Low Temperature Energy Recovery Designs

John P. Archibald, President
American Solar, Inc.

Abstract

This presentation discusses 3 low temperature energy recovery systems that have been designed and are being installed on three Federal buildings in the Washington, DC area. Each system uses a source of low temperature heat available from within the building to reduce fossil fuel fired heating.

One system recovers heat from the ventilation return air to heat water for the hydronic reheat loop serving VAV boxes in the building. A second system recovers heat from an attic space under a plywood roof deck covered with asphalt shingles to heat a domestic hot water loop in a barracks. The third system recovers heat from a solar re-roof of a pool building to supply heated air to the pool heating and HVAC system.

Background

Electricity-There is a thriving market for all things electrically productive and efficient. Every year progress is made, new electric power and electronic devices are introduced, power management and storage systems are developed, policies and incentives evolve and the next year starts with more focus on producing, saving, and managing our electric supply and expenses. This is all for the better, as we increase our electrical efficiency, using less electricity to do more.

It is not hard to see why we focus on electric power and management concerns. With more connected devices, and our increasing use of all things digital, we now have now shifted our every day measure of energy's value from the 'price of a gallon of gas' to the available 'charge on our cell phone'.

What used to require a once daily drive by a gas station for a sense of our energy vulnerability now happens 10 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 should occur, we are nearly lost, measuring our anxiety by the minutes left on a battery, as we seek out and huddle around our fossil fueled electric generators. From a perception standpoint, electricity is all we want or need. It powers our devices, our fans and pumps and equipment and machinery and now, our battery powered vehicles.

Heat- However, in our focus on electric devices and production and efficiency, <u>we sometimes forget that the largest 'NEED' for energy in US buildings and industry is for 'HEAT'</u>.

We use our current energy mix of energy 'sources' from; natural gas, fuel oil, lpg, and electricity, to meet the needs of a variety of end uses. Heating, cooling, refrigeration, drying, lighting, motor to power appliances, electronics, etc. are the needs that force us to use energy sources. And among those needs, <u>heating loads dominate</u>. Low temperature heat for space heat, hot water, and clothes drying in our homes, accounts for 63% of the energy we need to satisfy those end uses. That is 7 times more than the cooling energy use and 13 times more than the energy used for computers and electronics.

In commercial buildings, low temperature heating energy use for space heating and water heating is 33% of all the energy used. This is 3 times larger than the lighting energy used, 5 times larger than the cooling energy used and 6 times larger than the energy used for our electronics and computers.

So, with this overwhelming need for low temperature heat, why do we not see more market action, innovation, and policy development for devices to cut our largest energy use?

Perhaps the answer is that the improvements in the heating field are stagnant at worst and incrementally small at best. Perhaps these minimal improvements are all that is allowed in an economic market where the per unit cost of heating energy is much smaller than the cost of electric energy. Perhaps the profits to be made from applying these minimally improved products are not enough to justify the costs of the installation. Perhaps these improvements are held back by the distributed nature of the heating installations done 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 probable causes are connected to what the market demands - Make a heating system that is more productive at lower cost than the present alternatives, when considering the cost of the devices, the installation, and the way it serves the energy loads.

Three ways to meet that market demand are: 1) switch to a lower cost energy source, 2) keep the installation simple and reliable, and 3) target the base load of heating energy use, not the peak load. Low cost, simple, base load heating.

This paper describes three projects that use simple systems in innovative ways to deliver low cost heat to buildings.

Health and Human Services Headquarters

The headquarters building of the Department of Health and Human Services is located next to the US Capitol complex, along the Mall in Washington, DC. The building operates 24/7/365 and is heated by steam from the central plant that supplies steam to several buildings along the Mall. The cost of the steam is $38 per million BTU.

The air conditioning system provides chilled air through the ventilation system with steam to hot water converters in the penthouse serving the VAV reheat piping loops that heat most zones. Reheat operates all year at about 120F. A separate two pipe ‘perimeter’ system sends hot water to fan coil units in the heating season and is switched over 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 55F supply temperature.

