System Performance Measurement Supports Design Recommendations for Solar Ventilation Preheat System

Fabric duct supplied with ventilation air. *Photo by Ed Hancock, NREL/PIX 19364*

The U.S. Department of Energy's (DOE) Federal Energy Management Program (FEMP) sponsored the installation of a data monitoring system to analyze the efficiency and performance of a large solar ventilation preheat (SVP) system. The system was installed at a Federal installation to reduce energy consumption and costs and to help meet Federal energy goals and mandates. SVP systems draw ventilation air in through a perforated metal solar collector with a dark color on the south side of a building, using the sun's radiation to heat the air as it is drawn into the building.

Data monitoring is a useful method for measuring and verifying the performance of a renewable energy system, and can also reveal that a system is not operating optimally. In such cases, the findings may indicate best practices to avoid problems and optimize system performance and may provide key information to be considered during system design.

A key finding of the data monitoring was that the system operated at low flow rates per unit collector area (cfm/ft^2) and a low pressure drop across the collector. The low flow rate reduces the SVP collector's efficiency because the plate operates at a higher temperature and there is more radiant heat loss. The low pressure drop leaves the collector vulnerable to outflow at the top of the air chamber (or the plenum) due to buoyancy effects, uneven flow distribution across the collector face (resulting in hot spots, which are low in efficiency), and the difficult-to-predict effects of wind on the face of the collector. National Renewable Energy Laboratory (NREL) researchers have generally advised that systems be designed to have a pressure drop above 25 pascals (Pa) (0.2 mm Hg) across the absorber.[1] A recent study[2] measured the relationships of pressure drop to flow rate and NREL researchers have documented air properties for all commercially-available transpired absorbers.[(2)] Designers should consider these correlations in specifying the collector size, collector porosity, and flow rate per unit collector area that will maintain a 25 Pa pressure drop at the desired flow rate. Even for systems with the least-porous absorber (low-flow steel) and no leaks, these measurements indicate that a flow rate of at least 6 and 10 cfm/ft^2, depending on type of collector materials and porosities, is required to meet the 25 Pa pressure drop line at sea-level atmospheric pressure and 0^{o}C air temperature.

A certain amount (a fixed cfm) of ventilation air is required for most buildings. Designers can increase flow rate per unit area (cfm/ft^2) by specifying a smaller area wall. In an effort to collect more solar heat and get a higher temperature increase, designers sometimes specify larger wall areas, which result in lower flow rate per unit area and lower efficiency, as was the case in this installation. While this does result in higher temperature rises and meeting a higher fraction of the load with solar, the increase in collected energy may be small due to the reduction in efficiency. In other words, there are diminishing returns.

Transpired collector mounted on the south wall of the building. *Photo by Ed Hancock, NREL/PIX 19363*

A SVP system typically includes a bypass damper, which allows the ventilation air to either be drawn through the collector before entering the building or bypass the collector and enter the building directly. When the space requires heat, the outside air damper is closed and air comes in through the solar ventilation preheat collector. When the space does not call for heat, the outside air damper is open and the ventilation air comes in directly without preheating.

In the case of the system at this installation, even the highest measured flow rates per unit area were very low compared to recommended values in design and operation, resulting in low collector efficiency. Additionally, a set of two modulating dampers modulated the amount of air between the ventilation air from the collector and the return air from the space. On cold/cloudy days, when heating was most needed, the air in the space was mostly circulated and a very low amount of air from the collector was allowed into the space. Both pressure drop and air flow per unit collector area decreased dramatically, and as a result, the collector was operating at very low efficiency. Another unfortunate result of this strategy was that on cold/cloudy days the ventilation rate was reduced to nearly zero and the electrical energy used to run the fans was used simply to recirculate indoor air, which was not needed.

