U.S. DEPARTMENT OF ENERGY

PNNL-19741

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

American Recovery and Reinvestment Act (ARRA)
Federal Energy Management Program
Technical Assistance Project 224

Altus Air Force Base Solar Technologies

BJ Russo

September 2010

Pacific Northwest
NATIONAL LABORATORY

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operated by
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UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

Altus Air Force Base (AFB) is located in southwestern Oklahoma, a relatively rural area of Oklahoma in Jackson County, and is well suited for solar technologies because the site is located in a relatively sunny area of the United States. The primary electricity provider for Altus AFB is Western Farmers, which charges Altus AFB electricity at a blended rate of 5.82¢/kWh. The marginal rate (i.e., the rate without demand charges) was calculated to be 4.2¢/kWh. Solar electric systems displace the direct energy charge, or the marginal rate, because they cannot produce baseload power. Natural gas is currently purchased from CenterPoint Energy at a rate of $11.17/MMBtu. Solar hot water and solar air heating applications displaced natural gas, and the value of the displaced energy was a function of the natural gas rate and the efficiency of the existing water heating or air heating system.

The principal goal of the visit was to evaluate the installation for building integrated silicon or thin film module photovoltaic (PV) opportunities. Solar hot water heating and solar air heating were also considered as a result of site interest and because these other technologies often have superior economics to PV systems. Bundling these projects along with building-integrated PV systems may be the best approach to allow some building-integrated PV to be funded. Because of the typical scale of building-integrated PV and solar hot water and air heating systems, the most feasible funding mechanism is the Department of Defense's (DOD) Energy Investment and Conservation Program (ECIP). To qualify for ECIP funds, projects must be economically feasible, which is defined to be a savings-to-investment ratio (SIR) of 1.0 or better.

Prior to the site visit, site maps and a building database were consulted to identify potential locations for renewable energy projects. During the site visit, a thorough tour of the buildings resulted in several projects and buildings being eliminated because of various practical issues. Ultimately, a number of projects were identified for additional analysis to determine project cost-effectiveness.

None of the building-integrated PV systems considered were cost-effective because of the high capital cost of PV systems and the relatively low marginal cost of electricity. SIRs for these projects ranged from 0.09 to 0.14, depending on the building and the PV technology. A sensitivity analysis concluded that system prices need to be reduced by half and electricity prices need to double before systems might be cost-effective. Similarly, none of the solar hot water systems considered proved to be cost-effective because of high system costs and the moderately low value of the displaced natural gas. SIRs for these projects ranged from 0.07 to 0.25 depending on the building use type and the efficiency of the proposed system and the existing hot water heater. A sensitivity analysis revealed that if gas rates double and system prices slightly decrease, solar hot water systems might be an economic option at Altus Air Force Base. Lastly, the solar air heating analysis proved to also be uneconomic. After a thorough examination of the various buildings typically suitable for solar air heating technologies, only three buildings proved to have the appropriate orientation, use type, and lack of shading from nearby structures. However, all the remaining buildings are conditioned via infrared (IR) heating systems, which negatively affects the performance of solar walls as these are air heating systems. SIRs for these projects ranged from 0.18 to 0.48. A sensitivity analysis indicated that a 40% increase in the natural gas rate may allow solar air heating projects to be economic.

If all projects were implemented, a total of 5,013 MMBtu of energy would be saved at a cost of $4.4 million dollars with an annual cost savings of $59,732. The total project investment would create 47.9 full-time employment opportunities and would reduce greenhouse gas emissions by 808.8 MT of CO_2e.

Acronyms

AFB	Air Force Base
CDC	Child Development Center
CdTe	cadmium telluride
CEA	Council of Economic Advisors
CIGS	copper-indium selenide
DFAC	dining facility
DOD	Department of Defense
DOE	U.S. Department of Energy
ECIP	Energy Investment and Conservation Program
ECM	energy conservation measures
ESPC	energy savings performance contract
FEDS	Facility Energy Decision System
FEMP	Federal Energy Management Program
FTE	full-time employment
FY	fiscal year
GaAs	gallium arsenide
IR	infrared
NASA	National Aeronautics and Space Administration
NIST	National Institute for Standards and Technology
O&M	operations and maintenance
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
RPG	renewable portfolio goal
RPS	renewable portfolio standard
SIOH	supervision, inspection and overhead
SIR	savings-to-investment ratio
SF	square feet
SPP	Southwest Power Pool
SPSO	SPP South
SSE	Surface Meteorology and Solar Energy
UESC	utility energy services contracts

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Background

In response to the economic crisis of 2009, the United States Congress enacted the American Recovery and Reinvestment Act of 2009 to stimulate job creation, investment, and spending. In fiscal year (FY) 2009, Federal Energy Management Program (FEMP) used more than $13 million of American Recovery and Reinvestment Act funding to finance 1-year technical assistance efforts stemming from the Call for Technical Services. Funds were provided to U.S. Department of Energy (DOE) National Laboratories and technical contractor teams to provide technical assistance. All agencies that submitted proposals for technical assistance received FEMP Recovery Act funding for at least one project. FEMP received 294 project proposals and funded 120. Altus Air Force Base submitted Project #224, which requested technical assistance for rooftop solar photovoltaics (PV). Pacific Northwest National Laboratory (PNNL) was tasked with this effort. Based on PNNL's previous analysis of Altus Air Force Base (AFB) PV potential, PNNL also recommended Altus AFB explore solar water heating and solar air heating technologies because these may be cost-effective even if PV systems prove to be uneconomic.

