Solar Furnace Heat Transfer Analysis

Leann Hernandez

3/29/20

Red Feather Team

Introduction

The Capstone team is partnered with Red Feather to create a solar furnace for the Native American people. Red Feather is a non-profit organization who organizes employees and volunteers to help people on the Native American reservations with their housing needs. The Native American people used to use coal to heat their homes but the coal plant that sourced their coal has closed in November of 2019. In addition, burning coal increases the risk of respiratory diseases. Therefore, the Capstone team is tasked with designing a solar heater due to being renewable energy and inexpensive long term [1].

Analytical calculations are important in designing a solar furnace. Equations needed for testing are described and some are calculated based on assumptions. In addition, heat loss in a home is calculated to figure out solutions.

Heat Conduction

Heat loss from conduction occurs when materials such as air come between the PV panel and the source which is the sun. The thermal resistance and way the materials are put together affect how much heat is transferred from the sun. The difference between the temperature from one surface to the other surface is a large force of heat conduction [2]. The equation is shown in equation 1.

$$\Delta T = \emptyset P_{heat} \quad \text{(eqn 1)}$$

Where P_{heat} is the heat from the PV panel, phi is the thermal resistance, and delta t is the change in temperature form one surface to the other surface. The equation for the thermal resistance is shown below in equation 2.

$$\emptyset = \frac{1}{k}\frac{l}{A} \quad \text{(eqn 2)}$$

Where A is the area of the surface of heat conduction, l is the length the material that the heat travels, and k is the thermal conductivity. For more complicated structures, thermal resistances would need to be added in series and parallel such as electrical circuits are. The structures of solar furnaces usually go from glass to PV panel, backsheet, then an aluminum sheet [2].

Convection

Convection is heat transfer through liquids or gas. In PV panels, the wind results in heat loss from convection. Convection is shown in the below equation.

$$P_{heat} = hA\Delta T \quad \text{(eqn 3)}$$

H could be calculated experimentally or estimated from a table [2]. This will be used when testing the solar furnace.

Radiation

$$P = \sigma\epsilon T^4 \quad \text{(eqn 4)}$$

P is the power from the PV panel, σ is Stefan-Boltzmann constant, ϵ is the emissivity of the surface, and T is the temperature of the solar cell in K. Assuming a temperature of 25°C and an emissivity of .85, because the system will not be a perfect blackbody, the power loss from radiation would be 380.1 W. Considering the net heat, the equation 4 becomes equation 5 [2].

$$P = \sigma\epsilon {T_{sc}}^4 - {T_{amb}}^4 \quad \text{(eqn 5)}$$

Where T_{sc} is the temperature of the solar cell and T_{amb} is the ambient temperature. Solar panel temperature normally range from about 15°C to 35°C but could get as high as about 65°C . A solar panel getting too hot would result in it overheating and losing a lot of power and even breaking completely. Assuming a solar cell temperature of 65°C and an ambient temperature of 20°C, the net power lost would be 273.8 W [3]. Assuming a temperature of 25 °C, the net power lost would be 24.9 W.

Heat Loss in a Home

Heat loss in a home is important for the solar furnace project so the team can know how efficient the design should be to accommodate for major heat loss. Finding a heat loss for a typical home is shown below [4].

$$H_c = AU(T - T_0) \quad \text{(eqn 6)}$$

H_c is the heat loss from conduction in the home, A is the area of surface, and U is the heat transmission coefficient. If a home on the Native American reservation has a surface area of 600 ft^2, made of wood having a transmission coefficient of 0.20, and being in Flagstaff having an outdoor design temperature of -5°F, then the heat loss would be 842.4 BTUH. This is a conservative estimate as there would often be even more heat loss.

Next heat loss through floor slab bottoms and walls would be calculated using equation 7[4].

$$H_s = FP(T - T_0) \quad \text{(eqn 7)}$$

P is the perimeter of the floor and F is the edge loss factor. The director at Red Feather said there was poor insulation in the Native American homes. To calculate the floor slab heat loss, F was 0.81 due to no edge insulation [4]. Assuming a 30ft x 20 ft floor slab, heat loss would be 6,319 BTUH [4].

Next, air infiltration, H_i was calculated using this equation.

$$H_i = 0.018q(T - T_0) \quad \text{(eqn 8)}$$

The q is infiltration volume in cubic feet per hour. The assumptions include two double hung metal frame windows, a wood non-weatherstripped door, and wind at 10 mph. The heat loss would be 9,106 BTUH. The total heat loss in that home would be 16,267 BTUH. This is all based on multiple assumptions meaning the number could be much higher or much lower.

Conclusion

The equations for conductive, convective, and radiative heat transfer were explained which will be important for testing purposes. Overall, power loss from radiation would be about 380.1 W based on a solar panel temperature of 25°C. In addition, considering heat loss from walls, floor slabs, and infiltration, total heat loss in a 600 ft^2 home on the Native American Reservation would be about 16,267 BTUH. This is important for designing a solar furnace to know how much heat loss would occur in a home. Based off these findings, the team can suggest that the people on the Native American Reservations should consider using more insulation in their homes as well as a weather strip on windows and doors if they have not already. This would result in less heat loss and would allow the solar furnace to work at a lower power output when there is less heat loss.

References

[1] “Red Feather Solar Furnace 2,” *Northern Arizona University*, Jan-2020. .

[2] “Heat Loss in PV Modules,” *PVEducation*. [Online]. Available: https://www.pveducation.org/pvcdrom/modules-and-arrays/heat-loss-in-pv-modules. [Accessed: 30-Mar-2020].

[3] J. Marsh, “How Hot Do Solar Panels Get? PV Temperature Explained: EnergySage,” *Solar News*, 01-Aug-2019. [Online]. Available: https://news.energysage.com/solar-panel-temperature-overheating. [Accessed: 30-Mar-2020].

[4] M. D. Egan, *Concepts in thermal comfort*. Englewood Cliffs, NJ: Prentice-Hall, 1975.