Solar Air Heating Roofs For Space Heating, Water Heating, And Cooling

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Abstract

In the last 5 years, over 250,000 square feet of solar air heating metal roofing and siding has been installed at residential, commercial, and government facilities. A recent Department of Defense ESTCP project (Ref. 1) funded the installation and monitoring of a solar air heating roof retrofit at a fitness facility in Fort Meade, MD. This roof is the third largest solar air heating roof in North America.

The solar heated air was used for domestic water preheating, outdoor air preheating, and direct space heating. The metal roof was installed over an existing, worn out, built up roof. The metal roof provides a code compliant, long life, weather tight roof with solar heating capability for little more than the cost of the roof itself. Air heat recovery from the roof with indoor air-to-water heat exchange provides for both air and water heating without the weight, cost, and risk of a large, distributed, outdoor water/glycol based solar collector system.

This paper discusses the design, installation, and testing of the roof over a 6 month testing period from summer to winter. The results discussed include the solar air delivery performance and development of a first of its kind model for predicting solar air temperatures for unglazed metal roofing with forced air flow. The result also include a discussion of the reduced summer heat load on the solar covered existing built up roof, compared to the nearby exposed built up roof and a "cool" roof.

Background

The largest end use of energy in most buildings is for heating. This includes space heating, water heating, equipment and process heating, and drying. Even in California, the state most often considered when hot summers drive electrical use for air conditioning, the largest energy end use and expense in homes is for heating. (Ref 2, 3)

Within the Department of Defense (DOD), which contains every type of building found within the larger population, there are nearly 2 billion square feet of building "under roof" that require "heating" for space heat, water heat, and equipment heat. DOD's total Operations and Maintenance expenses for all buildings are very high, but two of the largest recurring expenses in DOD facility operations are:

1. The annual "heating" energy bills, ~$1.28/square foot of occupied space/year
2. The infrequent, but expensive, re-roofing of buildings, ~$0.67/square foot of roof/year (~$10/sqft of roof about every 15th year).

With over 570,000 buildings and 1.9 billion square feet of occupied space, annual "heating" bills are $2.4 billion (2006) out of a $4 billion total energy bill. Roofing expenses are about $640 million per year.

A Solar Air Heating Roof

To reduce the impact of energy used to heat buildings, and reduce roofing costs, American Solar, Inc. demonstrated the benefits gained by using a Solar Air Heating Metal Roof. The solar heating roof eliminated continuing repair and replacement of built up roofs and reduced natural gas heating expenses at the Gaffney Fitness Center located at Ft. Meade, Md. The innovative solar air heating metal roofing system uses conventional, weathertight, metal roofing in a traditional, code approved, manner to provide a long life (40 year), weathertight roof and a solar air heating collector. The solar metal roof saves over $5,000/yr, and over $189,000 over 30 years for the 9,275 square foot roof.

The innovative combined use of the roof panel as both the roof and the solar collector surface greatly reduces the cost of collecting solar energy for heating. The collection of solar heat via solar heated air makes the system extremely efficient and productive at air heating, (the largest building heating load) and provides sufficiently high solar air temperatures for water preheating from a conventional air-to-water heating coil, placed in an easily maintainable location.

Just under the standing seam roof panel there is an air space. When sunlight hits the metal roof panel it heats the panel by as much as 80°F above outside air temperatures. The hot roof panel transfers its heat to the air in the air space. This air enters at the ridge of the roof and is solar heated as it passes below the metal panels on its way to the outlet plenums in the mechanical room. Within the new mechanical room; fans, ducts, and controls move the solar heated air to serve the varied loads. An air-to-water heat exchanger, in the mechanical room is piped to a 40 gallon solar preheat storage tank and a pump that are installed in a basement mechanical room.

The solar heated air is used for three separate purposes. During the heating season, it heats outdoor ventilation air before it enters the main air handler for the gym. The solar air is also used for direct space heating of the gym. Finally, on a year round basis, the solar heated air is used to heat cold water before it enters the domestic hot water boiler.

<u>The outdoor air preheat system</u> delivers solar heated air to the air intake when the existing building automation system calls for heat in the gym, and the solar controls confirm that the solar air is 8°F warmer than the outdoor air. Even on cold winter days, with outdoor temperatures below freezing, the solar air temperatures reach 20-35°F warmer than the outdoor air, reducing the gas heating needed to bring the cold outdoor air up to room temperature. In the mid-latitude Maryland climate, the outdoor air preheat system runs for 1,800 hours per year, delivering an average of 143,000 BTU/hour to the outside air stream.

