Subject: SunDrum Solar® HarvestHP™ Residential Performance

Introduction

In January 2016, SunDrum Solar® commissioned a 27kW (15.5kW thermal and 11.5kW DC electrical) HarvestHP™ residential system on a home in the Washington, D.C. area. The HarvestHP™ system combines the most efficient hybrid solar collectors in the world, developed and patented by SunDrum Solar®, with water heat pump technology to provide unprecedented performance. When the sun is shining, the system is in "Active Mode" and captures thermal and electrical energy from the sun, as any traditional solar system. When the sun's direct rays are weak or not available, "Harvest Mode" uses the collectors to absorb thermal energy from the air, and utilizes the heat pump to boost the useable thermal temperature of the fluid, making the system capable of running 24 hours a day. The energy produced in either mode can be applied to generate domestic hot water (DHW), space heating, or pool heating. In addition, by reversing the energy flow, space cooling can be provided. This system is the primary source of space heating, space cooling, pool heating, and DHW for a 2,100 square foot home with a 600 square foot outdoor pool.

SunDrum Solar® has been implementing HarvestHP™ systems since 2014. The design used in this home included improvements learned from the first generation of systems. In its first twelve (12) months, the HarvestHP™ system delivered over **90%** of the 2,100 square foot home's energy need and reduced the annual energy bill from 80 MWh to 7 MWh. The hybrid solar system provided **92%** of the home's pool, space, and DHW heating needs (1,400 therms), **100%** of space cooling (4,100 therms), while supplying **82%** of the home's electrical loads (16 MWh). Energy savings, combined with credits earned from the local Solar Renewable Energy Credit (SREC) program, represent $18,000 in savings for the customer in the first year of service.

System Description

The home was fitted with 46 SunPower 250W panels, of which 32 were installed as hybrid PVT panels using SunDrum Solar® SDM100 480W collectors. The unique design of the SunDrum Solar® thermal collectors enables them to be easily mounted behind the PV panels, providing the following benefits:

1. Cools PV panels, increasing their efficiency and extending their life.
2. Captures over five times more energy from the same footprint on the roof.
3. Preserves the aesthetics of a PV-only installation.

The resulting hybrid solar array is rated at 27kW (15.5kW thermal and 11.5kW DC electrical). The system also includes a four (4) ton water-to-water heat pump and 80 gallon DHW preheat tank. The existing gas furnace and gas water heater were retained as back-up heaters. Figure 1 shares the mechanical design.

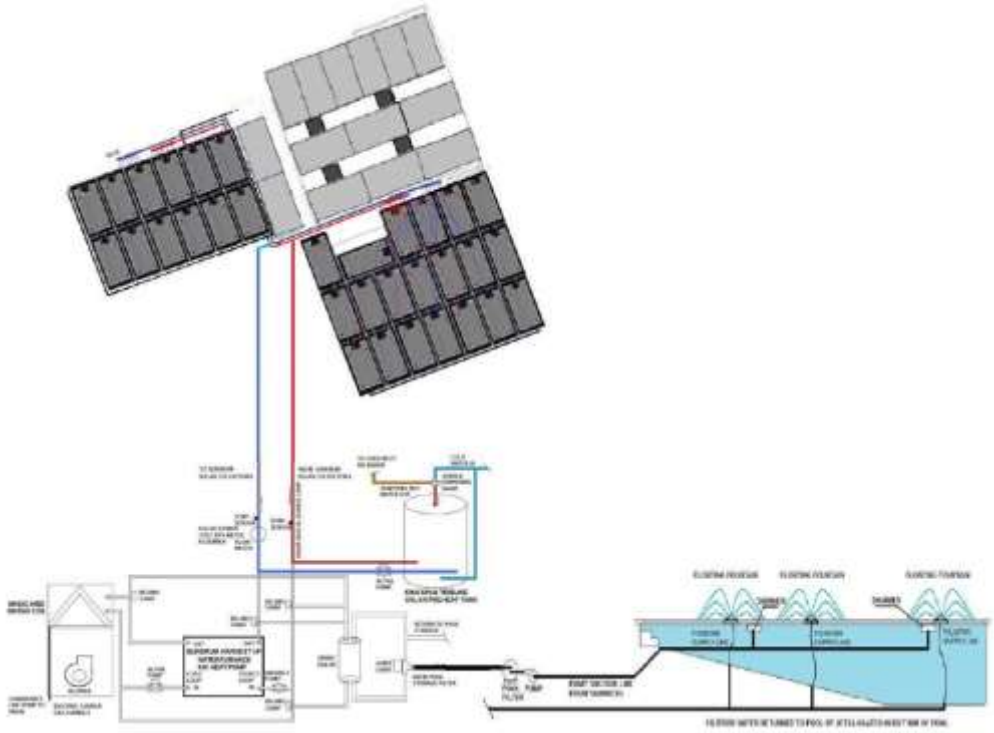

Figure 1 (2016 design implementation)

