ME 450 Team 9: Increasing Steam Load
Final Report
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Executive Summary

For 100 years, the University of Michigan Central Power Plant has provided utilities that have powered the world-class research and education this university is known for. Its main purpose is to generate steam for heating, cooling and sanitation; and electricity for lighting and power. These utilities are distributed over a network of tunnels throughout Central Campus and the hospital complex. The Central Power Plant, or CPP, relies on the steam it creates for the campuses to spin generators which produce electricity; it cannot make this electricity if there is no steam demand. Recently, this has been looking more like a reality than a possibility: over the past 20 years, campus buildings have been replacing their steam-driven absorption chillers for air conditioning with electric-driven ones which are more energy-efficient. While this increases the electric demand for the CPP, this is counteracted by the drop in steam demand during the summer months. The year-round steam demand is no longer constant between the winter and summer seasons. To boost steam demand in the summer, the CPP has asked us to brainstorm and research different concepts and report the top three with an economic analysis of each.

The CPP gave us few requirements as to what we could consider researching. The main requirement was to find ways to utilize 9 psig steam, the main type of steam which is circulated through the campuses. Another important requirement was maintaining the current condensate return rate of 80% (condensate is the heated water returning to the CPP after the steam is used), which is the level necessary to keep the CPP running normally. Ultimately, the concepts that we researched had to use enough steam to help raise the summer demand to meet the winter demand so that the CPP could generate the same amount of electricity year-round.

After going through a concept-generating process, we decided on six concepts to research further based on their potential ability to appreciably raise the steam demand during the summer. Then these six concepts were researched through a combination of benchmarking existing solutions and adapting them to our problem, and talking to specialists. For some concepts, we used a computer simulation based on campus steam demand and weather data to estimate the steam demand. For others, we used findings from our research such as specification sheets.

Unfortunately, we were unable to find a single solution which appreciably raised the steam demand during the summer months. As we were completing the project, we were realizing that we would have to replace the steam demand for several dozen buildings with concepts that were producing at most 2 klbs/hr of steam demand. We have also discovered that the University of Michigan has no unified energy usage plan. Each department and/or building decides on where the energy comes from, whether it is supplied by the CPP or an outside utility. While it may be more cost-effective for each independent entity to pay for and run their electric chillers, overall and in the long term it affects the energy sustainability of the university. If the situation is not resolved, the University of Michigan will lose its reliable, efficient, and cost-effective source of steam and electricity. Therefore, we strongly recommend that the University consider a campus-wide energy program and to think critically about where its energy comes from if it wants to remain at the forefront of sustainability and innovation.

Problem Description and Background

The Central Power Plant (CPP) is a cogeneration, combined-cycle, and traditional power plant which produces electricity and steam, among other utilities, for the central campus and hospital for the University of Michigan. Designating a power plant as “cogeneration” means that the plant produces both electricity and some form of useful thermal energy, such as steam or hot gas [1]. A combined-cycle power plant means the thermal energy produced from one electricity-generating method is used to produce electricity by another method [1]. A “traditional” power plant uses fossil fuels to boil water to turn an electricity-generating steam turbine [2]. The CPP has two 5 MW gas turbines run on natural gas which produce electricity [3]. Waste heat is captured by two waste heat boilers that heat up water to produce steam, part of the combined-cycle process. Meanwhile, up to five traditional boilers powered by natural gas boil water to produce steam, which is then combined with steam from the waste heat boilers to turn up to three steam turbines. These steam turbines turn generators which produce electricity for the university. Two types of steam are created as the steam travels through the turbines: 60 psig steam, which is used by the hospital for sanitation, and 9 psig steam, which is used mainly to heat and cool university buildings. Our project will focus on the 9 psig steam.

Once the 9 psig steam leaves the CPP, it travels through a series of steam tunnels to various buildings where it is used mainly for heating and cooling university buildings, depending on the season. Buildings equipped with air conditioning use absorption chillers powered by CPP steam to cool during the summer months; winter heating relies on steam-heated radiators. In the past, the steam loads year-round were relatively constant because both the heating and cooling systems ran on steam. However, within the last two decades university departments have been replacing their steam-powered absorption chillers with high-efficiency, electricity-powered chillers. These new chillers have the ability to run at different speeds, which means they can meet demand quicker and be more efficient compared to the on/off nature of the absorption chillers. Because steam-powered cooling equipment are no longer used, the steam load during the summer has dropped compared to the winter steam load. Generating electricity during the summer months is becoming a problem since the CPP depends on the steam demand to produce electricity using the steam turbines. If the CPP cannot produce more electricity, then the university will be forced to buy more expensive and more polluting electricity from the utility companies. Therefore, the CPP asked us to develop different ideas on how to use the 9 psig steam to increase their electricity production, and present our three best ideas with in-depth analyses for each idea.

One unique aspect of our project was that there will be no final prototype, which means our benchmarking and analysis must be thorough; we would be the first to look at most of the ideas we brainstormed. Naturally, there are many different ways to use steam other than electricity generation, from food processing to chemistry to sanitation [4]. It is also possible to re-use the steam a third time within the power plant, such as using the STIG cycle, in which steam is injected into a gas turbine to produce more electricity at a cost to efficiency [5]. Perhaps more electricity could be generated by changing the shape of the steam turbine blades, which can be done when maintenance is performed; more electricity could be generated without having to produce more steam, reducing steam waste [6]. There are also models which can be used to predict energy demand, providing greater optimization of resources and also reducing steam waste [7]. All of these ideas demanded careful research and studying to be able to report the most promising solutions. Shutting down the CPP would mean getting rid of an efficient and cost-effective source of power and heating, which is a scenario we had to avoid at all costs. We want the CPP to be around for the next 100 years as it grows and evolves with the university as it had for the previous 100 years.

User Requirements and Engineering Specifications

The user requirement with the highest priority was to find uses for the 9 psig steam, specifically during the warmer months. This was stated in our project description provided by the University of Michigan and stressed by the managers at the CPP. This steam can range from 4 psig to 14 psig, but usually ranges between 8 psig to 11 psig due to demand changes. This steam load must be utilized to ensure boilers do not have to be decommissioned in the warmer seasons when there is little to no steam demand; keeping the boilers offline for long periods of time could decrease their lifetimes and result in expensive maintenance. Additionally, the CPP wanted to keep its energy efficiency as high as possible because using the steam after the electricity generating process used more of its available energy, rather than releasing it to the atmosphere or condensing it before restarting the power generation cycle.

The plant staff told us that solutions which increase steam demand for the entire year are completely acceptable; however, the majority of our focus was directed on the warmer months. Currently, steam demand in the summer is around 250 klbs/hr and 550 klbs/hr in the winter. After initial searches during the concept generation process, we could not find anything with a 300 klbs/hr demand during the summer except for adding new buildings on campus. Therefore, we set a modest goal of 25 klbs/hr increase in the summer for a concept to be considered effective in raising the demand.

The concepts we looked at should maximize the condensate return to the plant. Reusing the condensate is a much more attractive option to the plant than purchasing extra water from the city of Ann Arbor and putting it through a purification process to reach an acceptable quality to put into the boilers. Purchasing domestic water can be costly and the water quality is poor so extensive chemical processing is necessary to purify the water. On the other hand, the condensate is relatively clean and requires far less effort to purify. In addition, the condensate returns to the plant at approximately 140 °F and therefore requires less energy to reheat in the boiler. Our team determined, through discussions with the plant operators, that we had to find solutions that allowed at least 80% of the steam/water to return to the plant.

We wanted to minimize the amount of infrastructure changes necessary in our concepts we researched. After touring the plant and learning more about the cost of the current infrastructure from the plant manager, we understood the benefit of producing a solution that requires minimal changes to the current infrastructure. Any changes in infrastructure would likely take many years to implement and could cost upwards of millions of dollars if much demolition and construction is needed. Available space was also a constraint at the CPP. Many university buildings have gone up over the years surrounding the plant making expansion nearly impossible. The solutions we looked into could not require infrastructure larger than the current footprint of the plant. While it might not have been ideal in terms of convenience, we did not rule out solutions that require the replacement or removal of equipment within the plant to accommodate more modern technology. We tried to avoid any solutions that require new piping to be laid, as it would have increased both the cost of the project and the time to implementation.

