

Introduction

Our client, Ruhstaller Brewery, is one of the only breweries in North America that grows its own hops for their beer production. This means that while most breweries purchase their hops already processed, our client grows, harvests, and dries their hops all onsite. To dry the hop cones, they must be kiln dried at **120 degrees Fahrenheit** with **constant air flow**.



Our client also has a strong desire to be independent of the power company, and for that reason wants **the ability to generate all of the needed power onsite**.

Objective

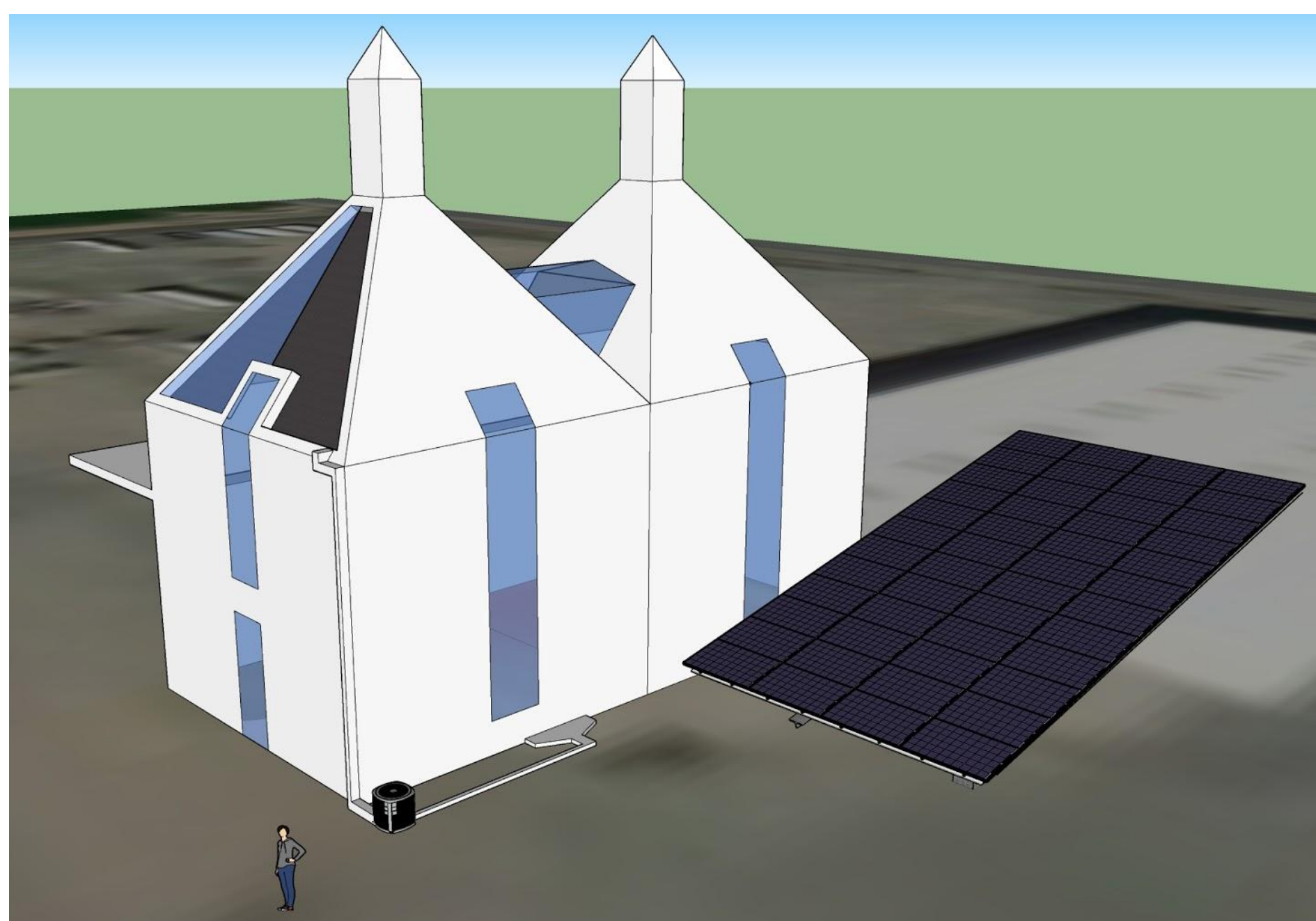
Given the realities of the site, and the client's main goals of independence, we realized we needed a system run on electricity that could also fulfill these other objectives:

- Air temp of 120 degrees F
- Constant air flow through the hop bed
- Heat must be available 24/7
- The aesthetics of the building must be preserved (i.e. no ugly, bulky machinery)

We had one other main objective during the design process. The client wanted the kiln to function as a tap room when the structure was not in use drying hops. Given that, the building also needed to have an integrated climate control system.

