ESTCP
Cost and Performance Report

(EW-201148)

Solar Air Heating Metal Roofing For Reroofing, New Construction, and Retrofit

June 2013

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE **Solar Air Heating Metal Roofing For Reroofing, New Construction, and Retrofit**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Environmental Security Technology Certification Program (ESTCP),4800 Mark Center Drive, Suite 17D08,Alexandria,VA,22350-3605**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**49**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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ACRONYMS AND ABBREVIATIONS

ASI	American Solar, Inc.
BLCC	Building Life-Cycle Cost
BTU	British Thermal Unit
BUR	built-up roof
cfm	cubic feet per minute
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
EF	degrees Fahrenheit
ft^2	square foot
FY	fiscal year
GHG	greenhouse gas
HGL	HydroGeoLogic, Inc.
HVAC	heating, ventilation and air-conditioning
LPG	Liquefied Petroleum Gas
O&M	operations and maintenance
PV	photovaltaic
TMY	Typical Meteorological Year
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture

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ACKNOWLEDGEMENTS

American Solar, Inc. would like to acknowledge the following individuals who contributed substantially to the completion of this project.

- Randy Williams, Engineering Division Chief, Department of Public Works, Fort Meade, Maryland
- Anthony Karwoski, the Sain Engineering Associates, Inc. Resource Efficiency Manager at Fort Meade
- Everett Carr, Facility Manager and the Staff of the Gaffney Fitness Center at Fort Meade
- Joseph Scott Morgan, Principal Engineer, formerly with American Solar, Inc.
- Dave Gochenaur, CEO, and Jerry Copp, Project Supervisor, Merit Builders, Inc.
- Carlo LaPorta, Principal, and Scott Woycio, Project Manager, Capital Sun Group, LLC

Special thanks to Dr. Jim Galvin, Program Manager for Energy and Water, Environmental Security Technology Certification Program Office and Johnathan Thigpen, formerly of HydroGeoLogic, Inc., for their support and guidance throughout the project.

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EXECUTIVE SUMMARY

OVERVIEW OF THE DEMONSTRATION

The Department of Defense (DoD) has nearly 2 billion square feet (ft^2) of building space under roof that require energy for heating, i.e., space heat, water heat, and equipment heat. The total operations and maintenance (O&M) expenses for DoD buildings are very high with the two largest recurring expenses for DoD facility operations being:

1. Annual heating energy bills: ~\$1.28/square foot (ft^2) of occupied space/year (2006), and
2. Infrequent, but expensive, re-roofing of buildings: ~\$0.67/ft^2 of roof/year (~\$10/ft^2 of roof approximately every 15th year).

With over 570,000 buildings and 1.9 billion ft^2 of occupied space, DoD's annual heating bills are \$2.4 billion (2006) out of a \$4 billion total energy bill. Roofing expenses are about \$640 million per year.

To reduce the impact of energy used to heat buildings and reduce roofing expenses, American Solar, Inc. (ASI) demonstrated the benefits of using a Solar Air Heating Metal Roof over continued repair and replacement of built up roofs (BUR) at the Gaffney Fitness Center, located at Fort Meade, Maryland. The solar air heating metal roofing system uses conventional metal roofing in a traditional, code-approved manner to provide a long life roof as well as a solar air heating collector. The dual use of the roofing system as both a weather barrier and a solar thermal collector greatly reduces the cost of collecting solar energy for heating. The solar air metal roof saves over \$5000 annually and \$189,000 over the 30-year life of the 9275 ft^2 roof.

The demonstration of the solar roof showed that the system can consistently provide solar heat to the outside air intakes, directly to the building, and to the hot water system. The system also reduces both unwanted heat losses in the winter and undesirable heat gain in the summer. The testing and analysis portion of the demonstration created a "first of its kind" analytical performance model of an unglazed, cost-effective solar air heating metal roof.

EXPERIMENTAL APPROACH

This demonstration required temperature sensors to be installed within and around the new solar roof to measure air and water temperatures in order to validate the solar heating performance for outdoor air preheating, direct space heating, and domestic water preheating.

Over 400,000 temperature readings were taken; one set of readings every 15 minutes, from late June 2012 through early January 2013, along with indicators of fan and pump run times. Local weather stations with time stamped solar insolation, wind speed, and ambient temperature data were used to track environmental conditions.

TECHNOLOGY DESCRIPTION

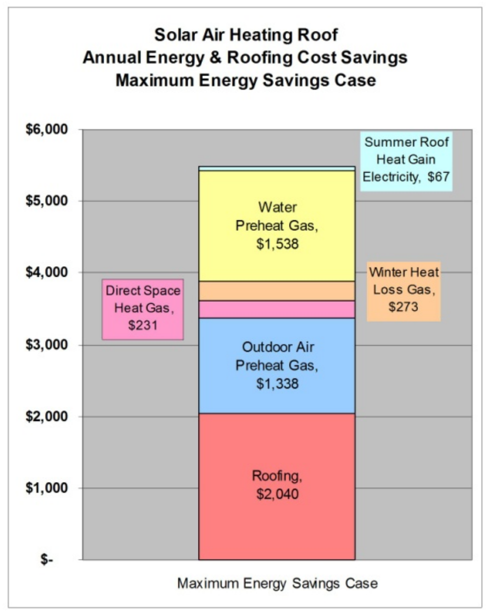
With the solar air heating metal roof system, the metal roof panels heat up to approximately 80 degrees Fahrenheit (EF) above ambient temperatures during daylight hours. The air directly below the metal panel is then heated to a temperature close to the panel temperature. With the application of conventional fans and ducts, the solar heated air is pulled from beneath the metal roof and delivered to the building heating and plumbing systems to serve a variety of useful purposes.

This specific project:

- Re-roofed a badly worn and patched BUR with a long life metal roof,
- Provided insulation to keep the old, covered roof warmer in winter and cooler in summer, and
- Delivered solar heated air used for:
  - outdoor air preheating of ventilation air during the heating season,
  - direct space heating of the gym during the heating season, and
  - domestic water preheating for showers and sinks on a year round basis.

DEMONSTRATION RESULTS

The solar roof demonstrated the capacity to provide weather protection comparable to other long life metal roofs, to keep the building warmer in winter and cooler in summer, as well as to deliver heating energy via outside air preheating, direct space heat, and water preheat. The combined energy and cost savings provide a net positive savings for the Fitness Center compared to the continued installation of a series of several BURs. In the best case, the cost savings are enough to pay for the re-roofing, which cannot be said for any other non-solar roof. A "first of its kind" predictive model was developed as part of the project. The model enables the prediction of solar roof temperatures and prediction of heat energy flows from solar heated air and water that can be applied to other buildings using local solar and weather data.



1.0 INTRODUCTION

1.1 BACKGROUND

The Department of Defense (DoD) has nearly 2 billion square feet (ft^2) of building space under roof that require energy for heating, i.e., space heat, water heat, and equipment heat. The total operations and maintenance (O&M) expenses for DoD buildings are very high with the two largest recurring expenses for DoD facility operations being:

1. Annual heating energy bills: ~\$1.28/square foot (ft^2) of occupied space/year (2006), and
2. Infrequent, but expensive, re-roofing of buildings: ~\$0.67/ft^2 of roof/year (~\$10/ft^2 of roof approximately every 15th year).

With over 570,000 buildings and 1.9 billion ft^2 of occupied space, DoD's annual heating bills are \$2.4 billion (2006) out of a \$4 billion total energy bill. Roofing expenses are about \$640 million per year.

Typically, roofing and heating systems are separately purchased, installed, and maintained. Often, the roofing system is installed based on the lowest first cost provided that it achieves with a minimum 15 year life span. This has resulted in millions of square feet of BUR or membrane roof that has been installed. After approximately 15 years, the roof is then torn off and transported to a landfill where it is dumped and buried, where the asphalt and polymer material are not likely to decompose. A new roof is then installed thereby starting the cycle over again.

In contrast, metal roofing has a nominal service life of 40 years, it can be recycled when removed, and it is recognized as a more cost-effective investment over the life of the roof. The traditional purchase of heating energy systems generally ignores the potential heating contribution of the roof because there is no way to harvest heating energy from a BUR.

Solar air heating metal roofs were first patented in the late 1800s. However, there was little commercial development of the concept until the late 1990s, when residential systems were installed in Japan. ASI began to patent, design, and install systems in 1995. In 2006, ASI began to install large commercial and government projects and has installed the largest solar air heating roofs in North America, which are all on DoD and other government buildings.

For the purposes of this demonstration, ASI installed 9275 ft^2 of solar air heating roof over existing BURs at the Gaffney Fitness Center, located at Fort Meade, Maryland (Figure 1). A simple before and after perspective of the roof is presented in Figure 2. A 7715 ft^2 roof section was installed over the sloped BUR above the gymnasium and another 1560 ft^2 of solar roof was installed above a flat BUR, forming one continuous roof surface and creating a new mechanical space.

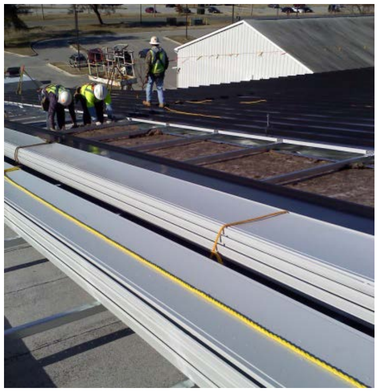


Figure 1. Solar air heating roof installation.

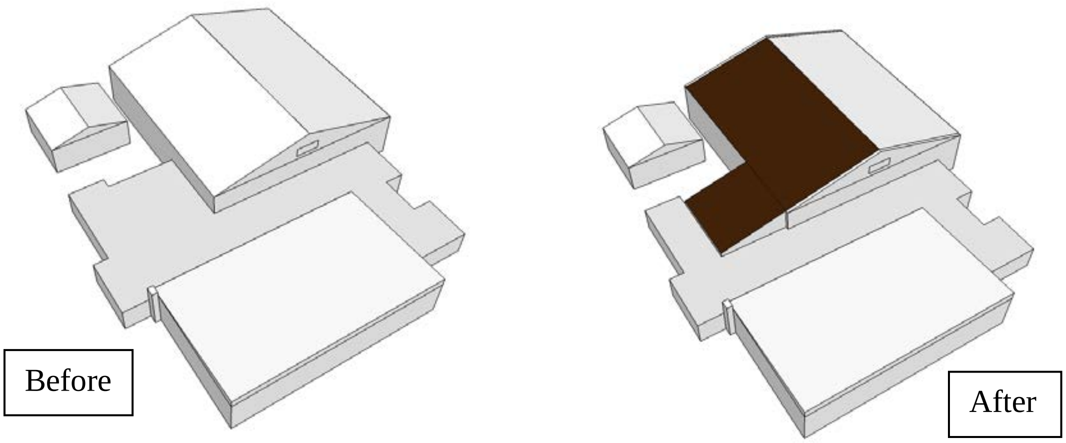


Figure 2. Before and after.

