Thermal Storage Solution for Vertical Farming

Team 20: Ana Cabriada, Dylan Hutra, Adrian Sperl, Michael Stamm

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Trusted Thermal Consulting

Evaluation form

ABSTRACT

Trusted Thermal Consulting, LLC is consulting for AgriTech North, a non-profit organization based in Dryden, ON, with a mission to battle the larger issue of food insecurity that plagues indigenous communities in Northern Ontario. The proposed vertical farm adopts a solar tri-generation system to provide energy, heating, and cooling for the facility, reducing the current demand for electricity and natural gas. The design proposes the use of a potassium formate heat transfer fluid (HTF) to capture heat generated by solar-thermal panels outside of the facility, as well as the excess heat generated by grow lights in the vertical farm. A well-insulated tank containing a phase-changing material (PCM), hexadecane wax, will be used to store the thermal energy, which will then be fed to an adsorption-based chiller. The process was simulated in Python using solar irradiance data collected hourly in Dryden for 18 years.

OBJECTIVES & OVERVIEW

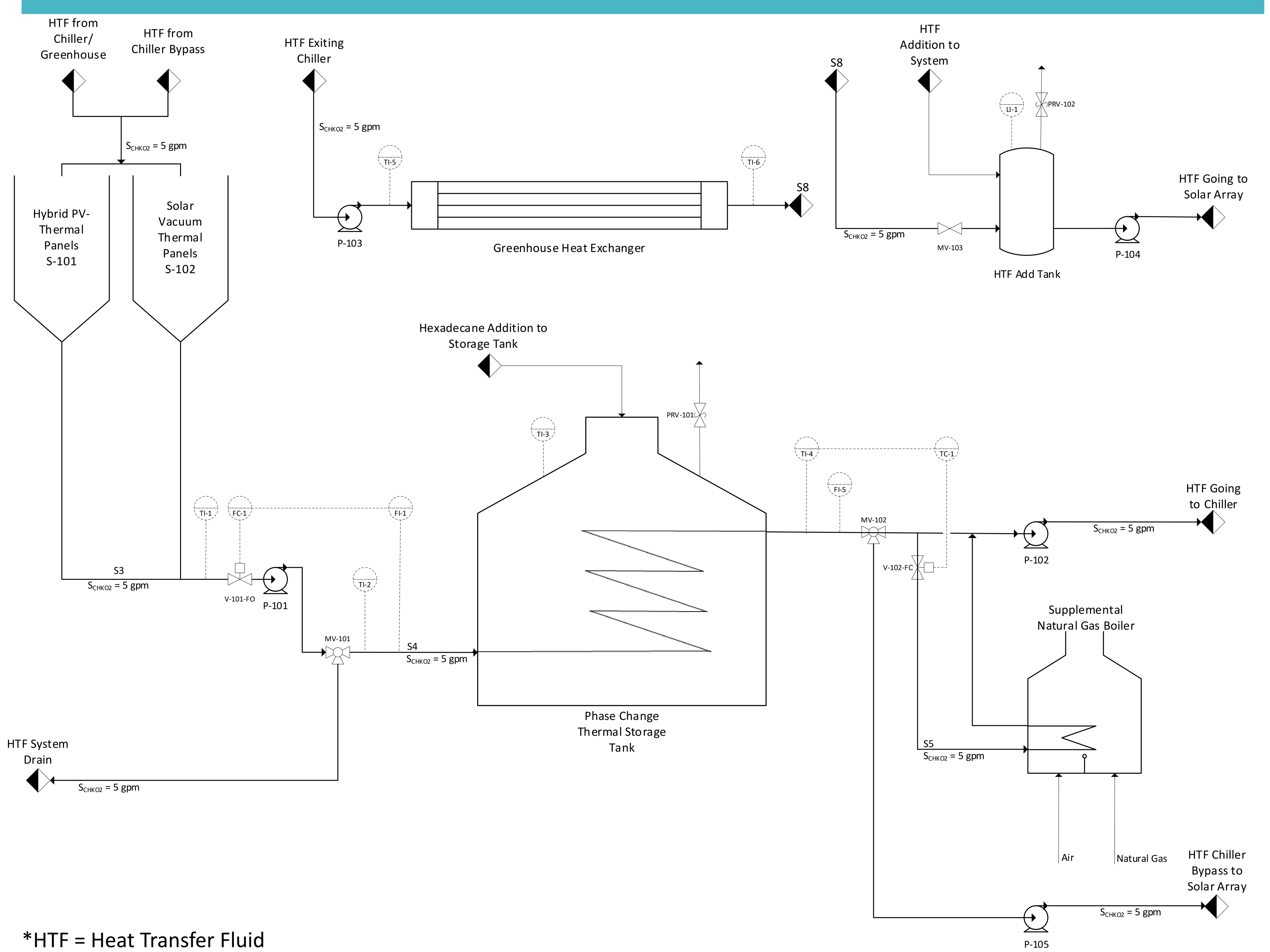
OVERVIEW

- Northern Ontario is a food desert due to sparse population and environmental limitations
  - Indigenous household food insecurity rates in Northern Ontario have been reported as high as 70%, as opposed to 16.9% province average
  - Traditional agricultural practices unfeasible due to frigid temperatures (down to -40°C) and rocky terrain
- Vertical hydroponic farming provides a consistent supply of produce by maximizing yield per area and enabling year-round operation, but has higher energy demand and emissions