System Scope

We devised a system in which a roof top thermal collector, integrated into the roof, would preheat air that was then funneled through a heat pump, heated the rest of the way, and then pushed into the building. The whole process would be powered by onsite solar. A simplified system, using existing building schematics, is shown here.:



Methods

Heating and Cooling Load

The HVAC (for taproom) and Drying Loads were analyzed and estimated separately.

Drying: To preserve hop quality, the system needs the ability to maintain a constant temperature (120°F) and a specific airflow. The heating load and airflow were quantified in [BTU]s and [cfm] respectively.

HVAC: We assumed that the system would provide heat up to 68°F and cooling to 72°F

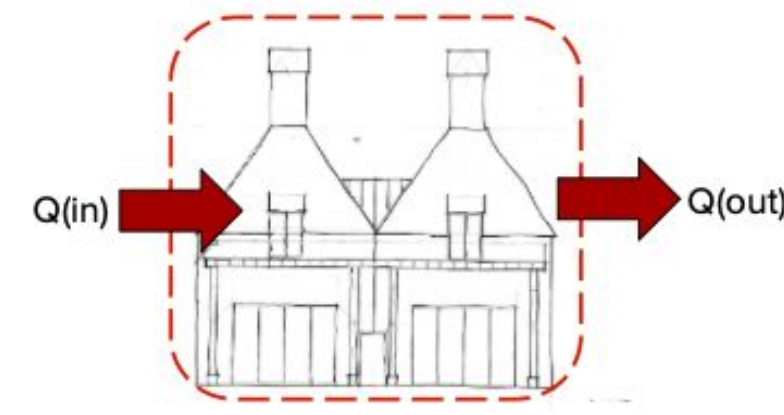
The heating and cooling load of the hop kiln was calculated with the following formula. It assumes that to achieve a constant temperature, the heat addition needs to equal the heat loss (see figure below)

The heating and cooling load of the kiln was then determined using Formula (1) and (2), whereas

- **U-Values** are a measurement of the heat transmission of each building aspect
- **HDD/ CDD** values are a measurement designed to quantify the daily heating/ cooling demand of a building
- **A** represents the Area of the single building parts.

$$(1) Q_h = A * U * HDD * 24h$$

$$(2) Q_c = A * U * CDD * 24h$$



Heat Pump

Sizing was calculated based on a daily maximum load assumption.

In general it can be assumed that a commercial heat pump can provide 400 cfm/rated tonnage. Additionally it is known that ideally the air-flow through the hop bed should be around 0.8 in*min/ft. This leads, assuming a hop-bed-thickness of 20 in, to a required air-flow of 18225 cfm. The tonnage required was the calculated according to formula (3).

$$(3) \text{Heat-Pump size [tons]} = (\text{required air flow [cfm]} / (400 \text{ cfm*tons}))$$

PV Array

The size of the PV-Array can then be determined from the heat pump tonnage, efficiency, and load. If the heating and cooling loads are known, the electricity demand of the heat Pump can be calculated as described in Formula (4) and (5). HSPF and SEER describe the Heating and Cooling efficiencies of the Heat Pump in BTU per Wh.

$$(4) W_h = Q_h / \text{HSPF}$$

$$(5) W_c = Q_c / \text{SEER}$$

The total number of PV-Cells of the array are then determined by dividing the maximum daily electricity load by the capacity of 1 PV cell, whereas the capacity of 1 PV-cell was assumed to be 2.6 kWh.

