Low Temperature Energy Recovery Designs

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ABSTRACT

This article discusses low temperature energy recovery systems that are being installed on three Federal buildings in the Washington, DC, area. The three projects discussed use simple systems that deliver low cost heat to buildings in innovative ways. Each uses a source of low temperature heating available from within the building to reduce fossil fuel use. One system recovers heat from the ventilation return air to heat water for the hydronic reheat loop serving variable air volume boxes in the building. The second system recovers heat from an attic space below a plywood roof deck covered with asphalt shingles to heat a domestic hot water loop for a barracks. The third system recovers heat from the solar re-roofing of a building to supply heated air for swimming pool heating and for a heating, ventilating, and air conditioning system. The purpose of this article is to demonstrate the versatility of these low temperature heat recovery systems.

BACKGROUND

Electricity

There is a thriving market for all things electrically productive and efficient. Each year, new electric power and electronic devices are introduced, power management and storage systems are developed, and policies and incentives evolve. Subsequently, there is greater focus on producing, saving, and managing our electric supply and expenses. As we improve electrical efficiency, we use less electricity while accomplishing more.

With a focus on electric power, management concerns, more connected devices, and increasing use of all things digital, we have shifted our daily measure of energy's value from the 'price of a gallon of gas' to the remaining 'charge on our cell phone'.

What once required a single daily drive past a gas station for a sense of our energy vulnerability now happens multiple times an hour, with every call or text draining power, shrinking bars on our battery indicator, and increasing our electric anxiety. If a power outage occurs, we measure our anxiety by the battery life remaining and huddle around our fossil fueled electric generators to recharge. Electricity energizes our devices, fans, pumps, equipment, machinery and now, our battery powered vehicles.

Heat

In our focus on electric devices and production and efficiency, we often forget that the greatest energy need in U.S. buildings and industry is for heating. We use a mix of energy resources (natural gas, fuel oil, liquefied petroleum gas, renewables and electricity) to meet the needs of a variety of uses. Heating, cooling, refrigeration, drying, lighting, motors that power appliances, and electronics, are among the needs that require us to consume energy resources. Among these needs, heating loads dominate. Low temperature heat for space heat, hot water, and clothes drying in our homes, accounts for 63% of all residential energy use. This is seven times more than cooling energy use and 13 times more than the energy used for computers and electronics.

In commercial buildings, low temperature energy use for space heating and water heating is a third of total energy used. This is three times more than the lighting energy used, five times more than the cooling energy used, and six times greater than the energy used for our electronics and computers. With such a great need for low temperature heat, why do we not see more innovation and policy development for devices to reduce our largest type of energy use?

Perhaps the answer is that improvements in heating systems have stagnated. Perhaps only incremental improvements are possible when economic markets value the cost of heating energy less than electric energy costs. Perhaps the profits to be made from applying such minimally improved products are inadequate to justify the total costs of installation. Perhaps these improvements are held back by the distributed nature of the heating installations performed by thousands of contractors, installing systems made of several devices in hidden locations in million of buildings instead of by manufacturers selling high profile, new appliances to consumers.

All these possible causes are connected to what the market demands—making heating systems that are more productive and less costly than the present alternatives. To achieve this, heating system designers must consider the cost of equipment, devices, installation and energy loads. Ways to meet such market requirements are to: 1) switch to a lower cost energy sources; 2) keep the installation simple and reliable; and 3) target the base load of heating energy use rather than the peak load. This can be accomplished by installing simpler low cost systems that provide base load heating.

Health and Human Services Headquarters

The headquarters building of the Department of Health and Human Services (HHS) is located next to the U.S. Capitol complex, along the Mall in Washington, DC. The building operates continuously and is heated with steam from the central plant that supplies steam to several buildings along the Mall. The cost of the steam is $38 per million British thermal units (MBTU). The air conditioning system provides chilled air through the ventilation system. Steam to hot water converters in the penthouse serve the variable air volume (VAV) reheat piping loops that heat most areas. The reheat system operates throughout the year at a temperature of 120°F. A separate two-pipe perimeter system circulates hot water to fan coil units in the heating season and is switched to cooling with chilled water on warmer days.

