# FINAL REPORT

## High-Performance Energy–Efficient Cool Metal Roof Assemblies Utilizing Building Integrated Renewable Solar Energy Technologies for New and Retrofit Building Construction

## ESTCP Project EW-201139

APRIL 2014


Robert Scichili
**Metal Construction Association Inc.**

# Report Documentation Page

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## List of Acronyms

| | |
|---|---|
| AIA | American Institute of Architects |
| AISI | American Iron & Steel Institute |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| ASV | Above Sheathing Ventilation |
| BIPV | Building Integrated Photovoltaic System |
| BIST | Building Integrated Solar Technology |
| BOMA | Building Owners and Managers Association |
| BTU | British Thermal Unit |
| DAS | Data Acquisition System |
| DHW | Domestic Hot Water |
| DoD | Department of Defense |
| DOE | Department of Energy |
| ESTCP | Environmental Security Technology Certification Program |
| FITC | Federal Investment Tax Credit |
| FHA | Forced Hot Air, as in a type of space heating system |
| FSRM | Facilities Sustainment, Restoration, and Modernization |
| FSEC | Florida Solar Energy Center |
| GFAFB | Goodfellow Air Force Base |
| HFT | Heat Flux Transducer |
| HVAC | Heating, Ventilation and Air Conditioning |
| IEC | International Electrotechnical Commission |
| KCFNG | Thousand Cubic Feet of Natural Gas |
| KGL | Thousands of Gallons |
| KBTU | Thousands of British Thermal Units |
| kWh | Kilowatt hours |
| KWH-T | Kilowatts per Hour Thermal Equivalent |
| LEED | Leadership in Energy and Environmental Design |
| LCOE | Levelized Cost of Electricity |
| MBCI | Metal Building Components Inc. |
| MCA | Metal Construction Association Inc. |
| NFPA | National Fire Protection Association |
| OH+P | Overhead and Profit |
| ORNL | Oak Ridge National Laboratory |
| PPA | Power Purchase Agreement |
| PV | Photovoltaic or Present Value when used in economics |
| PPV | Public Private Venture |
| RH | Relative Humidity |
| SIR | Savings to Investment Ratio |
| SSMRS | Standing Seam Metal Roof System |
| SRCC | Solar Rating and Certification Corporation |
| SIOH | Supervision, Inspection and Overhead (from NIST BLCC) |
| TUV | TÜV SÜD, product testing and certification entity |
| UL | Underwriters Laboratory, product testing and certification entity |

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| USGBC | United States Green Building Council |

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## Acknowledgements

The authors would like to acknowledge the following persons and organizations who contributed substantially to the completion of this project.

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Program Manager for Energy and Water, ESTCP Office and Johnathan Thigpen (formerly with ESTCP) for their support and guidance throughout the project.

## Executive Summary

The Department of Defense (DoD) manages over 577,500 buildings and structures. As the USA's single largest energy consumer, the DoD needs to reduce its carbon footprint and lower its demand for energy and water. Buildings with roofs more than 25 years old generally need to upgrade the roofs and insulation, ventilation and rainwater/drainage systems to meet current standards. The goal of this project was to determine if the dynamic integrated retrofit metal roofing system illustrated below could reduce overall energy consumption and cost when retrofitting existing buildings, to meet the DoD's energy intensity reduction targets.

The Demonstration Project constructed a retrofit roofing system that is illustrated in the following two figures. While the value of the data collected from the project was unfortunately compromised by a major renovation deemed essential by the project's host, Goodfellow Air Force Base, analyses in this report, detailed in Section 7, clearly indicate that retrofit roofing projects can play a significant role in reducing the energy intensity of older buildings in the DoD's real estate inventory and in the private sector. The Savings to Investment Ratios (SIR) range widely, from ~.16 to ~3.99, varying as a function of technology type, project location and energy offset, but this analysis does generally support the basic idea that high performance roofing systems do have a payback and a measurable return on investment as the DoD expands renewable energy and conservation programs through Public Private Ventures and Power Purchase Agreements.

**Figure 1 Cutaway Illustration of the retrofit roof in the Demonstration Project (see Appendix C for full descriptions of the components)**

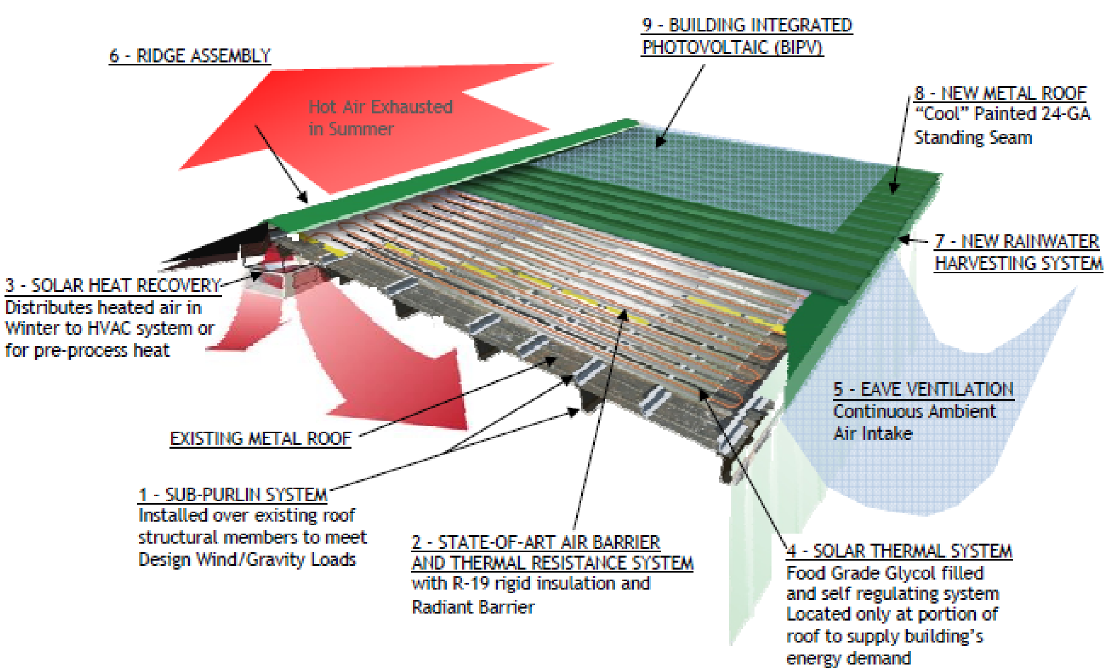


**Figure 2 Cutaway Photograph of full scale mockup of the retrofit roofing system on the Demonstration Project**

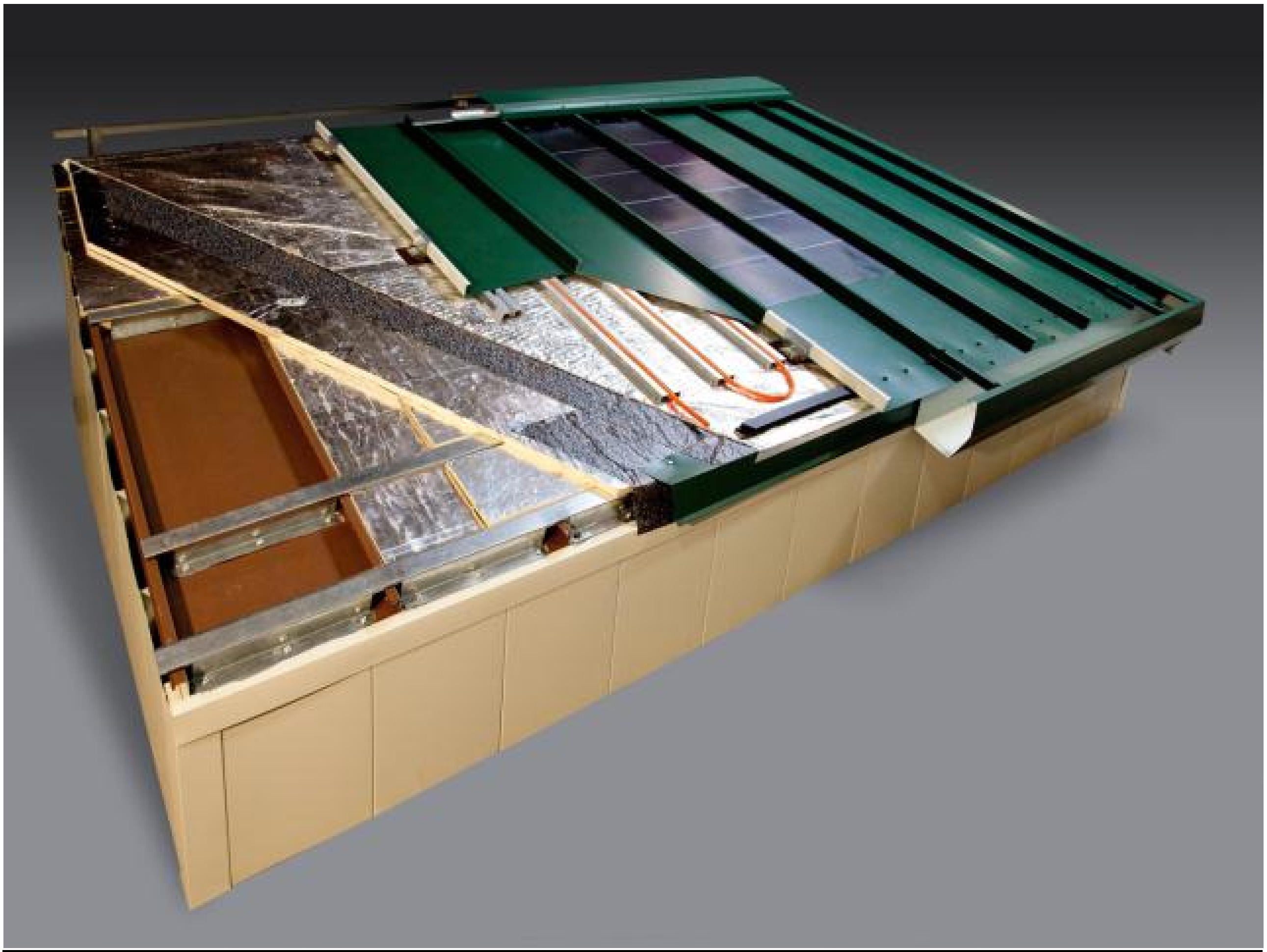


Photo Courtesy of MBCI

The project site selected for this demonstration was Building # 3323, Security Forces Building, Goodfellow Air Force Base (GAFB). The intent of this project is to demonstrate that higher quality and lower costs (capital and operating) can be achieved by prescribing a holistic retrofit roofing system that can be tailored to many building types, occupancies and locales. The investigators believe that this project provides the beginnings of a roadmap for building scientists, architects, engineers and project managers, all of whom recognize the interdependency of materials and trades to the successful outcome of a construction project, to design better building retrofits that combine multiple functions in one holistically designed integrated building envelope system.

The following table summarizes the Performance Objectives and the results of the project.

Table 1 SUMMARY OF PERFORMANCE OBJECTIVES
(Note that 1, 2, 3, 4 are comments from GFAFB Staff)

| Performance Objective | Metric | Data Requirements | Success Criteria | Results |
|---|---|---|---|---|
| **Quantitative Performance Objectives** | | | | |
| Facility Energy Usage | Reduction in Energy Intensity (Btu/ft2) | Meter readings of energy used by installation; square footage of buildings using energy | Overall targeted threshold value reduction in Energy Intensity of 768,130 KBTU/yr. or 76.8 KBTU /SF | Fail, the Energy Intensity of the building increased by 21.47 KBTU/SF/Year |
| Renewable Energy Usage (A) | Solar Electricity Used on Installation (kWh) | Meter readings of renewable energy used by installation | Targeted threshold value of 64884 kWh/YR | Pass; PV production is within 10% of projected values |
| Renewable Energy Usage (B) | Solar Thermal Energy used for DHW (offsetting KCFNG) | Meter readings of renewable energy used by installation | Targeted threshold value of 17.4KCFNG or kWh equivalent | Pass; 27KCFNG of natural gas were offset |
| Renewable Energy Usage (C) | Solar Thermal Energy used for space heating (offsetting KCFNG) | Meter readings of renewable energy used by installation | Targeted threshold value of 338 KCFNG or kWh equivalent | Fail; Heating loads were not reduced to the level projected. |
| Energy efficiency improvement (A) | Insulation reducing cooling loads (kWh) | Meter readings of electrical energy used by installation's cooling equipment | Targeted threshold value of 14683 kWh/YR | Inconclusive; the Electricity consumption increased during the test cycle, due to increases in internal building loads |
| Energy efficiency improvement (B) | Insulation reducing heating loads (KCFNG) | Meter readings of electrical energy used by installation's heating equipment | Targeted threshold value of 127 KCFNG | Fail; meter readings indicate 32.2 KCFNG less Natural Gas consumed less than the prior year vs the 127 KCFNG projected |

| | | | | |
|---|---|---|---|---|
| Water Usage for irrigation | Water (Gallons) | Calculate amount of rain water used by installation for irrigation | Targeted threshold value of 131 KGALS/YR | [1]"Inconclusive; since the system was not operated as intended during the project. |
| Direct Greenhouse Gas Emissions | Direct fossil fuel GHG emissions (pounds) | estimated release of GHG based on source of energy | Pounds of CO2 offset: 53242 lbs from KCFNG, 109,800 lbs from kWh electricity | Fail: 3201.12 lbs of CO2 from natural gas and 86196.9 lb. of CO2 from electricity were offset |
| System Maintenance | Number of hours or $ | Scheduled and unscheduled maintenance events; | 10% increase compared to historical data on building | [2]"Pass; Maintenance effort increased by less than 10%" |
| System Economics* | $, Years | Dollar construction and operating costs, values of energy saved or generated | Favorable NIST BLCC analysis outcome | Fail: as a result of low SIR's See discussions within report. |

| Qualitative Performance Objectives | | | | |
|---|---|---|---|---|
| **Performance Objective** | **Metric** | **Data Requirements** | **Success Criteria** | **Results** |
| | | | | |
| Ease of operation and maintenance | Survey | Survey results | Maintenance mechanic assimilates system into standard maintenance cycle-Testimonial | [3] Pass; assuming system maintenance is funded and performed per maintenance schedules |
| Validate Energy Plus modeling application/Template | Predicted % accuracy when template is employed of over multiple climate zones | Statistical Analysis of multiple simulations | Performance projections will be within 10% of roof energy performance | Pass; Energy Plus model results are accurate given the assumptions defined later in this report. |
| Establish the ease of retrofit implementations | Survey | Survey results | Secure testimonials from Goodfellow AFB Facility Management and the building occupants | [4] Pass; based on Goodfellow AFB Staff comments |

| | | | | |
|---|---|---|---|---|
| Educate and develop DoD Champions | Survey | Survey results | Secure testimonials from NAVFAC personnel | This was not achieved due to limitations to DoD staff travel budgets during the Demonstration period |

These integrated systems, when applied to the DoD's infrastructure, can play a dramatic role in reducing both water and energy consumption by providing retrofit roofing, insulation and ventilation improvements, and renewable energy systems in a turnkey package similar to that demonstrated during this project.

**Technology Results Summary.**

In summary, the facility used more electricity during the post construction monitoring period than it did in prior years, despite the PV system producing 59,039 kWh of solar electricity in FY 2013. The natural gas consumption in FY 2013 was 32.2 KCFNG less than FY 2012 of which 27.0 KCFNG was offset by the hydronic solar thermal system. The thermal energy savings total less than 10% of the savings projected in the Demonstration Plan and GFAFB personnel report that the rainwater harvesting system was not utilized due to issues with the irrigation system maintenance and a general ban basewide on irrigation due to the excessive drought conditions.

The final Energy Plus models produced by ORNL for the roofing assembly are limited to evaluating the impact of the retrofit measures of added insulation and ASV. The model results provide estimated 50-90% reductions in the roof-generated heating and cooling loads for a similarly-sized building in different climate zones. Of particular importance, the model could not determine the effect of ASV on the performance of the solar thermal system.

The building's utility meter readings furnished by GFAFB and the ORNL data collected suggested that the retrofit roofing system did not perform as anticipated in the Demonstration Plan. In fact, the energy intensity of the building increased by 22%, comparing FY 2012 to FY 2013, with FY 2012 serving as the baseline year for the demonstration.

These results prompted the investigators to make another site visit prior to completing the Final Report to determine if conditions or the building use had changed during the monitoring period. It was found that GFAFB had remodeled the building, eliminating the showers and laundry and converting the former detainment cells into a data center and video security observation unit that is manned by 5-6 staff 24/7/365. This renovation took place shortly after completion of the construction of the retrofit roof and at the beginning of the monitoring period of the demonstration project. A review with GFAFB maintenance staff indicated that the additional load of the data center requires the HVAC unit servicing the room to operate in cooling mode 24/7/365 to maintain the room temperature. The full Field Report can be found in Appendix J.

Since this renovation was unannounced and unanticipated, the ORNL data collection system installed during the construction phase did not collect data on any detailed aspects of the data center and video security observation unit. To attempt to assess the impact of the renovation on the building loads, the investigators compared electrical consumption in FY 2012 (pre-Demonstration Project) to FY 2013 (post -Demonstration Project) which indicated an increase in electricity consumption of 42,700 kWH in FY 2013, (including the energy produced by the PV System). The accuracy of this figure is further clouded by the fact that in FY 2013 the building, including the new data center, was operating with a roof renovation that increased the R- value of the roof assembly to R-51 from R-19, and that included a hydronic solar thermal system and ASV system. All of these factors led the investigators to believe that too many variables were changed to make a definitive answer as to the energy savings resulting from the roofing system.

The investigators conclude that the addition of the data center to the building after the baseline data collection period substantially compromised the investigators ability to contribute clean data to the body of knowledge available to building scientists. The design of the experiment did not include sufficient data collection to be able to crisply analyze the impact of adding a ~9-12 KW load to the buildings baseline load in conjunction with the complex roof assembly that was installed and pinpoint the effects of the many factors interacting on the building. These factors include the effect of ASV on the solar thermal system, variations in performance of the ASV system with varying wind loads, or the ability to distinguish the true source of energy savings; i.e., insulation vs. ASV technology, insulation vs. solar thermal energy systems etc.

While it is important to point out the uncertainties in comparing baseline data to the data collected in the monitoring phase, the investigators found that adding the retrofit measures does benefit the energy consumption of the building. The roof heat flux data clearly show the reduction in the heat gained and lost through the roof, and the modeling results provide estimates for similar reductions in roof-generated space conditioning loads in different climate types.

Since accurate sizing of the total load added by the data center is beyond the scope of this project, and since the impact of the interaction between systems and energy flows to and from the data center, and to and from the remainder of the building cannot be analyzed with the data on hand, the investigators will limit the discussion of the Demonstration Project data to the facts on hand and avoid speculation and subjective analysis. Accordingly, the investigators, in the authoring of the balance of this report and in an attempt to salvage years of effort, have attempted to analyze the potential of the subject retrofit roofing system using a set of assumptions defined later in this report. Each of the components of the retrofit roofing system has been analyzed as independent elements of a system, and have utilized industry standard modeling tools to estimate the performance of the entire building envelope design as well as the individual renewable energy systems incorporated in the project.

Retrospectively, the investigators have further concluded that the GFAFB building that was selected for us was a poor choice for the purposes of this Demonstration Project and that there are lessons to be taken from this exercise by all involved, including the investigators, DoD program management and assistant staff, site selection guidance staff, GFAFB staff and at every phase of the project from site selection and vetting onward. This will be discussed in more detail in Section 8 Implementation Issues.

# 1.0 INTRODUCTION

A successful outcome of this project will lead to the accelerated deployment of holistically designed new and retrofit metal roofing systems that have been demonstrated to be viable and effective across a range of climate zones. These systems will contribute to reducing both water and energy consumption by incorporating insulation and ventilation improvements, renewable energy systems and rainwater collection in holistically designed retrofit roofing systems.

## 1.1 BACKGROUND

The Department of Defense (DoD) manages over 577,500 buildings and structures. As the USA's single largest energy consumer, the DoD needs to reduce its carbon footprint and lower its demand for energy and water.

The renewable energy technology currently in general use by the DoD can be described as single mode type products; they collect energy as either solar electricity or solar thermal but rarely both. The technology that was employed in this demonstration project is a hybrid technology that consists of metal roofing, insulation, hydronic solar thermal system, engineered air pathways, and photovoltaic (PV) cells designed to work symbiotically.

These dynamic roofing systems can heat and cool air and water, produce electricity and collect rainwater in one common building envelope assembly that can be installed in conjunction with a retrofit roofing system on buildings with both flat and sloped roof designs. They are innovative in that they combine multiple functions in one holistically designed, integrated building envelope system that has historically been utilized on a limited basis.

The goal of this project was to determine if a dynamic integrated retrofit metal roofing system could reduce energy consumption and cost when retrofitting existing buildings, to meet the DoD's energy intensity reduction targets.

The WBDG states that the term "roof system" refers to the air or vapor retarder (if present), roof insulation (if present) and the roof covering. A search of the WBDG for roofing systems and the results are Unified Field Guide Specifications for copper, EPDM, and metal roofing specs; all as standalone systems absent of any "building system synergies". With the rise of building integrated solar technologies (labeled as "BIST" systems by the DOE), the WBDG and UFGS should be updated to reflect these holistically designed building integrated applications of solar technologies. This element of the DoD's technology transfer program will pave the way for a day soon when project specs will call for Public Private Venture (PPV) proposals on new or retrofit projects by a single private firm that will engineer, construct, own operate and manage the roof assets and sell the energy back to the DoD.

Early adoption, accelerated deployment, higher quality and lower construction and operating costs will be achieved by prescribing a holistic retrofit roofing system in the Whole Building Design Guide that can be tailored to many building types, occupancies and locales. Integrated systems, when applied to the DoD's infrastructure, will dramatically contribute to reducing both water and energy consumption by providing retrofit roofing, insulation and ventilation improvements, rainwater management and renewable energy systems in a turnkey package.

This project demonstrated the advantages of specifying a holistically designed high performance roofing system during the roof retrofit cycle. Additionally, the project illustrated the benefits of installing these systems with trained and certified building envelope technicians (heretofore roofing contractors) under a single turnkey supplier with both performance and warranty accountability. Such an approach recognizes the interdependency of the components and trades and maximizes the likelihood of a successful outcome of a construction project.

## 1.2 OBJECTIVE OF THE DEMONSTRATION

The project incorporated BIST systems including solar thermal and solar electric (photovoltaic or PV) systems along with additional insulation, air barrier improvements, above sheathing ventilation, rainwater harvesting and a retrofit roofing system (see Figure 1). It sought to prove that by integrating these dynamic solar and energy efficiency technologies with a retrofit metal roofing system that a DoD installation can reduce energy and water consumption, mitigate the buildings environmental impact, lower construction and operating costs and reduce the buildings overall energy intensity.

The objectives of the project were:

(a) To measure and authenticate the energy savings potential of full-scale metal retrofit roof assemblies through both energy efficiency measures as well as active solar energy harvesting techniques.

(b) To use the results to predict how energy efficient metal roofs will play a role in net-zero energy buildings.

(c) To educate stakeholders, the design community, and regulatory bodies on the impact of retrofit metal roofing assemblies and their ability to reduce energy consumption in existing buildings.

(d) To demonstrate that these cost-saving roofing technologies can be utilized in new building construction.

(e) To demonstrate that a holistically designed retrofit roofing system is sufficiently adaptable, scalable and repeatable in terms of its ability to provide renewable energy and air barrier, insulation, ventilation and rainwater/drainage improvements across a large segment of the DoD's building inventory.

Since demonstration projects promote technology transfer by reducing perceptions of novelty and risk, and barriers to rapid adoption are removed with the publishing of 3rd party independently verified results, in this case by ORNL, the investigators believe the result will be accelerated deployment of the technology demonstrated in this project, facilitated by new performance modeling protocols promulgated by ORNL via enhancements to the DOE Energy Plus performance modeling system.

Additionally, since the project was sponsored by the Metal Construction Association, a non-profit trade organization representing metal construction product manufacturers, the project deliverables can be widely disseminated to the membership and used to promote the expansion of the metal industry into the renewable energy and energy efficiency market segments. The expected outcome of this private sector affiliation is that the broader US economy will benefit from the acceleration of the design and implementation of higher value, high performance building envelope systems, both new and retrofit that will be installed by a certified building envelope workforce with enhanced skill sets.

The project validated the following:

- Typical 20th century DoD roof systems are suitable for high performance metal roof retrofits that can be installed with minimal disturbance to the occupants.
- The roofing system can be used on new and retrofit applications and that it is suitable for inclusion into the Whole Building Design Guide as a holistic system.
- The system will reduce operating costs and the carbon footprint of the following types of building, among others: barracks, infirmaries, cafeterias, commissary, hospitality sites, apartment complexes, hospitals.
- That existing performance modeling applications used to develop the projections of discrete components of the system are sufficiently accurate.
- Enhanced performance modeling tools are needed that accurately predict the performance of the holistically designed systems over a broad range of climate and insolation zones
- A holistically designed retrofit metal roofing system is sufficiently adaptable, scalable and repeatable in terms of its ability to provide renewable energy and air barrier, insulation, ventilation and rainwater/drainage improvements across a large segment of the DoD's building inventory.

## 1.3 REGULATORY DRIVERS

- *Executive Orders: EO 13423, EO 13514;*
    a. Executive Order (E.O.) 13423, Strengthening Federal Environmental, Energy, and Transportation Management, signed on January 24, 2007, sets even more challenging goals for the federal government. The 2007 E.O. mandates that 50% of all renewable energy required under EPAct 2005 must come from "new" renewable energy (meaning energy from facilities placed in service after January 1, 1999). The guidance under E.O. 13423 allows a limited amount of thermal energy to count toward the E.O. goal for new renewable energy, but not toward the EPAct 2005 goal.[1] The FEMP guidance on E.O. 13423 and EPAct 2005 requires agencies to own the renewable energy credits (RECs) associated with any renewable energy counted toward the goal.
    b. E.O. 13514, Federal Leadership in Environmental, Energy, and Economic Performance, was signed on October 5, 2009. This order establishes "an integrated strategy towards sustainability in the Federal Government" and makes "reduction of greenhouse gas emissions a priority for federal agencies" [2]. This E.O. builds on the federal energy

[1] See www.eere.energy.gov/femp/regulations/eo13423.html.

[2] www.eere.energy.gov/femp/pdfs/eo13514.pdf; accessed June 8, 2010

efficiency mandates of EPAct 2005, EISA 2007, and E.O. 13423 by using greenhouse gas (GHG) emissions as a unifying metric for federal sustainability. The order requires agencies to:

  - Establish a GHG-emission baseline for fiscal year 2008
  - Set GHG-emission reduction targets for fiscal year 2020

- *Legislative Mandates: Energy Policy Act of 2005, Energy Independence and Security Act of 2007*

  The Energy Policy Act of 2005 (EPAct 2005) set the primary renewable energy requirements for federal agencies. It requires that renewable energy be tapped—to the extent that is economically feasible and technically practicable—to generate the following percentages of the federal government's total electricity usage:

  1. Not less than 5% in fiscal years 2010 through 2012
  2. Not less than 7.5% in fiscal year 2013 and thereafter
  3. The Energy Independence and Security Act of 2007 (EISA 2007) requires that 30% of the hot water demand of new federal buildings (and major renovations) be met with solar water heating equipment, as long as the solar system remains cost effective over its life cycle

  - *Federal Policy:*
    - *Federal Leadership in High Performance and Sustainable Buildings MOU 2006:* Outlines the Guiding Principles for Federal Leadership in high Performance and Sustainable Buildings (Guiding Principles)
    - *DoD Policy: Strategic Sustainability Performance Plan, Energy Security MOU with DOE*
    - *Service Policy: Army, Navy, Air Force:* Each branch of the military has issued various policies promoting and requiring energy efficiency and renewable energy implementations.
  - Regulations:
    - *Air Force Instructions; Engineering Technical Letter (ETL) 08-13*: Incorporating Sustainable Design and Development (SDD) and Facility Energy Attributes in the Air Force Construction Program. This ETL provides requirements, recommendations, and guidance for sustainable strategies and energy reduction practices when planning, programming, designing, and constructing Air Force facilities. By providing information and detail on the requirements of the Air Force Sustainable Design and Development (SSD) Policy memorandum, this ETL will allow the Air Force military construction (MILCON) program to successfully pursue sustainability goals and objectives. This ETL is interim guidance that will be revised when efforts of the CE Transformation Commission Initiatives, Project A-5, "Incorporating Sustainable Design and Development," are completed.
    - *USACE ECB 2011-11:* Gives clear guidance; Include 30% solar water heating in areas where the average sun exposure is equal or greater than 4.0 kWh/m2 per day according to the National Renewable Energy Lab
    - *NAVFAC Engineering & Construction Bulletin (ECB*): Provides programming & design/construction guidance –June/July 2010

*Industry Standards*

- *ASHRAE 189.1-2009, on which the DoD based the Unified Facilities Criteria 1-20002 High Performance and Sustainable Building Requirement*
- USGBC Leadership in Energy and Environmental Design (LEED) Various branches within the DoD and other Federal Agencies stipulate that significant renovations and new construction meet the minimum requirements of the LEED Silver standard. The solar energy systems, cool roofing materials, rainwater collection systems, recycled material content and commissioning practices in this project allow for a LEED registered project to qualify for points in a number of LEED credits.

## 2.0 TECHNOLOGY DESCRIPTION

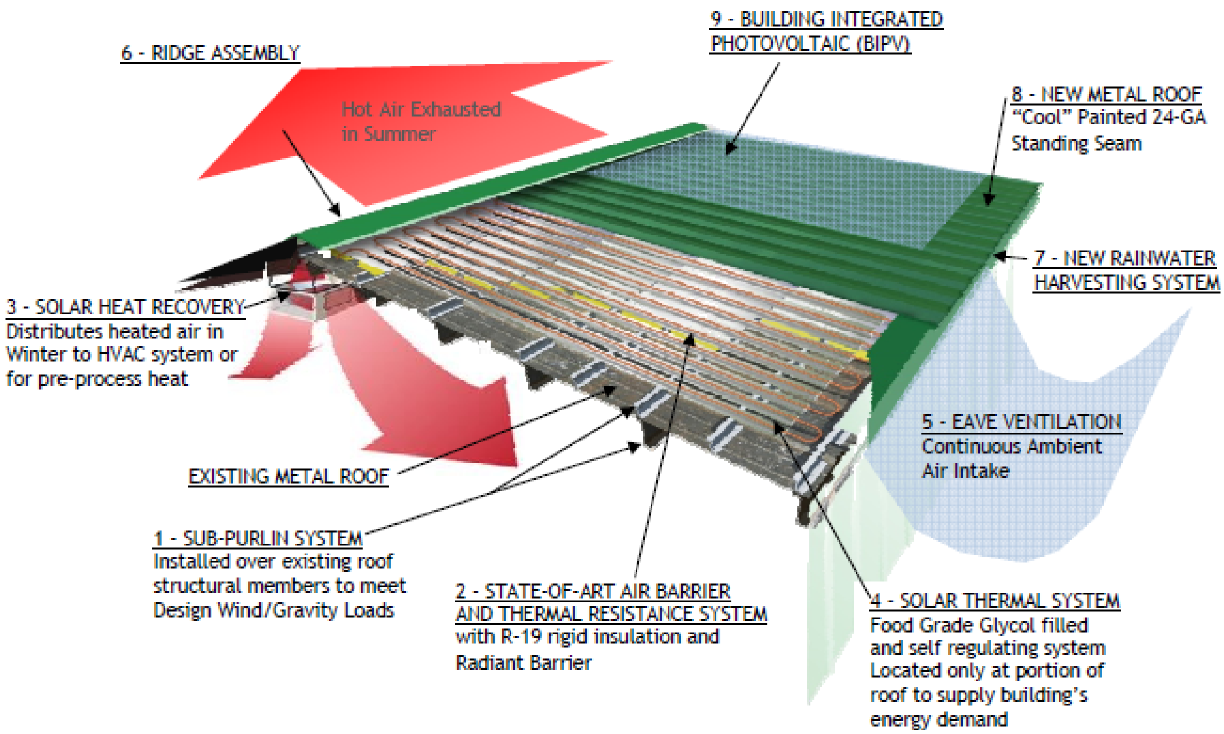
### 2.1 TECHNOLOGY OVERVIEW

The demonstration project undertook the installation of a retrofit metal roofing system over an existing metal standing seam metal roof that was in need of replacement. Retrofit metal roofing systems are highly adaptable and can be installed on all types of buildings. The retrofit roofing project creates a cavity between the existing and new roofs. This space is usually no more than 3" to 5" deep, depending on the energy-efficiency retrofit objectives. This approach provides a unique opportunity to install, at the building Owner's option, a variety of proven technologies that are specifically selected to satisfy each building's energy demands and energy savings goals.

The retrofit metal roofing system serves as a platform for mounting Building Integrated Solar Technology (BIST) systems that included solar thermal and solar electric (photovoltaic or PV) systems and other energy efficiency measures such as additional insulation, air barrier improvements, above sheathing ventilation and rainwater harvesting (see Figure 3).

All of these elements were combined to create a unique holistic roofing system that was the subject of this research project. However, the investigators emphasize that system designers must take care to match their system designs to a specific building's use, location and energy loads and that the high performance retrofit metal roofing system discussed herein is not a universal solution, but rather only one of many variants of systems available today.

**Figure 3 Cutaway Schematic** Illustrating the Technology Components (see Appendix C for full descriptions of the components)



## 2.2 TECHNOLOGY DEVELOPMENT

The component parts of the holistic retrofit roofing system utilized in this proposal are all fully engineered building components/assemblies that are commercially available in the marketplace today. Each has been installed in numerous projects, but never together as a fully integrated building envelope assembly that combines all of the elements outlined above. ORNL has been researching several of the component parts of the system, including ASV, rigid insulation and metal roofing with "cool[3]" color finishes, with positive results. Additional research is planned for certain versions of the integrated systems

An outline of the various efforts follows:

- The Metal Construction Association is involved in a 3-year research project on Dynamic Building Envelope systems at Oak Ridge National Laboratory (ORNL). The objective of the research is to evaluate the effects of integrating metal roofing, ASV, insulation, phase change materials and photovoltaics on heat gain and energy consumption of space immediately below the roof assembly. The work is funded by MCA and by DOE. However, there is no integration of solar water heating, solar air heating, or rainwater harvesting.
- Additional activity by the Metal Construction Association with Oak Ridge National Labs over the past 8 years is outlined below:
    - In early 2000, a full test protocol was established to evaluate Cool Metal Roofing using coatings with heat reflective pigments designed to affect heat gain in a building. This 3 year research project called for comparisons with other roofing materials such as asphalt, clay tile and other metal roofing without heat reflective pigments. The results proved that Cool Metal Roofing provided a 17% drop in peak heat gain over the test period. (See Appendix U)
    - In late 2005 an Above Sheathing Ventilation project was entered into with ORNL to measure the effects on further reduction of the peak heat gain in a roof thru the use of Above Sheathing Ventilation. The results were a dramatic further reduction of 30% in peak heat gain. When coupled with Cool Metal Roofing reduction of 17%, we are now near or over 50% reduction in peak heat gain. (See Appendix U)
    - A current research project is underway to model the results with Above Sheathing Ventilation heat reduction and translating this to what it will contribute in reflectivity terms. This will aid the expansion of the choices one has for roof products that use ventilation instead of reflectivity, but where the code calls for a cool roof with a reflectivity minimum of 25%. (See Appendix U)
- The metal-over-metal structural sub-framing systems with new metal roofing employed in this project have been installed on over 50 million square feet of buildings since 1992,

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[3] The EPA's Energy Star program has a Roofing Products component that defines a cool roof as a material that has the following characteristics:
Steep slope: initial Solar Reflectance ≥0.25 3-year aged Solar Reflectance ≥0.15
Low slope: initial Solar Reflectance ≥0.65 3-year aged Solar Reflectance ≥0.50

including 1.85 million on military and federal facilities nationwide. Many of these projects have employed additional insulation and/or ASV.

- Metal roofing has matured by gaining market share year after year. It now represents over 22% of the overall roofing market. A survey of two military bases (Goodfellow AFB and MCLB Albany GA) performed in conjunction with this proposal revealed that metal roofing exists on over 50% of all buildings on these bases. These high performance systems reduce the environmental impact of a building and provide a service life of more than 60 years in most climates. This minimizes the need and frequency of replacing the roofing material, which lowers the environmental impact from the manufacturing of replacement material. The fact that metal roofing is fully recyclable helps to reduce the solid waste stream going to landfills. The EPA estimates up to 10% of landfill space is filled with roofing debris other than metal.[4]
- The hydronic solar thermal technology described in this proposal was first commercialized in 2004. It has been installed in 35 states and 5 countries primarily on residential and light commercial projects. During the course of the Demonstration Project, solar thermal systems similar to that installed on this project have been installed at 6 sites listed below in Table 2. They have been the subject of an independent multi-year monitoring project performed under the auspices of the USDOE Building America Program[5], which demonstrated that the technology actually performs better than predicted by industry standard performance modeling software. The solar thermal system has been independently tested and performance certified by the Florida Solar Energy Center and it holds an SRCC OG100 Certification by the Solar Rating and Certification Corporation.
- The BIPV laminates proposed for this project have been in use for over 10 years with hundreds of megawatts installed around the world. They have been embraced by the metal construction industry and are becoming a feature of new and retrofit roofing projects. These products are certified by UL, IEC and TUV.
- Rainwater harvesting has been used for centuries in different parts of the world. It has recently become popular again in the United States due to the concern over water conservation issues related to sustainable building design, operations and maintenance. Several commercial manufacturers of rainwater harvesting systems, of all sizes and uses, are serving the building industry. Many metal roofing manufacturers are providing integrated rainwater harvesting technologies in the market today.

[4] http://www.epa.gov/osw/nonhaz/industrial/cd/basic.htm

[5] http://energy.gov/eere/buildings/building-america-bringing-building-innovations-market

**Table 2 Recently Constructed Projects That Include Component Technology**

| | |
|---|---|
| 1. Oak Ridge National Laboratory- Building 3114 | Retrofit metal roofing system, insulation, ASV |
| 2. Langley AFB – Building 374 | Retrofit metal roofing system, insulation |
| 3. Edwards AFB – Buildings 2, 3, 4 and 3500 | Retrofit metal roofing system, insulation |
| 4. Tyndall AFB – Building CDC 1410 | Retrofit metal roofing system, insulation |
| 5. Fort Lewis – Buildings 2003, 7955 and 7956 | Retrofit metal roofing system, insulation |
| 6. Kennedy Space Center, FL | Retrofit metal roofing system, insulation |
| 7. Camp Lejeune P1188 CDC | New metal roofing system, insulation, hydronic solar thermal system |
| 8. Camp Lejeune P1246 EOD | New metal roofing system, insulation, hydronic solar thermal system |
| 9. Camp Lejeune P1256 Mess Hall | New metal roofing system, insulation, hydronic solar thermal system |
| 10. Camp Lejeune P1267 Mess Hall | New metal roofing system, insulation, hydronic solar thermal system |
| 11. Camp Lejeune P1317 BEQ | New metal roofing system, insulation, hydronic solar thermal system |
| 12. Camp Lejeune P1319 BEQ | New metal roofing system, insulation, hydronic solar thermal system |

## 2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The high performance retrofit metal roofing system demonstrated in this project should be considered as one of a number of possible retrofit roofing designs that are adaptable to the current DoD building stock, particularly on those buildings that have metal roofs,. The results of this project, which undertook the evaluation of a complex multi-component retrofit roofing system, suggest that not every building is a suitable candidate for a roofing retrofit that includes all of the system components that were included in this project. Care must be taken to thoroughly evaluate each building, and design a roofing retrofit that includes only those components applicable to that building, thereby maximizing the SIR on each project. For example, a building with a large year round domestic hot water or space heating load might benefit from the hydronic solar thermal system that is one of the components of this project, but that same building might not benefit from the additional insulation or the ASV components of this project. Conversely, an administrative building, which is what the GFAFB Security building became after the change in use, will not realize a significant benefit from the hydronic solar thermal system studied during this project.

Historically, the various components of this retrofit roofing system have been installed by multiple trades employed on any given project. On future implementations, the investigators expect that project costs will be reduced by avoiding scope overlap and the incremental costs associated from mobilizing multiple subcontractors, since the paradigm is shifting toward these integrated systems being installed by trained and certified building envelope technicians under a single turnkey supplier that often holds multiple licenses.

Many of the existing DoD buildings have old roofs that need to be inspected to ensure that they will be able to carry the added weight of the metal retrofit roof system. A key assumption and advantage of this retrofit roofing system is that most if not all roofs can support the additional five (5) pounds per square foot of load imposed by the high performance retrofit roofing system. In every case, however, the load carrying capability of a structure must be established by a structural engineering review performed by an engineer.

The various components of the system are "integrated" into the roof assembly. With a properly installed roofing system, the entire assembly can be engineered to withstand 125-140 MPH wind speeds. Conventional modular renewable energy systems with raised box profiles and wind uplift points require considerable reinforcement and roofing penetrations to meet similar wind speed requirements, adding to installation costs.

The hydronic solar thermal system included in the design is by definition an "unglazed collector". As such, they are fully protected from the harmful effects of UV radiation. As an unglazed collector, they will never overheat, even when fully stagnated. By comparison, glazed collectors run the risk of severe overheating in the event of a facility shutdown or a circulating pump failure. Severe overheating can cause costly damage to a systems heat transfer fluids and mechanical components.

Some of the advantages of the various components of the high performance retrofit roofing system are outlined below:

- High performance Galvalume metal roofing systems typically have 25-year substrate warranties 30-35 year paint finish warranties and provide a very low lifecycle cost.
- The existing roof surface and substrate (metal, membrane and /or insulation) remains on the roof and the new retrofit metal roof assembly is constructed directly over the old roof, eliminating a waste stream and avoiding any operational disruptions to the occupants.

- With a service life of 40-60 years, the integrated systems are sustainable insofar as they are extremely durable and continue providing a return on the investment even after the initial cost has been recouped.
- The framing and new metal roofing is manufactured from steel, which is made with a recycled content of 28% to 45%. Once the system is installed, all of the metal materials are 100% recyclable.
- The hydronic solar thermal heating technology can be applied to DHW, space heating, and process heating and cooling loads, lowering energy demand.
- The BIPV laminates are commercialized but generally new to the market, when compared to conventional, modular PV panel technology. Over time, this aspect of the demonstration will provide valuable information to the DoD on the potential for high efficiency BIPV technology. PV laminates are made of an extremely lightweight and highly impact resistant material which becomes part of a hardened building envelope.
- ASV extracts thermal heat from the under-roof cavity, which makes PV laminates 10% more efficient when operating in high ambient temperatures.
- Rainwater harvesting systems help reduce demands on potable water systems and help crowded cities manage stormwater drainage problems. They can be designed to meet the requirements of almost any structure for delivering non-potable water and can have up to a 95% collection efficiency.
- Many existing DoD buildings with existing metal roofs could receive some version of the high performance retrofit roofing systems. Many will be ideal candidates due to their 180° southerly exposure (azimuth), but others may not be as efficient. For buildings with a Southwest or Southeast exposure, system efficiency is reduced by 8%. Due West or East orientations reduce the system efficiency by 28%.
- All DoD buildings will benefit from the state-of-art air barrier and insulation assembly components.

The following outlines the environmental and sustainability benefits available to the DoD:

- Reduced carbon footprint through improved energy efficiency from added insulation, air-barrier and above sheathing ventilation
- Cost savings through a much improved building envelope and the use of renewable solar energy and thermal systems supporting the DoD's EO 13423 Federal Facilities Provisions that: Renovations be 20% better than the 2003 baseline, 50% reduction in outdoor water use from conventional means and 15% of existing inventory incorporate above guidelines by end of FY 2015, Produce or procure 25% renewable energy by 2025.
- Improved water conservation through rainwater harvesting and reduction of potable water demand
- Facility sustainability through the use of new steel materials (roofing and framing) that originate from already recycled content (28% to 45%) steel, which are 100% recyclable once installed.
- Reduced landfill waste of roofing materials due to not having to dispose of existing non-metal/conventional petroleum based roof materials (existing metal roof remains in place)
- Increased opportunity to achieve USGBC LEED certification for existing buildings if so desired. Through evaluation of the LEED program, it is estimated that this type of retrofit system can help a LEED 2009-registered project achieve up to 28 points.

- As an added benefit, the DoD will save because the majority of the work is conducted without the occupants of the building being relocated. This is due to the fact that most of the work is performed atop the existing roof. Thus, very little if any costs are imposed for relocation and temporary facilities.

**Limitations.**

As stated earlier, this project combined hydronics, solar technologies and a retrofit roofing system, all of which were successfully installed by one prime contractor. While the successful installation process reinforced the benefits of employing a trained and certified workforce under one contractor, the results of the project also reinforce a fundamental design perspective that not all projects can benefit from all of the component technologies employed in this retrofit roofing system design.

Designers and engineers of high performance retrofit roofing systems must be sensitive to the building use and loads and employ only those components of the system that provide the greatest return on investment. Additionally, the results of this project suggest that certain system components can interact with others in a non-productive fashion; i.e. employing ASV in conjunction with a building integrated solar thermal system may be counterproductive, unless the design employs active controls over the air flow through the ASV system.

The initial installed costs of metal roofs are known to be higher than membrane and asphalt roof systems. However, first cost should not be the only consideration. As stated earlier, metal roofing has been documented to have about twice the service life of its closest competitors – BUR and Mod Bit roofing. Again, depending on the type of metal substrate, service life can be 60 years or more. The original Galvalume roofs were first installed in 1972 and are still performing well, after 41 years in service. A Ducker Worldwide study showed that other conventional membrane roofs are typically 10-20 years in life. The Ducker study also shows that metal had one of the lowest maintenance costs per square foot per year of roofing materials studied.

This all adds up to a very low life cycle cost for metal roofing, despite the relatively higher installed cost. When integrated renewable energy systems are installed in conjunction with metal roofing the outcome is a system with matching warrantees, closely aligned lifecycles and robust construction

Mainstream solar thermal and PV systems utilize modules that mount on racks on roof systems. Rack mounted solar thermal modules have limited warranties due to their complex construction using copper, aluminum and plastic gasketing that degrades when exposed to UV light.

When this project was conceived, BIPV products were gaining market share and there were several viable US manufacturers of fully commercialized products. The investigators chose to incorporate a BIPV system that utilized Uni-solar PV laminates manufactured by Energy Conversion Devices Inc. through its subsidiary, United Solar Ovonics. Energy Conversion Devices and its subsidiaries ceased operations and the company's assets were liquidated during the course of this project. During this same period, the BIPV market has stagnated as a result tremendous pricing pressure from manufacturers of crystalline PV panels who have dropped their prices dramatically over this period.

As this report is written, BIPV products are 50% to 200% more expensive than conventional modular PV panels that employ crystalline PV cells. Project economics and industry trends suggest that building owners and PV system designers favor the use of modular PV panels, particularly on buildings with flat roofs and on ground mounted PV systems where aesthetics don't matter. When aesthetics factor into a building design and PV technology is desired, BIPV products become the preferred solution. It is generally accepted in the renewable energy industry, that, as the inventory of flat roofs and suitable locations for ground mounted array sites become absorbed, growth of the BIPV market will resume and accelerate, since new and retrofit buildings are ultimately the perfect platform for renewable energy systems.

# 3.0 PERFORMANCE OBJECTIVES

## 3.1 SUMMARY OF PERFORMANCE OBJECTIVE RESULTS

**Table 3 SUMMARY OF PERFORMANCE OBJECTIVES**

(Note that superscript items 1, 2, 3, 4 indicate comments from GFAFB Staff)

| Performance Objective | Metric | Data Requirements | Success Criteria | Results |
|---|---|---|---|---|
| **Quantitative Performance Objectives** | | | | |
| Facility Energy Usage | Reduction in Energy Intensity (Btu/ft$^2$) | Meter readings of energy used by installation; square footage of buildings using energy | Overall targeted threshold value reduction in Energy Intensity of 768,130 KBTU/yr. or 76.8 KBTU /SF | Fail, the Energy Intensity of the building increased by 21.47 KBTU/SF/Year |
| Renewable Energy Usage (A) | Solar Electricity Used on Installation (kWh) | Meter readings of renewable energy used by installation | Targeted threshold value of 64884 kWh/YR | Pass; PV production is within 10% of projected values |
| Renewable Energy Usage (B) | Solar Thermal Energy used for DHW (offsetting KCFNG) | Meter readings of renewable energy used by installation | Targeted threshold value of 17.4KCFNG or kWh equivalent | Pass; 27KCFNG of natural gas were offset. |
| Renewable Energy Usage (C) | Solar Thermal Energy used for space heating (offsetting KCFNG) | Meter readings of renewable energy used by installation | targeted threshold value of 338 KCFNG or kWh equivalent | Fail; Heating loads were not reduced to the level projected[6]**.** |
| Energy efficiency improvement (A) | Insulation reducing cooling loads (kWh) | Meter readings of electrical energy used by installation's cooling equipment | targeted threshold value of 14683 kWh/YR | Inconclusive; the Electricity consumption increased during the test cycle, due to increases in internal building loads |

[6] Note that the natural gas savings in the table above are summarized in Renewable Energy Usage A, since the data collection system could not distinguish between offsets to the DHW or space heating systems.

| | | | | |
|---|---|---|---|---|
| Energy efficiency improvement (B) | Insulation reducing heating loads (KCFNG) | Meter readings of electrical energy used by installation's heating equipment | targeted threshold value of 127 KCFNG | Fail; meter readings indicate 32.2 KCFNG less Natural Gas consumed less than the prior year vs the 127 KCFNG projected |
| Water Usage for irrigation | Water (Gallons) | Calculate amount of rain water used by installation for irrigation | targeted threshold value of 131 KGALS/YR | [1] Inconclusive; since the system was not operated as intended during the project. |
| Direct Greenhouse Gas Emissions | Direct fossil fuel GHG emissions (pounds) | estimated release of GHG based on source of energy | Pounds of CO2 offset: 53242 lbs from KCFNG, 109,800 lbs from kWh electricity | Fail: 3201.12 lbs of CO2 from natural gas and 86196.9 lb. of CO2 from electricity were offset |
| System Maintenance | Number of hours or $ | Scheduled and unscheduled maintenance events; | 10% increase compared to historical data on building | 2"Pass; Maintenance effort increased by less than 10%" |
| System Economics* | $, Years | Dollar construction and operating costs, values of energy saved or generated | Favorable NIST BLCC analysis outcome | Fail: as a result of low SIR's See discussions within report. |

| **Qualitative Performance Objectives** | | | | |
|---|---|---|---|---|
| **Performance Objective** | **Metric** | **Data Requirements** | **Success Criteria** | **Results** |
| | | | | |
| Ease of operation and maintenance | Survey | Survey results | Maintenance mechanic assimilates system into standard maintenance cycle-Testimonial | [3] Pass; assuming system maintenance is funded and performed per maintenance schedules |
| Validate Energy Plus modeling application/Template | Predicted % accuracy when template is employed of over multiple climate zones | Statistical Analysis of multiple simulations | Performance projections will be within 10% of roof energy performance | Pass; Energy Plus model results are accurate given the assumptions defined later in this report. |

| | | | | |
|---|---|---|---|---|
| Establish the ease of retrofit implementations | Survey | Survey results | Secure testimonials from Goodfellow AFB Facility Management and the building occupants | [4] Pass; based on Goodfellow AFB Staff comments |
| Educate and develop DoD Champions | Survey | Survey results | Secure testimonials from NAVFAC personnel | This was not achieved due to limitations to DoD staff travel budgets during the Demonstration period |

## 3.2 PERFORMANCE OBJECTIVES DISCUSSION

**Facility Energy Usage;** baseline data was collected on the subject building at GAFB.

- *Purpose:* Baseline data and post construction data was compared to accurately assess the impact of the project on the buildings' overall energy intensity. As stated earlier, the demonstration site underwent a major change in use during the monitoring phase, rendering this metric of limited use in gauging project success or failure.
- *Metric: Energy Intensity (Btu/ft$^2$)*: Electricity (kWh) and natural gas (KCFNG) consumption, post construction, was collected and converted to Btu/square foot of occupied building area.
- *Data:* Electric, gas, water and BTU meter readings were used in the analysis
- *Analytical Methodology*: Simple spreadsheet analysis of the data was used.
- *Results:*
  - *The project failed to significantly reduce the Energy Intensity of the building due to the issues discussed in the sections below. The Energy Intensity of the building increased by 22%, from 95.7 kBtu/SF/Year to 117.19 kBtu/SF/Year.*

**Renewable Energy Usage (Labeled A, B and C in Table 3 above)**; the project employed solar energy collected as thermal and electric energy to reduce the overall energy intensity of the building. This objective sought to measure renewable energy savings in three areas, offsets to electricity from the PV system(A), offsets to DHW costs from the hydronic solar thermal system (B) and offsets to space heating costs from the hydronic solar thermal system (C)

- *Purpose:* Post construction data was collected to accurately determine the systems overall efficiency which was then extrapolated to estimate its impact on DoD goals of incorporating renewable energy systems in new and retrofit construction projects
- *Metric:* kWh production data was collected with the use of revenue grade electric meters. BTUs generated were collected from water and air BTU metering systems
- *Data:* Electric, gas, water and BTU meter reading were used in the analysis
- *Analytical Methodology:* Simple spreadsheet analysis of the data was used.
- *Results:*
  - *Renewable Energy Usage "A" passed.*

- *Renewable Energy Usage "B" was graded "passing", but only as a result of the inability of the data collection system to distinguish between DHW and space heating savings*
- *Renewable Energy Usage "C" failed the success criteria with the total production of the Solar Thermal System being less than 10% of the amount projected in the Demonstration Plan.*

**Energy Efficiency Improvement A-B;** the project incorporated insulation and air barrier enhancements that contributed to the overall reduction of the energy intensity of the building.

- *Purpose:* Post construction data was collected to accurately describe the systems overall increase in efficiency in terms of reductions in heat flux through the roof system resulting from the installation of the ASV system and the additional insulation.
- *Metric:* kWh production data was collected with the use of revenue grade electric meters. BTUs generated were collected from a water and air BTU metering systems
- *Data:* Electric, gas, water and BTU meter reading were used in the analysis
- *Analytical Methodology*: Simple spreadsheet analysis of the data was used.
- *Results:*
  - Energy Efficiency Improvement "A" (increase in insulation reducing cooling loads /electricity) failed the success criteria based exclusively on electric meter data which indicated a considerable increase in electricity consumption occurred during the months with cooling loads. To further validate this result, the investigators calculated the additional electrical load imposed on the building by the additional equipment installed during the project. The additional electrical load proved to be minimal as seen in the table below:

**Table 4 Additional Electrical Loads Imposed by the Project**

| | Wattage | New Equipment description |
|---|---|---|
| DHW | 60 | pump |
| Rm 153 | 60 | pump |
| Rm 131 | 60 | pump |
| | 250 | blower |
| Rm 116 | 60 | pump |
| | 375 | blower |
| East array | 125 | pump |
| West array | 125 | pump |
| | 1115 | total wattage for all equipment |
| | 3255.8 | annual kWh from new equipment** |
| ** assuming 365 days at 8 hours per day run time | | |

  - Energy Efficiency Improvement "B" (increase in insulation reducing heating loads) failed the success criteria with the total reduction in natural gas consumption of 32.2 KCFNG realized vs the 127 KCFNG projected in the Demonstration Plan.