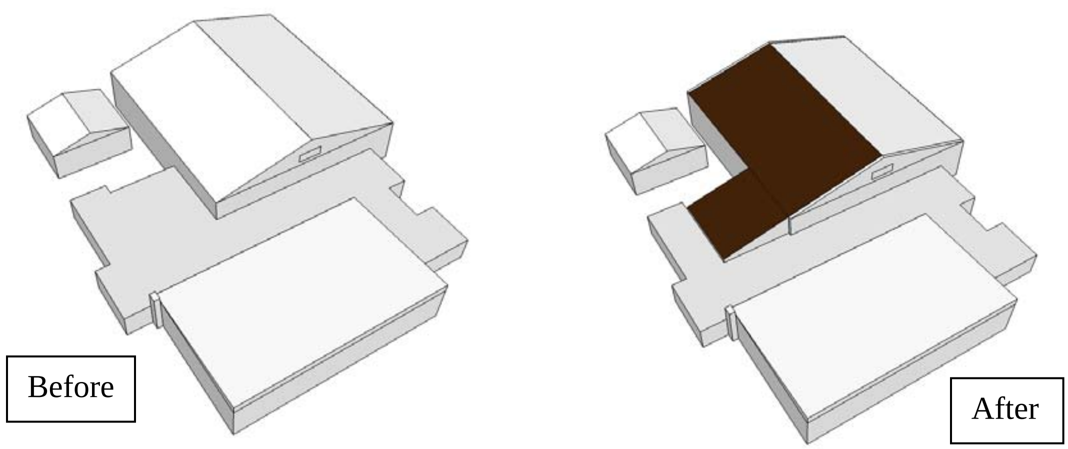

Figure 1 Solar Air Heating Roof Before & After

A solar air heating roof was installed over the worn out built up roof of the Fitness Center. The new roof covered the sloped, southwest half of the gym roof and a flat section of roof over the locker rooms. See Figure 1. Both sections of old built up roof had been patched several times and were in need of replacement. Unlike a typical 'in-kind' replacement of the built up roof, which would have required a 'tear-off' and disposal of the old roof, the solar roof is installed above the old roof. The solar roof incorporates metal support structure attached through the old roof, insulation, and a new standing seam metal roof. See Figure 2. The installation formed a continuous roof from ridge to eave and created a new mechanical room over the old flat roof. See Figure 3.

<u>The water preheat system</u> operates whenever solar heated air in the roof is 8°F warmer than the water at the top of the solar preheat tank. When the solar air temperature in the roof is warmer than the preheat tank, solar fans run and blow air across the air-to-water heat

exchanger while a circulating pump moves the water from the tank through the heat exchanger. As hot water is drawn from the showers and sinks in the building, preheated water (instead of cold city water) enters the cold water loop headed to the domestic hot water boiler and cold water enters the preheat tank, where it mixes with the preheated water and circulates to the heat exchanger.

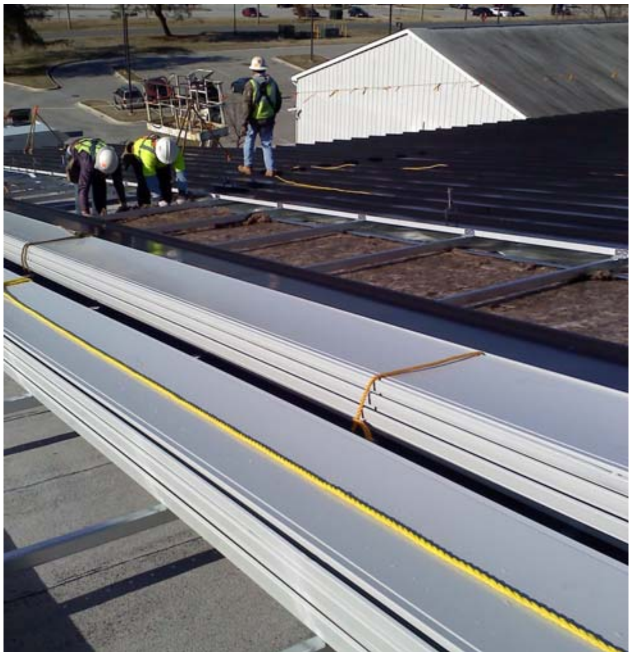

Figure 2 Solar Air Heating Roof Installation

The water preheat system runs for about 3,000 hours per year and delivers hot water at tempetures as high 120°F with solar air in the 140°F range during hot summer days. Even in January the system can deliver heat to the cold city water at a rate as high as 40,000 BTU/hour.