- Solar tri-generation mitigates this energy demand by using solar-thermal panels for energy and heating, and by using an adsorption-based chiller for cooling
  - Cooling occurs from spontaneous evaporation inside the chiller's vacuum, and heat is fed to the chiller to regenerate the system

OBJECTIVES

- Generate equations for estimating the thermal energy harvested by the solar-thermal panels, emitted by the grow room lights, transferred via heat exchange to the HTF, and lost through the walls/tubing
- Simulate the heat transfer in Python using irradiance and temperature data to determine chiller demand
- Size the well-insulated PCM tank based on the chiller demand
- Select environmentally friendly materials for the PCM and heat transfer fluid
- Present AgriTech North with a detailed final design and economic analysis

THERMAL STORAGE SOLUTION SYSTEM P&ID



*HTF = Heat Transfer Fluid

DESIGN DETAILS

CRITERIA

- Provide 73.5 kWh of Demand between 5pm and 11am daily from April through November (Assuming 70% of cycle time of 105kW chiller)
- Store thermal energy in 2,500 gallon tank containing environmentally friendly phase change material (PCM) of hexadecane wax
- 120 PV panels and 30 Thermal Panels to be installed at AgriTech North facility

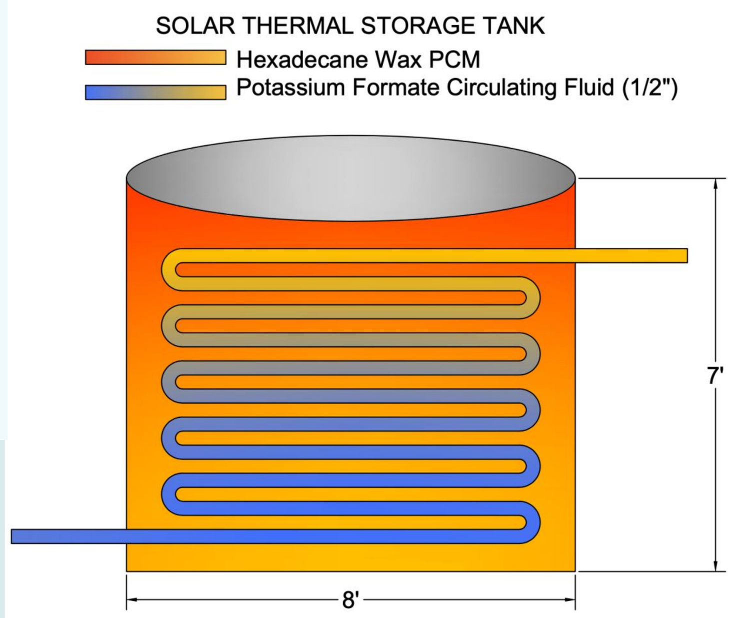
SAFETY

	Melting Point (°C)	Boiling Point (°C)	Flashpoint (°C)
Potassium Formate HTF	-55	118	N/A
Hexadecane PCM	18	287	112

The HTF is biodegradable, nontoxic, and operable year-round when capturing heat from solar panels. To mitigate PCM flashing hazards, the storage tank will have a maximum operational temperature of 95°C. The tank will operate between 14 psi and 20 psi to mitigate accidental release of the HTF and PCM.

