UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Thermal Mass for UBC Campus and Nexterra Bioenergy Research and Demonstration Project

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Final Report

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UBC SEEDS Thermal Mass Team

Objectives

The UBC SEEDS (Social Ecological Economic Development Studies) program focuses on uniting academics and students with campus operations in order to promote and develop sustainability. The objective of the SEEDS thermal mass project is to investigate a solution that will contribute to the campus goal of being Carbon neutral by 2050. To determine the success of the proposed solution, the project has be evaluated using three performance metrics:

- GHG (Greenhouse gas) emissions
- Capital cost
- Payback time

Further detail on these evaluation criteria and their respective weightings can be found in Dossier Section 6. The primary target is GHG emission reductions, but in order for the solution to be implemented it must also be economically feasible.

The solution investigated involved the augmentation of the Nexterra Bioenergy Plant cooling loop with a thermal storage unit. This unit would capture heat during low heat demand periods that would otherwise be rejected to atmosphere and release this heat during high heat demand periods. A heat exchanger is currently implemented to transfer the majority of waste heat into the district hot water system. During normal operation the supply of waste heat exceeds what is required, but during times of high heat demand the waste heat is insufficient and natural gas is burned in order to compensate. A simulation was generated to investigate the effectiveness of a thermal storage unit as a solution and a feasibility study was created to outline the costs and benefits associated with this solution.

Design and Testing

A simulation of the cooling loop system for the IC (Internal Combustion) engine was chosen over a physical prototype for several reasons, namely the scale of the system, time requirements to observe system responses, varying environmental conditions, and the ability to test and compare a number of different configurations rapidly. The system was modeled in SimuLink, a model-based design program ideal for dynamic systems and a member of the MatLab suite.

The primary components of the system level simulation are the Internal Combustion Engine (ICE), the PCM Heat Exchanger, the Heat Exchanger (a conventional plate heat exchanger), and the Radiator. Each of these components is represented as a block with inputs and outputs and various internal operations to model the physical behaviour of the device1.

[1] For a more detailed explanation of the processes involved see Dossier Phase 11 – Detailed Design

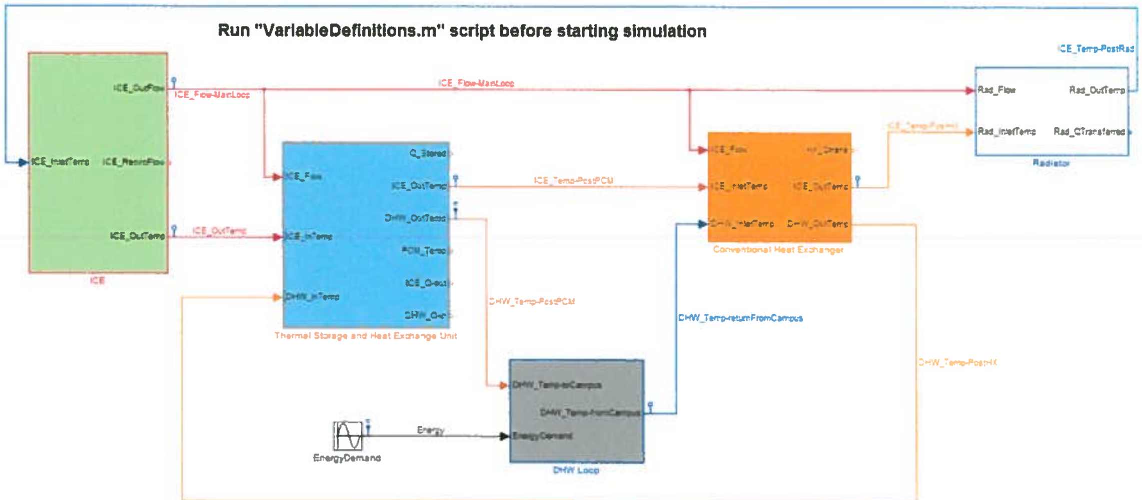


Figure 1: Simulink User Interface

The user is able to define inputs for

- DHW (District Hot Water) supply and return temperatures
- Campus heating demand
- DHW flow rate
- ICE (Internal Combustion Engine) inlet and outlet temperatures
- Heat exchanger effectiveness
- ICE cooling loop flow rate

Results are produced graphically showing the performance of the thermal mass with the two systems over a defined period of time. Currently the demand data is fictitious but as operation of the Nexterra Bioenergy Plant continues and data collected, more accurate and relevant results can be obtained.