**Water Usage for Irrigation;** the project incorporated a rainwater collection and distribution system to reduce the total water consumption of the building.

- *Purpose*: Post construction data was collected to accurately describe the amount of rainwater collected which could then be used to estimate the impact that rainwater harvesting system might have DoD water conservation goals.
- *Metric:* Gallons of water collected and used for irrigation
- *Data:* water meter readings were used in the analysis
- *Analytical Methodology*: Simple spreadsheet analysis of the data was used.
- *Results:*
    - This system is rated as "Inconclusive" since the system was not used by Goodfellow AFB during the project.

**Direct Green House Gas (GHG) Emissions;** all project data was used to determine the reduction in the carbon footprint of the facility by converting renewable energy and energy efficiency improvements to GHG equivalents.

- *Purpose*: To provide data which can then be extrapolated to estimate the systems' impact on DoD GHG goals.
- *Metric:* Pounds of CO2 offset
- *Data:* Electric, gas, water and BTU meter reading were used in the analysis
- *Analytical Methodology: Simple spreadsheet analysis of the data was used.*
- *Results:*
- *The metric is rated as a "fail"*
    - *CO2 offsets for the test period at Goodfellow AFB for:*
    - *Natural gas* *27360 kBtu* *3201.1 lb CO2*
    - *Electricity* *59039 kWh* *86196.9 lb CO2*
    - *For a total of* *89398.1 lb CO2*

**System Maintenance;** project surveys were used to determine the amount of increase in building maintenance costs resulting from the installation of the demonstration system.

- *Purpose:* To provide data which can then be used in operating cost budgeting and LCCA exercises.
- *Metric*: maintenance hours and dollars
- *Data:* maintenance time and material information was reported from comments collected from GFAFB staff.
- *Analytical Methodology*: simple survey of the feedback from maintenance staff was used.
- *Results:*
    - *Pass; GFAFB staff report that building maintenance will increase less than 10%*

**System Economics;** the project cost and performance data were utilized in a NIST BLCC Analysis based on the actual results produced by the demonstration system.

- *Purpose*: To provide data which can then be used in building system design process within the DoD.
- *Metric:* simple payback in years, lifecycle energy cost in dollars
- *Data:* system construction and operating costs along with energy generated or saved

- *Analytical Methodology*: simple spreadsheet analysis and NIST BLCC analysis of the data were used.
- *Results:*
  - *Fail: as a result of low SIR's. See detailed discussion in Section 7*

**Ease of Operation and Maintenance**; the project included training operational staff in the use and ongoing maintenance of the systems.

- *Purpose:* To assess, from the users perspective, the degree of difficulty with the integration of these types of systems into mainstream building maintenance systems/practices.
- *Metric:* a survey of the maintenance staff
- *Data*: survey analysis
- *Analytical Methodology*: subjective assessment of survey results and stakeholder input.
- *Results*:
  - GFAFB staff has provided positive feedback regarding training and operation of the system.

**Validate Energy Plus Modeling Application;** the project included ORNL developing an Energy Plus "template" for use by DoD and other interested parties when modeling similar projects in other climate zones.

- *Purpose:* To facilitate the deployment and support the technology transfer of this building system across the DoD and the commercial sector.
- *Metric*: % accuracy when template is employed over multiple climate zones
- *Data:* Statistical Analysis of multiple simulations
- *Analytical Methodology*: Statistical analysis of probability of accurate performance projections.
- *Results:*
  - The EnergyPlus models were validated using pre- and post-retrofit temperature data from the roof of the test building and used to evaluate the reduction in roof-generated heating and cooling loads due to the added insulation and ASV for different climate zones.

**Ease of Retrofit Implementations;** the project was intended to demonstrate the degree of difficulty or simplicity of implementing this type of project on retrofit projects.

- *Purpose:* To document the ease and pace at which this type of project could be deployed across the DoD and the commercial sector.
- *Metric:* a survey of the Goodfellow AFB stakeholders
- *Data:* survey analysis
- *Analytical Methodology*: subjective assessment of survey results and stakeholder input.
- *Results:*
  - GFAFB staff has provided positive feedback about the ease with which the retrofit was completed.

**Educate DoD Champions;** the project intended to engage two DoD building design or energy management professionals to observe the overall effectiveness of the design, and implementation and the operational efficiency of the this type of project executed on a retrofit basis, however this was not done as a result of government employee travel being curtailed during the 2012-2013 budget period.

## 4.0 FACILITY/SITE DESCRIPTION

### 4.1 FACILITY/SITE LOCATION AND OPERATIONS

The demonstration site was the Security Forces Building No. 3323 located at Goodfellow Air Force Base in San Angelo, Texas. The building's floor area is 9,950 square feet. The building's roof geometry is a simple gable measuring 66'-4" by 150'-0" with a 4:12 roof slope, which represents a total of 11,050 square feet of roof surface area.

A pre-construction, aerial view of demonstration building with renewable energy systems delineated is shown below in Figure 4

1. Building Integrated Solar Thermal Roof Array was installed inside of the red lined rectangles.
2. Building Integrated Solar Electric (PV) Array was to be installed on blue colored area.

**Figure 4 Pre-Construction Aerial View of the project site**

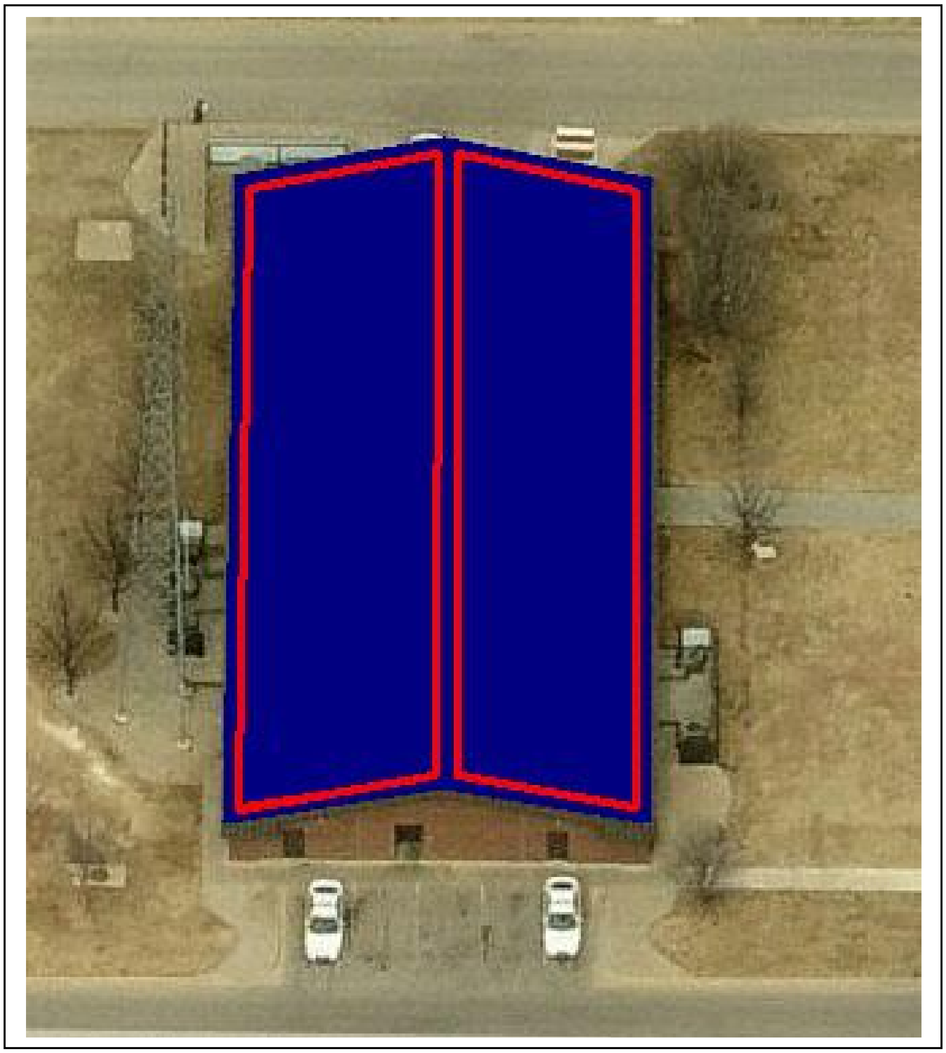


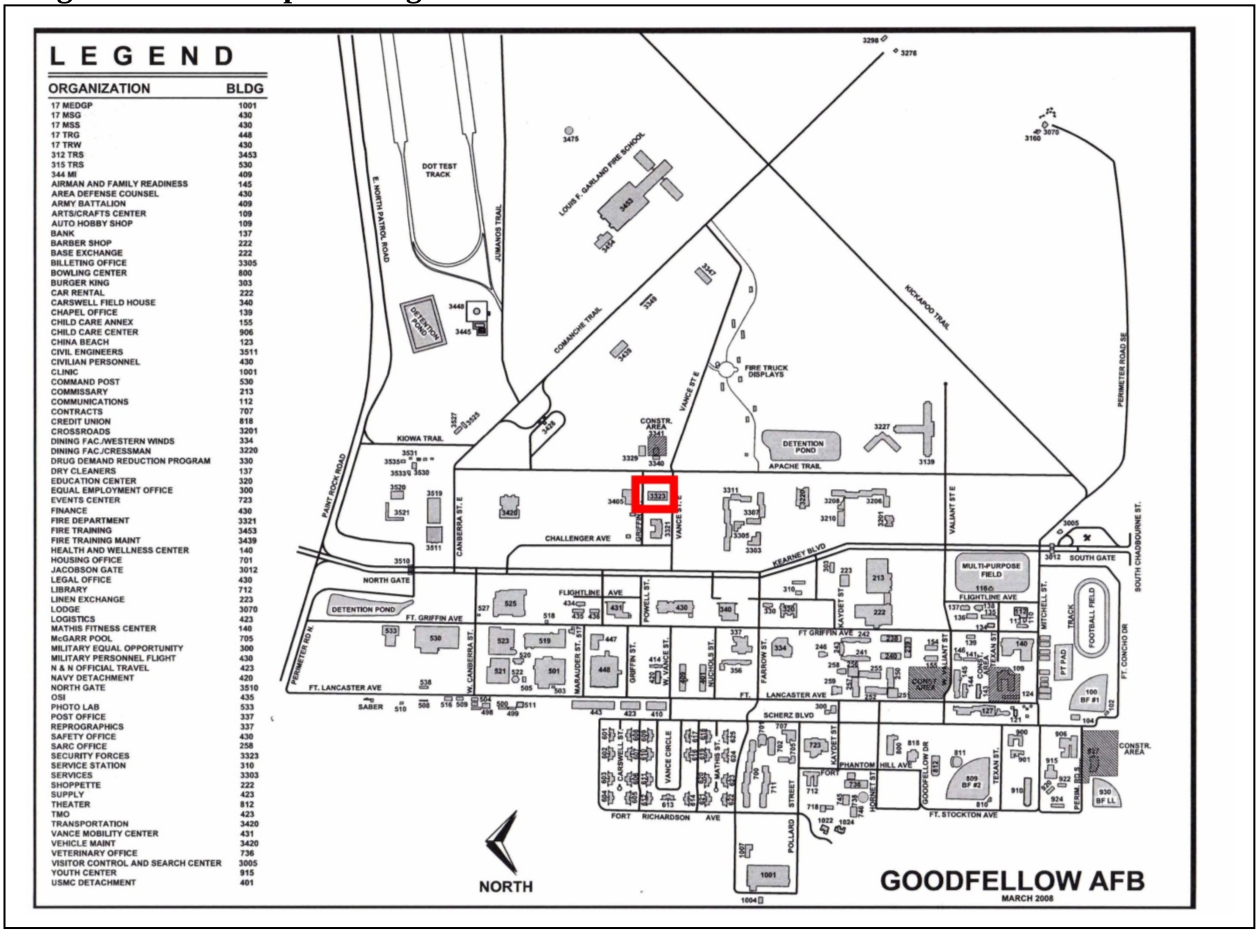
**Figure 5 Goodfellow Air Force Base Building 3323 before (left) and after (right)**

Photos Courtesy of Paramount Metal Systems LLC

**Figure 6 Google Earth Post Construction aerial view of the building.**

Photo Courtesy Google Earth

**Figure 7 Locus map showing the location of the site on Goodfellow Air Force Base.**




The building was a thermally controlled administrative operation with a 24/7 multi-personnel occupancy. There is approximately 3/4$^{th}$ of an acre landscape area to be serviced by rainwater harvesting. Due to extreme drought conditions during the demonstration period and problems with the irrigation system, the rainwater harvesting portion of the project was not used and the investigators cannot offer any results other than the comments received from GFAFB personnel that are noted in Table 1, Summary of Performance Objectives.

The electrical and natural gas energy supply systems for the building are separately metered and served the project's needs for pre- and post-construction data collection of electricity and natural gas consumption. The building's utility demands are serviced by the following:

- HVAC
  - Heating – Boiler Remote Coil System
  - Cooling – Electric Split System
- Domestic Hot water – 50 GAL natural gas
  - The facility does not have a domestic hot water sub meter
- Potable Water System
  - 7 Commodes

        - 8 Lavatories
        - 2 Urinals
    - Landscape Irrigation (separate meter)
    - Electrical Service – 800A 208/230/460 3-Phase

## 4.2 FACILITY/SITE CONDITIONS

From a solar orientation standpoint, the building's roof surfaces face East and West, which is not the ideal scenario for solar renewable energy systems. However, the project's solar energy projections initially took this into account from an efficiency and performance standpoint. Because of this, it is important to note that other DoD buildings equipped with this same technology could realize much better performance and savings if the renewable energy systems are installed on the south facing roof planes. The building was not shaded by foliage or adjacent facilities.

As discussed previously, building loads are a function of the design, location and use of a building. The GFAFB Security Building which was the subject of this demonstration project underwent a major change in use resulting from the elimination of detention facilities and related loads and the addition of a data center. This change significantly impacted project results in terms of the usefulness of the hard data collected. This will be discussed in more detail in Sections 6 and 7 of this report.

## 5.0 TEST DESIGN

The following schematic describes the component system incorporated in the demonstration project discussed in more detail later in this section.

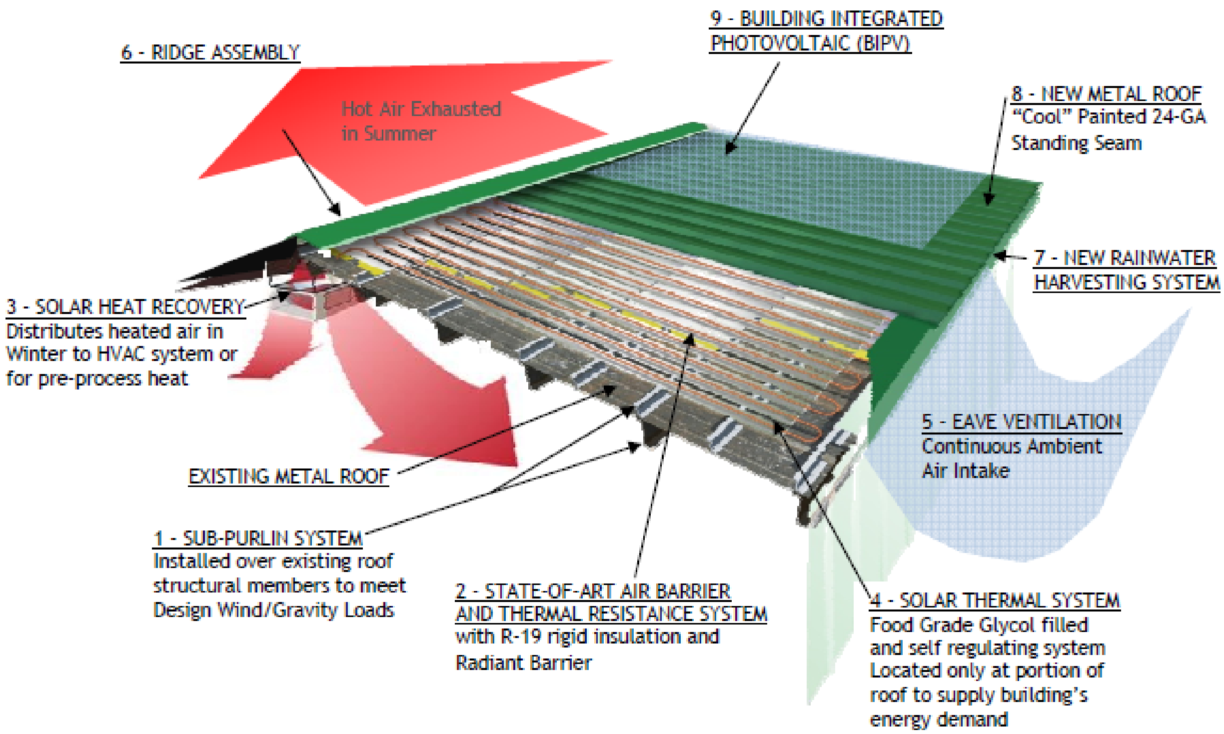



**Figure 8: Schematic showing the retrofit roofing component technologies**

## 5.1 CONCEPTUAL TEST DESIGN

This project undertook the evaluation of a complex, multi-faceted, high performance retrofit roofing system that had never been constructed before. The approach taken was a straight forward "before and after" type of study, comparing baseline data collected pre construction, to post construction data collected over the following year.

A facility was secured at GFAFB upon which a full scale, 10,000 square foot demonstration was built by a design-build contractor who was expert in the field of retrofit roofing systems. The performance objectives defined were evaluated using pre- and post-construction data collected from temperature and heat flux sensors, energy flow meters, utility meters and surveys of onsite staff.

ORNL was the project partner charged with collecting all of the pre- and post-construction data and to provide an analysis of the temperature and heat flux data collected from the system. An additional goal of the project was the production of a performance projection model that could be utilized by Energy Plus practitioners to accurately analyze and predict the performance of this retrofit roofing system on other projects in the future.

Other members of the project team were tasked with analyzing the data collected from the onsite utility meters and the PV and Solar Thermal systems installed on this project.

The project team defined the list of performance objectives that were discussed earlier in this report. Pass or fail grades were to be given based on whether or not the post construction metric related to a particular performance objective met or exceeded the metric that was projected by the investigators during the pre-construction test design phase of the project.

Retrospectively, the test design that was implemented did not contain sufficient controls or data collection points to allow the investigators to adapt to the major change in use that the facility underwent during the post construction monitoring period, Section 7 and 8 of this report contain extrapolations of the actual data in an attempt to more clearly depict the impact of this system on future projects.

## 5.2 BASELINE CHARACTERIZATION

A data acquisition system (DAS) was installed in the test building to measure the temperatures across the roof configuration (old and new) and heat flows through the roof, and parameters related to the solar thermal and photovoltaic systems.

Before retrofitting the roof, the original building/roof was monitored for a period of about three (3) months and post-retrofit, the building was monitored for a period of twelve (12) months. The following equipment and sensors were used for monitoring.

- CR1000 datalogger[7]
- Precision thermistors
- Heat flux transducers
- BTU and kWh monitoring systems
  - WattNode for the output of the invertor (in kWh)
  - Water flow meter and water temperature measurements to estimate the output of the solar thermal system (in BTU)
- Weather sensors
  - Pyranometer to measure solar irradiance on a horizontal surface
  - Thermistor to measure outdoor temperature

All sensors were monitored at 60 second intervals and data were averaged into hourly or 1-minute blocks for recording, as appropriate.

[7] http://www.campbellsci.com/cr1000

**Equipment Calibration Process**

The CR1000 datalogger comes from the factory newly calibrated and subsequent calibrations are recommended every two years, which was beyond the duration of the experiment. The operation of the datalogger was verified before installation in the test building. The temperature sensors were precision thermistors with an accuracy of better than ±0.2°C. The heat flux transducers were calibrated using a heat flow meter apparatus (HFMA) while sandwiched by a metal sheet and fiberglass insulation, similar to the actual installation in the test building. The HFMA is used for thermal transmission property measurements following ASTM Test Method C518[8]. The HFMA consists of two independently temperature-controlled plates, both of which are equipped with heat flow sensors. The calibration constants of the HFTs were obtained by correlating the measured heat flows of the HFMA to the HFT voltage outputs.

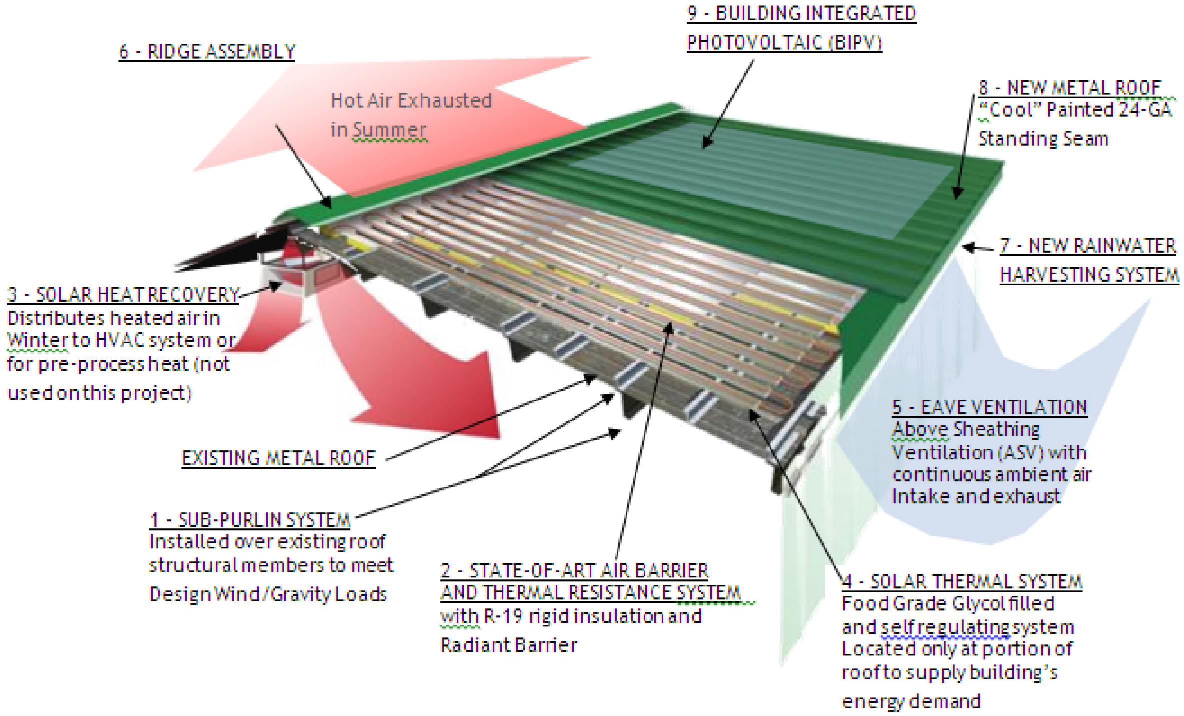
For all other sensors, the factory calibrations were used as no suitable means of alternate calibration exists in the field.

In addition, models of the test building, with the old and new roof assemblies, were created using EnergyPlus. The models were validated using the measured temperature and heat flow data from the old and new roof configurations. The models can be used to estimate the benefits of the retrofit options in all eight ASHRAE/DOE climate zones.

## 5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The illustration below is provided again for ease of reference.

**Figure 9 Graphic of Technology Components**




[8] ASTM C518-10. 2010. Standard Test Method for Steady-State Thermal Properties by Means of the Heat Flow Meter Apparatus. ASTM International, West Conshohocken, PA, USA.

The high performance retrofit roofing system employed in this demonstration project consists of the following components, numbered as they are shown in the schematic.

1. STRUCTURAL STEEL SUB- FRAMING SYSTEM: A light-gage "zee"-shaped member is installed over the existing roofing directly over the building roof purlins. The members are pre-notched to nest over the existing roof's standing seams or ribs and result in a low-profile system, the thickness of which is dictated by the total thickness of new insulation and solar thermal systems being installed. This sub-framing system is manufactured from 16-gauge G-90 galvanized coated steel having a minimum yield strength of 50,000 PSI and it is fully-engineered to meet specified design loads and building code requirements.

   The sub-framing systems have been laboratory tested in accordance with The American Iron and Steel Institute's (AISI) 1996 Cold-formed Steel Specification Supplement No. Appendix A – July 1999 Base Load Test Method. This series of tests indicate that the sub-framing system increases the downward acting load carrying capacity (gravity load, dead weight, etc.) of the existing building roof purlins, significantly offsetting, and more than compensating for the added weight of the entire integrated roof assembly being installed atop the existing roof, including the renewable energy systems.

**Figure 10 Structural Steel Subframing System**

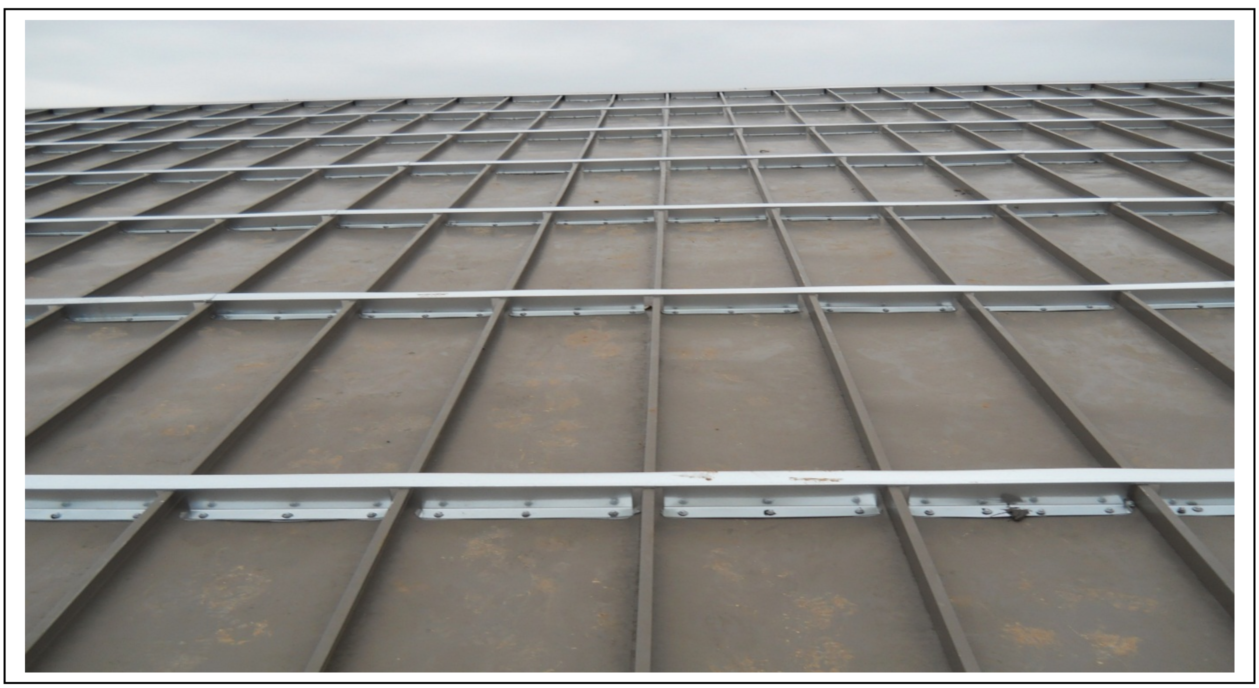


Photo Courtesy of Roof Hugger Inc.

2. AIR BARRIER AND THERMAL RESISTANCE SYSTEM installed between and on top of the Sub-Purlin System. The air-space that is created by the addition of the structural sub

purlin between the old and new roofs provides a natural opportunity to install additional insulation. This improves the building's energy efficiency by allowing the designer to meet or exceed current code requirements. The placement of the additional insulation is non-destructive and does not disturb the activities of the building occupants. The construction consists of a continuous rigid board insulation layer installed over the existing roof to comply with applicable design standards.

This component of the system typically includes two-layers of high density polyisocyanurate rigid insulation board installed over the existing roof and between the sub-purlins with the top layer taped to prevent air-infiltration and a reflective radiant barrier then installed. Any voids at roof-wall junctures and similar locations are filled with spray foam and sealed.

For this project, a layer of 2.5 inches (63.5mm) of high density rigid insulation board was installed onto the existing metal roof to the top of the new sub-framing. Then a 1.0 inch (25.4mm) layer of high density rigid insulation board was installed above, with aluminum foil taped board joints, along with a reflective radiant barrier providing a continuous insulating thermal break. Considering the demonstration site's existing R-19 rated insulation below the existing roof and the new insulation installed with a radiant barrier, the retrofit increased the thermal resistance of the roof assembly to a total of R-51.9.

**Figure 11 Rigid Board Insulation System**

Photo Courtesy of Dow Corporation

3. SOLAR HEAT RECOVERY: (not used on this project) can be designed to seasonally move heated air either into the building or out of the roof assembly cavity. The solar heat recovery system also includes the eave ventilation and ridge assembly described below.

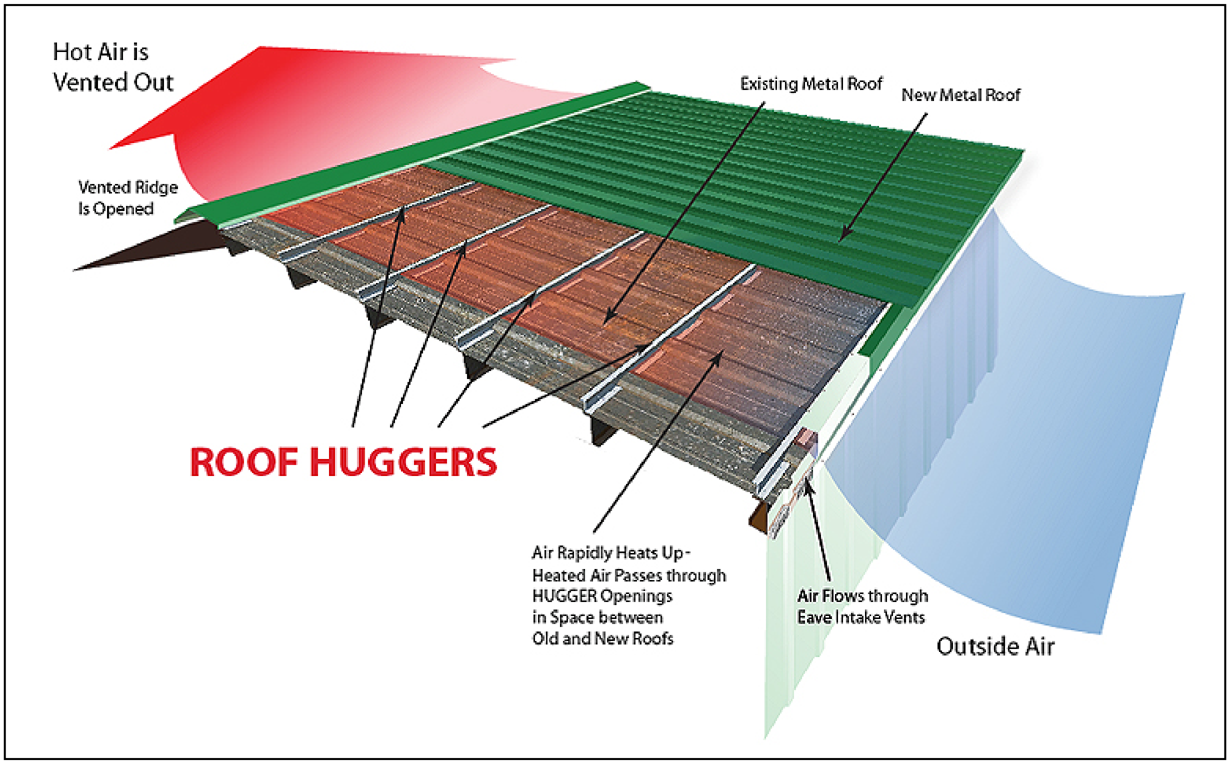
4. SOLAR THERMAL SYSTEM**:** The hydronic solar thermal collector or array was installed above the insulating layer and radiant barrier and below the new metal roof. See Appendix F for a detailed array layout and Appendix D for a detailed Mechanical Plan of the installation. The system was a closed loop, glycol protected system comprised of flexible cross-linked polyethylene tubing (Pex Al Pex) installed into 24-gauge Galvalume® coated steel purlins. The steel purlins are positioned to permit a continuous air-flow between each other. The entire system has an overall depth of one-inch.
    a. The Solar Thermal System can distribute energy in three ways as explained below:
        a. In space heating applications using hot water or hot air; when the thermostat calls for heat and sufficient energy is available, solar energy will be transferred through a dedicated, wall, floor or duct mounted water to air heat exchanger or solar space heating unit and distributed to the building until the thermostat is satisfied or the solar energy supply is exhausted.
        b. In process heating applications; (not used on this project) when the thermostat calls for heat and sufficient energy is available in the solar storage tank or the solar array, solar energy will be transferred to the process application until the thermostat is satisfied or the solar energy supply is exhausted.
        c. As a closed loop, indirect domestic hot water heating system that uses a food-grade glycol protected system; as domestic hot water (DHW) is drawn from the primary water heater, water replacing it will be drawn from the dedicated solar storage (preheat) tank, thereby reducing the use of fossil fuels, bio-fuels or electricity for DHW heating.

**Figure 12 Building Integrated Solar Thermal Collector and Fan Coil heating unit**

Photo Courtesy of Pfister Energy Inc.

5. EAVE VENTILATION: The roof system can optionally be used to provide heat to the building (not done in this project) or to cool the building via a technique known as Above Sheathing Ventilation (ASV), which was included in the scope of the demonstration project. Both modes of operation use the one-inch deep air-space in the roof assembly located between the radiant barrier and the metal roof. In ASV mode, the system is constructed with continuous low-eave and ridge ventilation. This allows the air introduced through the low-eave/soffit vent to be heated by the sun's radiance onto the new metal roof surface and by natural convection, the heated air flows through the roof assembly and is exhausted through the ridge vent. This technology is utilized in summer months to cool the roof assembly and further reduce heat gain/flux. ASV has proven to reduce the heat transmission through a roof assembly by as much as 45% according to research conducted at the DOE's Oak Ridge National Laboratory (see Appendix U for a white paper on this topic). In space/process heating mode, the roof assembly can be equipped with ducting or eave venting that will allow either internal air or external air to be heated by the sun's energy striking the surface of the roof system. This heated air can be directly or indirectly ducted into the building and be used to supplement space or process heating, improve the performance of energy recovery ventilating systems or used to heat fluids with air to water heat exchangers.

**Figure 13 Graphic Illustrating Above Sheathing Ventilation**




Courtesy of Roof Hugger Inc.

6. RIDGE ASSEMBLY:  This is part of the standing seam metal roofing system and works in conjunction with the eave ventilation.
7. RAINWATER HARVESTING SYSTEM:  Rainwater harvesting systems are comprised of standard components that are uniquely configured for each building type and use (see Appendix V for the GFAFB rainwater harvesting system details).  They include gutters, downspouts, first flush diverters, pumps, tanks, controls and potentially a wide variety of filtering and distribution systems. They are designed specifically to meet the requirements of each individual project with the goal of effectively capturing, managing and reusing rain water for non-potable applications, such as landscape irrigation in this case.  Rainwater harvesting can be accomplished on virtually all roofing materials, with the harvested water quality varying widely from one type of roofing material to another.  Steep or low slope metal roofing is considered an ideal roofing material for rainwater harvesting, eliminating design issues around ponding or the granule loss associated with some roofing materials. If the system at GFAFB is operated as intended, the following “what if scenario”, based on the assumption of 6.7 rain events9 per season that will fill the 10,000 gallon storage tank, depicts the anticipated outcome.

    a. There are 6 irrigation zones on the GFAFB building with an average estimated volume of 16 gal/min.
    b. Based on a 20 min watering cycle, that amounts to 1920 gallons of water for each 20 minute irrigation cycle for the complete system.
    c. The tank capacity @ 10,000 gal will supply = 5.2 watering cycles per tank full of rain water.
    d. If the irrigation frequency is twice a week, the system supply 2.6 weeks of irrigation capacity per tank full.
    e. The 6.7 rain events that are projected to fill the tank would provide 17.5 weeks of irrigation annually based on a twice per week irrigation.

**Figure 14 Rainwater Harvesting Tank and Equipment Package**


[9] See Appendix V for details on the Rainwater Harvesting System Design.

Photo Courtesy of Paramount Metal Systems LLC

8. NEW STANDING SEAM METAL ROOF: A new 24-gauge standing seam metal roof system (SSMR) was installed with concealed clips. The finish was furnished in a medium bronze color to match the aesthetics of all other metal roofs at the base and conform with the design standard. The metal roof was engineered to meet specified design loads and building code requirements. Its exposed finish is a durable “cool” rated solar reflective and emissive polyvinyldene fluoride (PVDF) paint system. This paint finish utilizes Kynar® 500 or Hylar® 5000 or Sinox® 2000 based resin systems.

**Figure 15 Standing Seam Metal Roof and Rainwater Collection Downspout Detail**


Photos Courtesy of MBCI

9. BUILDING INTEGRATED PHOTOVOLTAICS (BIPV): The photovoltaic (PV) system employed was “peel and stick” thin film amorphous silicon BIPV laminate that was applied directly to the flat pan portion of the new standing seam metal roof. This product is one of several that are currently available on the market that are suitable for this type of application. See Appendix G for detailed PV array layout and Appendix H for detailed Electrical Plan of the PV System. BIPV systems do not penetrate the metal roof, eliminating potential sources of leaks. The BIPV laminates were connected to an inverter that converts the DC power produced by the PV system to AC power that is used onsite as needed, with any surplus energy feeding back into the electrical grid. Replacement of BIPV laminates at the end of their useful life is non-destructive to the standing seam metal roof system.

**Figure 16 Building Integrated PV Laminates and Inverters**


Photos Courtesy of Pfister Energy Inc.

The following schematics represent the old and new roof configurations and where data sensors were placed by ORNL. The old roof consisted of standing-seam metal panels supported by 8 inch purlins, with R-19 (hr-ft$^2$-°F/Btu) fiberglass insulation installed under the roof.

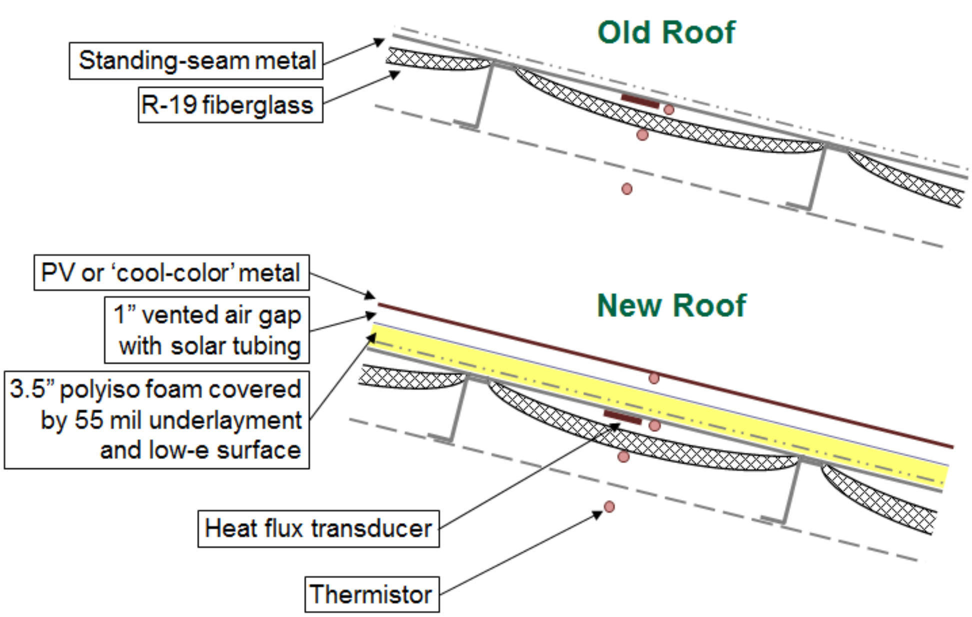


**Figure 17 Schematic showing the old and new roof configurations.**

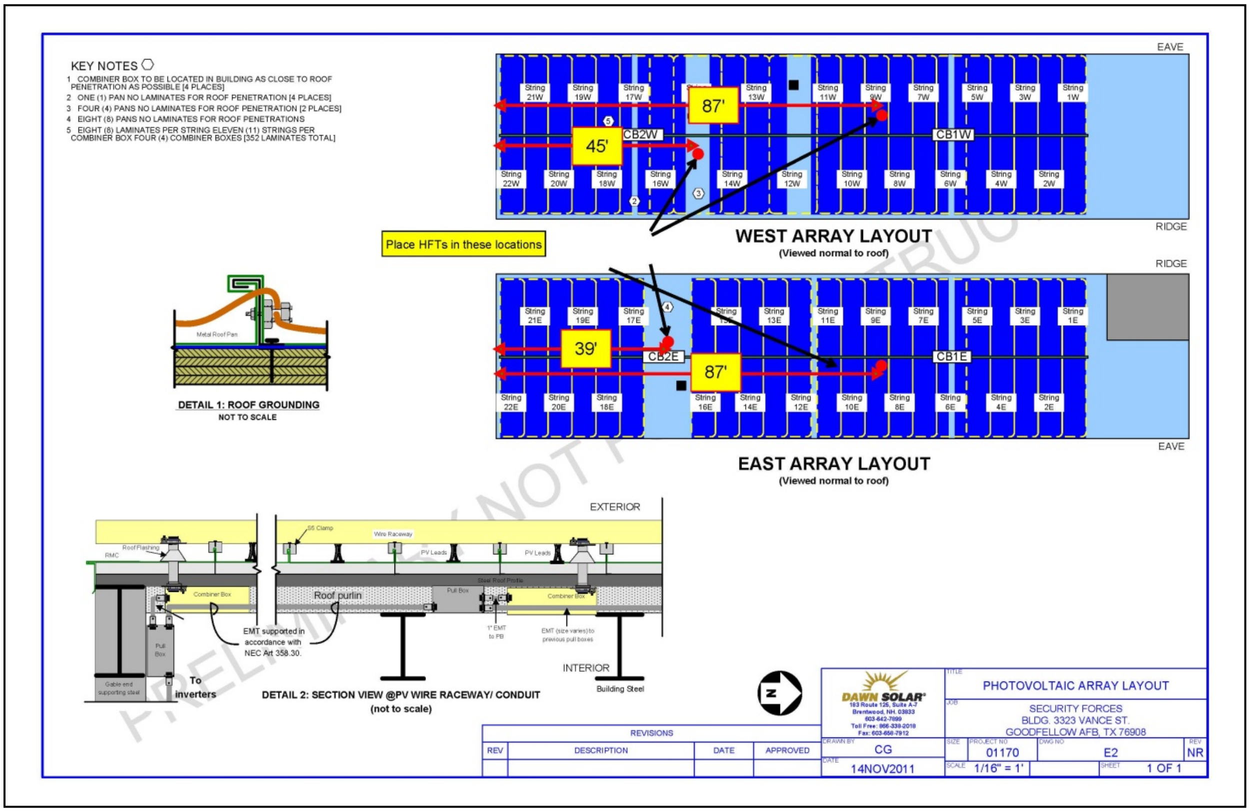



**Figure 18 Schematic showing the location of the heat flux transducer in plan view**

The combination of added foam insulation, a low-e surface, ASV and cool-color metal roof was expected to greatly enhance the overall building thermal performance. Figures 17 and 18 also show the instrumentation of the new and old roofs. Four sets of thermistors and a heat flux transducer, as shown in Figures 17 and 18, were installed on four sloped roof sections (one set each on each roof quadrant). Data from these sensors were also useful in validating EnergyPlus models of the old and new roofs.

## 5.4 OPERATIONAL TESTING

The significant operational phases of the project are outlined below. (See Appendix Q for a complete table of Project Milestones):

1. Pre-construction Data Collection Phase;
    a. The pre-retrofit monitoring period extended from December, 2011 through February, 2012.
    b. As described earlier in Section 5.2, a data acquisition system (DAS) was installed in the test building to measure the temperatures across the roof configuration (old and new) and heat flows through the roof, and parameters related to the solar thermal and photovoltaic systems.
2. Construction Phase;

    a. The construction of the project began in March of 2012 and was completed in May of 2012.
3. Post Construction Data Collection;
    a. The post-retrofit monitoring period start was delayed due to internet communications challenges between ORNL and GFAFB and began in November, 2012 and continued through October, 2013.
    b. It utilized the same DAS described above in 5.4.1.b.
4. System Operation Phase;
    a. The system was commissioned in May of 2012 and continues in operation to this day.
    b. The operating parameters of the components of the system are described below:
        i. The PV component of the system (see Appendix H for a schematic) collects the sun's energy and converts it to electricity in the form of DC current. Low voltage wiring carries the DC current to combiner boxes within the attic space of the building where many low voltage circuits merge into a large DC circuit that runs to the inverter. The inverter converts the DC power to AC power and feeds the AC power into the building's main power distribution panel. The power produced by the PV system is either consumed by the buildings electrical load or diverted back to the electrical grid for use by others in conjunction with a net metering system. The output of the PV system varies minute by minute as a function of the level of solar insolation that the system is exposed to at any given time. Operation of this component of the system is under the control of the inverter, which is activated when the PV array output passes a minimum volt threshold that is designed into the inverter.
        ii. The hydronic solar thermal component of the system (see Appendix F for a schematic) collects the suns energy as heat, which is absorbed by a heat transfer fluid, in this case non-toxic propylene glycol, and transferred to heat exchangers within the building as the glycol is circulated through the roof integrated collector. The heat exchangers in this system transfer the solar energy to domestic hot water using a water to water heat exchanger, and to the forced hot air heating using a water to air heat exchanger. Each of the solar thermal distribution systems are controlled using standard of solar differential controls that receive temperature data from temperature thermistors in the solar collector and within the distribution system. The solar differential control will activate the solar thermal system provided that the building is calling for heat and that the solar thermal array has thermal energy (heat) that is available to be delivered. As stated earlier, the heat is delivered by circulating solar heated glycol through the distribution systems at the direction of the solar differential control.
        iii. The ASV component of the system is an entirely a passive component of the retrofit roofing system, meaning that as the roof and air temperatures climb outside the building, a convective loop develops in the interstitial space within the roof assembly. Cool air enters the eave vents and exits as warm air from the ridge vent. See Figure 8 for a graphic representation of this component of the system.

   iv. The insulation and radiant barriers are also passive components of the system and serve as the primary elements contributing to the reduction in the heat flux through the roof assembly.

5. Monitoring Equipment Removal;
   a. The monitoring equipment was removed from the test building during November, 2013, after the post-retrofit monitoring was completed.
6. Transfer of real property to GFAFB;
   a. The entire real property associated with the retrofit roofing system was transferred to GFAFB on 11/9/2012.
   b. See Appendix T DoD Real Property Transfer form.

## 5.5 SAMPLING PROTOCOL

Every sensor connected to the data acquisition system was monitored on an approximate 60 second interval. Temperature, heat flux and weather data were averaged into hourly blocks and written to weekly files. The solar thermal and PV-related data were recorded every minute and also stored into weekly files. The data acquisition system was outfitted with remote monitoring, and weekly data files were accessed and downloaded at ORNL. The raw data files were processed into report files, using an Excel template. The weekly data files were monitored for any obvious erroneous data and stored for further analysis. Three months of data was collected prior to the retrofit through March of 2012 and twelve months of data was collected afterwards, commencing in November of 2012 and concluding in October of 2013. .

In addition to the data collection described above, the investigators utilized the utility bills provided by GFAFB personnel for Fiscal Years 2010, 2011, 2012 and 2013 as shown in the tables below.

**Table 5 Historical Electricity consumption at GFAFB Building 3323**

| **Fiscal Year** | **2008** | **2009** | **2010** | | 2011 | | 2012 | 2013-Post Construction |
|---|---|---|---|---|---|---|---|---|
| October | 15360 | 16320 | 16,320 | EST | 16,320 | EST | 20,800 | 19520 |
| November | 20480 | 11840 | 11,840 | EST | 11,840 | EST | 21,280 | 16640 |
| December | 11040 | 11040 | 11,040 | EST | 11,040 | EST | 16,160 | 19360 |
| January | 16960 | 14080 | 14,080 | EST | 14,080 | EST | 15,040 | 16960 |
| February | 13120 | 11840 | 11,840 | EST | 11,840 | EST | 16,160 | 15520 |
| March | 11520 | 13280 | 13,280 | EST | 17,600 | new meter | 17,600 | 15520 |
| April | 16800 | 16960 | 16,960 | EST | 19,200 | | 15,680 | 16160 |
| May | 17280 | 17280 | 17,280 | EST | 23,680 | | 16,800 | 17154 |
| June | 18240 | 18240 | 18,240 | EST | 22,560 | | 12,592 | 16391 |
| July | 23040 | 23040 | 18,240 | EST | 30,400 | | 20,688 | 21470 |
| August | 20160 | 20160 | 20,160 | EST | 26,720 | | 17,440 | 18308 |
| September | 15200 | 15200 | 18,400 | EST | 22,560 | | 18,560 | 27998 |
| Annual TTL | 199,200 | 189,280 | 187,680 | | 227,840 | | 208,800 | 221,001 |
| | | | | | | | FY 13 vs 12 | 12,201 |

**Table 6 Historical Gas consumption at GFAFB Building 3323**

| | | | | Natural Gas (cubic feet) | | |
|---|---|---|---|---|---|---|
| **Fiscal Year** | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| October | 0 | 6226 | 4,520 | 23,923 | 8,480 | 15007 |
| November | 21452 | 19992 | 27,692 | 23,808 | 17,340 | 20400 |
| December | 44007 | 24631 | 42,770 | 46,670 | 66,557 | 45721 |
| January | 34781 | 24520 | 49,184 | 45,341 | 35,341 | 33950 |
| February | 31388 | 24916 | 34,161 | 34,040 | 34,988 | 35588 |
| March | 26664 | 14597 | 35,360 | 15,303 | 23,180 | 23779 |
| April | 12131 | 3718 | 20,106 | 7,623 | 9,403 | 3589 |
| May | 2458 | 3577 | 24,123 | 4,888 | 6,349 | 3582 |
| June | 3158 | 2980 | 7,769 | 2,805 | 3,462 | 2372 |
| July | 3028 | 2654 | 4,035 | 2,628 | 4,579 | 2134 |
| August | 3522 | 2395 | 4,271 | 3,446 | 3,635 | 1968 |
| September | 3078 | 3901 | 5,043 | 3,423 | 9,659 | 2673 |
| Annual TTL | 185,667 | 134,107 | 259,034 | 213,898 | 222,973 | 190,763 |
| | | | | CFNG FY 13 vs 12 | | -32210 |
| | | | | KCFNG FY 13 vs 12 | | -32.2 |

## 5.6 SAMPLING RESULTS

### 5.6.1 HEAT FLOW, HEAT FLUX and ROOF TEMPERATURE DATA SAMPLES

Some sample heat flux and temperature data from the pre- and post-retrofit periods are shown in this section. Figures 19 and 20 show sample roof temperatures and heat flows through the roof during pre-retrofit and post-retrofit periods. During the pre-retrofit condition, the roof temperatures shown in Figure 19 were measured at the bottom surface of the pre-existing metal roof (see Figure 15), while the roof temperatures from the post-retrofit period were measured at the bottom surface of the new “cool” color metal roof (Figure 15). The two respective days were chosen for comparison because during those days the peak roof surface temperatures were comparable. Ideally, periods of similar weather conditions (outdoor temperature and solar) should be chosen for comparison between the pre- and post-retrofit periods. However, the local outdoor temperatures and solar irradiance data are not available from the pre-retrofit period. Therefore, the exterior roof surface temperature was chosen as a surrogate basis for performance comparison.

During March 3-4, 2012 (pre-retrofit) and April 6-7, 2013 (post-retrofit), the outer roof surfaces exhibited similar peak temperatures. Therefore those days were chosen to compare the heat flows through two roof sections, to evaluate the efficacy of the retrofit measures in reducing the roof heat gains. ‘Cool-color Metal’ refers to the section of the roof which contained the polyiso insulation, ASV and the cool-color metal. ‘PV’ refers to the section of the roof which also contained the BIPV and the solar thermal system. Figure 20 shows 60 to 70% reduction in the peak roof heat flux resulting from the retrofit measures.