HEAT TRANSFER

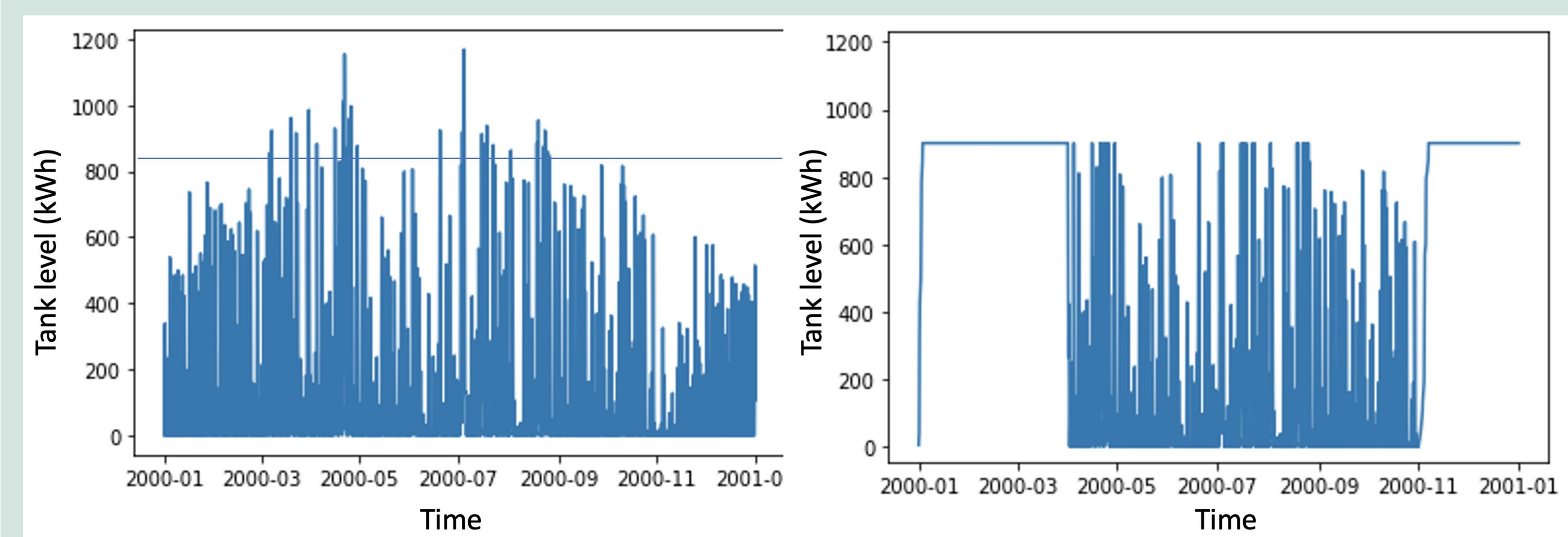
EQUATION	APPLICATION
$Q_{solar}(t)\,[kWh] = DNI(t)\left[\frac{W}{m^2}\right] \times \frac{1kW}{1000W} \times 1hr \times (\eta_{thermal}N_{thermal} + \eta_{PV}N_{PV})$	Collection of solar irradiance
$Q_{lights}\,[kWh] = \eta_{LED} \times \frac{1\,kW}{1000\,W} \times 1hr \times \sum (N_{lights,i} \times W_i)$	Energy generated by grow rooms
$Q_{cond,walls}(t)\,[kWh] = \sum_{i=1}^{n_{external}} \left(k_i A_i \frac{T_i - T_{outside}(t)}{L_i}\right) + \sum_{j=1}^{n_{internal}} \left(k_j A_j \frac{T_j - T_{office}(t)}{L_j}\right)$	Energy loss through facility walls
$Q_{HEX}\,[kWh] = -kA_{lm}\frac{dT}{dr} = \frac{2\pi kL\Delta T}{\ln\frac{r_o}{r_i}}$	Heat exchange in grow rooms



The suggested tank design based on system modeling and environmental considerations is a 2,500 gallon tank, which must be custom built of carbon steel for chemical compatibility with the hexadecane wax and potassium formate fluid.