Throughout the entire system, intermediate temperatures were output for testing and troubleshooting purposes. Hand calculations confirmed that the energy transferred or absorbed across each process is being accounted for correctly. At the PCM section, the energy lost by the ICE loop does not match the energy gained by the DHW system, but this is reflected by the change in thermal mass temperature. The system provides appropriate energy balances before, during and after the phase change.

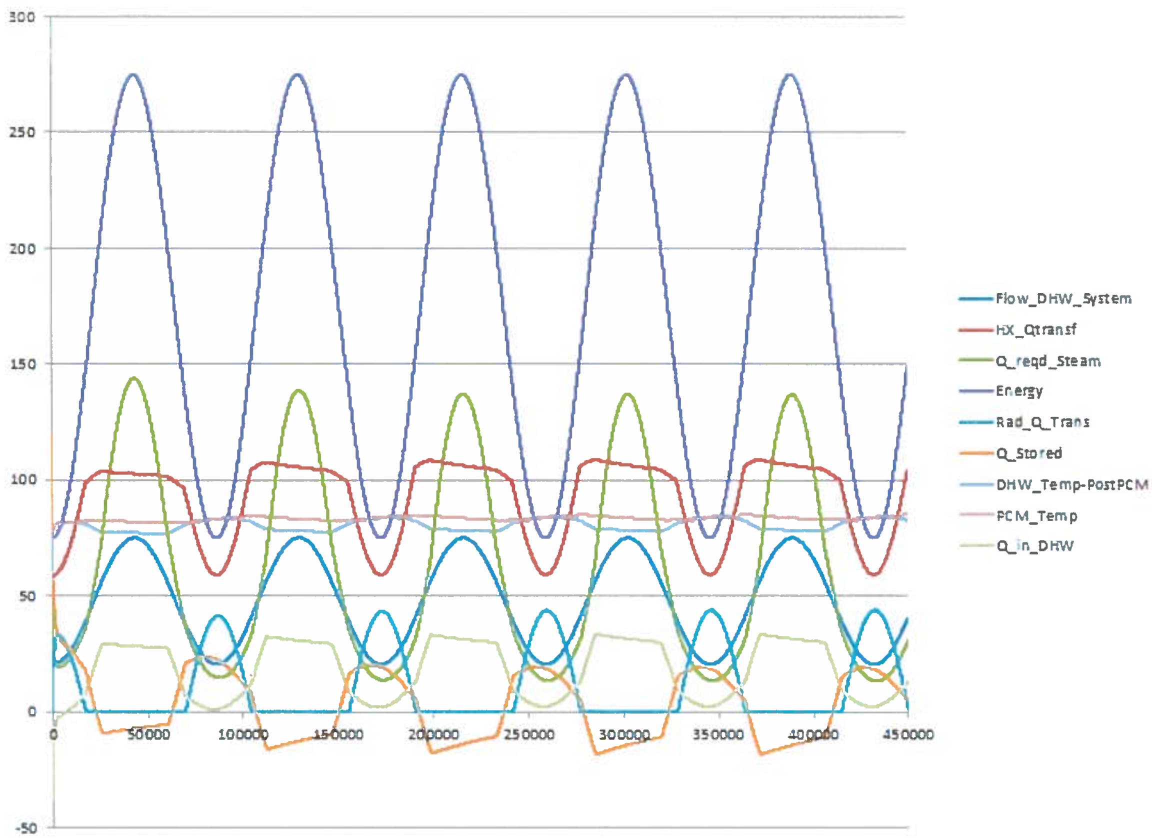
An Excel spreadsheet was also produced to be used in conjunction with the Simulink model in order to evaluate the simulation results against the prescribed evaluation criteria. This Excel file takes the output of the daily amount of energy supplied by the thermal mass and requires the user to input values for

- Safety factor
- Peak hours
- Peak to normal ratio
- Heat pump coefficient of performance

