges colder ethylene glycol back into the vat. This appears to be a nefarious assumption, and is regarded as one of two major plot holes for the given project. The second plot hole assumes that the cooling vat does not release any energy into the building. This assumption is explored in greater depth in the design considerations (REF?). The effectiveness of the system is dependent on the type of system in use. For a single pass, cross flow exchanger with both fluids unmixed, ϵ is defined as

$$\epsilon = 1 - e^{\frac{1}{Cr}\ NTU^{0.22}(e^{-Cr\ NTU^{0.78}} - 1)} \tag{2}$$

where NTU is the dimensionless number of transfer units and C_r is the ratio of C_{min} over C_{max}. It is assumed that a single pass, cross flow exchanger with both fluids unmixed is the best solution, and is optimized for this proposal. C_i is the product of the mass flow rate of one fluid and the specific heat capacity at constant pressure. C_i is calculated for both working fluids and the lesser and greater quantities are assigned to C_{min} and C_{max}, respectively. This correlation is taken from Introduction from Heat Transfer [1]. NTU is defined as

$$NTU = \frac{U\ Ae}{Cmin} \tag{3}$$

where U is the overall heat transfer coefficient [W/m^{2}K] and Ae is the area exposed by the exchanger to the air [m^2]. The equations for both U and Ae are both provided by Thermotopia, Inc., and are based on empirical results from previous designs. The overall heat transfer rate is given as

$$\frac{1}{U} = \frac{0.023}{V_{air}^{0.5}} + \frac{0.0088N_f + 0.25}{430V_{eg}^{0.8}} + 0.0039 \tag{4}$$

where V_{air} is the mean velocity of the air in the duct [m/s], N_f is the spacing of the fins [fins/m], and V_{eg} is the velocity of the ethylene glycol in one tube [m/s]. The properties to calculate the velocities are tabulated in Appendix A. It is assumed that all fouling factors are accounted for in this equation, as ethylene glycol can render heat exchangers less effective over time.

The area of the heat exchanger exposed to air incorporates the basic geometry of the exchanger. These parameters include the length of the pipes, the number of layers, and the number of tubes deep the exchanger is. These are multiplied by an in-house factor which accounts for fin geometry. The equation is as follows

$$Ae = N_w \ N_r \ L \ (0.0502 + 673 \times 10^{-6} N_f) \tag{5}$$

where N_w is the number of rows wide in the direction of airflow, N_r is the number of tubes high, and L is the length of the pipes across the duct [m]. These equations govern the heat transfer through the heat exchanger.

The required power for the ethylene glycol pump is found by solving for head loss. Head loss occurs in both the heat exchanger and the intermediate pipes between the heat exchanger. It is assumed that the ethylene glycol is incompressible. The pressure drop in the heat exchanger is found from a Thermotopia equation

$$pdHX = 5200[0.15N_wL + 0.0875(N_w - 1) + 0.3]V_{eg}^{1.85} \tag{6}$$

where $pdHX$ is the pressure drop across the heat exchanger [Pa]. This number is then converted to meters of head and added to the head loss of the two intermediary pipes

$$HL_{pipe} = 2(K_L + f\frac{L_{pipe}}{D_{pipe}})\frac{V_{pipe}^2}{2g} \tag{7}$$

where V_{pipe} is the velocity of the ethylene glycol in the intermediary pipe [m/s], g is the constant of gravity [m/s^2], f is the friction factor dependant on laminar or turbulent regimes, L_{pipe} is 25.3 m of pipe length, and D_{pipe} is 3 inches of pipe diameter. The entire head loss is doubled because of the return pipe. The friction factor was determined by numerically solving the Colebrook equation for a smooth pipe and solving it as a function of Reynolds Number. The diameter of the pipe was given as 3 inches and can be changed if desired. The pipe travels at a 10 degree angle across the factory floor yielding a total length of 25.3 meters. It was understood that this routing would not create an obstacle and that no heat loss would occur in the pipe. Equations 6 and 7 are added together and converted to kilowatts. They are then divided by the pump efficiency to yield the required pump power for the system.