Whatever solutions we came up with were expected to last for the foreseeable future. What this meant was any ideas we looked into should not have been something that could have become obsolete in the next 10 years. This was something we wanted to avoid because we wanted a long-term solution to this problem, and not just a “quick fix.” It was difficult to put an actual number of years we expected the solution to be useful to the plant with the information we had, but we defined an absolute minimum for lifetime at 20 years from installation.

Table 1: Summary of User Requirements and Engineering Specifications

System	User Requirement	Engineering Specification
Steam-Producing Equipment	Increase/Maximize 9 psig Steam Production	4 - 14 psig steam (8 – 11 psig nominally)
	Maintain Condensate (Return Liquid) Amount	80% Condensate Return
	Increase Summer Steam Demand	Current Summer: 250 klbs/hr
		New Summer: 275 klbs/hr
	Maximize Solution Life Expectancy	> 20 years life expectancy

Concept Generation

To begin generating concepts for evaluation, we began by learning about steam power and the processes it can be involved in. The initial scope of our research did not focus on only the processes that could take place at a university, but also on multiple industries and applications. This allowed us to gather the maximum amount of information to generate 20 ideas per team member. Discussions with the plant managers ended with a consensus that we should not limit ourselves from looking into any possibilities based on budget constraints, infrastructure changes, or implementation timeframe. If a concept idea was proposed that was costly and would take many years to implement, it would be acceptable if we could prove the long-term benefit was worth the cost and time. A solution with long-term benefits would have appropriate lifetime expectancy, eventually generate profit, and/or sustain university functions in some other manner.

Concepts were generated through extensive online research, reading published works, and through communicating with professors and other professionals. To begin our research we created a functional decomposition to organize the factors of steam that we had to account for in our many solution concepts.

The first and most important factor we considered was the heat content necessary for the processes the steam could be used for. The heat content is the storage of energy in the steam and is most often measured by temperature, although other factors can affect the exact energy amount. The steam is provided at a temperature of approximately 240 °F. Many of the processes the team initially thought were good ideas were could not consider any longer once we realized the temperature required of the process in question was in excess of 600 °F. An example was our research into using the steam for a dyeing process, which met the pressure requirements when we initially found the idea.

The second factor we considered was the steam pressure. There were dozens of processes we found that can use steam, but only a portion of those required steam between 4 and 14 psig, the steam pressure range the CPP can produce. An example we researched that seemed a good idea at first was using the steam in a papermaking process. This papermaking process could have used steam at very similar temperatures to those provided from the steam at the plant, but this process would require steam at pressures drastically different than those available.

The third factor we considered was the steam chemistry. This is not always an important factor, depending on the work being done. Mechanical processes or processes that only use the heat energy of the steam are not, in general, affected by the chemistry of the steam. Some processes that the team thought could have been useful to the university, however, would have been very affected by the chemical balances of the steam. Such processes included use of the steam in chemistry lab processes, where the pH balance of the steam, among other factors, can be of great importance to the process taking place. Any other uses of the steam for research purposes may also be affected by the chemistry of the steam.

Figure 1 shows our functional decomposition diagram to show how we developed our concepts using the three aforementioned factors with an additional breakdown of what can be done for each factor.

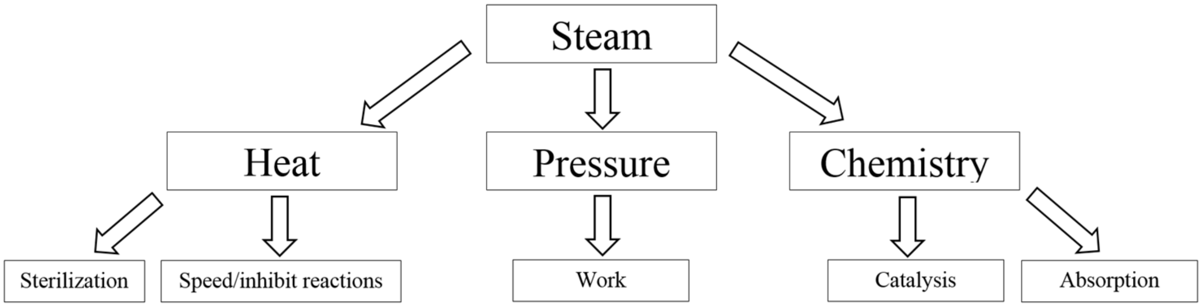

Figure 1: Functional Decomposition Diagram

Once the initial ideas were compiled, we began looking for processes that met the specifications outlined in our functional decomposition explained above. Ideas were also categorized based on function: the university, the power plant, industrial use, commercial use or residential use. This allowed us to look at uses for the steam that were significantly different. Industrial processes focused on the production of something, such as candle making or tea production. Commercial uses at the university were processes that use the steam in the kitchens for tasks such as steaming food, boiling water for cooking or potato peeling. Only one process was categorized as residential use, which was using the steam for heating the sidewalks in the winter to decrease the amount of time and money spent plowing, though it could have been put into multiple categories. Only a few concepts were found that could be utilized right in the power plant. These included feed water heating and using a low-pressure steam turbine.

Appendix A (Page 26) shows all of our generated concepts with a brief explanation of why they did not pass our initial criteria.

Concept Selection

To choose the ten best solutions for further analysis, we elected to use an interpolated scoring system. We selected nine criteria that we felt best aligned with sponsor goals and then determined their relative importance through a weighting system. The table that we used to calculate each solution's score is shown below in Figure 2.

To evaluate a score for each criterion, we used the following equation:

$$\frac{Solution\ Parameter - Minimum}{Maximum - Minimum} * Weight$$

After scoring the criteria, we added each category score to get a total score for our solution. The range of each criterion was very important for evaluating the solutions. We estimated that we could not accurately predict the lifetime of a solution, its profit per year, or its years to recoup cost without extensive analysis. Because of the large number of concepts that we were filtering, only back of the envelope calculations were possible. Therefore, if we predicted values beyond the ranges, we used the respective maximum or minimum for the range instead of our calculated value.

In all other cases, a solution had to fit within the confines of the ranges we selected. A solution that required more steam than our defined maximum for instance, was not a feasible solution and discarded rather than scored.

In addition to failing criteria, concepts would be discarded if we discovered during research that the concept could not be used for some other technical or economical reason. For example: using the steam to speed methane generation in a landfill was impossible because there are no pre-existing landfills in a near enough vicinity to the plant to receive steam.

After initial research and preliminary analysis, we found that very few of the concepts we generated had the potential for enough steam demand or used the appropriate steam pressure and temperature. Therefore, we were able to end up with an appropriate number of concepts to work on without having to use our scoring criteria. However, this was a useful exercise for us because for future work the criteria could be used to rate potential solutions.

Criteria		**Minimum**	**Maximum**	**Solution Parameter**	**Weight**	**Score**
Steam	Additional Summer Demand (klbs/hr)	25	700		15	
	Demand Rate of Change (klbs/hr^2)	300	0		9	
	Condensate Return (%)	0	100		7	
	Winter Demand (klbs/hr)	0	400		4	
Lifetime (Years)		20	50		20	
Profit/Year ($/Year) (x1000)		-10	100		17	
(Installation Cost)/(Years to Recoup Cost)		50	0		13	
Mechanical/Thermal Efficiency (%)		10	100		10	
Environmental Friendliness/Sustainability (0 [no] or 1 [yes])		0	1		5	
Total					**100**	

Figure 2: Scoring System for Proposed Solutions

Risk Analysis/Failure Modes and Effects Analysis (FMEA)

