Modeling Direct-Expansion Solar-Assisted Heat Pumps

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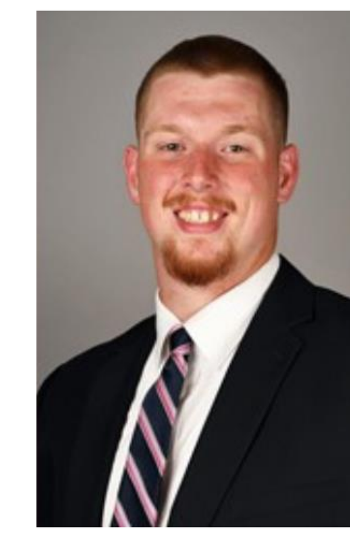

BACKGROUND

The foundational system for SAHPs is the heat pump itself. One of the primary purposes of a heat pump is to absorb heat from a reservoir and use it for heating. These systems are typically a key component for HVAC systems. Heat pumps typically use the ambient air to directly supply heat as the reservoir source.

Heat pumps operate by a standard vapor-compression refrigeration cycle (VCRC) as shown in Fig. 1. A refrigerant absorbs heat through the evaporator and reaches its highest enthalpic state leaving the compressor. The heat is extracted through the condenser and returns to the evaporator by passing through an expansion valve.

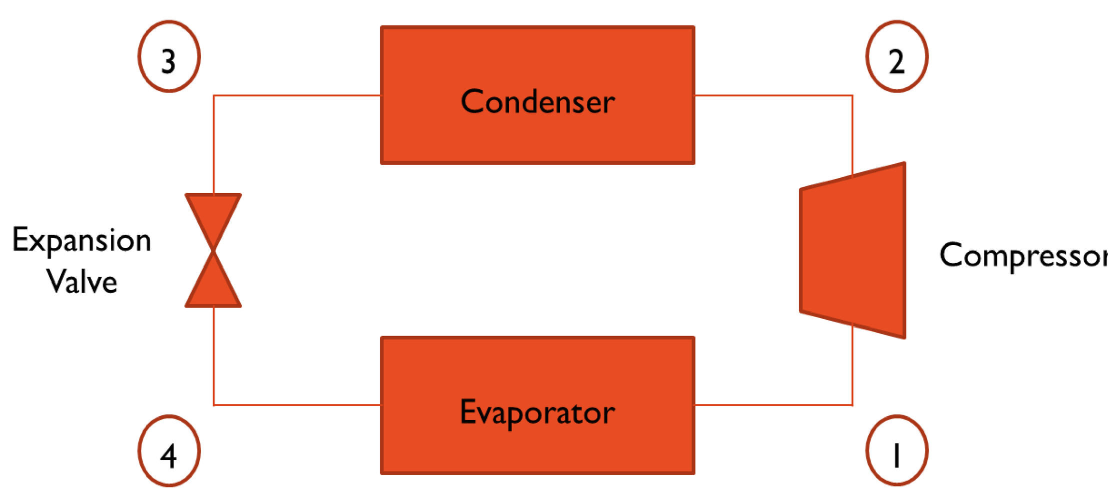

Fig. 1: Standard Vapor-Compression Refrigeration Cycle.

MOTIVATION

Looking at the Coefficient of Performance (COP) of a Carnot heat pump, it can be seen that the low and high temperatures of the thermal reservoirs dictate the COP. If there is a constant high temperature reservoir and temperature of the low temperature reservoir is increased, the COP will increase as well. This trend is shown in Fig. 2.