1.2 OBJECTIVES OF THE DEMONSTRATION

This project addresses the emerging need to create a more sustainable roofing strategy for DoD buildings. By employing a proven metal roofing system augmented with a low cost solar air heating configuration, this system has proven it can become a sustainable, cost-effective, and energy saving choice for roof replacement.

Toward that need, there were many specific quantitative and qualitative objectives in the testing, analysis, and reporting of the solar roofing system. These objectives are highlighted below and summarized in detail in Section 3.0.

Among the quantitative objectives:

1. Validate the solar energy delivery of the roof to heating air;
2. Validate the solar energy delivery to the domestic hot water system;
3. Validate the renewable energy delivery to the building;
4. Validate the economic performance of the system;

5. Document the greenhouse gas emission reductions; and
6. Document the performance of the solar roof as it compares to a reflective "Cool Roof."

Among the Qualitative Objectives:

1. Report on system maintenance with operations and design build guides and a report on roof maintenance cycle; and
2. Report on systems reliability, including percent downtime.

The demonstration proved that the solar air heating roof system can meet or exceed each of the performance objectives by providing valuable heating energy for the building, reducing cooling energy demands, and providing long life roofing, all at lower cost than continuing the use of traditional roofing and heating systems.

1.3 REGULATORY DRIVERS

Existing Federal law, Executive Orders, and Agency implementing directives and instructions require the reduction of energy use and greenhouse gas emissions, increased use of renewable energy, and sustainable building design. Key among these drivers are Executive Order 13423, Executive Order 13514, and the Energy Independence and Security Act 2007.

The requirements in these documents call for the following.

- A 30% reduction in energy use per square foot by Fiscal Year (FY) 2015 compared to 2003.
- An increase in renewable energy use from new renewable energy sources.
- A reduction in greenhouse gas emissions.
- An increase in sustainable building design, construction, and operations by pursuing cost-effective, innovative strategies to minimize consumption of energy and materials.

The Energy Independence and Security Act 2007 requires that "each agency shall apply energy conservation measures to, and shall improve the design for the construction of, the Federal buildings of the agency" to achieve a reduction in building energy use of 30% by FY 2015.

Executive Order 13423 specifically calls for a reduction in energy intensity by 3% each year, leading to 30% by the end of FY 2015, compared to an FY 2003 baseline. It also requires agencies to ensure that at least half of the statutorily required renewable energy consumed by the agency in a FY comes from new renewable sources, and to the extent feasible, the agency implements renewable energy generation projects on agency property for agency use. Implementing Federal Renewable Energy Requirement Guidance of January 28, 2008, from the Federal Energy Management Program states that solar thermal energy qualifies to meet this Executive Order requirement.

Executive Order 13514 requires agencies to set greenhouse gas emission reductions goals that DoD set and described in the DoD Strategic Sustainability Performance Plan FY 2012. This plan states that DoD will reduce greenhouse emissions by 34% by 2020 using energy efficiency for 37.5% of the reduction and renewable energy, including solar thermal energy, for an 18% reduction in facility electrical use.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

For this demonstration, ASI installed 9275 ft^2 of solar air heating roof over existing BURs at the Gaffney Fitness Center. A schematic is presented in Figure 3. A total of 7715 ft^2 was installed over the sloped BUR above the gym. Another 1560 ft^2 of solar roof was installed above a flat BUR, forming one continuous roof surface and creating a new mechanical space.

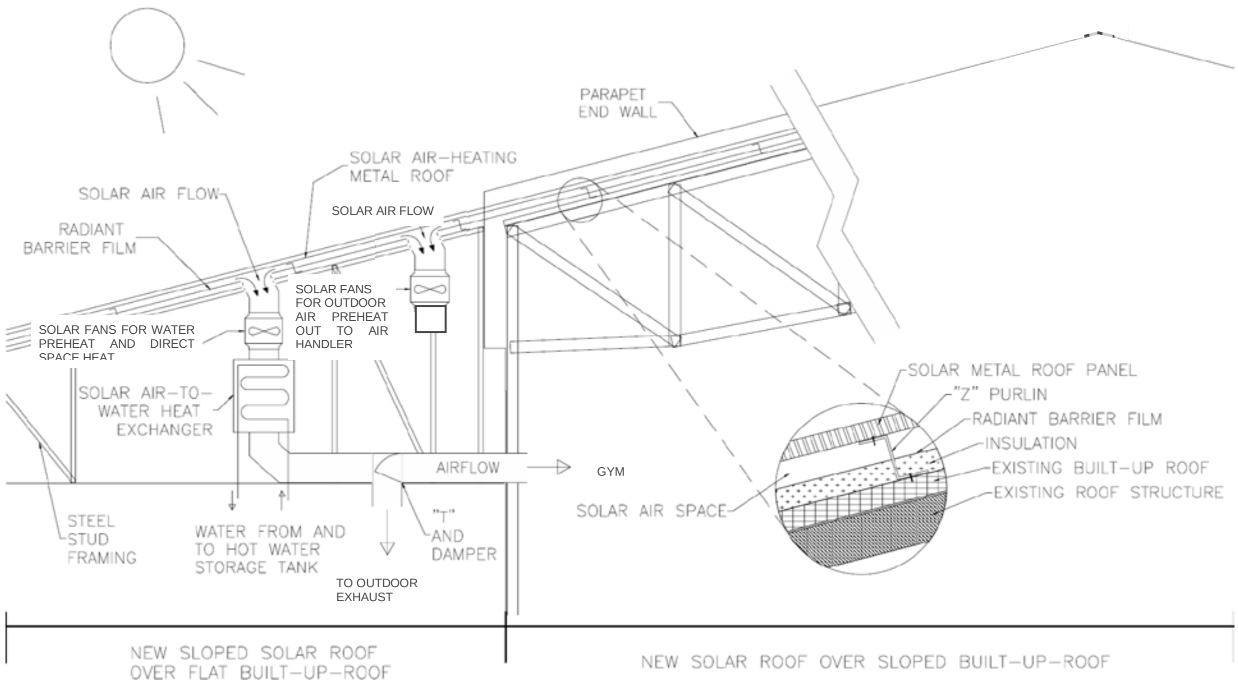


Figure 3. Concept schematic section.

Fans were installed in the newly created mechanical space to draw solar heated air from the roof, deliver it to the outdoor air intake of an air handler and to the air-to-water heat exchanger and then delivered directly to the gym or exhausted. Cold domestic water was drawn into the system and preheated in the solar air-to-water heat exchanger. The preheated water is then returned to the domestic hot water boiler where the water undergoes a final few degrees of heating to reach the required temperature of the building domestic hot water loop. Temperature sensors were installed throughout these systems to facilitate calculations of energy delivery and cost savings.

Solar air heating metal roofs were first patented in the late 1800s. However, there was little commercial development of the concept until the late 1990s, when residential systems were installed in Japan. ASI began to patent, design, and install systems in 1995. In 2006, ASI began to install large commercial and government projects and has installed the largest solar air heating roofs in North America, which are all on DoD and other government buildings.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

The primary advantage of the solar air heating roof is that it is more economical than traditional solar electric (photovoltaic [PV]) and solar thermal hot water energy systems, providing lower heating costs. The cost savings comes from dual use: 1) it serves as a weathertight envelope, and 2) it acts as a solar heating system. Because the roof contributes positive savings in the utility bills, it will pay for itself over time. Traditional roofs are considered an expense, whereas the solar air heating roof is an asset that generates cost savings.

The solar air heating roof is often more aesthetically acceptable than a conventional, add-on solar hot water panel system. In addition, the long-life roof with no penetrations for solar water piping add a level of reliability and reduced risk of water leaks compared to a solar panel water heating system that is fastened throughout the roof.

An additional advantage is the sustainability of using a long-life, recyclable (metal) roof that greatly reduces the amount of material transported during the roof replacement process. The longevity of the solar metal roof reduces the number of replacements needed compared to built-up or membrane roofs thereby reducing the amount of material sent to a landfill.

In general, there is no specific climate dependence for the solar air heating roof. While the roof can deliver more solar heat in sunnier southern climates, there is generally less need for space heating in those climates, but more need for air conditioning reheat particularly with high outdoor humidity levels. However, there is a nearly constant demand for water heating, regardless of climate. The “cool roof” equivalence of the solar air heating roof can also provide electric cooling savings in hot sunny climates. So, instead of targeting a climate, it is often more important to target a building that has a higher heating demand and consider all of the heating and preheating loads.

A solar re-roof in a mid-latitude-to-northern climate with a high outdoor air load and a mid-to-high year round heating load for water, industrial processes, boiler air preheat, or HVAC reheat will make a good, economical candidate building for solar re-roofing. In contrast, an unconditioned warehouse building in southern latitudes with minimal heating needs, just for a few hours a year of freeze protection, will not be able to take maximum advantage of the solar heat available.

A limitation of the solar air heating roof is that it cannot provide heat during all hours of the day. There is reduced or no production of solar heat at night, on cloudy days, or during winter months when the sun is at low angles. As a result, a backup heating system must be installed to accommodate the full heating load. Heat generated from the solar roofing system can reduce the overall use of this conventional heating system when conditions are favorable.

For some loads, such as outdoor air preheating, the solar roof can be used no matter the temperature of the outdoor air. For other loads, such as domestic water preheating, the solar roof system can be used, even on cold January days, as long as the solar air temperature is above the incoming cold water temperature. In these cases, the backup water heating system will only need to raise the temperature of the solar preheated water by a few degrees to meet the final temperature required by the building domestic hot water piping loop.

For the direct space heating of the gym, a portion of the system may not be used at all on the coldest days, when the solar preheated air is below about 75EF, as that temperature is too cold for comfortable direct space heating. However, this temperature limitation can be overcome by using a solar assisted heat pump. The combination of a heat pump to deliver higher temperature air and solar heat to improve the performance of the heat pump provides an efficient way to deliver hot air (or water) year round, in all climates. (Note: Solar assisted heat pumps are not part of this study, but the solar air delivery system and calculation methods from the Gaffney roof system are identical to the solar air system of a solar assisted heat pump.)

One item to consider in implementing solar roofs is providing funding for the re-roof. Where facility funding is not available for a solar roof, there is an opportunity to have a third party own the metal roof and solar heating system. Because the solar re-roof is a solar heating system, it is eligible for many Federal and state tax credits. While the government cannot take advantage of these tax credits, third party, commercial providers can. This has become common with solar electric (PV) systems installed on many military facilities. The private contractor installs the system and is paid, over time, by the facility from the energy cost savings that accrue to the facility. Because the private contractor can access the Federal and state incentives, the installed cost after taxes is lower, which can be passed on to the facility through the contractor's lower installed cost. This translates into lower long term energy payments by the facility to the contractor and the utility companies. In many cases, the facility may not have an adequate budget to do the roofing that is necessary, but private contractors can provide the roofing at no upfront cost to the facility, saving the roofing budget for the most important priorities. This approach has already been used with several energy savings performance contracts and utility service contracts that have installed solar air heating roofs and walls.