Table 2: Risk Analysis Table

Hazard	Hazardous Situation	Likelihood	Impact	Technical Performance	Schedule	Cost	Action to Minimize Hazard
Steam Leakage	Steam is very hot and under pressure. Can cause burns and other injuries to workers, and loss of utilities to campus. Also, leaked steam is wasted steam.	Unlikely	Catastrophic/ Serious	Effectiveness/efficiency of machine is reduced. Can cause costly replacement in case of damage.	> 1 day to several weeks	N/A	Assure all steam pipes are secured and sealed. Inspect pipes as required by maintainence department.
Condensate Leakage	Condensate loss is detrimental to system operation, as well as causing a hazard by possibly causing falls to personel or corrosion to system.	Unlikely	Serious	Effectiveness/efficiency of machine is reduced. Can cause costly replace in case of damage. Will cause power plant to buy and purify unecessary municipal water.	> 1 day to several weeks	N/A	Assure all condensate pipes are secured and sealed. Inspect pipes as required by maintainence department.
Heavy Equipment	Heavy equipment may pose crushing hazard, as well as strain-related injuries to personel	Likely	Medium	Injury leave/medical bills to pay out may increase. Equipment may be damaged if it falls over.	> 1 week to several weeks	N/A	Minimize size of equipment. Ensure personel get proper training on equipment.
Sabotage	Equipment may be vulnerable to vandalism from petty criminals to terrorist attack.	Extremely Unlikely	Catastrophic	Equipment may be damaged or destroyed. Possible loss of utilities to campus. Possibility of injury or death to bystanders.	> 1 week to long-term closure	N/A	Ensure equipment is secure and in safe location. Minimize risk to bystanders by placing equipment underground or far away from public areas.
Burst Pipe	Same as steam leakage. In addition, the burst pipe will result in a massive pressure drop in the system which could result in the power plant trying to exceed its rated load. A large amount of high temperature steam could also melt various components in the system that were previously insulated.	Unlikely	Catastrophic/ Serious	Same as leakage. In addition: Likely component damage at location of the burst. Potential damage to plant equipment if pressure drop is out of control.	A few days to a few months depending on infrastructure damage	N/A	Same as leakage. Ensure that an adequate safety factor is considered in the pipe selection.

Table 3: FMEA Table

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity of Effect	Potential Causes of Failure	Risk of Occurence	Current Design Control	Detection	Risk Priority Number	Recommended Action
Steam Conduit System	Takes steam from CPP to university buildings and steam-powered equipment.	Pipe Breaks	Device shuts off	8	Deferred Maintenance	2	TBD	2	32	TBD
				8	Bad Equipment	2	TBD	2	32	TBD
			Device breaks due to lack of steam	10	Deferred Maintenance	2	TBD	2	40	TBD
				10	Bad Equipment	2	TBD	2	40	TBD
		Power Plant goes offline	Device shuts off	8	Boiler Breaks	1	TBD	1	8	TBD
				8	Water Shut Off	1	TBD	1	8	TBD
				8	Natural Gas Shut Off	1	TBD	1	8	TBD
			Device breaks due to lack of steam	10	Boiler Breaks	1	TBD	1	10	TBD
				10	Water Shut Off	1	TBD	1	10	TBD
				10	Natural Gas Shut Off	1	TBD	1	10	TBD
Condensate Conduit System	Returns condensate from university to CPP for reuse	Pipe Breaks	Device shuts off	8	Deferred Maintenance	2	TBD	2	32	TBD
				8	Bad Equipment	2	TBD	2	32	TBD
			Device breaks due to lack of steam	10	Deferred Maintenance	2	TBD	2	40	TBD
				10	Bad Equipment	2	TBD	2	40	TBD

We decided to conduct both a risk analysis (Table 2) and a failure modes and effects analysis (FMEA) (Table 3) because each concept we studied had at least one risk and failure mode each. Since these risks and failure modes were unique to each concept, we generalized our analyses to be applicable to any solution. The main focus was on analyzing the steam and condensate conduit systems that would connect to each concept. The largest risk we predicted for each concept was the sudden loss of steam due to a pipe leak/break or the CPP goes offline. Though the likelihood of this risk is low because of regular maintenance and back-up systems, each concept had to be able to withstand this immediate loss without sustaining damage or being destroyed. Otherwise, the University might lose money in infrastructure, such as within the CPP or on campus, or there might even be injuries or fatalities depending on location. Fortunately, we predicted the chance of a steam system failure is very low, so the risk to each design is currently at an acceptable level. However, during our concept analysis, we took this risk analysis and FMEA into consideration.

Key Design Drivers and Challenges

To successfully complete our project, we needed to utilize a large amount of thermodynamic analysis. Our project did not easily fit into the traditional ME 450 mold because we were not asked to produce a physical design. Rather, we were instructed to research and present a list of our three most promising methods of increasing 9lb steam demand. Without a physical prototype to test, it was challenging to validate our findings. We had to rely on thermodynamic modeling to validate the feasibility and benefits of our chosen solutions, which we accomplished using a combination of research and a computer simulation.

Our largest design driver was the 25 klb/hr increase in summer steam demand specification. As the University moves away from steam absorption chillers, the summer steam demand has dropped significantly, so much so that it has become difficult to find a solution that replaces the lost steam demand. The steam absorption chillers used much more steam than all other non-industrial steam applications we found in our research. Short of putting in several new buildings, it was difficult to find solutions which used that much steam individually or together.

The number of potential stakeholders in our project also posed a challenge. Because our sponsor is only responsible for the steam while it is inside the plant, investigating and proposing a solution in other campus buildings required that we work with the appropriate department. Communicating with and coordinating multiple departments at the same time could have quickly become over overwhelming if we were not careful. To address this, we let our sponsor handle the coordination of our project with other university parties. While we were in contact with potential stakeholders to assess the demand for our proposed solution, as well as its feasibility, the final concepts were presented directly to our sponsor. We successfully coordinated with our potential

Concept Descriptions and Modeling

In-Ground Air Conditioning for Artificial Turf Athletic Fields

Similar to an ice hockey rink, shown in Figure 3 [8], this system would use an absorption chiller pumping refrigerant underneath a turf athletic field, like one in Figure 4 [9], to cool it off during a hot summer day. The steam would run the absorption chiller akin to how absorption chillers function on university buildings. This system could be used to reduce heat-related injuries, including heatstroke, as well as minimizing water used to cool down the field. Though this concept would work well with the South Campus athletic fields, the steam infrastructure does not extend south of Hill Street, so this system would have to be installed somewhere around Central Campus.

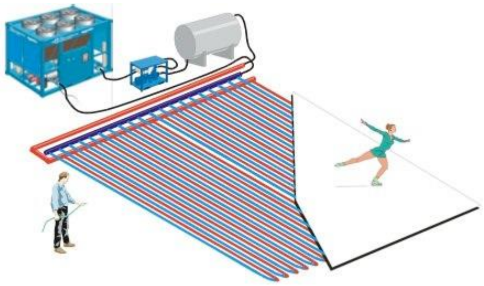

Figure 3: Ice hockey rink set up with chiller, pump, and circulation unit similar to concept

Figure 4: Turf Field Example

We decided to use a model similar to an ice hockey rink. Ice on a rink sits above a thin layer of concrete which contains small pipes. These pipes hold a cooling liquid that is circulated by pump system which includes a chiller. As shown in Figure 5, the turf field would have a similar construction, except the ice is replaced with a layer of grass fibers, granulated rubber, and sand before the concrete, a common technique in installing a turf field [10]. The pipes in our model circulate water. We decided to make the size of our turf field model 150 yards by 75 yards, large enough to fit a regulation-size football field.

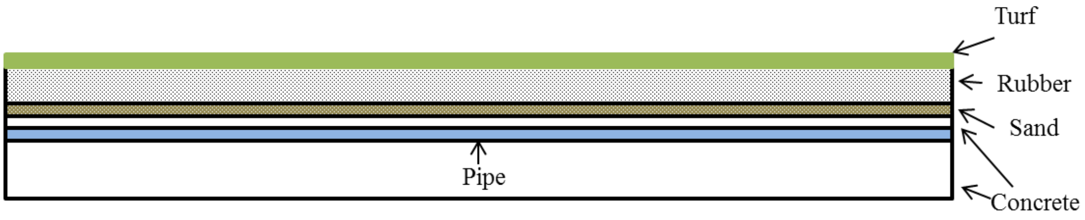

Figure 5: Turf Field Layers

To calculate the heat transfer from the turf surface to the water pipes, we approximated the different layers from the turf to the concrete as flat plates and the pipe as a long cylinder, and derived Equation 1,

$$Q_{out} = \frac{T_r - T_w}{R_1 + R_2 + R_3 + R_4} \qquad \text{(Eq.1)}$$

, where Q_{out} is the amount of heat transfer from the turf to the circulating water; T_r is the turf temperature, provided by our weather data; T_w is the circulating water temperature, set at 60 °F, or about 15.6 °C; and R_1, R_2, R_3, and R_4 are the thermal resistances of the various layers between the turf and water pipes. Table 2 shows how the thermal resistances were derived for Equation 1.