Cost Calculations

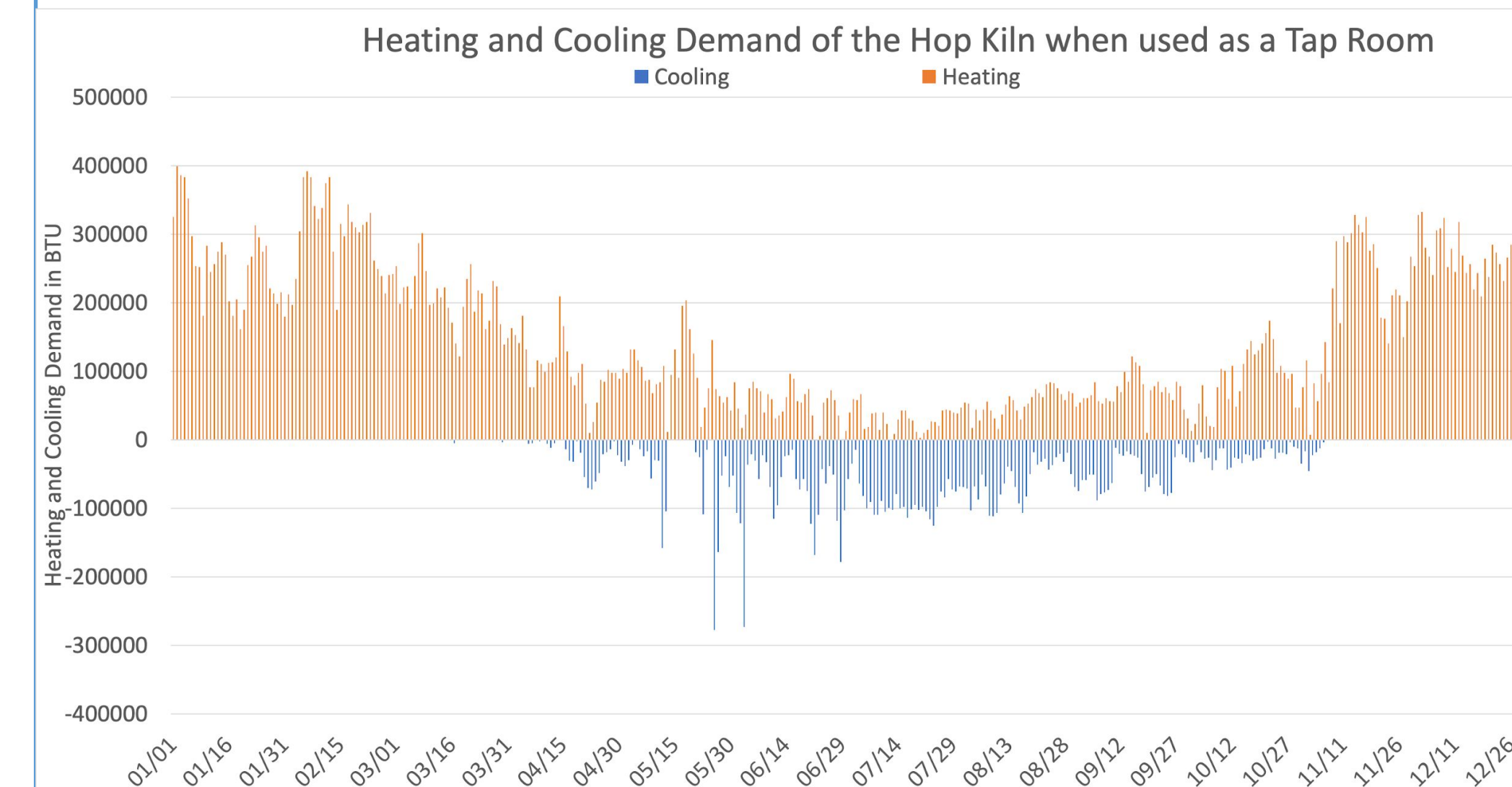
Currently the heat for the drying process is supplied by combusting Natural Gas. It is assumed that 1,037 BTU can be generated from 1 ft³. The cost is then calculated assuming a price of \$ 8.76 per thousand ft³ of natural gas and \$ 0.16 per kWh of electricity. The operational cost of the system can then be calculated by multiplying the demand with the cost.

The capital expenditures were estimated using national averages as well. For **PV-Cells \$ 3.05 per kWh installed** were assumed. The installation cost of solar thermal was estimated to be similar to the installation cost of a solar ventilation preheat and therefore assumed to be \$ 31 per ft² installed.