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3.0 PERFORMANCE OBJECTIVES

3.1 QUANTITATIVE OBJECTIVES

The performance evaluation of the solar roof was done in two ways: 1) "as installed" and operated, and 2) by calculating the "maximum savings" performance of the system using the developed analytical model.

The "as installed" and operated objective assesses the installation costs and how the system operated during the testing period. The "as installed" system is economical and provides positive roofing and energy cost savings. However, in an effort to support future installations, the roofing system that was installed for this demonstration was deliberately configured and operated in a manner designed to gather the most information about system cost and performance, instead of minimizing the costs for installation and operation.

The "as installed" system incorporated all costs of the installation divided by the total square feet of solar roof. The portion of the solar roof installed over the flat BUR provided valuable data on the heating performance of a roof erected several feet above a flat roof that enclosed a new mechanical space. However, this addition added significant cost to the solar roof ($\$74/ft^2$ vs. $\$20/ft^2$ for the cost for the solar roof installed above the sloped BUR.) As a result, the average cost of the installed solar roof was $\$37/ft^2$. If the solar roof had been built only over the sloped BUR of the gym, the installed cost would have been lower, and the life cycle cost savings per square foot would have been much higher. This data is reported as part of the values considered in the "maximum savings" case.

The solar hot water heating system was run at all hours to reduce natural gas usage, even if operation during those hours resulted in higher electric expenses to run the fan and pump. By doing so, this enabled the collection of the broadest set of data to identify the key operating parameters (ON-OFF temperatures, Delta-T water, etc.) important to developing the performance model.

Once the performance model was established, the prediction of annual energy and cost savings was possible. This model also enabled the refinement of operating parameters such as ON-OFF temperatures and increased cold water input to increase heat transfer in the heat exchanger. Both of these changes in operations result in higher predicted annual energy and cost savings that are referred to in the reports as the "maximum savings" case.

A column for performance "Results" is presented in Table 1. For each performance objective, two values are provided. The lower value represents the "as installed" and operated case. The higher value represents the "maximum savings" case, which is based on the analytical model.

Table 1. Quantitative performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Solar energy delivery to air (Energy)	Million British thermal unit (BTU) of renewable energy delivered to heat the building	Temperature and flow of solar air	Peak heat transfer to air, 50 BTU/ft^2/hr Peak daily heat flow 300 BTU/ ft^2/day Peak monthly heat flow 4500 BTU/ft^2/winter months	Peak 47-60 BTU/ft^2/hr Peak daily heat flow 318-350 BTU/ft^2/day Peak monthly heat flow 3903-4727 BTU/ft^2/winter months
Solar energy delivery to water (Energy)	Million BTU of energy delivered to the domestic hot water	Temperature and flow of solar air, and air to water heating	Peak heat transfer to water 20 BTU/ft^2/hr average 2000 BTU/ft^2/month April to October	Peak 13.9-64 BTU/ft^2/hr Average 1405-5851 BTU/ft^2/month April to October
Renewable energy use	% of energy use by Gaffney Gym	Monthly solar energy delivered and monthly energy billing use from utility bills	7% of building heating energy use (combination gas and electric heat)	10-19% of building heating energy use
System economics	Roof cost savings $ energy cost savings $, years	Dollar costs, discount rate, usable life, energy cost savings	5% reduction in life cycle roofing costs 7% reduction in life cycle heating energy expenses	(31% [increase]) - 25% reduction in roof cost (see note) 8-20% reduction in heating costs
Direct greenhouse emissions	Direct fossil fuel greenhouse gas (GHG) emissions (metric tons)	Measured or estimated release of GHG based on source of energy	7% reduction compared to baseline heating energy greenhouse emissions	5-15% Reduction versus baseline heating energy greenhouse emissions

Note: The system was deliberately installed over two types of roof (sloped and flat) with different per square foot costs and operated to gather the maximum information on the construction cost and energy performance limitations of the system, with a focus on building a model of system performance for many types of future installations. As a result, the "as installed" roof system, with a combination of high and low cost roof sections, shows an increase in installed cost of 31%. The data collected validates that the lower cost system reduces roofing cost by up to 25%.

Table 2. Qualitative performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Demonstrated
System maintenance	Consolidate all component maintenance and operations requirements	Maintenance and operating instructions for each component	O&M guide (facilities)	O&M guide complete
	Report on overall solar re-roof design/build opportunities, processes, procurement approaches	Document steps taken to assess, design, and build a solar metal air-heating re-roof	Design build guide (facilities)	Design build guide complete
	Report on roof maintenance cycle	Years to repair or replace roof	30 year solar roof repaint 40 year solar roof life	Roof maintenance cycle report complete
System Reliability	% time system performs as designed	Run time / downtime hours	5% downtime hours 95% run time hours	2% downtime hours 98% runtime hours

The qualitative objectives provide an O&M guide for the system at Fort Meade and a design build guide to educate other facility managers on the benefits and considerations of installing solar air heating metal roofs.

- An O&M guide was prepared for the Fort Meade maintenance staff as part of a turnover package for the Department of Public Works.
- A Design Build Guide was prepared for use by other facility managers considering the use of a solar air heating re-roof.
- A roof maintenance cycle report was prepared and incorporated in the O&M report for Fort Meade.
- The system operated for 98% of all hours and had only 1 downtime incident caused by intermittent operation of one of the fans. A switch over to a second fan enabled the system to continue operation.

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4.0 SITE DESCRIPTION

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The Gaffney Fitness Facility includes a gym that was converted to an exercise room with various free weights, treadmills, and other exercise equipment. There are men's and women's locker rooms and other activity rooms. The building recently received a major heating, ventilation and air-conditioning (HVAC) modification to add air conditioning to the gym and upgrade the HVAC systems throughout the rest of the building. The building is heated by a natural gas boiler that supplies hot water to a coil in the ductwork in the gym. There is a pool that has its own heating and dehumidification systems. The building is open from 05:00 (5 a.m.) to 21:00 (9 p.m.).

This facility represented a good test site with substantial and varying heating loads for outdoor air preheat, space heat, and domestic water heat. The mid-latitude climate had outside air temperature ranging from below 0EF in January to above 100EF in July and cold city water temperatures ranging from the high 40s to the high 70s. In addition, the roof had been patched several times and needed replacement. The U.S. Department of Agriculture (USDA) maintains several weather and solar monitoring stations nearby that provided reliable data for evaluation of performance.

4.2 FACILITY/SITE CONDITIONS

The Gaffney Fitness Center is located between Washington, DC and Baltimore, MD and is centrally located on the Fort. It has a southwest facing roof over the gym, which is not shaded by surrounding trees or structures. See Figures 4 and 5.

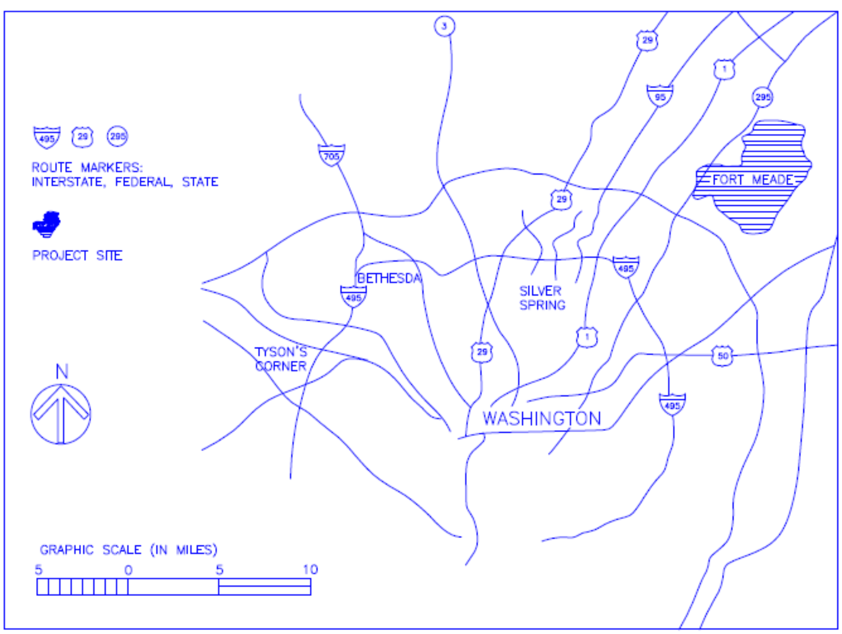

Figure 4. Regional map.

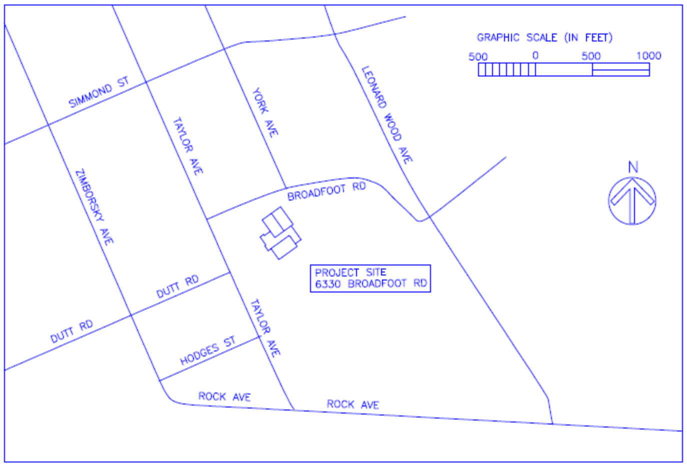

Figure 5. Local map.

The condition of the Gaffney Fitness Center roof before the re-roof is presented in Figures 6 through 8. Shortly after award of the Environmental Security Technology Certification Program (ESTCP) contract, the U.S. Army Corps of Engineers (USACE) began work under a separate contract to install new air-conditioning systems for the building. This relocated the outside air intakes from the wall in Figure 6 to the air handler shown in Figure 7. ASI revised its design to deliver solar preheated air to the outdoor air intake of the new air handler.

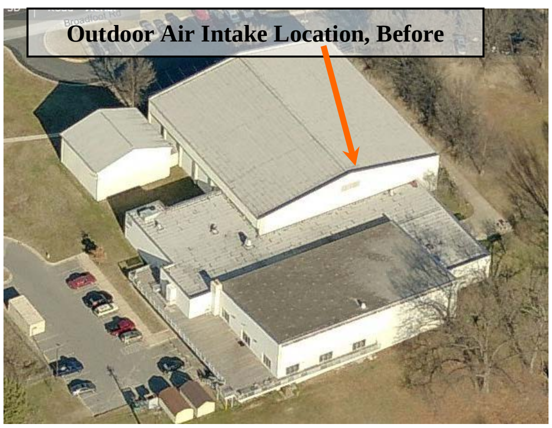

Figure 6. Gaffney aerial view.