Table 2: Thermal Resistances for Equation 1

Equations		Constants					Value
		l (m)	k ($\frac{W}{mK}$)	r_1(mm)	r_2 (mm)	A (m^2)	$\frac{K}{W}$
R_1	$\frac{l}{kA}$	0.0254	0.2 [11]			9406.43	$1.35 * 10^{-5}$
R_2	$\frac{l}{kA}$	0.00635	0.2 [11]				$3.38 * 10^{-6}$
R_3	$\frac{l}{kA}$	0.00635	1.11 [11]				$6.1 * 10^{-7}$
R_4	$\frac{\ln(\frac{r_2}{r_1})}{2\pi l k}$	137.16	0.19 [12]	76.2	82.55		$4.89 * 10^{-4}$

In addition to calculating the heat transfer, we had to calculate the temperature change of the turf ΔT_r in Kelvin to approximate the temperature change of the turf, which feeds back into a loop reading in our temperature data to approximate the turf field temperature. We calculated this value by using Equation 2,

$$\Delta T_r = \frac{Q_{sun} - Q_{out}}{m_r C_{p_r}} \qquad \text{(Eq. 2)}$$

, where $Q_{sun}$is the amount of solar radiation onto the turf field, m_r is the mass of the turf field, and C_{p_r} is the specific heat of the turf field (rubber, in this case). Table 3 shows the constants used to calculate Equation 2.

Table 3: Constants for Equation 2

m_p	C_{p_r}
$2.11 * 10^5$ kg	1380 $\frac{J}{kgK}$

After modeling our solution and running the simulation, we found that the steam demand was at most 2 klbs/hr, not nearly enough to make an impact in year-round steam demand. To meet the difference in steam demand of summer and winter, there would have to be at least 30 fields running, a highly unlikely scenario when there are few viable places to put a turf field such as this one on Central Campus. However, perhaps this model will spur development of these cooled turf fields to reduce heat-related injuries and help another university with a steam demand problem with more land available for installation.

Condensing Steam Turbine

Unlike the turbines currently in use at the CPP, a condensing steam turbine, shown in Figure 6 [13], utilizes all steam flowing from the boilers, leaving only condensate behind. This condensate would be similar to what is returned to the plant currently after the steam travels throughout the university, and its residual thermal energy could be used for another process within the plant. A condensing steam turbine is also more efficient than the current steam turbines for producing electricity because it uses more of the steam's thermal energy. Although this may not solve the problem of using the excess steam produced to generate electricity, this may improve electricity production to the point where they might not have to make as much steam to produce the electricity necessary to meet the demand. The most obvious location for this steam turbine would be within the CPP; however, a major disadvantage is that it can become very large, and there is only so much space in the CPP. Additionally, this is the most expensive concept proposal, one that could cost millions of dollars in purchasing, installation, and maintenance. For our analysis, we will be researching turbines that could meet the electricity demand and find out the steam demand necessary to produce that electricity.

We have used a condensing steam turbine that has a 12 MW rating, the same as the current turbines in the CPP. The maximum steam rate for this turbine is listed at 54,000 kg/hr, or about 119 klbs/hr [13]. While this is not a solution explicitly for using 9 psig steam, it is a solution for utilizing more energy from the steam.

Figure 6: Condensing Steam Turbine used as example to model steam demand

Lumber Kiln

After being cut, lumber must be dried to be able to use in construction or other uses. Heat and steam can be used to dry lumber effectively in a large oven-like space, such as a shed shown in Figure 7 [14]. This lumber could be used by the University for construction or could be sold for profit. In theory, this lumber kiln could be placed anywhere where there is a steam pipe and condensate return, as the only necessary equipment needed are a heat exchanger converting steam to heat, a large shed, and some sort of circulation system. The space needed for this concept, however, may be difficult to come by, and we would need to verify the market at the University for this wood.

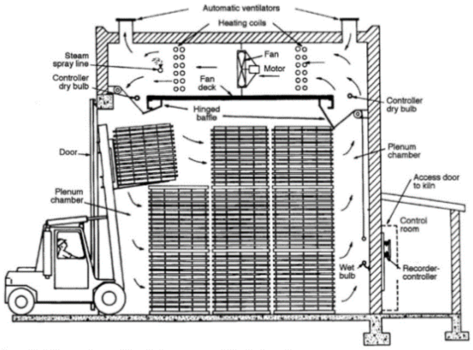

Figure 12–6. Package-loaded kiln with fans connected directly to motors.

Figure 7: A Typical Lumber Kiln Configuration

Steam heated kilns are very popular in the lumber industry where steam is routed through heat coils to increase the temperature of the room. In terms of condensate return, this is an attractive solution as there is a very high percentage returned to the boiler. Various areas of heat control within the kiln are known as zones, or stations. Track kilns, package kilns and continuous kilns typically have a system in place where the lumber is automatically moved through the dry kiln in either the same direction or opposite direction from each other. Track kilns are the most common type of lumber dry kilns and they are used for everything except hardwood. Kilns can be heated with steam, thermal oil, direct fired, hot water or electricity through de-humidification. The species dried is driven mostly by the region as the handling and transportation of lumber increases production costs. Lumber is usually dried soon after it has been cut before transporting if possible. This is because drying the lumber decreases the weight of the lumber and therefore the shipping cost.

Steam requirements for a lumber kiln can range from approximately 1.8 lbs/bf to 3 lbs/bf, depending on the kiln type, desired grade or production. Kiln holding capacity is based on the desired production. Production rate is found using drying time, kiln capacity and number of kilns. From an economic standpoint, we can estimate annual hours of operation to be 8,400 hours. At a steam supply of 50,000 lbs/hr, this would require 420,000,000 pounds of steam.

It is important to look at the location of the kilns with respect to the steam source. Pipe run length and diameter determine steam pressure and pipe back pressure. This is also affected by the number of turns in the line. The diameter of the pipe will determine the total pounds per hour of steam used. Michigan has a lot of hardwoods, so if this concept were implemented a side loader kiln would likely be used. Such a kiln with a holding capacity of 45,000 bf and an efficiency of 3 lbs/bf drying in 10 days would use about 600 lbs/hr, plus any energy losses through the structure or ground. Therefore, 10 kilns would be necessary to maintain a load of 50 klbs/hr. Using a 10 day drying schedule plus another day for change-out time, we could get about 32 charges out of each dry kiln. With 10 kilns, using the previous assumptions, we could potentially produce 14.4 million bf of hardwood per year.

Including equipment, freight, mechanical and electrical installation and startup/training services, the first kiln would cost approximately $550,000 with each additional one costing approximately $440,000. This does not include the steam main or condensate return if our concept does not utilize the existing distribution network [15].

Our team has determined that due to economic factors, this concept should not be considered. As mentioned, lumber is usually dried nearby where it is being processed and there is not much lumber being produced in southeast Michigan. Another reason is the potential economic impact a university powered lumber kiln could have on local lumber businesses. After communicating with Fingerle Lumber Co. of Ann Arbor, MI, we discovered almost all of the lumber they sell is kiln dried. This makes it impossible for the university to ever sell lumber it produces due to competition laws and regulations.

Feedwater Heating

To improve plant efficiency, water flowing into a boiler should be pre-heated to a certain temperature, as shown in Figure 8 [16]. The steam could be used through a series of heat exchangers to heat this water, slowly becoming a condensate and being fed back into the boilers itself. This concept would keep the steam in the power plant, minimizing infrastructure changes to the university. Additionally, this concept can be used in conjunction with the condensing steam turbine because the condensate from the turbine can be used to pre-heat water flowing to the boilers. According to the CPP, only two of the boilers they operate currently use this system; the other boilers use fuel gas to pre-heat their feedwater. The system using steam now uses the high-pressure 60 psig steam, which would be replaced with 9 psig steam.