Altus Air Force Base

Altus Air Force Base is located in southwestern Oklahoma, a relatively rural area of Oklahoma in Jackson County. The area is mostly dominated by ranching and agriculture, and Altus AFB is an important part of the local economy. Altus AFB hosts the 97th Air Mobility Wing, and its mission is primarily focused on education and command training.

Altus AFB is well suited for solar technologies because the site is located in a relatively sunny area of the United States. Figure 1 presents the site's annual average insolation on a latitude-tilted surface (NREL 2008). The annual insolation level at Altus AFB on a latitude-tilted surface is 5.23 kWh/m^2/day.

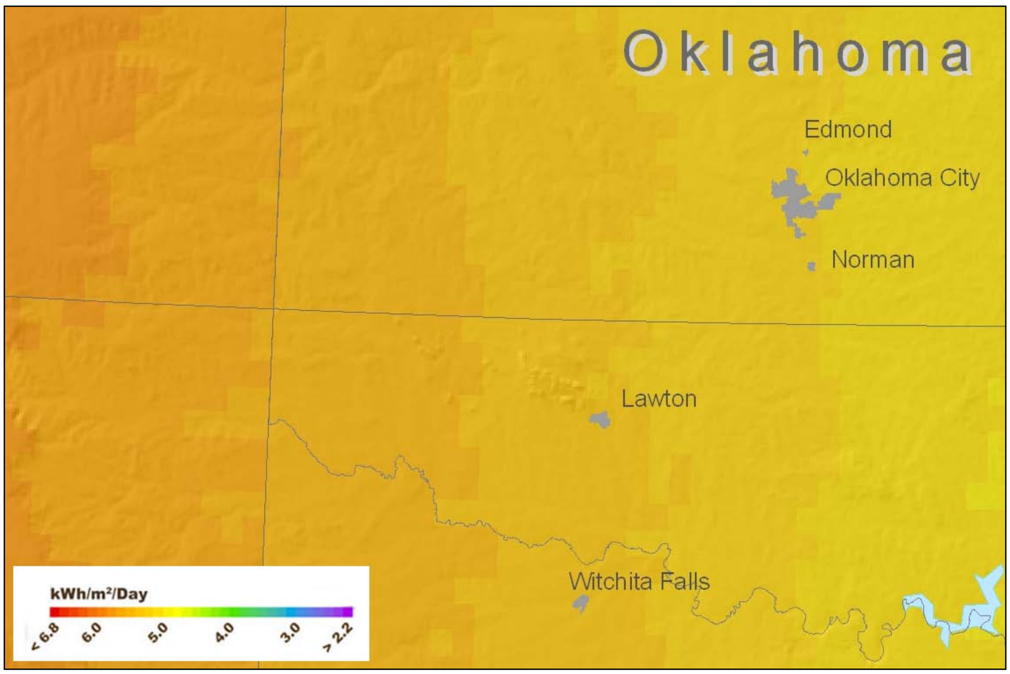

Figure 1. Solar Insolation Levels at Altus AFB (NREL 2008)

Figure 2 presents the solar insolation levels for three different cases:

- Horizontal Tilt—A collector installed at a 0° (flat) tilt (e.g., on a flat roof).
- Latitude Tilt—A south-facing collector installed at an angle equal to the latitude, which is the generally accepted way to optimize annual electricity production.
- Vertical Tilt (wall)—A collector installed against a vertical, south-facing surface (i.e., on a wall).

At Altus AFB, a flat-mounted collector receives a daily average of 4.76 kWh_{solar}/m^2 of insolation. A latitude-tilted collector receives a daily average of 5.23 kWh_{solar}/m^2 of insolation, while a vertically mounted collector receives a daily average of 3.32 kWh_{solar}/m^2 of insolation.