Figure 7. Gaffney mechanical renovation before the ESCTP project.

Figure 8. Gaffney flat roof, gym wall and roof before the ESTCP project.

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

The solar re-roof system provides heating energy to the building in three ways:

1. Outdoor air preheating for the gym air handler
2. Direct space heating for the gym
3. Preheat domestic hot water in an air-to-water heat exchanger.

In addition, the solar roof reduces summer heat gain and winter heat losses through the building envelope.

The fan based operations are all controlled by differential temperature controllers, which compare temperatures of the solar heated air in the roof to temperatures of the air or water of the load being served. When the solar air is warmer than the load being served, the differential temperature controllers turn the solar fans ON. A connection to the existing building automation system ensures that the solar fans only provide space heat or outdoor air preheat when there is a "call for heat" in the building. Additional controls ensure that the system is protected from freezing by supplying warm air and water to the heat exchanger and piping in the most vulnerable areas.

Temperature sensors and fan and pump ON-OFF inputs were installed throughout the roof and heat exchanger, on piping, and in the control panel to monitor the system. Data was collected every 15 minutes of all temperatures and operating conditions. For 7 months, from June 2012 to January 2013, the data was recorded to a computer file for analysis along with solar and weather data from a local weather station.

5.2 BASELINE CHARACTERIZATION

While a review and summation of the annual heating energy bills was conducted, and it does provide a gross baseline for comparison of solar energy delivered, it is not practical to precisely characterize the existing energy use of the Gaffney building for that purpose. This is true of most buildings with heating loads that have varying occupancy and face varying weather conditions from day to day and year to year.

For the solar air heating roof, the best measurement to characterize the system performance is to simply measure the energy delivered when the solar roof system contributes to a reduction in building energy use. For example, when solar heated air is being delivered to the outdoor air intake, the solar energy savings can be calculated using the temperature difference between solar air and outdoor air, the mass flow of solar air, and the inefficiency of the boiler based system at providing an equivalent amount of heat. That calculation results in the energy savings, which can be summed for all hours of the year when the solar system is operating. For example, when the building automation system called for heat and the outdoor air preheat fans were running, multiplying the measured temperature difference of the solar heated air minus the outdoor air, times the known mass flow of air, times the specific heat of air provides a total heat flow to the outdoor air. By comparing this value of the heat delivered to the outdoor air temperature, wind speed, and solar conditions, a baseline performance of the system can be established against existing weather and solar conditions. This permits the use of a performance model for any location where solar and weather conditions are known. Total annual energy delivery can be predicted for any location with available typical meteorological year (TMY) data that characterizes weather conditions at that location.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

A schematic diagram of the three fan based systems for outdoor air preheating, direct space heat, and the air to water heat exchanger for water preheat is shown in Figure 9. The additional components of the water preheat system in the boiler room are shown in Figure 10.

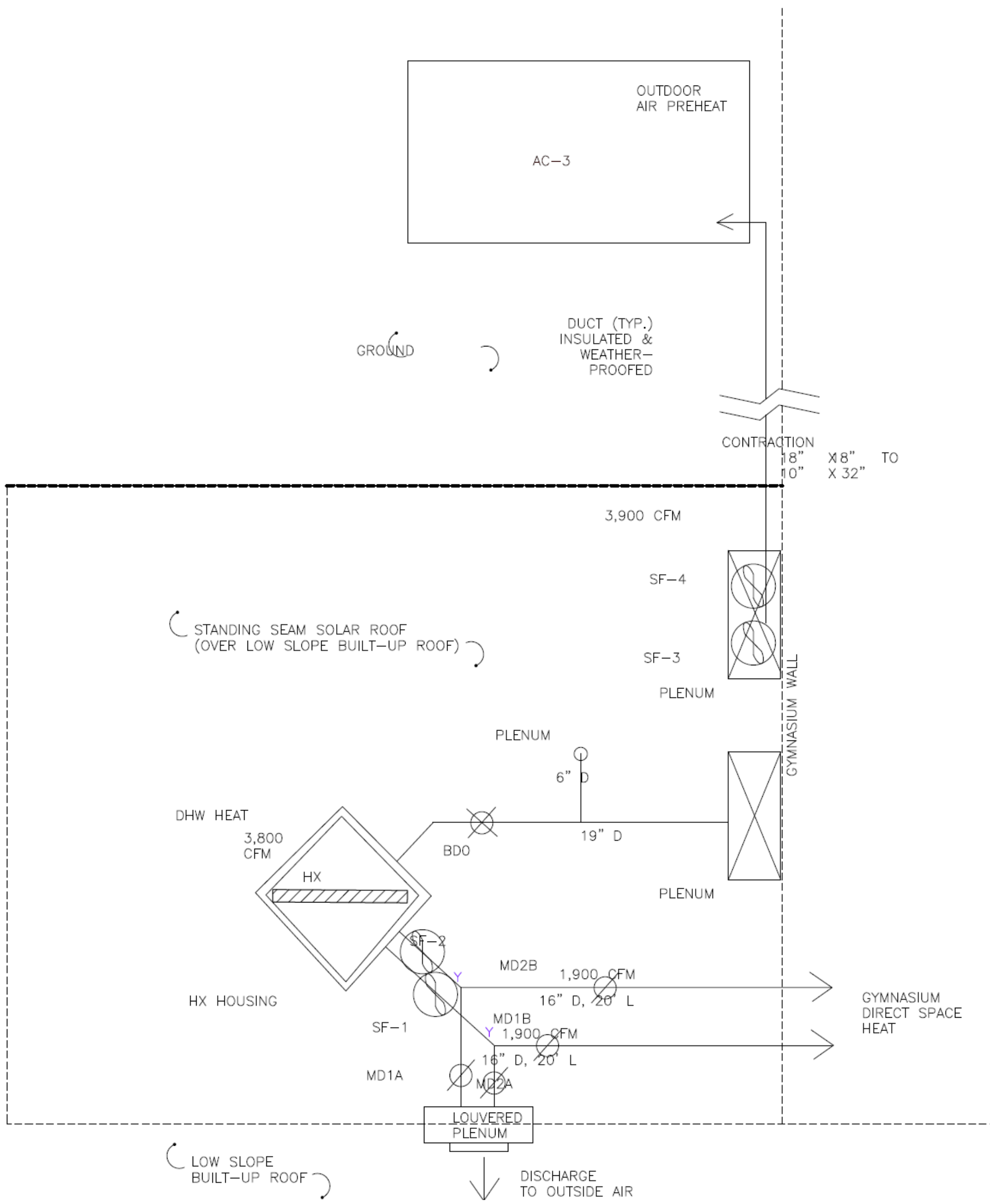

Figure 9. Plan view schematic of solar air heating mechanical systems.

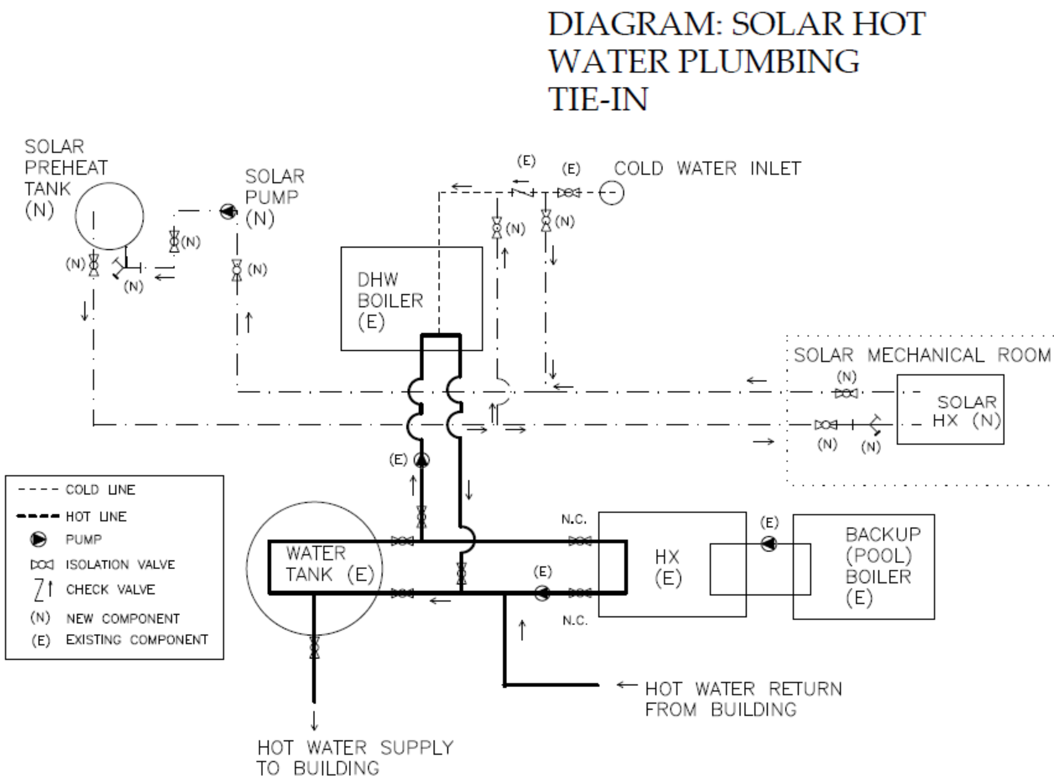

Figure 10. Schematic of domestic hot water heating system

The systems are controlled by differential temperature controllers, which are standard components within the solar industry. They turn ON and OFF the fans, the pump, and the motor dampers depending on temperatures of the solar air, outdoor air, water in the preheat tank, and other thermostats and signals from the main building automation system.

5.4 OPERATIONAL TESTING

The construction of the system started January 2012. Testing began in May and data collection ended in December.

Table 3. Project schedule.

January 2012	Start of Construction
May 2012	Fan air flow testing
June 26, 2012	Start Water preheat data logging, with 2 fans
August 15, 2012	Start Water preheat data logging, with 1 fan
September 12, 2012	End of water preheat data analysis period
October 2012	Start Outdoor air preheat and Direct Space heat data logging
December 2012	End Outdoor air preheat and Direct Space heat data analysis period

5.5 SAMPLING PROTOCOL

Air flows speeds were measured for each duct section for the water preheat and direct space heat system. The air flows were measured once for each operating condition with one fan or two fans operating. For the outdoor air preheating systems, air flow was measured once with two fans operating. These measurements, combined with the recorded temperatures of air and water, permitted calculation of the heat transfer in the system.