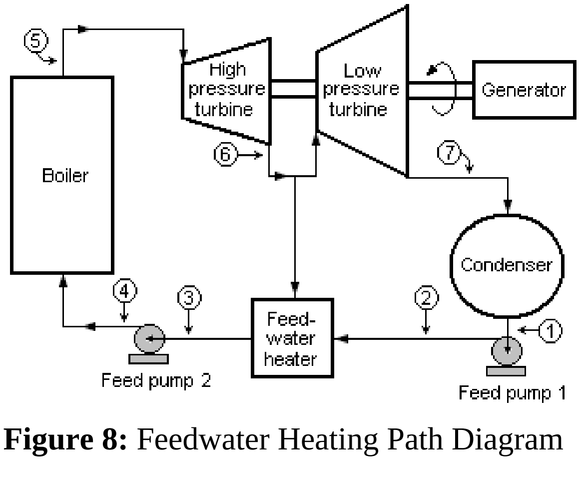

Figure 8: Feedwater Heating Path Diagram

To begin the analysis of using 9 psig steam to pre-heat the water, we were given access to a spreadsheet which estimated the cost of using 60 psig. This spreadsheet calculated the cost to heat the feedwater using the steam and the cost saving to using the steam to pre-heat the water before it is fed into the boiler, considering the entrance and exit temperatures of the steam and feedwater; the cost of natural gas to fire the boilers; the value of the electricity generated; and the boiler efficiency.

Table 4 details the variables and numbers used to figure out the net cost of using 60 psig steam to pre-heat the feedwater.

Table 4: 60 psig Steam Feedwater Heating Variables and Values

Description	Variable	Value
Extraction Steam Flow for 60 psig Steam	$\dot{m_{60}}$	$13\ \frac{klbs}{hr}$
Exhaust Steam Rate (9 psig)	$\dot{k_9}$	$16\ \frac{lbs}{kW}$
Boiler Efficiency	μ	0.83
Boiler Feedwater Flow	$\dot{m_{fw}}$	$180\ \frac{klbs}{hr}$
Steam Net Heat Input	E	$1182\ \frac{BTU}{lb}$
Feedwater In Temperature	T_{fw-in}	238 °F
Feedwater in Enthalpy	h_{fw-in}	$207.6\ \frac{BTU}{lb}$
60 psig Steam Temperature	T_{S-60}	350 °F
60 psig Condensate Temperature	T_{C-60}	307.3 °F
Feedwater Out Temperature	T_{fw-out}	295 °F
Feedwater Out Enthalpy	h_{fw-out}	$265.6\ \frac{BTU}{lb}$
Cost of Natural Gas	X_{gas}	\$7.25 / BTU
Value of Electricity	$X_{electricity}$	\$0.20 / kWh

Table 5 shows the equations used to determine the net cost/benefit to the CPP by using 60 psig steam to pre-heat the feedwater. These calculations involve finding the cost to produce the 60 psig steam using an extraction process (directly from the steam turbines used to generate electricity) and the savings by not using natural gas to heat the feedwater to its current exit temperature. Based on the numbers used in this analysis, the CPP saves \$102.67 per hour the feedwater heating system is running, which works out to over \$37,000 per year assuming the boiler is running all the time and the conditions remain the same.

Table 5: Equations 3-8 Used to Calculate 60 psig Steam Cost/Savings

Calculation	Eq.	Description	Equations	Value
Fuel Consumed w/ Extraction	3	Energy amount needed to produce 60 psig steam by extraction	$= \left(\frac{\dot{m_{60}} * E}{\mu}\right) * X_{gas}$	\$134.22 / hr
Electricity Value	4	Money CPP earns by producing electricity	$= \left(\frac{\dot{m_{60}}}{\dot{k_9}}\right) * X_{electricity}$	\$162.50 / hr
60 psig Production Cost	5	Net Cost to Produce 60 psig Steam	= *Eq. 3 – Eq. 4*	-\$28.28 / hr
Feedwater Energy Increase	6	Energy increase in feedwater due to rise in temperature	$= \dot{m_{fw}} * (T_{fw-out} - T_{fw-in}) * \left(\frac{1BTU}{1\ °\mathrm{F}}\right)$	10.26 mBTU/hr
Boiler Fuel Savings	7	Savings from not having to use natural gas to heat the feedwater	$= (Eq.\ 6) * X_{gas}$	\$74.39 / hr
Net Cost using 60 psig Steam	8	Money spent/saved by using feedwater heating	= *Eq. 5- Eq 7*	\$102.67 / hr

To begin analyzing whether or not it was possible to use 9 psig steam, we had to estimate the area over which the heat transfer was occurring to be able to compare to the current 60 psig system. On the suggestion of the CPP results engineer, we used Equation 9 to find the heat transfer area, *UA*.

$$\dot{Q} = \dot{m_{fw}}\left(h_{fw-out} - h_{fw-in}\right) = UA\,\frac{(T_s - T_{fw-in}) - (T_s - T_{fw-out})}{\ln\left(\frac{T_s - T_{fw-in}}{T_s - T_{fw-out}}\right)} \qquad \text{(Eq. 9)}$$

$\dot{Q}$ is the heat transfer rate in $\frac{BTU}{hr}$, $\dot{m_{fw}}$ is the feedwater flowrate in $\frac{klbs}{hr}$, h_{fw-in} is the enthalpy of the incoming feedwater in $\frac{BTU}{lb}$, h_{fw-out} is enthalpy of the outgoing feedwater in $\frac{BTU}{lb}$, T_s is the temperature of the condensed steam after it leaves the heat exchanger in °F, T_{fw_in} is the temperature of the incoming feedwater in °F, and T_{fw-out} is the temperature of the outgoing feedwater in °F. From this equation, we were able to estimate the heat transfer area using numbers from Table 4 to be around $32,000\ \frac{BTU/hr}{ft^2}$.

Next, we tried iterating to find the new feedwater exit temperature using 9 psig steam values as followed above, setting $T_{fw-in} = 238$ °F and $T_{fw-out} = 237$ °F from CPP data. Unfortunately, we found that at this temperature combination, the heat transfer between the steam and feedwater is practically nonexistent. Therefore, the temperature of the 9 psig steam would have to be higher than the 238 °F feedwater temperature, which means the 9 psig steam would not be 9 psig steam any longer but at a higher pressure.

While using a lower-pressure steam for feedwater heating is feasible, it would reduce the amount of steam available to generate electricity, compounding the problem. Additionally, the increase in natural gas usage would negate any savings by using the 9 psig steam. For example: the CPP earns $13.05 per hour producing the 9 psig steam using relevant numbers, whereas the increase cost for natural gas from 245 °F to 295 °F would be $66.37 hour, a net cost of more than $50 per hour. It seems that using 9 psig will be more expensive than using 60 psig steam and is not a good solution.

Steam Pump

Useful for any kind of work, a steam pump, similar to the one seen in Figure 9 [17], has many uses. For our purposes, a steam pump would be used to move liquid, such as water for fountains or irrigation. Instead of using electricity that is needed for other purposes during the summer, a steam pump could replace an electric pump. Though we have not determined a use for a steam pump yet, many of our concepts did involve some sort of pumping mechanism, and the CPP staff suggested studying steam pumps to figure out their steam demands. A steam pump could be placed anywhere on campus, making it versatile to implement. Like the condensing steam turbine, we would only need to look at the pump's specifications to figure out its steam demand for a certain loading condition.

Figure 9: A Steam Pump Example

Our team focused on the application of condensate return, investigating replacing electric pumps with steam powered variants. While specific pumps exist for this application, we discovered that 9 psig steam is unsuitable to run them. Most pumps have a minimum motive pressure of 15 psig with recommended pressures around 50psi. While the 9lbs steam is insufficient to power these pumps, they could be run on the 60lbs steam the CPP produces. While this is outside the scope of our project, we want to speak with the CPP staff to explore this possibility. The electric condensate pumps are found all over campus and present an opportunity to create a significant steam demand. This makes it one of our more promising concepts even though it does not fit our initial project description.

Composting

One of the most challenging aspects of composting is keeping the pile at the correct temperature. An open air pile, shown in Figure 10 [18], needs constant attention to maintain the process. Since we have an energy source in the steam that can be transformed into heat energy, we thought that this would be a perfect opportunity for the University or an outside group to take advantage of it and use the steam for composting during cooler months of the year, such as fall or spring. Similar to the lumber kiln concept, composting would require a heat exchanger, a shed or building, and a circulation system. Unlike the lumber kiln, the scale of composting is flexible, but we would still have to consider location because of space and smell.