SIMULATION RESULTS

SIZING OF THERMAL TANK: 850 KWH

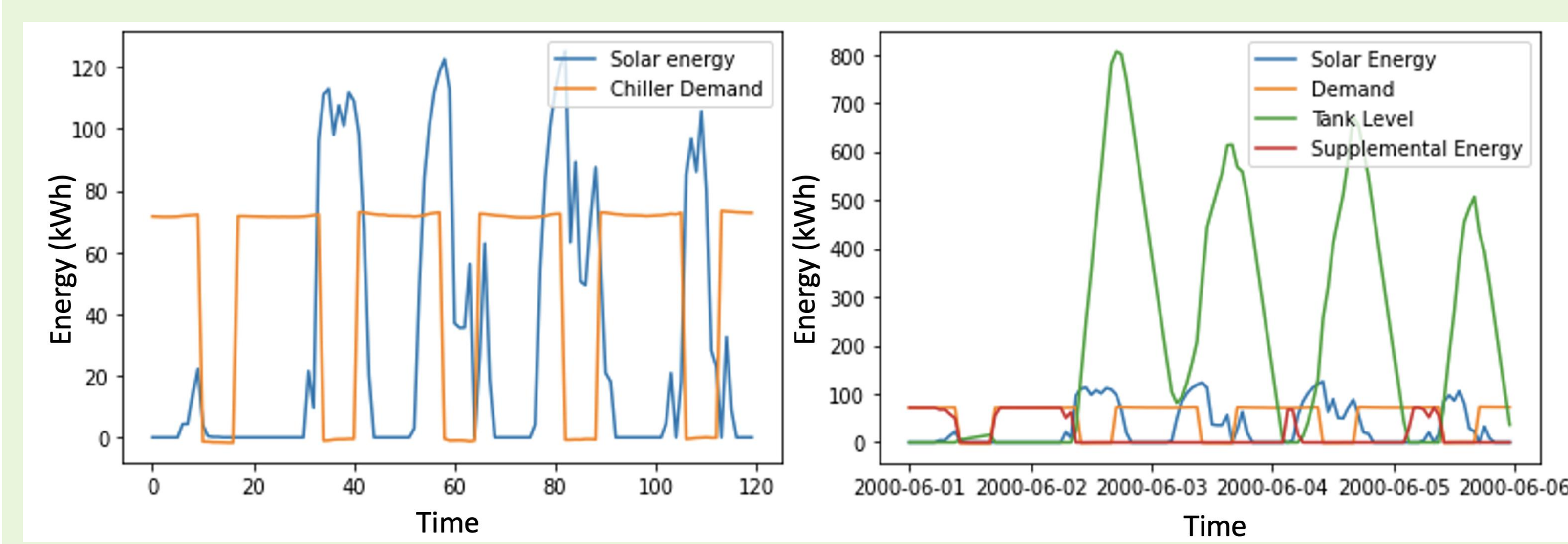


Solar supply and demand was modeled for a typical operational year to determine amount of storage required to maximize use of available solar energy.

The solar thermal tank size was determined to be 850 kWh equivalent of hexadecane wax, which equates to a 2,500 gallon thermal tank based on phase change properties of hexadecane wax, the average daily temperature (14 °C), and the maximum operational temperature (95 °C).

It was determined that accumulating storage from low demand months (November-April) would lead to small efficiency improvements compared to high capital costs.

TYPICAL OPERATION IN SUMMER INDICATES NEED FOR SUPPLEMENTAL ENERGY



When supply and demand are modeled for a typical 5-day operational window, it is evident that supplemental energy is needed to meet the full chiller demand when the tank level is depleted.

Natural gas will be used to supplement the remaining energy demand via a boiler.

CONCLUSIONS

Solar energy can be harvested to meet some of the cooling demand between April and November at the AgriTech North grow rooms. Based on typically available solar energy, a 2,500 gallon carbon steel thermal storage tank with hexadecane wax should be installed to utilize daytime solar energy during evening chiller demand. The client-proposed solar configuration of 120 PV panels and 30 solar thermal panels is not sufficient to meet the full projected 73.5 kWh of demand, so natural gas will be required to supplement remaining heat via a boiler. The final design solution consists of potassium formate circulating fluid and hexadecane thermal storage material, which meet the client's objectives for low environmental toxicity. Further work must be done to conduct an economic analysis on the final design compared to current operation.