Temperatures of all the thermistor sensors in the solar roof, on piping, in the outdoor air, and in the heat exchanger were measured every 15 minutes. A 1 hour sample of the data in Table 4 shows temperatures (EF) of the thermistor sensors. The sensors are coded with the datalogger terminal location and a text description of the location. For example in row 1, “a2f06zone1_hi_air” represents a datalogger terminal “a2f06,” which is measuring solar air temperature in the roof, high up in roof zone 1. The last four rows of the table also show the status (ON-OFF, ON (=0)) of the fans, pump, and motor dampers sensed from relay contacts in the solar control panel. The last row shows Fans 1&2 and the pump (c5ci3powertofans1_2atcontactor) for the air to water heat exchanger switch ON (=0) at 8:59.

Table 4. Datalogging sample temperatures and relay status.

Row	The Time	41115.3537 7/25/12 8:29	41115.36412 7/25/12 8:44	41115.37454 7/25/12 8:59	41115.38495 7/25/12 9:14	41115.39537 7/25/12 9:29
1	a2f06zone1_hi_air	93.3	95.9	104.1	106.2	108.4
2	a2f0zone1bur_hi_air	90.6	93.6	100.5	103.1	106.6
3	a2f1zone1bur_belo_FG	85.3	84.7	85.0	85.1	84.2
4	a2f2zone1belo_iso	83.9	82.9	84.1	83.8	82.7
5	a2f3_zone1bur_belo_RB	86.6	88.7	92.8	96.4	99.5
6	a2f4OAT	82.1	81.5	85.5	86.9	85.7
7	a2f7fan3and4	85.1	86.1	84.4	85.3	84.9
8	a5e0h2o_into_hx	76.5	76.2	76.0	80.6	83.5
9	a5e1h2o_out_hx	76.4	76.2	79.2	82.2	84.7
10	a5e2solarintohx	75.3	75.4	85.0	87.8	90.7
11	a5e5returnh2otobldg	76.1	78.0	77.8	82.9	86.4
12	a5e6solarairoutofhx	73.3	74.0	79.9	84.4	87.7
13	a5f0zone1_mid	77.0	79.8	81.8	87.0	91.4
14	a5f1zone1lo	78.9	82.6	91.7	97.0	102.3
15	a5f2zone1_high	83.5	90.4	93.5	96.4	101.8
16	a5f3zone1_atticair	72.9	74.3	75.3	75.7	77.0
17	a5f4zone4lowest	79.6	85.3	88.4	94.4	101.8
18	a5f5zone4mid	79.2	83.5	85.8	89.0	95.2
19	a5f6zone4loeast	78.2	80.6	85.3	91.9	97.1
20	a5f7zone4lhi	84.9	88.3	92.2	94.3	99.8
21	a5e7coldcityh20	70.2	75.9	70.7	70.1	76.6
22	c5ci0basgymcallforheat	1.0	1.0	1.0	1.0	1.0
23	c5ci1mtrdmpr1b2bopentogym	1.0	1.0	1.0	1.0	1.0
24	c5ci2powertofan3_4atcontactor	1.0	1.0	1.0	1.0	1.0
25	c5ci3powertofan1_2atcontactor	1.0	1.0	-	-	-

Local solar and weather data were collected from a USDA weather station within 10 miles of the Gaffney Fitness Center. A sample of the data is shown in Table 5. This information was required to develop the analytical model to predict solar air temperature and fan and pump ON-OFF times based on local weather conditions at the facility. Having developed this “first of its kind” model, it can then be applied to any facility using local weather data as found in typical meteorological year data files.

Table 5. Local weather and solar conditions from USDA site.

Time	Air Temp EF: Station #4 (−F)	Wind Speed Max mph: Station #4 (mph)	Wind Speed Avg mph: Station #4 (mph)	Wind Speed Min mph: Station #4 (mph)	SlrW_AVG: Station #4 (W/m2)	RH: Station #4 (%RH)	WindDir_ D1_WVT: Station #4 (degrees)	Rain: Station #4 (in)
7/6/12 8:15	85.406	7.19936	4.15072	0.35168	423.8	37.2	53.52	0
7/6/12 8:30	86.144	6.97984	4.4576	1.12	449.5	34.89	63.17	0
7/6/12 8:45	87.026	8.34176	5.30432	2.02048	491.6	37.57	97.3	0
7/6/12 9:00	87.62	6.43104	3.69376	1.0752	529.8	34.05	59.93	0
7/6/12 9:15	88.232	8.51648	4.9728	0.39424	565.8	33.51	75.1	0
7/6/12 9:30	88.97	7.85792	4.58304	0.68096	454.9	32.91	126.9	0
7/6/12 9:45	88.88	10.77888	4.21568	0.0224	617.4	33.68	66.53	0

5.6 SAMPLING RESULTS

A sample of the water preheating system results is presented in Figures 11 and 12. The figures show the temperatures of the solar air in and out of the heat exchanger; the cold city water entering the solar preheat system; the water temperature into and out of the heat exchanger and returning to the building; and the fan ON or OFF status. The chart in Figure 11 shows that on this July day, the cold city water entering the building at about 79EF was preheated by solar air that entered the heat exchanger at up to 130EF and returned water to the building at up to 120EF.

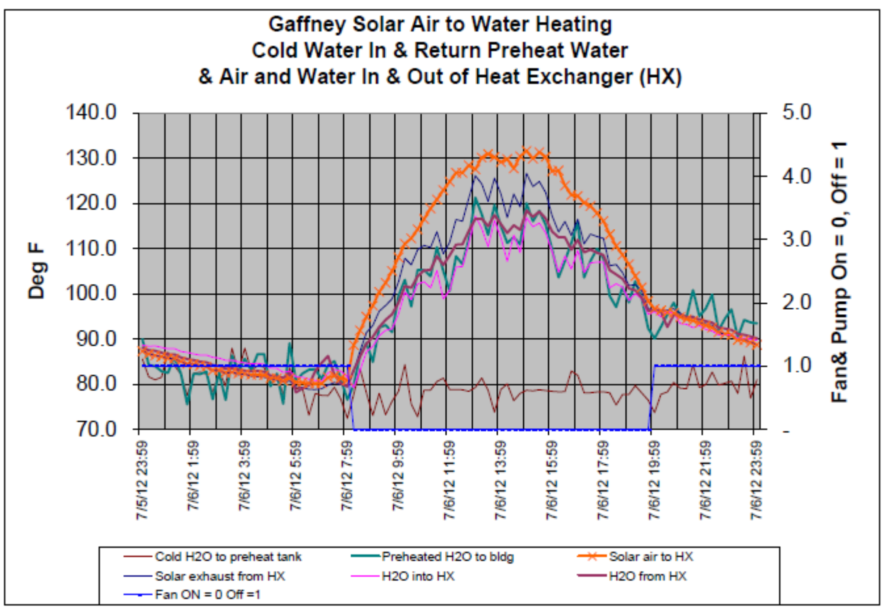

Figure 11. Solar air and water at air to water heat exchanger.

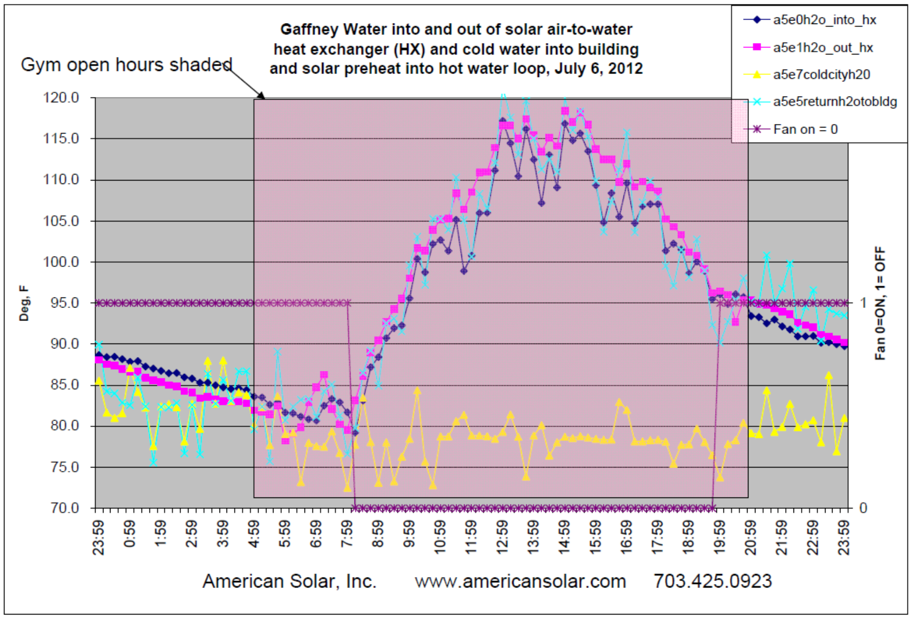

Figure 12. Solar air and water and gym hours.

A sample of the data collected for the Outdoor Air Preheat is shown in Figure 13. This Figure shows that on December 12, with outdoor air temperature no warmer than 45EF, the solar roof provided solar heated air to the outdoor air intake via fans 3&4, at temperatures up to 80EF.

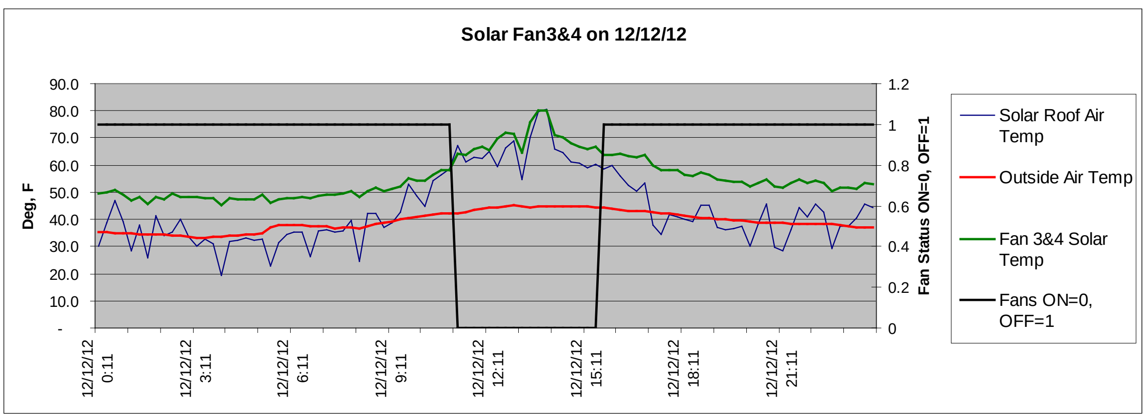

Figure 13. Solar and Fan 3&4 air temperature.