Performance Monitoring

The data monitoring system consisted of a Campbell Scientific CR10X datalogger with a 16-channel mechanical multiplexer. All data were measured on a 20-second interval and stored in two separate files: one at one-minute averaging intervals and one at 60-minute averaging intervals. Data were collected remotely through a telephone modem from March 2006 through June 2007.

The SVP system, designed and installed in 2006, consists of a 340 m^2(3,664 ft^2) unglazed transpired solar collector mounted on the exterior of the southern wall of a building and two parallel ventilation fans. In this SVP system, flow rates through the collector are controlled by temperature sensors rather than fixed at a constant rate, allowing the effect of flow rate to be measured. Recirculated indoor air is mixed with air from the plenum to deliver conditioned air at 13^{o}C (55^{o}F), so the air flow through the collector is not constant.

Over the course of the monitoring period, ventilation flow rates per unit area averaged 0.007 m/s (or 1.40 cfm/sf), and at these low flow rates the average collector efficiency over the period was 26.9%. **Transpired collector systems are known to have overall collector efficiencies of close to 60%[3] when:**

- **The pressure drop is above the recommended value of 25 Pa to avoid non-uniform flow through all the holes, and**
- **The flow rate per unit area is high enough to keep the collector plate temperature low and radiant heat loss off the plate relatively low.**

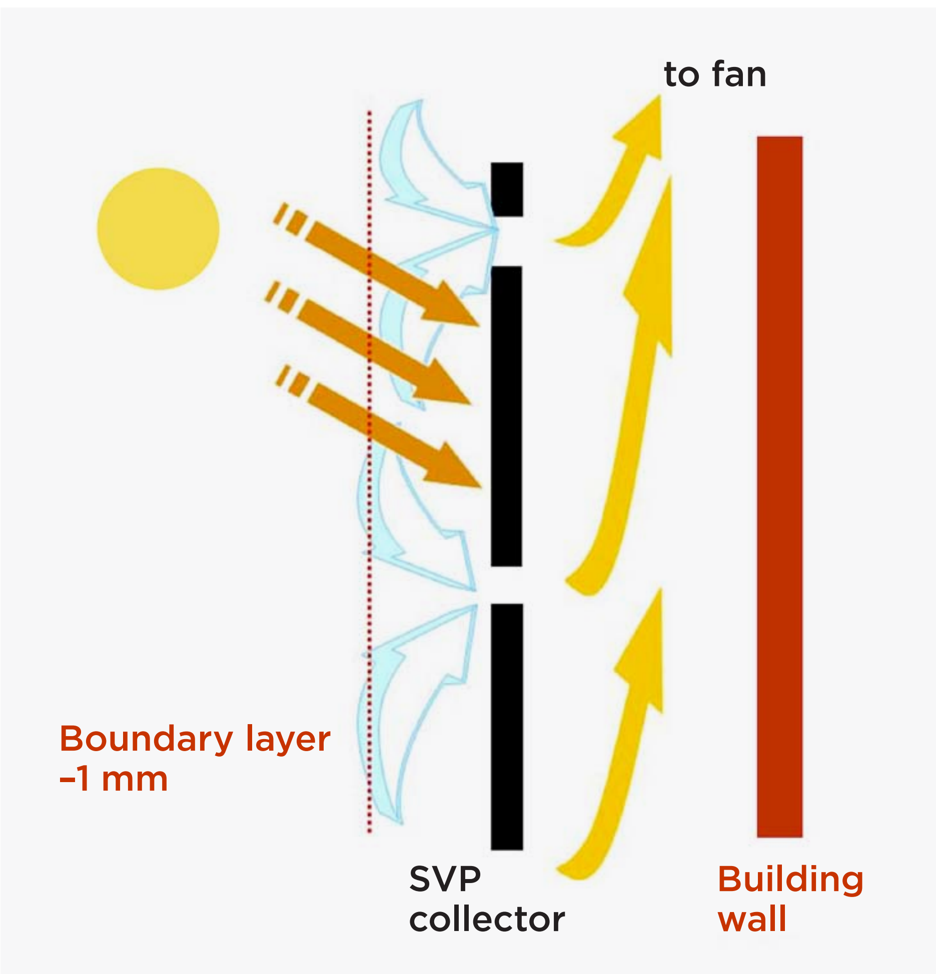
At 2.85 to 3.15 cfm/ft^2, the highest range of flow rate recorded here, the efficiency was measured at 50.5%. The savings from the solar preheat ventilation system were (99,326 kWh) 339 MBtu, accounting for 48% of the energy needed to heat the delivered ventilation air to the building over the year-long monitoring period.