Annual steam use costs around $1 million per year and, with very high unit cost of steam heat, HHS explored several options to cut heating costs. A proposal to replicate a similar project recently installed at the Army Research Lab, in Adelphi, Md. was investigated in detail. The approach used simple packaged air-to-water heat pumps to recover heat from the return air (a lower cost source of heat) and generate high temperature (>130F) hot water for the hydronic heating loops and cool dry air (<60F) for the return air. To maximize the economics, the systems were sized and configured to serve only a base load. The remainder of the heating load was covered 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 around $860,000 resulted in total life cycle savings of $3.6 million to the building, with a savings to investment ratio of 4 and simple payback of 4 years. Life cycle CO_2 savings exceed 13,000 metric tons.

The detailed design was completed in 2015 and installation was completed in August 2016. Initial operations demonstrated hot water delivery temperatures of 130F and cool air exhaust temperatures of ~55F. This is compared to the 90+ F outside air during the hot Washington summer. Each heat pump uses around 5 kw of electric power to generate 16 kw of hot water and simultaneously deliver 11 kw of cool air.

Each of the (2) 5 ton heat pumps installed at each air handler delivers around 3.7 gallons per minute of hot water, a total of around 67 gpm for 18 installed units on 9 air handlers. The maximum reheat loop flow is 130 gpm. So, the total reheat from the heat pumps is about 50% of the maximum required. The perimeter heating system capacity is much larger, about 950 gpm. So, 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 sizing of the heat pumps ensures that they are delivering to the base load and not trying to service a seasonal peak load. In serving the base load for heating and cooling, they operate every day, saving money every day, to quickly repay the initial investment.

Figure 1 HHS Heat Pump Heat Recovery System

Fort Meade Freedom Barracks

The Freedom Barracks at Fort Meade, located south of Baltimore, Maryland, are a set of 8 identical barracks buildings. The 3 story, wood framed buildings have 36 double occupancy suites. Domestic hot water is supplied by natural gas fired tank type water heaters in a ground floor mechanical room and pumped circulating loop feeding each room from the overhead of the central corridor on each floor.

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

The Fort has undertaken several heat recovery projects to support building heating needs using the heat recovered from the building envelope, as 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 (135F) water to the domestic hot water loop before it returns to the hot water heaters.

The Freedom Barracks project was developed by the Fort's Resource Efficiency Manager in the Engineering Office and American Solar, Inc. It was funded by the DOD Environmental Security Technology Certification Program (ESTCP) based on a proposal by American Solar. The design is complete and installation is scheduled for September 2106, with one year of monitored performance to follow.

The same heat pump used at the HHS building is used in the Freedom Barracks project. However, instead of using the return air, as a heat source, the hot attic air will be used to preheat the heat pump. The advantage of using hotter air is that the heat pump becomes much more productive for the same electrical energy use. For example, a heat pump fed with 78F degree air will produce 14.6 KW of hot water for 5.2 KW of electricity used (COP=2.8). When fed with 100F 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 100F, the exhaust air from the heat pump will be ~76F. When substituted for outdoor air at 90F, the exhaust air represents a cooling resource of around 3.7KW or a cooling COP of 0.8. The combined heating and cooling COP would be 4.3. On cooler days when the building does not need additional cooling, the cool heat pump exhaust air can be simply exhausted outdoors.

There will be hours during the night and on very cold days when the attic air is not hot enough to boost the heat pump performance to economical levels. For example, on a 30F day, the attic air may reach 60F degrees. 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 those conditions, the heat pump would simply 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 simply running the