A sample of the data for the roof temperatures taken in a vertical slice from the top of the solar air space down through the insulation to the roof deck below is shown in Figure 14. This sample also contains a roof surface temperature of the adjacent, non-solar BUR, and overlays of a "cool" roof and a non-reflective black roof tested under equivalent weather and solar conditions. The oval at 11:59 and 160EF is the temperature of the existing, exposed, non-solar BUR. The yellow line is the temperature of the existing BUR covered by the solar roof. The blue triangle data points are the "cool" roof tested at Oak Ridge National Lab under similar weather conditions. The figure shows that the BUR covered by the "hot" solar roof, is as much as 70EF cooler than the adjacent, non-solar BUR. During peak air conditioning hours when electric rates are typically highest, the BUR covered by the “hot” solar roof is up to 20EF cooler than a “cool roof” tested by Oak Ridge. Therefore, the “hot” solar roof is actually cooler for the building than the existing BUR or a “cool” roof.

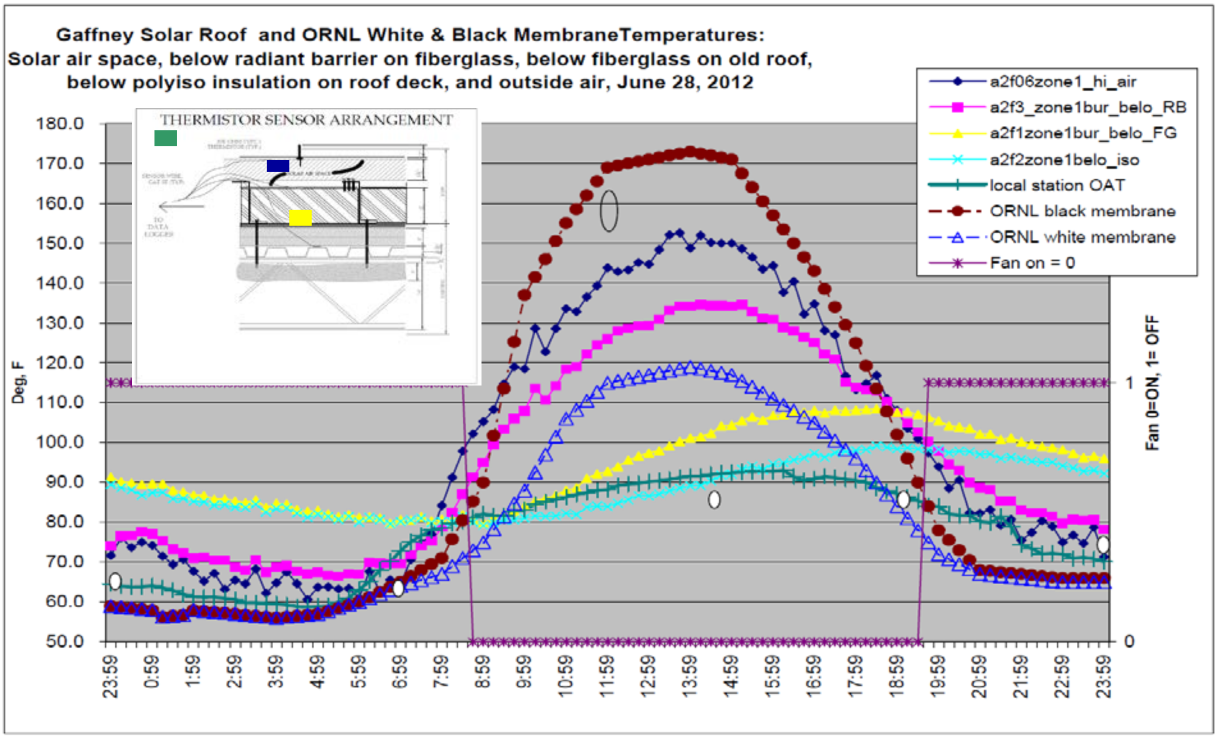

Figure 14. Solar roof temperatures vs. existing BUR and ORNL “cool” white and black roofs.

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6.0 PERFORMANCE ASSESSMENT

Once the data was collected, the energy delivered to the fitness center was calculated. This represented the "as built" and operated case. Separate calculations were performed for each of the five elements required in the performance objectives. These included:

- Heating energy delivered to the domestic hot water system
- Heating energy delivered to the outdoor air
- Heating energy delivered directly to the gymnasium space
- Heat loss reduction through roof (winter months)
- Heat gain reduction through roof (summer months)

In addition to the "as built" case, an analytical model was developed that permitted calculation of the energy delivery based on a system operated for maximum savings. This included higher cold water demand and the most efficient ON-OFF temperatures for the fans and pump and making maximum use of the roof area available. This approach is referred to as the "maximum savings" case.

The basic calculation of each of the five heat transfer mechanisms is discussed below, along with a discussion of how the data was numerically processed using regression models to predict annual performance for both the "as built" case and the "maximum savings" case.

6.1 WATER PREHEAT

For a single day, the heat transfer from the solar air to the water can be calculated using the temperature difference of the solar air into and out of the heat exchanger, the mass flow of air and the specific heat of air.

The formula for the heat transfer is $\dot{Q} = Cp \times \dot{m} \times dT$

Where:

$\dot{Q}$ is the heat transfer in BTU/hr,
Cp is the specific heat of air = 0.24 BTU/#dry air/DegF,
$\dot{m}$ is the mass flow in #dry air/hr = 3320 cfm $\times$ 60 min/hr/14.6cuft/#dry air = 13,644#dry air/hr,
dT is the temperature drop in air across the heat exchanger = 13.4F at 11:59.

For example, at 11:59 on July 6th, 2012, the heat transfer is:

$$\dot{Q} = 0.24 \times \dot{m} \times dT = 0.24 \times 13{,}644 \times 13.4 = 43{,}800\ BTU/hr$$

The same process was conducted for every 15 minute period that data was collected. Then a regression analysis was performed using solar, wind, and outdoor air temperatures collected from the local weather station to predict the solar roof air temperature for all weather conditions. An analysis was also performed to predict the temperature difference between outside air and solar air when solar fans turned ON and OFF. A final regression analysis was performed to predict water temperature into the heat exchanger based on solar and weather conditions. Together these calculated values permit the calculation of heat transfer from the solar roof to the water over any multiday period, using Typical Meteorological Year (TMY) weather and solar data.

A sample prediction model is presented in Figure 15 for the cases where one fan and two fans are used to move solar heated air through the heat exchanger during several July days.

With this model in place, a calculation of all hours of the year can be made to calculate the ON–OFF times, and the temperature difference and heat transfer in the air to water heat exchanger. The sum of the hourly heat transfers gives the monthly and annual heat transfer. Dividing by the efficiency of the natural gas boiler (assumed to be 90%) gives the total heating energy saved by the solar water preheat system. A review of the hourly data gives the peak hourly and monthly heat transfer.

A second analysis with the model uses 100% cold water entering the heat exchanger. This is the "maximum savings" case. This scenario uses only cold water in the heat exchanger to improve heat transfer and maximize savings. The analysis is the same and it generates monthly and annual savings.

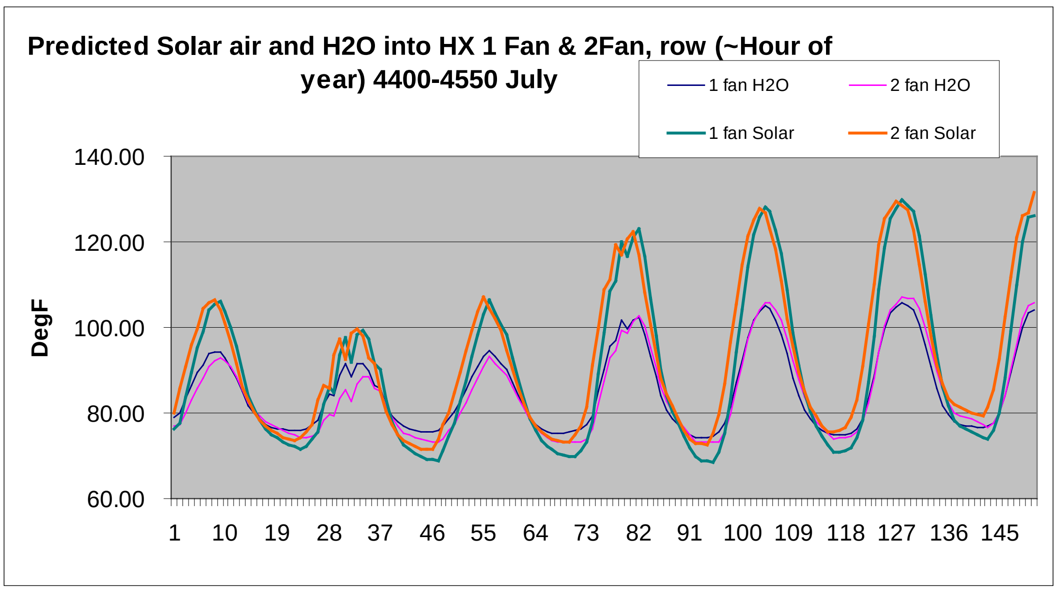

Figure 15. Predicted solar air and water temperatures - 1 and 2 fans.

6.2 OUTDOOR AIR PREHEAT AND DIRECT SPACE HEAT

Similar analyses were performed to predict the solar roof temperature and fan ON-OFF times for outdoor air preheating and direct space heating using TMY data. Results of these models to predict solar air temperature are shown in Figure 16. Once this predicted air temperature is known, the heating energy that can be delivered to the outdoor air can be calculated. The calculation for direct space heating is similar to the prediction for outdoor air preheating with the exception of using a temperature difference of the solar air temperature minus 78EF, where 78EF is 8 degrees warmer than the gym air and the minimum temperature for direct space heating to operate.

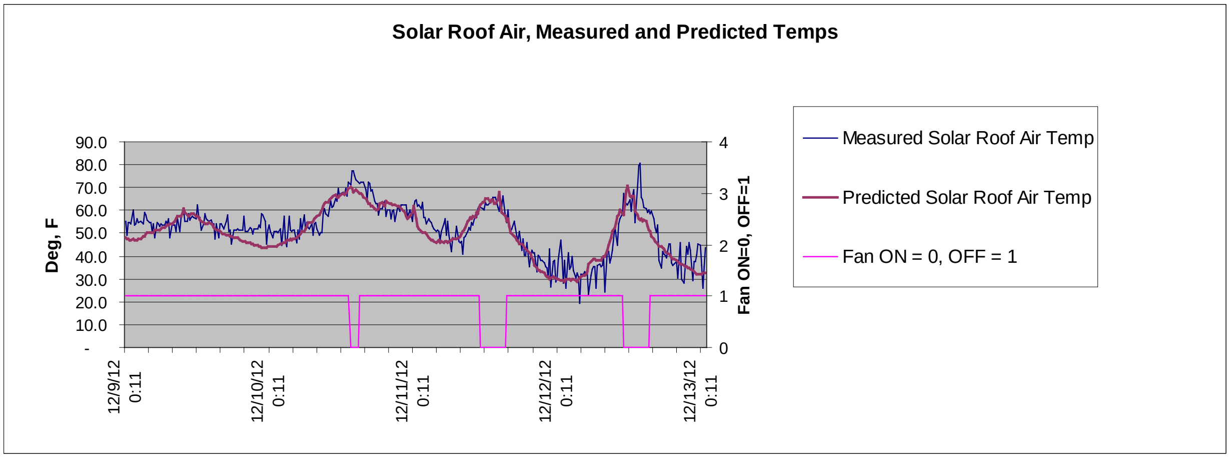

Figure 16. Measured and predicted solar air temperatures.