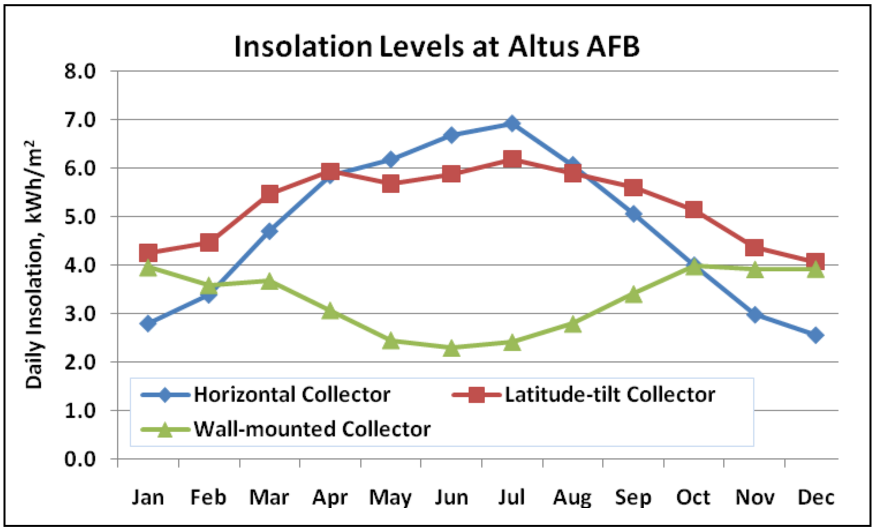

Figure 2. Average Daily Insolation for Altus AFB,
Data from MNRC 2010 and NASA 2010

Energy Use Accounting

In FY 2009, Altus AFB purchased electricity from Western Farmers Electric Coop (45,332 MWh), Altus Power (6,823 MWh), Frederick Public Works Authority (222 MWh), and Harmon Electric (1.9 MWh). Based on this total consumption of 52,379 MWh, the average demand was 6.0 MW. A total of 102,094 MMBtu of natural gas was purchased from CenterPoint Energy in FY 2009 at a cost of $11.17/MMBtu. Table 1 displays the rates for FY 2009 for these utilities.

Table 1. Utility Consumption Patterns and Rates for Altus AFB

	Electric Consumption (MWh)	Electric Expenditures ($)	Blended Electric Rate ($/MWh)	Natural Gas Consumption (MMBtu)	Natural Gas Expenditures ($)	Natural Gas Rate ($/MMBtu)
Oct	4,712	299,389	63.54	4,575	79,934	17.47
Nov	4,099	272,591	66.50	10,034	103,843	10.35
Dec	4,376	268,963	61.47	25,369	207,993	8.20
Jan	4,303	262,459	61.00	30,055	239,279	7.96
Feb	3,805	236,974	62.28	14,547	133,847	9.20
Mar	4,190	244,682	58.40	8,735	94,196	10.78
Apr	4,119	237,948	57.76	3,645	65,873	18.07
May	4,543	252,426	55.56	1,953	51,278	26.26
Jun	4,533	260,144	57.39	879	42,013	47.79
Jul	4,842	272,144	56.21	881	42,019	47.70
Aug	4,834	271,709	56.21	860	41,900	48.72
Sep	4,024	236,591	58.79	1,055	43,607	41.33
Total	52,379	3,116,020	59.49	102,588	1,145,783	11.17

Solar electric renewable energy resources displace the direct energy (kWh) charge, or the marginal rate. Western Farmers, the primary electricity provider, charges Altus AFB for electricity as described in Schedule R-14. This schedule has both demand and energy charges. Demand charges are $7.50/kW. Energy charges are $0.00336/kWh for the months of December through January, $0.00636 for June through August, and $0.00486 for all other months. In addition to energy charges, there is a fuel surcharge that varies from $0.028/kWh to $0.037/kWh. For Altus Air Force Base, Western Farmers charged an average rate of 5.823¢/kWh and a marginal (excluding demand charges) rate of 4.2¢/kWh.

Solar hot water and solar air heating applications displaced natural gas, and the value of the displaced energy was a function of the average natural gas rate of $11.85/MMBtu and the efficiency of the existing water heating or air heating technology.

Energy Conservation Measures (ECM) Considered

The principal goal of the visit was to evaluate the installation for building-integrated PV opportunities. Solar hot water heating and solar air heating systems (i.e., solar walls or transpired solar collectors) were also considered because of site interest and because these other technologies often have superior economics. Bundling these projects along with building-integrated PV systems may be the best approach to allow some building integrated PV to be funded. Because of the typical scale of building-integrated PV and solar hot water and air heating systems, the most feasible funding mechanism is the Department of Defense's (DOD) Energy Investment and Conservation Program (ECIP). The Energy Conservation Investment Program is a Military Construction (MILCON) funded program to improve energy efficiency of DOD facilities while reducing associated utility energy and non-energy related costs. ECIP projects focus on energy and water savings, implementing renewable energy, and converting systems to cleaner energy sources. To qualify for ECIP funds, projects must be economically feasible, which is defined to be a savings-to-investment ratio (SIR) of 1.0 or better. Energy savings performance contract (ESPC) and utility energy services contract (UESC) funding may be an option for these projects, but are unlikely, given the project scale and risks associated with measurement and verification of solar hot water and air heating systems.

