EXECUTIVE SUMMARY

Thermally Assisted High Temperature Heat Pump

ESTCP Project EW-201516

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1.0 INTRODUCTION

American Solar, Inc. installed an air to water heat pump to deliver hot water to the domestic water loop in the Freedom Barracks building at Fort Meade, Maryland. The heat pump received a thermal assist from warm air drawn from the attic to boost heat pump performance and deliver heated water. The heat pump also simultaneously delivered cooler drier air that could reduce the air conditioning load when heating water. The purpose was to demonstrate and validate heat pump performance with and without attic heat recovery and to compare performance to the existing heating and air conditioning systems.
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2.0 OBJECTIVES

The objective of the project was to validate the performance of the Thermally Assisted Heat Pump (TAHP) at reducing energy use and cost for water heating and space cooling, and reducing water use for cooling.

- **Validate**: The demonstration installed and monitored the performance of the TAHP at heating water in a barracks building. Measurements of energy delivered and consumed in water heating, compared to comparable energy from the gas hot water heaters, was established. In addition, the demonstration established the space cooling and water saving potential of the TAHP and the outdoor air preheating potential of the solar heated attic air.

- **Findings and Guidelines**: Findings from the demonstration enable Department of Defense (DOD) facility managers to confidently design and specify TAHP systems in buildings with hot water demand and sources of waste or solar heat. First of their kind algorithms were developed that predict performance of the heat pump and attic heat recovery at heating and cooling anywhere in the US.

- **Technology Transfer**: Outreach activities include technical publication in energy and facility management magazines and technical journals, in addition to presentations at energy and DOD conferences. Information will be disseminated to Energy Service Companies (ESCOs), Utility Energy Service Companies, and to the manufacturers and manufacturers’ representatives of high-temperature heat pumps, as well as on American Solar’s website.

- **Acceptance**: The demonstration and the documentation of the technology will provide facility managers with a well-documented model, allowing them to assess the appropriateness of the system for their own facilities and to specify the system to meet their needs.
3.0 TECHNOLOGY DESCRIPTION

Air to water heat pumps have been introduced for residential and commercial use in the last several years. These systems use air as the thermal resource to heat water to temperatures as high as 160 degrees Fahrenheit (160°F). Air that passes through the heat pump is cooled as the heat is extracted from the air and delivered to the water. The diagram at left shows the heat pump cycle.

![Diagram of heat pump cycle](image1)

**Figure 1. Thermally Assisted High Temperature Heat Pump**

The warmer the air entering the heat pump, the more productive and efficient it is at heating water with a minimal increase in electricity use. When simultaneous delivery of cool exhaust air with hot water is accomplished with no added electricity use—compared to just water heating—the performance of the system can produce up to 5+ times the heating and cooling energy of the electricity consumed.

Commercial systems are compact units capable of delivering upward of 60,000 BTU/hour. The system installed in the Freedom Barracks is a COLMAC HPA4 unit (shown below left). The photograph (below right) shows the system as installed with ductwork and piping in the Freedom Barracks.

![COLMAC HPA4 Unit](image2)

**Figure 2. COLMAC HPA4 Unit**
During the day, attic air becomes solar-heated as the sun heats the asphalt shingles and plywood roof deck. A fan pulls the solar-heated air from the attic space through the ducts and delivers it to the heat pump.

In addition to the heat pump testing for domestic water heating, two other options were analyzed. First was the option of using the heat pump instead of a gas fired boiler to reheat ventilation air after cooling and dehumidifying the air in the central air handler. The second option was to preheat outside ventilation air entering the central air handler during the heating season by using the heated attic air.
4.0 PERFORMANCE ASSESSMENT

Both the solar heat from the attic and the heat pump performed as expected, delivering a combination of higher heating performance than the heat pump alone would deliver. The additional energy benefit of cool dry air from the heat pump exhaust stream added to the overall efficiency of the system. However, the economics of the system is dependent on the relative cost and energy use of the particular installation.

The chart below shows the east attic air temperature in dark blue and pink. The Outdoor Air Temperature (OAT) is shown in light blue. The brown line (Poly. east...) is a trendline for the east attic air temperature. The blue line (Poly. OAT) is a trendline of the outdoor air temperature. A peak attic air temperature of 121F was measured along with a maximum attic temperature of 37F above outdoor air temperatures. On average, the attic air temperature was 12F warmer than the outdoor air temperature during the 9 month test.

The heat pump water heater performed as expected by increasing energy delivery with increased supply air temperature. In one example, using a steady state heat pump inlet air temperature of 66F, the heat pump produced a COP\(^1\) of 2.47 with hot water outlet at ~120F compared to steady state inlet air temperature of 75F and a COP of 2.52. In another example, with cold city water entering the heat pump at 42F and air entering at 67F, the maximum COP was 5.55.