The direct space heat system uses the same solar air flow path and fans as the water preheat system. It pulls air from the roof outlet plenum and draws it across the air-to-water heat exchanger before delivering it to the gym. In the summer months, when there is no need for heat in the gym, but there is a need for water preheating, the solar air is sent to an outdoor exhaust louver. During cold winter months when there is a call for heat in the gym, the solar air is sent into the gym. In the spring and fall, there will be several hours when both water heating and direct space heating may be called for simultaneously. During those hours the solar air will first heat the water, and if it is still warm enough to heat the gym, it will be sent to the gym, otherwise it will be exhausted outdoors. The direct space heat system operates for about 130 hours per year and delivers about 75,000 BTU/hr.

For the three heating needs, the solar roof is capable of delivering much more heat than is required. This is due to the fact that it is installed to cover a large area of 9,275 square feet of worn out built up roof, but less than 6,000 square feet of roof is needed to serve the three different heating loads. However, because the long life metal roof was actually the most life cycle cost effective roof, it was installed over all the worn out roof areas. The energy savings were treated as secondary to the roofing in

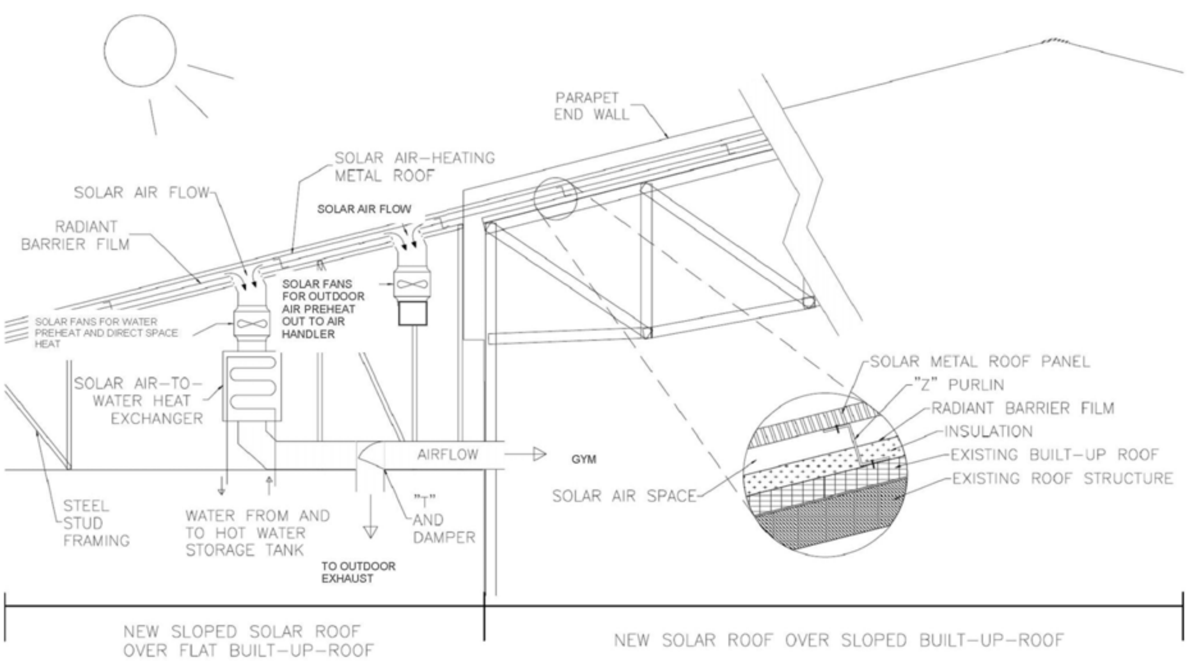

Figure 3 Solar Air Heating Roof Schematic

designing the installation, even though the annual energy cost savings are larger than the annual roofing savings and are the energy savings are enough to pay for the roof over its useful life.

Cooling the building during hot summer days is not something people expect from a 'hot' solar roof. However, testing showed that the hot solar air-heating roof reduces cooling costs and is the thermal equivalent of a "Cool Roof".

In one section of the Gaffney solar roof, thermistor sensors were installed in a vertical stack from the top of the solar air space down to the surface of the old built up roof that the solar roof covered. Temperatures were measured every 15 minutes and compared to the temperature of the nearby, uncovered built up roof, and to prior roof test data on hot and 'cool' roofs, tested during similar weather and solar conditions at Oak Ridge National Labs.

Figure 4 shows the results of the tests for one day in June. During that day, like most summer days, the solar roof actually keeps the old built up roof beneath it as much as 65°F cooler than the exposed built up roof or a black membrane roof. The oval shown at 11:59 and 160°F shows the surface temperature of an exposed section of the old built up roof, taken a few feet away from the solar roof, which is only 90°F.