Submissions for the ECIP system must use the fuel discount factors prescribed by National Institute for Standards and Technology (NIST) in its regular Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis publications. For this analysis, the discount factors for 2010 (NIST 2010) were used because these were the most recently available set of factors. These factors attempt to account for inflation and fuel-specific escalation rates to determine a gross discount factor for economic analyses.

Opportunities Identified

Prior to the site visit, site maps and a building database were consulted to identify potential locations for renewable energy projects. During the site visit, a thorough tour of the buildings resulted in several projects and buildings being eliminated because of building constraints, demolition, changes in use types, and shading issues. Ultimately, a number of projects were identified for additional analysis to determine project cost-effectiveness.

Table 2 identifies the opportunities that were explored.

Table 2. Opportunities Identified at Altus AFB

Building Number	Opportunities to Evaluate
47	A solar hot water heating system on the south-facing roof.
53	Building integrated PV. Solar hot water heating system on the south-facing roof.
76	Building integrated PV.
81	A solar hot water heating system on southeast/west-facing roof. Buildings 83, 84, 85 are identical to 81.
156	Building integrated PV.
187	A transpired solar collector on the south wall.
189	A transpired solar collector on the south wall.
213	Building integrated PV. Solar hot water heating system on the south-facing roof.
316	A solar hot water heating system on the southeast-facing roof. Building 315 is identical to 316.
317	A solar hot water heating system.
331	Building integrated PV. Solar hot water heating system on south-facing roof. Building 335 and 336 are identical to 331.
424	A transpired solar collector on the south wall.

Building Integrated PV Opportunities

Solar electric collectors are either PV arrays or concentrating solar arrays. Concentrating arrays were not considered because they are not typically suitable for buildings installation. Solar conversion is an inefficient process; typical PV cells have a conversion efficiency ranging from 10% to 20%. The most common building-integrated PV technology considered is an array comprised of flat PV modules mounted on racks either at ground level or on rooftops at a fixed angle. Generally, this angle is equal to the location's latitude. On rooftops, the angle can be the angle of the rooftop or an angle set by specialized mounting brackets attached to the roof. In addition, there are two common PV technologies on the market, silicon PV and cadmium telluride (CdTe) "thin film" PV. Other PV technologies, such as gallium arsenide (GaAs) and copper-indium selenide (CIGS) are available, but uncommon.

Buildings Considered for PV

Several buildings were considered for building-integrated PV. In general, buildings suitable for PV typically have pitched metal roofs, face south, and have sufficient room for reasonably sized arrays. Metal roofs are especially ideal because these roofs do not need frequent replacement, and there is a wide range of mounting brackets that do not require roof penetrations.

Building 53 is the 25,953-sf Child Development Center (CDC). There is approximately 5,000-sf of space available on the southwestern pitched metal roof that could feature a 55- to 96-kW array, depending on the technology. The panels can be located almost directly above the mechanical room, which is a suitable location for an inverter. Note that space is limited in the mechanical room. Also, the placement of this array may conflict with any other roof system, such as a solar hot water system. Other areas of the roof, such as the southeast facing portion of the northern roof, can also be considered. Figure 3 displays an image of this building and the proposed collector area.

Figure 3. Building 53 (Google 2010)

Building 76 is a barracks with a nearly perfectly south-facing metal panel roof. There is approximately 4,000-sf of roof area available on the south-facing portion of the metal roof that can house a 42- to 72-kW PV array depending on the technology. A small amount of space will be needed to site the inverter. Building 79 is similar to 76, and the proposed system for building 79 would also be suitable for building 76. Figure 4 displays an image of this building and the proposed collector area.

Figure 4. Building 76 (Google 2010)

Building 156 is a physical fitness center with a large, flat roof that could be suitable for several PV arrays ranging in size from 47 to 82 kW depending on the technology. A small amount of space will be needed to site the inverter. Because of the flat mounting of the PV array, this building generally has the poorest economics for PV arrays. Tilted panels can be installed on a flat roof, although they are not often cost-effective when the marginal value of energy produced is compared to the marginal cost of using tilted collectors over flush-mounted collectors. Figure 5 displays an image of this building and the proposed collector area.

Figure 5. Building 156 (Google 2010)

Building 213 is a 33,241-sf dormitory with two distinct wings, although both wings are connected by a common space. The suitable, available roof space could accommodate between 44- and 75-kW of PV depending on the technology. There is about 1,200 square feet of space available on the south section of the building for a PV array. A small amount of space will be needed to site the inverter. Note that the placement of this array may conflict with any other roof system, such as a solar hot water system. Other areas of the roof, such as the south-facing portion of the northern roof, could also be considered for array placement (Figure 6), which could potentially double the array capacity.