An advantage of recent generation HarvestHP™ system design is the ability to use the home's pool as a thermal battery. In the summer, space cooling is provided by using the heat pump to reject heat from the home into the pool, thereby cooling the home and heating the pool simultaneously. As basically free energy, this is a key to the superior financial performance of the system, regardless if installed on a residential or a commercial application. To prevent the pool from overheating, at night the system is designed to cool the pool by pulling heat and rejecting it to the sky through the thermal panels on the roof. This ability to reject heat to the sky is also the key to providing solar space cooling for the home - an exceptional feature of our system, since we are actually cooling the planet by rejecting heat into outer space. All other cooling systems only reject hot air to the immediate surroundings of the home.

In the colder months, this thermal battery feature can be operated in reverse, where the heat pump is used to transfer heat from the pool to the home to provide space heating. When the sun is shining, the HarvestHP™ system will heat the pool using thermal energy from the solar collectors, storing it for space heating at night[1]. Due to the large thermal mass of the pool, the pool water remains significantly warmer than the outdoor air throughout the winter. This allows the HarvestHP™ system to operate at much higher Coefficients of Performance (COPs) than a traditional air heat pump system, which extracts heat from the cold winter air instead of the warmer pool water. Additionally, the ability to recharge the pool using solar heat provides an advantage over traditional geothermal heat pump systems, which do not replace the heat they remove from the ground on a daily basis.

Early SunDrum Solar® HarvestHP™ systems used the thermal battery feature in the summer only. The system documented here represents the first time that the pool was also used in the colder months to provide space heating. Earlier systems experience a dramatic drop in usability at night in the winter due to the low COPs from extracting heat from the cold air through the collectors on the roof. The ability of the HarvestHP™ system to extract heat from the solar heated pool allows the system to continue to operate in a major role in space heating and financial energy savings for the winter.

Using an 80 gallon preheat tank, the fluid sent to the collectors is kept cool, allowing the maximum amount of thermal energy to be extracted from the collectors. This also increases the electrical efficiency and longevity of the PV system by cooling the PV panels. In addition to direct solar heating of the DHW tank, this system also includes a desuperheater loop which heats the DHW tank using waste (free) heat from the heat pump, further decreasing the amount of gas needed to heat the water.

The HarvestHP™ system also includes the optional feature of manual (owner-controlled) snow melting capability, which uses the heat pump to extract energy from the pool or home and direct it to the solar collectors to melt the snow. If the heat is being pulled from the home, the natural gas burner is turned on to keep the home from cooling. Once a portion of the panels becomes exposed to the sun, the resulting heat will engage circulation and the heat will be transferred to the still covered panels, melting the snow on those panels. Owners are encouraged to minimize the use of this feature, as it uses valuable energy that would otherwise be used to heat the home.

First Twelve (12) Months: Performance Data

Figure 2 shows how much of the home's energy demand was met by the HarvestHP™ system in its first year of service. From the graph, it is evident that the HarvestHP™ system is providing a substantial portion of the heating and cooling loads for the home, with minimal backup from the natural gas heaters. In fact, the home has no backup cooling system, thus the HarvestHP™ system is providing 100% of the space cooling load in the summer and shoulder months.