6.3 REDUCED ROOF HEAT LOSS IN WINTER AND HEAT GAIN IN SUMMER

Thermistor sensors were placed in the roof in a vertical stack. See the inset in Figure 14. The upper sensor (blue in Figure 14) was in the solar air space, another sensor was 9 inches below it on top of the old BUR (yellow in Figure 14). This sensor measured the temperature of the old BUR that was covered by the solar roof. It enables a comparison to the temperature of an exposed, non-solar BUR to evaluate the insulating effect of a solar roof. The temperatures of the outdoor air and the old BUR are presented in Figure 17. Assuming a non-solar BUR would be at outdoor air temperature, while the covered BUR stays warmer in winter, there is reduced heat loss through the solar roof. By calculating the temperature difference between solar covered and exposed roofs, and knowing the R value of the roof, we can calculate the heat loss avoided in winter.

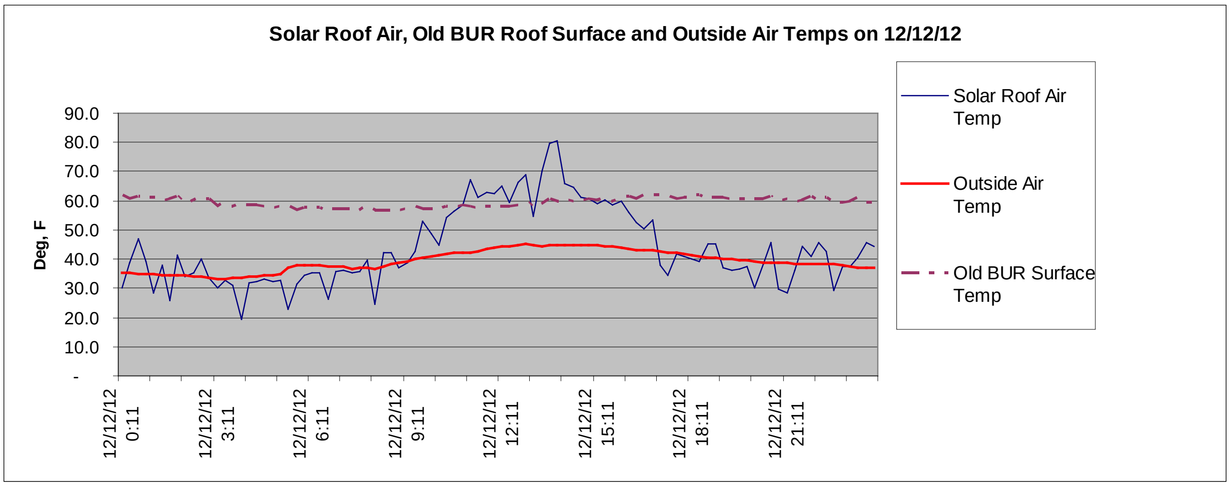

Figure 17. Solar air and old roof surface temperature.

A similar analysis was conducted for summer heat gain in response to an ESTCP request to compare the roof to a reflective “cool roof.” Hourly calculation of the temperature difference and the R value provide a total avoided heat gain. This avoided heat gain causes a reduction in the air conditioning electrical energy use and cost. The added insulation of the solar roof, including the use of a radiant barrier, actually keeps the solar roof cooler in summer than a non-solar BUR and, as a result, the solar roof is equal to a “cool roof” in its cooling performance (see Figure 14.)

7.0 COST ASSESSMENT

7.1 COST MODEL

When estimating the cost of the solar roof compared to a conventional BUR, two key parameters are necessary, first cost and useful life cycle. A BUR or membrane roof has a useful life cycle of approximately 15-17 years. A solar air heating roof has a useful life cycle of 40 years. A solar air heating metal roof will last as long as 2.7 BURs. At the end of the life for each BUR, the roof is either re-covered or the old roof is torn off and a new roof is installed.

When the BUR is installed there is no energy benefit to the building. It is simply an expense to keep the weather out of the building. When a solar metal roof is installed, there is a measureable cost savings because of the solar heating energy supplied to the building, which reduces energy costs from natural gas, fuel oil, propane, or electric heating sources.

The typical costs and savings for a solar air heating metal roof that is installed over a sloped BUR are presented in Table 6.

Table 6. Cost model for solar air heating metal re-roof.

Cost Element[1]	Data Tracked During the Demonstration	Estimated Costs[1]
Hardware capital costs	Solar roof over sloped BUR Fans Duct & Electrical Plumbing Roof Trim & Tie in to BUR Note: Higher cost if sloped built up system is required. Lower cost if over metal roof.	$18/ft^2$ $4/ft^2$ $3/ft^2$ $1/ft^2$
Installation costs	Labor and material required to install	$5/ ft^2$
Consumables	Estimates based on rate of consumable use during the field demonstration	$0/ft^2$
Facility operational costs	Reduction in energy required vs. baseline data	Net $0.46/ft^2/yr (heat-electricity)
Maintenance	Repaint roof, replace fans at 25 years, $11,316 Replace tank and pump at 10 years, $500	$0.04/ft^2/yr
Hardware lifetime	Estimate based on components degradation during demonstration	40 year roof 25 year fans 10 year tank and pump
Operator training	Estimate of training costs	$0.05/ft^2/yr

[1] Detailed list of materials and analytical costs provided in Final Report

The contribution of each element of energy and cost savings to the whole of the annual savings of the Gaffney Solar Air Heating Re-roof is presented in Figure 21.

7.2 COST DRIVERS

There are five cost drivers to consider when selecting this technology.

1. Roofing need
2. Building heating loads

3. Building structural support of the roof
4. Energy rates for heating vs. electricity
5. Roof configuration

Roofing Need – To replace a roof on a building, DoD will need to spend 75% of the cost of a solar roof just to have the roof replaced. So, 75% of the "first cost" of the solar roof is covered just from the avoided roofing expense of a non-solar roof. Over its lifetime, the solar air heating metal roof will actually save money in roofing costs over those of built-up or membrane roofs. Obviously, if the existing roof is new and does not need replacement for 10+ years, the immediate cost savings will be reduced, but the solar roof is still likely to save more over time than a series of membrane or built-up roofs.

Building Heating Loads – A building that has a high heating load can maximize the use of all the solar heating capacity from the solar air heating roof. This includes year-round heating loads or combinations of seasonal loads. For example, a high outdoor air load that might be found in a laboratory or contaminated air environment will have a high winter heating load in most mid-latitude and northern climates. A high water heating load for building heating or domestic hot water loop can be served by the solar air heating roof either as demonstrated at Gaffney or when combined with a solar assisted heat pump. Annual heating loads larger than 40,000 BTU/ft^2 of roof tend to make good candidates.

In addition, a building with a high temperature heating load, e.g. above 140EF, may not have many hours when the solar heated air will be hot enough to contribute heating energy. Often, there are other lower temperature inputs to a high temperature process that can be offset with solar energy. In other cases, a solar assisted, high temperature, air to water heat pump can be used to convert the low cost solar heat to high temperature hot water at much lower costs than a heat pump alone or other heating source.

Beyond the typical solar heating applications that come to mind (space heating, domestic water heating and outdoor air preheating), there are many specific applications that are good candidates for solar air heating. These include: combustion air preheating, paint booth preheating, desiccant dehumidification, swimming pool heating, emergency generator standby heating, air conditioning reheat, heat pump preheating, and process equipment drying and heating.

Building Structural Support – The solar air heating roof can add about 3 pounds/ft^2 to the roof. Normally, this is not a concern as a structural analysis will confirm that the roof structure is adequate to support the load. In some cases, added structure is required to build up the slope of the roof to tie in different sections or get above obstructions on the roof. In those cases, the added structural cost can be an important economic consideration. For large roofs over 10,000 ft^2, the added cost of slope build up systems can be minimal. For smaller roofs, the cost of the added structure can make the solar roof uneconomical.

Energy Rates for Heating and Electricity – Solar air heating roofs use electric power to run fans and pumps. Normally, the cost of this power is less than 20% of the savings from the heating fuel use. However, heating energy saved for any operating hour must be balanced against the electrical cost for that hour. For each set of electric and heating fuel rates, a balance can be set to ensure that the solar fans and pumps only run when there is a positive net cost savings.

Roof Configuration – It is not necessary to install a solar air heating metal roof at an optimum tilt or azimuth angle. In many cases, the roof surface is so large and it delivers so much heat, a less than optimum orientation will still provide more heat to many loads than is required. It is typically more economical to minimize the roofing cost instead of trying to maximize the solar heating with optimal orientation. Several roof and wall systems with east and west orientations work well.

Color is also not a critical issue. It is often better to satisfy the local aesthetic needs of the building with an appropriate color and recover whatever solar heat is available than to have the design rejected because dark colors may not be appropriate.

One element that can raise the cost of a solar re-roof is if there are numerous obstructions on the roof, particularly high volume exhaust vents with contaminated air. Many individual vents can be ducted away from the solar roof air intakes, but if there are many widely scattered obstructions that each require time consuming sealing and flashing, then the installed cost will be higher.

7.3 COST ANALYSIS AND COMPARISON

The project at the Gaffney Fitness Center was designed to demonstrate and document the installation and operating cost savings from two kinds of solar roof structures, and three applications of solar heat. The two structures included a re-roof over an existing sloped BUR and a re-roof over a flat BUR with a "slope build up" structure. The three applications of solar heat included outdoor air preheating, direct space heating, and domestic water preheating.

Approach – The approach to developing a life cycle cost was to document all capital costs, operating costs, and energy cost savings for the existing roof and natural gas heating system vs. the solar metal air heating roof. The capital costs of all solar roofing, piping, electrical, and air handling systems were collected. The avoided roofing cost is based on the projected cost of having to re-roof with an existing BUR several times over the comparable life of a solar air heating metal roof. The operating cost to run the fans and pumps was measured and the annual heating cost savings from solar heat delivered was calculated. The total annual cost and savings were projected over 30 and 40 year periods to provide a total discounted savings using the Building Life-Cycle Cost (BLCC) program.

The energy operating cost savings were calculated based on the solar heat delivered, which displaced the need for natural gas heating in the existing boilers. The annual heating cost savings were calculated by creating a predictive performance model for the solar roof.

Roofing Costs – For the roofing system, the costs were allocated to each of the two roofing types to be used as a gauge by facility managers as an input to future roof budgeting projects. The re-roof over the sloped BUR requires less structural support, no wall construction or siding, and minimal edge trim and tie in to the existing roof and parapets. As a result, it is less expensive than the sloped built-up section over the flat roof. The cost allocation for the entire project showed the solar roof section over the sloped BUR was \$20/ft^2 compared to \$74/ft^2 for the section with the sloped built-up section above the flat roof.