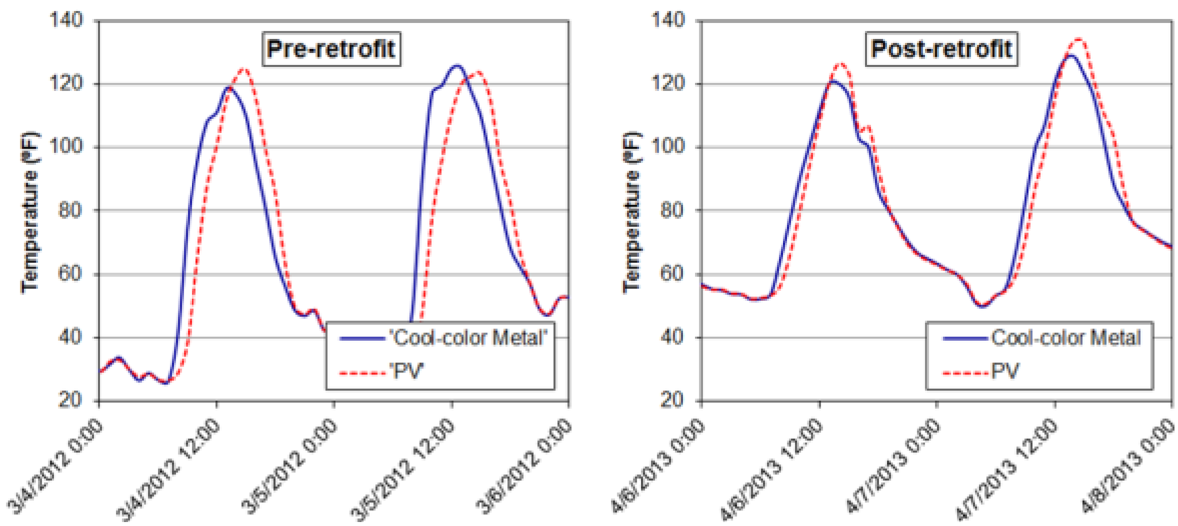



**Figure 19 Roof temperatures over two days during the pre- and post-retrofit periods.**

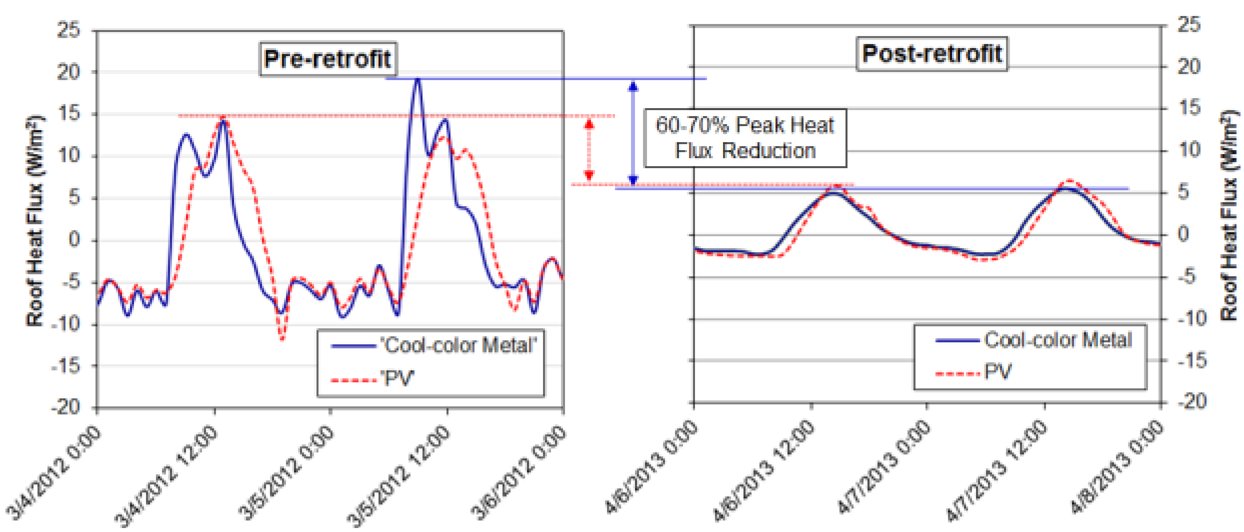



**Figure 20 Roof heat fluxes over two days during the pre- and post-retrofit periods.**

To further evaluate the retrofit measures, weekly temperature and heat flow statistics were studied. Figure 21 shows the weekly attic temperatures during the pre- and post-retrofit periods. Since the attic is within the conditioned space, as expected, no significant differences were observed in the attic temperatures between the pre- and post-retrofit periods. Significant differences, however, were seen in the integrated weekly heat flows, as seen in figure 22. The heat gains (heat flow into the attic) and heat losses (heat flow out of the attic) were integrated separately, and both were significantly reduced following the roof retrofit.

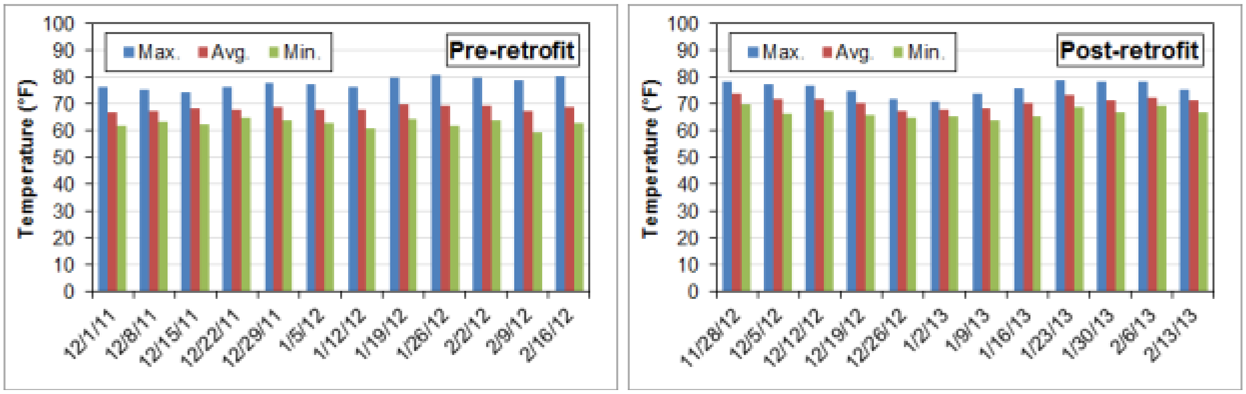



**Figure 21 Weekly maximum, average and minimum attic temperatures during the pre- and post-retrofit periods.**

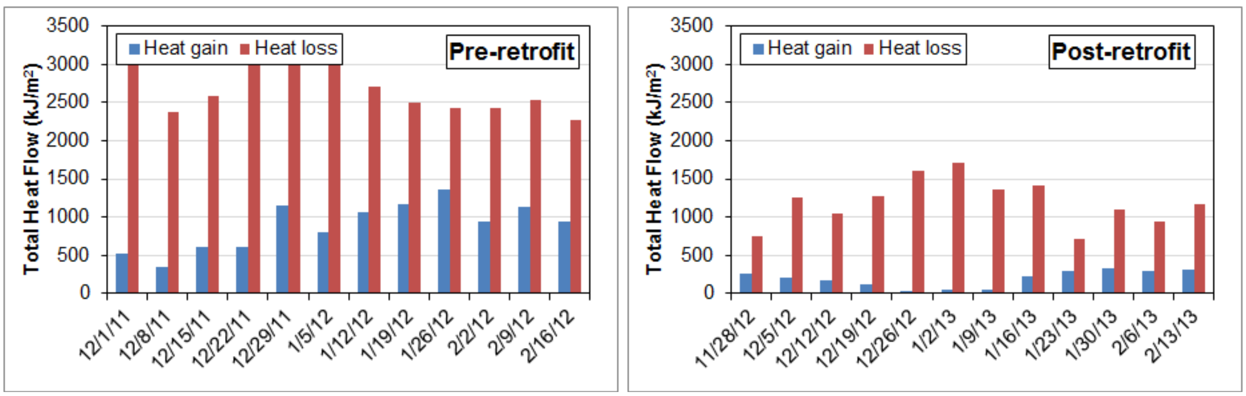
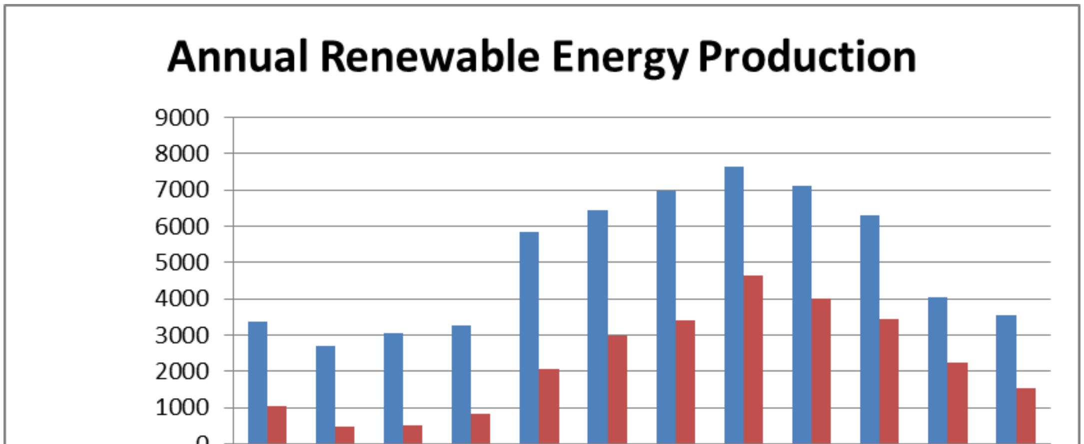



**Figure 22 Weekly total heat gains and losses through a roof section during the pre- and post-retrofit periods.**

**Solar Thermal and Photovoltaic System Data Samples**

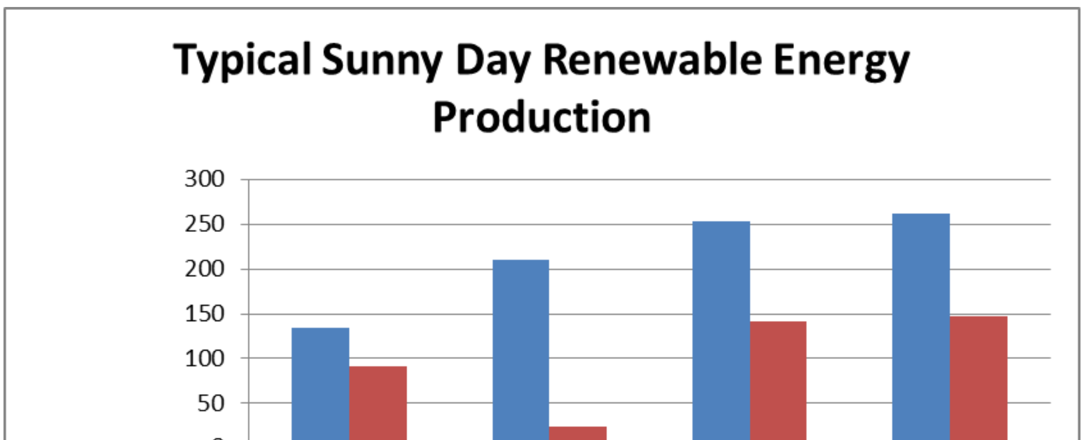
The following graphs summarize the actual data collected from the ORNL monitoring system at the GFAFB Demonstration Project. See Appendix R for individual graphs detailing each of data sets.




| | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric kWh | 3368 | 2692 | 3068 | 3264 | 5844 | 6443 | 6982 | 7639 | 7116 | 6315 | 4050 | 3555 |
| Thermal kBtu | 1046 | 479 | 502 | 823 | 2081 | 2981 | 3401 | 4654 | 4010 | 3461 | 2241 | 1533 |

**Figure 23, 12 Monthly production of the electric and thermal renewable energy systems**

The graphs below illustrate the actual performance of the renewable energy systems on sunny days.




| | 4-Nov | 7-Feb | 21-Apr | 5-Aug |
|---|---|---|---|---|
| Electric (kWh) | 134 | 211 | 254 | 262 |
| Thermal (kBtu) | 92 | 24 | 142 | 148 |

**Figure 24 Actual renewable energy production on a sunny day for the four seasons.**

### 5.6.2 IMPACT OF RETROFIT ON ENERGY CONSUMPTION

The data from the roof heat flux transducers (HFT) can be utilized to estimate the effect of the retrofit measures on the roof-generated heating and cooling loads on the building, and the associated energy consumption. For comparison purposes, HFT data from similar pre- and post-retrofit periods were used. The pre-retrofit monitoring period was limited from Dec, 2011 to mid-March, 2012. During the post-retrofit monitoring, some data were lost between Feb 19 and Feb 25, 2013. Therefore, based on data availability, the following periods were chosen for the energy calculations and comparison:

1. Pre-retrofit: Dec 1, 2011 – Feb 18, 2012
2. Post-retrofit: Dec 1, 2012 – Feb 18, 2013

There were two HFTs installed on each sloped roof. The total heat gain/loss was calculated by simply multiplying the average of the two HFTs by the sloped roof areas. As an approximation, it was assumed that the HFT data were representative of the heat flows through the entire roof area. The heat gains and losses through the roof were converted to cooling electricity ($E_{cooling}$, *kWh*) and heating energy ($E_{heating}$, *Therms*) consumption as follows:

$$E_{cooling}\ (kWh) = \begin{cases} 0, & T_{outdoor} \le 65°\text{F} \\ Q_{gain}/(SEER \cdot 3.412), & T_{outdoor} > 65°\text{F} \end{cases} \quad (1)$$

$$E_{heating}\ (Therm) = \begin{cases} 0, & T_{outdoor} \ge 65°\text{F} \\ (Q_{loss} \cdot 3.41 \times 10^{-5})/\eta_{heating}, & T_{outdoor} < 65°\text{F} \end{cases} \quad (2)$$

For these calculations, it was assumed that no heating was required if the outside temperature was above 65ºF (18.3ºC); conversely, no cooling was required below 65ºF outside temperature. '$Q_{gain}$' is the net heat gain through the roof when the outside temperature was greater than 65ºF and '$Q_{gain}$' is the net heat loss when outside temperature was below 65ºF. The factors, 3.412 and 3.41 x $10^{-5}$, used in the equations are conversion factors from Btu to Wh and Wh to Therm, respectively. A cooling seasonal energy efficiency ratio (SEER) of 9 Btu/Wh and a boiler efficiency ($\eta_{heating}$) of 0.8 were used for the calculations. These values were based on a site-survey report.

Any heat gains when the outside temperature was below 65ºF was assumed to alleviate the heating load of the building and was not considered part of the cooling load; vice-versa for heat losses when the outside temperature was above 65ºF. These calculations were performed for the pre- and post-retrofit periods listed above. Table 5 lists the calculated cooling energy and heating energy consumption for the two periods.

**Table 7 Heating and cooling energy consumption estimated from roof heat flux data.**

| | Pre-retrofit | Post-retrofit | % Difference |
|---|---|---|---|
| Heating Load (kWh) | -6490 | -3573 | -45.0 |
| Cooling Load (kWh) | 289 | 327 | 13.4 |
| Heating Energy (Therm) | -277 | -152 | -45.0 |
| Cooling Energy (kWh) | 109 | 124 | 13.4 |

The raw data in Table 5 suggest that the roof-generated cooling load increased during the post-retrofit period. However, both heating and cooling loads are correlated to the outdoor conditions. An investigation of the outdoor temperatures revealed that the post-retrofit period (Dec 1, 2012 – Feb 18, 2013) was much warmer than the corresponding pre-retrofit period (Dec 1, 2011 – Feb 18, 2012). A more appropriate comparison would be to normalize the cooling and heating loads using the heating and cooling degree days (HDD65 and CDD65) of the corresponding periods. The heating and cooling degree days are calculated using the average daily outdoor temperatures ($T_{avg,out}$) as follows,

$$HDD65 = \begin{cases} (65 - T_{avg,out}), \; T_{avg,out} < 65°\text{F} \\ 0, \; T_{avg,out} \geq 65°\text{F} \end{cases} \tag{3}$$

$$CDD65 = \begin{cases} (T_{avg,out} - 65), \; T_{avg,out} > 65°\text{F} \\ 0, \; T_{avg,out} \leq 65°\text{F} \end{cases} \tag{4}$$

The total HDD65 was 1366.9 during the pre-retrofit period and 1028.4 during the post-retrofit period. Total CDD65 during the pre- and post-retrofit periods were 2.5 and 23.8, respectively. The normalized post-retrofit heating ($E'_{heating,\ post}$) and cooling loads ($E'_{cooling,\ post}$) were calculated as,

$$E'_{cooling,\ post} = E_{cooling,\ post} \cdot \left( {CDD65_{pre}}/{CDD65_{post}} \right) \tag{5}$$

$$E'_{heating,\ post} = E_{heating,\ post} \cdot \left( {HDD65_{pre}}/{HDD65_{post}} \right) \tag{5}$$

The normalized heating and cooling loads (listed in Table 6) are about 27% and 88% lower after the retrofit. It should, however, be noted that the normalization only considers the outdoor temperatures and not other factors like solar irradiance, wind, etc. that could also impact the heating and cooling energy consumption.

**Table 8 Normalized heating and cooling energy consumption estimated from roof heat flux data**

| | Pre-retrofit | Post-retrofit (normalized) | % Difference |
|---|---|---|---|
| Heating Load (kWh) | -6490 | -4749 | -26.8 |
| Cooling Load (kWh) | 289 | 34 | -88.2 |
| Heating Energy (Therm) | -277 | -203 | -26.8 |
| Cooling Energy (kWh) | 109 | 13 | -88.2 |

# 6.0 PERFORMANCE ASSESSMENT

## Performance Assessment Overview

As discussed previously, the mid-stream change in use that occurred at the GFAFB facility compromised the investigators ability to utilize the data for clean comparisons of pre and post construction performance metrics. In an effort to fully leverage the project and provide more useful information to the engineering community, the investigators have expanded Section 6 to include the three subsections described below.

Section 6.1 contains a discussion of the actual results vs the simulated projections developed during the proposal development phase of the project.

Section 6.2 broadens the discussion to include extrapolations of the impact of the entire holistic system on building performance in the climate zones identified earlier below:

- Zone 1: Miami FL
- Zone 2: Austin TX
- Zone 3: Atlanta GA
- Zone 4: Baltimore MD
- Zone 5: Chicago IL
- Zone 6: Minneapolis MN
- Zone 7: Fargo ND
- Zone 8: Fairbanks AK

In the sections described above, and in the following sections of the report, where simulations are presented, the data is an output of one of the following performance modeling application:

- Energy Plus (http://apps1.eere.energy.gov/buildings/energyplus/); used in this project for simulating the impact of changes in the roof assembly's heat flux on GFAFB and across the 8 climate zones, EP is a whole building energy simulation program that engineers, architects, and researchers use to model energy and water use in buildings

- PV Watts (http://rredc.nrel.gov/solar/calculators/pvwatts/version1/); used in the project to simulate the output of the PV system on GFAFB and across the 8 climate zones, NREL's PVWattsTM calculator determines the energy production and cost savings of grid-connected photovoltaic (PV) energy systems throughout the world. It allows homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations.

- Polysun (http://www.velasolaris.com/english/product/overview.html); used to model the performance of the hydronic solar thermal system incorporated on GFAFB and across the 8 climate zones, Polysun's database contains all SRCC, SPF and Solar Keymark tested and certified collectors, plus many more and can account for all of the variables in play with the modeling of solar thermal systems.

The change in use of the test site reinforces that not all types and categories of buildings are candidates for all of the technologies included in the demonstration project. When considering the complete retrofit roofing system that was the subject of this demonstration, one can consider the following building types, amongst others, as prime candidates for retrofitting:

1. restaurants/dining halls,
2. barracks/hotels/hospitality buildings, dormitories
3. food processing facilities,
4. hospitals/infirmary's,
5. commercial and industrial sites with high electric and high thermal loads.

Conversely, it should be said that buildings with low electric and low thermal loads are poor candidates for retrofits of this type.

## 6.1 ACTUAL RESULTS

The actual results related to the eleven performance objectives described earlier in Section 3 are found below:

### 6.1.1 Facility Energy Usage;

The project failed to significantly reduce the energy intensity of the building due to the results discussed in the sections below.

### 6.1.2 Renewable Energy

Renewable Energy usage was measured in in three separate forms; "A" being PV, "B" being hydronic solar thermal DHW heating and "C" being hydronic solar thermal FHA heating;

The project employed solar energy collected as solar thermal and solar electric energy with the goal of reducing the overall energy intensity of the building.

- *Renewable Energy Usage "A"(PV)* passed the success criteria with the PV system producing 96.30% of the value predicted by the NREL PV system modeling application PV Watts. It is important to note that the original PV system projection was based on a conceptual system size of 50.6 KW. The final, as built size of the PV system was 47.8 KW. See the tables below for PV Watts projections of the "as built" east and west PV array. The actual PV system production in FY 2013 was 59,039 kWh vs. the 61,279kWh shown in the projections below.

**Table 7 East Facing PV Array Performance Projection based on "as built" system size:**

| Station Identification | |
|---|---|
| City: | San_Angelo(GFAFB) |
| State: | Texas |
| Latitude: | 31.37° N |
| Longitude: | 100.50° W |
| Elevation: | 582 m |
| **PV System Specifications** | |
| DC Rating: | 23.9 kW |
| DC to AC Derate Factor: | 0.770 |
| AC Rating: | 18.4 kW |
| Array Type: | Fixed Tilt |
| Array Tilt: | 14.0° |
| Array Azimuth: | 90.0° |
| **Energy Specifications** | |
| Cost of Electricity: | 9.7 ¢/kWh |

| Results | | | |
|---|---|---|---|
| Month | Solar Radiation (kWh/m $^2$/day) | AC Energy (kWh) | Energy Value ($) |
| 1 | 3.23 | 1770 | 171.69 |
| 2 | 3.99 | 1988 | 192.84 |
| 3 | 4.98 | 2694 | 261.32 |
| 4 | 5.79 | 2965 | 287.60 |
| 5 | 6.09 | 3124 | 303.03 |
| 6 | 6.59 | 3233 | 313.60 |
| 7 | 6.77 | 3377 | 327.57 |
| 8 | 6.29 | 3151 | 305.65 |
| 9 | 5.26 | 2619 | 254.04 |
| 10 | 4.51 | 2361 | 229.02 |
| 11 | 3.19 | 1620 | 157.14 |
| 12 | 2.93 | 1584 | 153.65 |
| Year | 4.97 | 30485 | 2957.04 |

**Table 8 West Facing PV Array Performance Projection based on "as built" system size:**

| Station Identification | |
|---|---|
| City: | San_Angelo(GFAFB) |
| State: | Texas |
| Latitude: | 31.37° N |
| Longitude: | 100.50° W |
| Elevation: | 582 m |
| PV System Specifications | |
| DC Rating: | 23.9 kW |
| DC to AC Derate Factor: | 0.770 |
| AC Rating: | 18.4 kW |
| Array Type: | Fixed Tilt |
| Array Tilt: | 14.0° |
| Array Azimuth: | 270.0° |
| Energy Specifications | |
| Cost of Electricity: | 9.7 ¢/kWh |
| | |

+

| Results | | | |
|---|---|---|---|
| Month | Solar Radiation (kWh/m $^2$/day) | AC Energy (kWh) | Energy Value ($) |
| 1 | 3.26 | 1780 | 172.66 |
| 2 | 4.02 | 1993 | 193.32 |
| 3 | 5.04 | 2711 | 262.97 |
| 4 | 5.82 | 2964 | 287.51 |
| 5 | 6.34 | 3252 | 315.44 |
| 6 | 6.84 | 3337 | 323.69 |
| 7 | 6.75 | 3338 | 323.79 |
| 8 | 6.25 | 3128 | 303.42 |
| 9 | 5.33 | 2652 | 257.24 |
| 10 | 4.56 | 2374 | 230.28 |
| 11 | 3.34 | 1697 | 164.61 |
| 12 | 2.93 | 1570 | 152.29 |
| | | | |
| | | | |
| Year | 5.04 | 30794 | 2987.02 |

- *Renewable Energy Usage* "B (Solar Thermal energy used for DHW heating); passed the success criteria with the total production of the solar thermal system exceeding the value projected in the Demonstration Plan (see Table 3 for details). This arbitrary passing grade is awarded on this performance objective because the experiment design did not include sufficient energy monitoring to measure and distinguish between the solar energy distributed to the DHW system as compared to the FHA system.

- *Renewable Energy Usage* "C (Solar Thermal Energy used for FHA space heating) failed the success criteria with the total production of the Solar Thermal System being less than 10% of the amount projected in the Demonstration Plan. As above, this arbitrary failing grade is awarded on this performance objective because the experiment design did not include sufficient energy monitoring to measure and distinguish between the solar energy distributed to the DHW system vs the FHA system.

### 6.1.3 Energy Efficiency Improvement A-B;

The project incorporated insulation and air barrier enhancements that contributed to the overall reduction of the energy intensity of the building.

- *Energy Efficiency Improvement A* (increase in insulation reducing cooling loads /electricity) failed the success criteria based exclusively on electric meter data which indicated that a considerable increase in electricity consumption occurred during the months with cooling loads. To further validate this result, the investigators calculated the additional electrical load imposed on the building by the additional equipment installed during the project. The additional electrical load proved to be minimal as shown in the table below:

**Table 9 Additional Electrical Loads Imposed by the Project**

| | Wattage | New Equipment description |
|---|---|---|
| DHW | 60 | pump |
| Rm 153 | 60 | pump |
| Rm 131 | 60 | pump |
| | 250 | blower |
| Rm 116 | 60 | pump |
| | 375 | blower |
| East array | 125 | pump |
| West array | 125 | pump |
| | 1115 | total wattage for all equipment |
| | 3255.8 | annual kWh from new equipment** |
| ** assuming 365 days at 8 hours per day run time | | |

- *Energy Efficiency Improvement B* (increase in insulation reducing heating loads) failed the success criteria with the total reduction in natural gas consumption of 32.2 KCFNG (see Table 6) realized vs. the 127 KCFNG projected in the Demonstration Plan. Intuitively, given the change in building use that generated more heat, one would expect that there would have been additional natural gas savings. However, despite the lack of supporting data, the investigators believe that most of the heat generated by the data center was removed from the building by the air conditioning unit that operated 24/7/365 in the data center portion of the building, and accordingly, did not contribute to the reduction in the amount of natural gas consumed during the test period.

The midstream change in use of the building by GFAFB makes it impossible to accurately analyze the actual savings resulting from the addition of the insulation to the roof system. However, the combination of measured heat fluxes at GFAB and EnergyPlus results for other climate zones clearly indicate reductions in the heat gained and lost through the roof. This is discussed further in Section 6.2.

Additionally, the investigators have a concern that cannot be fully substantiated based on the data from this project, that adding insulation beyond a certain point has a diminishing return. This is discussed in a white paper titled "Economics of Energy-Efficient Envelopes; Chasing Diminishing Returns of Over-Insulation" by Holt Architects attached as Appendix O.

### 6.1.4 Water Usage for Irrigation;

The project incorporated a rainwater collection and distribution system to reduce the total water consumption of the building. This portion of the project was not utilized during the monitoring period due to mechanical problems with the irrigation system at GFAFB and a basewide ban on irrigation due to extensive drought conditions.

- This system is graded as inconclusive; since the system was not operated as intended during the project.

### 6.1.5 Direct Green House Gas (GHG) Emissions*;*

All project data was used to determine the reduction in the carbon footprint of the facility by converting renewable energy and energy efficiency improvements to GHG equivalents.

This performance objective received a "failed" grade due to it not meeting the CO2 offset metrics established in Section 3.

The conversion factors for CO2 offsets were based on the following:

1. For electricity the conversion factor used was 1.46 lb/kWh obtained from: http://www.eia.gov/oiaf/1605/ee-factors.html

2. For natural gas the conversion factory used 117 lb/MBtu obtained from: http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11

CO2 offsets for the test period at Goodfellow AFB are as follows:

| | | |
|---|---|---|
| Natural gas | 27,360 kBtu | 3,186.2 lb CO2 |
| Electricity | 59,039 kWh | 85,097.1 lb CO2 |
| For a total of | | 88,283.2 lb CO2 |

### 6.1.6 System Maintenance*;*

Informal, oral surveys were conducted by the GFAFB Energy Manager with the maintenance staff and used to determine the amount of increase in building maintenance costs resulting from the installation of the demonstration system..

- *Pass; GFAFB staff report that building maintenance will increase less than 10%*

### 6.1.7 System Economics;

The project cost and performance data were utilized in a NIST BLCC Analysis based on the actual results produced by the demonstration system.

- *Results: Fail*
    - *See discussion in Section 7*

### 6.1.8 Ease of Operation and Maintenance;

The project included training operational staff in the use and ongoing maintenance of the systems.

- *Results: Pass*
    - *Based on informal, oral surveys conducted by the GFAFB Energy Manager, GFAFB staff provided positive feedback regarding training and operation of the system.*

### 6.1.9 Validate Energy Plus Modeling Application*;*

The project included ORNL developing an Energy Plus "template" for use by DoD and other interested parties when modeling similar projects in other climate zones. The final Energy Plus models produced by ORNL for the roofing assembly are not able to accurately predict the impacts of the individual components and their interaction within the integrated roof assembly. Of particular importance, the model could not determine the effect of ASV on the performance of the solar thermal system.

EnergyPlus[10], a whole-building modeling tool, was utilized for assessing the performance of the roof-retrofit measures on the roof-generated heating and cooling loads in the demonstration building. Further the efficacy of the roof-retrofit in different climate zones was evaluated and is discussed in more detail in Section 6.2.

Roof and attic models were developed using construction details and geometry per drawings and other construction-related internal communications. The EnergyPlus models were focused only on roof and attic details. No internal load, fenestration, infiltration, occupancy, HVAC equipment, HVAC ducts, etc., were considered in the model. Therefore, whole-building heating/cooling loads and energy consumption could not be compared. Further, the simulations for the post-retrofit period did not consider the BIPV and solar thermal systems, which were outside the scope of the numerical modeling portion of the study. The post-retrofit model consisted of the pre-existing roof, polyiso insulation with reflective surface, air gap and the 'cool-color' metal roof at the top.

Before performing simulations for the different climate zones, EnergyPlus models were first validated by comparing the model results to the measured temperature and heat flux data from the actual demonstration building, under both pre- and post-retrofit conditions. Due to lack of direct measurements of sufficient weather-related parameters, AMY (actual meteorological year)

[10] http://apps1.eere.energy.gov/buildings/energyplus/energyplus_about.cfm

weather data[11] from a local weather station (near Goodfellow AFB, San Angelo, TX 76908) were utilized.

For the post-retrofit case, two simulations were performed for validation: assuming 'closed-cavity' and 'open cavity' to approximate the above-sheathing-ventilation. Open-cavity meant that the air was vented at the eave and ridge, while close-cavity meant the vents were blocked. The preliminary 'open-cavity' and 'closed-cavity' simulation results were found to be comparable on an averaged-monthly basis. Therefore, for the 8 climate zone-simulations, the air cavity was modeled as a closed cavity and no solar thermal system tubing was considered in the model.

For the post-retrofit case, the HFTs were sandwiched between metal roofing (with polyiso foam layers above the metal layer) and fiberglass insulation. EnergyPlus can only output heat flux at the outside face and the inside face, and not at the interface of two layers. Therefore, EnergyPlus simulation results could not be compared to the post-retrofit HFT measurements. For the post-retrofit case, model validation was limited to comparison of the simulated and measured temperatures across the roof assembly.

Figure 25 compares the measured and simulated roof heat fluxes from the pre-retrofit period.

Figures 26 and 27 compared monthly averages of measured and simulated roof heat fluxes and temperatures, respectively, from the pre-retrofit period.

[11] http://www.weatheranalytics.com/get-weather-data

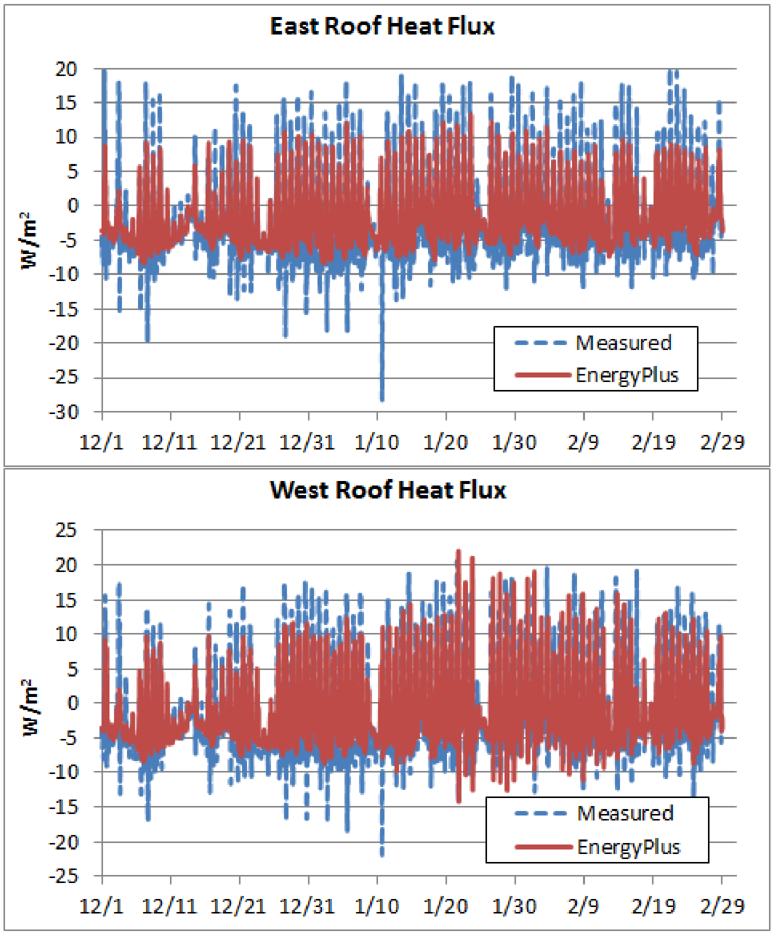



**Figure 25 Comparison of measured and simulated roof heat fluxes from the pre-retrofit period.**

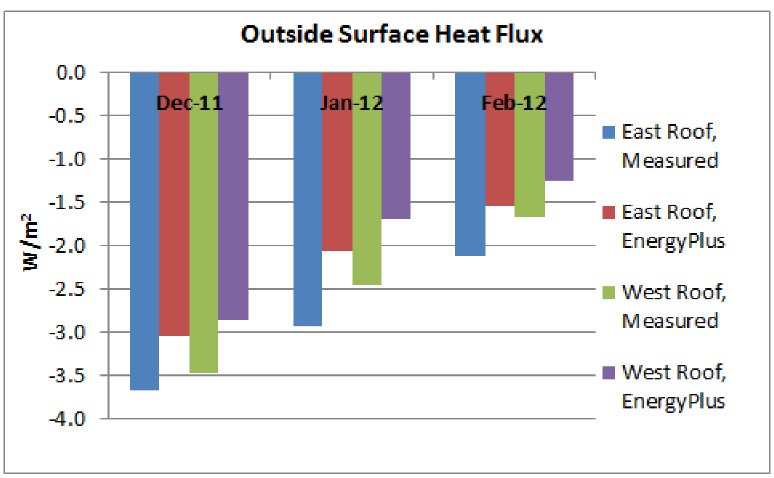



**Figure 26 Comparison of monthly averages of measured and simulated roof heat fluxes from the pre-retrofit period.**

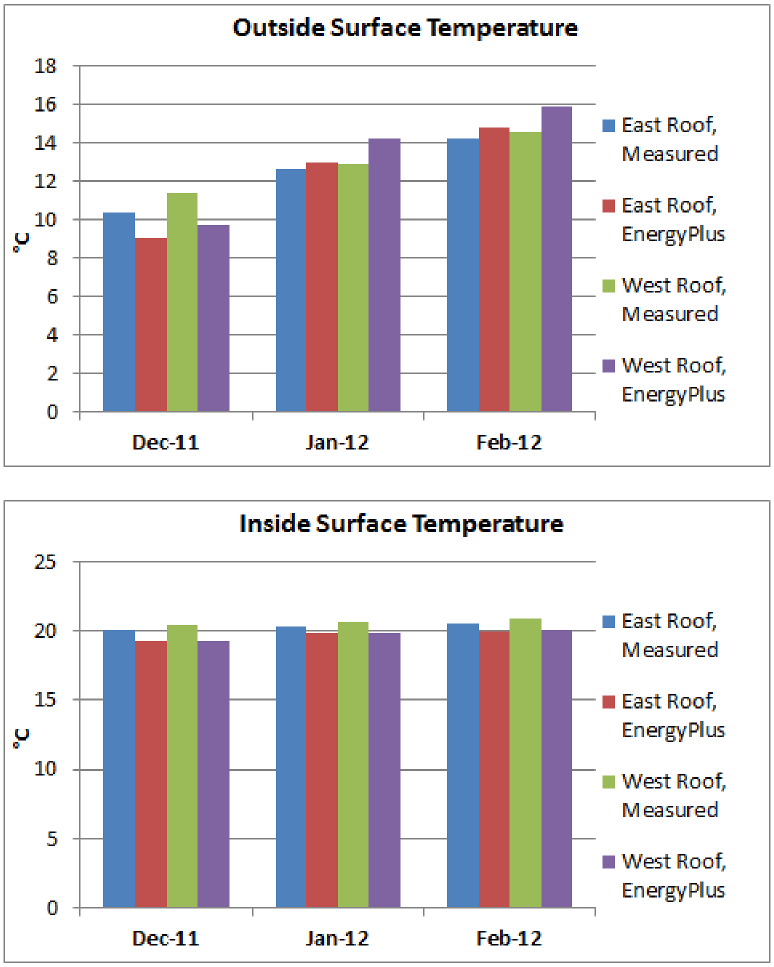



**Figure 27 Comparison of monthly averages of measured and simulated roof temperatures from the pre-retrofit period.**

Next, simulation results from the post-retrofit period are shown. Figure 28 shows the comparison of modeled results, using the 'open-cavity' and 'closed-cavity' models. As mentioned earlier, the modeled results were observed to be similar. For further comparison with measured post-retrofit data, only the 'closed-cavity' model results are considered.

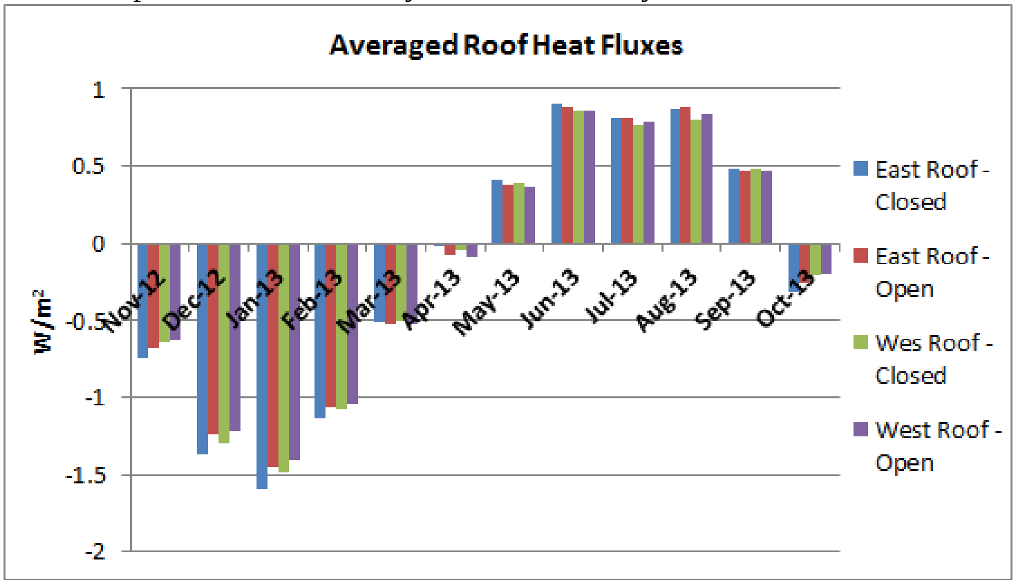



**Figure 28 Comparison of simulated roof heat fluxes using the 'closed' and 'open' air cavity models.**

Figures 29, 30 and 31 compare the monthly-averaged measured and simulated roof surface and attic temperatures during the post-retrofit period.

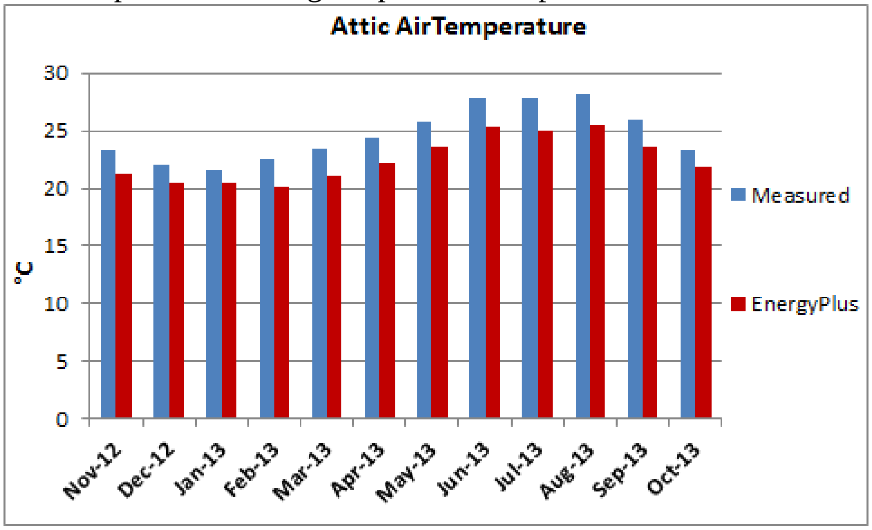



**Figure 29 Comparison of monthly-averaged measured and simulated attic air temperatures from the post-retrofit period.**

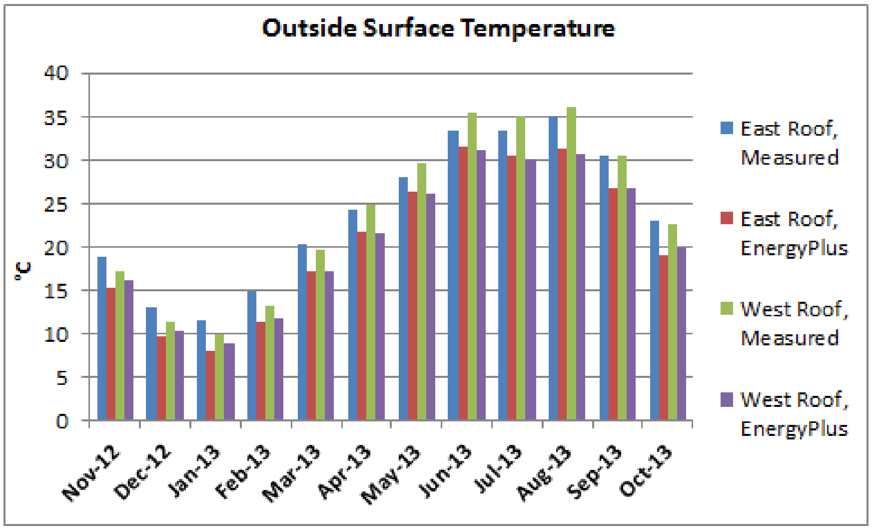



**Figure 30 Comparison of monthly-averaged measured and simulated outside roof surface temperatures from the post-retrofit period.**

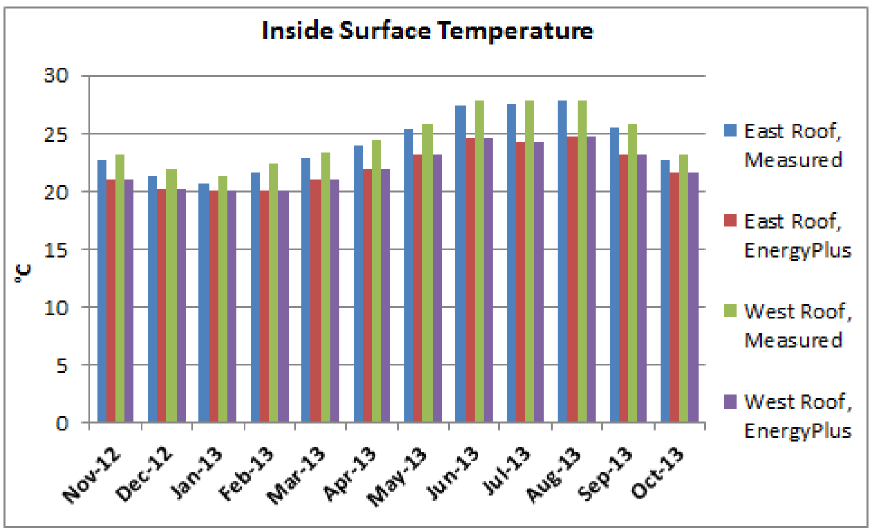



**Figure 31 Comparison of monthly-averaged measured and simulated inside roof surface temperatures from the post-retrofit period.**

- *Results: Pass*
    - *The EnergyPlus modeling and data analysis results show that adding the retrofit measures does benefit the energy consumption of the building. The measured data clearly show the reduction in the heat gained and lost through the roof, and the modeling results provide estimates for similar reductions in roof-generated space conditioning loads in different climate types.*
    - *Experimental data show peak daytime roof heat flux reductions of 60-70%, for similar outside conditions, after the retrofit.*
    - *Modeling results predict roof-generated heating and cooling loads can be reduced by 50-90% due to the added insulation and air gap, depending on climate zone.*

#### 6.1.10 Ease of Retrofit Implementations;

The project was intended to demonstrate the degree of difficulty or simplicity of implementing this type of project on retrofit projects.

- *Results: Pass*
    - *Based on informal, oral surveys conducted by the GFAFB Energy Manager, GFAFB staff has provided positive feedback about the ease with which the retrofit was completed.*

#### 6.1.11 Educate DoD Champions;

The project intended to engage two DoD building design or energy management professionals to observe the overall effectiveness of the design, and implementation and the operational efficiency of the this type of project executed on a retrofit basis, however this was not performed as a result of government employee travel being curtailed during the 2012-2013 budget period.

- *Results: Inconclusive*

## 6.2 SIMULATED RESULTS FOR THE TESTED SYSTEM in 8 CLIMATE ZONES

This section describes the impact of the tested roof system if deployed across the 8 climate zones. Section 6.2.1 focuses on the impact of the reduction in the heat flux of the tested roof and Section 6.2.2 summarizes the impact of the change in heat flux along with all of the other elements of the tested assembly.

### 6.2.1 Heat Flux Impact in 8 Climate Zones

Following a procedure similar to section 5.6.2, the energy impacts of the calculated roof heat gains and losses were estimated. Since TMY3 weather conditions were used for simulating both the pre- and post-retrotfit buildings, no weather normalization was needed. For heating energy use, a boiler efficiency of 0.8 was assumed. For cooling energy use, two different SEER values, 9 and 13 Btu/Wh, were used for calculations to study the impact of older, lower-efficiency cooling equipment to newer, higher-efficiency equipment. The roof area and building geometry were identical to the one used to model the Goodfellow test building. Again, it was assumed that no heating was required if the outside temperature was above 65ºF and no cooling was required below 65ºF outside temperature.

The calculated results for heating and cooling energy use, and the associated reductions due to the roof retrofit are shown in figures 56 and 57.

| Climate Zone | City, State | Heating Energy (Therm) | | % Difference |
|---|---|---|---|---|
| | | Pre-retrofit | Post-retrofit | |
| 1 | Miami, FL | -62 | -38 | -38.2 |
| 2 | Austin, TX | -282 | -169 | -40.1 |
| 3 | Atlanta, GA | -456 | -280 | -38.6 |
| 4 | Baltimore, MD | -707 | -416 | -41.2 |
| 5 | Chicago, IL | -948 | -529 | -44.2 |
| 6 | Minneapolis, MN | -1126 | -626 | -44.4 |
| 7 | Fargo, ND | -1340 | -727 | -45.7 |
| 8 | Fairbanks, AK | -2066 | -1100 | -46.8 |

**Table 10 Comparison of the calculated roof-generated heating energy use for the pre- and post-retrofit configurations**

| Climate Zone | City, State | Cooling Energy (kWh) SEER = 9 | | % Difference | Cooling Energy (kWh) SEER = 13 | | % Difference |
|---|---|---|---|---|---|---|---|
| | | Pre-retrofit | Post-retrofit | | Pre-retrofit | Post-retrofit | |
| 1 | Miami, FL | 6247 | 1391 | -77.7 | 4325 | 963 | -77.7 |
| 2 | Austin, TX | 5416 | 1212 | -77.6 | 3750 | 839 | -77.6 |
| 3 | Atlanta, GA | 4440 | 940 | -78.8 | 3074 | 651 | -78.8 |
| 4 | Baltimore, MD | 3248 | 676 | -79.2 | 2248 | 468 | -79.2 |
| 5 | Chicago, IL | 2685 | 514 | -80.9 | 1859 | 356 | -80.9 |
| 6 | Minneapolis, MN | 2345 | 450 | -80.8 | 1624 | 312 | -80.8 |
| 7 | Fargo, ND | 2255 | 420 | -81.4 | 1561 | 291 | -81.4 |
| 8 | Fairbanks, AK | 810 | 156 | -80.7 | 561 | 108 | -80.7 |

**Table 11 Comparison of the calculated roof-generated cooling energy use for the pre- and post-retrofit configurations**

Results: The retrofit measures, for a building similar to the one tested at Goodfellow AFB, were estimated to yield 38-47% reduction in roof-generated heating energy use and 78-81% cooling energy use across different climate zones.

The 8 climate zone-related simulations were also focused on the roof-retrofit measures, so only heat gains and losses through the roof from simulation results were considered. These simulations were performed using typical meteorological year (TMY) weather data[12]. Simulations were performed for the following representative cities, one in each climate zone as described again the Table below, for the convenience of the reader:

[12] http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

| | |
|---|---|
| • Zone 1: Miami FL | • Zone 5: Chicago IL |
| • Zone 2: Austin TX | • Zone 6: Minneapolis MN |
| • Zone 3: Atlanta GA | • Zone 7: Fargo ND |
| • Zone 4: Baltimore MD | • Zone 8: Fairbanks AK |

**Table 12 Climate Zones and Cities**

Figures 53 and 54 show the total monthly heat gains and losses through the roof, for a similar building, with (post-retrofit) and without (pre-retrofit) the retrofit technologies applied to the roof, for climate zones 2 and 7. The retrofit technologies significantly reduced both the heat gains and losses in both hot (2) and cold (7) climate zones. Figure 55 shows tabulated annual heat gains and losses for all 8 cities representing different climate zones. For the different climate zones, on an annual basis, the retrofit technologies reduced the roof heat gains by 77-89% and heat losses by 48-58%.

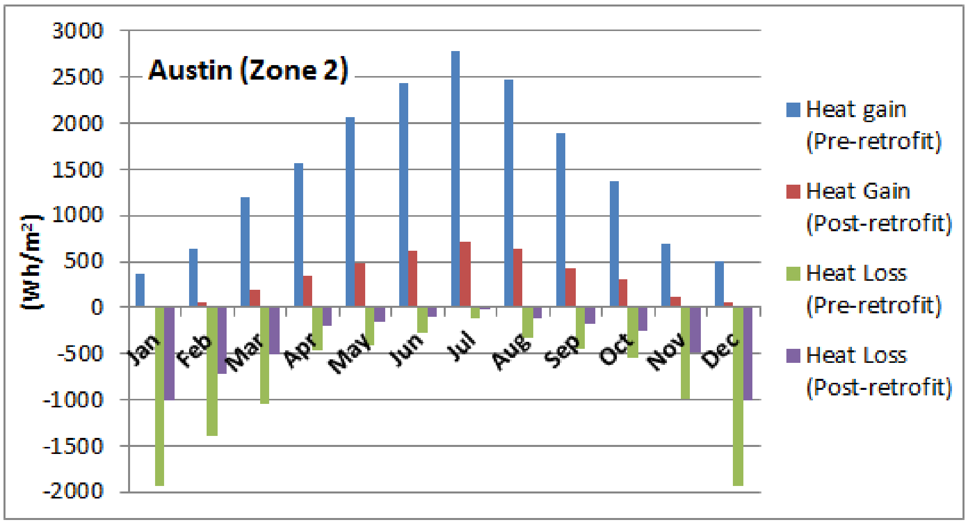



**Figure 32 Comparison of monthly total heat gains and losses through the pre- and post-retrofit roof assemblies in climate zone 2.**

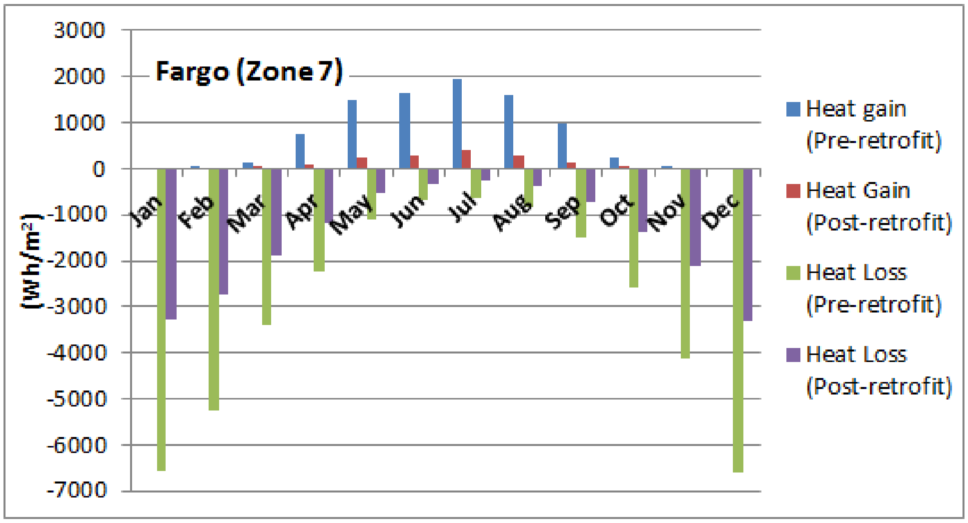



**Figure 33 Comparison of monthly total heat gains and losses through the pre- and post-retrofit roof assemblies in climate zone 7.**

| Climate Zone | City | Heat Gain (Wh/m$^2$) | | % Difference | Heat Loss (Wh/m$^2$) | | % Difference |
|---|---|---|---|---|---|---|---|
| | | Pre-retrofit | Post-retrofit | | Pre-retrofit | Post-retrofit | |
| 1 | Miami | 19769 | 4583 | -77 | -4001 | -1673 | -58 |
| 2 | Austin | 17977 | 3946 | -78 | -9909 | -4742 | -52 |
| 3 | Atlanta | 15837 | 3105 | -80 | -14767 | -7397 | -50 |
| 4 | Baltimore | 12197 | 2295 | -81 | -20597 | -10647 | -48 |
| 5 | Chicago | 10106 | 1809 | -82 | -25982 | -13399 | -48 |
| 6 | Minneapolis | 9366 | 1582 | -83 | -30563 | -15734 | -49 |
| 7 | Fargo | 8792 | 1437 | -84 | -35507 | -18167 | -49 |
| 8 | Fairbanks | 5170 | 566 | -89 | -53761 | -27187 | -49 |

**Table 13 Comparison of annual heat gains and losses through the pre- and post-retrofit roof assemblies in all climate zones**

### 6.2.2 Summary Data for the Entire System in 8 Climate Zones

The following tables contain the results of simulations for the entire retrofit roofing system using results obtained from the modeling tools described earlier. Energy unit costs vary by climate zone and are based on values obtained from the websites below:

- Electricity: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a
- Natural Gas: http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm
    - Fuel Oil: http://www.eia.gov/dnav/pet/pet_pri_wfr_a_EPD2F_prs_dpgal_w.htm

The Thermal Savings table below incorporates the impact of the change in the heat flux of the roof insofar as it reduces the building heating load, as well as the impact of the hydronic solar thermal system on the water heating and space heating loads of the building.

| Thermal (Mbtu) | | | | | | |
|---|---|---|---|---|---|---|
| Zone/City | | Insulation | Solar | Total | $/Mbtu | Savings |
| 1 | Miami | 2.4 | 20.73 | **23.13** | 6.68 | **$154.51** |
| 2 | Austin | 11.3 | 86.76 | **98.06** | 8.22 | **$806.05** |
| 3 | Atlanta | 17.6 | 97.81 | **115.41** | 10.63 | **$1,226.81** |
| 4 | Baltimore | 29.1 | 92.07 | **121.17** | 10.58 | **$1,281.98** |
| 5 | Chicago | 41.9 | 72.11 | **114.01** | 11.27 | **$1,284.89** |
| 6 | Minneapolis | 50 | 77.53 | **127.53** | 6.68 | **$851.90** |
| 7 | Fargo | 61.3 | 79.7 | **141** | 6.7 | **$944.70** |
| 8 | Fairbanks | 96.6 | 80.29 | **176.89** | 8.28 | **$1,464.65** |

**Table 14 Thermal Savings in 8 Climate Zones**

The Electric Savings table below incorporates the impact of the change in the heat flux of the roof insofar as it reduces the building cooling load, as well as the impact of the PV system offsetting electrical consumption.

| Electric (kWh) | | | | | | |
|---|---|---|---|---|---|---|
| Zone/City | | Insulation | Solar | Total | $/kWh | Savings |
| 1 | Miami | 3362 | 58386 | **61748** | 0.0944 | **$5,829.01** |
| 2 | Austin | 2911 | 58233 | **61144** | 0.0804 | **$4,915.98** |
| 3 | Atlanta | 2423 | 56465 | **58888** | 0.0965 | **$5,682.69** |
| 4 | Baltimore | 1780 | 49586 | **51366** | 0.1099 | **$5,645.12** |
| 5 | Chicago | 1503 | 48322 | **49825** | 0.0798 | **$3,976.04** |
| 6 | Minneapolis | 1312 | 49425 | **50737** | 0.0938 | **$4,759.13** |
| 7 | Fargo | 1270 | 48276 | **49546** | 0.0855 | **$4,236.18** |
| 8 | Fairbanks | 453 | 30716 | **31169** | 0.1603 | **$4,996.39** |

**Table 15 Electric Savings in 8 Climate Zones**

The Rainwater Harvesting Savings table below is based on average monthly rainfall May through September on 5000sf of roof. Rainfall amounts are taken from the Weather Channel website, and water and sewer rates were obtained directly from the municipalities named in the eight climate zones. Links to the weather, water and sewer data can be found in Appendix I:

| Rainwater (kgal) | | | | |
|---|---|---|---|---|
| Zone/City | | Collection | $/kgal | Savings |
| 1 | Miami | 99.40 | 8.62 | **$856.82** |
| 2 | Austin | 42.75 | 9.37 | **$400.52** |
| 3 | Atlanta | 66.35 | 16.45 | **$1,091.44** |
| 4 | Baltimore | 60.95 | 5.27 | **$321.21** |
| 5 | Chicago | 60.86 | 6.51 | **$396.17** |
| 6 | Minneapolis | 59.39 | 8.62 | **$511.93** |
| 7 | Fargo | 45.66 | 6.30 | **$287.65** |
| 8 | Fairbanks | 25.37 | 19.10 | **$484.61** |

**Table 16 Rainwater Savings in 8 Climate Zones**

The Saving to Investment Ratios found in the table below are included here to provide continuity and for the convenience of the reader. The SIR's are based on the complete system cost structures as described in detail Section 7.1.

| Savings To Investment Ratio | | |
|---|---|---|
| Zone/City | | |
| 1 | Miami | 0.32 |
| 2 | Austin | 0.31 |
| 3 | Atlanta | 0.42 |
| 4 | Baltimore | 0.38 |
| 5 | Chicago | 0.29 |
| 6 | Minneapolis | 0.31 |
| 7 | Fargo | 0.28 |
| 8 | Fairbanks | 0.36 |

**Table 17 Saving to Investment Ratios of the Simulated System**

# 7.0 COST ASSESSMENT

Sub-Section 7.1, 7.2 and 7.3 discuss the economics of the system as installed at GFAFB. Section 7.4 has been included by the investigators to provide a broad overview of the performance and economics of the PV and Solar Thermal components of the system in the public and private sectors.