In fact, the performance of the 'hot' solar roof at reducing heat transfer through the roof and down to the building below, is as good as a 'cool' white roof. Referring again to Figure 4, the graph shows the temperature of the old built up roof covered by the solar roof, and the temperatures of a 'cool' white membrane roof and a black membrane roof. These membrane roofs were tested by Oak Ridge National Lab (ORNL) (4) under similar weather and solar conditions as the Gaffney roof. The 'cool' white roof reaches 120°F during peak cooling hours when electric rates are highest. The old roof under the solar roof never gets above 110°F, reducing heat transfer through the roof and lowering cooling costs during peak rate periods. More importantly, the solar roof recovers the summer heat in the roof for domestic hot water heating to lower utility expenses, … something that the "cool" membrane roof can not do.

In addition, to the summer cooling savings, the solar roof also keeps the old, covered built up roof warmer in winter by its insulating and heating effects, reducing heat loss from the warm air inside to the colder ambient air outside.

Economics

When compared to the typical "cool" roof cost savings of a less that $0.02 per square foot of roof per year (5), the Gaffney solar air heating roof provides about $0.50 per square foot per year in roofing and energy savings. With a 40 year life, the solar air heating metal roof can more than pay for itself.

Figure 5 shows a breakdown of the maximum annual savings that would be delivered from 9,275 square foot roof at the Gaffney Fitness Center at Fort Meade.

The applicability of solar tax credits and renewable energy credits varies widely depending on the state incentives and regulations. Federal rules indicate that a commercially owned solar air-heating roof system should be eligible for a 30% tax credit and accelerated depreciation allowance, which could result in a 50% reduction in after tax cost for many installations.

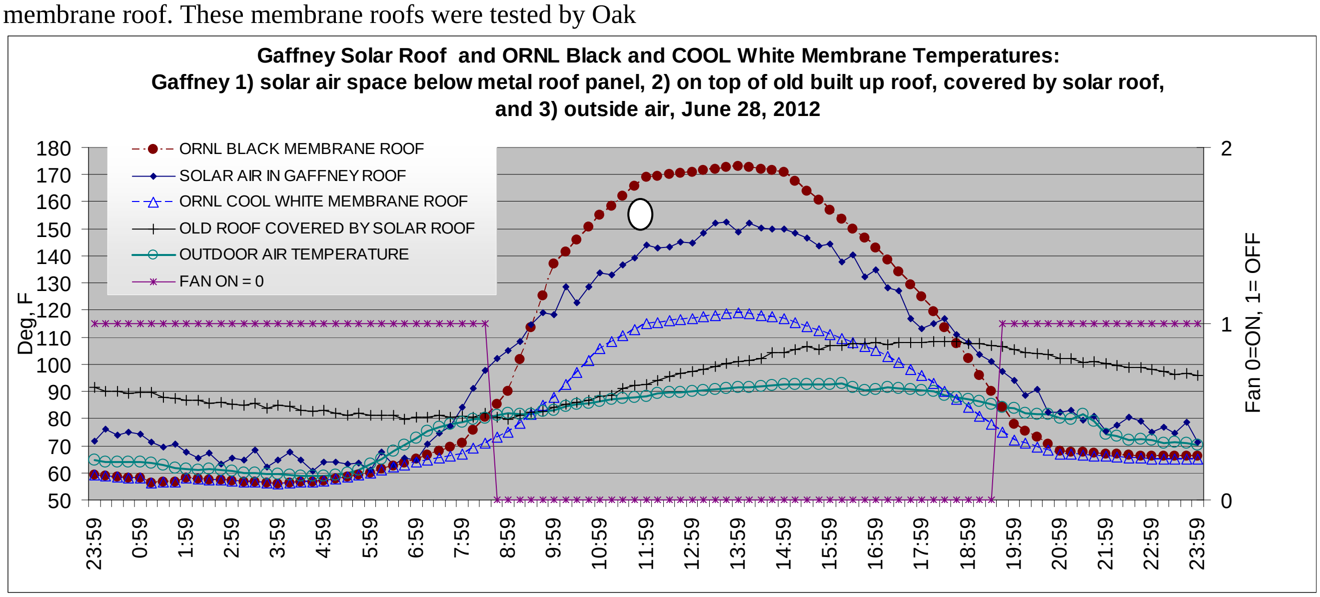

Figure 4 Temperatures of a "Cool" Roof and Built up Roof Covered by the Solar Roof

For the Gaffney Fitness Center, a life cycle cost analysis indicates that the solar air heating roof will pay for itself in about 13 years, compared to re-roofing with a series of built up roofs and continuing to pay for natural gas for all heating energy needs. While a 13 year payback might seem like a long payback period, it is useful to point out that the investment in a solar air heating roof includes the cost of a new, long life roof. When compared to the option of continuing with 40 years of built up roofs, which offers no return on investment, …only an expense, … the solar roof is a bargain.