Figure 6. Building 213 (Google 2010)

Building 331 is a 33,755-sf dormitory. Buildings 333 and 335 are nearly identical to building 331. The suitable, available roof space could accommodate a 37- to 65-kW of PV arrays, depending on the technology. The orientation of these buildings is slightly different, however; although each building has a south-facing roof. The PV panels could be located on the south-facing roof of the north building section. There is about 1,500-sf of roof space available on the northern section of the building. Note that the placement of this array may conflict with any other roof system, such as a solar hot water system. Other areas of the roof, such as the south-facing portion of the southern roof, could also be considered (Figure 7), which could potentially double the array capacity.

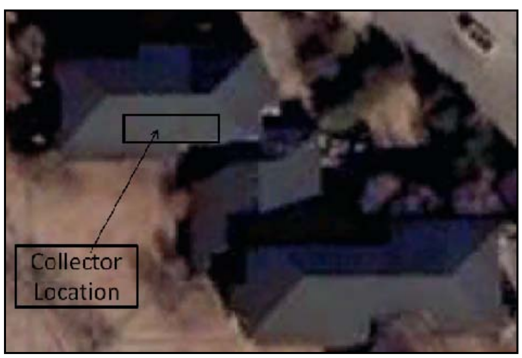

Figure 7. Building 331 (Google 2010)

Table 3 summarizes the performance and economic results of the building-integrated PV analysis at Altus AFB. Two different technologies, Si and CdTe modules, were considered for each building. Si modules are more efficient, but typically are more expensive than CdTe modules. As can be seen, none of the systems are cost-effective because of the high capital cost of PV systems and the relatively low marginal cost of electricity. Because the primary funding mechanism for these small-scale arrays is DOD's ECIP, no tax-based incentives were included because the Federal Government does not qualify for these programs.

Table 3. Summary of Building Integrated PV Performance and Economics

Building Number	Array Capacity (kW)	PV Technology	Renewable Energy Delivered (kWh)	Efficiency (%)	Capital Cost ($/kW)	Total Capital Cost ($)	SIR	Simply Payback (yrs)
53	96	Si	145,847	18.7%	$4,500	$525,972	0.11	124
53	55	CdTe	85,180	10.8%	$4,000	$268,424	0.13	108
76	72	Si	111,683	18.7%	$4,500	$341,200	0.12	120
76	42	CdTe	66,418	10.8%	$4,000	$205,252	0.14	105
156	82	Si	127,190	18.7%	$5,625	$561,507	0.09	151
156	47	CdTe	74,279	10.8%	$5,125	$293,784	0.11	135
213	75	Si	111,925	18.7%	$4,500	$411,169	0.11	128
213	44	CdTe	66,920	10.8%	$4,000	$214,971	0.13	107
331	65	Si	97,002	18.7%	$4,500	$356,501	0.11	128
331	37	CdTe	56,273	10.8%	$4,000	$180,955	0.13	111

In light of the lackluster economic performance of these PV systems, a sensitivity analysis was performed to explore the impact of changes in the marginal electric rate and system capital cost. This analysis was performed on a CdTe array because these arrays generally have superior economics to Si arrays at Altus AFB under the analysis conditions. Note that during this sensitivity analysis, factors such as the operations and maintenance (O&M), contingencies, SIOH (supervision, inspection and overhead)/design costs, and discount factors were held constant. Table 4 displays the SIRs for a variety of system costs and electric rates. Note that the base case was run with a system cost of $4,000/kW and a marginal rate of 4.2 ¢/kWh.

Table 4. PV Economic Feasibility Sensitivity Analysis

		Marginal Electric Rate (¢/kWh)						
		4.0	**5.0**	**6.0**	**7.0**	**8.0**	**9.0**	**10.0**
System Cost ($/kW)	**$500**	0.90	1.25	1.59	1.94	2.28	2.62	2.97
	$1,000	0.46	0.64	0.82	0.99	1.17	1.35	1.52
	$1,500	0.31	0.43	0.55	0.67	0.79	0.90	1.02
	$2,000	0.23	0.32	0.41	0.50	0.59	0.68	0.77
	$2,500	0.19	0.26	0.33	0.40	0.47	0.55	0.62
	$3,000	0.16	0.22	0.28	0.34	0.40	0.46	0.52
	$3,500	0.13	0.19	0.24	0.29	0.34	0.39	0.44
	$4,000	0.12	0.16	0.21	0.25	0.30	0.34	0.39

As can be seen, system prices generally need to be between $500 and $1,000 per kilowatt, and rates need to be more expensive than the current marginal rate of 4.2¢/kWh, for PV systems to have an SIR greater than one at Altus AFB. The addition of production- and investment-based incentives may positively affect the projects economics, which would allow for a wider range of cost-effective projects. Moreover, Oklahoma does not have a renewable portfolio standard (RPS), although it does have a noncompulsory renewable portfolio goal (RPG). A properly structured RPS with carve outs for either solar technologies or distributed generation may encourage utilities and other developers to seek out the most cost-effective location for renewable energy systems.