The additional fan power is calculated by another equation provided by Thermotopia. The head loss due to the addition of the heat exchanger is calculated as

$$pdFan = 4.1 N_w V_{air}^{1.95}(0.25 + 0.0025 Nf) \tag{8}$$

where $pdFan$ is the head loss of the fan. Like the pump, it is converted into kilowatts and divided by efficiency to obtain the additional work required to move the the air through the heat exchanger. It is assumed that the current fan can handle the increased load and that Equation 8 accounts for the compressibility of air. This entire analysis depends on the accuracy of the Thermotopia equations. These equations may over or under predict the actual scenario. It is recommended that Thermotopia tune the product after installation to gaurantee optimal performance and consumer satisfaction.

4.2 Optimization

Variable	Minimum	Step Size	Maximum
Length of Pipe (m)	0.4	0.1	1
Number of Tube Layers	1	1	24
Number of Tubes Wide	2	2	72
Fins Per Meter	0	10	1250
Mass Flow Rate of Ethylene Glycol (kg/s)	0.2	0.2	10

Table 3: The five optimization parameters that span the design space considered. The upper and lower bounds are based upon the constraints of the system.

The final system design was found by using an exhaustive search approach that found the maximum savings output based on the manipulation of the 5 input variables (mass flow rate of ethylene glycol, number of rows and columns of pipes carrying ethylene glycol, the spacing of the fins parallel to the flow, and the length of each tube down the width of the vent). The range for the input variables was determined by determining the minimum and maximum possible values, which were either given in the problem statement or calculated based on constraints, and are shown in table 3. The step size for each variable was determined based on constraints of each variable, such as needing an integer amount of tube layers and a multiple of 2 for the amount of tubes in the flow direction, or in order to have an acceptable calculation time. Once an initial optimized solution was found, the bounds for each variable were focused to the first solution value and the step sizes were reduced to create a more refined search. This was repeated multiple times until the output results converged across multiple iterations. In total, roughly 775 million heat exchanger combinations were analyzed.

4.3 Economics

The cost savings of the proposed system are two-fold. Firstly, currently 71.7 kWh of electricity is used to heat the facility; with the proposed system this will be reduced to 4.8 kWh. This saves \$314,000 over the twenty year lifetime of the system before taxes. The capital costs of the system will depreciate over their lifetime. Based on a twenty year asset lifetime and MACRS-style depreciation, this translates into a total tax savings of \$1,900. The MACRS table for a 20 year asset class is shown in table 4 along with the P/F conversion factor based upon an assumed 8% interest rate to the present value tax savings based upon an assumed 25% effective tax rate. This gives a savings after taxes of \$236,000.

Year	**Rate**	**Amount Deducted**	**Amount Saved**	P/F	**Present Value**
1	3.750%	\$562.50	\$140.63	0.9259	\$130.21
2	7.219%	\$1,082.85	\$270.71	0.8573	\$232.09
3	6.677%	\$1,001.55	\$250.39	0.7938	\$198.77
4	6.177%	\$926.55	\$231.64	0.7350	\$170.26
5	5.713%	\$856.95	\$214.24	0.6806	\$145.81
6	5.285%	\$792.75	\$198.19	0.6302	\$124.89
7	4.888%	\$733.20	\$183.30	0.5835	\$106.95
8	4.522%	\$678.30	\$169.58	0.5403	\$91.62
9	4.462%	\$669.30	\$167.33	0.5002	\$83.70
10	4.461%	\$669.15	\$167.29	0.4632	\$77.49
11	4.462%	\$669.30	\$167.33	0.4289	\$71.76
12	4.461%	\$669.15	\$167.29	0.3971	\$66.43
13	4.462%	\$669.30	\$167.33	0.3677	\$61.53
14	4.461%	\$669.15	\$167.29	0.3405	\$56.95
15	4.462%	\$669.30	\$167.33	0.3152	\$52.75
16	4.461%	\$669.15	\$167.29	0.2919	\$48.83
17	4.462%	\$669.30	\$167.33	0.2703	\$45.22
18	4.461%	\$669.15	\$167.29	0.2502	\$41.86
19	4.462%	\$669.30	\$167.33	0.2317	\$38.77
20	4.461%	\$669.15	\$167.29	0.2145	\$35.89
21	2.231%	\$334.65	\$83.66	0.1987	\$16.62
			Total Present Worth Savings		**\$1,898.41**

Table 4: The MARCS depreciation table and present value of total tax savings based upon a tax rate of 25%, an interest rate of 8%, and a capital cost of \$15,000.