Since current solar energy modeling tools do not have the ability to integrate the impact of ASV on system performance, the following cost benefit analyses reflect the performance of standalone PV and Solar Thermal Systems on sites that would be described as of the first priority within the DoD building inventory for retrofitting with some or all of the technologies demonstrated in this project.

The following key lessons learned from this project should be considered during the process of prioritizing buildings for retrofits;

1. not all types and categories of buildings are candidates for all of the technologies included in the demonstration project. As stated earlier, one can consider the following building types, amongst others, as prime candidates for retrofitting:
   - restaurants/dining halls,
   - barracks/hotels/hospitality buildings, dormitories
   - food processing facilities,
   - hospitals/infirmary's,
   - commercial and industrial sites with high electric and high thermal loads.

   Conversely, it should be said that buildings with low electric and low thermal loads are poor candidates for retrofits of this type.

2. The performance of each technology will vary considerably with respect to the location of the building and loads within the building;

3. Implementation sites should be surveyed for suitability; i.e. is the building in need of a new metal roof and if so, implementation schedules should prioritize those buildings that will deliver a maximum rate of return on the investment and

4. An above sheathing ventilation system is detrimental to the efficiency of the building integrated solar water and space heating system in this demonstration

## 7.1 COST MODEL

**Table 18 Cost Model**

| Cost Element | Data Tracked During the Demonstration | Estimated Costs based on 1 million square feet annually |
|---|---|---|

| Hardware capital costs | Actual component costs for demonstration | |
|---|---|---|
| Retrofit Roofing | $ 5.00 per square foot | $ 4.50 per square foot |
| Insulation | $ 4.50 per square foot | $ 4.05 per square foot |
| Solar Thermal Array | $ 6.56 per square foot | $ 4.17 per square foot |
| Solar Thermal Balance of Systems | $ 3.61 per square foot | $ 2.30 per square foot |
| Solar Electric Array | $ 2.50 per watt (DC) | $ .75 per watt (DC) |
| Solar Electric Balance of Systems | $ 1.00 per watt (DC) | $ 0.55 per watt (DC) |
| Rainwater Collection | $ 2.21 per square foot | $ 2.05 per square foot |
| Installation costs | Labor and material required to install | |
| Retrofit Roofing | $ 3.52 per square foot | $3.25 per square foot |
| Insulation | $ 1.30 per square foot | $ 1.20 per square foot |
| Solar Thermal Array | $ 9.43 per square foot | $6.00 per square foot |
| Solar Thermal Balance of Systems | $ 6.07 per square foot | $3.86 per square foot |
| Solar Electric Array | $ 1.00 per watt (DC) | $ 0.50 per watt (DC) |
| Solar Electric Balance of Systems | $ 0.50 per watt (DC) | $ 0.20 per watt (DC) |
| Rainwater Collection | $ 2.70 per square foot | $ 2.45 per square foot |
| Consumables | Not applicable, prices above are all in | Not applicable, prices above are all in |
| Facility operational costs | Not applicable, ion in energy required vs. baseline data | Varies based on system design |

| | | |
|---|---|---|
| **Maintenance** | • **Not applicable,** | • **Annual**<br>• **Labor and material are incidental** |
| **Hardware lifetime** | **Estimate based on generally accepted industry estimates** | • **Standing Seam Metal Roofing-50 yrs**<br>• **Photovoltaic System-30 years**<br>• **Solar Thermal System- 50 years** |
| **Operator training** | **Not applicable** | **Not applicable** |
| **Salvage Value** | **Not Applicable** | **Not Applicable** |

## 7.2 COST DRIVERS

The construction costs in the table above are based on retrofitting existing buildings that have sloped roofs with existing metal roofing on them or other sloped roof coverings that are suitable for a direct "go over" type replacement with a standing seam metal roof assembly, such as sloped roofs covered with asphalt or membrane roofing materials. The costs are appropriate for structures from 1 story in height to 4 stories in height that are completed under normal daytime working conditions, in fair weather with reasonable site access. No demolition costs are included, since demolition is rarely required on these types of projects. With these caveats, it can generally be stated that the costs in the table above are appropriate for use when evaluating projects in the lower 48 states during the course of FY 2014.

After 2014, the costs are factored for the inflation rate structures included in the NIST BLCCA program.

## 7.3 COST ANALYSIS AND COMPARISON

**Site and Technology Description and Assumptions;**

In this section, the investigators present life cycle cost analyses over a 40 year study period for the holistic retrofit roofing system utilized in the Demonstration Project. The retrofit roofing system, ASV and insulation components of the subject roof system are included, along with the PV and hydronic solar thermal components of the systems. The details of the project modeled are consistent with the project description provided earlier.

**Cost and Economic Assumptions;**

To explore the financial feasibility of this DoD implementation, the investigators performed NIST BLCCA modeling of the actual project. The capital or construction costs utilized are those detailed in the Section 7.1 Cost Model, for a deployment in the range of one million square feet annually. The DoD/Federal project costs utilized are unsubsidized, and do not reflect any tax credits, or other federal, state or local incentives.

### 7.3.1 NIST BLCCA Data Summary;

## ΝΙΣΤ ΒΛΧΧ 5.3–13: Χομπαρατιϖε Αναλψσισ

**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**

**Base Case: Existing Building**

**Alternative: System exactly as installed at GFAFB**

**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\GoodfellowAFB.xml |
| **Date of Study:** | Fri Mar 14 22:53:27 EDT 2014 |
| **Project Name:** | Goodfellow AFB Bldg 3323 |
| **Project Location:** | Texas |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | System exactly as installed at GFAFB |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months including a 2 year construction period(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

## Χομπαρισον οφ Πρεσεντ–ςαλυε Χοστσ

**PV Life-Cycle Cost**

| | **Base Case** | **Alternative** | **Savings from Alternative** |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $663,450 | -$663,450 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $469,972 | $344,846 | $125,126 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $10,365 | $6,413 | $3,953 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $22,112 | -$22,112 |
| **Major Repair and Replacements** | $0 | $15,656 | -$15,656 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |

| | | | |
|---|---|---|---|
| **Subtotal (for Future Cost Items)** | $480,337 | $389,026 | $91,311 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $480,337 | $1,052,476 | -$572,139 |

## Net Savings from Alternative Compared with Base Case

| | |
|---|---|
| **PV of Non-Investment Savings** | $106,967 |
| **- Increased Total Investment** | $679,106 |
| | ------------ |
| **Net Savings** | -$572,139 |

## Savings-to-Investment Ratio (SIR)

**SIR =** 0.16

**SIR is lower than 1.0; project alternative is not cost effective.**

## Adjusted Internal Rate of Return

**AIRR =** -1.43%

**AIRR is lower than your discount rate; project alternative is not cost effective.**

## Payback Period

### Estimated Years to Payback (from beginning of Beneficial Occupancy Period)

**Simple Payback never reached during study period.**
**Discounted Payback never reached during study period.**

## Ενεργψ Σαϖινγσ Συμμαρψ

## Energy Savings Summary (in stated units)

| Energy | -----Average | Annual | Consumption----- | Life-Cycle |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 208,800.0 kWh | 149,761.0 kWh | 59,039.0 kWh | 2,361,398.4 kWh |
| **Natural Gas** | 223.0 MBtu | 190.8 MBtu | 32.2 MBtu | 1,288.3 MBtu |

## Energy Savings Summary (in MBtu)

| Energy | -----Average | Annual | Consumption----- | Life-Cycle |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 712.5 MBtu | 511.0 MBtu | 201.4 MBtu | 8,057.4 MBtu |
| **Natural Gas** | 223.0 MBtu | 190.8 MBtu | 32.2 MBtu | 1,288.3 MBtu |

## Εμισσιονσ Ρεδυχτιον Συμμαρψ

| Energy | -----Average | Annual | Emissions----- | Life-Cycle |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Electricity** | | | | |
| **CO2** | 136,503.16 kg | 97,906.37 kg | 38,596.79 kg | 1,543,765.94 kg |
| **SO2** | 687.83 kg | 493.35 kg | 194.49 kg | 7,778.98 kg |
| **NOx** | 203.72 kg | 146.12 kg | 57.60 kg | 2,303.94 kg |
| **Natural Gas** | | | | |
| **CO2** | 11,777.21 kg | 10,075.89 kg | 1,701.32 kg | 68,048.27 kg |
| **SO2** | 95.05 kg | 81.32 kg | 13.73 kg | 549.17 kg |
| **NOx** | 9.88 kg | 8.45 kg | 1.43 kg | 57.09 kg |

**Total:**

| | | | | |
|---|---|---|---|---|
| **$CO_2$** | 148,280.37 kg | 107,982.26 kg | 40,298.11 kg | 1,611,814.22 kg |
| **$SO_2$** | 782.88 kg | 574.66 kg | 208.22 kg | 8,328.15 kg |
| **$NO_x$** | 213.60 kg | 154.57 kg | 59.03 kg | 2,361.03 kg |

### 7.3.2 COST ANALYSIS DISCUSSION

The renewable energy systems analyzed in this report and detailed in Section 7 and various appendices, clearly indicate that retrofit roofing projects that encompass insulation enhancements and renewable energy systems can and will play a significant role in reducing the energy intensity of older buildings in the DoD's real estate inventory and in the private sector.

In many cases the technologies do not have a simple payback within the 40 year study period. Despite that, the future holds promise for these technologies and retrofit roofing systems, as economies of scale and technology innovation improve system efficiency and bring construction costs down, while conventional energy prices continue their inevitable rise.

## 7.4 SYSTEM COMPONENT TECHNOLOGIES SIMULATED in 8 CLIMATE ZONES

This Section is provided as an additional resource to the reader. The simulations contained in this section reflect the performance of the individual ***renewable energy component technologies*** in the 8 climate zones described earlier in this report.

To explore the financial feasibility of DoD implementations as well as non-Federal, private sector implementations including Public Private Ventures (PPV) or Power Purchase Agreements (PPA), the investigators performed NIST BLCCA modeling for both public and private sector implementations. The life cycle cost analyses model PV and solar thermal projects on buildings located in all 8 climate zones. Additionally, Baltimore, Chicago and Minneapolis were modeled to illustrate project economics where fuel oil may be the dominant fossil fuel offset by renewable energy.

In this section, the investigators present life cycle cost analyses over a 40 year study period for the component PV and Solar Thermal technologies utilized in the Demonstration Project. The roofing, ASV and insulation components of the subject roof system are not analyzed due lack of data and the limitations that exist with contemporary performance modeling software. The prototypical site modeled is a building requiring a new or retrofit standing seam metal roof that covers a 5000 square foot roof area of the building. The roof has a 14 degree slope and is south facing.

The capital or construction costs utilized are those detailed in the Section 7.1 Cost Model, for a deployment in the range of one million square feet annually. The DoD/Federal project costs utilized are unsubsidized, and do not reflect any tax credits, or other federal, state or local incentives.

Private sector costs include the impact of the Federal Investment Tax Credits (FITC) and Modified Accelerated Cash Recovery System, otherwise known as MACRS accelerated depreciation. The FITC and MACRS combine to effectively reduce the Section 7.1 Costs structure by 50%. However the reader must be warned that these elements of the Federal Investment Tax Credit are retired at the end of 2016 and it remains to be seen if they will be extended by Congress.

When reviewing these analyses, it is important to note that the NIST BLCC analyses performed are highly sensitive to the type and price of the conventional fuel that the renewable energy system or conservation measure is offsetting. These prices vary widely across the 8 climate zones, resulting in the wide variations in Savings to Investment Ratios (SIR) that are found in the tables below.

### 7.4.1 PV System Performance in 8 Climate Zones

The PV system discussed in this section is a 23.9 KW (DC) BIPV array mounted on a standing seam metal roof. It is a grid tied array with no battery backup.

The subject PV System's performance, in all 8 climate zones, for east, south and west system orientations at the same slope as the demonstration site at GFAFB, is found in the table below:

| Climate Zone | City | System Size (KW) | Slope | Average Solar Radiation (kWh/m 2/day) / kWH Projection | | |
|---|---|---|---|---|---|---|
| | | | | East Array | West Array | South Array |
| 1 | Miami | 23.9 | 14 | 4.84/29,459 | 4.79/28927 | 5.2/31,599 |
| 2 | Austin | 23.9 | 14 | 4.76/28,807 | 4.87/29426 | 5.24/31,870 |
| 3 | Atlanta | 23.9 | 14 | 4.6/28,324 | 4.59/28141 | 5.04/31,203 |
| 4 | Baltimore | 23.9 | 14 | 3.99/24,745 | 4.02/24841 | 4.46/27,990 |
| 5 | Chicago | 23.9 | 14 | 3.88/24,229 | 3.86/24093 | 4.28/27,112 |
| 6 | Minneapolis | 23.9 | 14 | 3.92/24,775 | 3.92/24650 | 4.42/28,393 |
| 7 | Fargo | 23.9 | 14 | 3.81/24,249 | 3.8/24027 | 4.31/27,916 |
| 8 | Fairbanks | 23.9 | 14 | 2.55/15,460 | 2.53/15256 | 2.96/18,472 |

**Table 19 PV System Performance in 8 Climate Zones**

### 7.4.2 Hydronic Solar Thermal System Performance in 8 Climate Zones

The solar thermal systems discussed in this section incorporate a building integrated hydronic solar thermal array identical in design to that installed on the Demonstration Project. The array is 5000 square feet in size, on a 14 degree roof slope and has been modeled on east, south and west roof planes.

The following tables contain performance modeling data for the subject hydronic solar thermal system in conjunction with distribution systems designed to preheat domestic hot water or preheat return air in a forced hot air (FHA) heating system. For clarity, the tables contain performance projections for systems that perform one function or the other but not both. System designs that include both the solar preheating of both DHW and FHA systems, are possible, however they are very site specific and beyond the scope of this report.

Note that the solar thermal space heating system proves to be of limited value on this prototypical installation, a result which is supported by the limited data collected at GFAFB. Accordingly, NIST BLCC analyses for the solar thermal space heating system for Atlanta and Minneapolis are shown for reference only.

The following table illustrates the projected performance of a DHW solar preheating system in the eight climate zones, with a high DHW load such as what might be found in a hotel, restaurant, dining hall or barracks.

| Climate Zone | City | System Size (SF) | Slope | Solar DHW preheat - KBTU Offset Projection | | |
|---|---|---|---|---|---|---|
| | | | | East Array | South Array | West Array |
| 1 | Miami | 5000 | 14 | 152,548.9 | 165,631.1 | 155,660.1 |
| 2 | Austin | 5000 | 14 | 167,053.7 | 183,018.6 | 170,190.3 |
| 3 | Atlanta | 5000 | 14 | 168,930.1 | 186,853.3 | 173,165.2 |
| 4 | Baltimore | 5000 | 14 | 148,275.9 | 167,990.6 | 153,333.7 |
| 5 | Chicago | 5000 | 14 | 158,937.5 | 176,557.6 | 162,307 |
| 6 | Minneapolis | 5000 | 14 | 157,391.6 | 182,536 | 160,184.6 |
| 7 | Fargo | 5000 | 14 | 156,114.6 | 175,623.9 | 156,840.2 |
| 8 | Fairbanks | 5000 | 14 | 117,457.6 | 133,175.1 | 119,116.5 |

**Table 20 Solar DHW Preheating performance for east, south and west facing roof arrays**

The following table illustrates the projected performance of a dedicated solar FHA return air pre-heating system in the eight climate zones.

| Climate Zone | City | System Size (SF) | Slope | Solar FHA preheating of return air - KBTU Offset Projection | | | |
|---|---|---|---|---|---|---|---|
| | | | | East Array | South Array | West Array | South Wall Array |
| 1 | Miami | 5000 | 14 | 11,217.8 | 12,723 | 12,023.1 | 12,544.1 |
| 2 | Austin | 5000 | 14 | 56,488.6 | 73,289.9 | 59,637.6 | 69,172.2 |
| 3 | Atlanta | 5000 | 14 | 65,468.1 | 84,974.6 | 68,218.3 | 75,142.5 |
| 4 | Baltimore | 5000 | 14 | 53,601.6 | 74,397.1 | 56,707 | 60,274 |
| 5 | Chicago | 5000 | 14 | 49,591.6 | 64,360.7 | 52,120.5 | 46,236.2 |
| 6 | Minneapolis | 5000 | 14 | 43,594.7 | 57,014.4 | 48,462.5 | 45,373 |
| 7 | Fargo | 5000 | 14 | 52,464.4 | 64,740 | 56,171.8 | 49,269.5 |
| 8 | Fairbanks | 5000 | 14 | 49,054.9 | 66,543.7 | 54,342.8 | 63,166.1 |

**Table 21 Solar FHA Preheating System performance**

#### 7.4.3 BLCCA Data Summary for PV and Solar Thermal components on Federal and Private Sector Projects

The Savings to Investment Ratios (SIR) range widely, from ~1.01 to 3.99 varying as a function of technology type, project location and energy offset, but this analysis does support the basic idea that high performance roofing systems do have a payback and a measurable return on investment as the DoD expands renewable energy and conservation programs through Public Private Ventures and Power Purchase Agreements.

The more favorable SIRS for Private sector projects reinforces the rationale behind current DoD energy procurement strategies that employ PPA's and PPV's to procure very large quantities (10+ megawatts) of renewable and alternative energy through multiple award task order contracts.

The full NIST BLCCA reports for climate zone 6 (Minneapolis MN) and climate zone 3 (Atlanta GA) for both public and private sector implementations are included for reference in Appendix K, L, M, N.

The tables following summarize the NIST BLCC analyses for both PV and Solar Water Heating Systems in the 8 climate zones. Additionally, for comparison purposes, NIST BLCCA data for identical projects with Private Sector economics (described above) are included.

#### 7.4.3.1 PV Systems in Federal Projects

| PV Systems with Federal Project Economics | | | |
|---|---|---|---|
| **Climate Zone** | **City** | **Electric Rate (cents/kWh)** | **Savings to Investment Ratio (SIR)** |
| 1 | Miami | 9.44 | 1.32 |
| 2 | Austin | 8.04 | 1.13 |
| 3 | Atlanta | 9.65 | 1.33 |
| 4 | Baltimore | 10.99 | 1.36 |
| 5 | Chicago | 7.98 | 1.01 |
| 6 | Minneapolis | 9.38 | 1.28 |
| 7 | Fargo | 8.55 | 1.04 |
| 8 | Fairbanks | 16.03 | 1.23 |
| Electric rates from: | | | |
| http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a | | | |

**Table 22 PV Systems in Federal Sector Projects - NIST BLCCA Summary**

#### 7.4.3.2 PV Systems in Private Sector Projects

| PV Systems with Private sector/PPV/PPA Economics | | | |
|---|---|---|---|
| **Climate Zone** | **City** | **Electric Rate (cents/kWh)** | **Savings to Investment Ratio (SIR)** |
| 1 | | | |
| 2 | | | |
| 3 | Atlanta | 9.65 | 2.39 |
| 4 | Baltimore | 10.99 | 2.44 |
| 5 | Chicago | 7.98 | 1.80 |
| 6 | Minneapolis | 9.38 | 2.30 |
| 7 | | | |
| 8 | | | |
| Electric rates from: | | | |
| http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a | | | |

**Table 23 PV Systems in Private Sector Projects - NIST BLCCA Summary**

### 7.4.3.3 Solar Water Heating Systems in Federal Projects

| | Solar Water Heating Systems with Federal Project Economics | | | | |
|---|---|---|---|---|---|
| | | | | | |
| **Climate Zone** | **City** | **Natural Gas Rate (dollars/kcf)** | **Savings to Investment Ratio (SIR) offsetting natural gas** | **Heating Oil Rate (dollars/gallon)** | **Savings to Investment Ratio (SIR) offsetting oil** |
| 1 | Miami | $ 11.18 | 0.68 | | |
| 2 | Austin | $ 8.22 | 0.54 | | |
| 3 | Atlanta | $ 10.83 | 0.74 | | |
| 4 | Baltimore | $ 10.58 | 0.64 | $ 3.99 | 1.90 |
| 5 | Chicago | $ 11.27 | 0.76 | $ 3.48 | 1.74 |
| 6 | Minneapolis | $ 6.68 | 0.45 | $ 3.57 | 1.85 |
| 7 | Fargo | $ 6.70 | 0.43 | | |
| 8 | Fairbanks | $ 8.28 | 0.42 | | |
| | | | | | |
| Natural Gas prices from: | | http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm | | | |
| Oil prices from: | | http://www.eia.gov/dnav/pet/pet_pri_wfr_a_EPD2F_prs_dpgal_w.htm | | | |

**Table 24 Solar Water Heating Systems in Federal Sector Projects - NIST BLCCA Summary**

### 7.4.3.4Solar Water Heating Systems in Private Projects

| Solar Water Heating Systems with Private sector/PPV/PPA Economics | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| **Climate Zone** | **City** | **Natural Gas Rate (dollars/kcf)** | **Savings to Investment Ratio (SIR) offsetting natural gas** | **Heating Oil Rate (dollars/gallon)** | **Savings to Investment Ratio (SIR) offsetting oil** |
| 1 | | | | | |
| 2 | | | | | |
| 3 | Atlanta | $ 10.83 | 1.40 | | |
| 4 | Baltimore | $ 10.58 | 1.22 | $ 3.99 | 3.58 |
| 5 | Chicago | $ 11.27 | 1.44 | $ 3.48 | 3.29 |
| 6 | Minneapolis | $ 6.68 | 0.84 | $ 3.57 | 3.49 |
| 7 | | | | | |
| 8 | | | | | |
| | | | | | |
| Natural Gas prices from: | | http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm | | | |
| Oil prices from: | | http://www.eia.gov/dnav/pet/pet_pri_wfr_a_EPD2F_prs_dpgal_w.htm | | | |

**Table 25 Solar Water Heating Systems in Private Sector Projects - NIST BLCCA Summary**

# 8.0 IMPLEMENTATION ISSUES

Key lessons learned from this project are as follows:

1. Not all types and categories of buildings are candidates for all of the technologies included in the demonstration project. It is imperative that the current and proposed **future** use of a building are reviewed when considering it as a candidate for a high performance retrofit roofing system.

2. The performance of each technology will vary considerably with respect to the location and architecture of the building and loads within the building;

3. Implementation sites should be surveyed for suitability; i.e. is the building in need of a new metal roof and if so, implementation schedules should prioritize those buildings that will deliver a maximum rate of return on the investment and

4. An above sheathing ventilation system is detrimental to the efficiency of the building integrated solar water and space heating system in this demonstration.

## Codes and Permitting

The components of the integrated roof system discussed in this report are each covered within their respective sections of the building codes in use in the USA. Of all of the elements of the integrated roof system, building mounted and building integrated PV systems are widely recognized as the most dangerous of the components of the systems discussed in this report.

Building codes, fire codes, electrical codes etc. are known to vary to a considerable degree around the country. However, the National Fire Protection Association issues the National Electrical Code (NEC), which is often adopted by state and local code enforcement bodies.

Additionally, trade associations such as the Solar Energy Industries Association and the Solar America Board of Codes and Standards provide a robust set of resources of interest to those considering the deployment of solar energy systems. Links to their respective websites follow:

1. http://www.seia.org/policy/health-safety/fire-safety-solar

2. http://www.solarabcs.org/codes-standards/NFPA/index.html

The resources described above contain a very robust overview of code related requirements for PV Systems, the discussion of which is beyond the scope of this report. It can be accurately stated however, that PV systems are now considered mainstream and allowed in every jurisdiction, with a basic parameter that PV systems are not allowed to cover an entire roof surface. It varies from one jurisdiction to another, but generally, direct access to the roof surface (for firefighting) must be preserved at the ridge and roof edges (rakes and sometimes eaves) with the width of access varying from 3’ to 10’.

## Building Integrated Photovoltaic Systems (BIPV)

When this project was conceived, BIPV products were gaining market share and there were several viable US manufacturers of fully commercialized products. The investigators chose to incorporate a BIPV system that utilized Unisolar PV laminates manufactured by Energy Conversion Devices Inc. through its subsidiary, United Solar Ovonics.

Energy Conversion Devices and its subsidiaries ceased operations and the company’s assets were liquidated during the course of this project. During this same period, the BIPV market has stagnated and contracted as a result tremendous pricing pressure from manufacturers of crystalline PV panels who dropped their prices dramatically over the period of time covered by this project.

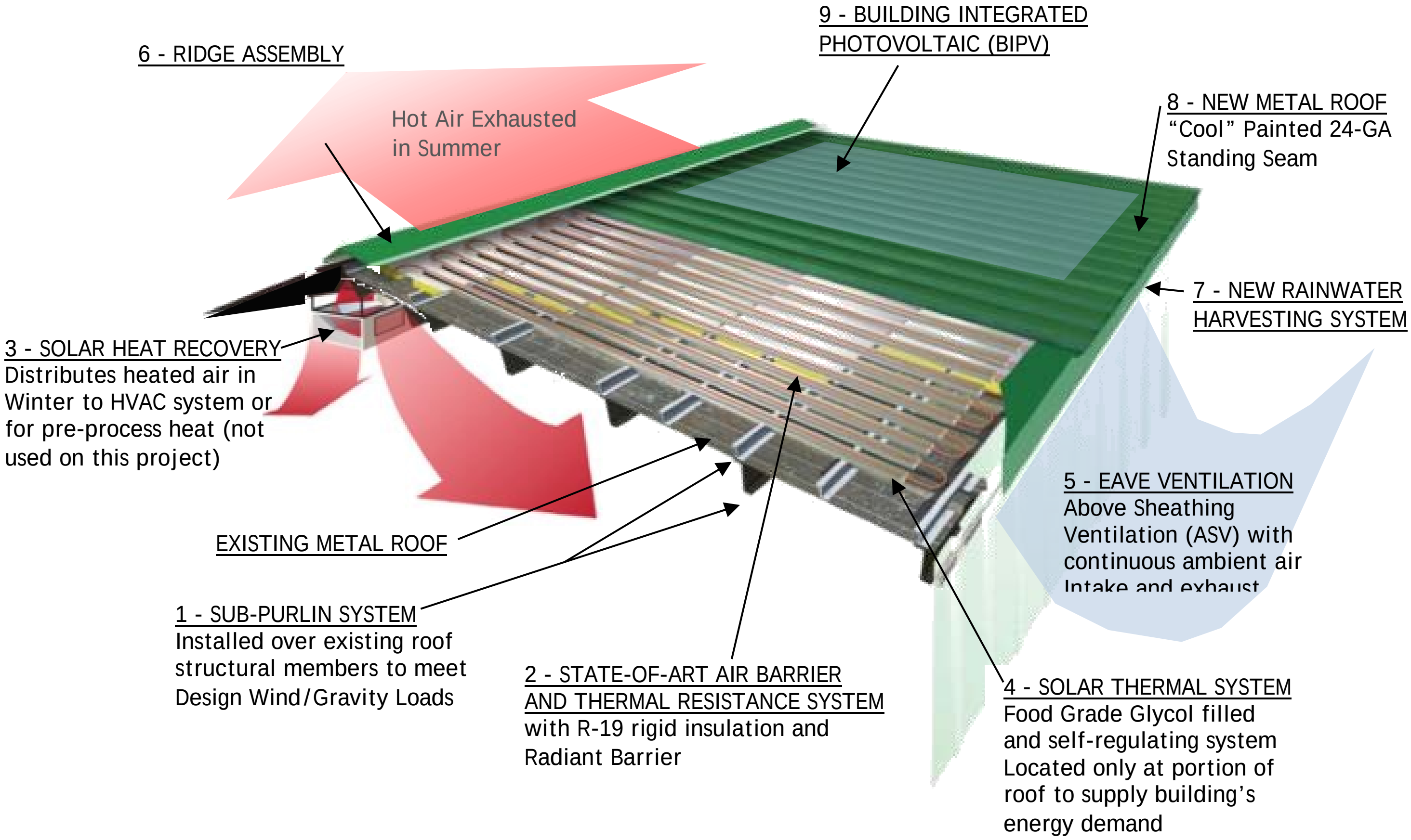
As this report is written, BIPV products are 50% to 200% more expensive than conventional modular PV panels that employ crystalline PV cells. Project economics and industry trends suggest that building owners and PV system designers favor the use of modular PV panels, particularly on buildings with flat roofs and on ground mounted PV systems where aesthetics don’t matter. When aesthetics factor into a building design and PV technology is desired, BIPV products become the preferred solution. It is generally accepted in the renewable energy industry, that, as the inventory of flat roofs and suitable locations for ground mounted array sites become absorbed, growth of the BIPV market will resume and accelerate, since new and retrofit buildings are ultimately the perfect platform for renewable energy systems. There is considerable evidence of this evolutionary process available in the archives of the IEA that is based on research conducted in the European Union.

## Appendix A: Points of Contact

| POINT OF CONTACT Name | ORGANIZATION Name Address | Phone Fax E-mail | Role in Project |
|---|---|---|---|
| Mary Lumsdon | Goodfellow Air Force Base | mary.lumsdon@us.af.mil | Energy Manager for GFAFB and primary on site point of contact. |
| Mark Engle | Metal Construction Assoc. Inc. 8735 W. Higgins Rd, Ste 300, Chicago, IL 60631 | 847-375-4708 MEngle@metalconstruction.org | Grantee Exec. Director |
| Scott Kriner | Metal Construction Assoc. Inc. | 610-966-2430 skriner1@verizon.net | Grantee POC |
| Debbie Gold | Metal Construction Assoc. Inc | 847.375.4778 DGold@Connect2amc.com | MCA Sr. Project Manager |
| Robert Scichili | Robert Scichili Assoc. Inc. | 972-234-0180 RGScichili@aol.com | Principal Investigator |
| David Dodge | Paramount Metal Systems LLC | 501-312-9062 ddodge@paramountmetalsystems.com | Prime Sub Contractor Exec |
| Jeff Slagle | Paramount Metal Systems LLC | 512-745-2509 jslagle@paramountmetalsystems.com | Prime Sub Contractor Project Manager |
| William Poleatewich | Energy Integration Partners LLC. | 603-608-7561 Bill.P@e-ipartners.com | Renewable Energy System Consultant |
| Dale Nelson | Roof Hugger Inc. | 214-213-1070 dnelson@roofhugger.com | Retrofit Roofing System Consultant |
| Andre Desjarlais | Oak Ridge Nat, Laboratory | desjarlaisa@ornl.gov | Testing/Monitoring POC |

## Appendix B: Graphic illustrating technology in roof assembly

The below illustration provides a visual explanation to assist the reader in understanding the components that are encapsulated between the old and new roofs in this project. Each component is engineered to meet all established design criteria including structural, mechanical, electrical and plumbing as well essential and adopted building codes specified by the DoD.




***Refer to Appendix D for Detailed Descriptions of each "Number Keyed" Component***

## Appendix C: Notes to Appendix B

**KEYED REFERENCES TO APPENDIX "B" ILLUSTRATION**

**1. SUB-PURLIN SYSTEM** is installed onto the existing roof and its structural support system. It is a factory-notched zee-shaped sub-purlin manufactured to nest into and over the existing metal roof's major ribs and profile. This creates a very low-profile assembly that is dictated by the total thickness of new insulation and solar thermal systems being installed. These structurally correct systems are manufactured from 16-gauge G-90 galvanized coated steel having a minimum yield strength of 50,000 PSI. The entire sub-purlin system is engineered to satisfy the most currently adopted building code for wind uplift and gravity/snow loads.

**2. AIR BARRIER AND THERMAL RESISTANCE SYSTEM** is installed between and on top of the Sub-Purlin System, which includes the following:

A. Two-layers of high density polyisocyanurate rigid insulation board installed over the existing roof and between the Sub-Purlins with the top layer taped to prevent air-infiltration and a reflective radiant barrier then installed. Depending upon the existing insulation, total insulation values of R30 to R40 will be achieved. Any voids at roof-wall junctures and similar locations are spray foam filled and sealed.

**3. thru 5. SOLAR HEAT RECOVERY** is designed to seasonally move heated air either into the building or out of the roof assembly cavity as described below:

a. In summer, using Above Sheathing Ventilation (ASV) the warm air in the cavity moves naturally by convection and is vented through an optional damperable ridge ventilator to the ambient environment, reducing the cooling load on the building.

b. In winter, the heated air in the cavity can be captured and re-directed inside the building and then distributed to a HVAC system with a solar-powered fan, to process heating applications or to improve the efficiency of geo-thermal heating or heat recovery ventilation systems. (not used on this project)

**6. SOLAR THERMAL SYSTEM** is a three-fold technology as explained below:

a. In-space heating applications using hot water or hot air; when the thermostat calls for heat and sufficient energy is available, solar energy will be transferred through a dedicated, wall, floor or duct mounted heat exchanger or solar space heating unit and distributed to the building until the thermostat is satisfied or the solar energy supply is exhausted.

b. In-process heating applications; when the thermostat calls for heat and sufficient energy is available in the solar storage tank or the solar array, solar energy will be transferred to the process application until the thermostat is satisfied or the solar energy supply is exhausted.

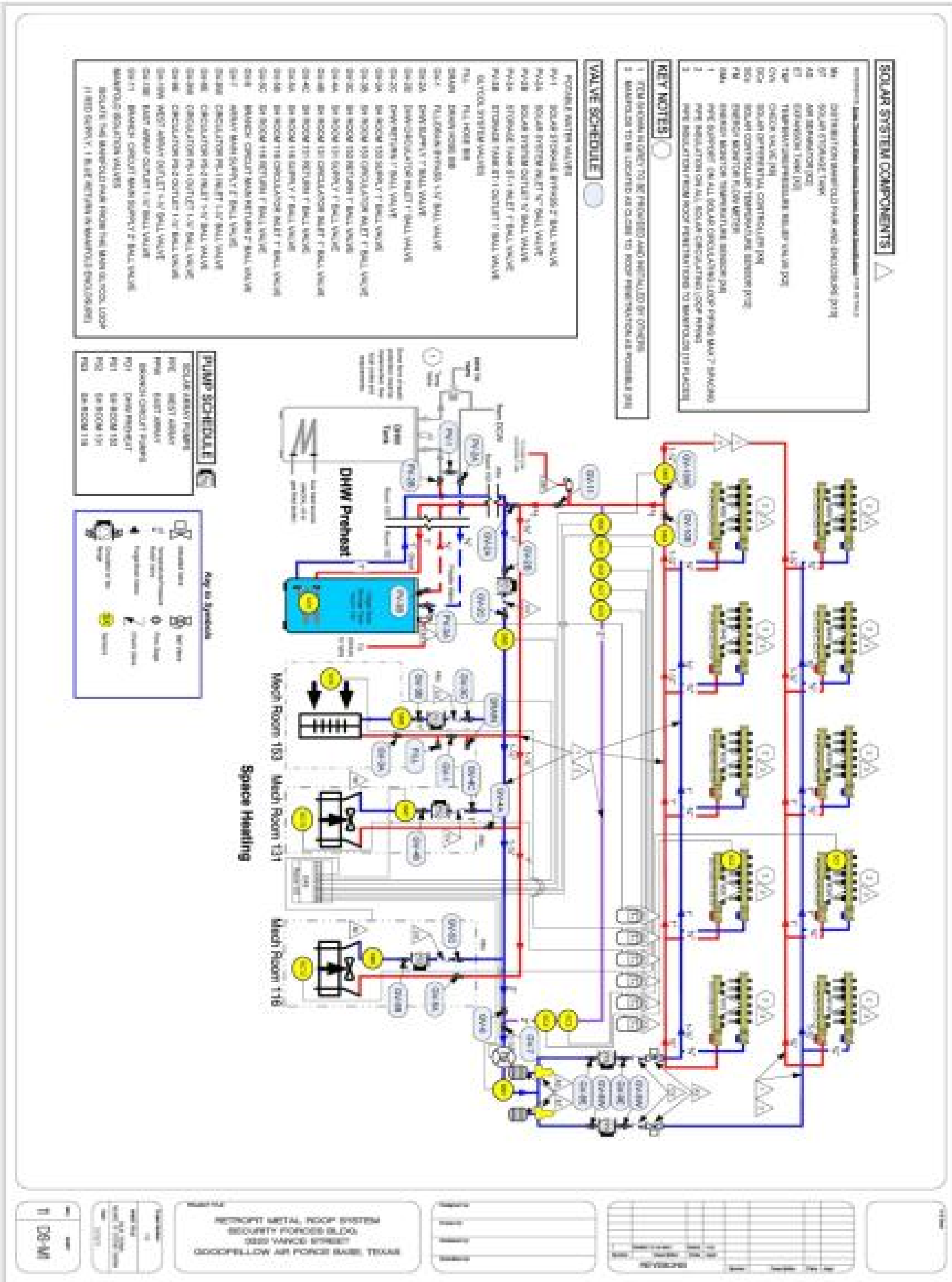
c. As a closed loop, indirect domestic hot water heating system that uses a food-grade glycol protected system; as domestic hot water (DHW) is drawn from the primary water heater, water replacing it will be drawn from the dedicated solar storage (preheat) tank, thereby eliminating or reducing the use of fossil fuels, bio-fuels or electricity.

**7. RAINWATER HARVESTING SYSTEM**: These systems are designed specifically to meet the requirements of each individual project with one goal in mind – to effectively capture, manage and reuse rain water for non-potable or potable applications.

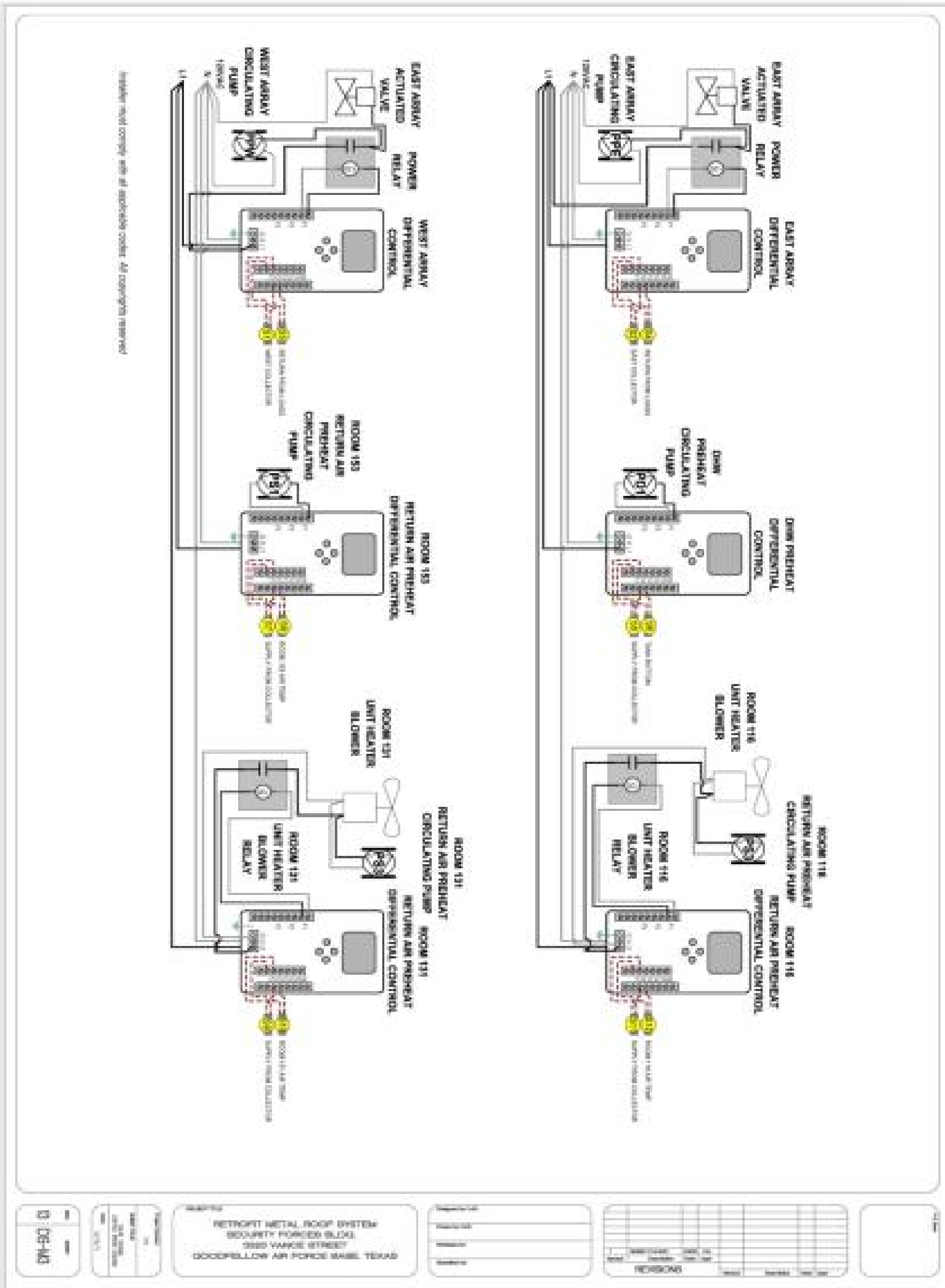
**8. NEW METAL ROOF** is 24-Gauge standing seam, profile and color matched to the DoD Base Roofs.

**9. BUILDING INTEGRATED PHOTOVOLTAIC (BIPV)** that are applied atop the roof include amorphous silicon PV laminated panels that are bonded to the new metal roof.

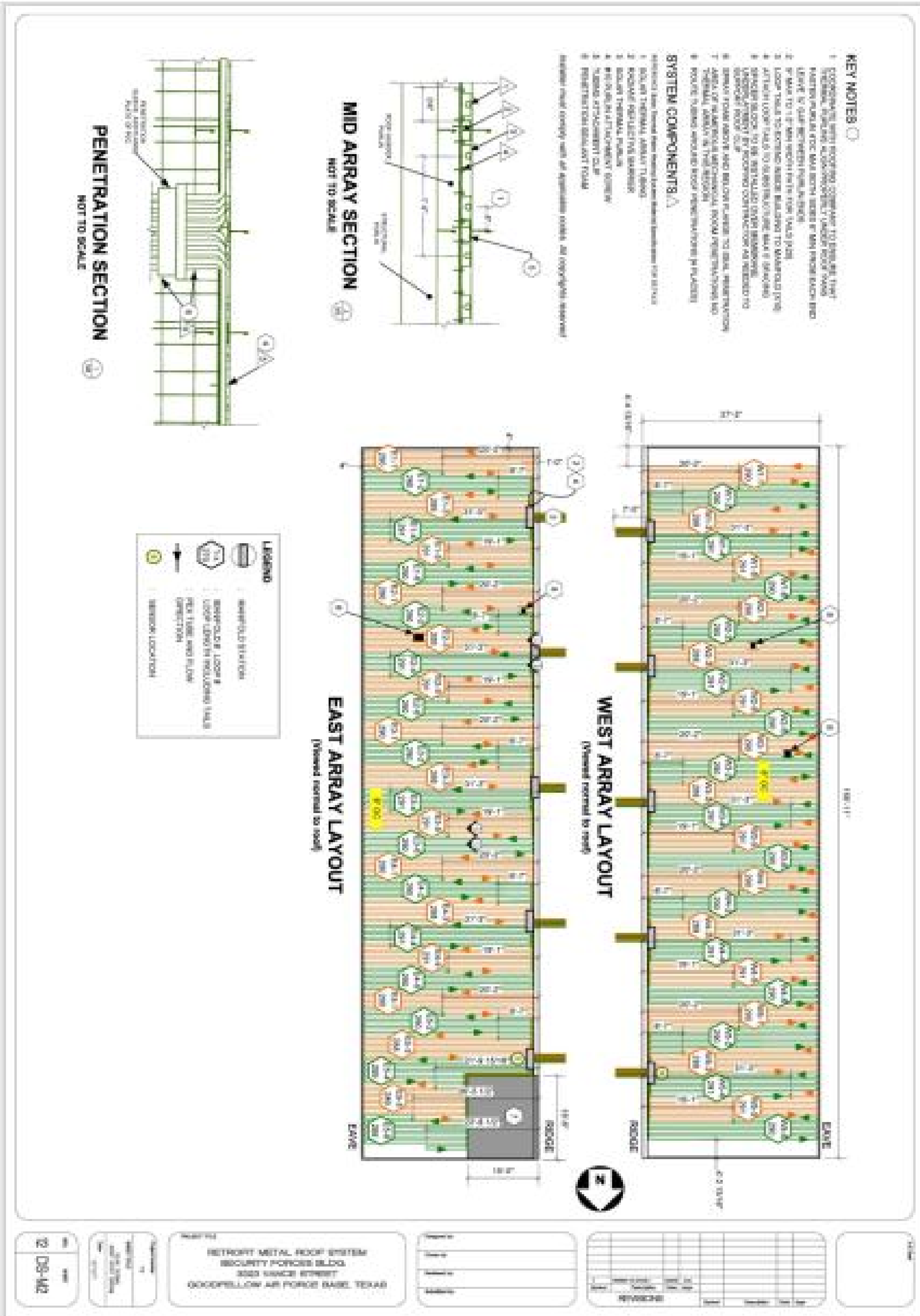
# Appendix D: Solar Thermal System Mechanical Schematic



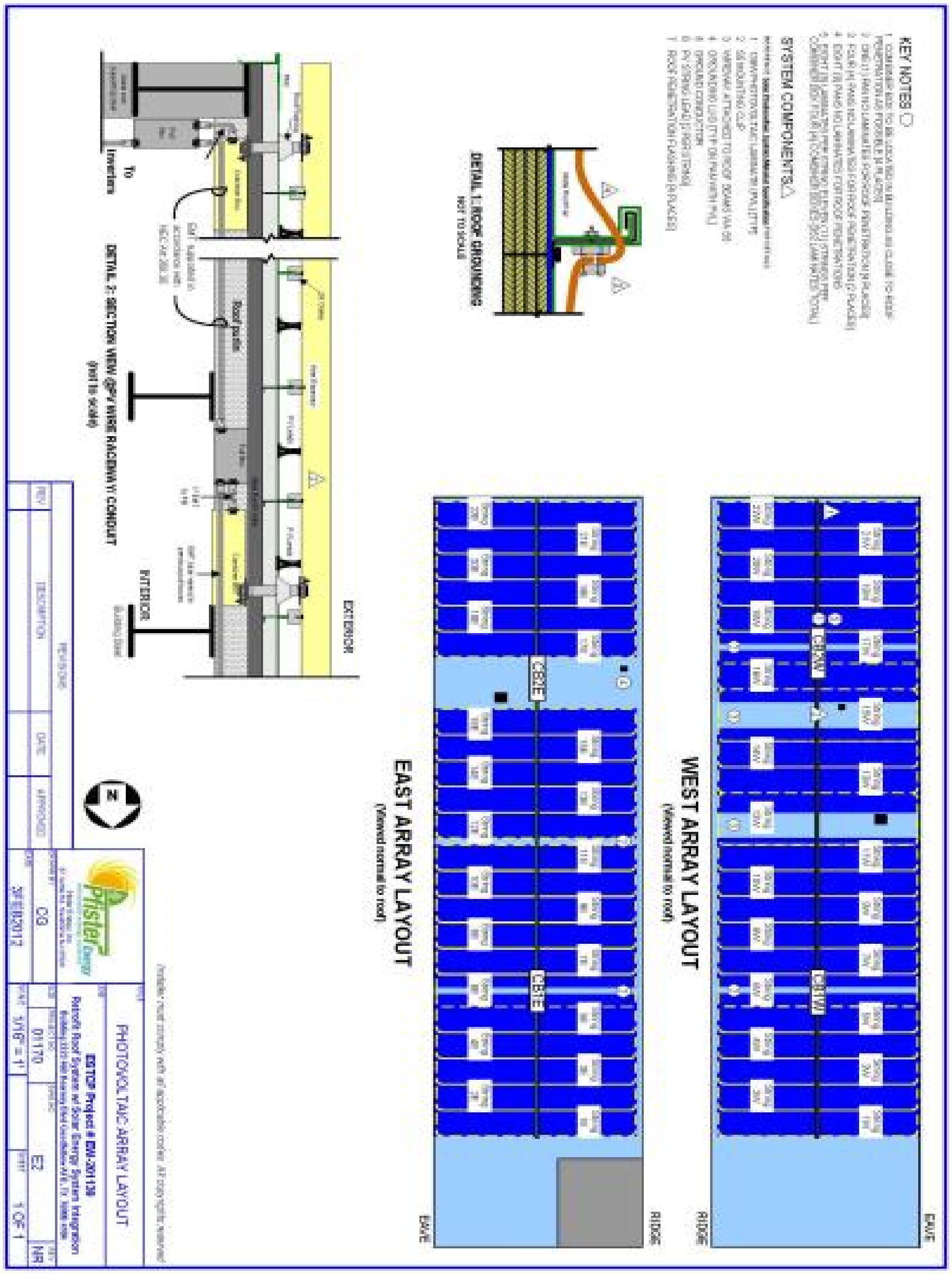
## Appendix E: Solar Thermal Control Wiring Schematic



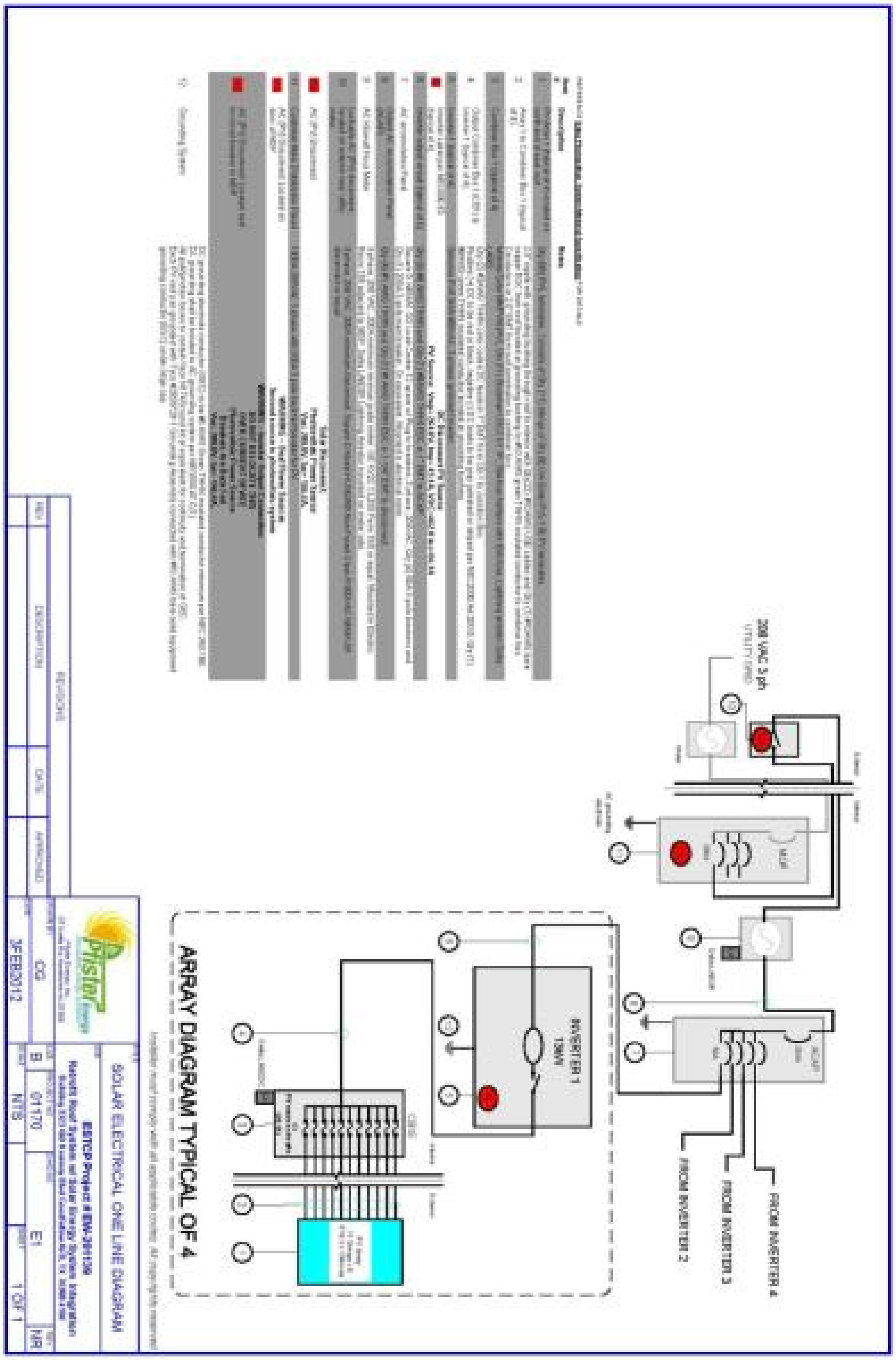
# Appendix F: Building Integrated Solar Thermal System Array Layout



# Appendix G: Solar Electric-PV System Array Layout



# Appendix H: Solar Electric-PV System Schematic



## Appendix I: Rainfall and Water and Sewer Data Links

**Miami:**
http://www.weather.com/weather/wxclimatology/monthly/graph/USFL0316

http://www.miamidade.gov/water/library/fees/rate-schedule-2013-14.pdf

**Austin:**
http://www.weather.com/weather/wxclimatology/monthly/graph/USTX0057

https://www.austintexas.gov/department/austin-water-utility-service-rates

**Atlanta:**
http://www.weather.com/weather/wxclimatology/monthly/graph/USGA0028

http://www.atlantawatershed.org/default/?linkServID=49AD882E-63E7-40F7-9F55E532CDCA6B1F&showMeta=2&ext=.pdf

**Baltimore:**
http://www.weather.com/weather/wxclimatology/monthly/USMD0018

http://www.baltimorecountymd.gov/Agencies/publicworks/metro/metro_swrsrvchg.html

**Chicago:**
http://www.weather.com/weather/wxclimatology/monthly/graph/USIL0225

http://www.cityofchicago.org/city/en/depts/water/provdrs/cust_serv/svcs/know_my_water_sewerrates.html

**Minneapolis:**
http://www.weather.com/weather/wxclimatology/monthly/graph/USMN0503

http://www.minneapolismn.gov/utilitybilling/utility-billing_rates

**Fargo:**
http://www.weather.com/weather/wxclimatology/monthly/graph/USND0115

http://www.cityoffargo.com/Business/WaterandSewerRates/

**Fairbanks:**
http://www.weather.com/weather/wxclimatology/monthly/graph/USAK0083

http://www.akwater.com/billcalc.php?co=CUC&typ=Commercial

## Appendix J: Field Trip Report 11014

January 10, 2014
ESTCP Project - GFAFB
In Field Service Report
Jeff Slagle
On Site Date: 01/09/13 10:30AM – 3:00 PM
Interviewed: Mary Lumsdon, HVAC Lead Tech, Facility Building Management Operator

Systems Checks and Observations:

1. Additional Load Speculation
2. On Interview with Mary Lumsdon and the Facility personnel:

The former area used for the detainment cells of the building which is the South East corner of the building has been converted into a server area and the video security observation unit. The server area houses several large server racks and the video area is has +/- 20 video monitors and supporting equipment. At the time of the site visit the area had 6 personnel in this area.
This area is heated/cooled by Unit #1 – A 5 ton AC unit with a boiler supplied heat coil and air handler for heat. The unit is believed to be the original installation for this area.
The server area went into service July of 2012 which is one month after completion of construction of the ESTCP project.
Comments and observations of the GFAFB staff are that the HVAC unit is undersized for the increased load of the heat created by the new equipment. The unit is has been in continuous operation on the cooling cycle since the area went into service. At the time of the site visit (11:00 AM) the Outdoor air temperature was 38 degrees and conditions were cloudy. The set point on the unit was 68 degrees and the recorded temp in that area was 74 degrees. Staff at the video monitoring stations reported that they often open the door to the outside and place a fan at the door to help exhaust the heat. To no one's knowledge has the unit not been running on the cooling cycle since start of operations of the area except for a brief time when the unit malfunctioned, The techs believe the unit has run 24/7 since the Data center went into service.
In addition to the increased load of this area it also effects the HVAC Unit #2 that is adjacent to Unit 1 in the East Mechanical room. Unit #2 serves the conference room and other areas of the building. These 2 units share return air through the systems in the mechanical room. Result is that the return air Unit 2 is tempered by the return air from the server area. This reduces the efficiency of Unit # 2 in cooling mode and during heat mode for the Unit #2 areas, the two systems are counteracting each other due to the Data Center area calling for cooling and sending cooler air back to return while Unit #2 is calling for heating and sending heated air back to return.