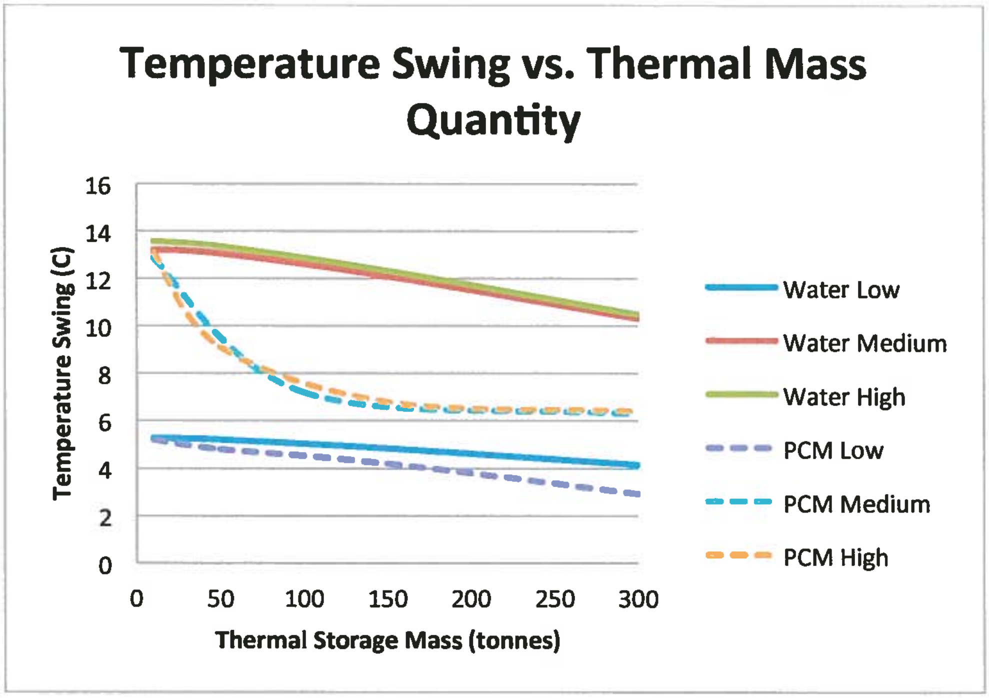
This was done to allow flexibility on the performance parameters of the ICE and DHW systems since they are newly implemented and insufficient data has been produced for comprehensive analysis.

Conclusions

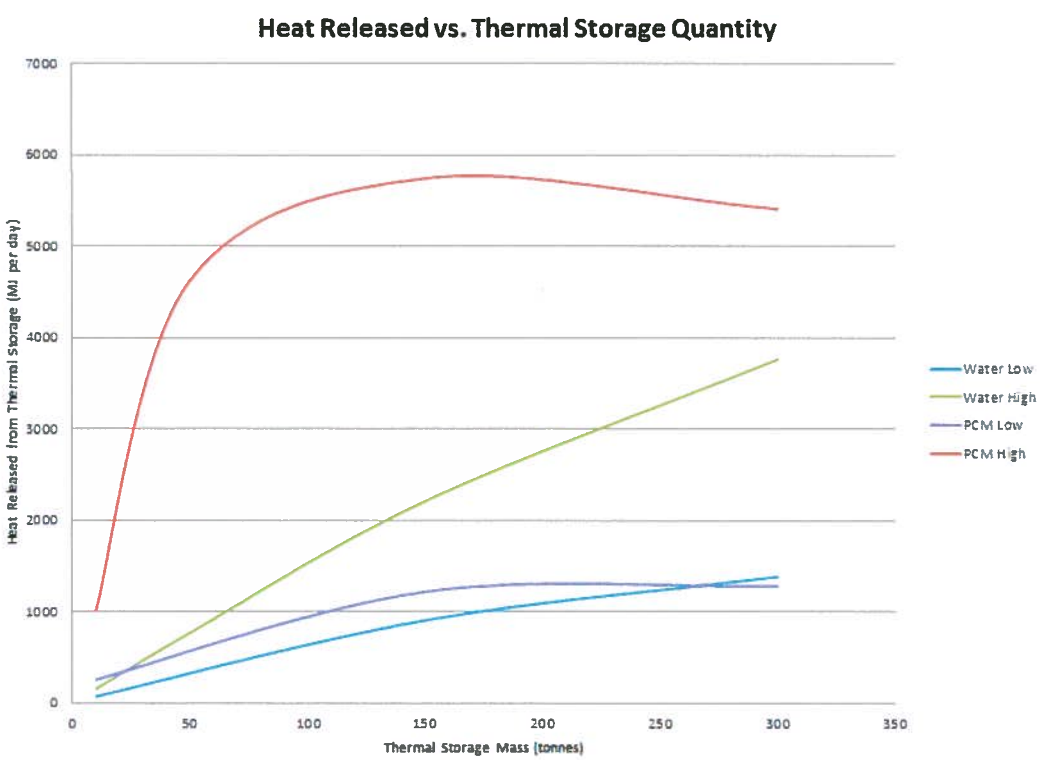
After first constructing, and then verifying and validating the results of the SimuLink performance simulation, three differently designed systems were simulated—the currently designed cooling loop without a thermal storage device, with a phase-change material (PCM) thermal storage device, and with a water thermal storage device—for three different demand curves—low heat demand, normal heat demand, and high heat demand. An example of the post-processed result of such a simulation, in this case for the cooling loop with a PCM thermal storage unit experiencing normal demand, is shown below:



The temperature swing measures the variation in outlet temperature of the district hot water after passing through the thermal storage heat exchanger. With water as the thermal storage material, the temperature swing is more pronounced. The phase change material shows a quick improvement as the mass increases, but this benefit quickly levels off for the medium and high demand cases, as can be seen in the figure below.



As the mass of the thermal storage material increases, more energy can be stored, but there is a point where adding more mass will not increase the energy recovery for a given demand case. By plotting energy recovery against mass, an optimal size for the PCM thermal mass system was determined. The optimal size for the water thermal mass system was chosen to offset the same amount of GHGs as the PCM thermal mass. This comparison is demonstrated in the graph below:



Simulation results show a slight advantage for the phase change material in the metrics evaluated. The highly non-linear behavior of the phase change material creates more potential for optimization, but it also limits the returns over varying load cases. With phase change material, the optimal mass for thermal storage is between 100 and 150 tonnes, but with water there is no clear optimal point. Since water is essentially a free material, the cost of increase the storage mass is limited to the cost of building a bigger storage vessel.

After the simulation was used to generate optimal sizes for the thermal mass storage units, the costs and savings were calculated for both the water and PCM storage units. Savings were created through a reduction in natural gas usage, and corresponding reductions in emissions taxes, and costs arose from capital purchase up front, and maintenance over time. The following values were generated:

	Water Thermal Mass	PCM Thermal Mass
Optimal Size (tonnes)	150	50
Capital Cost ($x1000)	60	140
Annual Savings ($x1000)	11.5	14
Payback Time (years)	~5	~10
Natural Gas Reduction (GJ per day)	2.2	2.7
GHG Reduction (tonnes per year)	40	49

Recommendations

In order to determine the risks associated with our use of a thermal mass to augment the cooling loop of the Nexterra internal combustion engine, our key goals were to:

1. Analyze the impact of the failure of individual system components on the entire system.
2. Investigate the possible risks involved if the thermal mass storage system was improperly designed.
3. Consider the impact of extreme environmental conditions on the system.

The most valuable conclusions from this analysis were regarding Goals 2 and 3. We found that improper design of the thermal mass would prevent it from performing its desired task, and we recommend:

- Extensive simulation and testing to analyze the performance of the system prior to implementation of the full-scale system

- Considering various thermal mass configurations to find the optimal one

We found that extreme environmental conditions, such as unusually high heat demand, or the IC engine shutting down, would have a very small impact on the system, which would return to normal operating conditions once the extreme conditions had passed. We do recommend:

- Installation of bypass loop for DHW to prevent loop and thermal mass acting as heat sink

The primary method of generating value with this project is the reduction of natural gas required for heating the district hot water loop. The phase change material performs better than water, but the margin is less than five percent. Given the significant cost of salt hydrate phase change materials, the slight benefits gained from selecting an optimum mass are still not economically justified.

We recommend a water thermal storage unit of roughly 150 tonnes, which would occupy a volume of 150 cubic metres. This unit would be installed next to the current heat exchanger on the cooling loop and would require roughly 5 years to pay for itself.