When simultaneous hot water heating and outside air cooling were considered, with 99F air and 73F cold city water entering the heat pump, the peak combined COP was 7.21. The heat pump and fan require 3,532 Watts-hr of electric energy but eliminate 3,305 watt-hr of electric use by the chiller. Over the course of a year at Fort Meade, the average COP for combined heating of cold city water and outside air cooling was 4.73. The chart below shows the COP for hours when the heat pump is ON (i.e. COP > 0) and water heating and outside air cooling are taking place simultaneously.

\[ y = 0.000000151 + 0.0004842253x + 45.57141272765 \]

\[ y = 0.0000001516x + 0.0003205978602x + 32.0304542199 \]

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\(^1\) COP = Coefficient of Performance: heat energy delivered divided by energy consumed
In many facilities, rejecting heat from air conditioning is done through a wet cooling tower and is a significant source of water use. Because the heat pump water heater rejects heat to the hot water, there is no need for a separate cooling tower to reject heat to support the cooling function provided by the exhaust air. This reduces water use where a wet cooling tower is in use. Calculations indicate the tested system would provide annual water savings of 7,800 gallons per year compared to a wet cooling tower installation in a Fort Meade climate, and 15,000 gallons per year for an identical system in Jacksonville, Florida, barracks building with a higher annual cooling load.
5.0 COST ASSESSMENT

The cost of the Thermally Assisted Heat Pump is dependent on the configuration of the system and the varied heating and cooling needs it serves. A simple system installed in a commercial kitchen with a high water heating and simultaneous cooling load could use simple ducting and recycle the cold exhaust air directly back to the kitchen space. Such a system might cost around $43,000 installed for the COLMAC HPA4 heat pump with a non-competitive, pre-design bid price. A competitive, post-design price would be closer to $28,000. A more complex system with long duct and piping runs serving hot water, outside air preheating and precooling could cost closer to $45,000 to $50,000.

Cost savings vary depending upon the weather and solar conditions, the entering cold water temperature, the loads served by the hot water and cool exhaust air, the efficiency of energy conversion from existing equipment (e.g. natural gas boiler to hot water heat) and the relative cost of the existing heating energy source vs. the electric energy cost. Of these, the relative cost of heating vs. electricity is the largest driver followed by the efficiency of conversion and the entering cold water temperature. At Fort Meade, with a relatively low cost of heating energy (natural gas), the system only provides cost savings when it is providing simultaneous hot water heating and cooling or when it is preheating outside air with warm attic air. At an identical barracks in Jacksonville, Florida, the heat pump would deliver higher energy savings when simultaneously heating and cooling due to the both higher water heating and cooling energy savings. These higher savings are driven by a $5+$$ increase in the number of hours of heat pump operation each year due to weather and solar conditions in Jacksonville vs. Fort Meade.

As mentioned above, the relative cost of heating energy vs. electric energy is a significant driver in determining the annual savings. The heating energy price is largely driven by the heating energy source (gas, fuel oil, propane, electricity). Natural gas at Fort Meade was calculated from monthly bills at $5.91/million BTU (now $6.48/MMBTU). Typical prices for other energy sources are $2.50/gal fuel oil burned = $18/MMBTU. Propane at $2.70/ gal = $33/MMBTU. Electric resistance heat $0.10/kwhr = $29/MMBTU.

The chart below shows how the price ratio for heat/electricity changes the annual savings. For example, a facility with oil heat at $18/MMBTU would have a heat to electricity ratio of 180 ($18/$0.10). With combined heating and cooling the facility would save ~$1,600 per year vs. a 95% efficient boiler and ~$3,000 per year vs. a 60% efficient boiler.
Figure 5. Effect of Heating Energy Price on TAHP Annual Savings
6.0 IMPLEMENTATION ISSUES

The operation of the existing natural gas fired domestic hot water system at the Fort Meade Freedom Barracks changed significantly during the course of the project. Problems with the 17-year-old hot water heaters resulted in the Fort changing out all the hot water heaters to more efficient condensing boilers. This improved the efficiency of the existing system, but it also resulted in high (140F) domestic hot water loop temperatures for several months. These temperatures were above where normal economical heat pump operations would take place. For many other weeks during the test, the circulating domestic hot water systems temperature was at or near room temperature. In addition, shutdowns of the central air handler unit for several months eliminated the use of outside air preheating or precooling.

The issue raised by all these failures of the existing heating and cooling systems indicates how important it is to monitor the performance of existing systems in order to maintain design conditions in the spaces and to take advantage of savings under normal operating conditions.