A communication building containing 2 x 3 ton Package cooling units has been installed adjacent to the Building just north of the communication tower west of the building. The electricity for this system is fed from the Main Building. This building and systems was put in operation in November, 2013. This would indicate little effect on the increased electrical issues.

3. Solar Thermal

   Under direction of Carl Gettelman via phone the setpoints for the Solar Thermal heat-assist air handling units was set back to 69 degrees to prevent the coils operating during cooling cycles.

   The Sim cards for the 6 Solar thermal controllers were removed and will be sent to Carl for download and analysis.

4. PV

   The inverter meter readings were logged and seemed to be operating as expected per Carl. Mary Lumsdon has been monthly recording the EAC meter readings of each inverter and tracking output. She commented that recently she has seen a reduction in output but the area has experienced an abnormally high number of cloudy days and winter weather events for this time of year. Upon roof inspection the PV Panels were clean and in excellent condition.

5. RWCS

   The RWCS has not been utilized as all irrigation has been shut down on the Base due to drought restrictions. Upon inspection the tank was +/- 80% of capacity. The submeter for output is reading 0000100, indicating very little operation after initial testing of the system.

   The inlet basket screen is torn and needs to be replaced or a wire screen inserted into the bottom of the basket. I repaired a leak on a connector at the middle downspout while at the site. The gutters have a large collection of leaves and leaves are restricting flow at the screen guards at the downspout inlets. Mary put in a work order for gutter cleaning.

6. Roof

   The roof was inspected and shows no signs of issues other than the gutters needing to have leaves removed. All curbs and penetration seals appear to be in good condition and there are no reports or signs of leaks in any areas. The PV panels and connections appear to be clean and in good condition.

End of report -

# Appendix K: Atlanta Solar Water Heating System Performance Modeling Report[13]

## Comparison Report

**Location of the system**

Atlanta, GA
Longitude: -84.378°
Latitude: 33.781°
Elevation: 935 ft

**This report has been created by:**

Energy Integration Partners
Carl Gettelman

**Map section**

**System overview (annual values)**

| | |
|---|---|
| Comfort demand | Energy demand covered |
| Saved energy compared to reference system | 205,916.6 kBtu |
| CO2 savings compared to reference system | 30,461.3 pound |
| Total fuel and electrical energy consumption of the system | 629,215.7 kBtu |
| Total fuel and electrical energy consumption of the reference system | 835,132.3 kBtu |

**Overview solar thermal energy (annual values)**

| | |
|---|---|
| Collector area | 5,005.2 ft² |
| Savings compared to reference system | 24.7 % |
| Total annual field yield | 207,828 kBtu |
| Collector field yield relating to gross area | 41.5 kBtu/ft²/Year |
| Collector field yield relating to aperture area | 41.5 kBtu/ft²/Year |

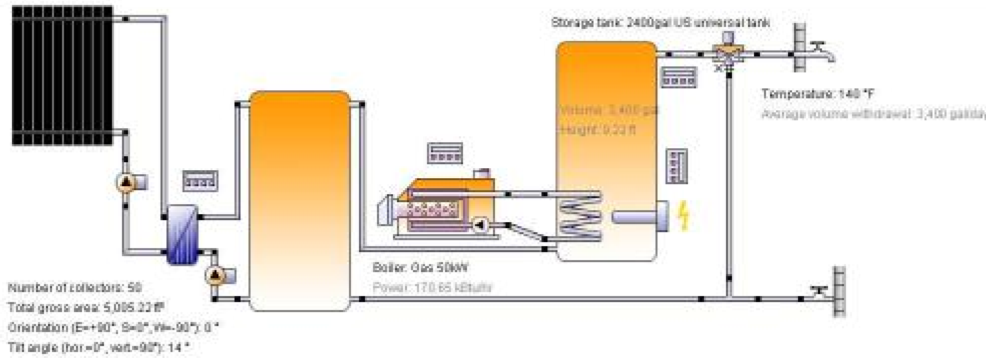
2 / 8 V6.2.9.18650 / 10.01.2014 / 14:26:50 polysun

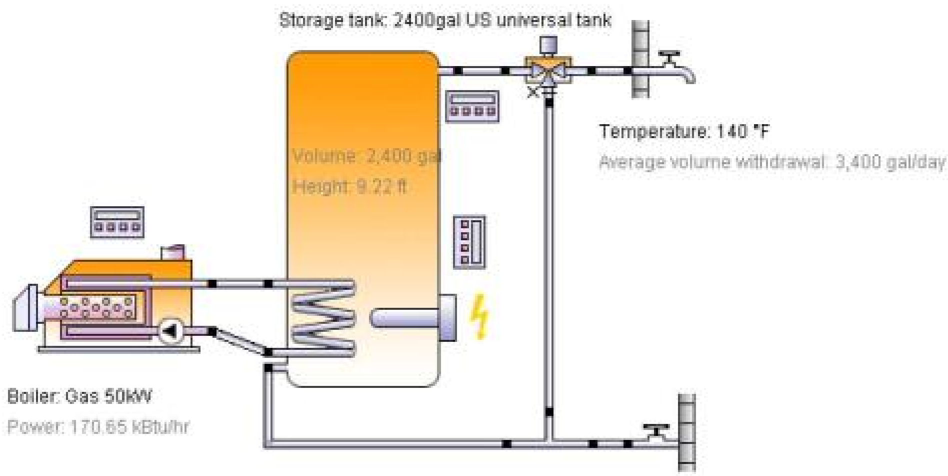
Vela Solaris AG, their distribution partners or SPF do not accept any liability for the correctness of the specifications and the results.

[13] Solar Thermal Performance Projections are based on SRCC OG 100 Certification #100-2004-009A for Dawn Solar Model 304L in Appendix S

# Comparison Report

**Atlanta Solar Water Heating** **DHW Preheat South Facing Array**

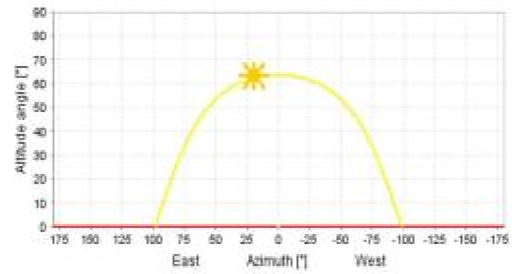


# Comparison Report

**Savings compared to reference system [Fss]**


**Horizon line**




**Meteorological data-Overview**

| | |
|---|---|
| Average outdoor temperature | 62.3 °F |
| Global irradiation, annual sum | 536.4 kBtu/ft² |
| Diffuse irradiation, annual sum | 217.4 kBtu/ft² |

**Component overview (annual values)**

| | | |
|---|---|---|
| **Boiler** | **Gas 50kW** | |
| Power | kBtu/hr | 170.65 |
| Total efficiency | % | 88.7 |
| Energy from/to the system [Qaux] | kBtu | 556,785.6 |
| Fuel and electrical energy consumption [Eaux] | kBtu | 627,435.2 |
| Fuel consumption of the back-up boiler [Baux] | therms | 6,143.1 |
| **Collector North America South** | **3004L** | |
| Data Source | | SRCC |
| Total gross area | ft² | 5,005.22 |
| Total aperture area | ft² | 5,006.295 |
| Total absorber area | ft² | 5,006.29 |
| Tilt angle (hor.=0°, vert.=90°) | ° | 14 |
| Orientation (E=+90°, S=0°, W=-90°) | ° | 0 |
| **Hot water demand** | **Mess Hall** | |
| Volume withdrawal/daily consumption | gal/d | 3,404 |
| Temperature setting | °F | 140 |
| Energy demand [Qdem] | kBtu | 803,829.9 |
| **External heat exchanger Solar** | **huge** | |
| Transfer capacity | W/K | 30,000 |
| **Pump Solar loop pump** | **Wilo Star 21** | |
| Circuit pressure drop | psi | 10.066 |
| Flow rate | gpm | 15 |

# Comparison Report

| | | |
|---|---|---|
| Fuel and electrical energy consumption [Epar] | kBtu | 890.3 |

| **Pump HX to Tank** | **Wilo Star 21** | |
|---|---|---|
| Circuit pressure drop | psi | 1.85 |
| Flow rate | gpm | 15 |
| Fuel and electrical energy consumption [Epar] | kBtu | 890.3 |

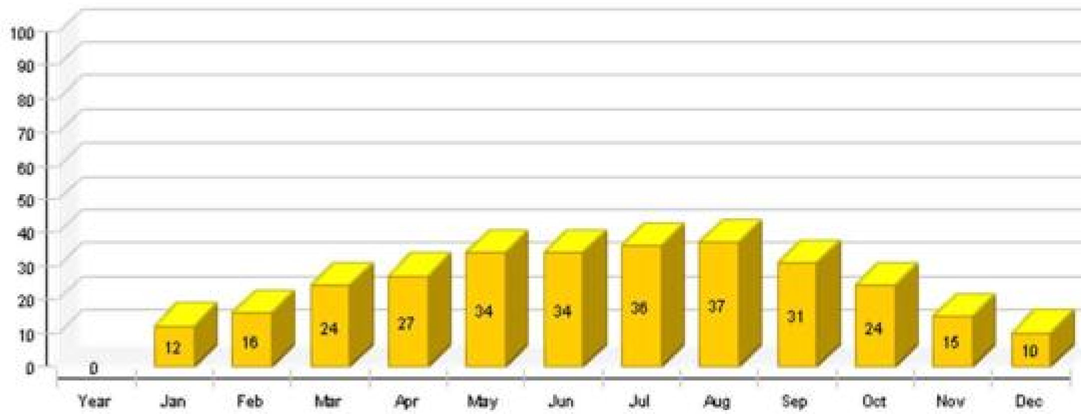
| **Storage tank Potable water tank 2** | **2400 gal US universal tank** | |
|---|---|---|
| Volume | gal | 2,400 |
| Height | ft | 9.22 |
| Material | | Enameled steel |
| Insulation | | Flexible polyurethane foam |
| Thickness of insulation | in | 4 |
| Heat loss | kBtu | 6,342.4 |
| Connection losses | kBtu | 856.6 |

| **Storage tank Solar** | **800 coiless** | |
|---|---|---|
| Volume | gal | 800 |
| Height | ft | 7.22 |
| Material | | Enameled steel |
| Insulation | | Flexible polyurethane foam |
| Thickness of insulation | in | 4 |
| Heat loss | kBtu | 726.6 |
| Connection losses | kBtu | 78.8 |

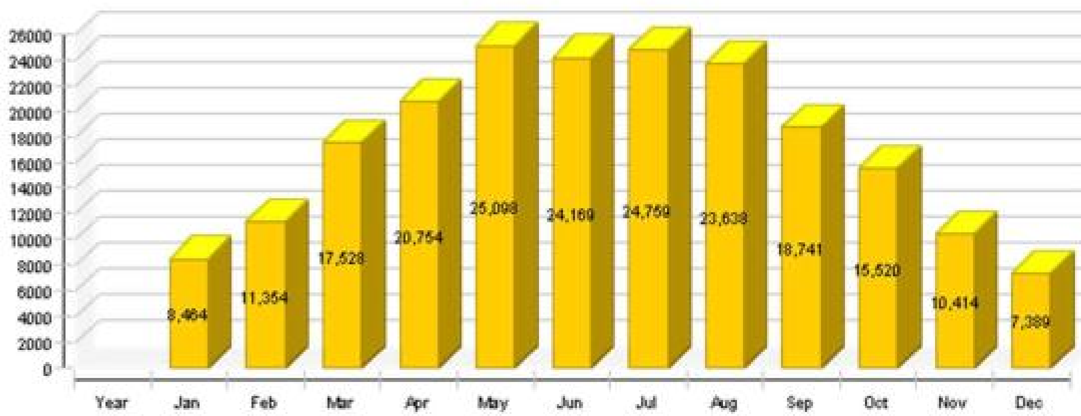
## Loop

| **Solar loop** | | |
|---|---|---|
| Fluid mixture | | Propylene mixture |
| Fluid concentration | % | 50 |
| Fluid domains volume | gal | 114.1 |
| Pressure on top of the circuit | psi | 58 |

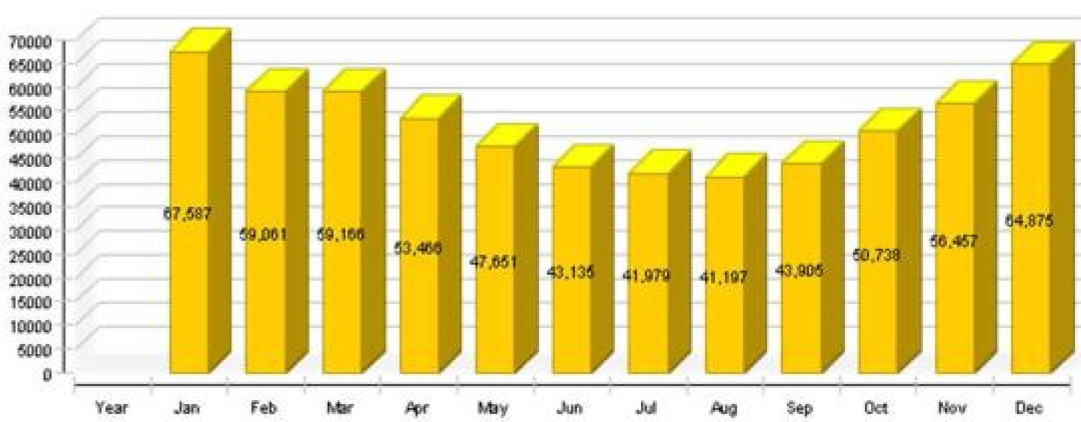
# Comparison Report




**Solar thermal energy to the system [Qsol]** **kBtu**

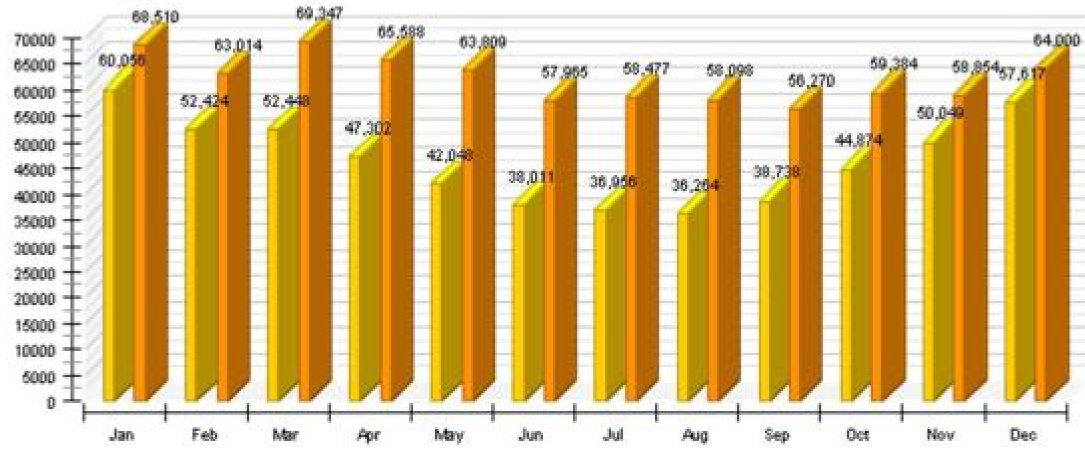



**Total fuel and/or electrical energy consumption of the system [Etot]** **kBtu**



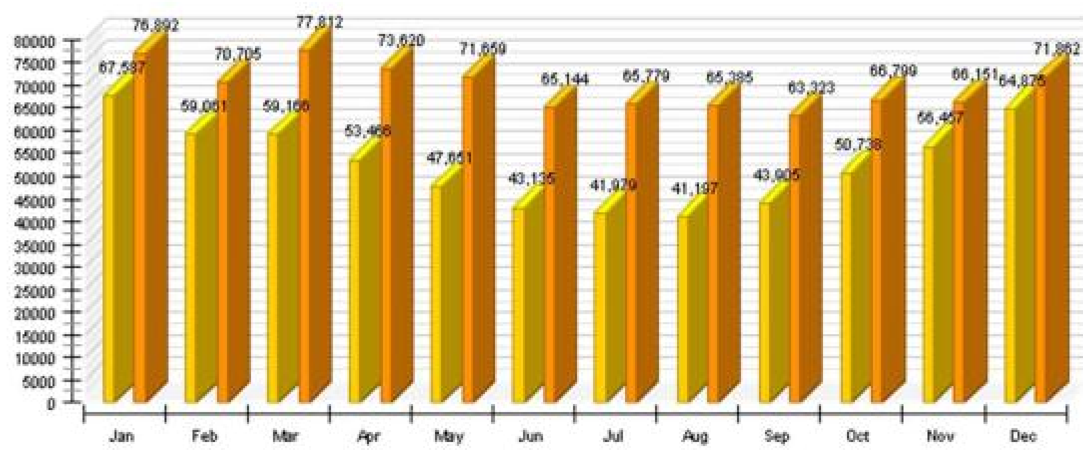
## Comparison Report

**Heat generator energy to the system (solar thermal energy not included) [Qaux]** kBtu




Key: Right->Results of the reference system

**Total fuel and/or electrical energy consumption of the system [Etot]** kBtu




Key: Right->Results of the reference system

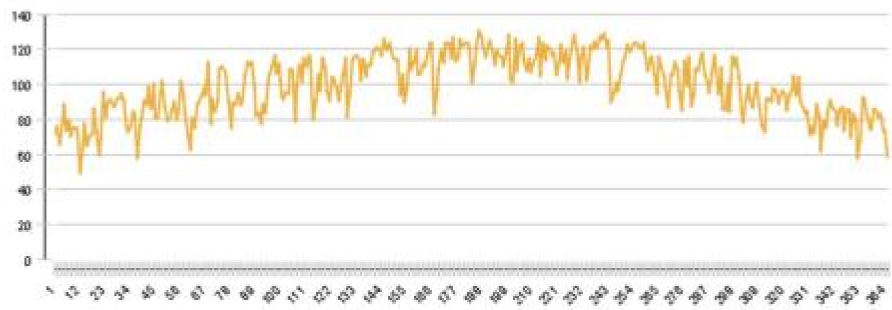
| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solar thermal energy to the system [Qsol]** | | | | | | | | | | | | | |
| kBtu | 207828 | 8464 | 11354 | 17528 | 20754 | 25098 | 24169 | 24759 | 23638 | 18741 | 15520 | 10414 | 7389 |
| **Total energy demand [Qdem]** | | | | | | | | | | | | | |
| kBtu | 803830 | 73439 | 67771 | 74893 | 70659 | 69852 | 64127 | 63221 | 61524 | 59690 | 63617 | 64649 | 70387 |

## Comparison Report

| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total energy demand [Qdem] (Reference)** | | | | | | | | | | | | | |
| kBtu | 803834 | 73439 | 67771 | 74894 | 70659 | 69852 | 64128 | 63223 | 61525 | 59690 | 63618 | 64648 | 70386 |
| **Total fuel and/or electrical energy consumption of the system [Etot]** | | | | | | | | | | | | | |
| kBtu | 629216 | 67587 | 59061 | 59166 | 53466 | 47651 | 43135 | 41979 | 41197 | 43905 | 50738 | 56457 | 64875 |
| **Total fuel and/or electrical energy consumption of the system [Etot] (Reference)** | | | | | | | | | | | | | |
| kBtu | 835132 | 76892 | 70705 | 77812 | 73620 | 71659 | 65144 | 65779 | 65385 | 63323 | 66799 | 66151 | 71862 |
| **Total energy consumption [Quse]** | | | | | | | | | | | | | |
| kBtu | 756158 | 67494 | 63129 | 69504 | 67091 | 66405 | 61232 | 60576 | 59143 | 56819 | 59815 | 60049 | 64901 |
| **Total energy consumption [Quse] (Reference)** | | | | | | | | | | | | | |
| kBtu | 735780 | 67550 | 62539 | 69013 | 65008 | 62836 | 57266 | 58160 | 57504 | 55640 | 58749 | 58482 | 63035 |

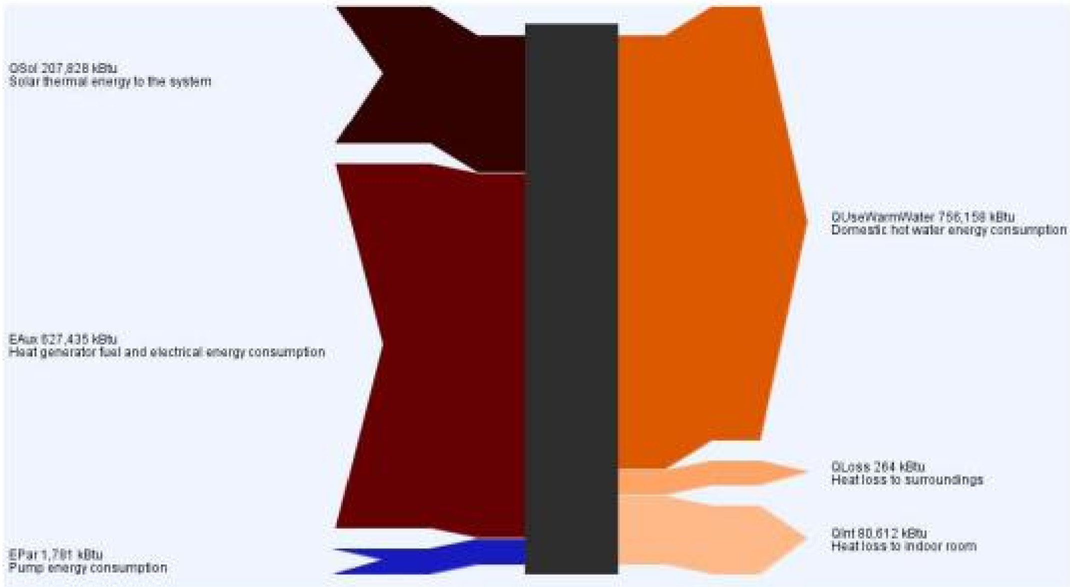
### Collector North America South

Daily maximum temperature [ °F]



## Comparison Report

### Energy flow diagram (annual balance)



# Appendix L: Atlanta Solar Space Heating System Performance Modeling Report[14]

[14] Solar Thermal Performance Projections are based on SRCC OG 100 Certification #100-2004-009A for Dawn Solar Model 304L in Appendix S

# Comparison Report

**Location of the system**

Atlanta, GA
Longitude: -84.351°
Latitude: 33.786°
Elevation: 997 ft

**This report has been created by:**

Energy Integration Partners
Carl Gettelman

**Map section**


**System overview (annual values)**

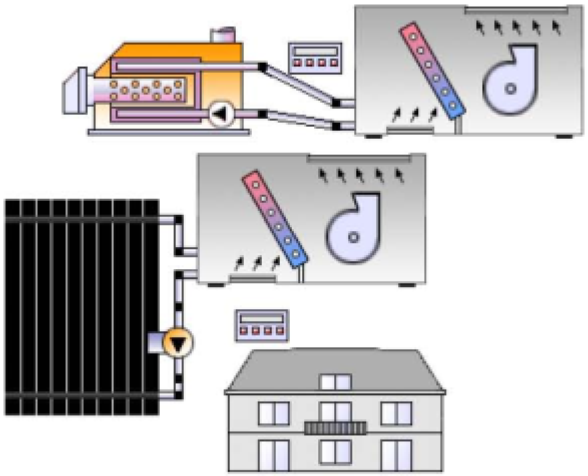
| | |
|---|---|
| Comfort demand | Energy demand covered |
| Saved energy compared to reference system | 94,554.5 kBtu |
| CO2 savings compared to reference system | 14,143.2 pound |
| Total fuel and electrical energy consumption of the system | 223,495.3 kBtu |
| Total fuel and electrical energy consumption of the reference system | 318,049.8 kBtu |

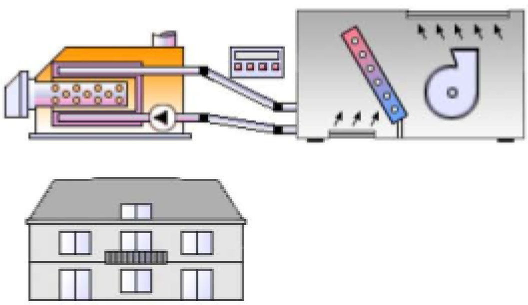
**Overview solar thermal energy (annual values)**

| | |
|---|---|
| Collector area | 5,005.2 ft² |
| Savings compared to reference system | 29.7 % |
| Total annual field yield | 153,394.6 kBtu |
| Collector field yield relating to gross area | 30.6 kBtu/ft²/Year |
| Collector field yield relating to aperture area | 30.6 kBtu/ft²/Year |

## Comparison Report

**Atlanta** **Space Heating South Facing Array**





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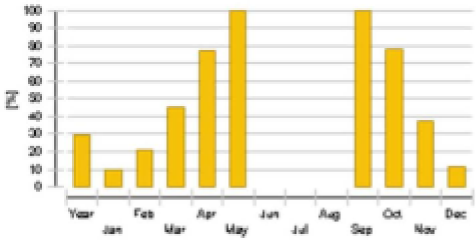
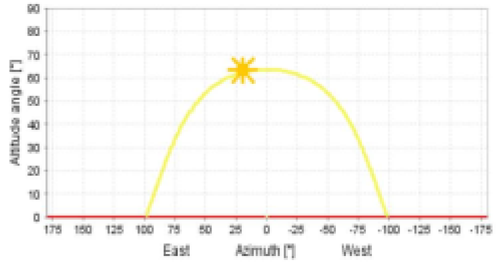
## Comparison Report

**Savings compared to reference system [Fss]**




**Horizon line**




**Meteorological data-Overview**

| | |
|---|---|
| Average outdoor temperature | 62 °F |
| Global irradiation, annual sum | 536.7 kBtu/ft² |
| Diffuse irradiation, annual sum | 219.3 kBtu/ft² |

**Component overview (annual values)**

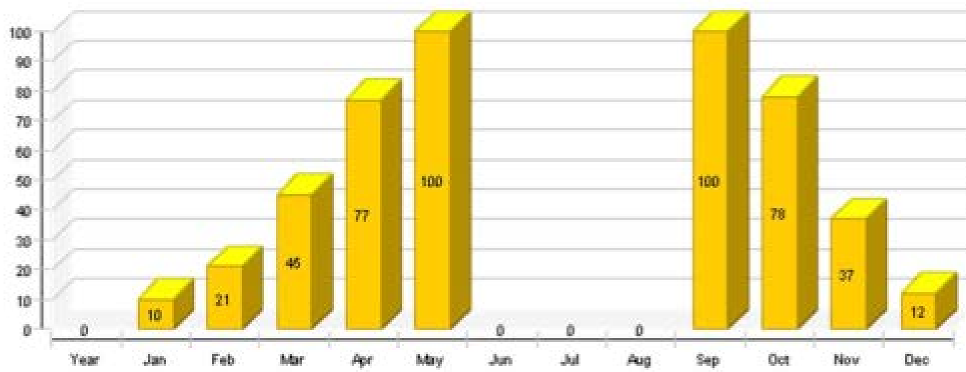
| | | |
|---|---|---|
| **Boiler 2** | **Gas 50kW** | |
| Power | kBtu/hr | 170.65 |
| Total efficiency | % | 89.8 |
| Energy from/to the system [Qaux] | kBtu | 200,709.4 |
| Fuel and electrical energy consumption [Eaux] | kBtu | 223,468.6 |
| Fuel consumption of the back-up boiler [Baux] | therms | 2,187.9 |
| **Collector North America South** | **3004L** | |
| Data Source | | SRCC |
| Total gross area | ft² | 5,005.22 |
| Total aperture area | ft² | 5,006.295 |
| Total absorber area | ft² | 5,006.29 |
| Tilt angle (hor.=0°, vert.=90°) | ° | 14 |
| Orientation (E=+90°, S=0°, W=-90°) | ° | 0 |
| **Building** | | |
| Heated/air-conditioned living area | ft² | 9,900 |
| Heating setpoint temperature | °F | 68 |
| Heating energy demand excluding DHW [Qdem] | kBtu | 354,088.2 |
| **Fan coil Solar** | **Four-pipe system size 7** | |
| Number of fan coils | - | 42 |
| Nominal heating power | kBtu/hr | 18 |
| Nominal hot water inlet temperature | °F | 176 |
| Nominal hot water return temperature | °F | 140 |
| Energy from/to the system [Quse] | kBtu | 153,395.4 |

## Comparison Report

| Fan coil 2 | Four-pipe system size 7 | |
|---|---|---|
| Number of fan coils | - | 48 |
| Nominal heating power | kBtu/hr | 18 |
| Nominal hot water inlet temperature | °F | 176 |
| Nominal hot water return temperature | °F | 140 |
| Energy from/to the system [Quse] | kBtu | 200,692.9 |

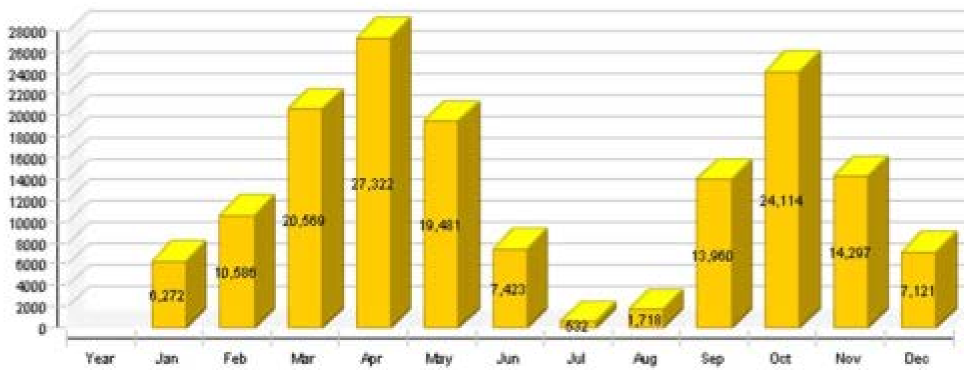
| Pump SSH | Eco, small | |
|---|---|---|
| Circuit pressure drop | psi | 2.117 |
| Flow rate | gpm | 15.9 |
| Fuel and electrical energy consumption [Epar] | kBtu | 26.7 |

**Savings compared to reference system [Fss]** %

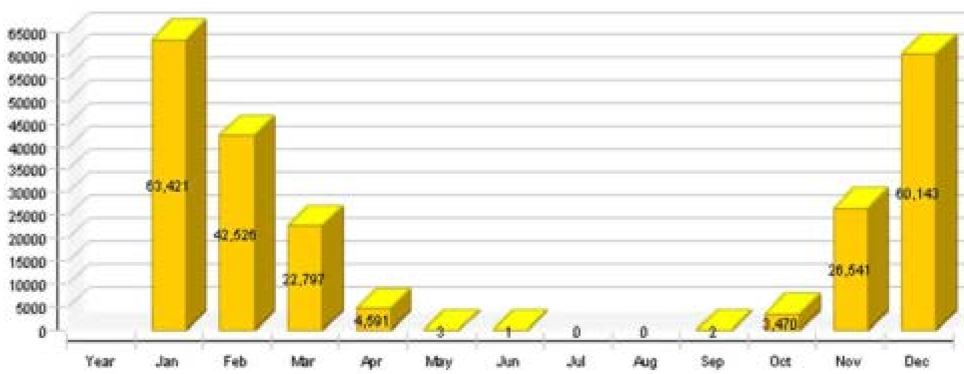


## Comparison Report

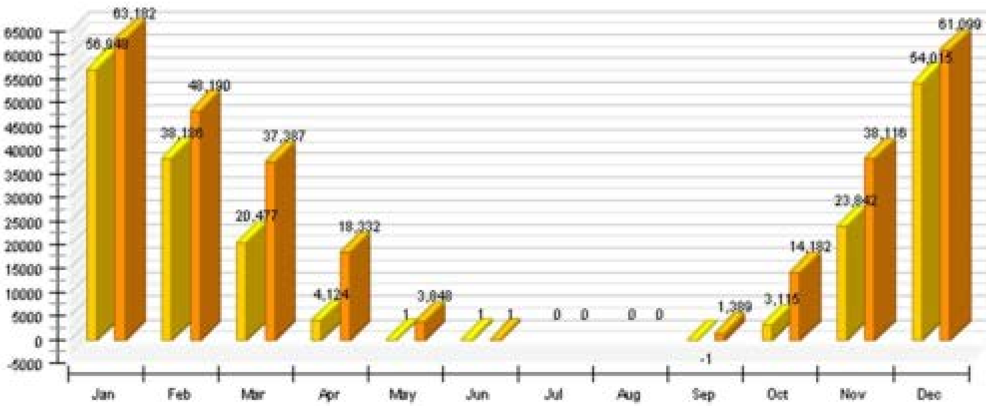
**Solar thermal energy to the system [Qsol]** kBtu




**Total fuel and/or electrical energy consumption of the system [Etot]** kBtu

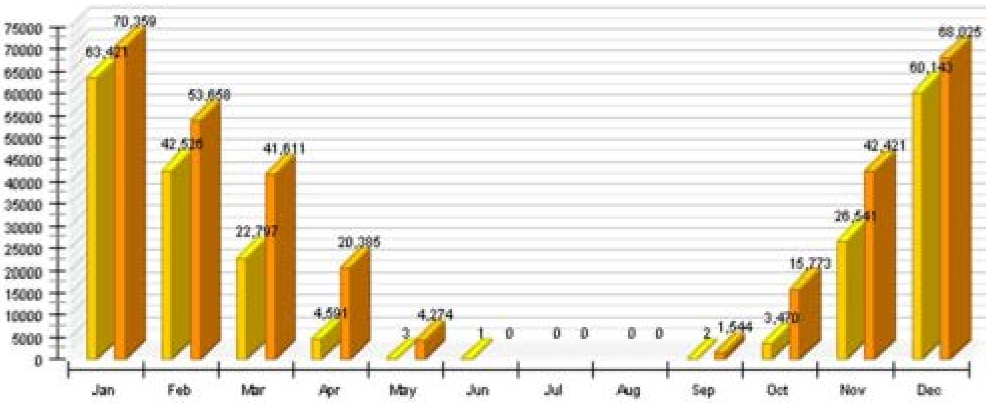


## Comparison Report




Key: Right->Results of the reference system

**Total fuel and/or electrical energy consumption of the system [Etot]** kBtu




Key: Right->Results of the reference system

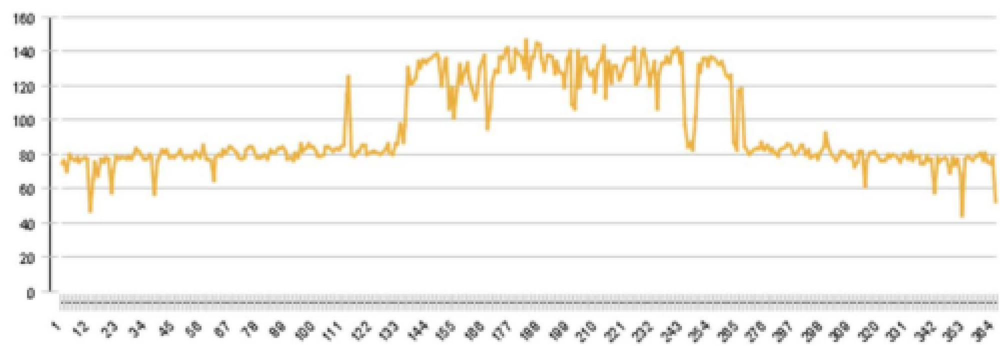
| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solar thermal energy to the system [Qsol]** | | | | | | | | | | | | | |
| kBtu | 153395 | 6272 | 10586 | 20569 | 27322 | 19481 | 7423 | 532 | 1718 | 13960 | 24114 | 14297 | 7121 |
| **Total energy demand [Qdem]** | | | | | | | | | | | | | |
| kBtu | 354088 | 63197 | 48774 | 41027 | 31439 | 19466 | 7422 | 524 | 1725 | 13967 | 27252 | 38140 | 61153 |
| **Total energy demand [Qdem] (Reference)** | | | | | | | | | | | | | |
| kBtu | 285706 | 63177 | 48185 | 37386 | 18331 | 3848 | 0 | 0 | 0 | 1390 | 14182 | 38115 | 61093 |

## Comparison Report

| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total fuel and/or electrical energy consumption of the system [Etot]** | | | | | | | | | | | | | |
| kBtu | 223495 | 63421 | 42526 | 22797 | 4591 | 3 | 1 | 0 | 0 | 2 | 3470 | 26541 | 60143 |
| **Total fuel and/or electrical energy consumption of the system [Etot] (Reference)** | | | | | | | | | | | | | |
| kBtu | 318050 | 70359 | 53658 | 41611 | 20385 | 4274 | 0 | 0 | 0 | 1544 | 15773 | 42421 | 68025 |
| **Total energy consumption [Quse]** | | | | | | | | | | | | | |
| kBtu | 354088 | 63197 | 48774 | 41027 | 31439 | 19466 | 7422 | 524 | 1725 | 13967 | 27252 | 38140 | 61153 |
| **Total energy consumption [Quse] (Reference)** | | | | | | | | | | | | | |
| kBtu | 285706 | 63177 | 48185 | 37386 | 18331 | 3848 | 0 | 0 | 0 | 1390 | 14182 | 38115 | 61093 |

### Collector North America South

**Daily maximum temperature [ °F]**



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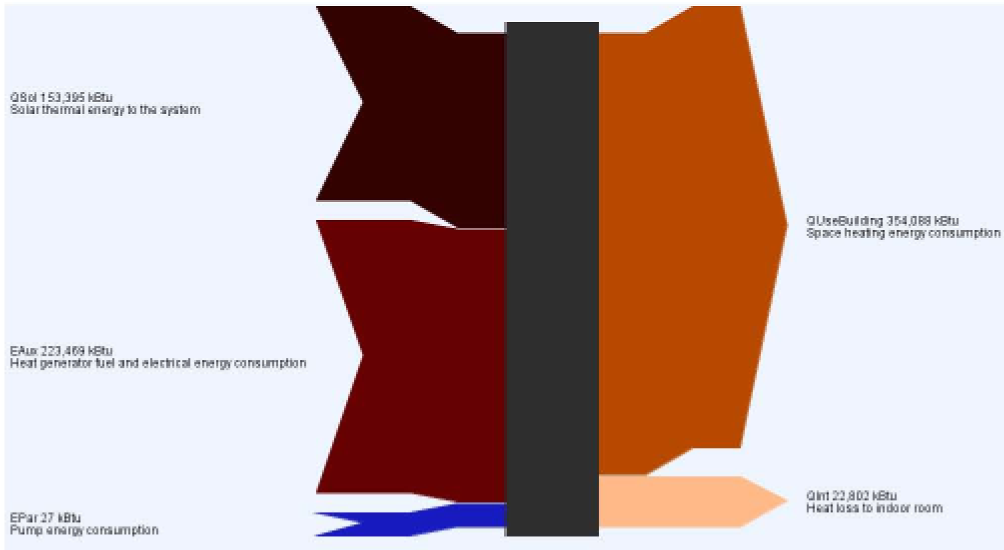
## Comparison Report

### Energy flow diagram (annual balance)



## Appendix M: Minneapolis Solar Water Heating System Performance Modeling Report[15]

[15] Solar Thermal Performance Projections are based on SRCC OG 100 Certification #100-2004-009A for Dawn Solar Model 304L in Appendix S

# Comparison Report

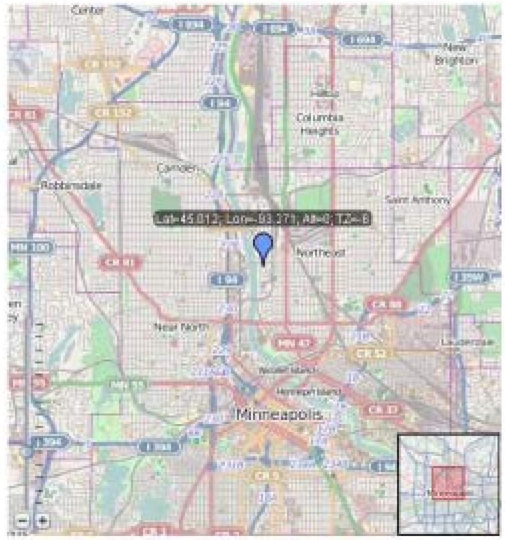
**Location of the system**

Minneapolis, MN
Longitude: -93.271°
Latitude: 45.012°
Elevation: 850 ft

**This report has been created by:**

Energy Integration Partners
Carl Gettelman

**Map section**




**System overview (annual values)**

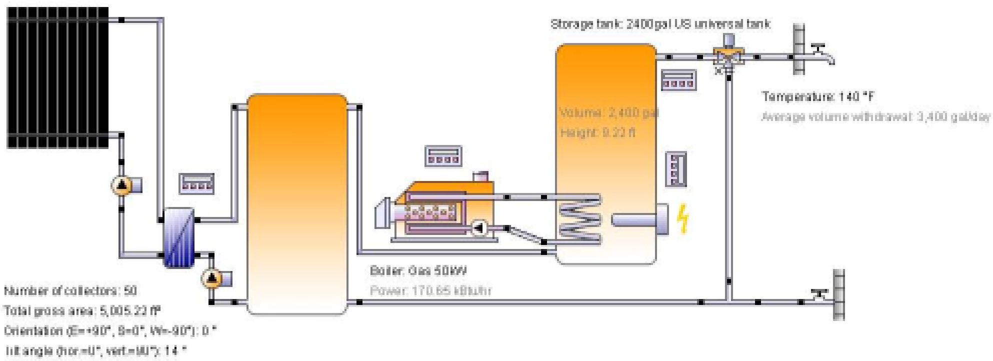
| | |
|---|---|
| Comfort demand | Energy demand covered |
| Saved energy compared to reference system | 200,739.1 kBtu |
| CO2 savings compared to reference system | 29,709 pound |
| Total fuel and electrical energy consumption of the system | 802,052.6 kBtu |
| Total fuel and electrical energy consumption of the reference system | 1,002,791.6 kBtu |

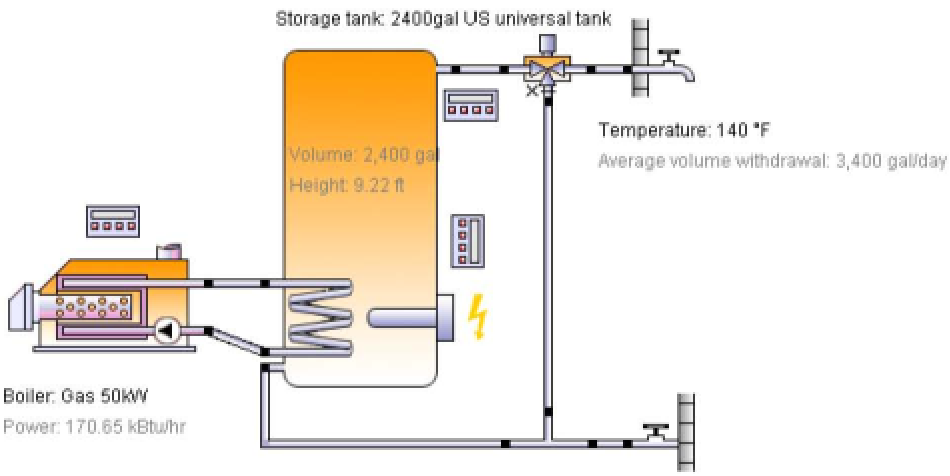
**Overview solar thermal energy (annual values)**

| | |
|---|---|
| Collector area | 5,005.2 ft² |
| Savings compared to reference system | 20 % |
| Total annual field yield | 188,233.3 kBtu |
| Collector field yield relating to gross area | 37.6 kBtu/ft²/Year |
| Collector field yield relating to aperture area | 37.6 kBtu/ft²/Year |

## Comparison Report

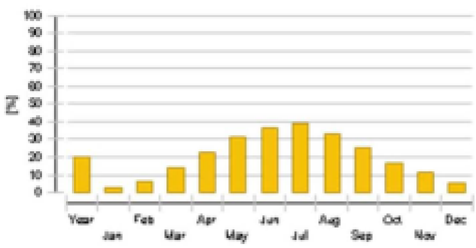
**Minneapolis Solar Water Heating** | **DHW Preheat South Facing Array**



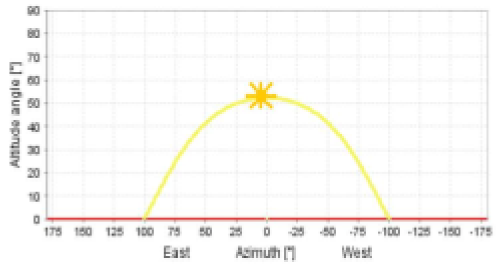



# Comparison Report

**Savings compared to reference system [Fss]**




**Horizon line**




**Meteorological data-Overview**

| | |
|---|---|
| Average outdoor temperature | 47.2 °F |
| Global irradiation, annual sum | 449.7 kBtu/ft² |
| Diffuse irradiation, annual sum | 180.1 kBtu/ft² |

**Component overview (annual values)**

| | | |
|---|---|---|
| **Boiler** | **Gas 50kW** | |
| Power | kBtu/hr | 170.65 |
| Total efficiency | % | 89 |
| Energy from/to the system [Qaux] | kBtu | 712,355.8 |
| Fuel and electrical energy consumption [Eaux] | kBtu | 800,386.3 |
| Fuel consumption of the back-up boiler [Baux] | therms | 7,836.4 |

| | | |
|---|---|---|
| **Collector North America South** | **3004L** | |
| Data Source | | SRCC |
| Total gross area | ft² | 5,005.22 |
| Total aperture area | ft² | 5,006.295 |
| Total absorber area | ft² | 5,006.29 |
| Tilt angle (hor.=0°, vert.=90°) | ° | 14 |
| Orientation (E=+90°, S=0°, W=-90°) | ° | 0 |

| | | |
|---|---|---|
| **Hot water demand** | **Mess Hall** | |
| Volume withdrawal/daily consumption | gal/d | 3,404 |
| Temperature setting | °F | 140 |
| Energy demand [Qdem] | kBtu | 960,950.1 |

| | | |
|---|---|---|
| **External heat exchanger Solar** | **huge** | |
| Transfer capacity | W/K | 30,000 |

| | | |
|---|---|---|
| **Pump Solar loop pump** | **Wilo Star 21** | |
| Circuit pressure drop | psi | 11.316 |
| Flow rate | gpm | 15 |

# Comparison Report

| | | |
|---|---|---|
| Fuel and electrical energy consumption [Epar] | kBtu | 833.1 |

| **Pump HX to Tank** | **Wilo Star 21** | |
|---|---|---|
| Circuit pressure drop | psi | 1.891 |
| Flow rate | gpm | 15 |
| Fuel and electrical energy consumption [Epar] | kBtu | 833.1 |

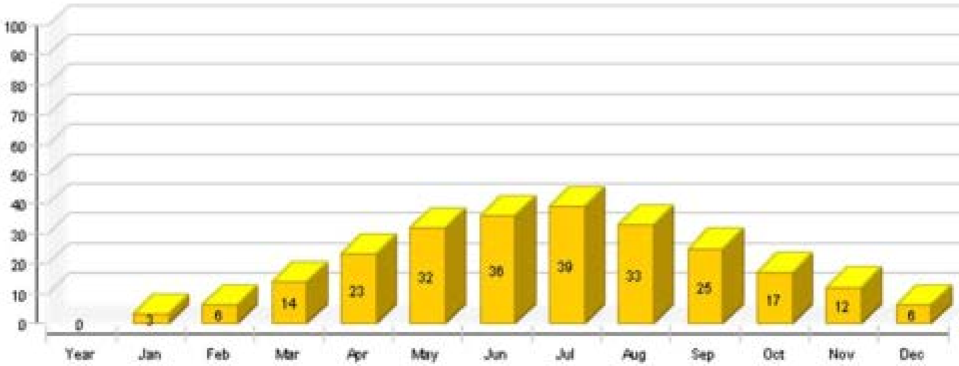
| **Storage tank Potable water tank 2** | **2400gal US universal tank** | |
|---|---|---|
| Volume | gal | 2,400 |
| Height | ft | 9.22 |
| Material | | Enameled steel |
| Insulation | | Flexible polyurethane foam |
| Thickness of insulation | in | 4 |
| Heat loss | kBtu | 5,582.6 |
| Connection losses | kBtu | 717.1 |

| **Storage tank Solar** | **800 coiless** | |
|---|---|---|
| Volume | gal | 800 |
| Height | ft | 7.22 |
| Material | | Enameled steel |
| Insulation | | Flexible polyurethane foam |
| Thickness of insulation | in | 4 |
| Heat loss | kBtu | -171.5 |
| Connection losses | kBtu | -119.3 |

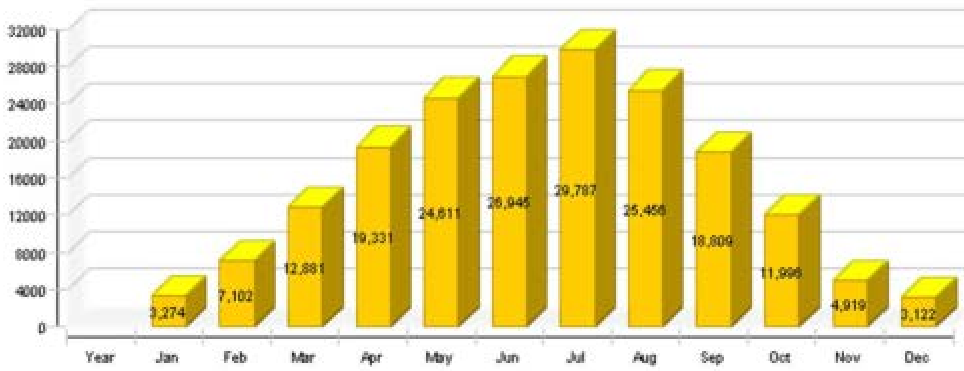
## Loop

| **Solar loop** | | |
|---|---|---|
| Fluid mixture | | Propylene mixture |
| Fluid concentration | % | 50 |
| Fluid domains volume | gal | 114.1 |
| Pressure on top of the circuit | psi | 58 |