The sloped built-up section of Gaffney, with many areas of new wall and roof to tie into the existing building, is considered to be more expensive than a typical sloped built-up over a wide flat roof. On an open flat roof, structure is simplified and standardized, and new wall surfaces and tie-ins to the old building walls are minimized. A typical sloped built-up that spans from one side of the roof to the other is shown in Figure 18. This system costs closer to \$25/ft^2.

Figure 18. Sloped built-up roof example.

Figure 19. Army Research Lab low slope air heating roof.

Another approach is to use a low slope solar air heating roof over a flat BUR. The system at the Army Research Lab Office Building, Figure 19, is one example. This system installed a solar air heating metal roof at a slope of 1/8th inch per 12 inches of run. The structure is 9.5" above the old BUR, the same as the Gaffney structure over the sloped BUR. The expected cost of this 11,000 ft^2 system would be approximately \$20/ft^2 installed.

Another roof system is a metal re-roof over an existing leaking metal roof, Figure 20. A solar metal roof can be installed directly over the original metal roof. This is the most economical system because it requires no added insulation and minimal structure of about 2-3" deep over the old metal roof. This system costs about \$12-15/ft^2.

Figure 20. Metal over metal solar re-roof.

***Solar Air and Water Component Costs* –** Once the roof cost is set, the cost of the fans, ducts, heat exchangers, plumbing, and electric power can be determined. In general, the costs for the Gaffney building are representative of solar air heating roof installations. Fans, ducts, and electric power typically cost \$4/ft^2 of solar roof. This is for systems with short duct runs of less than 50 feet and supply and return piping runs up to 100 feet within the building. Solar heated air has been successfully ducted indoors and outdoors up to 120 feet with minimal added cost. Plumbing cost can be \$3/ft^2 for a system that uses from 250-3,000 cubic feet per minute (cfm) of solar air. The estimation of both solar air and water heating system costs for any particular building can be reliably predicted using standard mechanical estimating techniques based on duct or pipe diameters, length of runs, insulation thickness, etc.

The fans can be any type required to move the air. Direct drive fans capable of 140EF temperature are preferred as there are no belts to change or bearings to grease. Fans have an expected life cycle of 50,000 hours, which can be 25 years of service for a fan operating during 2000 sunny hours per year. As a rule of thumb, the fans will deliver about 1 CFM of solar heated air for every 1 square foot of solar roof, but the designer can adjust this to match the load or the roofing area needed. For example, the Gaffney roof was designed for the 9275 ft^2 of roofing are that was needed to cover the old, worn out roof. However, the hot water preheat and outside air preheat airflows only needed to be about 3,500 CFM for each system to satisfy the loads. The electric power required is about ½-1 watt/ft^2 or CFM. Ordinary mechanical design principles can be applied to the fan and duct design.

Energy Source, Climate, & Building Type – The DoD has within its building inventory, every type of building, in every climate zone, with all types of heating energy sources. These include residential (family housing), commercial (commissaries), and industrial (aircraft maintenance hangars). The solar air heating roof has been applied across all these types of buildings, but when comparing the cost and savings of different buildings with different characteristics in varied climates, the following discussion can lead the facility manager to buildings that will produce higher savings.

Often the most important consideration is the local cost of heating energy. The higher the cost of the heating energy source, the higher the energy savings will be for a particular building. For example, if electric resistance heat is delivered with $0.10 per kilowatt hour electric rates, then that heat costs $29 per million BTU delivered. Heat from fuel oil at $3 per gallon or propane (LPG) at $2 per gallon via a 90% efficient boiler will cost $24 per million BTU delivered. At the Gaffney facility, with natural gas heat delivered to the load via 90% efficient boiler, the cost is $9 per million BTU. So, buildings with electric resistance heat, fuel oil, or propane heat, will see more than twice the savings for the same solar roof application.

A quick assessment of the heating loads including space heating, outdoor air, cold water preheat, boiler air preheat, hot water loop heating, or geothermal ground loop heating can determine if a combination of loads will be adequate to generate solar cost savings. A focus on the low temperature incoming air or water sources feeding the conventional heating systems will yield many locations where solar heat can be economically deployed. Larger industrial systems (10,000+ square feet) will be more economical than small, residential systems. This is because the industrial installation will require less time and money per square foot on mobilizing to a single location for the project and trimming it out to satisfy the industrial aesthetics than would be required for a small residential project.

In general, savings of 30,000-50,000 BTU/ft^2 of roof/yr can be expected with higher savings, if there are more low temperature heating/preheating loads. Cost savings of $0.25-$0.50/ft^2 of roof per year can be expected when competing with natural gas at $6-$8/million BTU. However, cost savings can be up to four times higher when competing against electric resistance heat or fuel oil or propane at typical market rates of $0.10/kwhr or $3/gallon.

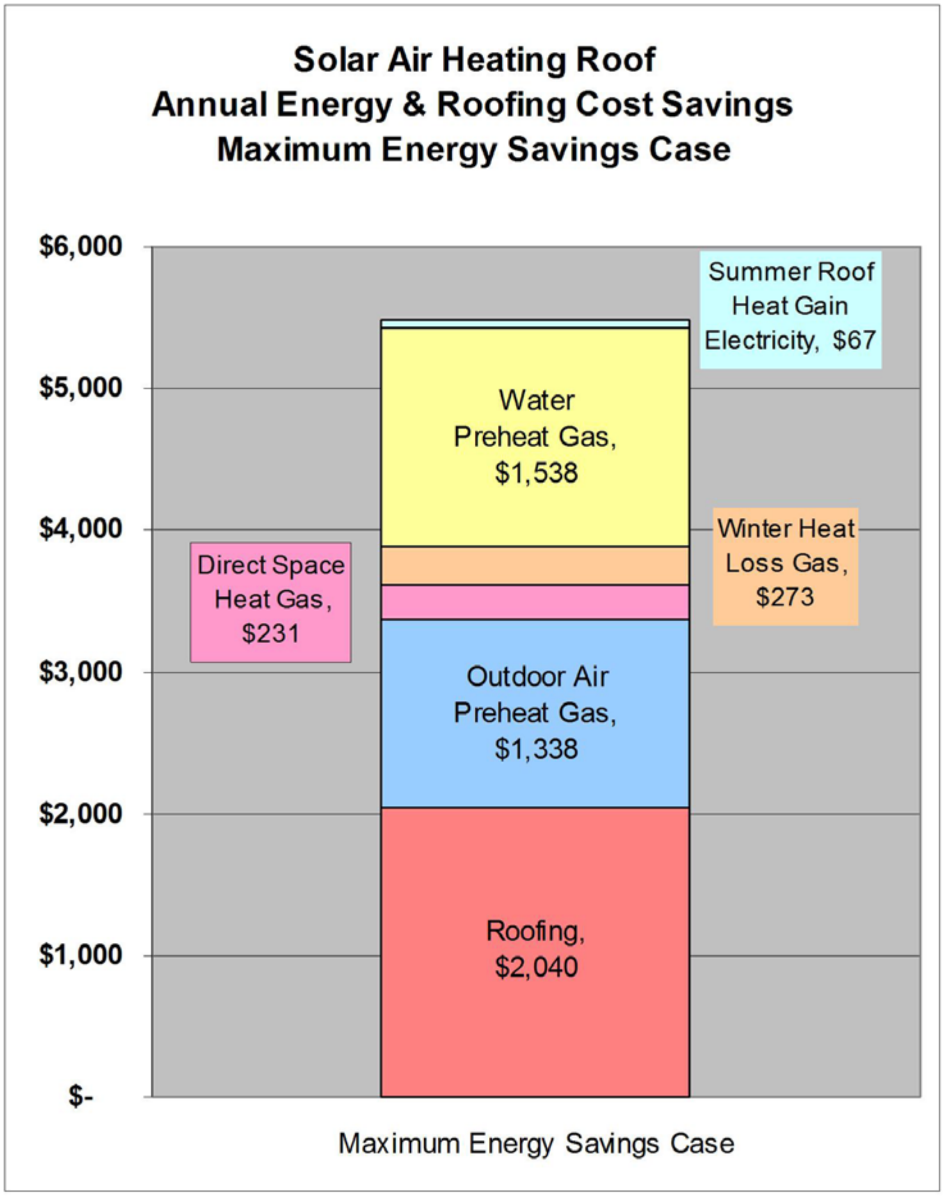

Figure 21. Gaffney solar reroof annual cost savings.

8.0 IMPLEMENTATION ISSUES

The solar air heating metal roof involves a standard metal re-roof over an existing worn out roof. There is considerable knowledge within the roofing industry and code reviewers on how the millions of square feet of this metal reroof system have been installed. The HVAC and plumbing systems are also standard systems using conventional materials and design approaches. There is no special permitting required beyond the standard design review required for any re-roof or HVAC or plumbing modification.

One of the challenges in installing solar air heating roofs and re-roofs is that very few of the public works designers, roofing managers, or the architects and engineers they hire are familiar with the solar roofing and re-roofing approach. Often an inquiry about solar re-roofing occurs after the building has been designed and initial cost estimates and budgets are in place and detail design is underway. It is important to inject the solar roof or re-roof approach during the early planning stages. This will increase the likelihood that the full energy savings available from the solar roof can be captured for the next 40 years.

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9.0 REFERENCES

The following are references to the full final report of the project and may serve as background material for this cost and performance report.

1. Transpired Collectors (Solar Preheater for Outdoor Ventilation Air) Federal Technology Alert, Federal Energy Management Program, U.S. Dept. of Energy, DOE/GO-10098-528, April 1998.

2. Solar Water Heating with Low-Cost Plastic Systems, Federal Energy Management Program, U.S. Dept. of Energy, DOE/GO-102012-3177 January 2012.

3. Archibald. June 8-9, 2010. Solar Heat Recovery from Roofs and Walls. Sustainable Solutions Conference: Engineering High Performance Buildings, Chicago, IL, Engineered Systems.

4. FM Global Property Loss Prevention Data Sheet 1-31, Metal Roofing Systems, FM Global, Johnston, RI, July 2008.

5. Typical Meteorological Year (TMY) Data file, available from the National Solar Radiation Database, http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/.

6. EPRI TR-100212, Commercial Water Heating, Electric Power Research Institute, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=TR-100212.

7. ASHRAE Handbook, 2001 Fundamentals, American Society of Heating Refrigerating and Air Conditioning Engineer, Atlanta, GA.

8. Delaney, PE, LEED AP, Sustainable Architecture and Building Magazine, reporting on a survey report by Ducker Worldwide in 2007, August 2010 http://www.sabmagazine.com/blog/2010/08/16/rethinking-roofing/.

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APPENDIX A

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