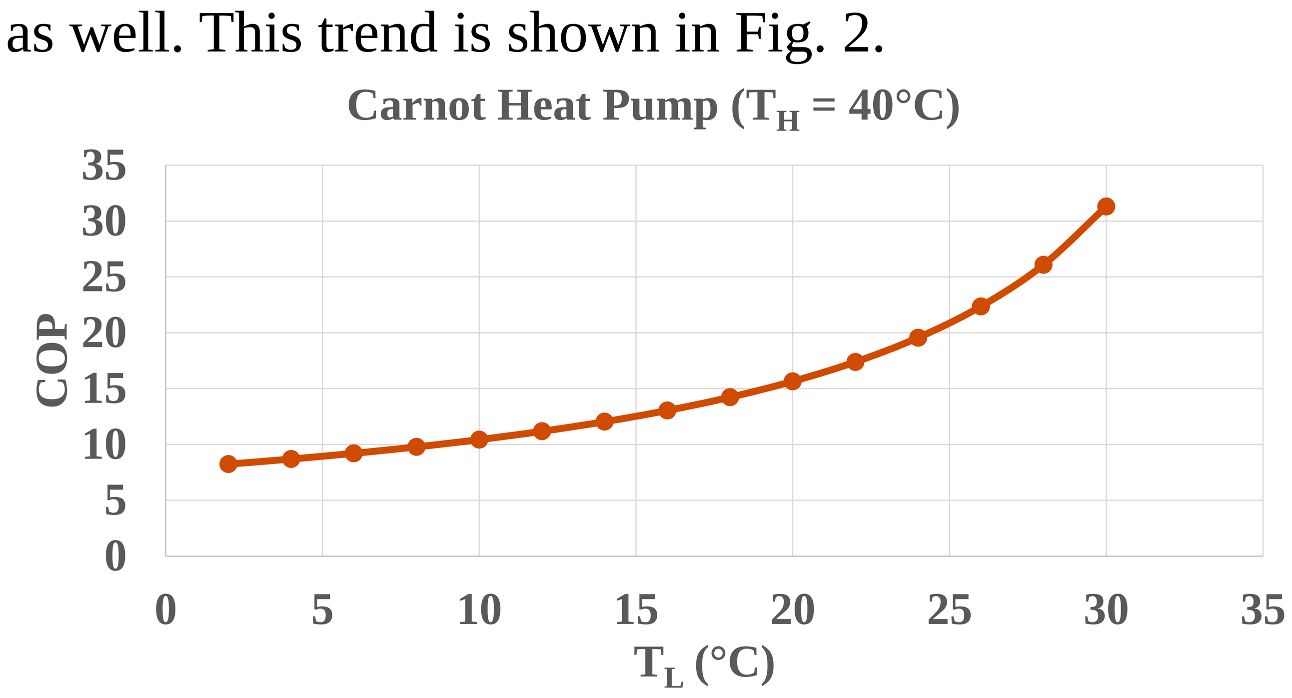

Fig. 2: COP as a function of the low temperature reservoir of a Carnot Heat Pump.

This concept provided the foundation for introducing solar energy to the heat pump system. In this project, solar thermal collectors were used to convert the solar energy from the sun directly to heat.

METHODOLOGY

There are two configurations used to implement solar thermal technology into a heat pump system: Direct-Expansion and Indirect-Expansion. This project examined SAHPs with Direct-Expansion configurations. This means that the solar thermal collector takes the refrigerant from the heat pump cycle as the working fluid and replaces the use of an evaporator in the cycle. A schematic for this configuration is shown in Fig. 3.

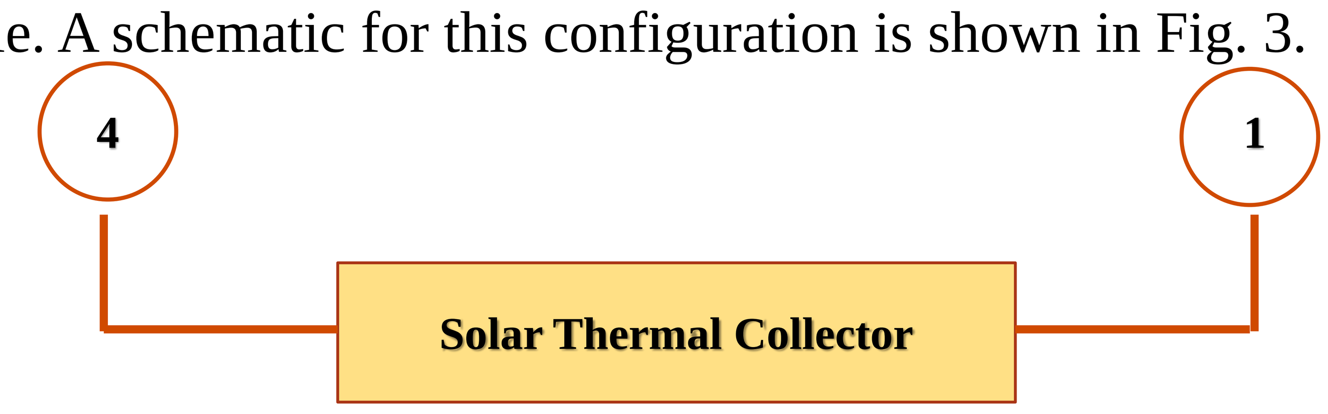

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Fig. 3: Direct-Expansion SAHP Configuration.