## Comparison Report




**Solar thermal energy to the system [Qsol]** **kBtu**



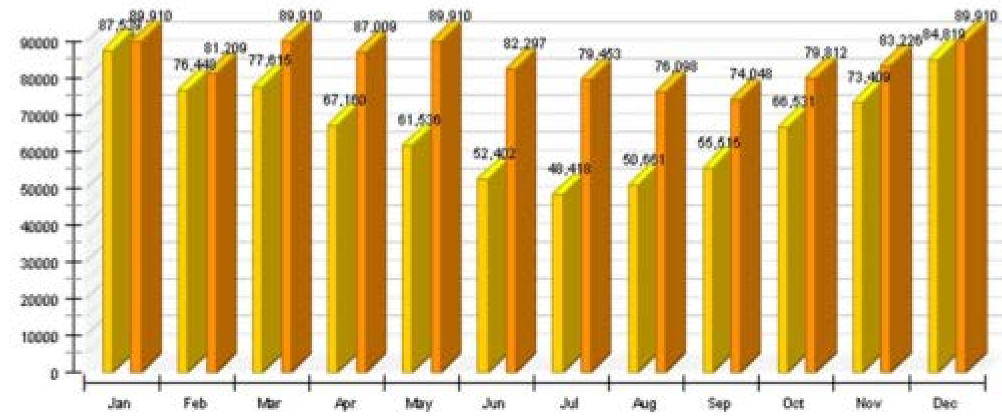

**Total fuel and/or electrical energy consumption of the system [Etot]** **kBtu**

## Comparison Report

Heat generator energy to the system (solar thermal energy not included) [Qaux] kBtu


Key: Right->Results of the reference system

Total fuel and/or electrical energy consumption of the system [Etot] kBtu




Key: Right->Results of the reference system

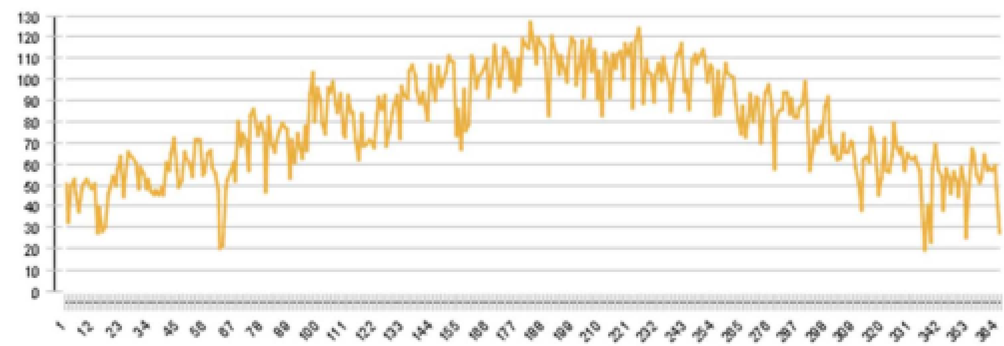
| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solar thermal energy to the system [Qsol]** | | | | | | | | | | | | | |
| kBtu | 188233 | 3274 | 7102 | 12881 | 19331 | 24611 | 26945 | 29787 | 25456 | 18809 | 11996 | 4919 | 3122 |
| **Total energy demand [Qdem]** | | | | | | | | | | | | | |
| kBtu | 960950 | 87702 | 80910 | 89415 | 84389 | 83478 | 76698 | 75669 | 73669 | 71468 | 76133 | 77310 | 84108 |

## Comparison Report

| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total energy demand [Qdem] (Reference)** | | | | | | | | | | | | | |
| kBtu | 960954 | 87703 | 80910 | 89415 | 84390 | 83479 | 76698 | 75670 | 73668 | 71468 | 76135 | 77311 | 84108 |
| **Total fuel and/or electrical energy consumption of the system [Etot]** | | | | | | | | | | | | | |
| kBtu | 802053 | 87539 | 76448 | 77615 | 67160 | 61536 | 52402 | 48418 | 50661 | 55515 | 66531 | 73409 | 84819 |
| **Total fuel and/or electrical energy consumption of the system [Etot] (Reference)** | | | | | | | | | | | | | |
| kBtu | 100279 | 89910 | 81209 | 89910 | 87009 | 89910 | 82297 | 79453 | 76098 | 74048 | 79812 | 83226 | 89910 |
| **Total energy consumption [Quse]** | | | | | | | | | | | | | |
| kBtu | 894699 | 80858 | 75060 | 81618 | 78030 | 78265 | 72571 | 71860 | 70030 | 66819 | 70741 | 70448 | 78399 |
| **Total energy consumption [Quse] (Reference)** | | | | | | | | | | | | | |
| kBtu | 888212 | 79834 | 72117 | 79790 | 77115 | 79555 | 72860 | 70034 | 67464 | 65465 | 70441 | 73778 | 79760 |

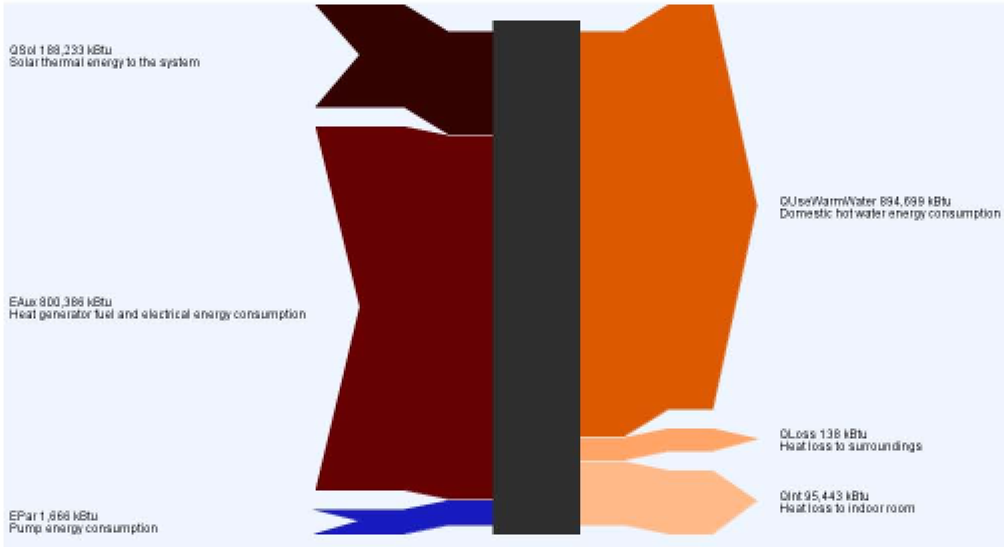
### Collector North America South

**Daily maximum temperature [ °F]**



## Comparison Report

### Energy flow diagram (annual balance)



## Appendix N: Minneapolis Solar Space Heating System Performance Modeling Report[16]

[16] Solar Thermal Performance Projections are based on SRCC OG 100 Certification #100-2004-009A for Dawn Solar Model 304L in Appendix S

# Comparison Report

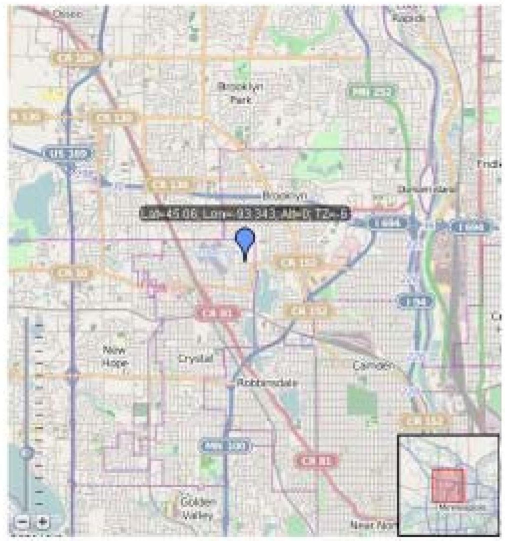
**Location of the system**

Minneapolis, MN
Longitude: -93.343°
Latitude: 45.06°
Elevation: 869 ft

**This report has been created by:**

Energy Integration Partners
Carl Gettelman

**Map section**




**System overview (annual values)**

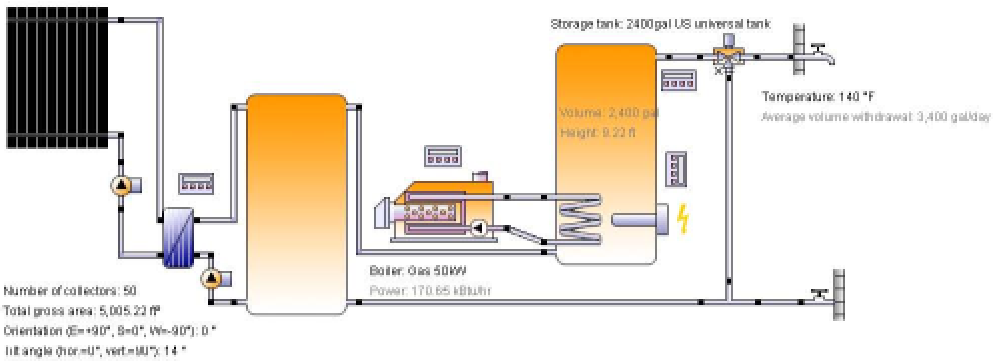
| | |
|---|---|
| Comfort demand | Energy demand covered |
| Saved energy compared to reference system | 64,180.9 kBtu |
| CO2 savings compared to reference system | 9,599.2 pound |
| Total fuel and electrical energy consumption of the system | 684,851.6 kBtu |
| Total fuel and electrical energy consumption of the reference system | 749,032.6 kBtu |

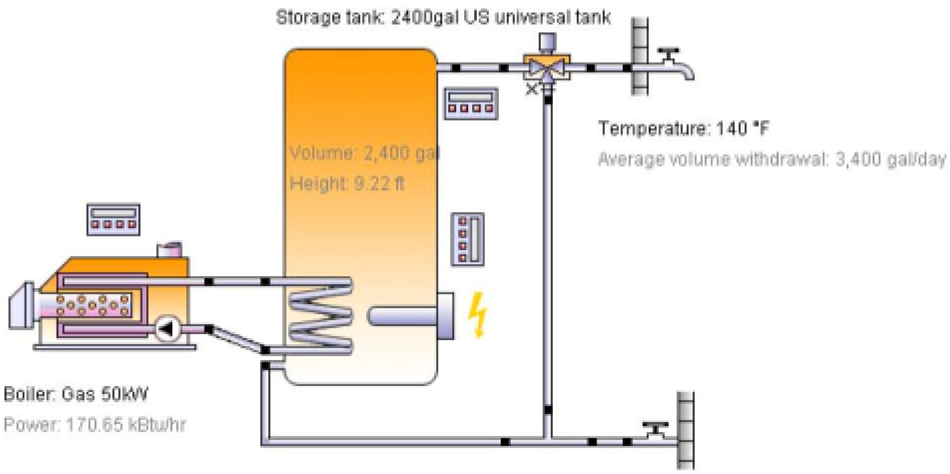
**Overview solar thermal energy (annual values)**

| | |
|---|---|
| Collector area | 5,005.2 ft² |
| Savings compared to reference system | 8.6 % |
| Total annual field yield | 126,747.8 kBtu |
| Collector field yield relating to gross area | 25.3 kBtu/ft²/Year |
| Collector field yield relating to aperture area | 25.3 kBtu/ft²/Year |

# Comparison Report

**Minneapolis Solar Water Heating** | **DHW Preheat South Facing Array**



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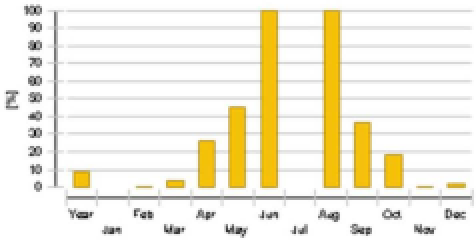
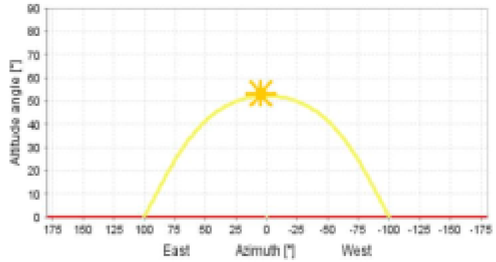
## Comparison Report

**Savings compared to reference system [Fss]**




**Horizon line**




**Meteorological data-Overview**

| | |
|---|---|
| Average outdoor temperature | 46.6 °F |
| Global irradiation, annual sum | 450.2 kBtu/ft² |
| Diffuse irradiation, annual sum | 185.2 kBtu/ft² |

**Component overview (annual values)**

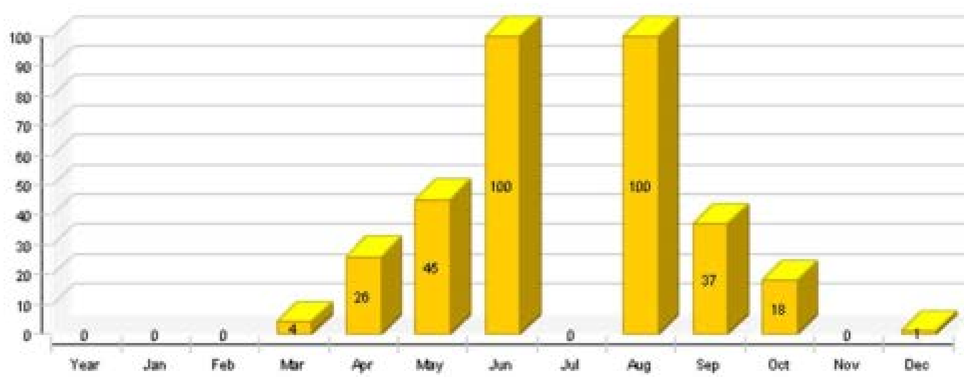
| | | |
|---|---|---|
| **Boiler 2** | **Gas 100kW** | |
| Power | kBtu/hr | 341.3 |
| Total efficiency | % | 89.7 |
| Energy from/to the system [Qaux] | kBtu | 614,609.4 |
| Fuel and electrical energy consumption [Eaux] | kBtu | 684,829.6 |
| Fuel consumption of the back-up boiler [Baux] | therms | 6,705 |
| **Collector North America South** | **3004L** | |
| Data Source | | SRCC |
| Total gross area | ft² | 5,005.22 |
| Total aperture area | ft² | 5,006.295 |
| Total absorber area | ft² | 5,006.29 |
| Tilt angle (hor.=0°, vert.=90°) | ° | 14 |
| Orientation (E=+90°, S=0°, W=-90°) | ° | 0 |
| **Building** | | |
| Heated/air-conditioned living area | ft² | 9,900 |
| Heating setpoint temperature | °F | 68 |
| Heating energy demand excluding DHW [Qdem] | kBtu | 741,310.5 |
| **Fan coil Solar** | **Four-pipe system size 7** | |
| Number of fan coils | - | 42 |
| Nominal heating power | kBtu/hr | 18 |
| Nominal hot water inlet temperature | °F | 176 |
| Nominal hot water return temperature | °F | 140 |
| Energy from/to the system [Quse] | kBtu | 126,763.6 |

## Comparison Report

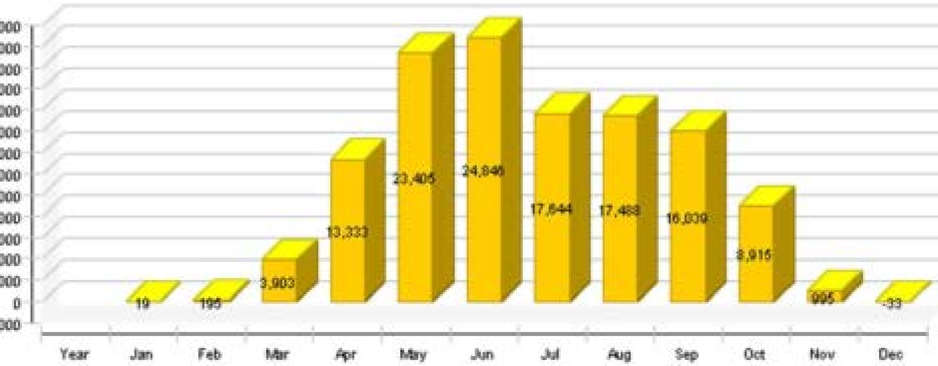
| Fan coil 2 | Four-pipe system size 7 | |
|---|---|---|
| Number of fan coils | - | 48 |
| Nominal heating power | kBtu/hr | 18 |
| Nominal hot water inlet temperature | °F | 176 |
| Nominal hot water return temperature | °F | 140 |
| Energy from/to the system [Quse] | kBtu | 614,547 |

| Pump SSH | Eco, small | |
|---|---|---|
| Circuit pressure drop | psi | 2.114 |
| Flow rate | gpm | 15.9 |
| Fuel and electrical energy consumption [Epar] | kBtu | 22 |

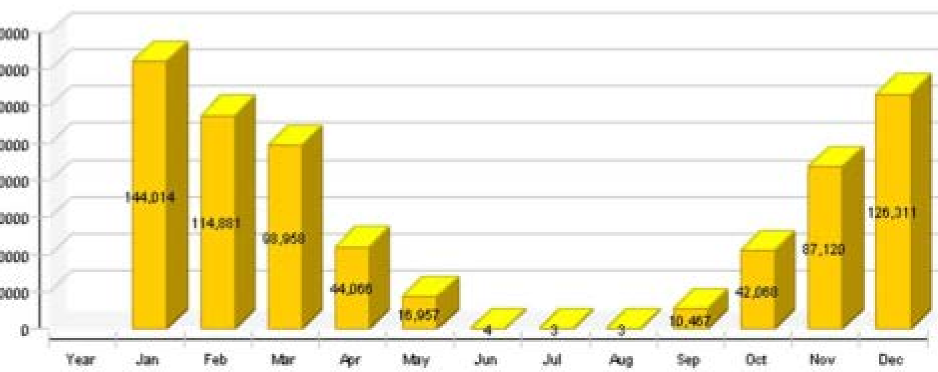
Savings compared to reference system [Fss] %



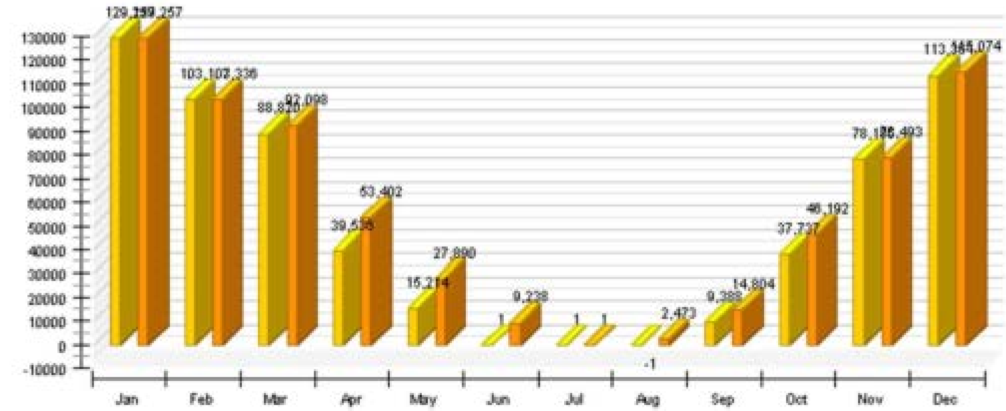
## Comparison Report




**Total fuel and/or electrical energy consumption of the system [Etot]** **kBtu**

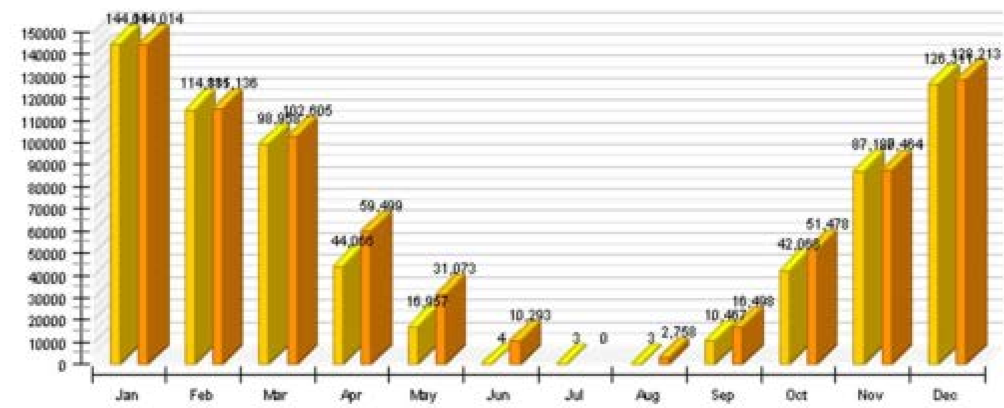


## Comparison Report




Key: Right->Results of the reference system

**Total fuel and/or electrical energy consumption of the system [Etot]** **kBtu**




Key: Right->Results of the reference system

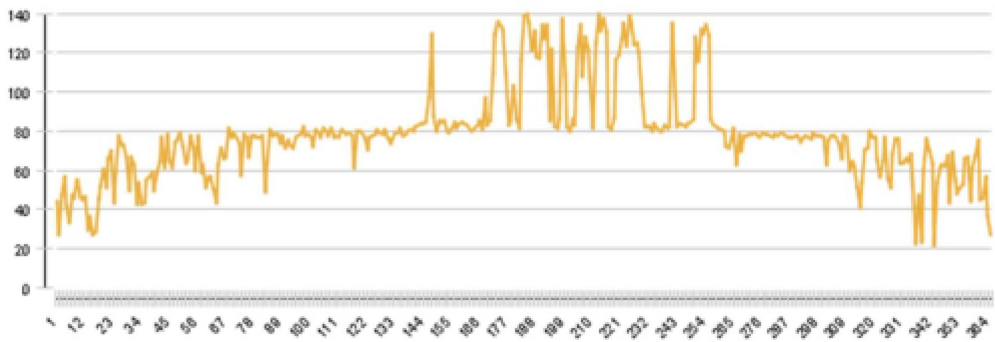
| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solar thermal energy to the system [Qsol]** | | | | | | | | | | | | | |
| kBtu | 126748 | 19 | 195 | 3903 | 13333 | 23405 | 24846 | 17644 | 17488 | 16039 | 8915 | 995 | -33 |
| **Total energy demand [Qdem]** | | | | | | | | | | | | | |
| kBtu | 741311 | 129243 | 103295 | 92690 | 52857 | 38605 | 24836 | 17642 | 17501 | 25437 | 46670 | 79180 | 113353 |
| **Total energy demand [Qdem] (Reference)** | | | | | | | | | | | | | |
| kBtu | 672190 | 129243 | 103325 | 92090 | 53398 | 27892 | 9237 | 0 | 2473 | 14802 | 46186 | 78483 | 115061 |

## Comparison Report

| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total fuel and/or electrical energy consumption of the system [Etot]** | | | | | | | | | | | | | |
| kBtu | 684852 | 144014 | 114881 | 98958 | 44066 | 16957 | 4 | 3 | 3 | 10467 | 42068 | 87120 | 126311 |
| **Total fuel and/or electrical energy consumption of the system [Etot] (Reference)** | | | | | | | | | | | | | |
| kBtu | 749033 | 144014 | 115136 | 102605 | 59499 | 31073 | 10293 | 0 | 2758 | 16498 | 51478 | 87464 | 128213 |
| **Total energy consumption [Quse]** | | | | | | | | | | | | | |
| kBtu | 741311 | 129243 | 103295 | 92690 | 52857 | 38605 | 24836 | 17642 | 17501 | 25437 | 46670 | 79180 | 113353 |
| **Total energy consumption [Quse] (Reference)** | | | | | | | | | | | | | |
| kBtu | 672190 | 129243 | 103325 | 92090 | 53398 | 27892 | 9237 | 0 | 2473 | 14802 | 46186 | 78483 | 115061 |

### Collector North America South

**Daily maximum temperature [ °F]**





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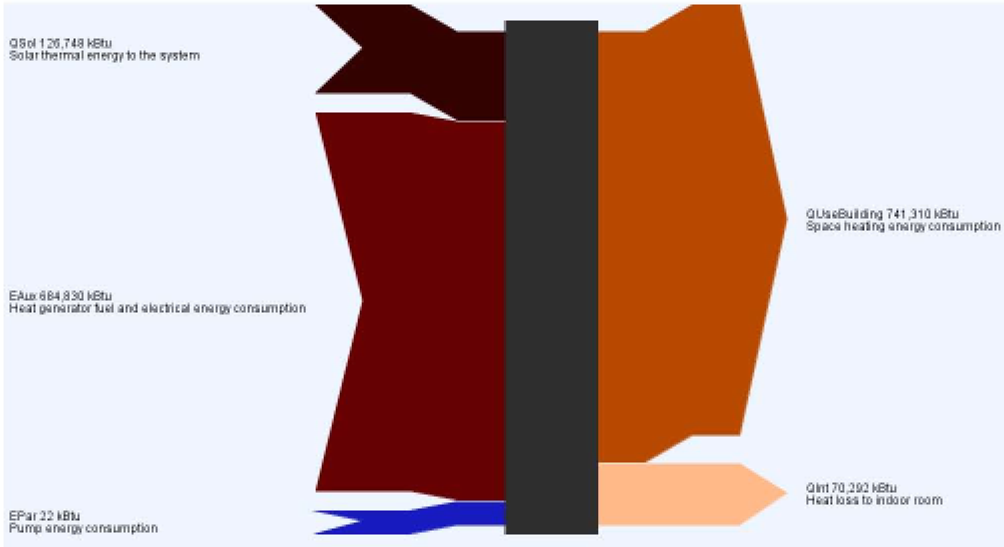
## Comparison Report

### Energy flow diagram (annual balance)



# Appendix O: Economics of Energy-Efficient Envelopes , Chasing Diminishing Returns of Over-Insulation



## Economics of Energy-Efficient Envelopes

### Chasing Diminishing Returns of Over-Insulation

This paper addresses cold-climate conditions present in the northern tier of the United States.

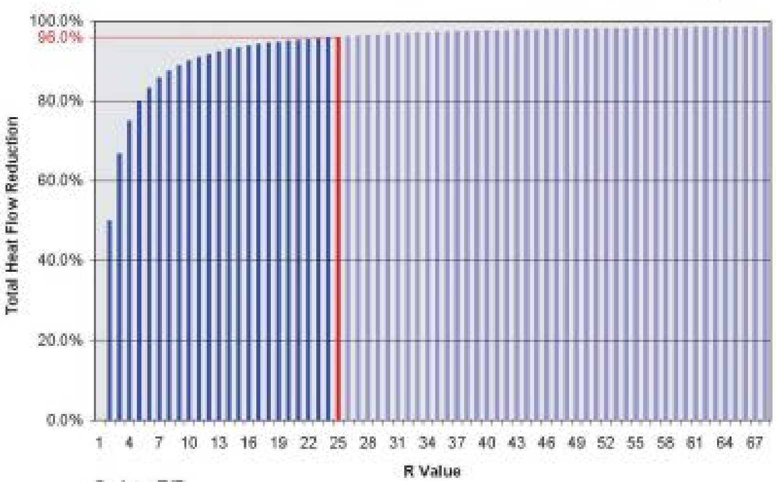
We insulate our building envelopes against conductive heat flow (loss or gain). As a measure of this flow we use the R-value, which is established by the test procedures specified in ASTM C 518.

Most people imagine that the value of insulation is linear, so that, for example, doubling the R-value will double the amount of energy saved. The physics of the situation is quite different. While R is the measure of resistance to heat transfer for a product of a given thickness, the U-factor is the measure of overall heat transfer, and its value is the inverse of R. As a result, the conductive heat flow reduction achieved by adding insulation to the assembly increases at a decreasing rate. As Figure 1 indicates, 96 percent of all possible heat flow reduction is achieved at R 25. After that, as more and more insulation is added, the reductions will slowly, and at a decreasing rate, approach, but never reach, 100 percent. To illustrate, if you double the insulation to R 50, the heat flow is further reduced by only 2 percent. If you double it again, to R 100, the further reduction is only 1 percent more than R 50. So for the addition of *four times* the amount of insulation, the heat transfer reduction improves by only 3 percent.

Excessive insulation is often applied to or within the roof structure, largely because the deeper framing in the roof or attic floor accepts more depth of insulation fill, and on the mistaken belief that it will be more effective because "hot air rises." Heat transfers in all directions from higher to lower temperature, seeking equilibrium (Second Law of Thermodynamics). The greater the difference in temperature (Δt) between the two objects, the greater the flow of heat. Hot air rises in relation to cooler air, which, being denser, displaces it (Archimedes' Principle). In a well-insulated, relatively airtight structure with modern environmental control systems, this stratification is largely absent.

Another building component that is often over-insulated, particularly in so-called "Passive Houses," is the basement floor. Here the constant soil temperature is only about 20 degrees lower than the indoor design temperature (Δt = 20). While the same insulation performance curve applies, the absolute heat transfer for any given R-value is only 28.5 percent of what it is for the above grade walls (Δt = 20 + Δt = 70). The actual basement slab heat transfer is so comparatively small that it is equal to the exterior wall with R 25 insulation when the slab has only R 7 insulation. The same is true for the lower portions of the basement wall, but this changes throughout its height, becoming more like the above-grade wall as it passes above the frost line.

The second important strategy for reducing conductive heat flow is the thermal break. In a wall of framed construction, whether steel or wood, the studs and other framing members are far more conductive of heat than the




$Q = A \times \Delta T / R$

where:

Q = Rate of heat flow (Btu/hr)
A = Area ($ft^2$)
ΔT = Difference in Temperature (°F)
R = Resistance to conductive heat flow (hr $ft^2$ °F/Btu)

Total Heat Flow Reduction = $1 - (Q_R / Q_1)$

***Figure 1:** Decreasing Return of Increased R Value*

cavity spaces which are filled with insulation. To interrupt these lines of heat flow, a thermal break must be introduced between the outside air and the conductive framing members. One method to achieve this break is to apply rigid insulation, such as expanded polystyrene or polyisocyanurate foam board, over the outside of the framing. A second method is to install lines of furring strips horizontally across the studs, on their outside surfaces, so that most of their surface can be covered by the cavity insulation. Without this thermal break, much of the value of added insulation within the wall cavity is diminished.

## Looking at Windows

The greatest source of heat-transfer in a building envelope is the windows. A high-quality window with low-e-coated insulating glass can achieve a U-factor of 0.330 Btu/(hr x sq. ft. x deg. F), or the equivalent of a section of solid wall with R 3 insulation, which is only a 67 percent heat flow reduction. There is 8.33 times more thermal flow through the window than through the surrounding wall with R 25 insulation. In view of this, there is a temptation to reduce the window area to an absolute minimum, but this has its disadvantages. People crave natural light, and studies show that building inhabitants are more productive, creative, and able to learn in environments with abundant natural light. In addition, ample natural light in well designed buildings for occupancies like classrooms and offices can reduce or eliminate the need for artificial lighting during most of the daylight hours. In a typical office building, lighting accounts for more than 40 percent of the electrical load, and offsetting this with natural light can realize significant energy savings.

Even in residences, where the lighting load may be a lower percentage of the overall electrical consumption, there is great benefit to be reaped from natural light. Here, the solution may be to use even higher-performance windows, albeit at significantly increased cost. Installing triple-glazed windows with heat-mirror technology can reduce the U-factor to 0.20 Btu/(hr x sq. ft. x deg. F), or the equivalent of a wall with R 5 insulation, which is an improvement of 40 percent in R value and 13 in overall heat flow reduction when compared to the standard insulating glass window.

Another reason to strive for lower U-factors in windows is the radiant transfer toward the cold (or relatively colder) surface of the glass. The colder the surface, the more heat transfer, by radiation, from the occupants of the building to the glass. This makes the occupants feel cold. But, since even with the highest performing windows, the heat flow reduction (80 percent) is significantly lower than the solid wall (96 percent), the compensating strategy is to place a heat-producing source below the glass surface and let the convective heat flow warm the glass surface sufficiently to offset its cooling effect on the occupants, and to prevent condensation of indoor water vapor on the surface of the glass. [Relative humidities up to 40% can be maintained without excessive window condensation on double-glazed windows down to 0° F (-18° C), and on triple-glazed windows down to -22° F (-30° C).][1]

## Conclusion

Adding insulation – increasing R-value – has long been the low-hanging fruit for improving energy performance of the building envelope. However, because increasing insulation thickness suffers diminishing returns of performance at higher values, there is a point at which the economic choice is to redirect resources toward other systems where greater gains can be realized. Windows are the obvious next choice, because there is so much improvement to be attained, though at a significantly higher incremental cost than was the case for added insulation. Still, at a point where doubling the amount (and cost) of insulation and building envelope to enclose it, to achieve only a 2 percent improvement in heat flow reduction, the cost of choosing premium-grade, triple-glazed windows for a 13 percent improvement becomes more feasible.

The next most important factor in optimizing the energy-efficiency of the building envelope is airtightness, which is the subject of another white paper.

1 Handegord, G.O., "Air Leakage, Ventilation, and Moisture Control in Buildings," Moisture Migration in Buildings ASTM STP 779, M. Lieff and H.R. Trechsel, Ed., American Society for Testing and Materials, 1982, pp. 223-233.

# Appendix P: NIST BLCCA Reports

## *Atlanta GA Solar Water Heating System- Federal-offsetting Nat. Gas*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 5000 sf BIST**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Atlanta DHW.xml |
| **Date of Study:** | Mon Jan 20 13:46:46 EST 2014 |
| **Project Name:** | Atlanta DHW |
| **Project Location:** | Georgia |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 5000 sf Thermal system to an existing Mess Hall to supplement domestic water heating |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | **Base Case** | **Alternative** | **Savings from Alternative** |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $81,650 | -$81,650 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $276,897 | $208,035 | $68,862 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $4,422 | -$4,422 |
| **Major Repair and Replacements** | $0 | $5,219 | -$5,219 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $276,897 | $217,676 | $59,221 |
| | ------------ | ------------ | ------------ |

| | | | |
|---|---|---|---|
| **Total PV Life-Cycle Cost** | $276,897 | $299,326 | -$22,429 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $64,439 |
| **- Increased Total Investment** | $86,869 |
| | ------------ |
| **Net Savings** | -$22,429 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 0.74

**SIR is lower than 1.0; project alternative is not cost effective.**
**Adjusted Internal Rate of Return**

**AIRR =** 2.27%

**AIRR is lower than your discount rate; project alternative is not cost effective.**
**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**
**Discounted Payback never reached during study period.**

**Simple Payback occurs in year** 32

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 835.1 MBtu | 627.4 MBtu | 207.7 MBtu | 8,307.0 MBtu |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 835.1 MBtu | 627.4 MBtu | 207.7 MBtu | 8,307.0 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Natural Gas** | | | | |
| **CO2** | 44,111.34 kg | 33,141.21 kg | 10,970.13 kg | 438,775.10 kg |
| **SO2** | 355.99 kg | 267.46 kg | 88.53 kg | 3,541.05 kg |
| **NOx** | 37.01 kg | 27.81 kg | 9.20 kg | 368.13 kg |
| **Total:** | | | | |
| **CO2** | 44,111.34 kg | 33,141.21 kg | 10,970.13 kg | 438,775.10 kg |
| **SO2** | 355.99 kg | 267.46 kg | 88.53 kg | 3,541.05 kg |
| **NOx** | 37.01 kg | 27.81 kg | 9.20 kg | 368.13 kg |

## *Atlanta GA Solar Space Heating System- Federal-offsetting Nat. Gas*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 5000 sf BIST**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Atlanta SH.xml |
| **Date of Study:** | Mon Jan 20 14:20:57 EST 2014 |
| **Project Name:** | Atlanta SH |
| **Project Location:** | Georgia |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 5000 sf Thermal system to an existing 10,000 sf office building to supplement space heating |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | **Base Case** | **Alternative** | **Savings from Alternative** |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $81,650 | -$81,650 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $106,444 | $77,380 | $29,065 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $4,422 | -$4,422 |
| **Major Repair and Replacements** | $0 | $3,131 | -$3,131 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $106,444 | $84,933 | $21,511 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $106,444 | $166,583 | -$60,139 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $24,642 |
| **- Increased Total Investment** | $84,781 |
| | ------------ |
| **Net Savings** | -$60,139 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 0.29

**SIR is lower than 1.0; project alternative is not cost effective.**
**Adjusted Internal Rate of Return**

**AIRR =** 0.01%

**AIRR is lower than your discount rate; project alternative is not cost effective.**
**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**
**Simple Payback never reached during study period.**
**Discounted Payback never reached during study period.**

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 321.0 MBtu | 233.4 MBtu | 87.7 MBtu | 3,506.2 MBtu |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 321.0 MBtu | 233.4 MBtu | 87.7 MBtu | 3,506.2 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Natural Gas** | | | | |
| **CO2** | 16,957.24 kg | 12,327.07 kg | 4,630.18 kg | 185,194.40 kg |
| **SO2** | 136.85 kg | 99.48 kg | 37.37 kg | 1,494.58 kg |
| **NOx** | 14.23 kg | 10.34 kg | 3.88 kg | 155.38 kg |
| **Total:** | | | | |
| **CO2** | 16,957.24 kg | 12,327.07 kg | 4,630.18 kg | 185,194.40 kg |
| **SO2** | 136.85 kg | 99.48 kg | 37.37 kg | 1,494.58 kg |
| **NOx** | 14.23 kg | 10.34 kg | 3.88 kg | 155.38 kg |

## *Atlanta GA PV System- Federal*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 23.9 kW PV system**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Atlanta PV.xml |
| **Date of Study:** | Mon Jan 20 14:36:07 EST 2014 |
| **Project Name:** | Atlanta PV |
| **Project Location:** | Georgia |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 23.9 kW PV system to an existing 10,000 sf office building |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | **Base Case** | **Alternative** | **Savings from Alternative** |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $47,800 | -$47,800 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $473,897 | $399,665 | $74,232 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $2,211 | -$2,211 |
| **Major Repair and Replacements** | $0 | $6,262 | -$6,262 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $473,897 | $408,139 | $65,758 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $473,897 | $455,939 | $17,958 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $72,021 |
| **- Increased Total Investment** | $54,062 |
| | ------------ |
| **Net Savings** | $17,958 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 1.33

**Adjusted Internal Rate of Return**

**AIRR =** 3.71%

**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**

**Simple Payback occurs in year** 16

**Discounted Payback occurs in year** 27

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 199,200.0 kWh | 167,997.0 kWh | 31,203.0 kWh | 1,248,034.6 kWh |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 679.7 MBtu | 573.2 MBtu | 106.5 MBtu | 4,258.5 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Electricity** | | | | |
| **CO2** | 136,236.31 kg | 114,896.04 kg | 21,340.27 kg | 853,552.32 kg |
| **SO2** | 913.67 kg | 770.55 kg | 143.12 kg | 5,724.38 kg |
| **NOx** | 167.82 kg | 141.53 kg | 26.29 kg | 1,051.42 kg |
| **Total:** | | | | |
| **CO2** | 136,236.31 kg | 114,896.04 kg | 21,340.27 kg | 853,552.32 kg |
| **SO2** | 913.67 kg | 770.55 kg | 143.12 kg | 5,724.38 kg |
| **NOx** | 167.82 kg | 141.53 kg | 26.29 kg | 1,051.42 kg |

## *Atlanta Solar Water Heating System-Private Sector -offsetting Nat. Gas*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 5000 sf BIST**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Atlanta DHW ppa.xml |
| **Date of Study:** | Mon Jan 20 13:45:10 EST 2014 |
| **Project Name:** | Atlanta DHW |
| **Project Location:** | Georgia |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 5000 sf Thermal system to an existing Mess Hall to supplement domestic water heating |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | Base Case | Alternative | Savings from Alternative |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $40,825 | -$40,825 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $276,897 | $208,035 | $68,862 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $4,422 | -$4,422 |
| **Major Repair and Replacements** | $0 | $5,219 | -$5,219 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $276,897 | $217,676 | $59,221 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $276,897 | $258,501 | $18,396 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $64,439 |
| **- Increased Total Investment** | $46,044 |
| | ------------ |
| **Net Savings** | $18,396 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 1.40

**Adjusted Internal Rate of Return**

**AIRR =** 3.83%

**Payback Period**

**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**

**Simple Payback occurs in year** 17

**Discounted Payback occurs in year** 27

**Energy Savings Summary**

**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 835.1 MBtu | 627.4 MBtu | 207.7 MBtu | 8,307.0 MBtu |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 835.1 MBtu | 627.4 MBtu | 207.7 MBtu | 8,307.0 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Natural Gas** | | | | |
| **CO2** | 44,111.34 kg | 33,141.21 kg | 10,970.13 kg | 438,775.10 kg |
| **SO2** | 355.99 kg | 267.46 kg | 88.53 kg | 3,541.05 kg |
| **NOx** | 37.01 kg | 27.81 kg | 9.20 kg | 368.13 kg |
| **Total:** | | | | |
| **CO2** | 44,111.34 kg | 33,141.21 kg | 10,970.13 kg | 438,775.10 kg |
| **SO2** | 355.99 kg | 267.46 kg | 88.53 kg | 3,541.05 kg |
| **NOx** | 37.01 kg | 27.81 kg | 9.20 kg | 368.13 kg |

## *Atlanta Solar Space Heating System-Private Sector -offsetting Nat. Gas*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 5000 sf BIST**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Atlanta SH PPA.xml |
| **Date of Study:** | Mon Jan 20 14:19:19 EST 2014 |
| **Project Name:** | Atlanta SH |
| **Project Location:** | Georgia |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 5000 sf Thermal system to an existing 10,000 sf office building to supplement space heating |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | **Base Case** | **Alternative** | **Savings from Alternative** |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $40,825 | -$40,825 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $106,444 | $77,380 | $29,065 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $4,422 | -$4,422 |
| **Major Repair and Replacements** | $0 | $3,131 | -$3,131 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $106,444 | $84,933 | $21,511 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $106,444 | $125,758 | -$19,314 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $24,642 |
| **- Increased Total Investment** | $43,956 |
| | ------------ |
| **Net Savings** | -$19,314 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 0.56

**SIR is lower than 1.0; project alternative is not cost effective.**
**Adjusted Internal Rate of Return**

**AIRR =** 1.59%

**AIRR is lower than your discount rate; project alternative is not cost effective.**
**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**
**Discounted Payback never reached during study period.**

**Simple Payback occurs in year** 40

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 321.0 MBtu | 233.4 MBtu | 87.7 MBtu | 3,506.2 MBtu |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 321.0 MBtu | 233.4 MBtu | 87.7 MBtu | 3,506.2 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Natural Gas** | | | | |
| **$CO_2$** | 16,957.24 kg | 12,327.07 kg | 4,630.18 kg | 185,194.40 kg |
| **$SO_2$** | 136.85 kg | 99.48 kg | 37.37 kg | 1,494.58 kg |
| **$NO_x$** | 14.23 kg | 10.34 kg | 3.88 kg | 155.38 kg |
| **Total:** | | | | |
| **$CO_2$** | 16,957.24 kg | 12,327.07 kg | 4,630.18 kg | 185,194.40 kg |
| **$SO_2$** | 136.85 kg | 99.48 kg | 37.37 kg | 1,494.58 kg |
| **$NO_x$** | 14.23 kg | 10.34 kg | 3.88 kg | 155.38 kg |

### *Atlanta PV System-Private Sector or PPV*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 23.9 kW PV system**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Atlanta PV ppa.xml |
| **Date of Study:** | Mon Jan 20 14:34:25 EST 2014 |
| **Project Name:** | Atlanta PV |
| **Project Location:** | Georgia |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 23.9 kW PV system to an existing 10,000 sf office building |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | **Base Case** | **Alternative** | **Savings from Alternative** |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $23,900 | -$23,900 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $473,897 | $399,665 | $74,232 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $2,211 | -$2,211 |
| **Major Repair and Replacements** | $0 | $6,262 | -$6,262 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $473,897 | $408,139 | $65,758 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $473,897 | $432,039 | $41,858 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $72,021 |
| **- Increased Total Investment** | $30,162 |
| | ------------ |
| **Net Savings** | $41,858 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 2.39

**Adjusted Internal Rate of Return**

**AIRR =** 5.16%

**Payback Period**

**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**

**Simple Payback occurs in year** 8

**Discounted Payback occurs in year** 10

**Energy Savings Summary**

**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 199,200.0 kWh | 167,997.0 kWh | 31,203.0 kWh | 1,248,034.6 kWh |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 679.7 MBtu | 573.2 MBtu | 106.5 MBtu | 4,258.5 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Electricity** | | | | |
| **CO2** | 136,236.31 kg | 114,896.04 kg | 21,340.27 kg | 853,552.32 kg |
| **SO2** | 913.67 kg | 770.55 kg | 143.12 kg | 5,724.38 kg |
| **NOx** | 167.82 kg | 141.53 kg | 26.29 kg | 1,051.42 kg |
| **Total:** | | | | |
| **CO2** | 136,236.31 kg | 114,896.04 kg | 21,340.27 kg | 853,552.32 kg |
| **SO2** | 913.67 kg | 770.55 kg | 143.12 kg | 5,724.38 kg |
| **NOx** | 167.82 kg | 141.53 kg | 26.29 kg | 1,051.42 kg |

## *Minneapolis Solar Water Heating System – Federal-offsetting Nat. Gas*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 5000 sf BIST**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Minneapolis DHW.xml |
| **Date of Study:** | Mon Jan 20 15:14:31 EST 2014 |
| **Project Name:** | Minneapolis DHW |
| **Project Location:** | Minnesota |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 5000 sf Thermal system to an existing Mess Hall to supplement domestic water heating |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | Base Case | Alternative | Savings from Alternative |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $81,650 | -$81,650 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $214,128 | $170,911 | $43,217 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $4,422 | -$4,422 |
| **Major Repair and Replacements** | $0 | $5,219 | -$5,219 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $214,128 | $180,552 | $33,576 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $214,128 | $262,202 | -$48,074 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $38,794 |
| **- Increased Total Investment** | $86,869 |
| | ------------ |
| **Net Savings** | -$48,074 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 0.45

**SIR is lower than 1.0; project alternative is not cost effective.**
**Adjusted Internal Rate of Return**

**AIRR =** 1.04%

**AIRR is lower than your discount rate; project alternative is not cost effective.**
**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**
**Simple Payback never reached during study period.**
**Discounted Payback never reached during study period.**

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 1,002.8 MBtu | 800.4 MBtu | 202.4 MBtu | 8,095.0 MBtu |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 1,002.8 MBtu | 800.4 MBtu | 202.4 MBtu | 8,095.0 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Natural Gas** | | | | |
| **CO2** | 52,967.09 kg | 42,276.91 kg | 10,690.18 kg | 427,578.09 kg |
| **SO2** | 427.46 kg | 341.19 kg | 86.27 kg | 3,450.69 kg |
| **NOx** | 44.44 kg | 35.47 kg | 8.97 kg | 358.74 kg |
| **Total:** | | | | |
| **CO2** | 52,967.09 kg | 42,276.91 kg | 10,690.18 kg | 427,578.09 kg |
| **SO2** | 427.46 kg | 341.19 kg | 86.27 kg | 3,450.69 kg |
| **NOx** | 44.44 kg | 35.47 kg | 8.97 kg | 358.74 kg |

## *Minneapolis Solar Space Heating System – Federal-offsetting Nat. Gas*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 5000 sf BIST**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Minneapolis SH.xml |
| **Date of Study:** | Mon Jan 20 15:22:05 EST 2014 |
| **Project Name:** | Minneapolis SH |
| **Project Location:** | Minnesota |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 5000 sf Thermal system to an existing 10,000 sf office building to supplement space heating |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | **Base Case** | **Alternative** | **Savings from Alternative** |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $81,650 | -$81,650 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $161,291 | $147,459 | $13,833 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $4,422 | -$4,422 |
| **Major Repair and Replacements** | $0 | $3,131 | -$3,131 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $161,291 | $155,012 | $6,279 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $161,291 | $236,662 | -$75,371 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $9,410 |
| **- Increased Total Investment** | $84,781 |
| | ------------ |
| **Net Savings** | -$75,371 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 0.11

**SIR is lower than 1.0; project alternative is not cost effective.**
**Adjusted Internal Rate of Return**

**AIRR =** -2.25%

**AIRR is lower than your discount rate; project alternative is not cost effective.**
**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**
**Simple Payback never reached during study period.**
**Discounted Payback never reached during study period.**

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| Energy | -----Average | Annual | Consumption----- | Life-Cycle |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 755.4 MBtu | 690.6 MBtu | 64.8 MBtu | 2,591.0 MBtu |

**Energy Savings Summary (in MBtu)**

| Energy | -----Average | Annual | Consumption----- | Life-Cycle |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 755.4 MBtu | 690.6 MBtu | 64.8 MBtu | 2,591.0 MBtu |

**Emissions Reduction Summary**

| Energy | -----Average | Annual | Emissions----- | Life-Cycle |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Natural Gas** | | | | |
| **CO2** | 39,897.38 kg | 36,475.72 kg | 3,421.66 kg | 136,857.10 kg |
| **SO2** | 321.98 kg | 294.37 kg | 27.61 kg | 1,104.48 kg |
| **NOx** | 33.47 kg | 30.60 kg | 2.87 kg | 114.82 kg |
| **Total:** | | | | |
| **CO2** | 39,897.38 kg | 36,475.72 kg | 3,421.66 kg | 136,857.10 kg |
| **SO2** | 321.98 kg | 294.37 kg | 27.61 kg | 1,104.48 kg |
| **NOx** | 33.47 kg | 30.60 kg | 2.87 kg | 114.82 kg |

## *Minneapolis PV System – Federal*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 23.9 kW PV system**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Minneapolis PV.xml |
| **Date of Study:** | Mon Jan 20 15:17:54 EST 2014 |
| **Project Name:** | Minneapolis PV |
| **Project Location:** | Minnesota |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 23.9 kW PV system to an existing 10,000 sf office building |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | Base Case | Alternative | Savings from Alternative |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $47,800 | -$47,800 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $456,266 | $384,796 | $71,470 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $2,211 | -$2,211 |
| **Major Repair and Replacements** | $0 | $6,262 | -$6,262 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $456,266 | $393,269 | $62,997 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $456,266 | $441,069 | $15,197 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $69,259 |
| **- Increased Total Investment** | $54,062 |
| | ------------ |
| **Net Savings** | $15,197 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 1.28

**Adjusted Internal Rate of Return**

**AIRR =** 3.61%

**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**

| | |
|---|---|
| **Simple Payback occurs in year** | 16 |
| **Discounted Payback occurs in year** | 28 |

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 199,200.0 kWh | 167,997.0 kWh | 31,203.0 kWh | 1,248,034.6 kWh |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 679.7 MBtu | 573.2 MBtu | 106.5 MBtu | 4,258.5 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Electricity** | | | | |
| **CO2** | 154,965.90 kg | 130,691.80 kg | 24,274.10 kg | 970,897.57 kg |
| **SO2** | 385.84 kg | 325.40 kg | 60.44 kg | 2,417.36 kg |
| **NOx** | 323.44 kg | 272.78 kg | 50.66 kg | 2,026.45 kg |
| **Total:** | | | | |
| **CO2** | 154,965.90 kg | 130,691.80 kg | 24,274.10 kg | 970,897.57 kg |
| **SO2** | 385.84 kg | 325.40 kg | 60.44 kg | 2,417.36 kg |
| **NOx** | 323.44 kg | 272.78 kg | 50.66 kg | 2,026.45 kg |

***l***

## *Minneapolis Solar Water Heating System-Private Sector -offsetting Nat. Gas*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 5000 sf BIST**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Minneapolis DHW ppa.xml |
| **Date of Study:** | Mon Jan 20 15:12:53 EST 2014 |
| **Project Name:** | Minneapolis DHW |
| **Project Location:** | Minnesota |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 5000 sf Thermal system to an existing Mess Hall to supplement domestic water heating |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | Base Case | Alternative | Savings from Alternative |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $40,825 | -$40,825 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $214,128 | $170,911 | $43,217 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $4,422 | -$4,422 |
| **Major Repair and Replacements** | $0 | $5,219 | -$5,219 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $214,128 | $180,552 | $33,576 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $214,128 | $221,377 | -$7,249 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $38,794 |
| **- Increased Total Investment** | $46,044 |
| | ------------ |
| **Net Savings** | -$7,249 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 0.84

**SIR is lower than 1.0; project alternative is not cost effective.**
**Adjusted Internal Rate of Return**

**AIRR =** 2.58%

**AIRR is lower than your discount rate; project alternative is not cost effective.**
**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**
**Discounted Payback never reached during study period.**

**Simple Payback occurs in year** 31

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 1,002.8 MBtu | 800.4 MBtu | 202.4 MBtu | 8,095.0 MBtu |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 1,002.8 MBtu | 800.4 MBtu | 202.4 MBtu | 8,095.0 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Natural Gas** | | | | |
| **$CO_2$** | 52,967.09 kg | 42,276.91 kg | 10,690.18 kg | 427,578.09 kg |
| **$SO_2$** | 427.46 kg | 341.19 kg | 86.27 kg | 3,450.69 kg |
| **$NO_x$** | 44.44 kg | 35.47 kg | 8.97 kg | 358.74 kg |
| **Total:** | | | | |
| **$CO_2$** | 52,967.09 kg | 42,276.91 kg | 10,690.18 kg | 427,578.09 kg |
| **$SO_2$** | 427.46 kg | 341.19 kg | 86.27 kg | 3,450.69 kg |
| **$NO_x$** | 44.44 kg | 35.47 kg | 8.97 kg | 358.74 kg |

## *Minneapolis Solar Space Heating System-Private Sector -offsetting Nat. Gas*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 5000 sf BIST**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Minneapolis SH PPA.xml |
| **Date of Study:** | Mon Jan 20 15:21:03 EST 2014 |
| **Project Name:** | Minneapolis SH |
| **Project Location:** | Minnesota |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 5000 sf Thermal system to an existing 10,000 sf office building to supplement space heating |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | Base Case | Alternative | Savings from Alternative |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $40,825 | -$40,825 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $161,291 | $147,459 | $13,833 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $4,422 | -$4,422 |
| **Major Repair and Replacements** | $0 | $3,131 | -$3,131 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $161,291 | $155,012 | $6,279 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $161,291 | $195,837 | -$34,546 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $9,410 |
| **- Increased Total Investment** | $43,956 |
| | ------------ |
| **Net Savings** | -$34,546 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 0.21

**SIR is lower than 1.0; project alternative is not cost effective.**
**Adjusted Internal Rate of Return**

**AIRR =** -0.71%

**AIRR is lower than your discount rate; project alternative is not cost effective.**
**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**
**Simple Payback never reached during study period.**
**Discounted Payback never reached during study period.**

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 755.4 MBtu | 690.6 MBtu | 64.8 MBtu | 2,591.0 MBtu |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Natural Gas** | 755.4 MBtu | 690.6 MBtu | 64.8 MBtu | 2,591.0 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Natural Gas** | | | | |
| **CO2** | 39,897.38 kg | 36,475.72 kg | 3,421.66 kg | 136,857.10 kg |
| **SO2** | 321.98 kg | 294.37 kg | 27.61 kg | 1,104.48 kg |
| **NOx** | 33.47 kg | 30.60 kg | 2.87 kg | 114.82 kg |
| **Total:** | | | | |
| **CO2** | 39,897.38 kg | 36,475.72 kg | 3,421.66 kg | 136,857.10 kg |
| **SO2** | 321.98 kg | 294.37 kg | 27.61 kg | 1,104.48 kg |
| **NOx** | 33.47 kg | 30.60 kg | 2.87 kg | 114.82 kg |

## *Minneapolis PV System-Private Sector or PPV*

**NIST BLCC 5.3-13: Comparative Analysis**
**Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A**
**Base Case: Existing Building**
**Alternative: 23.9 kW PV system**
**General Information**

| | |
|---|---|
| **File Name:** | C:\Users\cgettelman\Documents\Jobs\ESTCP Goodfellow AFB\BLCC\Minneapolis PV ppa.xml |
| **Date of Study:** | Mon Jan 20 15:19:06 EST 2014 |
| **Project Name:** | Minneapolis PV |
| **Project Location:** | Minnesota |
| **Analysis Type:** | MILCON Analysis, Energy Project |
| **Analyst:** | Carl Gettelman |
| **Comment** | Add 23.9 kW PV system to an existing 10,000 sf office building |
| **Base Date:** | April 1, 2014 |
| **Beneficial Occupancy Date:** | April 1, 2016 |
| **Study Period:** | 42 years 0 months(April 1, 2014 through March 31, 2056) |
| **Discount Rate:** | 3% |
| **Discounting Convention:** | Mid-Year |

**Comparison of Present-Value Costs**
**PV Life-Cycle Cost**

| | **Base Case** | **Alternative** | **Savings from Alternative** |
|---|---|---|---|
| **Initial Investment Costs:** | | | |
| **Capital Requirements as of Base Date** | $0 | $23,900 | -$23,900 |
| **Future Costs:** | | | |
| **Energy Consumption Costs** | $456,266 | $384,796 | $71,470 |
| **Energy Demand Charges** | $0 | $0 | $0 |
| **Energy Utility Rebates** | $0 | $0 | $0 |
| **Water Costs** | $0 | $0 | $0 |
| **Routine Recurring and Non-Recurring OM&R Costs** | $0 | $2,211 | -$2,211 |
| **Major Repair and Replacements** | $0 | $6,262 | -$6,262 |
| **Residual Value at End of Study Period** | $0 | $0 | $0 |
| | ------------ | ------------ | ------------ |
| **Subtotal (for Future Cost Items)** | $456,266 | $393,269 | $62,997 |
| | ------------ | ------------ | ------------ |
| **Total PV Life-Cycle Cost** | $456,266 | $417,169 | $39,097 |

**Net Savings from Alternative Compared with Base Case**

| | |
|---|---|
| **PV of Non-Investment Savings** | $69,259 |
| **- Increased Total Investment** | $30,162 |
| | ------------ |
| **Net Savings** | $39,097 |

**Savings-to-Investment Ratio (SIR)**

**SIR =** 2.30

**Adjusted Internal Rate of Return**

**AIRR =** 5.06%

**Payback Period**
**Estimated Years to Payback (from beginning of Beneficial Occupancy Period)**

| | |
|---|---|
| **Simple Payback occurs in year** | 8 |
| **Discounted Payback occurs in year** | 10 |

**Energy Savings Summary**
**Energy Savings Summary (in stated units)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 199,200.0 kWh | 167,997.0 kWh | 31,203.0 kWh | 1,248,034.6 kWh |

**Energy Savings Summary (in MBtu)**

| **Energy** | **-----Average** | **Annual** | **Consumption-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Savings** | **Savings** |
| **Electricity** | 679.7 MBtu | 573.2 MBtu | 106.5 MBtu | 4,258.5 MBtu |

**Emissions Reduction Summary**

| **Energy** | **-----Average** | **Annual** | **Emissions-----** | **Life-Cycle** |
|---|---|---|---|---|
| **Type** | **Base Case** | **Alternative** | **Reduction** | **Reduction** |
| **Electricity** | | | | |
| **CO2** | 154,965.90 kg | 130,691.80 kg | 24,274.10 kg | 970,897.57 kg |
| **SO2** | 385.84 kg | 325.40 kg | 60.44 kg | 2,417.36 kg |
| **NOx** | 323.44 kg | 272.78 kg | 50.66 kg | 2,026.45 kg |
| **Total:** | | | | |
| **CO2** | 154,965.90 kg | 130,691.80 kg | 24,274.10 kg | 970,897.57 kg |
| **SO2** | 385.84 kg | 325.40 kg | 60.44 kg | 2,417.36 kg |
| **NOx** | 323.44 kg | 272.78 kg | 50.66 kg | 2,026.45 kg |

## Appendix Q: Project Milestone Table

The following table contains the actual dates and durations of various phases of the project.

| **Milestones** | **Plan Date** | **Revised Date** | **Actual Date** |
|---|---|---|---|
| Submit Draft Table 1 Performance Objectives | 07/2011 | | 08/2011 |
| Design/Engineering Completion | 09/2011 | 10/2011 | 02/2012 |
| Submit Draft Demonstration Plan | 11/2011 | 12/2011 | 12/2011 |
| Final Demonstration Plan Approved | 12/2011 | | 02/2012 |
| Monitoring Equipment Installation - Start | 09/2011 | 12/2011 | 12/2011 |
| Permitting/Interconnect Agencies | 10/2011 | 12/2011 | 02/2012 |
| Preconstruction Data Collect - Start | 09/2011 | 12/2011 | 12/2011 |
| Product/Material Acquisition | 11/2011 | 01/2012 | 02/2012 |
| Material Delivery | 12/2011 | 02/2012 | 03/2012 |
| Preconstruction Data Collect - Complete | 12/2011 | 02/2012 | 03/2012 |
| Construction Start | 01/2012 | 03/2012 | 03/2012 |
| Quality Control Inspection | 02/2012 | 04/2012 | 04/2012 |
| Construction Complete | 03/2012 | 05/2012 | 05/2012 |
| Post Construct Data Collect - Start | 03/2012 | 05/2012 | 05/2012 |
| System Commissioning | 03/2012 | 05/2012 | 05/2012 |
| Data Collection Complete | 03/2013 | 05/2013 | 10/2013 |

# Appendix R: Renewable Energy Production on Sunny and Cloudy Days

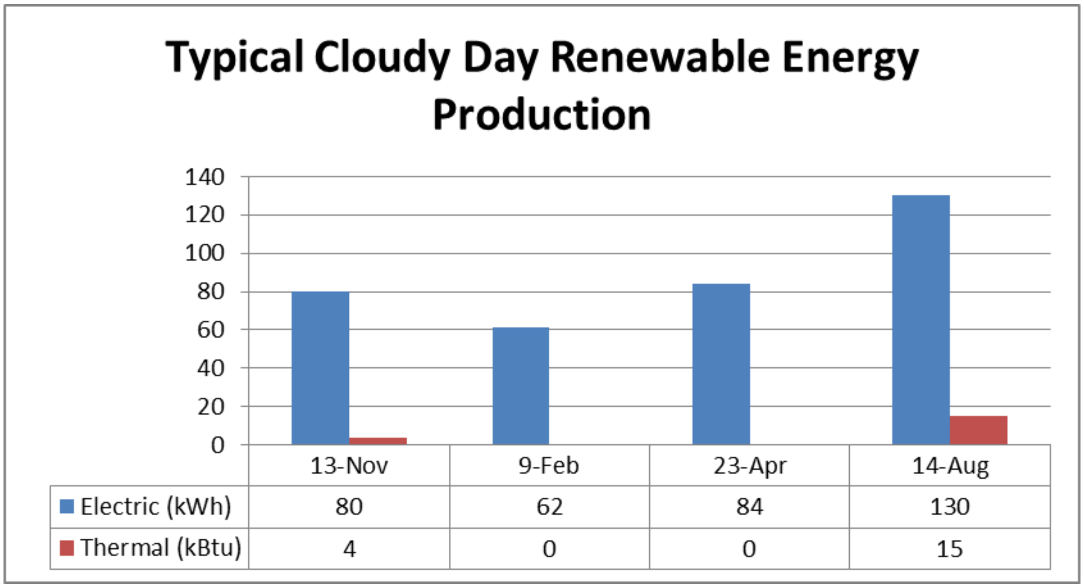



**Figure 34 Actual renewable energy production on a cloudy day for the four seasons.**

The following graphs illustrate the daily production curve of the PV system installed at San Angelo TX, where GFAFB is located, over 4 seasons and sunny and cloudy days.