5 Evaluation of Design and Other Constraints

5.1 Health

Ethylene glycol is odorless, clear, and rated as fairly dangerous to human health. It is dangerous not in immediate physical damage but, with repeat exposure, causes organ damage. Short term exposure can cause drowsiness or dizziness in inhalation, and being harmful if swallowed. The ThemoFisher SDS [2] rates ethylene glycol as a 2 for health risk, 1 in flammability, and 1 in instability, updated in 2018. When lit on fire, the chemical releases not only CO and CO_2, but irritating gasses and vapors. Additionally, the health risk is rated as a level 4 with acute oral toxicity. Recommended treatment is calling poison control immediately, and not to induce vomiting if swallowed. If inhaled, removal from the environment into fresh air is recommended and, if on skin, to wash skin for up to 15 minutes.

The heat exchanger is not expected to increase any risk of ethylene glycol exposure. The ethylene glycol is already present in the plant and no different handling requirements are necessary with pumping the ethylene glycol. It has a flash point of 110 °C, which is far outside the temperature range used in this setting. There are two new possibilities of ethylene glycol leaks; either the intermediate pipe could break spilling ethylene glycol onto the shop floor or a leak could develop in the heat exchanger itself. In the case of the intermediate pipe leaking or rupturing, it is recommended to follow the same cleaning procedure as if existing pipe broke between the machines. Appendix B has an example safety data sheet (SDS) for viewing. If a leak were to develop in the heat exchanger, it is recommended to service the unit and have the leak patched. Ethylene glycol does not evaporate easily into the air [3], but it is not an ideal vapor to have in the air supply for the building. In the relevant range of temperature for the heat recovery unit, ethylene glycol is a liquid and has low risk of inhalation.

5.2 Environment and Regulations

Ethylene glycol is commonly used as a refrigerant, coolant, and solvent, and has a half life in the atmosphere of between 0.3 and 0.5 days. It biodegrades into nontoxic materials, though, if it combusts, releases CO_2 and CO. It has a low ability to accumulate in bio-organisms or the environment, and is not heavily regulated by the EPA except requiring documentation of production and use. The substance has a mandated designation as a hazardous air pollutant [4].

The 4.67 kW used for the pump and added fan power produces a carbon footprint of 17.4 metric tons of CO_2 per year of system use [5], a 93% reduction in emissions from the current system. This is due to the initial capital costs which do not contribute to the electrical consumption. The carbon footprint savings does not take into account the CO_2 released in creating the pump, piping and heat exchanger. Including this in the reduced CO_2 calculations would drive the savings percentages closer together.

5.3 Economic

A constant tax and interest rate are assumed. The maintenance costs are assumed to be negligible. The inflation rate is also neglected when considering future expenditures. The final proposed design is optimized to maximize cost savings, and so economic considerations were paramount in this design.

During the heat transfer analysis, an equation for the system efficiency was used that assumed two unmixed fluids within the heat exchanger. In reality, the air moving through the system is mixed, pertaining to a different efficiency relation. This would slightly reduce the efficiency of the system, and the resulting total present worth savings. With the amount of uncertainty in the calculations and assumptions, the difference in efficiency is within false precision.

5.4 Social, Political, and Other Considerations

Construction of this heat exchanger does not have any negative social, political, ethical ramifications. The positive effects involve this being a very green initiative, saving both Juno Enterprises a large amount of money and the environment from significant emissions. Additionally, based on the available air duct dimensions and proposed design, there are not any issues regarding the installation of the heat exchanger system.

6 Conclusions and Recommendations

Based on the provided constraints and specifications of the requested ethylene glycol heating system, our recommended course of action is to move forward with our proposal to begin immediate installation and use of the proposed system. Using the preexisting conditions of Juno Enterprises and available pricing information, the proposed solution will save an estimated \$236,000 over the 20 year lifespan of the system using an 8% interest rate and a tax rate of 25%. This averages to about \$11,800 in savings per year assuming the provided duty of the system remains constant over the entire lifespan. This total savings value is also inclusive of a capital cost of \$15,000 to install the heat exchanger, pump, and other initial expenditures.