The majority of supply and return fans are located in the penthouse mechanical room. Capacities vary from 15,000 to 64,000 cfm to serve different zones. Return air mixing with outside air provides most of the tempering to deliver 55°F air to the supply fans during the heating season. Cooling coils further reduce the mixed air temperature to achieve a 55°F supply temperature.

Annual steam use costs about $1 million annually. With high unit costs for steam, HHS explored several options to reduce heating costs. A proposal to replicate a similar project recently installed at the Army Research Lab in Adelphi, Maryland was investigated in detail. The approach used simple air-to-water heat pumps to recover heat from the return air (a lower cost source of heat) and generate higher temperature (>130°F) hot water for the hydronic heating loops and cool dry air (<60°F) for the return air. To maximize the economic viability, the systems were sized and configured to serve only their base loads. The remaining heat loads were provided by the existing steam system.

An economic analysis indicated that at least 10 of the large supply air handlers could be served by the heat pump heat recovery systems. An estimated installed cost of $860,000 resulted in total life cycle savings of $3.6 million to the building, with a savings-to-investment ratio (SIR) of 4 and simple payback period (SPP) of 4 years. The life cycle CO_2 reduction exceeded 13,000 metric tons.

The installation was completed in August 2016. Initial operations demonstrated hot water delivery temperatures of 130°F and cool air exhaust temperatures of about 55°F. This is compared to the 90°F+ outside air temperatures during the summers. Each heat pump uses roughly 5 kW of electric power to generate 16 kW of hot water and simultaneously delivers 11 kW of cool air.

Each of the two five ton heat pumps serving each air handler deliver 3.7 gallons per minute (gpm) of heated water, totaling 67 gpm for the 18 heat pumps installed on the nine air handling units. The maximum reheat loop flow is 130 gpm while the total reheat from the heat pumps is about 50% of the required maximum. Since the perimeter heating system capacity is about 950 gpm, the heat pump hot water capacity is only 7% of the perimeter system maximum flow. From an air flow perspective, the system is small relative to the air handlers (2,500 cfm vs. 15,000 – 64,000 cfm). The cool exhaust air in the summer contributes cooling savings by reducing the chiller load, without overcooling the return air during the winter heating operations.

The size of the heat pumps ensures that they are delivering to the heating and cooling base loads and not servicing seasonal peak loads. They operate daily to service the base loads, reducing costs and quickly repaying their initial investment.

Fort Meade Freedom Barracks

The Freedom Barracks at Fort Meade in Maryland are a set of eight identical barracks buildings. The three story wooden framed buildings have 36 double occupancy suites. Domestic hot water (DHW) is supplied by natural gas fired water heaters located in a ground floor mechanical room. Hot water is supplied to each room by a circulating piped loop located in each floor's central corridor.

The storage temperature is 140°F. A tempering valve distributes water to the loop at 125°F. The temperature of the hot water at the far end of the circulating loop is about 120°F.

Figure 1. HHS heat pump heat recovery system.

The fort has undertaken several heat recovery projects to support building heating needs using the heat recovered from the building envelope, a low cost source of heat. This approach to heat recovery uses the 'solar' heated air from the attic under a dark grey shingled roof to preheat an air to water heat pump that supplies hot water (135°F) to the DHW water loop before it circulates to the hot water heaters.

This project was developed by the fort's resource efficiency manager in the engineering office and American Solar, Inc. It was funded by the Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) based on a proposal by American Solar. The installation was completed in 2016, with one year of monitored performance to follow.