Solar Water Heating

Several buildings were considered for solar hot water systems. Buildings suitable for these systems typically have pitched metal roofs, a south-facing face, and sufficient room for additional hot water storage. Metal roofs are especially ideal because these roofs do not need frequent replacement and there is a wide range of mounting brackets that do not require roof penetrations.

Building 47 is a 10,827-sf dental clinic. There is approximately 850-sf of space available on the south-facing roof. The suitable, available roof space could accommodate a seven-panel solar hot water system (Figure 8). Insulated copper pipe runs can be installed from the manifold to the mechanical room located in the northwest portion of the building. The building currently has a recirculating hot water system with a natural gas heater.

Figure 8. Building 47 (Google 2010)

Building 53 is a 25,953-sf child development center building. There is approximately 2,000-sf of space available on the southwestern roof slope. The suitable, available roof space could accommodate a seven-panel solar hot water system. The panels will be located almost directly above the mechanical room. Insulated copper pipe runs can be installed from the manifold to the mechanical room (Figure 9). There is a recirculating hot water system throughout most of the building. The kitchen and laundry facilities are served by a high-temperature distributed line. The existing system uses a natural gas water heater. Note that space is somewhat limited in the mechanical room, which will have to be considered during the system design phase.

Figure 9. Building 53 (Google 2010)

Buildings 81, 83, 84, and 85 are nearly identical barracks. Each building is 15,552-sf and has about 2,900-sf of available space for panels. These roof locations are suitable and available for eight-panel solar hot water systems. The panels can be installed on the southwest facing roofs for buildings 81 and 83 and the southeast facing roofs for buildings 84 and 85 (Figure 10). The orientation of these buildings is not optimal. In addition, finding space for new hot water equipment in the mechanical rooms will be challenging. The mechanical rooms are located in the center of the building, directly below the proposed panel locations. Insulated copper pipe runs can be installed from the manifold to the mechanical room.

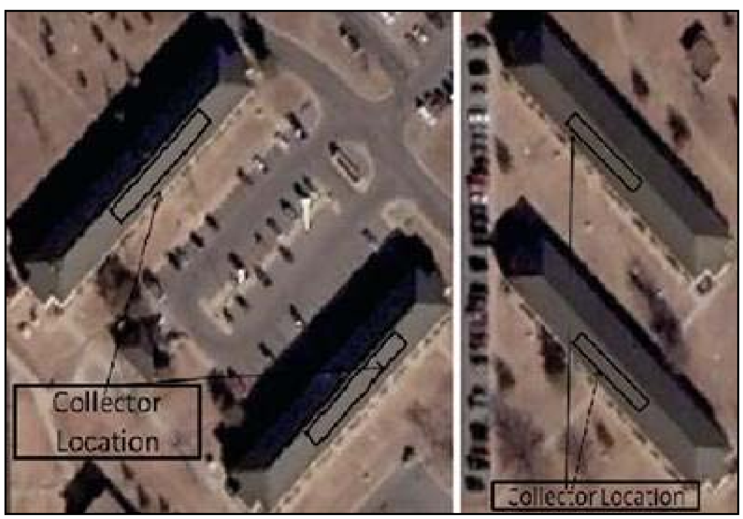

Figure 10. Buildings 81 and 83 (left); Buildings 84 and 85 (right) (Google 2010)

Building 213 is a 33,241-sf dormitory. It has two separate wings, although both wings are served by the same hot water recirculation system. There is about 1,200-sf of space available on the south section of the building for solar water heating. This suitable, available roof space could accommodate a 25-panel solar hot water system (Figure 11). The mechanical room is located on the east side of the southern section. Insulated copper pipe runs can be installed from the manifold to the mechanical room. Space is limited in the mechanical room. The existing equipment will need to be removed to install a new hot water tank.

Figure 11. Building 213 (Google 2010)

Building 317 is a 20,310-sf dining facility (DFAC). The DFAC currently houses a nonfunctioning evacuated tube solar hot water system. The existing evacuated tubes will need to be removed before installing the new system. It is possible that the existing storage tank, piping, heat exchanger, etc. could be reused, although the condition of the equipment would need to be verified. Once the old panels are removed, there will be adequate space for a 29-panel solar hot water system (Figure 12). The roof is flat and will require tilt mounts. If the existing piping cannot be reused, insulated copper pipe runs can be installed from the new manifold to the mechanical room. Note that the new system will be built with glazed flat plate collectors, rather than evacuated tubes. The economics of solar hot water are slightly better for building 317 than most of the other buildings analyzed. This is primarily because the actual hot water use is large relative to circulation loop losses, which increases the efficiency of the solar system.