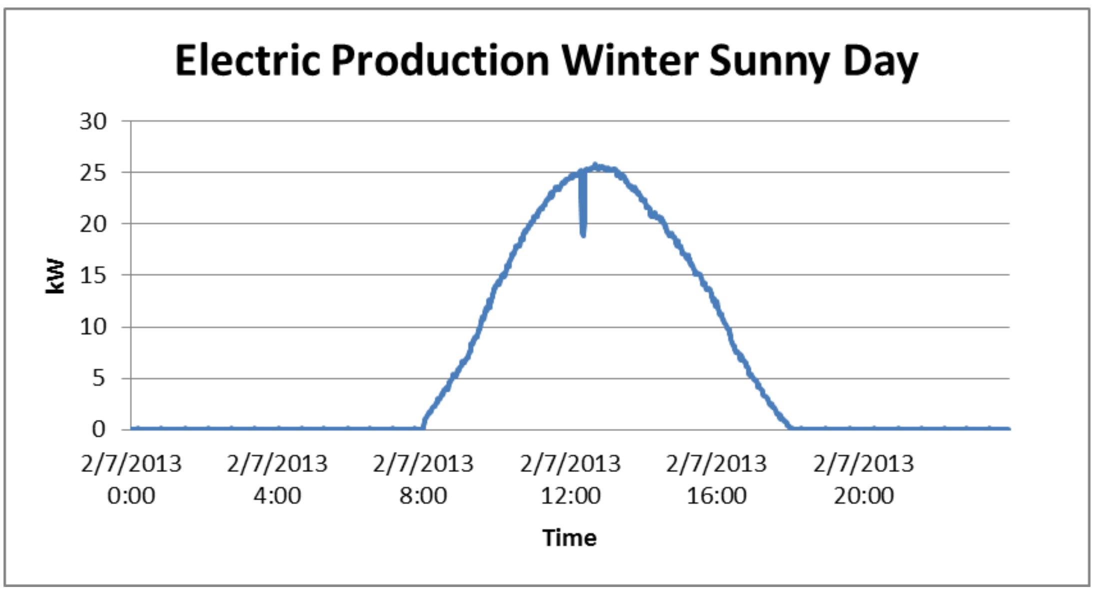



**Figure 35 PV Electricity production on a winter sunny day**

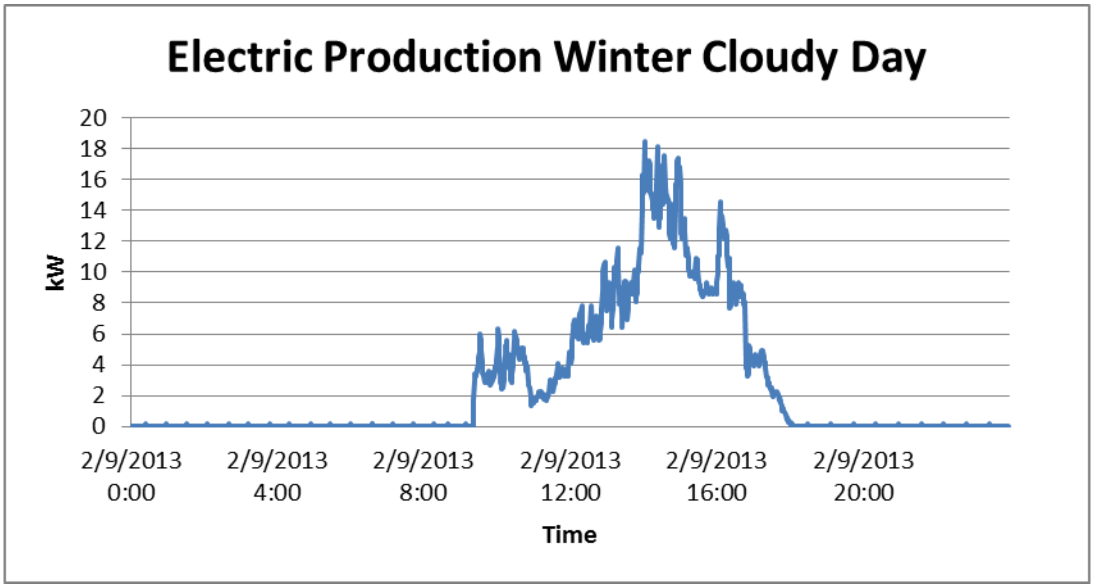



**Figure 36 PV Electricity production on a winter cloudy day**

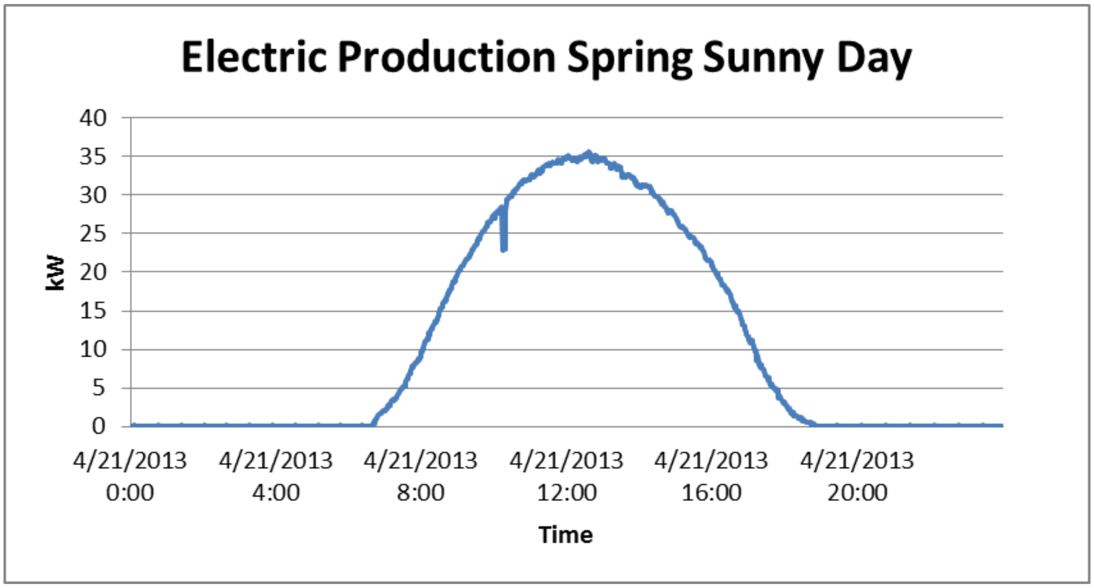



**Figure 37 PV Electricity production on a spring sunny day**

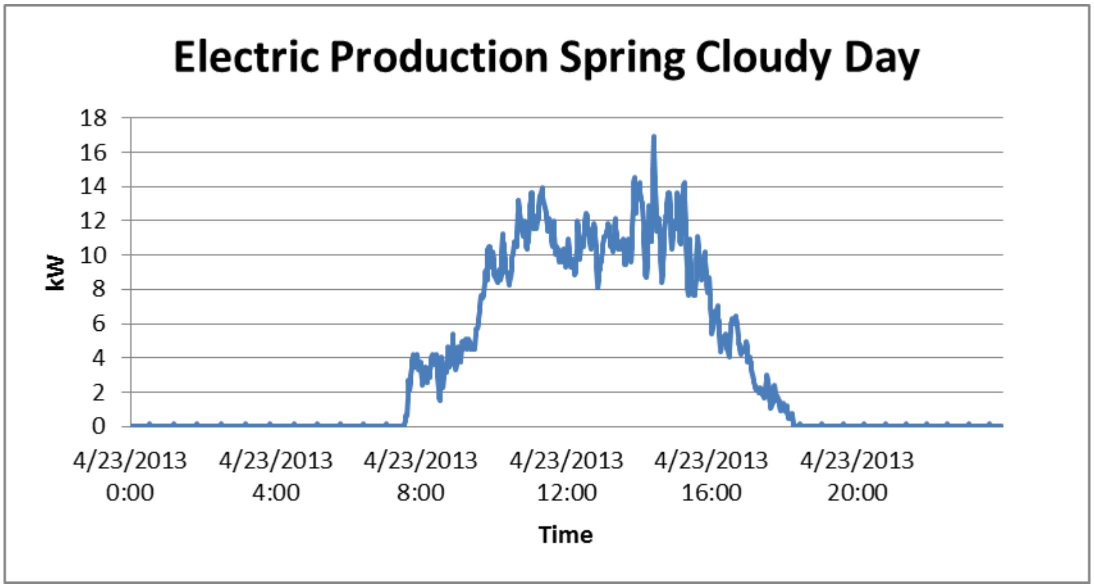



**Figure 38 PV Electricity production on a spring cloudy day**

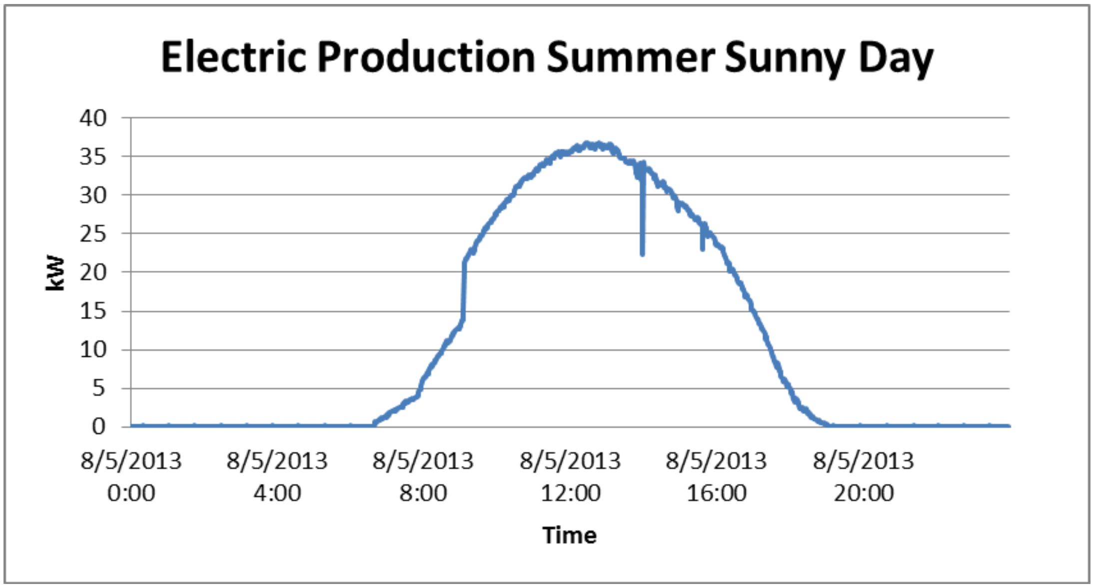



**Figure 39 PV Electricity production on a summer sunny day**

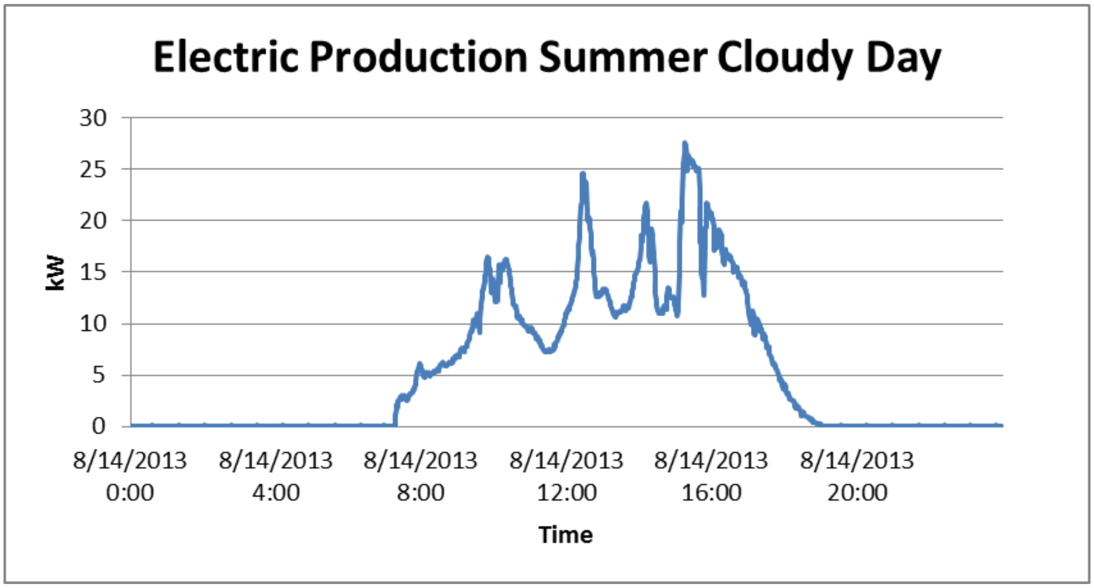



**Figure 40 PV Electricity production on a summer cloudy day**

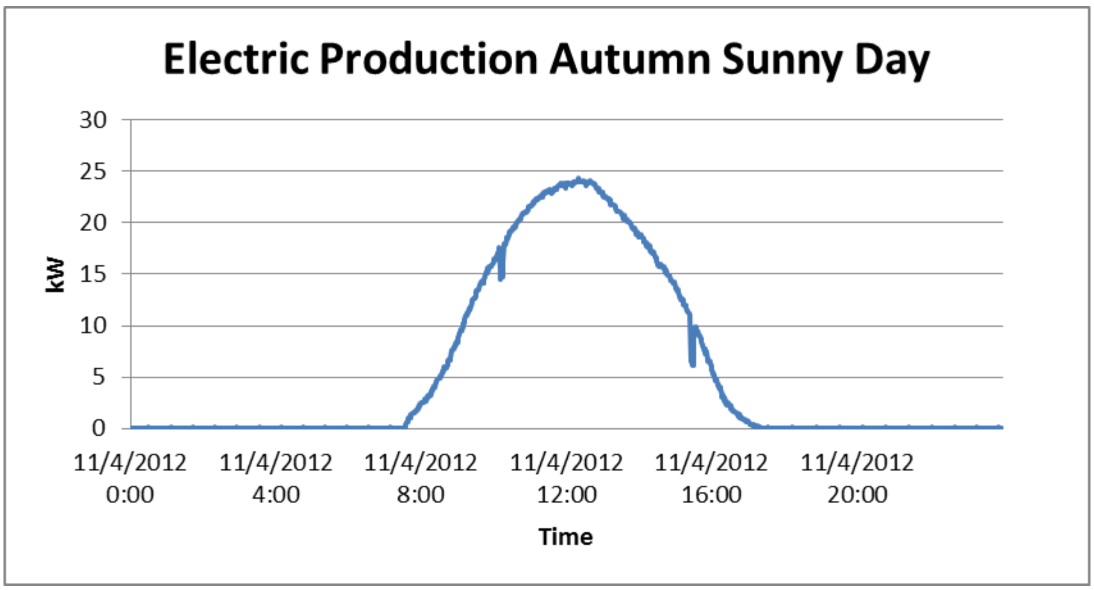



**Figure 41 PV Electricity production on an autumn sunny day**

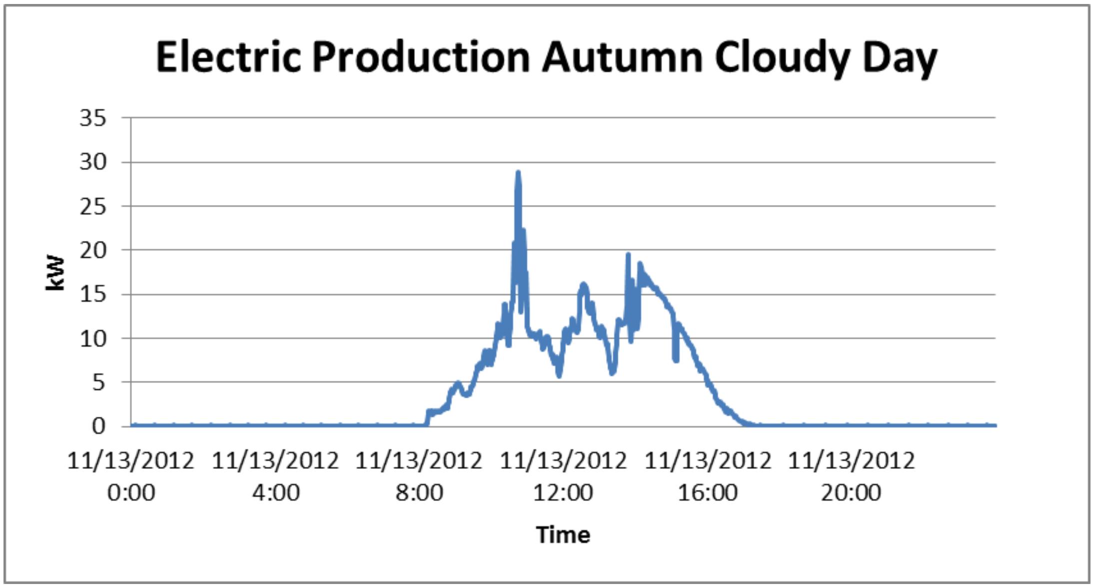



**Figure 42 PV Electricity production on an autumn cloudy day**

The following graphs illustrate the daily production curve of the solar thermal system installed at San Angelo TX, over 4 seasons and on both sunny and cloudy days.

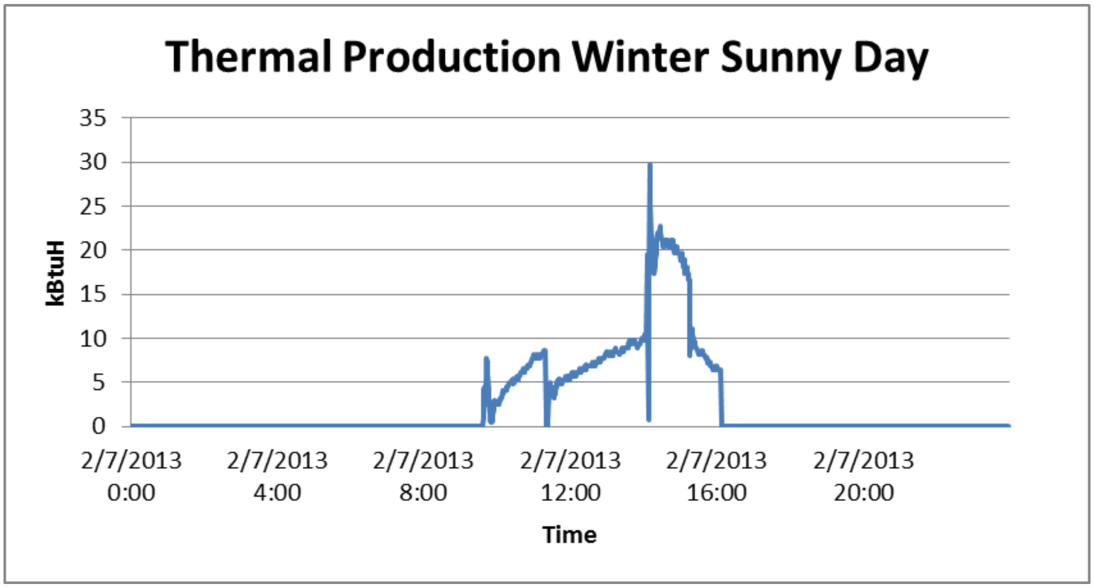



**Figure 43 PV Electricity production on a winter sunny day**

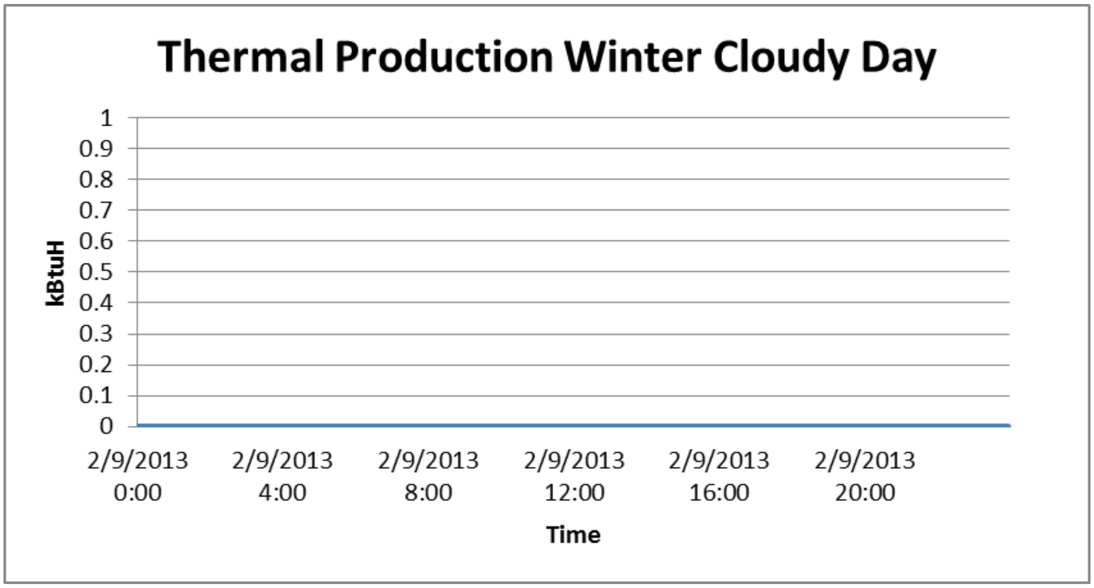


**Figure 44 Solar Thermal System production on winter cloudy day**

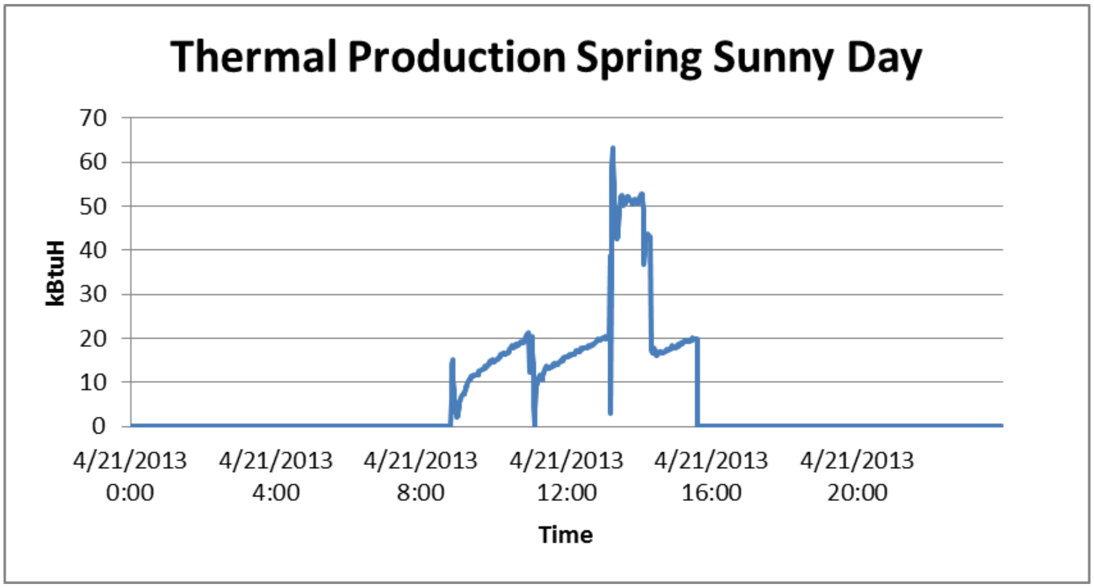


**Figure 45 Solar Thermal System production on a spring sunny day**

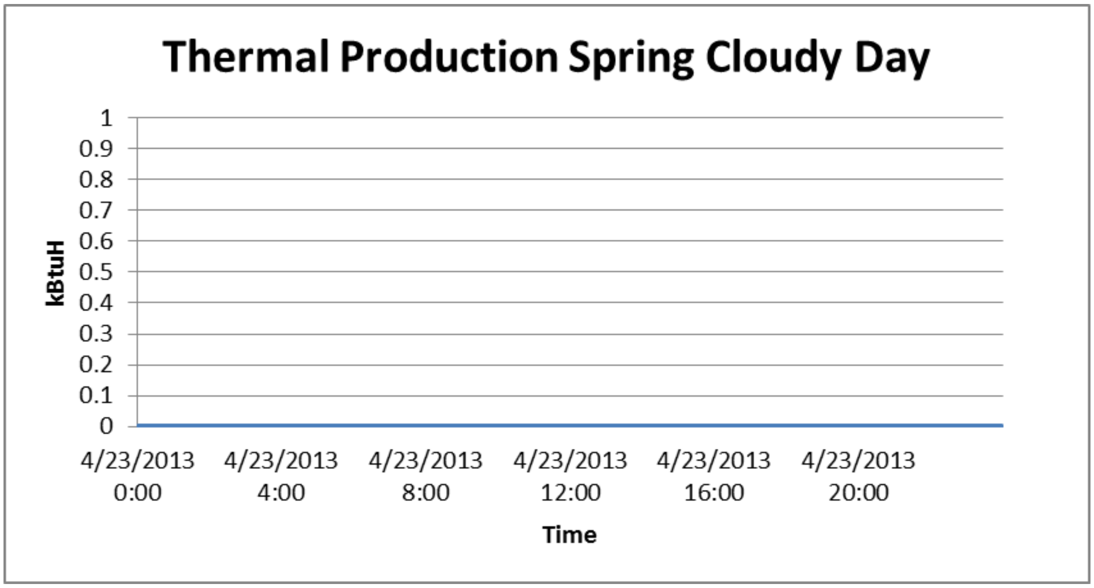



**Figure 46 Solar Thermal System production on a spring cloudy day**

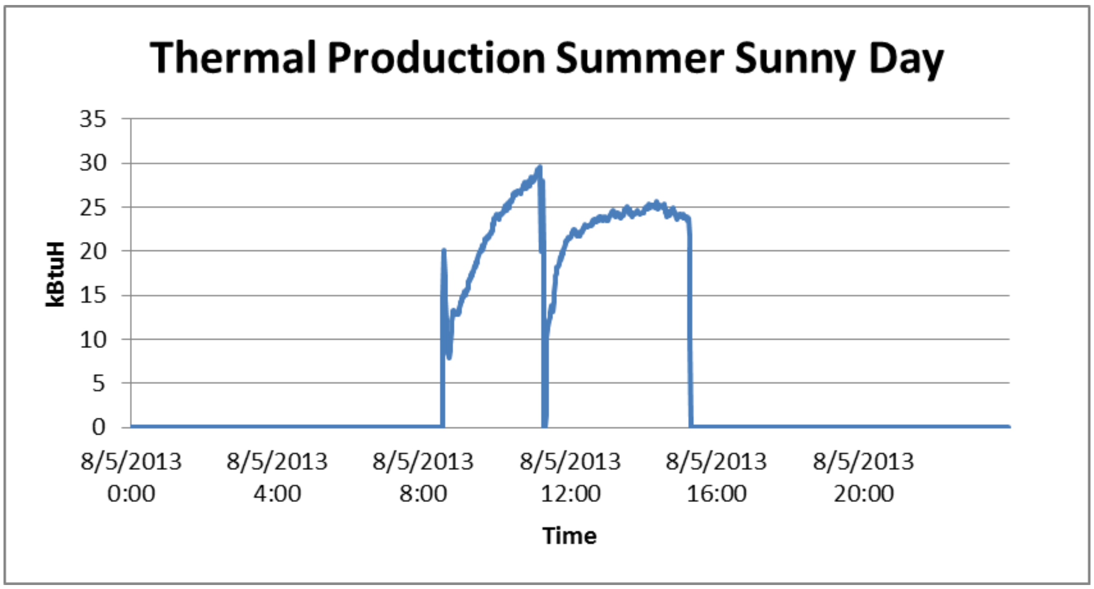



**Figure 47 Solar Thermal System production on a summer sunny day**

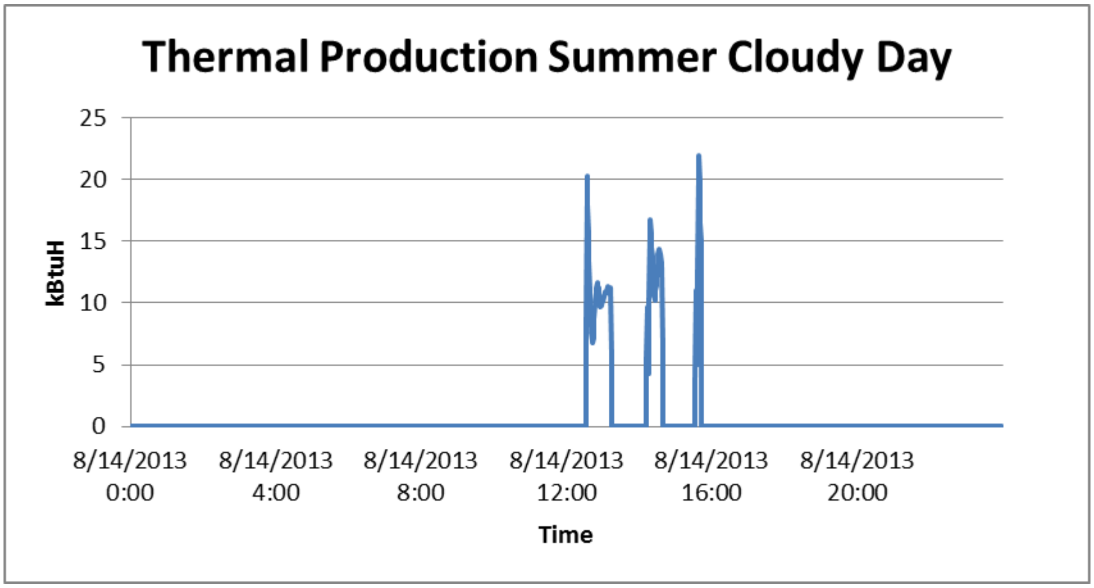


**Figure 48 Solar Thermal System production on a summer cloudy day**

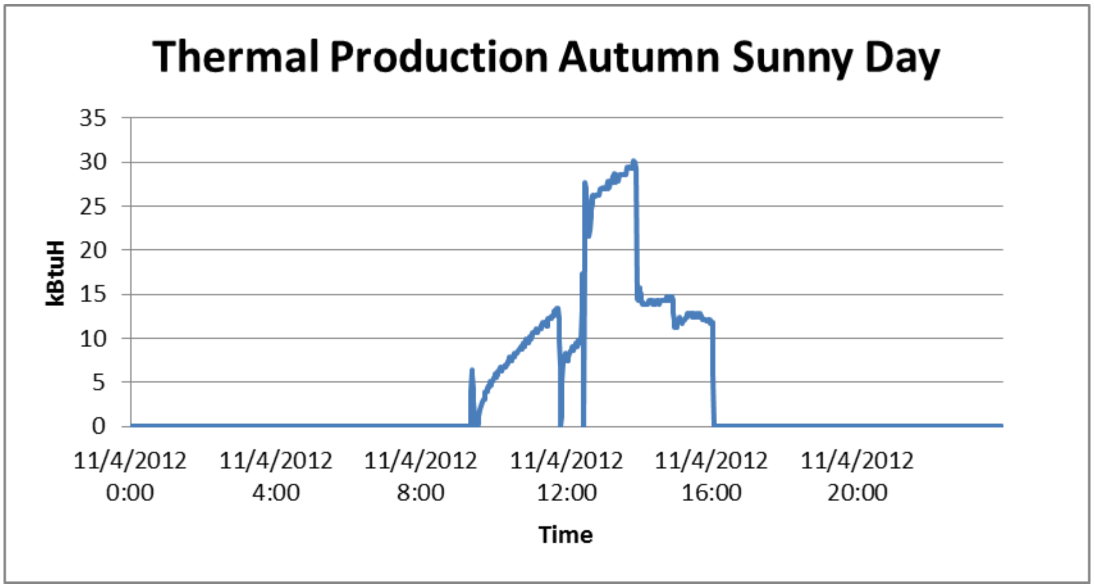


**Figure 49 Solar Thermal System production on an autumn sunny day**

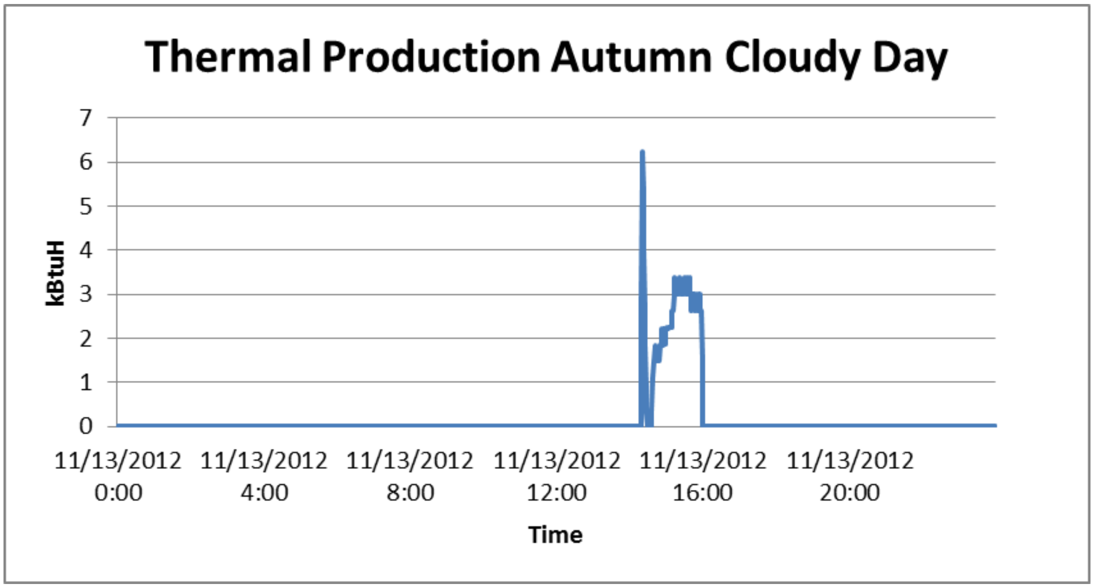


**Figure 50 Solar Thermal System production on an autumn cloudy day**

# Appendix S: SRCC Certification for the Solar Thermal System



| SOLAR COLLECTOR CERTIFICATION AND RATING | CERTIFIED SOLAR COLLECTOR |
|---|---|
| SRCC OG-100 | SUPPLIER: **Dawn Solar**<br>183 Route 125, Unit A-7<br>Brentwood, NH 03833<br><br>MODEL: Dawn Solar 3004L<br>COLLECTOR TYPE: Flat-Plate<br>CERTIFICATION #: 100-2004-009A |

**COLLECTOR THERMAL PERFORMANCE RATING**

| Megajoules Per Panel Per Day | | | | Thousands of Btu Per Panel Per Day | | | |
|---|---|---|---|---|---|---|---|
| CATEGORY (Ti-Ta) | CLEAR DAY 23 MJ/m²·d | MILDLY CLOUDY 17 MJ/m²·d | CLOUDY DAY 11 MJ/m²·d | CATEGORY (Ti-Ta) | CLEAR DAY 2000 Btu/ft²·d | MILDLY CLOUDY 1500 Btu/ft²·d | CLOUDY DAY 1000 Btu/ft²·d |
| A (-5°C) | 22 | 17 | 12 | A (-9°F) | 21 | 16 | 12 |
| B (5°C) | 16 | 11 | 6 | B (9°F) | 15 | 10 | 5 |
| C (20°C) | 3 | | | C (36°F) | 3 | | |
| D (50°C) | | | | D (90°F) | | | |
| E (80°C) | | | | E (144°F) | | | |

A-Pool Heating (Warm Climate) B-Pool Heating (Cool Climate) C-Water Heating (Warm Climate) D-Water Heating (Cool Climate) E-Air Conditioning

Original Certification Date: June 10, 2005

## COLLECTOR SPECIFICATIONS

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Gross Area:** | 9.302 | m² | 100.13 | ft² | **Net Aperture Area:** | 9.302 | m² | 100.13 | ft² |
| **Dry Weight:** | 0 | kg | 0 | lb | **Fluid Capacity:** | 8.2 | l | 2.2 | gal |
| **Test Pressure:** | 1104 | kPa | 160 | psig | **Max. Oper. Temp.:** | 160 | °C | 320 | °F |

## COLLECTOR MATERIALS

**Frame:** Galvanized Steel
**Cover (Outer):** None
**Cover (Inner):** None
**Absorber Material:** Tube - PEX / Plate - Steel
**Absorber Coating:** Dark Green Fluorocarbon
**Insulation (Side):** None
**Insulation (Back):** Polystyrene and plywood

## PRESSURE DROP

| Flow | | Δ P | |
|---|---|---|---|
| ml/s | gpm | Pa | in $H_2O$ |
| 20 | 0.32 | 2523 | 10.13 |
| 50 | 0.79 | 14934 | 59.96 |
| 80 | 1.27 | 27363 | 109.85 |

## TECHNICAL INFORMATION

**Efficiency Equation [NOTE: (P) = Ti-Ta]**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | **Y Intercept** | **Slope** | |
| **S I Units:** | $\eta =$ 0.125 | -1.8670 | (P)/I | -0.0806 $(P)^2/I$ | 0.126 | -3.669 | W/m²·°C |
| **I P Units:** | $\eta =$ 0.125 | -0.3290 | (P)/I | -0.0079 $(P)^2/I$ | 0.126 | -0.647 | Btu/hr-ft²·°F |

**Incident Angle Modifier [(S) = 1/cos θ - 1, 0°≤ θ ≤60°]**

$K_{\alpha\tau}$ = 1.0  -0.2119 (S)  +0.1184 $(S)^2$
$K_{\alpha\tau}$ = 1.0  -0.09 (S)  (Linear Fit)

**Model Tested:** 2004009A
**Test Fluid:** Water
**Test Flow Rate:** 33 ml/s 0.52 gpm

**REMARKS:** This collector is integrated into the roof.

June, 2005

Page 1 of 2

Certification must be renewed annually. For current status contact:
SOLAR RATING & CERTIFICATION CORPORATION
c/o FSEC ♦ 1679 Clearlake Road ♦ Cocoa, FL 32922 ♦ (321) 638-1537 ♦ Fax (321) 638-1010

**Notes to SRCC Certification Technical Information**

1. Due to size constraints imposed by the certified test labs, the Dawn Solar System Model 3004L was evaluated using a 100 Square Foot building section.

2. When conducting performance modeling of a proposed Dawn Solar System, use the table below to adjust the efficiency equations in accordance with the size of the collector under analysis.

| Collector Gross Area (Overall Width x Length) | | | | Collector Absorber area | | | | | Absorber: Gross % | Y Intercept | Slope (IP) | Slope (SI) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | sf | collector | with | 67 | sf | of | absorber | area | 67% | 0.126 | -0.647 | -3.669 |
| 300 | sf | collector | with | 252 | sf | of | absorber | area | 84% | 0.158 | -0.811 | -4.600 |
| 500 | sf | collector | with | 430 | sf | of | absorber | area | 86% | 0.162 | -0.830 | -4.709 |
| 1000 | sf | collector | with | 900 | sf | of | absorber | area | 90% | 0.169 | -0.869 | -4.929 |
| 1500 | sf | collector | with | 1395 | sf | of | absorber | area | 93% | 0.175 | -0.898 | -5.093 |

# Appendix T:DoD Transfer of Real Property

## TRANSFER AND ACCEPTANCE OF DoD REAL PROPERTY

Form Approved
OMB No. 0704-0188

PAGE 1 OF 5 PAGES

The public reporting burden for this collection of information is estimated to average 30 minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Washington Headquarters Services, Executive Services Directorate, Information Management Division, 1155 Defense Pentagon, Washington, DC 20301-1155 (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

**PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THE ABOVE ORGANIZATION.**

**1. FROM** *(Organization Name)*
Metal Construction Association, Inc.
4700 W. Lake Ave
Glenview IL 60025

**2. DATE PREPARED** *(YYYYMMDD)*: 20121109

**3. PROJECT/JOB NUMBER**: EW-201139

**4. SERIAL NUMBER**:

**5. TO** *(Organization - Installation Code and Name)*
17 CES/CEAO
460 E. Kearney Blvd
Goodfellow AFB, TX 76908-4104

**6. RPSUID/SITENAME/INSTCODE/INSTNAME**: JCGU

**7. CONTRACT NUMBER(S)**: 11 EB-SIR-039

**7a. PLACED-IN-SERVICE DATE** *(YYYYMMDD)*: 20120525

**8. TRANSACTION DETAILS**

a. METHOD *(X all that apply)*
- [X] ACQUISITION BY CONSTRUCTION
- [ ] TRANSFER BETWEEN SERVICES
- [ ] CAPITAL IMPROVEMENT
- [ ] INVENTORY ADJUSTMENT

b. WHEN/EVENT *(X one)*
- [ ] TOTAL ASSET PLACED-IN-SERVICE
- [ ] PARTIAL ASSET PLACED-IN-SERVICE

c. TYPE *(X one)*
- [ ] DRAFT
- [X] FINAL
- [ ] INTERIM

| 9. ITEM NO. | 10a. FACILITY NO. | 10b. RPUID | 11. CATEGORY CODE | 12. CATCODE DESCRIPTION | 13. TYPE CODE | AREA: 14. PRIMARY UM | AREA: 15. PRIMARY UM QUANTITY | OTHER: 16. SECONDARY UM | OTHER: 17. SECONDARY UM QUANTITY | 18. COST | 19. FUND SOURCE | 20. FUND ORG | 21. INTER-EST CODE | 22. ITEM REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3323 | | 890127 | PV Transmission Cabling - DC side | | LF | 500 | | | 47,199.68 | 04 | | | PV Transmission Cabling - DC side |
| 2 | 3323 | | 890127 | PV Transmission Conduit - DC side | | LF | 500 | | | 26,971.24 | " | | | PV Transmission Conduit - DC side |
| 3 | 3323 | | 891027 | PV Transmission Cabling - AC side | | LF | 75 | | | 10,114.22 | " | | | PV Transmission Cabling - AC side |
| 4 | 3323 | | 891027 | PV Transmission Conduit - AC side | | LF | 75 | | | 5057.11 | " | | | PV Transmission Conduit - AC side |
| 5 | 3323 | | 891027 | Combiner Boxes | | Ea | 4 | | | 10,114.22 | " | | | Combiner Boxes |
| 6 | 3323 | | 891027 | Inverters w/integrated AC/DC Disconnects | | Ea | 4 | | | 33,714.05 | " | | | Inverters |
| 7 | 3323 | | 891027 | Accumulation Panel - AC side | | Ea | 1 | | | 2022.84 | " | | | Switch Gear/Disconnects DC side |
| 8 | 3323 | | 891027 | Switch Gear/Disconnects AC side | | Ea | 1 | | | 1011.42 | " | | | Switch Gear/Disconnects AC side |
| 9 | 3323 | | 891027 | PV Cabling Roof Raceway | | LF | 300 | | | 6068.53 | " | | | PV Cabling Roof Raceway |
| 10 | 3323 | | 891027 | PV Laminate Panels 16" x 18' Long | | Ea | 352 | SF | 8446 | 194,867.23 | " | | | PV Laminate Panels 16" x 18' Long |

**23. STATEMENT OF COMPLETION.** The facilities listed hereon are in accordance with maps, drawings, and specifications and change orders approved by the authorized representative of the using agency except for the deficiencies listed on the reverse side.