The same heat pump used at the HHS building was used in the Freedom Barracks project. Rather than using the return air as a heat source, the hot attic air is used to preheat the heat pump. The advantage of using hotter air is that the heat pump becomes much more productive. A heat pump fed with 78°F degree air produces 14.6 kW of hot water using 5.2 kW of electricity when the coefficient of performance (COP) is 2.8. Using 100°F air, the COP increases to 3.5.

In addition to the hot water heating, the air to water heat pump delivers a stream of cool dry air as the attic air gives up heat and exits the heat pump. With attic air at 100°F, the exhaust air from the heat pump will be roughly 76°F. When substituted for outdoor air at 90°F, the exhaust air represents a cooling resource of about 3.7 kW or a cooling COP of 0.8. The combined heating and cooling COP is 4.3. On cooler days when the building does not require additional cooling, the cooler heat pump air can be exhausted outdoors.

There are times during nights and very cold days when the attic air is not hot enough to economically boost heat pump performance. On a day with the outside air temperature is 30°F the attic air may reach 60°F. The water heating COP of the heat pump would be about 2.3 and there would be no cooling required from the exhaust air. Under such conditions, the heat pump would be turned off and the hot water heating load would be handled by the existing hot water heaters.

However, in cold conditions, the installed attic ductwork and fan can still provide heat to the building in the form of preheated outside air. By operating the low power fan to move the warmer attic air to the outdoor air intakes, the building's heating load decreases. During a day with 30°F outside air, the fan delivers 1,200 cfm of 60°F attic air to the outdoor air intakes, providing 11.7 kW of heat with fan power of 0.5 kW, for a COP of 23.

Hourly calculations using typical meteorological year solar and weather data provide an indication of the annual economic performance of the heat pump system in differing climates. When fully deployed at the Freedom Barracks in Maryland, the system provides an SIR of 2 and a SPP of 10 years. However, in Jacksonville, Florida, where dehumidification and cooling are more dominant loads, the SIR is 5.6 and the SPP is 4 years.

The relatively *simple* approach involves: 1) capturing a low cost source of heat from attic air; and 2) boosting the performance of a heat pump and fan to deliver high temperature water, cool air, and warmer preheated outdoor air. This process can satisfy a portion of the heating and cooling *base loads* while making the project economically feasible. The Freedom Barracks project is repeatable and expandable to other buildings.

Fort Meade Gaffney Pool Roof

The Gaffney Fitness Center Gymnasium re-roofing project was the site of a previous solar roofing improvement funded by ESTCP in 2012. For this project, the engineering office at Fort Meade was presented an Army Innovation and New Technology Energy Award. The project provided a new metal roof and reduced energy costs for space heating, preheating DHW and outdoor air.