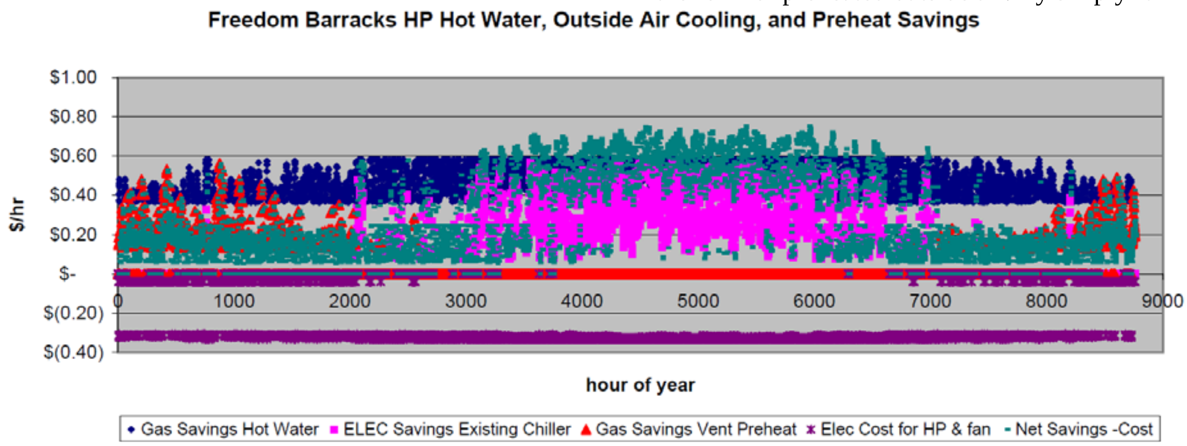

Figure 2 Freedom Barracks Hourly Cost Savings

low power fan to move the warmer attic air to the outdoor air intakes, the building would see an increase in outdoor air temperature and a reduction in the building heating load. With the fan delivering 1,200 cfm of 60F attic air to the outdoor air intakes, during a 30F day, it delivers 11.7KW of heat with fan power of 0.5KW, for a COP of 23.

Hourly calculations using typical meteorological year solar and weather files provide an indication of the annual economic performance of the heat pump system in different climates. When fully deployed at the Freedom Barracks in MD, the system would provide a savings to investment ratio (SIR) of 2 and a Simple Payback (SPB) of 10 years. However, in a different climate, such as Jacksonville, FL, where dehumidification and cooling are more dominant loads, the SIR is 5.6 and the SPB is 4 years.

The relatively simple approach of 1) capturing a low cost source of heat from attic air 2) to boost performance of a simple packaged heat pump and fan to deliver high temperature water, cool air, and warm preheated outdoor air, to 3) handle a portion of the base loads for heating and cooling, can make an economical project. In the case of the Freedom Barracks the project is repeatable and expandable to several other buildings.

Fort Meade Gaffney Pool Roof

The Gaffney Fitness Center Gym re-roof was the site of a previous 'solar' re-roof funded by ESTCP in 2012.

The Engineering Office at Fort Meade was recently given an Innovation / New Technology - Army Energy Award for the project, which provided both a new 40 year metal roof and heating savings for; space heat, outdoor air preheat, and domestic hot water preheat.

Another wing of the fitness center houses the 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 system controls indoor temperature, humidity, and air quality and pool water temperature. It uses a combination of outdoor air, gas fired boiler hot water, and compression refrigeration to manage air and water temperatures (80-85F), humidity, and air quality.

This type of pool environmental control system is recognized for its efficiency compared to a system which simply flushes the humid air from the pool and replaces it with outdoor air that often needs to be heated or cooled. However, the common approach for these efficient environmental control systems is to use a selective economizer that uses 100% outdoor air instead of pool air returning to the unit, whenever outdoor air is warmer and/or drier than the air leaving the evaporator coil. This approach allows all the refrigerant heat from the compressors to be transferred into the conditioned supply air and/or the pool water. This approach 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-roof, there will be several hours per year when the air from the roof will be 30