Although the building manager intended to meet a minimum ventilation air rate for the building, the system was designed to deliver air above a temperature set point, whether or not this resulted in enough ventilation air being delivered to the building. The result of this strategy was that there were large portions of time in which very little ventilation air was delivered to the building and the collector operated at very low efficiency, resulting in diminishing returns on investment in the SVP system. The resulting recommendation is to use the SVP system to preheat the necessary amount of ventilation air when the space requires heat, and not to throttle the flow through the collector to get a higher temperature.

System Operating Principles

The operating principle of a transpired solar collector is based on the concept of the "asymptotic boundary layer." As cool air passes over a hot absorber plate without transpiration (air is drawn through small holes in the plate), a layer of warm air develops at the surface of the plate. This layer gets thicker and thicker as the air moves along the plate. When the air blows off the end of the plate, there is thermal energy encapsulated in the warm boundary layer. This energy is the convection heat loss from the plate. When the plate is transpired, the boundary layer remains thin all along the plate, approaching an asymptotic thickness.[4] Because this boundary layer is so thin, the energy encapsulated in the warm boundary layer leaving the trailing edge of the plate is very small, so the convection heat loss is very small. Most of the heat loss from a transpired collector is then radiative (infrared heat loss), driven by the temperature difference between the absorber plate and the surroundings (foreground and sky). The asymptotic boundary layer and the low convection heat loss can only be maintained if there is flow into the plate at a relatively uniform rate over the entire surface of the absorber plate.

An ideal transpired plate has air drawn into its surface uniformly at every point. This is physically impossible, so transpired plates generally consist of a metal sheet punched with many small holes and/or slits. Transpired absorber plates must be designed so that the holes or slits are not too far apart. When the design deviates from the ideal transpired plate, the asymptotic boundary layer cannot be assumed, and the convection heat loss becomes large and vulnerable to the speed and direction of the wind.