Since temperatures in a VCRC are low upon entering the evaporator, solar collectors without covers will provide additional heat transfer instead of losing heat. This led to a selection of SunEarth OASIS OPP-40-2 pool collectors to be used in this SAHP system. Using the spec sheet, necessary parameters were deduced for the collector.

Solar data was collected from the National Solar Radiation Database (NSRDB) for a location in Schenectady, NY for every hour of the year and from 2015-2019. These values were used with the parameters from the solar collectors to determine the heat gained from the ambient environment and the solar thermal collector. The model used three solar collectors tilted to latitude to maximize the heat collected over the course of the year, R-410a as the working fluid in the VCRC with pressures of 0.5 MPa and pressure of 1.5 MPa. The COP was calculated based on a standard 10 kW residential heating load.

RESULTS

One way of evaluating the performance of a heat pump is by looking at the heat gained by the evaporator system. In Fig. 4, the heat gained as a function of time of day is plotted. If the collector only collected heat from the ambient environment, similar to an Air-Source Heat Pump, the heat gain would be represented by the blue line. The solar thermal collectors used in the modeled system collect the heat represented in yellow. The combination of these produces the total heat gained by the SAHP. It's important to note that the effects of solar heat are more valuable in the colder months than in the warmer months. Also, the warmer months gain more useful heat than the colder months due to the increase in ambient heat gained. This data was also used to determine the average COP for each month during the heating season (Fig. 5). Due to the trends observed from Fig. 4, the warmer months also experience a greater COP. The cold months gain less heat due to the colder ambient environments and less solar insolation.