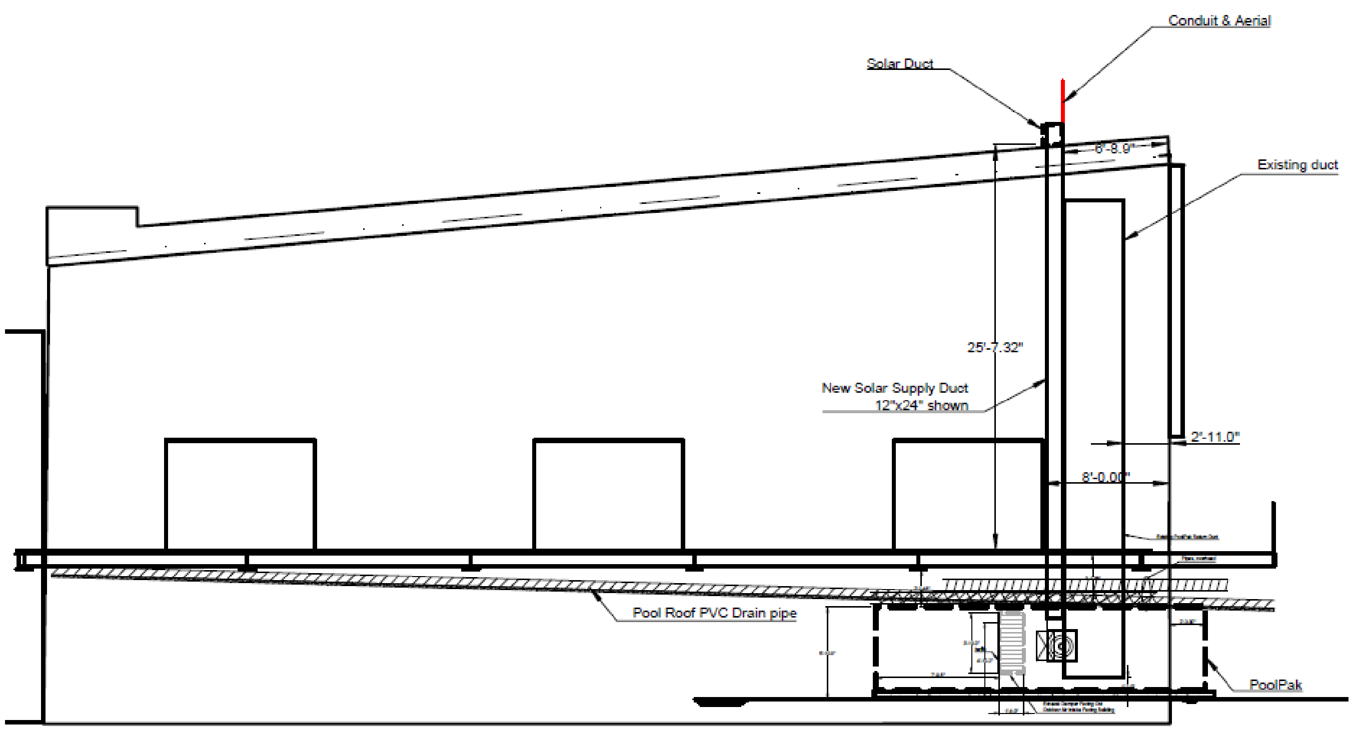

Figure 3 Gaffney Pool Roof Solar Heat Recovery

to 40F above outdoor air temperatures. By delivering that solar air to the outdoor air intake, the pool unit's selective economizer will have many more hours per year to operate with 100% outdoor air at lower energy use when compared to typical outdoor air temperatures.

The solar air heating re-roof is a straight forward metal roof installed with a few inches of air space below the conventional metal roof panels. When the panels are heated by the sun the air temperature in the air space can reach 80F above outdoor air temperatures. With proper air flow, the temperature of the delivered air typically peaks about 40F above outdoor air temperature. A simple fan can deliver air flow equal to 100% of the outdoor air requirement, but a more economical air flow will target only a minimum outdoor air or base load portion of the required flow. The current design calls for delivering 4,000 cfm of the 12,000 cfm 100% air flow. The 1.5 KW fan will deliver 50KW of heat to 4,000 cfm of air with a 40F temperature rise, 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 that surrounding air which is being pulled into the intake. Eliminating the hard ducts will also eliminate 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 certainly the lowest cost source of energy for heating the pool wing with most of the system cost going to the roof, which would have been replaced even without solar heat recovery. The system is designed to handle a base load and so will operate for many hours per year and will simply turn off whenever it can not provide economical heat, at night or on rainy days. It is simple and reliable with only simple thermostatic controls and a conventional fan that blows 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 conventional energy retrofits only in that they have used low cost sources of energy that are often ignored: return air, attic air, and roof air. They use simple conventional construction techniques and equipment and typically use simpler controls than traditional systems because they are intended to handle only a portion of the load, the base load. 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.

In most cases, even if the primary systems were replaced with the most efficient conventional systems that could handle the peak load, these systems would still produce lower cost energy because they start with the lowest cost source of energy, and simple design, and provide consistent savings for many hours of the year. These retrofit systems may take a bit more 'energy engineering' than straight replacements of equipment with more efficient systems sized for peak loads, but the engineering delivers more energy and cost savings than straight replacements.

References

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

John Archibald is President of American Solar, Inc., an Annandale, VA company that uses conventional walls and roofs to solar heat air. He has designed / installed all the largest solar air heating roofs in North America and designed heat recovery systems using low cost air heat. He can be reached at 703.425.0923 or info@americansolar.com.