In order to successfully heat the incoming air to the building, a heat exchanger must be installed within the air duct that features a pipe length of 1 m, the maximum allowed 24 layers of pipes, 22 rows of pipes, 364 fins/m along the pipes, and a ethylene glycol mass flow rate of 5.62 kg/s. This system will properly heat the incoming air to 24 °C in order to heat the building to the customer's desired conditions. This specific configuration was determined by analyzing all possible configurations of the heat exchanger and comparing the resulting savings value over the 20 year lifetime. In addition to the heat exchanger being installed, a piping system and pump must be designed in order to move the ethylene glycol. The selected pump, T-Mag TM6L-123, has a cost of \$4,000 and an associated efficiency of 60%. Based on the calculated head loss and power consumption of the system, the specified pump is far within the reasonable range of operating capacity as well as the maximum horsepower of the pump. Lastly, ethylene glycol requires no special considerations as the fluid is neither flammable nor corrosive within the range of temperatures used. Additionally, the proposed system includes a return connection to the storage vat of the ethylene glycol. As a result of this, the toxicity or disposal of the substance does not need to be considered as the fluid is returned to its original holding container to be used as it normally would be without the reheat system.

Within these calculations, there is some uncertainty with the final provided values as the exact thermodynamic properties of ethylene glycol are dependent on both the exact temperature and the percent water solution of the fluid; however, the proposed system only causes for the ethylene glycol to drop 6 °C which will help to limit the uncertainty based on changing thermodynamic properties from temperature.

Due to the aforementioned savings value, Thermotopia Inc. recommends that Juno Enterprises installs the proposed ethylene glycol reheat system within its Juneau, Alaska location.

7 References

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8 Appendices

A: Material Properties

B: ThemoFisher Saftey Data Sheet: Ethylene Glycol

C: MATLAB Optimization Code

Property	**Value**
Specific volume of glycol	9.11×10^{-4} m^3/kg
Density of air	1.25 kg/m^3
Specific heat of glycol	2310 J/kg K
Specific heat of air	1006 J/kg K
Dynamic viscosity of glycol	0.0162 Pa s

SAFETY DATA SHEET

Creation Date 02-Feb-2010 **Revision Date** 17-Jan-2018 **Revision Number** 4

1. Identification

Product Name	**Ethylene glycol**
Cat No. :	**E177-4; E177-20**
CAS-No	107-21-1
Synonyms	Monoethylene glycol; 1,2-Ethanediol
Recommended Use	Laboratory chemicals.
Uses advised against	Not for food, drug, pesticide or biocidal product use

Details of the supplier of the safety data sheet

Company
Fisher Scientific
One Reagent Lane
Fair Lawn, NJ 07410
Tel: (201) 796-7100

Emergency Telephone Number
CHEMTREC®, Inside the USA: 800-424-9300
CHEMTREC®, Outside the USA: 001-703-527-3887

2. Hazard(s) identification

Classification
This chemical is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200)

Acute oral toxicity	Category 4
Specific target organ toxicity (single exposure)	Category 3
Target Organs - Central nervous system (CNS).	
Specific target organ toxicity - (repeated exposure)	Category 2
Target Organs - Kidney, Liver.	

Label Elements

Signal Word
Warning

Hazard Statements
Harmful if swallowed
May cause drowsiness or dizziness
May cause damage to organs through prolonged or repeated exposure

Precautionary Statements
Prevention
Wash face, hands and any exposed skin thoroughly after handling
Do not eat, drink or smoke when using this product
Do not breathe dust/fume/gas/mist/vapors/spray
Use only outdoors or in a well-ventilated area
Response
Get medical attention/advice if you feel unwell
Inhalation
IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing
Call a POISON CENTER or doctor/physician if you feel unwell
Ingestion
IF SWALLOWED: Call a POISON CENTER or doctor/physician if you feel unwell
Rinse mouth
Storage
Store in a well-ventilated place. Keep container tightly closed
Store locked up
Disposal
Dispose of contents/container to an approved waste disposal plant
Hazards not otherwise classified (HNOC)

WARNING. Reproductive Harm - https://www.p65warnings.ca.gov/.

3. Composition/Information on Ingredients

Component	CAS-No	Weight %
Ethylene glycol	107-21-1	>95

4. First-aid measures

Eye Contact Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes. Get medical attention.

Skin Contact Wash off immediately with plenty of water for at least 15 minutes. Get medical attention immediately if symptoms occur.

Inhalation Move to fresh air. Do not use mouth-to-mouth method if victim ingested or inhaled the substance; give artificial respiration with the aid of a pocket mask equipped with a one-way valve or other proper respiratory medical device. Get medical attention immediately if symptoms occur. If not breathing, give artificial respiration.