Figure 12. Building 317 (Google 2010)

Building 331 is a 33,755-sf dormitory. Buildings 333 and 335 are nearly identical to building 331. The orientation of these buildings is slightly different. However, each building has a south-facing roof suitable for solar panels. There is about 1,500-sf of roof space available on the northern section of the building, more than enough for the solar hot water system. Insulated copper pipe runs can be installed from the manifold to the mechanical room. The panels will be located on the south-facing roof of the northern building section (Figure 13). This location allows for a shorter piping run from the panels to the tank. A 19-panel solar hot water system can be installed. Building 331 has two condensing gas water heaters. Because condensing boilers are more efficient than conventional equipment, the savings from the solar hot water system are lower in this building than similar buildings with non-condensing boilers.

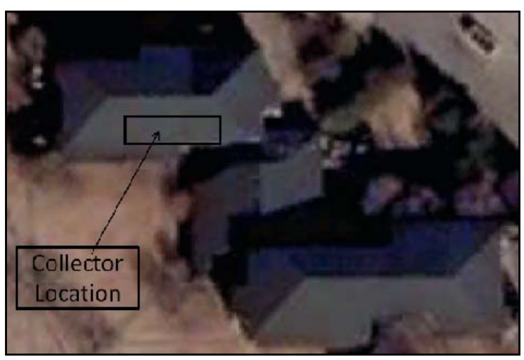

Figure 13. Building 331 (Google 2010)

Table 5 summarizes the performance and economic results of the transpired solar collector analysis at Altus AFB. As can be seen, none of the systems are cost-effective because of the moderately high capital cost of the systems, which was estimated to be $100/sf, and the relatively low price of the displaced natural gas. Moreover, some of the roof angles were less than optimal, which decreases the output of the systems. Also, some of the buildings have high efficiency water heaters (e.g., building 331), which decrease the amount of natural gas displaced by the solar system. Lastly, because the primary funding mechanism for these systems is DOD's ECIP, no tax-based incentives were included.

Table 5. Summary of Solar Water Heating Performance and Economics

Building Number	Renewable Energy Delivered (MMBtu)	Reduced Gas Consumption (MMBtu)	Annual Energy Savings ($)	System Size (sf)	Efficiency of Existing Water Heater	Total Capital Cost ($/system)	SIR	Simple Payback Period (years)
47	36.0	48	$474	281	75%	$36,445	0.14	153
53	51.6	69	$680	281	75%	$36,445	0.25	79
81	43.3	58	$570	321	75%	$40,704	0.16	135
83	43.3	58	$570	321	75%	$40,704	0.16	135
84	43.2	58	$569	321	75%	$40,704	0.16	135
85	43.2	58	$569	321	75%	$40,704	0.16	135
213	142.1	190	$1,873	1,004	75%	$128,949	0.17	123
317	175.4	234	$2,312	843	75%	$109,334	0.26	80
331	85.3	95	$937	763	90%	$95,029	0.07	360
333	85.3	95	$937	763	90%	$95,029	0.07	360
335	85.3	95	$937	763	90%	$95,029	0.07	360

In light of the lackluster economic performance of these systems, a sensitivity analysis was performed to explore the impact of changes in the natural gas and system capital cost. This analysis was performed on building 317 because this system was the most cost-effective system at Altus AFB under the analysis conditions. Note that during this sensitivity analysis, factors such as the O&M, contingencies, SIOH/design costs, and discount factors were held constant. Table 6 displays the SIRs for a variety of system costs and gas rates. Note that the reference case assumed a system cost of $100/sf and an energy rate of $11.17/MMBtu.

Table 6. Solar Hot Water Economic Feasibility Sensitivity Analysis

		Natural Gas ($/MMBtu)						
		8	10	12	14	16	18	20
System Cost ($/sf)	$10	0.95	1.44	1.93	2.42	2.91	3.4	3.89
	$20	0.59	0.90	1.21	1.51	1.82	2.13	2.43
	$30	0.43	0.66	0.88	1.10	1.33	1.55	1.77
	$40	0.34	0.52	0.69	0.87	1.04	1.22	1.39
	$50	0.28	0.43	0.57	0.71	0.86	1.00	1.15
	$60	0.24	0.36	0.48	0.61	0.73	0.85	0.98
	$80	0.18	0.28	0.37	0.47	0.56	0.66	0.75
	$100	0.15	0.23	0.3	0.38	0.46	0.53	0.61

As can be seen, system prices generally need to be below $60 per-sf, and gas rates need to be more expensive than the current rate of $11/MMBtu, for this system to have an SIR greater than one at Altus AFB. The addition of production- and investment-based incentives may positively affect the projects economics, which would allow for a wider range of cost-effective projects. Moreover, Oklahoma does not have a RPS, although it does have a noncompulsory RPG. A RPS that includes thermal technologies may encourage utilities and other developers to seek out the most cost-effective location for renewable energy systems.