Results

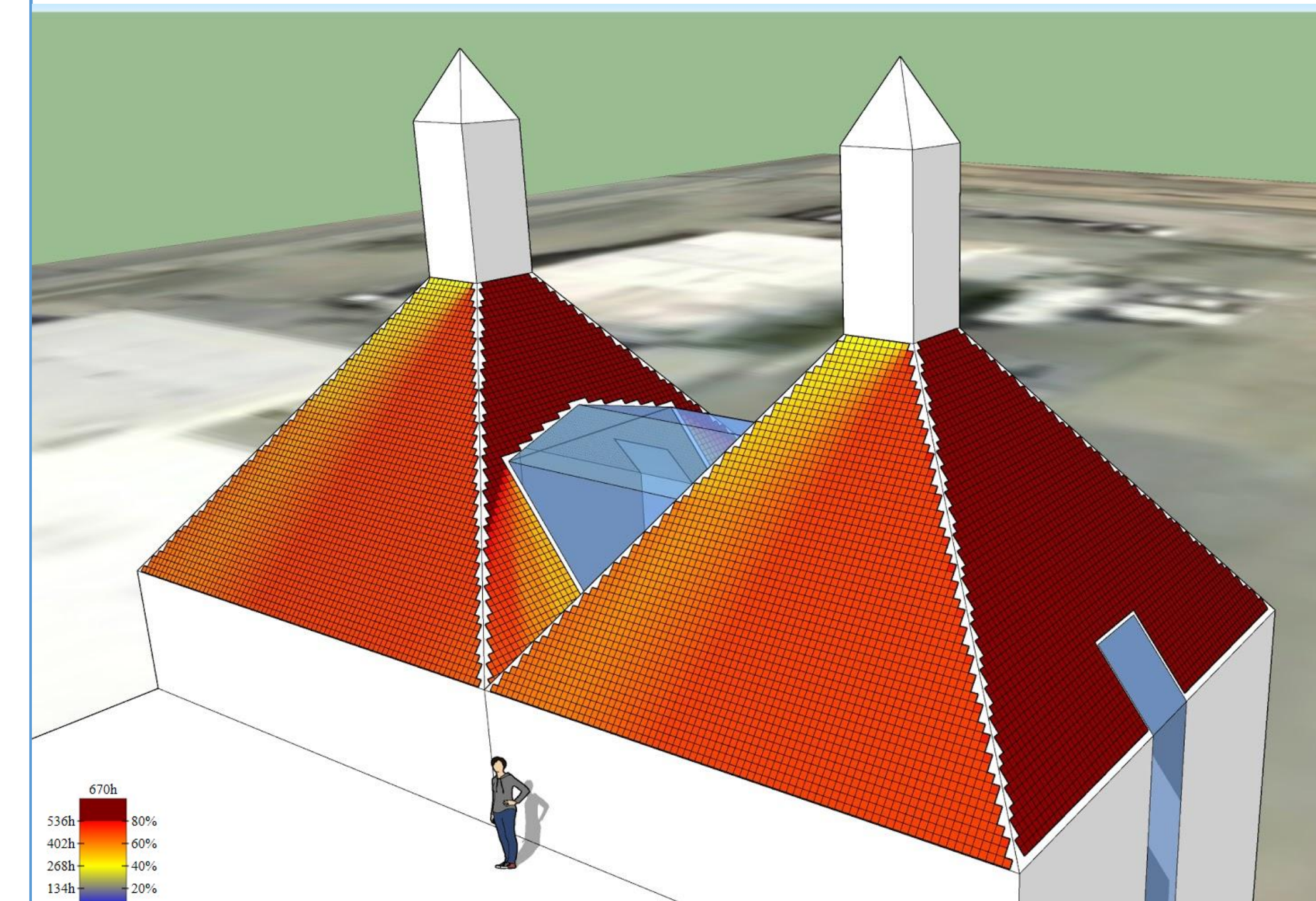
System Design

The following Figure shows the Heating and Cooling Loads of the Hop Kiln when used as a Tap Room when used as a Tap Room are presented. The highest load is during January with almost 400 MBTU.