Ingestion Do not induce vomiting. Call a physician or Poison Control Center immediately.

Most important symptoms and effects Breathing difficulties.

Notes to Physician Treat symptomatically

5. Fire-fighting measures

Suitable Extinguishing Media Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Unsuitable Extinguishing Media No information available

Flash Point 111 °C / 231.8 °F

Method - DIN 51758

Autoignition Temperature 413 °C / 775.4 °F

Explosion Limits
Upper 15.30 vol %
Lower 3.20 vol %
Sensitivity to Mechanical Impact No information available
Sensitivity to Static Discharge No information available

Specific Hazards Arising from the Chemical
Thermal decomposition can lead to release of irritating gases and vapors. Keep product and empty container away from heat and sources of ignition.

Hazardous Combustion Products
Carbon monoxide (CO) Carbon dioxide (CO_2)
Protective Equipment and Precautions for Firefighters
As in any fire, wear self-contained breathing apparatus pressure-demand, MSHA/NIOSH (approved or equivalent) and full protective gear.

NFPA

Health	Flammability	Instability	Physical hazards
2	1	1	N/A

6. Accidental release measures

Personal Precautions Ensure adequate ventilation. Use personal protective equipment.
Environmental Precautions Should not be released into the environment. See Section 12 for additional ecological information.

Methods for Containment and Clean Up Soak up with inert absorbent material. Keep in suitable, closed containers for disposal.

7. Handling and storage

Handling Wear personal protective equipment. Ensure adequate ventilation. Do not breathe vapors or spray mist. Avoid contact with skin, eyes and clothing.

Storage Keep containers tightly closed in a dry, cool and well-ventilated place. Keep away from heat and sources of ignition.

8. Exposure controls / personal protection

Exposure Guidelines

Component	ACGIH TLV	OSHA PEL	NIOSH IDLH	Mexico OEL (TWA)
Ethylene glycol	TWA: 25 ppm STEL: 50 ppm STEL: 10 mg/m³	(Vacated) Ceiling: 50 ppm (Vacated) Ceiling: 125 mg/m³		Ceiling: 100 mg/m³

Legend

ACGIH - American Conference of Governmental Industrial Hygienists
OSHA - Occupational Safety and Health Administration

Engineering Measures Ensure adequate ventilation, especially in confined areas. Ensure that eyewash stations and safety showers are close to the workstation location.

Personal Protective Equipment

Eye/face Protection	Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
Skin and body protection	Wear appropriate protective gloves and clothing to prevent skin exposure.
Respiratory Protection	Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.
Hygiene Measures	Handle in accordance with good industrial hygiene and safety practice.

9. Physical and chemical properties

Physical State	Viscous liquid Liquid
Appearance	Colorless
Odor	Odorless
Odor Threshold	No information available
pH	5.5-7.5 50% aq. sol
Melting Point/Range	-13 °C / 8.6 °F
Boiling Point/Range	196 - 198 °C / 384.8 - 388.4 °F @ 760 mmHg
Flash Point	111 °C / 231.8 °F
Method -	DIN 51758
Evaporation Rate	No information available
Flammability (solid,gas)	Not applicable
Flammability or explosive limits	
Upper	15.30 vol %
Lower	3.20 vol %
Vapor Pressure	0.12 mmHg @ 20 °C
Vapor Density	2.14 (Air = 1.0)
Specific Gravity	1.113
Solubility	miscible
Partition coefficient; n-octanol/water	No data available
Autoignition Temperature	413 °C / 775.4 °F
Decomposition Temperature	> 500°C
Viscosity	21 cP (20°C)
Molecular Formula	C2 H6 O2
Molecular Weight	62.06

10. Stability and reactivity

Reactive Hazard	None known, based on information available
Stability	Hygroscopic.
Conditions to Avoid	Incompatible products. Excess heat. Exposure to moist air or water.
Incompatible Materials	Strong oxidizing agents, Strong acids, Strong bases, Aldehydes
Hazardous Decomposition Products	Carbon monoxide (CO), Carbon dioxide (CO_2)
Hazardous Polymerization	Hazardous polymerization does not occur.
Hazardous Reactions	None under normal processing.