**a. TRANSFERRED BY** *(Typed Name and Signature)*: MARY LUMSDON, GS-11 — LUMSDON.MARY.C.1231045356

**b. DATE SIGNED** *(YYYYMMDD)*: 20121109

**c. TITLE** *(Area Engr./Base Engr./DPW/Construction Agent)*: Base Energy Manager

**24.a. ACCEPTED BY** *(Typed Name and Signature)*: RODELIO C. VILLEGAS

**b. DATE SIGNED** *(YYYYMMDD)*:

**c. TITLE** *(DPW/RPAO)*: Deputy, Base Civil Engineer

**25. PROPERTY VOUCHER NUMBER**: 2013002239

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PAGE 2 OF 5 PAGES

# TRANSFER AND ACCEPTANCE OF DoD REAL PROPERTY

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**1. FROM** *(Organization Name)*
Metal Construction Association, Inc.
4700 W. Lake Ave
Glenview IL 60025

**2. DATE PREPARED** *(YYYYMMDD)*: 20121109

**3. PROJECT/JOB NUMBER**: EW-201139

**4. SERIAL NUMBER**:

**5. TO** *(Organization - Installation Code and Name)*
17 CES/CEAO
460 E. Kearney Blvd
Goodfellow AFB, TX 76908-4104

**6. RPSUID/SITENAME/INSTCODE/INSTNAME**: JCGU

**7. CONTRACT NUMBER(S)**: 11 EB-SIR-039

**7a. PLACED-IN-SERVICE DATE** *(YYYYMMDD)*: 20120525

**8. TRANSACTION DETAILS**

a. METHOD *(X all that apply)*
- [X] ACQUISITION BY CONSTRUCTION
- [ ] TRANSFER BETWEEN SERVICES
- [ ] CAPITAL IMPROVEMENT
- [ ] INVENTORY ADJUSTMENT

b. WHEN/EVENT *(X one)*
- [ ] TOTAL ASSET PLACED-IN-SERVICE
- [ ] PARTIAL ASSET PLACED-IN-SERVICE

c. TYPE *(X one)*
- [ ] DRAFT
- [X] FINAL
- [ ] INTERIM

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 3323 | | 890127 | Thermal Pex Purlin (raceway) | | LF | 15000 | | | 30,561.25 | 84 | | | Thermal Pex Purlin (raceway) |
| 12 | 3323 | | 890127 | Thermal Collector Pex Piping | | LF | 16800 | | | 43,207.68 | " | | | Thermal Collector Pex Piping |
| 13 | 3323 | | 890127 | Thermal Solar reflective Blanket | | SF | 11220 | | | 29,331.77 | " | | | Thermal Solar reflective Blanket |
| 14 | 3323 | | 891027 | Thermal Manifold Assembly | | Ea | 10 | | | 7552.49 | " | | | Thermal Manifold Assembly |
| 15 | 3323 | | 891027 | Thermal Transmission Piping Copper | | LF | 600 | | | 29,683.05 | " | | | Thermal Transmission Piping Copper |
| 16 | 3323 | | 891027 | Thermal Piping Insulation | | LF | 600 | | | 12,821.67 | " | | | Thermal Piping Insulation |
| 17 | 3323 | | 891027 | Thermal Circulating Pumps | | Ea | 6 | | | 2634.59 | " | | | Thermal Circulating Pumps |
| 18 | 3323 | | 891027 | Hydronic Coil Unit Heaters | | Ea | 2 | | | 8430.69 | " | | | Hydronic Coil Unit Heaters |
| 19 | 3323 | | 891027 | Hydronic Coil HVAC insert | | Ea | 1 | | | 2107.67 | " | | | Hydronic Coil HVAC insert |
| 20 | 3323 | | 891027 | Thermal System Electronic Controllers | | Ea | 6 | | | 1405.11 | " | | | Thermal System Electronic Controllers |

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a. TRANSFERRED BY *(Typed Name and Signature)*
MARY LUMSDON, GS-11
LUMSDON.MARY.C.1231045356

b. DATE SIGNED *(YYYYMMDD)*: 20121109

c. TITLE *(Area Engr./Base Engr./DPW/Construction Agent)*
Base Energy Manager

24.a. ACCEPTED BY *(Typed Name and Signature)*
RODELIO C VILLEGAS

b. DATE SIGNED *(YYYYMMDD)*

c. TITLE *(DPW/RPAO)*
Deputy, Base Civil Engineer

25. PROPERTY VOUCHER NUMBER
201300 2239

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PAGE 3 OF 5 PAGES

# TRANSFER AND ACCEPTANCE OF DoD REAL PROPERTY

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Glenview IL 60025

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**4. SERIAL NUMBER**:

**5. TO** *(Organization - Installation Code and Name)*
17 CES/CEAO
460 E. Kearney Blvd
Goodfellow AFB, TX 76908-4104

**6. RPSUID/SITENAME/ INSTCODE/INSTNAME**: JCGU

**7. CONTRACT NUMBER(S)**: 11 EB-SIR-039

**7a. PLACED-IN-SERVICE DATE** *(YYYYMMDD)*: 20120525

**8. TRANSACTION DETAILS**

a. METHOD *(X all that apply)*
- [X] ACQUISITION BY CONSTRUCTION
- [ ] TRANSFER BETWEEN SERVICES
- [ ] CAPITAL IMPROVEMENT
- [ ] INVENTORY ADJUSTMENT

b. WHEN/EVENT *(X one)*
- [ ] TOTAL ASSET PLACED-IN-SERVICE
- [ ] PARTIAL ASSET PLACED-IN-SERVICE

c. TYPE *(X one)*
- [ ] DRAFT
- [X] FINAL
- [ ] INTERIM

| 9. ITEM NO. | 10a. FACILITY NO. | 10b. RPUID | 11. CATEGORY CODE | 12. CATCODE DESCRIPTION | 13. TYPE CODE | AREA 14. PRIMARY UM | AREA 15. PRIMARY UM QUANTITY | OTHER 16. SECONDARY UM | OTHER 17. SECONDARY UM QUANTITY | 18. COST | 19. FUND SOURCE | 20. FUND ORG | 21. INTER-EST CODE | 22. ITEM REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 3323 | | 890127 | Thermal Sensors | | Ea | 20 | | | 175.64 | 84 | | | Thermal Sensors |
| 22 | 3323 | | 891027 | Thermal Cabling - Control Wiring | | LF | 2000 | | | 702.56 | " | | | Thermal Cabling - Control Wiring |
| 23 | 3323 | | 891027 | Thermal Cabling - 110v | | LF | 500 | | | 1229.09 | " | | | Thermal Cabling - 110v |
| 24 | 3323 | | 891027 | Thermal Cabling - Conduit Control Wiring | | LF | 500 | | | 1580.75 | " | | | Thermal Cabling - Conduit Control Wiring |
| 25 | 3323 | | 891027 | Thermal Cabling - Conduit 110v. | | LF | 500 | | | 1580.75 | " | | | Thermal Cabling - Conduit 110v. |
| 26 | 3323 | | 891027 | Thermal Storage Tank | | Ea | 1 | GL | 119 | 2634.59 | " | | | Thermal Storage Tank |
| 27 | 3323 | | 730835 | Roof Polyiso Insulation 1/2" | | SF | 11,828 | | | 15,107.19 | " | | | Roof Polyiso Insulation 1/2" |
| 28 | 3323 | | 730835 | Roof Polylso Insulation 1" | | SF | 11,828 | | | 22,682.16 | " | | | Roof Polylso Insulation 1" |
| 29 | 3323 | | 730835 | Roof Polyiso Insulation 2" | | SF | 11,828 | | | 37,614.21 | " | | | Roof Polyiso Insulation 2" |
| 30 | 3323 | | 730835 | Roof Weathershield Underlayment | | SF | 11,828 | | | 6327.87 | " | | | Roof Weathershield Underlayment |

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a. TRANSFERRED BY *(Typed Name and Signature)*: MARY LUMSDON, GS-11 — LUMSDON.MARY.C.1231045356

b. DATE SIGNED *(YYYYMMDD)*: 20121109

c. TITLE *(Area Engr./Base Engr./DPW/Construction Agent)*: Base Energy Manager

24.a. ACCEPTED BY *(Typed Name and Signature)*: RODELIO C. VILLEGAS

b. DATE SIGNED *(YYYYMMDD)*:

c. TITLE *(DPW/RPAO)*: Deputy, Base Civil Engineer

25. PROPERTY VOUCHER NUMBER: 201300 2239

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# TRANSFER AND ACCEPTANCE OF DoD REAL PROPERTY

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- [ ] TRANSFER BETWEEN SERVICES
- [ ] CAPITAL IMPROVEMENT
- [ ] INVENTORY ADJUSTMENT

**b. WHEN/EVENT** *(X one)*
- [ ] TOTAL ASSET PLACED-IN-SERVICE
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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 3323 | | 730835 | 16g Structural Roof Sub purlin | | LF | 2700 | | | 18,932.72 | 84 | | | 16g Structural Roof Sub purlin |
| 32 | 3323 | | 730835 | 24g Metal Roof Panel 16" Pan width x 37' 5" | | Ea | 238 | SF | 11,828 | 76,328.56 | " | | | 24g Metal Roof Panel 16" Pan width x 37' 5" |
| 33 | 3323 | | 730835 | Interior Gutter system | | LF | 300 | | | 3522.25 | " | | | Interior Gutter system |
| 34 | 3323 | | 730835 | Vented Ridge Cap Assembly | | LF | 150 | | | 3650.65 | " | | | Vented Ridge Cap Assembly |
| 35 | 3323 | | 730835 | Roof Equipment Curbs | | Ea | 8 | | | 5779.37 | " | | | Roof Equipment Curbs |
| 36 | 3323 | | 841427 | Rainwater Collection Tank 10,000 gal | | Ea | 1 | GL | 10,000 | 15,497.59 | " | | | Rainwater Collection Tank 10,000 gal |
| 37 | 3323 | | 841427 | Booster Pump | | Ea | 1 | | | 4960.06 | " | | | Booster Pump |
| 38 | 3323 | | 841427 | Rainwater Collection Piping | | LF | 309 | | | 4730.84 | " | | | Rainwater Collection Piping |
| 39 | 3323 | | 841127 | Rainwater/Irrigation Distribution Piping | | LF | 76 | | | 1753.67 | " | | | Rainwater/Irrigation Distribution Piping |
| 40 | 3323 | | 841127 | Rainwater Collection Pressure Tank | | Ea | 1 | | | 1141.93 | " | | | Rainwater Collection Pressure Tank |

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Base Energy Manager

**24.a. ACCEPTED BY** *(Typed Name and Signature)*
RODELIO C. VILLEGAS

**b. DATE SIGNED** *(YYYYMMDD)*:

**c. TITLE** *(DPW/RPAO)*
Deputy, Base Civil Engineer

**25. PROPERTY VOUCHER NUMBER**: 2013002239

**DD FORM 1354, SEP 2009** PREVIOUS EDITION IS OBSOLETE. Adobe Professional 8.0

## TRANSFER AND ACCEPTANCE OF DoD REAL PROPERTY

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PAGE 5 OF 5 PAGES

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- [ ] TOTAL ASSET PLACED-IN-SERVICE
- [ ] PARTIAL ASSET PLACED-IN-SERVICE

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- [ ] DRAFT
- [X] FINAL
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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41 | 3323 | | 841427 | RWCS/Irrigation Make up water piping | | Ea | 54 | | | 1590.54 | 84 | | | RWCS/Irrigation Make up water piping |
| 42 | 3323 | | 841427 | RWCS/Irrigation Valves - Manual | | Ea | 7 | | | 912.71 | " | | | RWCS/Irrigation Valves - Manual |
| 43 | 3323 | | 841427 | RWCS/Irrigation Valves - Automatic | | Ea | 1 | | | 734.10 | " | | | RWCS/Irrigation Valves - Automatic |
| 44 | 3323 | | 841427 | RWCS / Cabling - Low Voltage | | LF | 95 | | | 122.35 | " | | | RWCS / Cabling - Low Voltage |
| 45 | 3323 | | 841127 | RWCS/Cabling - Line Voltage | | LF | 19 | | | 938.01 | " | | | RWCS/Cabling - Line Voltage |
| 46 | 3323 | | 841127 | RWCS Conduit - Line Voltage | | LF | 19 | | | 122.35 | " | | | RWCS Conduit - Line Voltage |
| 47 | 3323 | | 841127 | RWCS Switchgear/Disconnects | | Ea | 1 | | | 774.88 | " | | | RWCS Switchgear/Disconnects |
| 48 | 3323 | | 841127 | RWCS Water Meters | | Ea | 2 | | | 3099.52 | " | | | RWCS Water Meters |
| 49 | 3323 | | 841127 | RWCS Controls | | Ea | 1 | | | 4404.58 | " | | | RWCS Controls |
| 50 | | | | | | | | | | | | | | |

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c. TITLE *(Area Engr./Base Engr./DPW/Construction Agent)*: Base Energy Manager

**24.a. ACCEPTED BY** *(Typed Name and Signature)*: RODELIO C. VILLEGAS

b. DATE SIGNED *(YYYYMMDD)*:

c. TITLE *(DPW/RPAO)*: Deputy, Base Civil Engineer

**25. PROPERTY VOUCHER NUMBER**:

**DD FORM 1354, SEP 2009** PREVIOUS EDITION IS OBSOLETE. Adobe Professional 8.0

**26. CONSTRUCTION DEFICIENCIES** *(Attach blank sheet for continuations)*

**27. PROJECT REMARKS** *(Attach blank sheet for continuations)*

| | |
|---|---|
| Cost of Support to Demonstration Project = | 84,600.00 |
| Cost of Engineering (All systems) = | 30,000.00 |
| Cost of Construction (Listed above)= | 743,508.00 |
| Total = | 858,108.00 |

## INSTRUCTIONS

**GENERAL.** This form has been designed and issued for use in connection with the transfer of military real property between the military departments and to or from other government agencies. It supersedes ENG Forms 290 and 290B (formerly used by the Army and Air Force) and NAVDOCKS Form 2317 (formerly used by the Navy).

Existing instructions issued by the military departments relative to the preparation of DD Form 1354 are applicable to this revised form to the extent that the various items and columns on the superseded forms have been retained. The military departments may promulgate additional instructions, as appropriate.

For detailed instructions on how to fill out this form, please refer to Unified Facilities Criteria (UFC) 1-300-08, dated 16 April 2009 or later.

**SPECIFIC DATA ITEMS.**

1. **From.** Name of the transferring agency.

2. **Date Prepared.** Date of actual preparation. Enter all dates in YYYYMMDD format (Example: March 31, 2010 = 20100331).

3. **Project/Job Number.** Project number on a DD Form 1391 or Individual Job Order Number.

4. **Serial Number.** Sequential serial number assigned by the preparing organization (e.g., 2010-0001).

5. **To.** Name and address of the receiving installation, activity, and Service of the Real Property Accountable Officer (RPAO).

6. **RPSUID/SITENAME/INSTCODE/INSTNAME.** Real Property Site Unique Identifier and Site Name or Installation Code and Installation Name where the constructed facility is located.

7. **Contract Number(s).** Contract number(s) for this project.

7a. **Placed-In-Service Date.** RPA Placed In Service Date. This is the date the asset is actually placed-in-service.

8. **Transaction Details.**
   a. Method of Transaction. Mark (X) as many boxes as apply.
   b. When/Event. When or event causing preparation of DD Form 1354. X only one box.
   c. Type. Draft, interim, or final DD Form 1354. X only one box.

9. **Item Number.** Use a separate item number for each facility, no item number for additional usages.

10a. **Facility Number.** Assigned in accordance with the Installation/Base Master Numbering Plan.

10b. **RPUID.** Real Property Unique Identifier - Identified in Real Property Inventory.

11. **Category Code.** The category code describes the facility usage.

12. **Catcode Description.** The category code name which describes the facility usage.

13. **Type Code.** Construction Type Code - Type of construction: P for Permanent; S for Semi-permanent; T for Temporary.

14. **Primary Unit Of Measure.** Area unit of measure; use the unit of measure associated with the category code selected in 11.

15. **Primary Unit of Measure Quantity.** The total area for the measure identified in Item 14. Use negative numbers for demolition.

16. **Secondary Unit of Measure.** Unit of Measure 2 is the capacity or other measurement unit (e.g., LF, MB, EA, etc.).

17. **Secondary Unit of Measure Quantity.** The total capacity/other for the measure identified in Item 16.

18. **Cost.** Cost for each facility; for capital improvements to existing facilities, show amount of increase only. If there is no increase for the capital improvement, enter N/A.

19. **Fund Source.** Enter the Fund Source Code for this item.

20. **Funding Organization.** Enter the code for the organization responsible for acquiring this facility.

21. **Interest Code.** RPA Interest Type Code. Enter the code that reflects government interest or ownership in the facility.

22. **Item Remarks.** Remarks pertaining only to the item number identified in Item 9; show cost sharing.

23. **Statement of Completion.** Typed name, signature, title, and date of signature by the responsible transferring individual or agent.

24. **Accepted By.** Typed name, signature, title, and date of signature by the RPAO or accepting official.

25. **Property Voucher Number.** Next sequential number assigned by the RPAO in voucher register.

26. **Construction Deficiencies.** List construction deficiencies in project during contractor turnover inspection.

27. **Project Remarks.** Project level remarks and continuation of blocks.

**DD FORM 1354 (BACK), SEP 2009**

# Appendix U: ORNL ASV White Paper

## THE IMPACT OF ABOVE-SHEATHING VENTILATION ON THE THERMAL AND MOISTURE PERFORMANCE OF STEEP-SLOPE RESIDENTIAL ROOFS AND ATTICS


William (Bill) Miller
Research Scientist
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Joe Wilson
Product Manager
Metro Roof Products
Oceanside, California

Achilles Karagiozis
Research Scientist
Oak Ridge National Laboratory
Oak Ridge, Tennessee



ABSTRACT

Field studies were conducted on several attic assemblies having stone-coated metal shake roofs with and without infrared blocking color pigments (IrBCPs) and with and without above-sheathing ventilation. The combination of increased solar reflectance and above-sheathing ventilation reduced the heat flow penetrating the attic floor by 70% as compared with the heat flow penetrating the attic floor of a roof with conventional asphalt shingles. The venting strategy also eliminated the heating penalty associated with a reflective roof as compared with that of a dark heat-absorbing shingle roof.



KEYWORDS

Moisture and humidity; attic ventilation case studies; monitoring and analysis of energy data; data project case studies; building envelope issues; glazing; residential housing design; institutional, government, and utility energy policy; energy conservation; Rebuild America program


INTRODUCTION

Infrared blocking color pigments (IrBCPs) that are dark in color but highly reflective in the near-infrared (NIR) spectrum were a serendipitous by-product of research conducted for the U.S. Department of Defense. Military camouflage was tailored to match the reflectance of foliage in the visible and the NIR spectra. The chlorophyll in plants strongly absorbs in the non-green parts of the visible spectrum, giving the leaf a dark green color with high reflectance elsewhere in the solar spectrum (Kipling 1970). In the NIR the chlorophyll in foliage naturally boosts the reflectance of a plant's leaf from 0.1 to about 0.9; this enhanced reflectance explains why a dark green leaf remains cool on a hot summer day.

Tailoring color pigments to produce high NIR reflectance similar to that of chlorophyll provides an excellent opportunity for passive energy savings for exterior residential surfaces such as roofs exposed to the sun's irradiance. For example, a calcinated mixture of the black pigment chromic oxide ($Cr_2O_3$) and ferric oxide ($Fe_2O_3$) increases the solar reflectance of a standard black pigment from 0.05 to 0.26 (Sliwinski, Pipoly and Blonski 2001). Further details about identifying and characterizing dark yet highly reflective color pigments and calculating their potential energy benefits are discussed in Miller et al. (2004); Akbari et al. (2004); and Levinson, Berdahl, and Akbari (2004a–b).

Above-sheathing ventilation of a roof cover can also provide thermal benefits for comfort cooling. Residential roof tests by Beal and Chandra (1995) demonstrated a 45% reduction in the daytime heat flux penetrating a counter-batten concrete tile roof as compared with a direct-nailed shingle roof. Parker, Sonne, and Sherwin (2002) observed that a barrel-shaped terra-cotta concrete tile with moderate solar reflectance reduced a test home's annual cooling load by about 8% of the base load measured for an identical adjacent home with an asphalt shingle roof. These reported energy savings are attributable in part to a thermally driven airflow occurring above the sheathing within the air channel formed by the underside of the tile and the roof deck; this airflow is referred to in this paper as *above-sheathing ventilation*. The airflow is driven by buoyancy and/or wind forces. The air channel also provides an improvement in the insulating effect of the roofing system. Though few studies are available on heat transfer within the narrow air channel in counter-batten installations, insight can be gained from the work done on attic ventilation and from experimental studies of heat transfer in inclined ducts. Ozsunar, Baskaya, and Sivrioglu (2001) studied the effects of inclination on convection within a large-aspect-ratio duct heated from below.

To examine the effects of "cool color" pigments in combination with above-sheathing ventilation, a steep-slope roof assembly was constructed for field testing and documenting the energy savings and durability of stone-coated metal roofs with shake and S-mission profiles. Stone-coated metal is made from pre-primed 26-gauge galvanized steel that is coated with a layer of stone chips (Figure 1). An acrylic base coat and an overglaze are applied to seal the product.

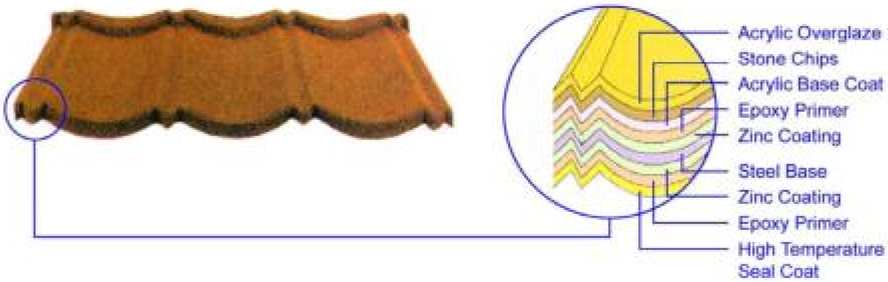


Figure 1. The construction of a commercially available stone-coated metal roof product.

FORMULATING STONE-COATED METALS WITH IRBCPs

Weathered Timber is a commercially available stone-coated metal product that has a solar reflectance of 0.06. To improve its solar reflectance, several granular-coated products of a given color were evaluated for the importance of the size of the aggregate, the type of cool paint pigment, and the effect of applying the paint pigments to the primer/binder adhesive holding the aggregate in place. Pigment testing showed that adding cool pigments to the base granite adhesive increased the solar reflectance only 0.03 reflectance points over an adhesive with conventional pigment. The results reveal that little irradiance penetrates the multiple finishing layers of the stone-coated metal (Figure 2). Blending a Weathered Timber color with individual granules with a somewhat lighter and more reflective color and then coating the stone chips with a clear acrylic overglaze increased the solar reflectance from 0.06 to about 0.19 (second bar from left in Figure 2). The acrylic overglaze is typically applied as a final coating and gives the stone granules a semigloss appearance. The acrylic finish bonds to the granules and encapsulates them with a coating that enhances the panel's resistance to physical damage.

When cool pigments were added to the granules and to the acrylic base coat adhesive, the solar reflectance again increased, to 0.22. The addition of cool pigments to the overglaze (right-hand bar in Figure 2) further increased the solar reflectance

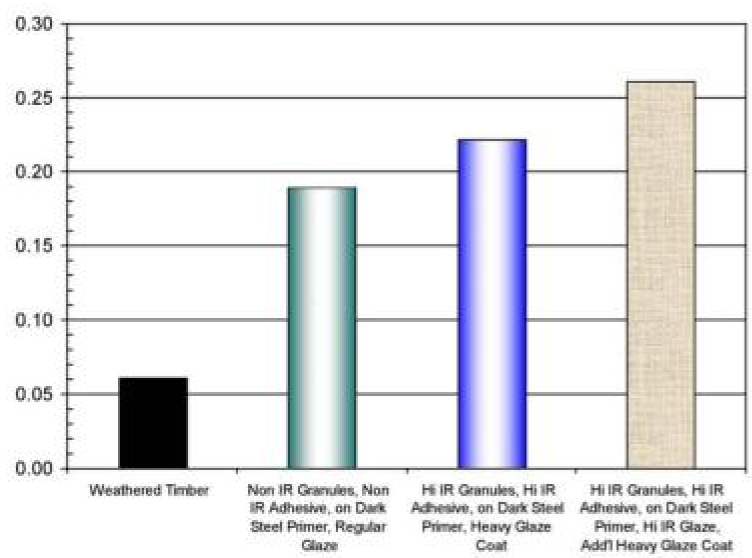


Figure 2. Improvements in solar reflectance of stone-coated metal through application of IrBCPs and acrylic overglaze.

above 0.25, which is the threshold set for steep-slope roofing for an ENERGY STAR rating. Given these results for improving solar reflectance, prototype stone-coated metal shakes and tiles meeting the 0.25 reflectance threshold were installed on an assembly of steep-slope attics and field-tested for a full year.

STEEP-SLOPE ATTIC ASSEMBLY

Light-gray and dark-gray stone-coated metal shakes (solar reflectances of 0.26 and 0.08, respectively) were installed on batten and counter-batten systems and field-tested against a control asphalt shingle roof assembly. The steep-slope assembly and characteristics of the shingles are summarized in Table 1. The stone-coated shake facsimile roofs were offset from the roof deck using a batten and counter-batten system made of 1 × 4 in. counter-battens nailed to the roof deck from soffit to ridge, and 2 × 2 in. battens placed above the counter-battens and nailed to the deck (Figure 3). The batten and counter-batten construction provides a unique inclined air channel running from the soffit to the ridge. The bottom surface of the air channel is formed by the sheathing. The top surface is created by the underside of the stone-coated metal and is broken at regular intervals by the 2 × 2 in. batten wood furring strip (into which the shakes are fastened). Each test roof has its own attic cavity with 5 in. of expanded polystyrene insulation installed between adjacent cavities to reduce the heat leakage between cavities so that each attic assembly and test roof can be tested as a stand-alone assembly.

A painted metal shake with a polyvinylidene fluoride (PVDF) base coat and two S-mission-profile stone-coated metal roofs were also tested (Figure 4); however, the discussion here will focus on the dark- and light-gray stone-coated metal roofs. Details about the metal shake with PVDF base coat and the S-mission profiles are provided in Miller (2006).

Instrumentation for Attic Assembly

The roof surface temperature, the air temperature in the inclined air gap, the temperatures of the roof deck on both sides of the oriented strand board (OSB), and the heat flux transmitted through the roof deck were directly measured and recorded by a data acquisition system (DAS). All roof decks have a 2-in.-square by 0.18-in.-deep routed slot with a heat flux transducer (HFT) inserted to measure the heat flow crossing the roof deck. Each HFT was placed in a guard made of the same OSB material used in construction and was calibrated using a FOX 670 heat flowmeter to correct for shunting effects (i.e., distortion due to three-dimensional heat flow). The assemblies also have an instrumented area in the attic floor (i.e., ceiling) for measuring the heat flows into the conditioned space. The attic floor consists of a metal deck, a 1-in.-thick piece of wood fiberboard

Table 1. Stone-coated metal shakes field tested on the steep-slope attic assembly

| Profile | Color | Pigment | Surface | Underside | Attachment | Above-sheathing ventilation[a] |
|---|---|---|---|---|---|---|
| *Lane 6: Control asphalt shingle (SR093E89)* | | | | | | |
| Shingle[b] | Dark-gray | Conventional | Aggregate | NA | Direct-to-deck | No |
| *Lane 7: Shk-LG-IRRagg-Upt-CB (SR246E90)* | | | | | | |
| Shake | Light-gray | IrBCP | Aggregate | Unpainted | Batten and counter-batten[c] | Yes |
| *Lane 8: Shk-DG-CNVagg-Upt-CB (SR08E90)* | | | | | | |
| Shake | Dark-gray | Conventional | Aggregate | Unpainted | Batten and counter-batten | Yes |
| *Lane 9: Shk-LG-IRRagg-Pt-CB (SR25E90)* | | | | | | |
| Shake | Light-gray | IrBCP | Aggregate | Painted | Batten and counter-batten | Yes |
| *Lane 12: Shk-LG-IRRagg-Upt-DDk (SR25E90)* | | | | | | |
| Shake | Light-gray | IrBCP | Aggregate | Unpainted | Direct to deck | Yes |

[a]All lanes have soffit and ridge venting. [b]Baseline conditions. [c]Battens are 2 × 2 in. wood run along roof width. Counter-battens are 1 × 4 in. and run from soffit to ridge (see Figure 3).

Figure 3. Roof deck construction with battens and counter-battens.

Figure 4. South-facing steep-slope attic assemblies placed atop the roof testing facility.

lying on the metal deck, and a ½-in.-thick piece of wood fiberboard placed atop the 1-in.-thick piece. The HFT for measuring ceiling heat flow is embedded between the two pieces of wood fiberboard. It was also calibrated in a guard made of wood fiberboard before being placed in field service.

FIELD RESULTS

The ridge vents for the stone-coated metal and asphalt shingle roofs were opened to observe the effects of attic ventilation and, more importantly, the effect of unrestricted airflow within the inclined air gap formed under the stone-coated metal roofs. The effects of venting of attic spaces on heat transmission and moisture have been studied at some length, but little has been done to analyze the venting and flow patterns observed in the inclined channel created by batten and counter-batten deck constructions. Rose (1995) gives an overview of the evolution of attic venting, and Romero and Brenner (1998) instrumented a test building for the study of ridge venting and the associated flow within the attic space. Beal and Chandra (1995) studied heat transfer through direct-nailed tile roofs and counter-batten tile roofs as compared with heat transfer through direct-nailed asphalt shingle roofs. Relative to the asphalt shingles, tile reduced heat transmission by 39% in the direct-nailed configuration and by 48% for the counter-batten configuration.

A commercially available asphalt shingle with a solar reflectance of 0.093 and a thermal emittance of 0.89 (SR093E89) was selected as the control for comparing the thermal performance of the metal products. (The control is shown in lane 6 from the right in Figure 4.) Another conventional shake, a dark-gray stone-coated metal (SR08E90), was also used for field testing. This shake has a solar reflectance and a thermal emittance almost identical to that of the control asphalt shingle. The asphalt shingle, however, was directly nailed to the roof deck, with no venting along its underside, while the dark-gray shake was attached to the batten and counter-batten arrangement. Both assemblies were equipped with attic ventilation through soffit and ridge vents. Thus, a comparison of the two test roofs can provide insight into the effects of above-sheathing ventilation. The light-gray stone-coated shake (SR246E90) had the same batten and counter-batten construction as the dark-gray shake. The light gray shake has a solar reflectance of 0.25 and thermal emittance of 0.90; its unpainted underside has a thermal emittance of 0.35. A comparison of the two stone-coated roofs reveals the benefits of IRR pigments in combination with above-sheathing ventilation.

Summer Field Exposure

A clear, cloudless summer day was selected to display the separate and combined effects of IrBCPs and above-sheathing ventilation as compared with the asphalt shingle roof. Venting the underside of the dark-gray stone-coated metal shake caused significant reductions in the heat flow crossing the deck during solar noon, as seen in Figure 5. The daytime values for deck heat flows for the 7-day period around August 2 are provided in Table 2. The interior walls of each attic assembly were insulated

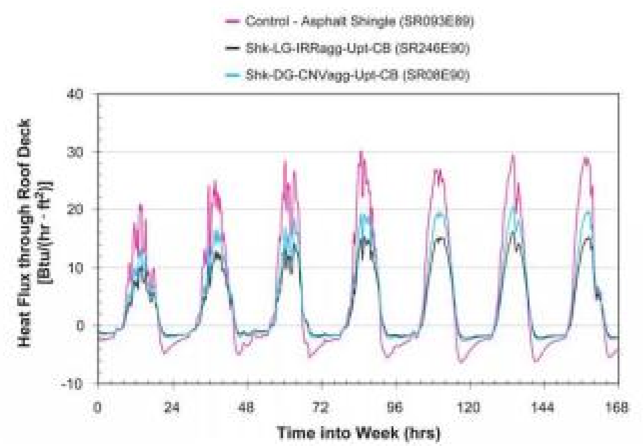


Figure 5. The effect of above-sheathing ventilation and solar reflectance for two stone-coated metal roofs compared with a direct-nailed shingle roof.

Table 2. Roof deck and attic floor heat flows (Btu/ft$^2$) integrated over the daylight hours for a week of data taken in July 2005

| | Control shingle (SR093E89) | Shk-LG-IRRagg-Upt-CB (SR246E90) | Shk-DG-CNVagg-Upt-CB (SR08E90) |
|---|---|---|---|
| Roof deck | 1216.4 | 670.3 | 853.9 |
| Attic floor | 326.6 | 95.5 | 112.2 |
| $Q_{Attic\ vent}$ | 889.7 | 574.8 | 741.8 |
| $Q_{Deck\ vent}$ | | 1280.6 | 2703.8 |

*Note:* Heat flows are corrected for projected attic floor area. Daylight is defined as the period when the solar flux normal to roof exceeds 30 Btu/hr·ft$^2$.

with at least 5 in. of foam insulation. Given the measurements of heat flow crossing the roof deck and the attic floor, the amount of heat removed by attic ventilation and above-sheathing ventilation can be approximated by the following energy balances:

$$Q_{Attic\,vent} = \frac{Q^{HFT}_{Roof\ Deck}}{COS(\theta)} - Q^{HFT}_{Attic\ floor} \quad (1)$$

and

$$Q_{Deck\,vent} = \frac{Q_{Solar\ Abs} - Q_{Mass} - Q^{HFT}_{Roof\ Deck}}{COS(\theta)}, \quad (2)$$

where

$Q_{Solar\ Abs}$ $= I_{Solar}(1-\rho_{SR}) - \hbar(T_S - T_{OD\ Air}) - \varepsilon\sigma(T_S^4 - T_{Sky}^4)$

$Q_{Mass}$ $= \Delta\rho C_P \frac{\partial T}{\partial t}$ (thermal mass of roof cover and OSB decking included in $Q_{Mass}$)

$Q^{HFT}_{Attic\ floor}$ = heat flux transducer (HFT) embedded in attic floor

$Q^{HFT}_{Roof\ deck}$ = heat flux transducer (HFT) embedded in roof deck

The dark-gray stone-coated metal shakes and the asphalt shingles have almost identical reflectance and emittance characteristics, yet the heat flow crossing the roof deck of the dark-gray shake is just 70% of the heat flow crossing the roof deck of the asphalt control shingle (Table 2). The 30% reduction in heat flow is due to above-sheathing ventilation despite the slight decrease in attic ventilation occurring under the dark-gray shake.

Above-sheathing ventilation ($Q_{Deck\ vent}$) of the dark-gray shake is nearly four times larger than is its attic ventilation ($Q_{Attic\ vent}$). Thus, above-sheathing ventilation of the dark-gray shake lowers the heat content of the attic and the interior surface temperatures, which in turn means that lower amounts of heat penetrate the attic's floor. As result, venting (above-sheathing and attic soffit and ridge) reduced the heat flow through the attic floor by about 65% of the heat flow crossing the floor of the attic assembly (326.6 vs 112.2 Btu/ft$^2$ of attic floor) with the conventional asphalt shingle roof.

The light gray shake (SR246E90) and the dark gray shake (SR08E90) have identical batten and counter-batten constructions and low underside emittance values (0.35). Both have soffit and ridge vents supporting attic ventilation. The 0.17 increase in the solar reflectance caused the heat flow crossing the roof deck of the light-gray shake to be less than the heat flow crossing the roof deck of the dark-gray stone-coated shake. The reduction is about 15% of the heat crossing the deck of the control shingle roof (Table 2). The 30% reduction due to above-sheathing ventilation of the dark stone-coated shake (previously discussed) can be added to the 15% reduction due to IrBCPs to yield a total of a 45% reduction in heat flow due to both above-sheathing ventilation and increased solar reflectance. The combined results (Figure 5) observed using both IrBCPs and above-sheathing ventilation show that ventilating the deck is just as important as the boost in solar reflectance and may be the stronger player in reducing the heat gain to the attic assembly. It should be noted that the heat flow due to above-sheathing ventilation of the hotter dark-gray shake is more than double the amount of heat flow swept away from the deck of the light-gray shake (Table 2). The hotter dark-gray shake induces greater buoyancy-induced airflows, and therefore above-sheathing ventilation is somewhat self-regulating and offsets the effect of the darker, less reflective color.

Winter Field Exposure

Cool roofs have received much positive trade press, and some state and federal support for installations where comfort cooling is the dominant building energy load. In mixed climates with both significant heating and cooling loads, the wintertime effect reduces the energy benefit because the desirable roof heat gain in winter is diminished somewhat by the higher solar reflectance of the roof. The Achilles heel of all cool roof systems continues to be the heating penalty that offsets the energy and cost savings associated with the cooling benefit of the reflective roof system. The colder the climate the greater the penalty, and the trade-off between climate and reflective roofs limits their penetration of the market in predominantly heating load climates. However, field data for the stone-coated metal roofs tested in East Tennessee's moderate climate are showing that the metal's above-sheathing ventilation negates the heating penalty associated with its IrBCP cool roof.

Data for a January week with clear skies, shown in Figure 6, illustrate the wintertime thermal performance of stone-coated metal roofs compared with that of a dark, heat-absorbing asphalt shingle roof. The ridge vents for these test sections were open, and both attic and above-sheathing ventilation were available for this week of January, which had an average daytime ambient air temperature of 36°F. At solar noon for each of the 7 days, the attic assembly with asphalt shingles (SR093E89) absorbed more solar radiation than either of the two more reflective stone-coated metal roofs (18 vs. 10 Btu/ hr·ft$^2$; see Figure 6). However, the nighttime losses for the direct-nailed asphalt shingle roof were significantly larger than losses for the attics with above-sheathing ventilation of the shake roofs (the abscissa in Figure 6 shows midnight as multiples of 24). The heat loss from the shingle roof at night was roughly twice that escaping from the two light-gray roofs or from the dark-gray shake roof, all with batten and counter-batten construction. The underside of the second light-gray stone-coated metal was painted to show the effect of thermal emittance, which increased from 0.34 (unpainted) to 0.85 (when painted). The higher underside emittance resulted in larger nighttime heat losses from the roof deck. Therefore, the air gap appears to be serving as an insulating layer that forces radiative and convective heat transfer from the roof deck to the metal roof's underside, as compared with the direct conduction path through relatively highly conductive solids in the case of the asphalt shingle roof. From about 8:00 p.m. through about 6:00 a.m. all the stone-coated metal roofs lose less heat to the night sky than does the asphalt shingle roof. The temperature of the stone-coated metal is colder at night than that of the shingle, yet the deck temperature for the stone-coated metal roof (with

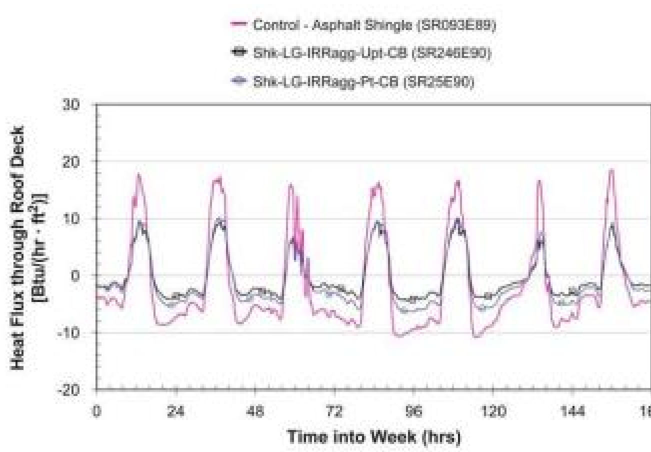


Figure 6. Heat flow measured through the roof deck for stone-coated metal shake and asphalt shingle roof during a week in January 2005. The one light-gray stone-coated metal roof [Shk-LG-IRRagg-Pt-CB(SR25E90)] has a painted underside to show the effect of thermal emittance within the air gap.

above-sheathing ventilation) is warmer than the deck temperature for the direct-nailed shingle roof.

Results integrated over the week of January data shown in Figure 6 indicate that the above-sheathing ventilation of the stone-coated metal roofs counterbalances the heating penalty associated with cool roofing for the moderate climate of Tennessee (Table 3). The asphalt shingle roof gains through its deck about 476 Btu/ft$^2$ of attic floor during the daylight hours for the week of January data. The light-gray stone-coated metal roofs gain only half as much heat because of their higher solar reflectance (0.25 vs. 0.09). During the evening hours, however, the heat lost through radiative cooling of the roof decks for the stone-coated metal roofs is 50% less than that lost from the asphalt shingle roof. In fact, during the evening hours the insulation air layer reduced the heat loss from the stone-coated metal roofs to the point that the heat loss from the attic floor was less than the loss from that of the control shingle (–562 Btu/ft$^2$ of attic floor for the shingle roof vs. –453 and –429 Btu/ft$^2$ for the stone-coated metal roofs). These data represent a very important finding because they show that stone-coated metal roofs negate the heating penalty associated with a cool roof in Tennessee's moderate climate (3662 $HDD_{65}$ and 1366 $CDD_{65}$).

The improved summer performance coupled with the reduced heat losses during the winter show that infrared reflective metal roofs negate the heating penalty associated with a cool roof. Offset-mounting the stone-coated metal roofs provides a synergistic effect (improved cooling performance and reduced winter heat losses) that the metal roof industry can exploit for marketing its products in predominately heating climates.

ABOVE-SHEATHING VENTILATION

Light-gray stone-coated shakes were direct-nailed to the roof deck to further quantify the effect of above-sheathing ventilation. Direct nailing the light-gray stone-coated metal shakes increased the heat transfer entering the roof deck as compared with the light-gray shake on battens and counter-battens (Figure 7). As already stated, offset-mounting the light-gray stone-coated metal shakes from the roof deck and increasing the solar reflectance from 0.093 to 0.25 caused a 45% drop in the heat flux entering the roof deck. Attaching the stone-coated metal shakes directly to the deck diminished the benefit by about 14% (Table 4), and rather than a 45% reduction, about a 30% reduction was measured because of the effect of solar reflectance and the smaller air pocket created between the direct nailed shakes and the decking. In addition, the offset-mounted stone-coated metal with above-sheathing ventilation lost less heat during the evening hours than the other stone-coated metal attached directly to the roof deck (Figure 7). Hence results show that an open free-flowing channel is the best configuration for reducing the roof heat gain and for minimizing roof heat loss.

Measurements were made of the airflow underneath two different stone-coated shake roofs both on batten and counter-batten systems. We designed a procedure using tracer gas techniques outlined in ASTM E 741 (ASTM 2000) and also by Lagus et al. (1988). The procedure, outlined by

Table 3. Roof deck and attic floor heat flows (Btu/ft$^2$) integrated over the daylight and nighttime hours for a week of data taken in January 2005

| | Control shingle (SR093E89) | Shk-LG-IRRagg-Upt-CB (SR246E90) | Shk-LG-IRRagg-Pt-CB (SR246E90) |
|---|---|---|---|
| *Heat flows during daylight hours* | | | |
| Roof deck | 476.2 | 257.3 | 223.7 |
| Attic floor | –166.0 | –195.8 | –185.9 |
| *Heat flows during nighttime hours* | | | |
| Roof deck | –768.1 | –313.3 | –392.1 |
| Attic floor | –562.0 | –452.8 | –428.9 |

*Note:* Heat flows are corrected for projected attic floor area. Daylight is defined as the period when the solar flux normal to roof exceeds 30 Btu/hr·ft$^2$. Similarly, nighttime is defined as the period when the solar flux normal to roof is less than 30 Btu/hr·ft$^2$. Entering heat is defined as a positive heat gain.

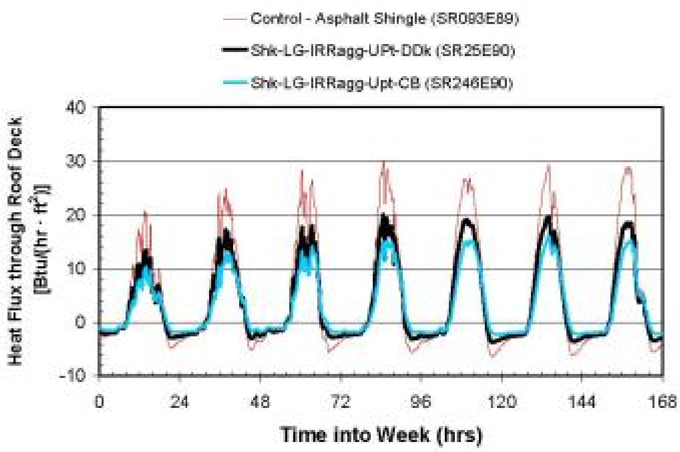


Figure 7. Stone-coated metal roof nailed directly to the roof deck show increased heat flows as compared to the stone-coated roof with batten and counter-batten construction.

Table 4. Deck heat flow for direct-to-deck attachment of stone-coated metal roofs as compared to batten and counter-batten construction (Btu/ft$^2$)

| | Control shingle (SR093E89) | Shk-LG-IRRagg-Upt-CB (SR246E90) | Shk-LG-IRRagg-UPt-DDk (SR25E90) |
|---|---|---|---|
| Roof deck | 1216.4 | 670.3 | 834.6 |

*Note:* Heat flows are corrected for projected attic floor area. Daylight is defined as the period when the solar flux normal to roof exceeds 30 Btu/hr·ft$^2$.

Miller (2006), required monitoring the decay rate of the tracer gas $CO_2$ with time using the following equation, derived from a continuity balance for the concentration of $CO_2$:

$$\dot{V}_{Air} = -\frac{VOL_{Channel}}{t} LN\left[\frac{C(t)-C_{\infty}}{C_i - C_{\infty}}\right] \quad \text{Equation (3)}$$

We injected the gas into the vent gap of the soffit and saturated the cavity with about 20,000 ppmv of $CO_2$ gas. After a substantial buildup of concentration registered on a monitor (20,000 ppmv of $CO_2$), the gas injection was stopped, and the concentration was recorded at timed intervals. All measurements were made around solar noon, when the two roofs were at their highest temperatures and thus had the highest heat flows penetrating the attic.

Data for the two stone-coated metal shakes were collected (Table 5); the calculated airflows were about 18 cfm. The average velocity was about 0.3 ft/s. Based on an integral technique for the case of a natural convection flow induced by a constant solar flux, the average velocity would be about 0.8 ft/sec after 14 ft of travel up a smooth, inclined channel. Therefore, the measured data is within reason of theory. The uncertainty of measurement for the tracer gas technique, calculated on the basis of a first-order error analysis, is estimated at about ±25% of the measurement.

The above-sheathing ventilation flow of about 18 cfm also helps assist with the removal of unwanted moisture. Moisture is a prevalent issue in all aspects of building design. As discussed in the following section, above-sheathing ventilation would remove both heat and moisture for the roof deck.

Table 5. Airflow rate and bulk velocity measured under the two stone-coated metal shake roofs using tracer gas techniques

| | Light-gray shake on batten and counter-batten | Light-gray shake on batten and counter-batten (fascia vent) |
|---|---|---|
| Volume ($V_{Channel}$ in$^3$)[a] | 6673 | 6673 |
| Airflow (cfm) | 16.3 | 17.7 |
| Av. velocity ($V_{air}$ ft/s) | 0.26 | 0.28 |

[a]Based on measured cross-sectional area of shake and distance from one $CO_2$ metering station to another.

MOISTURE REMOVAL BENEFIT

To better understand hygrothermal performance, a moisture engineering analysis was performed on the roof system depicted in Figure 3. The roof system was simplified for inclusion in the 2-D MOISTURE-EXPERT model (Karagiozis 2001), that has shown good agreement in ventilated wall systems.

A series of simulations were performed to provide a preliminary scoping study on the potential for reducing moisture-related problems in the roofing systems. The simulations were performed using hygrothermal material properties available in the open literature. Material properties employed in the analysis were the sorption and suction isotherms, vapor permeability as a function of relative humidity, the liquid transport coefficients for moisture uptake and for moisture redistribution, the moisture-dependent thermal conductivity, and the effective heat capacity. Approximations by taking material data from the open literature will not impact the results from this preliminary analysis, as the intention was to compare the performances of a ventilated versus a nonventilated roof system.

The following modes of heat and moisture transport were included:

- Vapor diffusion through all porous roof construction materials
- Liquid transport through all porous roof construction materials
- Air convection transport for both thermal and moisture components
- Moisture storage in all roof construction materials
- Radiative transport with nighttime sky conditions
- Radiative transport within the air gap provided by the stone coated metal roof
- Condensation and evaporation processes and freeze and thawing processes with the associated latent heat exchanges

In the simulation analysis, the exterior and interior environmental loads were assumed for the climatic conditions of Knoxville, Tennessee. The proposed ASHRAE SPC 160P, "Design Criteria for Moisture Control," were employed for both the exterior and interior hygrothermal loading conditions. All simulations were initiated using two times the equilibrium moisture content (EMC) at 80% relative humidity. Both the ventilated and nonventilated cases were simulated for a period of 2 years.

A snapshot of the moisture content in the sheathing board is given in Figure 8. The simulation period started October 1, 2005, one of the more difficult periods of the year to dry out. Above-sheathing ventilation accelerated the removal of unwanted moisture and reduced the moisture content of the OSB well below that of the OSB in an unvented cavity (Figure 8). Ventilating the roof deck dried the OSB within 200 days to safe moisture limits in which fungal growth would not typically occur. In comparison, the unvented roof deck required an additional 100 days to reach safe moisture content.

The number of air exchanges occurring within the ventilated cavity (Figure 9) tells the story. Air exchange rates are displayed for the assumed air changes per hour (ACH), which are dependent on both temperature and wind pressure flows acting along the roof ventilation cavity. Roughly 20–100 ACH are prevalent about 80% of the time during the 2-year simulation runs. The incidence of 60 ACH (the maximum air exchange rate) was observed to occur roughly 25% of the time. Therefore, the potential moisture removal benefits

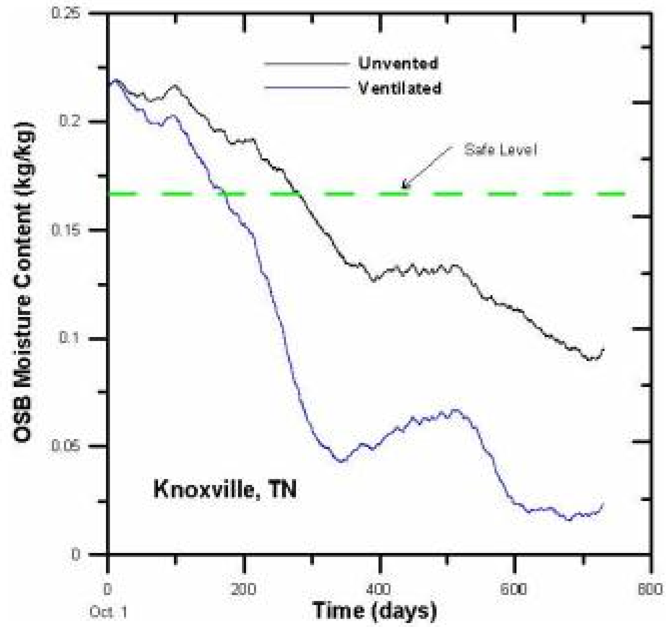


Figure 8. Comparison of moisture content of OSB layer as a function of ventilation strategy (ventilated vs. unvented) for a 2-year period.

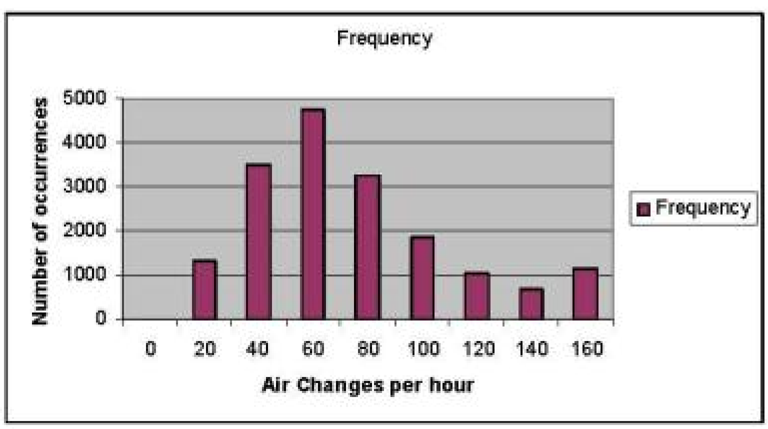


Figure 9. Period of time during 2-year simulation for cavity air changes per hour (wind- and temperature-dependent).

afforded by above-sheathing ventilation are evident from the vented compared to the unvented simulations.

## CONCLUSIONS

Field results show that the combination of improved solar reflectance afforded by IrBCPs and above-sheathing ventilation make stone-coated metal roofs energy-efficient. The light-gray stone-coated metal shakes offset-mounted with a batten and counter-batten system reduced the heat transfer penetrating the roof deck by about 45% compared with the heat penetrating the deck of an attic covered with an asphalt shingle roof. About 15% of the reduction was due to IrBCPs, and another 30% was due to above-sheathing ventilation. The combined effects of solar reflectance and above-sheathing ventilation supported a 70% reduction in the heat flow penetrating the ceiling into the conditioned space. Above-sheathing ventilation of the stone-coated metal roofs is just as important as the boost in solar reflectance for reducing the heat gain into the attic and conditioned space.

Above-sheathing ventilation improves the summer performance of the attic assembly and also reduces the heat losses by night-sky radiation during the winter. The reduction in night-sky radiation helps negate the heating penalty associated with the stone-coated metal cool roofs. Offset-mounting the infrared reflective stone-coated metal roofing provides a synergistic seasonal effect by improving cooling performance and reducing winter heat losses. Therefore, cool roofs using IrBCPs can be effectively utilized in more predominately heating climates provided the deck provides above-sheathing ventilation.

The roof employing above-sheathing ventilation has shown superior performance when compared with the unvented roof system in thermal and in hygrothermal performance. This preliminary analysis demonstrates the potential for ventilation to be employed in cool roofs using IrBCPs. More research could develop the pressure boundary dynamics for a number of roofing applications that could allow these roofs to be moisture-optimized.

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The metal roofing manufacturers and pigment (colorant) manufacturers selected appropriate color pigments. They applied them to stone-coated metal shakes and S-mission tile, and field-tested the prototypes on a steep-slope roof assembly for one year, collecting summer and winter exposure of the stone-coated metal products.

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**Appendix V: Rainwater Harvesting System**

**Rainwater Harvesting System Statistics and Specifications**

**System Summary**
Rainwater is collected from the roof, filtered and fed into the tank via gravity. When the submersible pump receives a signal from the irrigation controller to start a cycle, it will turn on and start pumping rainwater into the irrigation system. There are sensors inside the tank which monitor the water level, if the water level falls below the minimum level required, a float operated solenoid will turn on the make-up water line which is connected to the city water supply. An air gap above the tank prevents possible backflow into the city water system.

**Rainfall Statistics for San Angelo (NOAA data)**

| **Average** | | **Median** |
|---|---|---|
| **Jan** | 0.85 | 0.62 |
| **Feb** | 1.08 | 0.67 |
| **Mar** | 1.12 | 0.84 |
| **Apr** | 1.64 | 1.25 |
| **May** | 2.62 | 2.17 |
| **Jun** | 2.20 | 1.98 |
| **Jul** | 1.25 | 0.81 |
| **Aug** | 1.96 | 1.50 |
| **Sep** | 2.70 | 2.34 |
| **Oct** | 2.35 | 2.01 |
| **Nov** | 1.02 | 0.72 |
| **Dec** | 0.76 | 0.37 |
| **Total** | 19.54 | 15.24 |

Maximum days between rains: 116 Maximum 24 hour rainfall: 6.24 inches Statistics above based on period from 1/1/1945 – 5/1/2011

Maximum hourly rainfall (9/14/2005 – 1/18/2012): 2.13 inches 100 year 24 hour rainfall amount: 8.3 inches

**Catchment Area**
5780 square feet 1/2 roof footprint of building 3323 (west side only) Average annual rainfall falling on catchment area: 66,893 gallons

**Tank and Pad**

- Galvanized steel tank with AQUALINER® water storage liner which is ANSI/NSF 61 certified.
- 927 gallon capacity
- Sidewall height: 7 feet 3 inches
- Diameter: 15 feet 6 inches

- Roof is slightly domed Tank Pad:
- Sand pad 18 feet diameter, 6 inches deep; rip rap on exposed areas of tank pad; steel edging around pad
- 2.9 inches of rain on the catchment area will fill the tank
- With average rainfall, the tank will hold 1.68 months of rain falling on the catchment area.

**Pipe Sizing**
Makeup water line is a 2” schedule 40 PVC. Delivery capacity into the tank is approximately 60 gallons/minute. The pipes and fittings conveying water from gutters to the tank are 4” DWV PVC pipes, o.d. 4.215”.

A collector pipe buried along the west side of the building will collect water from three downspouts on that side and convey it to the tank area. The collector pipe will slope downward towards the tank at a 2% to 3% grade. The pipe size will increase to 6” at the third downspout, nearest to the tank.

The tank inlet and overflow outlet are 6” DWV pipe. Pipe head in the downspouts provides around 4 psi in the conveyance line to move the water into the tank. The maximum flow rate into the tank will be 230 gallons per minute, equivalent to 4.25 inches of rain per hour.

This rate is two times the highest hourly rainfall rate cited in the rainwater statistics above, covering the past 6 years.

The rainwater system has an in-tank pump with 1 1/2” inlet and outlet. It will deliver 35 to 40 gallons of water per minute at 50 psi.

**Rainwater Events and Rainwater Harvest Discussion:**

1. Roof Catchment Area= 5,780 SF
2. Based on the average rainfall data the 5,780 SF catchment area receives 66,893 gallons per year- average. (Based on NOAA data of 19.54” annual average rainfall)
3. The tank capacity rated at 10,000 gal: has a true capacity of 9,927 gal
4. 66,893/9927 = 6.73 Tank fill potential (Optimal)
5. This optimal figure would only be possible if it never rained more in any single rain event than it would take to fill the tank to full capacity. That would mean the tank would never go into overflow to bypass any excess runoff meaning that ALL RUNOFF would be captured and used.

**From another perspective**

1. Based on the Catchment area of 5,780 SF
2. 66,893 gal/9,927 gal capacity = 3,423.4 gallons per 1” rain
3. 9,927 gal capacity/3423.4 gal per 1” = 2.90” of rain to fill the tank from empty to full
4. So it takes 2.9” of rain to provide one true tank volume of harvested water.