Figure 10: A composting pile needs heat to speed up decomposition

This is a very basic concept that could consist of building a room or structure that could be maintained at specific temperatures for the various stages in the composting process. EPA Regulations suggest that to achieve appropriate reduction in pathogens during composting, a minimum room temperature of 40 °C should be maintained for 5 days and exceeding 55 °C for 4 hours during this period [19]. Our team decided to model this concept using a 20 x 40 x 10 foot room maintained at proper temperatures using a steam radiator. Using a BTU calculator [20], we found that for a room this size we can expect approximately 12,000 BTU's required for proper temperature management. This is with the assumptions that the room has a concrete floor, wood frame, no windows and a flat roof with insulation. The appropriate size radiator for a room of this size was should meet these estimated BTU requirements. A double convector steam radiator with a 14,000 BTU output rating we found that would work for this concept costs about $400. Most of the costs for this concept come from the construction of the room being used if no existing structures can be used.

Once we started calculating the workload of the radiator our team soon realized that this concept would not come close to meeting the steam demands requested by the plant. We would need hundreds of rooms and radiators to produce enough demand to have a useful impact on the current steam load. Therefore our team decided that we would not propose this concept as a suitable use of the steam power.

Simulink Model

The goal of our Simulink model was to simulate a full year of the power plant steam distribution system. We could then extract from this simulation the total impact that our solutions have on the demand for steam from the power plant.

Our model was composed of four primary blocks: the Environment, the Campus, the Power Plant, and the Solution. They will be organized in the manner shown in Figure 11 below. The black lines represent environmental inputs for the simulation while the red lines represent the 9 psig steam. The green line represents the steam "demand" to the power plant.

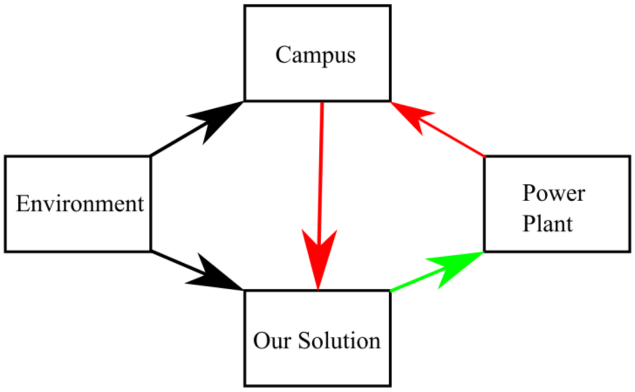

Figure 11: Simulink Model Primary Blocks

The environment block utilized the system time to reference a lookup table with weather and solar intensity data. This allowed us to simulate our concepts based on the time of year and, for the turf field concept, heat transfer from the sun.

The campus block utilized the system time to reference another lookup table with campus demand information. This table was generated using demand information from the year 2014 to not overestimate or underestimate the campus demand. The main reason for including the campus block was to ensure that at no time do our solutions result in the demand for steam exceeding the steam production capacity of the CPP.

The overarching model with all solution blocks is shown in Figure 12 below.

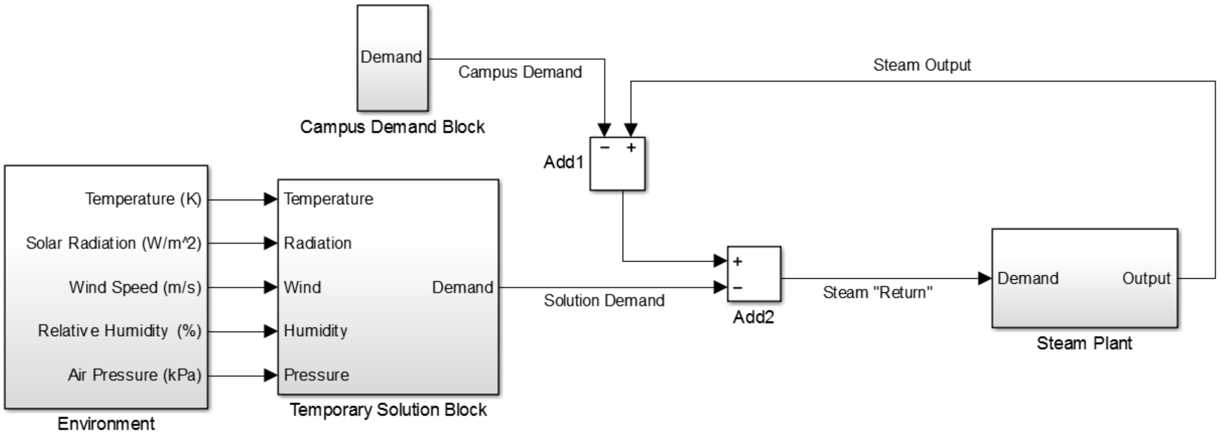

Figure 12: Simulink model with all subsystems

The campus block used a lookup table of the steam output from the year 2014 to get an approximation of the demand from the campus. The environment block used weather data from the power plant and solar radiation data from the National Solar Radiation Database provided by the National Oceanic and Atmospheric Administration [21]. The weather data came from the year 2014, while the radiation data came from 2005.

Because the CPP is operated by humans rather than a computer system, we elected to implement a simple delay between the demand coming in and the CPP responding to the output rather than implementing a PID controller.

During our research, we discovered that only the cooled turf field would need to be modeled. The feedwater system was not modeled by us because the CPP already had a model that we used for our analysis. The condensing steam turbine was not modeled because it came with a specification sheet which had steam demands listed. The other three concepts have turned out to be unusable for reasons explained earlier in this report.

The final model with the turf field system implemented is shown in Figure 13 and Figure 14 below. Figure 13 shows the overall model that the solution block feeds to determine the steam demand. Figure 14 shows how the model determines the outdoor temperature, decides whether or not to run the system (a temperature of 70 °F turns the system “on”), and runs the solution block to determine the heat transfer between the turf and circulating water and the increase in steam demand.