11. Toxicological information

Acute Toxicity

Product Information
Component Information

Component	LD50 Oral	LD50 Dermal	LC50 Inhalation
Ethylene glycol	7712 mg/kg (Rat)	9530 µL/kg (Rabbit) 10600 mg/kg (Rat)	Not listed

Toxicologically Synergistic Products No information available

Delayed and immediate effects as well as chronic effects from short and long-term exposure

Irritation May cause eye, skin, and respiratory tract irritation

Sensitization No information available

Carcinogenicity The table below indicates whether each agency has listed any ingredient as a carcinogen.

Component	CAS-No	IARC	NTP	ACGIH	OSHA	Mexico
Ethylene glycol	107-21-1	Not listed	Not listed	Not listed	Not listed	Not listed

Mutagenic Effects No information available

Reproductive Effects No information available.

Developmental Effects No information available.

Teratogenicity No information available.

STOT - single exposure Central nervous system (CNS)
STOT - repeated exposure Kidney Liver

Aspiration hazard No information available

Symptoms / effects,both acute and delayed No information available

Endocrine Disruptor Information No information available

Other Adverse Effects The toxicological properties have not been fully investigated.

12. Ecological information

Ecotoxicity
Do not empty into drains. .

Component	Freshwater Algae	Freshwater Fish	Microtox	Water Flea
Ethylene glycol	EC50: 6500 - 13000 mg/L, 96h (Pseudokirchneriella subcapitata)	LC50: = 16000 mg/L, 96h static (Poecilia reticulata) LC50: 40000 - 60000 mg/L, 96h static (Pimephales promelas) LC50: = 40761 mg/L, 96h static (Oncorhynchus mykiss) LC50: = 41000 mg/L, 96h (Oncorhynchus mykiss) LC50: 14 - 18 mL/L, 96h static (Oncorhynchus mykiss) LC50: = 27540 mg/L, 96h static (Lepomis macrochirus)	Not listed	EC50: = 46300 mg/L, 48h (Daphnia magna)

Persistence and Degradability Persistence is unlikely

Bioaccumulation/ Accumulation No information available.

Mobility Will likely be mobile in the environment due to its water solubility.

Component	log Pow
Ethylene glycol	-1.93

13. Disposal considerations

Waste Disposal Methods Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. Chemical waste generators must also consult local, regional, and national hazardous waste regulations to ensure complete and accurate classification.

14. Transport information

DOT Not regulated
TDG Not regulated
IATA Not regulated
IMDG/IMO Not regulated

15. Regulatory information

All of the components in the product are on the following Inventory lists: X = listed

International Inventories

Component	TSCA	DSL	NDSL	EINECS	ELINCS	NLP	PICCS	ENCS	AICS	IECSC	KECL
Ethylene glycol	X	X	-	203-473-3	-		X	X	X	X	X

Legend:
X - Listed
E - Indicates a substance that is the subject of a Section 5(e) Consent order under TSCA.
F - Indicates a substance that is the subject of a Section 5(f) Rule under TSCA.
N - Indicates a polymeric substance containing no free-radical initiator in its inventory name but is considered to cover the designated polymer made with any free-radical initiator regardless of the amount used.
P - Indicates a commenced PMN substance
R - Indicates a substance that is the subject of a Section 6 risk management rule under TSCA.
S - Indicates a substance that is identified in a proposed or final Significant New Use Rule
T - Indicates a substance that is the subject of a Section 4 test rule under TSCA.
XU - Indicates a substance exempt from reporting under the Inventory Update Rule, i.e. Partial Updating of the TSCA Inventory Data Base Production and Site Reports (40 CFR 710(B).
Y1 - Indicates an exempt polymer that has a number-average molecular weight of 1,000 or greater.
Y2 - Indicates an exempt polymer that is a polyester and is made only from reactants included in a specified list of low concern reactants that comprises one of the eligibility criteria for the exemption rule.