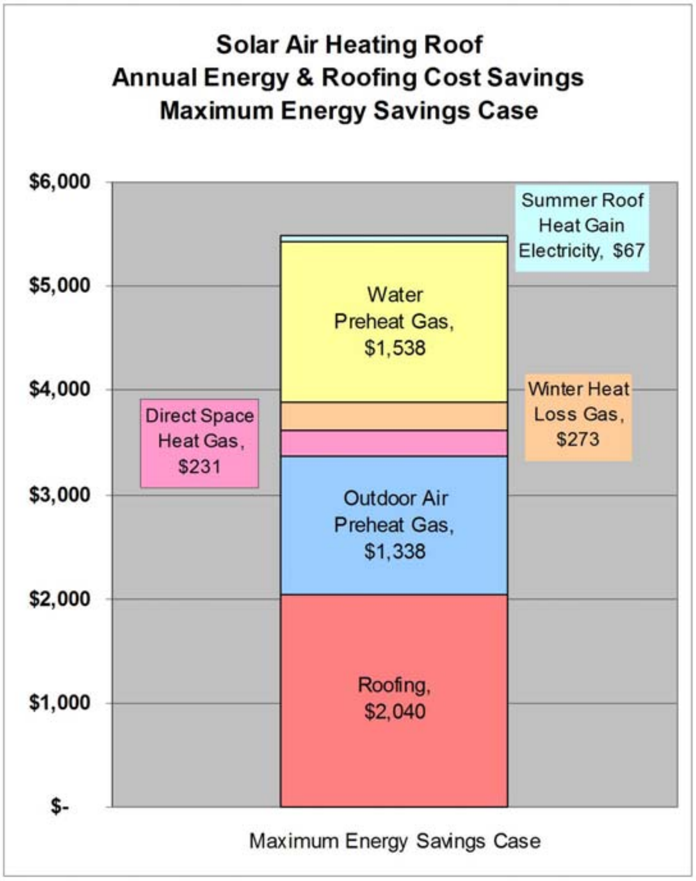

Figure 5 Roof and Energy Savings Gaffney Fitness Center

A Different Way to Look at Building Energy

Traditionally, there have been two ways to approach building energy cost savings;

1. reduce demand and
2. change to a lower cost energy supply.

For an existing building, added insulation or a "cool" roof have been about the only measures to reduce demand at the roof. These 'passive' or 'defensive' approaches have been used to simply try to reduce the unwanted heat transfer through the roof so the expensive purchased heated or cooled air stayed inside the building.

Within the building, demand can be reduced by swapping out inefficient equipment that uses the same the same energy source, or changing to a lower cost energy source. Again, these are somewhat'passive' or 'defensive' measures, that simply assume that the energy must be purchased from the usual suppliers of natural gas, fuel oil, propane or electricity.

A different way to approach building energy is to acknowledge that there is an 'active' way to help reduce the demand with a lower cost supply of energy. By harvesting and managing the solar energy that falls on the roof to meet the buildings heating and cooling needs we can play "offense" to win the energy savings game. By thinking 'offense" instead of "defense", we can collect, deliver, and manage energy from the building roof to meet a variety of needs. The concept of 'playing offense' to add new, low cost energy supplies to the building can result in lower cost energy than simply 'playing defense' to keep the expensive purchased energy inside the building. In many cases, this will be the lowest cost, most sustainable way to deliver a significant portion of the energy needed within the building.

Modeling Solar Energy Savings

The testing of the Gaffney solar roof showed that the system can consistently provide solar heat to the outside air intakes and directly to the building and to the hot water system, and that it reduces unwanted heat loss and gain through the roof. Testing and analysis created a 'first of its kind' analytical performance model for unglazed solar air heating metal roofs. That model permits calculation of solar energy production from any solar air heating metal roof given weather and solar data that would normally be found in a typical meteorological year file for most locations across the US.

Summary

The case study of the solar air heating re-roof of the Gaffney Fitness Facility at Fort Meade Maryland, documents the energy and economic performance of an unglazed standing seam metal roof at delivering roofing and heat to various loads within the building. The solar re-roofing with metal air heating roofs can provide weather tight long life roofing protection, large solar roof areas, with high energy delivery and sound economic results.

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