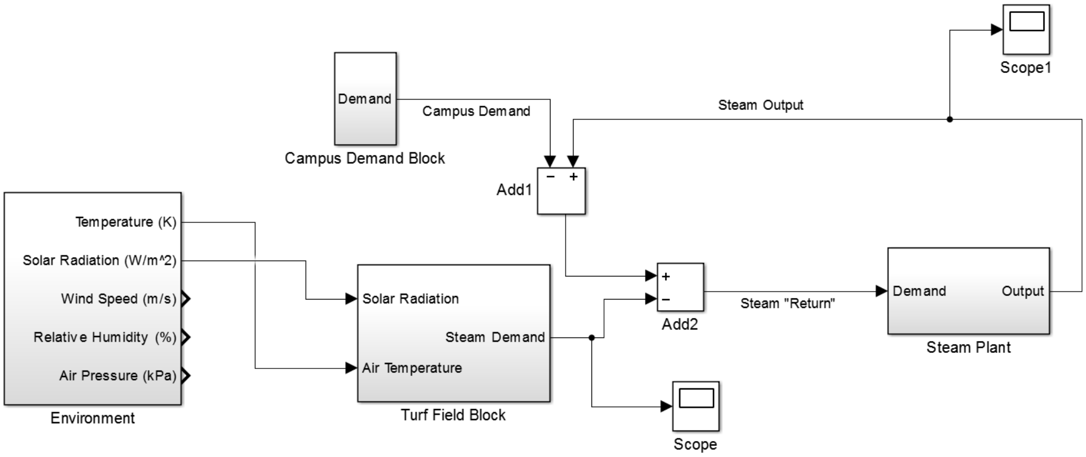

Figure 14: Overall Simulation Block

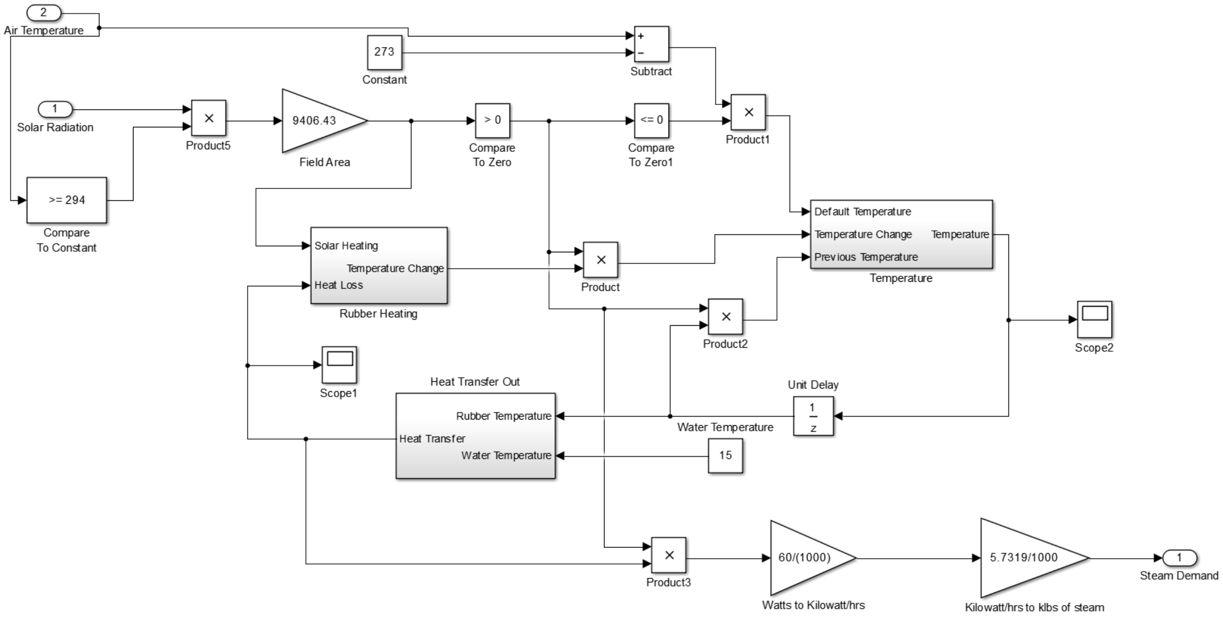

Figure 15: Turf Field Solution Block

After running the model for the turf field, we found that cooling a single field does not provide sufficient demand for a true solution. As Figure 16 shows, the turf field steam demand never exceeds 14 klbs/hr. This is not enough to reach our target and furthermore is only the instantaneous maximum rate. Averaging out the demand over a day leads to roughly 4 klbs/hr on the hottest days, and usually no more than 2 klbs/hr most days. Adding a single cooled turf field would not appreciably change the total campus steam demand. Because of the available locations that the CPP can provide steam to, it would be impossible to implement this system in more than one or two fields. Therefore, this concept is not effective enough to solve the steam demand problem

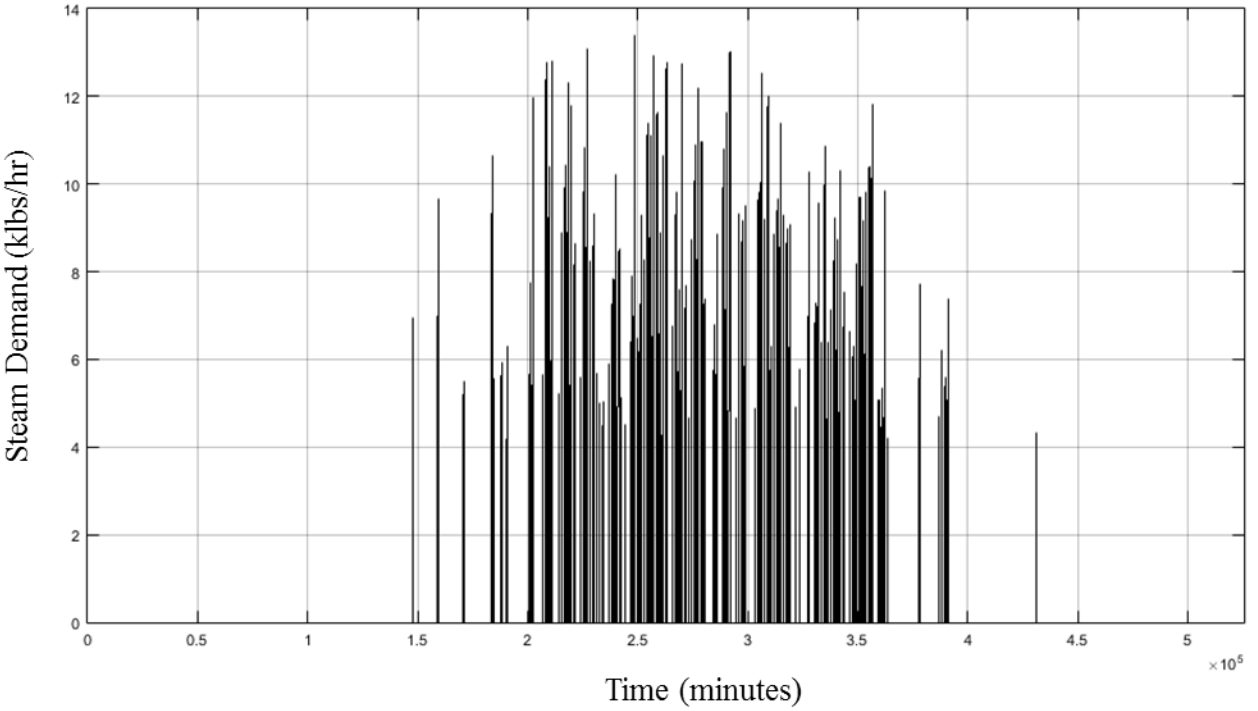

Figure 16: Turf Field Steam Demand

Conclusions

As stated earlier in the report, we could not find a solution which raised the steam demand during the summer months by more than 2 klbs/hr. Even if all the working solutions we found were installed, they would not have matched the 25 klbs/hr specification we set at the beginning of the project. Unfortunately, the steam demand from several buildings cannot be replaced by a single small-scale, inexpensive, and quick solution, much less a system that has existed for 100 years. The University created this system to consolidate all the other previous steam and electricity infrastructures, realizing the double benefit of cheap steam for heating (and later cooling) and cheap electricity for power for all buildings. This system works only if all departments and buildings support it.

Therefore, we recommend the University should consider and implement a campus-wide energy usage policy. We want to see the University encourage and perhaps require that its various departments and buildings on Central Campus and the hospital complex use utilities from the CPP rather than having these entities decide individually. This is important for the University for two reasons. The CPP produces its utilities at a lower rate than the outside utilities; since the electricity rate is low and the electric chillers are more efficient, the migration from steam-driven chillers to electricity-driven chillers has occurred. If the CPP were to stop producing electricity, the cost to cool these buildings would go up. Additionally, the CPP has to provide steam to heat the buildings during the winter months; if the CPP was to stop steam production completely, it would cost millions of dollars to convert the buildings to a different heat source. Finally, the University has committed to several environmental and sustainability efforts such as Planet Blue and the development of solar panel fields throughout its campuses; it should also commit itself to keeping the CPP in operation because it is a cleaner source of energy than traditional power plants. If the University wants to remain a leader in these fields, to find the solutions for the future, then it should keep the CPP open for the next 100 years.

If we were to change an aspect of the project, we would want to look at what we can change within the CPP itself, such as internal equipment. We think that focusing in that one area would have been more productive and a narrower scope. However, this would be a great project for a future ME 450 group. We would have not done anything different with our project because we got results that are helpful to the CPP.

Appendix A: Generated Concepts

Table A-1: Concept Generation Chart for all Concepts

	Category	Concept
1	Industrial	Heated Landfill
2		Steam Cracking
3		Lumber Kiln
4		Textile Production
5		Wine Bottling
6		Paper Production
7		Distillation
8		Fertilizer Production
9		Sulfuric Acid Production
10		Synthetic Dyeing
11		Food Canning
12		Cement Setting Moisture Control
13		Tea Production
14		Fish Farming
15		Steam Bending (woodwork)
16		Candle making
17	University	Ice Rink
18		Greenhouse
19		Heating/Cooling for Pools
20		Boiling Water in Kitchens
21		Humidify Buildings
22		Pressure Cookers
23		Cafeteria Freezers
24		Composting
25		Produce Vacuum
26		Athletic Dept. Laundry
27		Dish Sanitation
28		Potato Peeling
29		Chemistry Lab Processes
30		Cooking in Kitchens
31		Power Washing
32		Water Fountains
33		Steam Cleaning
34		Plastic Recycling
35		Irrigation
36		Toilets
37		Window Washing
38		Steam Power Demonstration Display
39		Wetlands
40		Research
41		Athletic Facilities
42		Cooling Turf for Athletic Fields

43		Fire Suppression
44		Steam Powered Tools
45	Power Plant	Water Pumps
46		Deaerator for Condensate
47		Feed Water Heating
48		Steam Engine
49		Low Pressure Steam Turbine
50	Commercial	Coffee Machine
51		Sauna
53	Residential	Heated Sidewalks

For references to Table A-1, please see Appendix C on page 31.