U.S. Federal Regulations

TSCA 12(b) Not applicable

SARA 313

Component	CAS-No	Weight %	SARA 313 - Threshold Values %
Ethylene glycol	107-21-1	>95	1.0

SARA 311/312 Hazard Categories See section 2 for more information

CWA (Clean Water Act) Not applicable

Clean Air Act

Component	HAPS Data	Class 1 Ozone Depletors	Class 2 Ozone Depletors
Ethylene glycol	X		-

OSHA Occupational Safety and Health Administration
Not applicable

CERCLA This material, as supplied, contains one or more substances regulated as a hazardous substance under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302)

Component	Hazardous Substances RQs	CERCLA EHS RQs
Ethylene glycol	5000 lb	-

California Proposition 65 This product does not contain any Proposition 65 chemicals

Component	CAS-No	California Prop. 65	Prop 65 NSRL	Category
Ethylene glycol	107-21-1	Developmental	-	Developmental

U.S. State Right-to-Know Regulations

Component	Massachusetts	New Jersey	Pennsylvania	Illinois	Rhode Island
Ethylene glycol	X	X	X	X	-

U.S. Department of Transportation

Reportable Quantity (RQ): Y
DOT Marine Pollutant N
DOT Severe Marine Pollutant N

U.S. Department of Homeland Security
This product does not contain any DHS chemicals.

Other International Regulations

Mexico - Grade Slight risk, Grade 1

16. Other information

Prepared By Regulatory Affairs
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Creation Date 02-Feb-2010
Revision Date 17-Jan-2018
Print Date 17-Jan-2018
Revision Summary This document has been updated to comply with the US OSHA HazCom 2012 Standard replacing the current legislation under 29 CFR 1910.1200 to align with the Globally Harmonized System of Classification and Labeling of Chemicals (GHS).