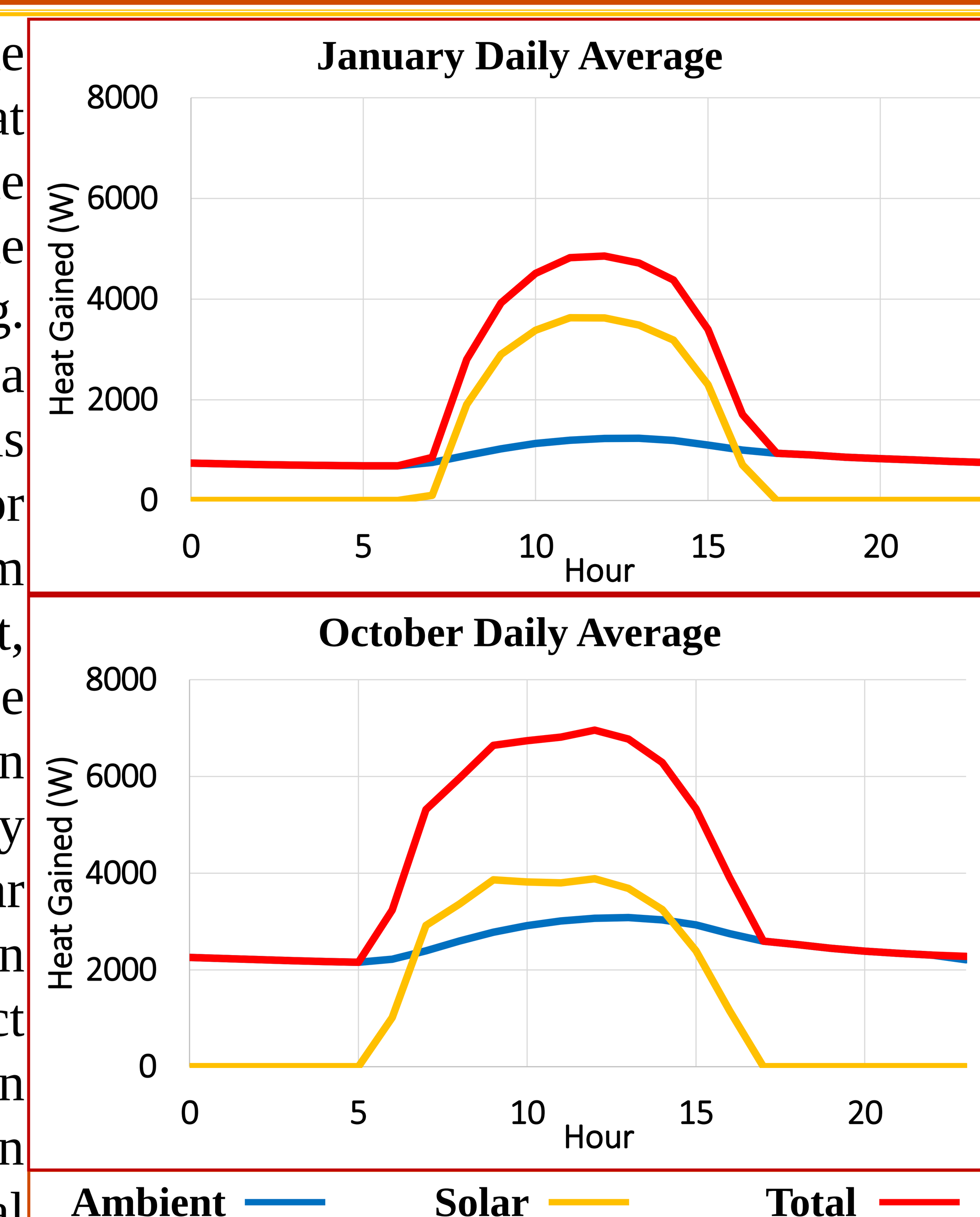

Fig. 4: Heat gained (W) as a function of time of day for the average day of the month.

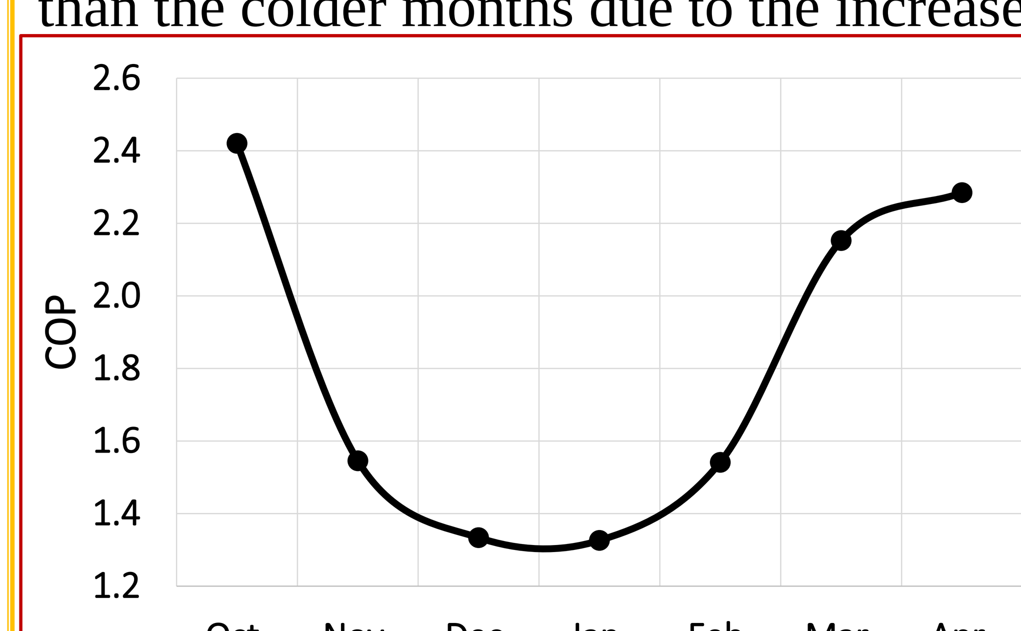

Fig. 5: COP as a function of the month during the heating season.

FUTURE WORK

In order to validate the results given by the developed model, a physical experiment should be implemented. A future model should also include specifications of an evaporator for an air-source heat pump to provide a more accurate comparison. This model should also be expanded to determine when collectors without covers become inefficient. Further, the effects of the tilt angle should be studied more to determine the most efficient configuration.

ACKNOWLEDGEMENTS

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