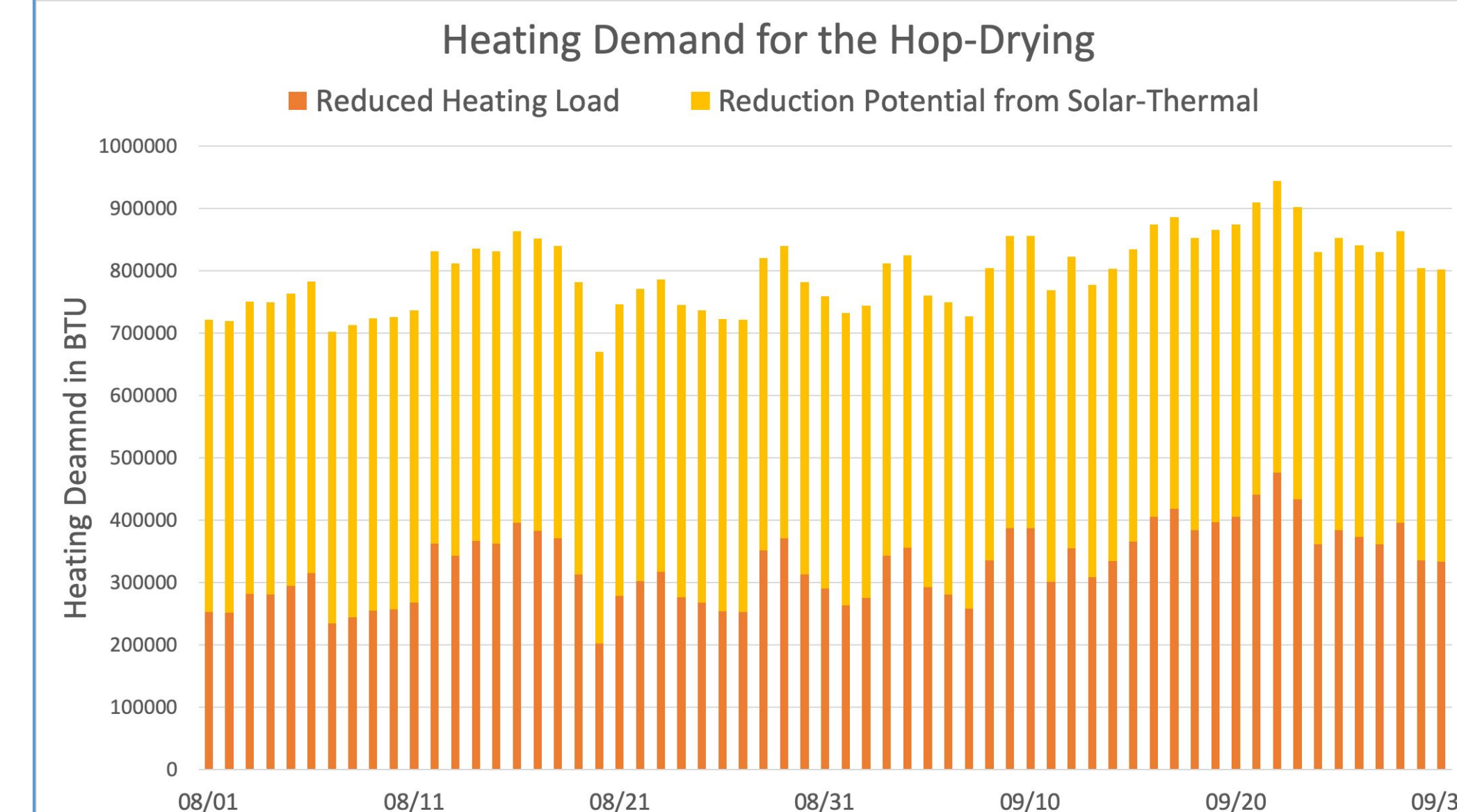


Solar Thermal Potential

The following graphic is a georeferenced, visual representation of the number of hours each roof section is in direct sun over the hop-drying period. We used this to ascertain both the optimal orientation of collectors, and the amount of solar energy we could potentially collect.



The following Figure shows the Heating Load with and without the potential reduction from a solar-thermal application. Without a solar thermal application the max heating load is approximately 950 MBTU, while in the reduced case it is approx. 480 MBTU.