Many of the concepts were deemed uneconomic, either due to infrastructure costs or general profitability. These included heated landfill, steam cracking, wine bottling, distillation, sulfuric acid production, synthetic dyeing, food canning, cement setting moisture control, tea production, fish farming, candle making, greenhouse, heating/cooling for pools, freezers, produce vacuum, potato peeling, plastic recycling, irrigation, window washing, wetlands, steam powered tools, steam engine, coffee machines, and heated sidewalks.

Several concepts were quickly determined unusable as they would not increase the steam load of the power plant enough to make an impact such as paper production, fertilizer production, boiling water in kitchens, humidifying buildings, pressure cookers, dish sanitation, chemistry lab processes, water fountains, steam cleaning, or fire suppression.

Other concepts required temperatures higher than that of the steam provided. These included steam bending and textile production.

Some concepts were eliminated if they exceeded the range of the current distribution network. Since the university’s south campus has their own plant, many of our concepts related to the athletic department were out of our scope. These included using athletic department laundry, athletic facilities, and saunas.

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Appendix D: Ethical Design Statements

Jay Ghesquiere

Our team had a unique project. While other teams were asked to address a specific problem by designing and fabricating a solution, our team had a more researched based project. The Central Power Plant asked us to find opportunities to increase steam use on campus with the goal of increasing their electricity production. After a semester of through research and modeling, our team has come to the conclusion that there are no practical ways to increase the steam demand on campus a significant amount. Rather than tell the power plant what they wanted to hear, our team has presented the power plant with our conclusions. Because the power plant affects so many on campus, and is facing such a large problem, our team felt the most ethical decision was to be honest and present our findings to the power plant as early as possible.

The power plant is facing a decreasing demand for steam, especially in the summer due to the phasing out of steam absorption chillers in university buildings. The plants ideal solution was to simply replace the steam demand from the chillers with another application on campus. While the main problem with this concept is the lack of demand for steam around campus, some of our investigated solutions were ruled out for other reasons. One of the main obstacles our team encountered was interference with local businesses. Steam is often used to produce a product or provide a service, however many of these products and services are available from local businesses. Because the university is public, it was decided that it would be unethical to try and compete with local businesses. For example, we investigated using steam to dry lumber that the university could then use or sell. However we found that two local lumber yards primarily sold dried lumber. For this reason we decided not to move forward with this concept.

Joshua Kotrba

From the NSPE Code of Ethics it is clear that user safety is the most important goal of any engineers work and the best chances of meeting that goal is through honesty and integrity. Our team put this into practice this semester as we selected our concepts by looking at the social, environmental and economic impacts of each one. For example, one of the concepts we investigated was a steam powered lumber kiln. Things other than design specs we had to consider included an economic analysis of the impact on the local lumber businesses. From our communication we were able to determine that this concept could have an impact on sales as the kiln dried lumber is a majority of their product. Another example is when we were investigating the use of steam power in composting. This is one of our more environmentally sustainable concepts and it was chosen for additional researching not only because it was feasible, but also because of the positive environmental impact.

Our team showed integrity in every step of our design process. This was demonstrated by our consistent communication with all of our project stakeholders to ensure we always fully understood our responsibilities. Our project does not fit the standard structure of the design review process and our team worked closely with our professor to adapt our project to the course requirements. This meant everyone was on the same page every step of the way and any major concerns relating to the expectations of our final deliverable have been avoided. We also worked closely with the plant managers throughout the semester to make sure we fixed any mistakes in our concept assumptions earlier in the design process to avoid larger errors later on. All of these steps helped us to produce accurate research for the many concepts proposed.

Lucas Rieckhoff

In terms of ethics, our project is difficult because we did not have a physical prototype to consider in terms of ethical engineering. That being said there were a few things that we did have to consider at all times.

Our project requires us to think of ways for the university to increase their demand for steam so that the power plant can operate more effectively. When coming up with solutions and evaluating them, we have to consider the effects that they have on local businesses. We do not want the university to start providing a service that hurts local businesses. We also do not want to suggest solutions that are intentionally inefficient. In this case, we would just be passing off the cost of the problem to another area of the university instead of helping the power plant actually solve the problem.

Ethan Shuman

We have definitely followed the Code of Ethics in our design process. First and foremost, we have been open and honest with our sponsor, our professor, and our audiences. We have a difficult project in that it takes a lot to fully explain and understand its scope. We also have more research and design than any other project, although we do not have to manufacture a prototype. Therefore, communication has been essential to convey our progress and thoughts to make the most effective project as possible.

Based on the openness we have striven towards, we have tried to remain objective in researching and deciding on important matters relating to our project. Admittedly, this has not been easy to do, given that there were obvious yet non-ideal solutions (such as just shutting down the plant, or venting the steam into the atmosphere, which would have environmental ramifications). However, we got past this by focusing on generating as many concepts as possible and setting guidelines on which would pass to be considered further.

Lastly, we have acted as trustees for our sponsor. We have avoided conflicts of interest and remained devoted to working solely on the work they have set out for us. This has been easy for this project since we have had only incidental contact with people other than our sponsor and professor. However, it was important to us to listen to our sponsor to understand their requests and deliver them to the best of our abilities.

Appendix E: Biographies

Jay Ghesquiere

Jay is a senior in Mechanical Engineering from Bloomfield Hills, MI. Jay spent his summer interning at Detroit Manufacturing Systems, a relatively new automotive supplier in Detroit that manufactures instrument panels. He has also spent summers working in an automotive service shop as a technician. Outside of class Jay is busy designing the braking system on the University of Michigan’s Formula SAE team. He is also a captain of the school’s Ski Racing Team. After graduation he hopes to stay in the Detroit area.

Joshua Kotrba

Josh is a senior in Mechanical Engineering from Laingsburg, MI graduating in December 2015. Josh has previously worked with DTE Energy on the analytics team tasked with optimizing the production schedule of their many power plants. Josh has also worked with the Operations team at Goldman Sachs optimizing procedures for tasks that help support the Investment Banking Division. Upon graduation, Josh will be returning to work with Goldman Sachs full time. Josh has had the opportunity this last year to be a part of a Multidisciplinary Design team, where he works with RACER Trust and the state of Michigan to research ways to reutilize brownfield sites, specifically those left after the bankruptcy of General Motors in 2008. He also works with a professor in the Electrical Engineering department conducting research on what causes intrinsic motivation to learn new engineering materials, or new information in general. This is a key part of learning the best way to present and teach new materials to students to increase the retention of that information. Hobbies include golfing, snowboarding and automotive restoration.

Lucas Rieckhoff

Lucas is a senior in Mechanical Engineering hailing from Ann Arbor, MI. Lucas interned this summer at C.L. Rieckhoff Co., Inc., a steel fabrication company focused on producing chutes and drive systems for conveyors in the package transportation, and metal wall and roof systems for both the industrial and commercial sectors. In previous summers, Lucas worked in the shop at the same company, acquiring hands on experience with a variety of steel fabrication techniques. Lucas has had no direct experience working with power plants; however, he did take ME 336 (Thermodynamics II) where a significant portion of the time was devoted towards calculating outputs of combined cycle reheating power plants. Lucas currently has no plans for the future but does hope to become fabulously wealthy before retiring to live a secluded life in Europe. In his spare time, Lucas enjoys making CAD models (he built a computer this summer specifically for this purpose) and is an avid historical fencer.

Ethan Shuman

Ethan is a senior at the University of Michigan and will graduate with a degree in Mechanical Engineering in December 2015. A self-proclaimed car nut, Ethan grew up dusting cars beginning at the age of five, eventually graduating to making coffee, sweeping the floors, driving customers around, and selling cars at his family's Chrysler dealership in Walled Lake, MI. This love of cars grew into a series of internship at Toyota's technical center in Saline, MI, in the interior trim and crash testing departments. Upon graduation, Ethan will work at Toyota in the powertrain calibration department. Apart from obsessing with cars on a daily basis, Ethan enjoys playing the trumpet in various music groups, which have included the Michigan Marching Band and Michigan Hockey Band. Ethan also enjoys traveling, especially to Europe, playing soccer with friends, and skiing.