Disclaimer
The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text

End of SDS

```
%% DOTS Project 3
% Erick Landreth, Adam Peterlein, Sam Veith, and Jack Edson
clear;

%% Given Technical Specs

Tamb = 5 + 273.15; % K
Texp = 24 + 273.15; % K
Aduct = 1; % m^2
Lduct = 3; % m
VAir = 3; % m^3/s
opHours = 5520; % Hours per year
Tglycol = 30 + 273.15; % K
dPipe = 16/1000; % Outer Pipe Diameter in m
tPipe = 1/1000; % Pipe thickness in m
sPipe = 41/1000; % Pipe spacing in m
tFins = 0.833/1000; % Fin thickness in m
fanEfficiency = 0.75; % Efficiency of air dict fan
pumpEfficiency = 0.6; % Efficiency of pump
dConnector = 3*0.0254; % Connecting pipe diameter in m
lConnector = sqrt(25^2 + 4^2); % Connecting pipe length in m

%% Given Economic Specs

lifespan = 20; % Years
iRate = 0.08; % Interest rate
connectingCost = 500; % Cost of connecting pipe and fittings in $
elecCost = 0.09; % Cost of electricity in cents per kW*hr
taxRate = 0.25; % Tax rate
PtoA = 9.82; % Annuity Conversion to PVW
pumpCost = 4000; % NEED TO FIGURE THIS ONE OUT

%% Found Thermodynamic Specs

vGlycol = 9.11e-4; % Specific volume of glycol m^3/kg
DAir = 1.25; % Density of air kg/m^3
cpGlycol = 2310; % Specific heat of glycol J/kg*K
cpAir = 1006; % Specific heat of air J/kg*K
dynVisc = 0.0162; %placeholder value
```

```
%% Exhaustive Search

lPipe = 1; % Length of pipe
NF = 200:500; % Fin spacing fins/m
NW = 10:2:30; % Number of tubes in horizontal direction
NR = 24; % Number of tube layers
mGlycol = 5:.01:7; % Mass flow rate of glycol kg/s

% lPipe = 1; % Length of pipe
% NF = 364; % Fin spacing fins/m
% NW = 22; % Number of tubes in horizontal direction
% NR = 24; % Number of tube layers
% mGlycol = 5.62; % Mass flow rate of glycol kg/s

% Creates array for results
results = zeros(length(lPipe)*length(NF)*length(NW)*length(NR)*length(mGlycol), 11);
row = 1;

for M=1:length(mGlycol)
% Re = mass flow rate of glycol / (pi d^2 / 4) * d / nu
Re = 4*mGlycol(M)/(pi*dConnector*dynVisc);

% V = glycol specific volume * m dot glycol / (pi / 4 d^2)
velInter = 4*vGlycol*mGlycol(M)/(pi*(dConnector^2));

% H = V^2 / (2 g)
vl = velInter^2/(2*9.81);

% Laminar case
if Re <= 2300
% Friction factor
f = 64/Re;
alpha = 1.05;
else
% Friction factor
f = fzero(@(x) -2*log10(2.51/(x*sqrt(Re)))-1/sqrt(Re), .05);
alpha = 2;
end
```

```
% Minor head loss
kl = 0.2*2;

% Total head loss
glycolHL = vl * 2*(kl + f*lConnector/dConnector);

for L=1:length(lPipe)
for F=1:length(NF)
for W=1:length(NW)
% Width of heat exchanger
wHX = sPipe*NW(W);

for R=1:length(NR)
% Height of heat exchanger
hHX = sPipe*NR(R);

% Heat exchanger area
AFlow = NW(W) * NR(R) * lPipe(L) * (0.0502 + NF(F)*673e-6);

AHDuct = lPipe(L) * hHX;

% Velocity of air m/s
velAir = VAir / AHDuct;

% Velocity of glycol through heat exchanger
velGlycol = 4 * vGlycol * mGlycol(M) /
(NR(R) * pi * (dPipe - 2*tPipe)^2); %m/s
mAir = DAir * VAir;

% Cost of the heat exchanger
costHX = 0.5 * (18 + 0.044*(NF(F) + 500)*NW(W)) * lPipe(L) * (NR(R)+1);

% U of heat exchanger
U = 1 / (0.023 / velAir^0.5 + 0.0039 + (0.0088*NF(F) + 0.25) /
(430 * velGlycol^0.8));

% Find C_min, C_max
C = [mGlycol(M)*cpGlycol, mAir*cpAir];
```

```
Cmin = min(C);
Cmax = max(C);
C_R = Cmin/Cmax;

% NTU Method
NTU = U*AFlow/Cmin;
ebs = 1-exp((1/C_R)*NTU^0.22*(exp(-C_R*NTU^0.78)-1));
Qact = ebs*Cmin*(Tglycol-Tamb);

% Pressure drop in the pump (Pa)
pdPump = 5.2*(0.15*NW(W)*lPipe(L)+0.0875*(NW(W)-1)+0.3)
*velGlycol^1.85*1000;

% Head of the pump
headPump = pdPump * vGlycol / 9.81 + glycolHL;

% Pump work
workPump = headPump * 9.81 * mGlycol(M)
/ pumpEfficiency / 1000; % Work in kW

% Pressure drop of the fan
pdFan = 4.1 * NW(W) * velAir^1.95 * (0.25 + 0.0025*NF(F));

headFan = pdFan / (9.81 * DAir);
workFan = headFan * mAir * 9.81 / fanEfficiency / 1000; % Work in kW

% Electricity savings
eUsed = mAir * cpAir * (Texp - Tamb) / 1000; % kW
eSaved = Qact / 1000; % kW
if eSaved > eUsed
eSaved = eUsed; % kW
end

% Costs and savings
elecSavings = (eSaved - workPump - workFan) * opHours * elecCost * PtoA;
taxSavings = (connectingCost + costHX + pumpCost) * 0.12656;
PV = elecSavings + taxSavings - connectingCost - costHX - pumpCost;

% Temperature Check
```

```
Tout = Qact / (mAir * cpAir) + Tamb;

% Output
results(row,1) = lPipe(L);
results(row,2) = NR(R);
results(row,3) = NW(W);
results(row,4) = NF(F);
results(row,5) = mGlycol(M);
results(row,6) = workPump;
results(row,7) = workFan;
results(row,8) = elecSavings+taxSavings;
results(row,9) = connectingCost+costHX+pumpCost;
results(row,10) = PV;
results(row,11) = Tout - 273.15;

% Increment rows
row = row + 1;
end
end
end
end
end

optdesign = results(results(:,10) == max(results(:,10)), :);

textline = "Pipe Length = %.2f m\nNR = %.0f layers\nNW = %.0f rows\n" + ...
"NF = %.0f fins/m\nmGlycol = %.2f kg/s\nPump Work = %.2f kW\n" + ...
"Fan Work = %.2f kW\nDelivered Temperature = %.2f C\n" + ...
"Savings = $%.0f\nCaptial Costs = $%.0f\nTotal Savings = $%.0f\n";
fprintf(textline, optdesign(1,1), optdesign(1,2), optdesign(1,3), ...
optdesign(1,4), optdesign(1,5), optdesign(1,6), optdesign(1,7), ...
optdesign(1,11), optdesign(1,8), optdesign(1,9), optdesign(1,10));
```