Results Continued

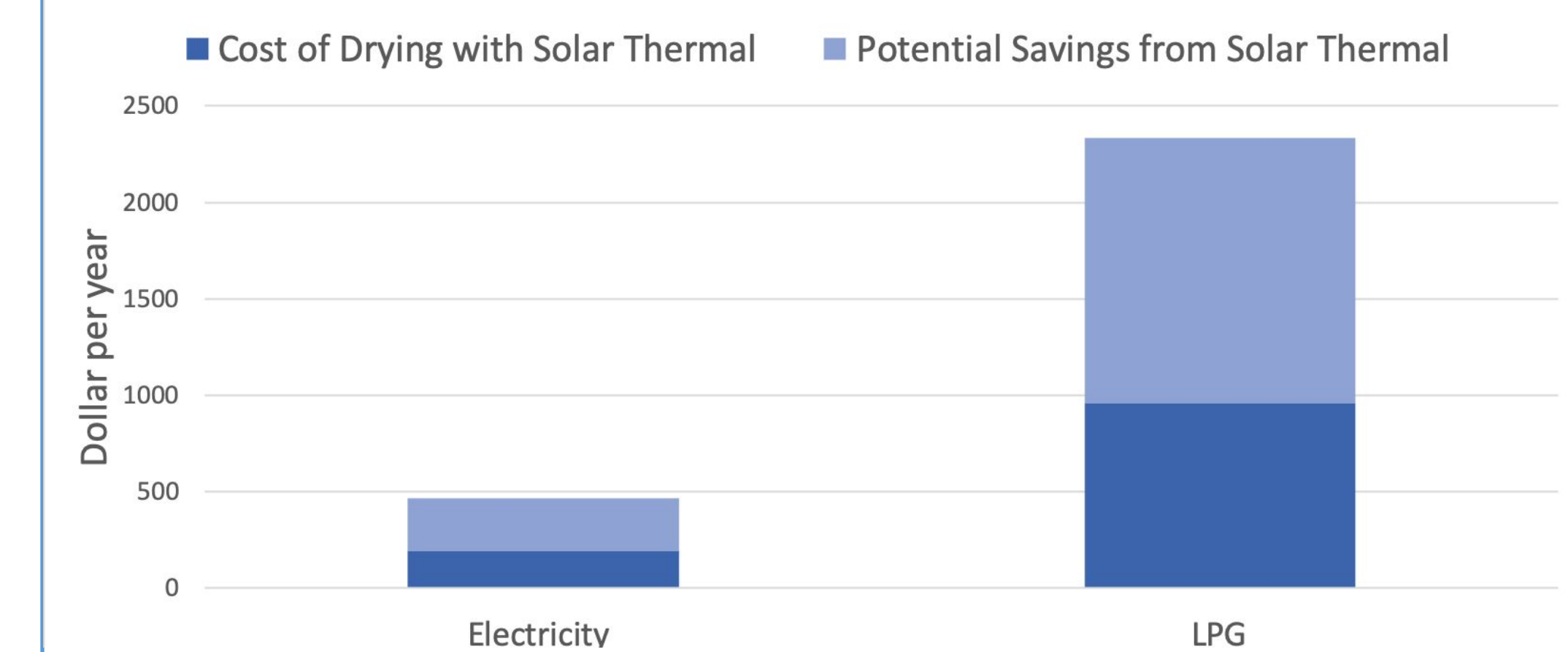
Cost Calculations

Assuming a HSPF of 8.5 and a SEER of 10, the highest Electricity Load can be determined. For an average PV cell a capacity of 2.6 kWh was assumed.

Scenario	Electricity Load	Number of PV-Cells	Cost of the PV Array
Electricity Load	111 kWh	43	\$34099
red Electricity Load	56 kWh	22	\$17446

Cost calculations have been performed in order to compare the operational costs of the new and old system. While the operational cost of the electricity-based system with the heat pump is significantly cheaper than the LPG-based-system. Additionally, the electricity can potentially be generated on-site through a solar PV-array. However, the capital expenditures for the heat pump are significantly higher than for a boiler.

Cost Comparison Electricity and LPG for the Hop-Drying Process



Conclusions

Given the high relative cost of a heat pump that could fulfill the significant airflow demand in conjunction with the desired kiln temperature, it is difficult to justify the heat pump aspect of the system on its economic or technological merits for powering the hop kiln. Even when considering the qualitative goal of independence, there may be a better alternative out there. That said, our calculations were completed with a high degree of uncertainty; more analysis is needed to ascertain the needed specifications of the heat pump.

The solar thermal system however, is a low cost, low maintenance, easily integrated preheat system that has been shown to significantly mitigate the heating load of the kiln. This system is also very versatile and could be integrated into a natural gas furnace or heat pump system.

Solar PV is also an efficient way to generate a versatile power source. Loads generated from lighting and other tap room applications could be more than satisfied by photovoltaics and would contribute to the grid-independence desired by the client.

References

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