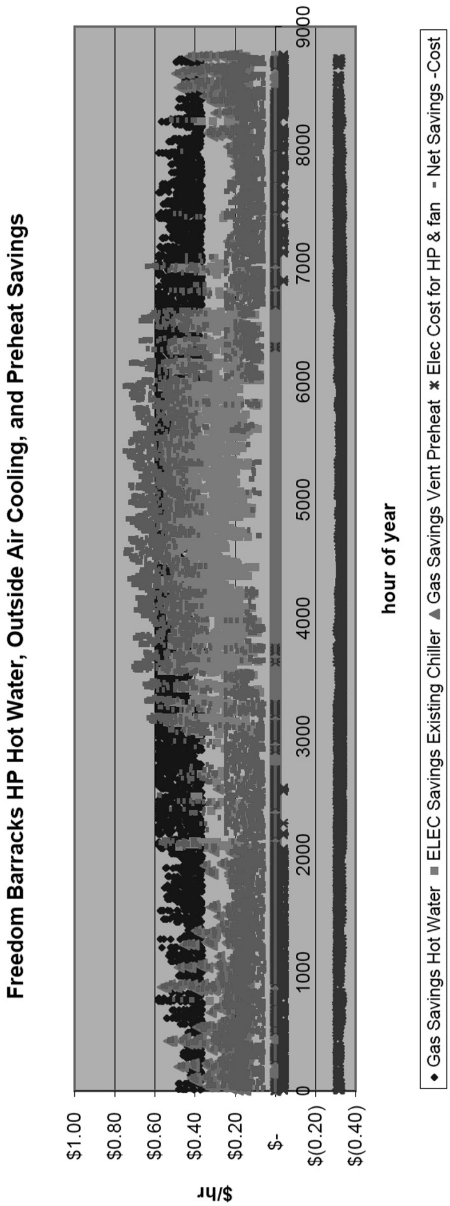

Figure 2. Freedom barracks hourly cost savings.

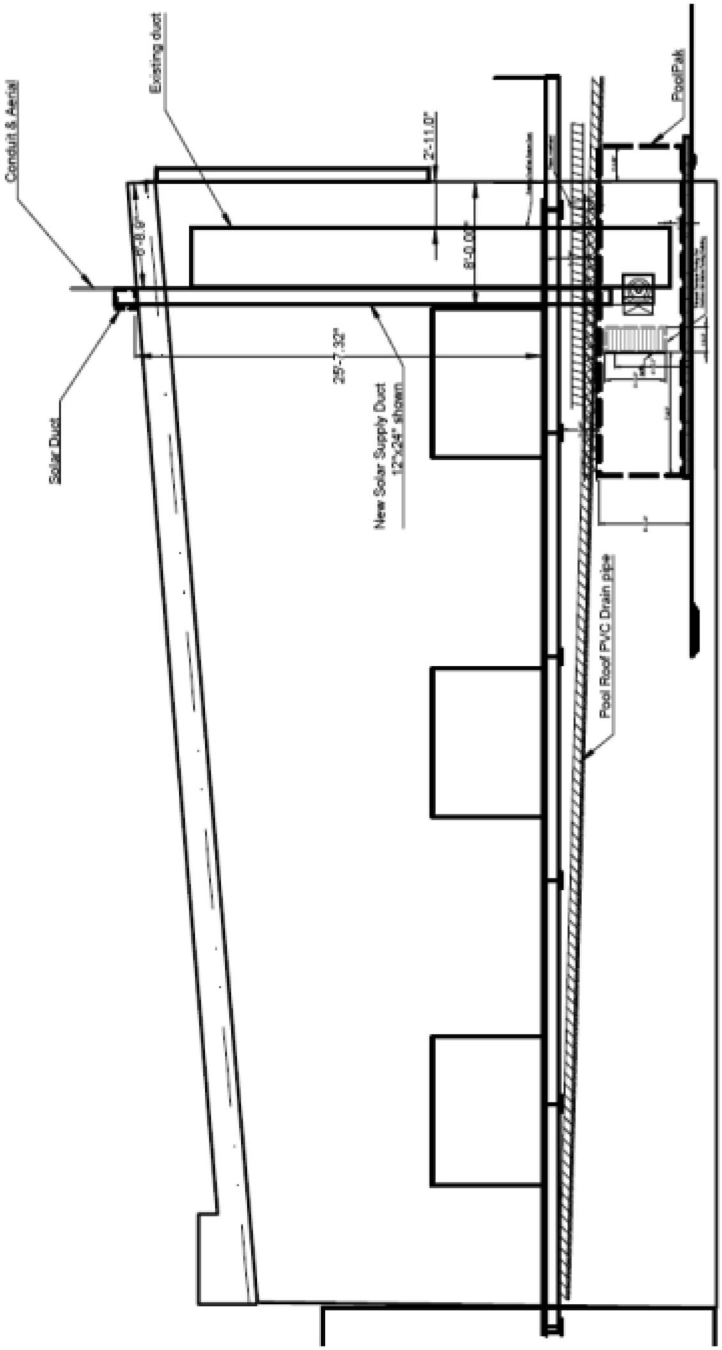

Figure 3. Gaffney pool roof solar heat recovery.