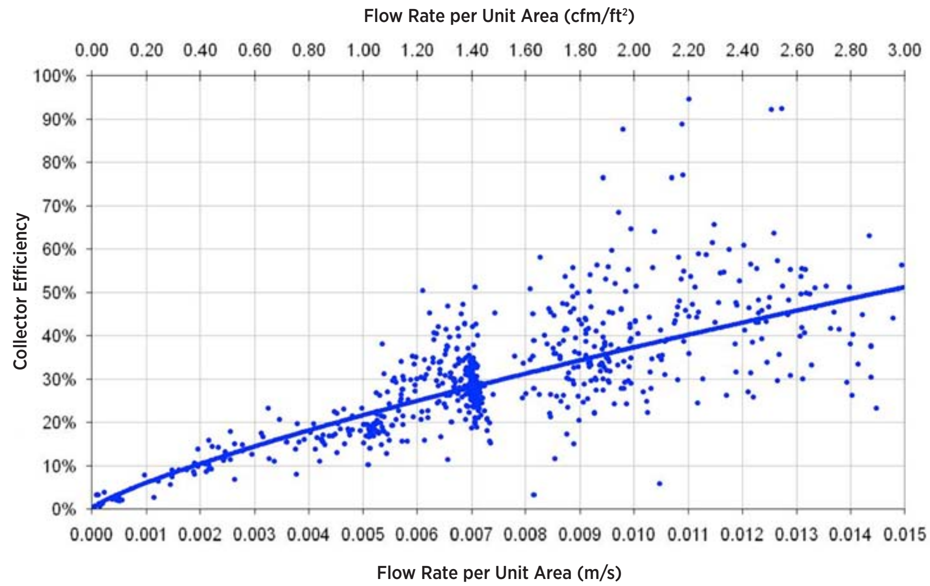


How a solar ventilation air preheating collector panel works

A sensible system design balances the desire to use a larger collector area to intercept more solar energy with a need to maintain flow rate per unit area and pressure drop that are keys to the high efficiency of the technology. In addition to deciding on the collector area, designers may also have a choice of porosities. Absorbers are manufactured with different porosities, each resulting in different pressure drop across the absorber for the same flow rate. Specifying a low porosity can achieve the 25 Pa pressure drop and avoid non-uniform flow through the holes, but a low flow rate per unit area will always result in a high plate temperature and increased heat loss to the ambient air. It is unavoidable that SVP offers diminishing returns when attempting to heat air to a higher temperature and meet a higher fraction of the energy load with solar. In any case, it is important to maintain a pressure drop across the absorber of at least 25 Pa to ensure that the suction rate is relatively uniform over all areas of the absorber regardless of wind conditions.

Results and Design Considerations

Results of the data monitoring support the relationship between efficiency and flow rate. Reducing the flow rate through the collector in an attempt to deliver high-temperature air causes a reduction in the efficiency of the collector. The efficiency of the collector can



Efficiency as measured over the range of flow rates at this installation. The solar collector operated below its ideal efficiency at low flow rates, but it operated at efficiencies approaching those expected at higher flow rates.

be kept high (in the 50 to 60% range) by maintaining the minimum flow rates per unit collector area and pressure drop. NREL recommends using the flow rate per area of 6 cfm/ft^2 and pressure drop of 25 Pa for a low-flow, steel SVP collector when designing and operating a SVP system at standard atmospheric pressure.

The performance measurements of this SVP system provide new insights into how solar ventilation preheat systems work, emphasizing the importance of ensuring that collector systems are designed and installed to meet minimum recommended values of flow rate per unit area and absorber pressure drop. When these requirements are met, the efficiency of the system is good, as there is uniform flow through all the holes and the flow rate per unit area is high enough to keep the plate temperature low and radiant heat loss off the plate relatively low. When these requirements are not met, the efficiency is much lower. For SVP and other renewable energy systems, the design of the system is critical to ensuring that the technologies perform according to a Federal agency's specifications and energy goals.

1 Kutscher, C.F., Christensen, C.B., and Barker, G.B., "Unglazed Transpired Solar Collectors: Heat Loss Theory," Transactions of the ASME, Vol. 115, August 1993.

2 Barker, G., Kiatreungwattana, K. (August 2011). "Pressure Drop as a Function of Air Flow Rate for Roll-punched Transpired Solar Collectors with Different Porosities." Proceedings of ASME 2011 5th International Conference on Energy Sustainability & 9th Fuel Cell Science, Engineering and Technology Conference. NREL/ CP-7A40-51628. Golden, CO: National Renewable Energy Laboratory, 6pp.

3 Barker and Hancock. "Performance Verification Report, Solar Ventilation Preheat System." Delivered to Sara Farrar-Nagy at the National Renewable Energy Laboratory, May 5, 2006.

4 Asymptotic thickness refers to the thickness that the boundary layer approaches but never reaches. For a transpired collector, the thickness that the boundary layer approaches is a function of face velocity (flow rate per unit area), wind speed, and air properties.

Resources:

Federal Energy Management Program
http://www.femp.energy.gov/

FEMP Solar Ventilation Preheating Resources and Technologies Page
http://www1.eere.energy.gov/femp/technologies/renewable_svp.html

FEMP Training
http://apps1.eere.energy.gov/femp/training

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