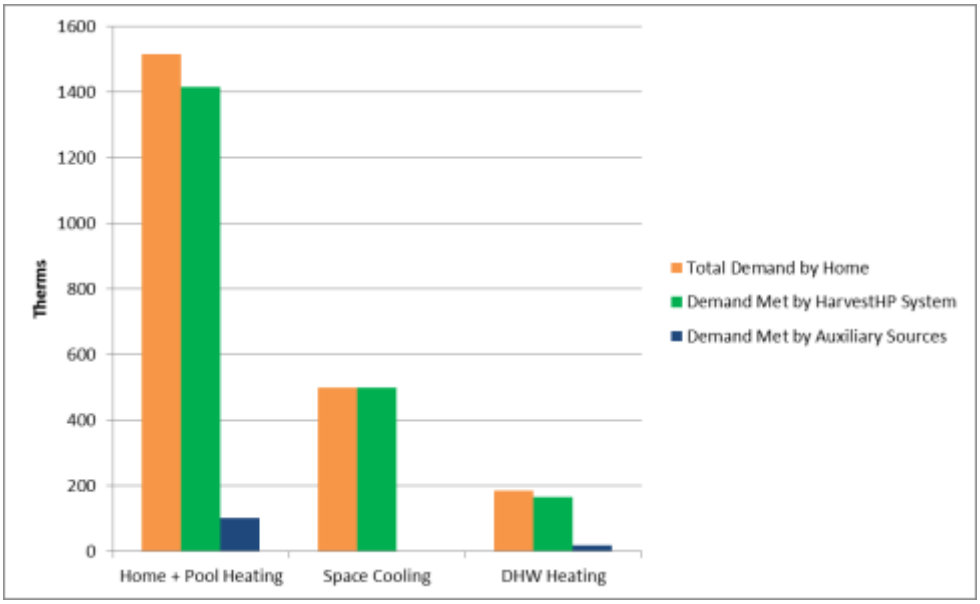

Figure 2: HarvestHP™ System Performance

During its first winter, the pool did an excellent job in its role as a thermal battery, allowing the system to continue heating primarily via the HarvestHP™ system. The pool temperature stayed in the 50's (^{o}F) for most of the winter, dipping into the upper 40's during a few cold spells. Due to an unusually warm February 2017, the temperature had climbed to 66 ^{o}F by the end of the month.

As previously discussed, space cooling is sometimes provided by rejecting heat to the night sky through the SunDrum Solar® thermal collectors. An important parameter for this process is the heat loss coefficient, which measures how well the collectors reject heat. During these cooling modes, this system was found to operate at a coefficient of 20 W/m^{2}K through the SunDrum Solar® collectors[2], which is equivalent to three (3) tons of cooling capacity at a temperature delta of 40^{o}F between the collectors and the night air.

Financial Performance
In the first twelve (12) months of service, the system provided 1,400 therms of heating energy for the home, which included space heating, pool heating, and DHW heating. All electric energy used by the heat pump to generate this heat was offset by electricity produced by the PV panels, so this heating represents true savings by the solar system. Assuming a natural gas heater efficiency of 80% and using the local (Washington, D.C.) natural gas price of $1.37/therm, the customer would have spent $2,400 to generate this amount of heat with their original gas-only system.

For space cooling, the system provided 4,100 tons of cooling energy during this time period. This would otherwise require 4,800 kWh of electricity to achieve this amount of cooling for a typical home[3]. At the local electric rate of $0.12/kWh, this represents a yearly savings of $578 on cooling costs for the customer. Since the electricity used by the heat pump is offset by the PV array, this represents true savings.

The customer also benefits from the federal tax incentive program, which grants a tax credit totaling 30% of the installed cost of a renewable energy system. This incentive is available anywhere in the United States, and is independent of the SREC program.

Conclusion

In the first twelve (12) months, the SunDrum Solar® HarvestHP™ system was able to offset over 90% of the 2,100 square foot home's energy bills, saving the customer a total of $2,900 as well as generating an additional $15,000 in income via the Washington, D.C. SREC program. The thermal system was able to offset over 92% of the home's heating bills, where a traditional solar thermal system typically only offsets 30% of the home's heating bills. These tremendous savings reflect the ability of SunDrum Solar®'s hybrid modules to collect the maximum energy from the roof, along with the ability of the HarvestHP™ heat pump to dramatically increase the number of hours the thermal system can operate on a daily/yearly basis. The SunDrum Solar® HarvestHP™ design is a direct result of our game-changing approach, representing an exciting step forward for our system and the solar industry.

SunDrum Solar® installs a monitoring system on all of our HarvestHP™ systems, allowing the customer to see real time savings, and allowing SunDrum Solar® to keep an eye on the performance. SunDrum Solar® has been installing its patented hybrid solar collectors since 2008.

[1] The ability to charge the pool during the day depends on the thermostat setting for space heating. If space heating is needed during the day, the ability to charge the pool will be reduced, as the heat will go to the home as a first priority. In the case documented here, the thermostat is turned down during the day, allowing the system to direct all solar heat to the pool.

[2] Heat loss coefficient was calculated using outdoor air temperature as measured from an air temperature sensor on the roof, rather than the night sky temperature.

[3] Assuming a traditional window-mounted A/C unit with a COP of 3.

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