The fitness center houses a swimming pool. Recently the pool roof showed signs of failure and the fort decided to recover the roof with another solar air heating metal roof. In this case, the solar heated air recovered from the roof will be used to heat outdoor air for the pool heating and cooling system. The pool control system manages indoor air temperature, humidity, air quality and pool water temperature. It uses a combination of outdoor air, a natural gas fired boiler for hot water, and a compression refrigeration system to manage air and water temperatures (80° to 85°F), humidity and air quality.

This type of pool environmental control system is more efficient than systems that flush the humid air from the pool and replace it with outdoor air that requires conditioning. Typically these more efficient environmental control systems have selective economizers that use 100% outdoor air instead of pool air returning to the unit when outdoor air is warmer and drier than the air leaving the evaporator coil. This allows all the refrigerant heat from the compressors to be transferred into the conditioned supply air and/or the pool water. This saves more energy than simply flushing the pool with outside air or conditioning the return air without solar heated air.

With the solar air heating re-roofing, there will be times when the air from the roof will be 30° to 40°F warmer than the outdoor air. By delivering that solar air to the outdoor air intake, the pool unit's selective economizer uses less energy, operating more often with 100% outdoor air.

Solar air heating re-roofing uses a metal roof installed with a few inches of air space below the conventional metal roof panels. When heated by the sun, the air temperature in the air space can be 80°F warmer than the outdoor air. With proper air flow, the temperature of the delivered air typically peaks about 40°F above the outdoor air temperature. A fan can deliver air flow equal to 100% of the outdoor air requirement. A more economical air flow will target only a minimum outdoor air or base load portion of the required flow. The design suggests delivering 4,000 cfm of the 12,000 cfm required for 100% air flow. The 1.5 kW fan delivers 50 kW of heat to 4,000 cfm of air with a 40°F temperature rise and a COP of 33.

The system is not 'hard ducted' to the outdoor air intake. Instead the solar heated air is simply blown at the outdoor air intake from a short distance away. This approach is practical when the solar air is a fraction of the maximum outdoor air. Any heat loss to the surrounding air will be heat gained by surrounding air which is being pulled into the intake. Eliminating the hard ducts also eliminates the cost of additional complicated duct and dampers to permit 100% outdoor air to enter the unit when the solar fan it turned off.

The solar air is the lowest cost source of energy for heating the pool wing with most of the system cost being the expense of the roof which needed replacement. The system is designed to supply a portion of base load and operates for many hours annually. It simply turns off whenever it is unable to provide economical heating, such as nights or rainy days. The system is simple and reliable. It uses only thermostatic controls and a conventional fan that delivers air at the outdoor air intakes.

SUMMARY

The three example projects show how heating energy savings can be achieved using low cost, simple, base load heating retrofits. These projects differ from many conventional energy retrofits. They use low cost energy sources that are often ignored—return air, attic air and roof air. They use conventional construction techniques and equipment. Instead of handling the peak load, they supplement the primary heating and cooling systems and allow the primary systems to consistently deliver the air and water at the final required temperature and flow. These systems are designed to supply only a portion of the base load requirements. Their environmental control systems are less complicated than traditional systems.

If the primary heating and cooling systems were replaced with the most efficient conventional systems that could handle peak load conditions, the systems used in these three examples would still produce lower cost energy. This is because they use a low cost source of energy, simple designs, and provide predictable base load savings for much of the year. These retrofitted systems may require a little more thought and energy engineering than direct equipment replacement since they are intended to handle only a portion of the base load requirements. Regardless, they can often provide consistent, reliable energy and cost savings when combined with existing peak load systems.

References

[1] U.S. Department of Defense, Environmental Security Technology Certification Program (ESTCP) project EW 201148.
[2] U.S. Department of Defense, Environmental Security Technology Certification Program (ESTCP) project EW 201512.

ABOUT THE AUTHOR

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