Solar Air Heating

Several buildings were considered for transpired solar collectors (i.e., solar walls). Buildings suitable for these collectors typically have a south-facing wall, year-round occupation, and high heating requirements. In addition, buildings with an existing air distribution and an outdoor air intake near or on the southern wall allow for the most cost-effective collector installation. Buildings without these features will require the installation of a dedicated blower system at additional cost. Although Altus AFB initially appeared to have several buildings suitable for solar walls, the site visit revealed that the orientation of doors and shading issues arising from the proximity of other buildings restricted a number of buildings from being candidates.

Three buildings were identified as suitable candidates for solar walls. However, all of the buildings currently use infrared (IR) heating, which is a direct heating technology that does not require blowers or air movement to function. Moreover, buildings typically employ IR heating when conventional space heating would be impractical or expensive. However, solar walls are an air heating technology. As a result, when installing a solar wall to serve a space that is conditioned by IR systems, care must be taken to properly estimate energy savings because there is not a direct one-for-one reduction of heating energy consumption. In other words, one unit of energy delivered by the solar air heating system will not displace one unit of IR produced heat because the heat delivery mechanisms are completely different.

Two nearly identical buildings, buildings 187 and 189, are both suitable for solar air heating systems. Buildings 187 and 189 are both used as training facilities and have roughly the same footprint and ventilation needs. A solar wall could be installed along the full length of the southeast face of both buildings encompassed within the outline seen in Figure 14. The proposed locations for the walls themselves are in red. In the case of building 187, the wall will be located above the first floor protrusion, which can also be seen in the figure.

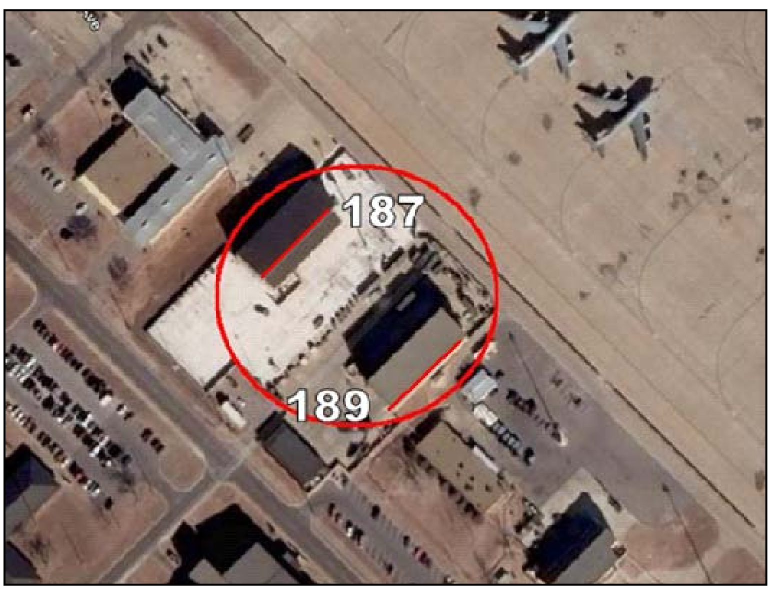

Figure 14. Buildings 187 and 189 (Google 2010)

Building 424 is the pallet-loading training and construction facility. Like buildings 187 and 189, this is a high-bay space with IR heating. Unlike the previous two buildings, building 424 has a nearly perfectly south-facing wall (Figure 15). However, the aspect ratio of the building does place a restriction on the practical size of the collector.

Figure 15. Building 424 (Google 2010)

Table 7 summarizes the performance and economic results of the transpired solar collector analysis at Altus AFB. As can be seen, none of the systems are cost-effective because of the moderately high capital cost of the systems, which was $52/sf, and the relatively low price of the displaced natural gas. Moreover, these systems displace IR heat, which is a more efficient form of heating for these space types. Consequently, the economics are not as positive as compared to similar building types that are air heated. An example of such a building is a gymnasium. The gymnasium at Altus AFB was considered, but severe shading and the location of doors and other openings precluded it from this analysis. Lastly, because the primary funding mechanism for these systems is DOD's ECIP, no tax-based incentives were included because the Federal Government is not eligible.

Table 7. Summary of Transpired Solar Collector Performance and Economics

Building Number	Renewable Energy Delivered (MMBtu)	Reduced Gas Consumption (MMBtu)	Annual Energy Savings ($)	System Size (ft^2)	Efficiency of Existing Space Heater	Total Capital Cost ($/system)	SIR	Simple Payback Period (years)
187	87.7	110	$858	1,017	80%	$64,799	0.18	103
189	83.9	105	$822	968	80%	$61,674	0.24	75
424	421.8	527	$4,867	2,492	80%	$158,731	0.48	37

In light of the lackluster economic performance of these systems, a sensitivity analysis was performed to explore the effect of changes in the natural gas and system capital cost. This analysis was performed for building 424 because this system was the most cost-effective system at Altus AFB under the analysis conditions. Note that during this sensitivity analysis, factors such as the O&M, contingencies, SIOH/design costs, and discount factors were held constant. Table 8 displays the SIRs for a variety of system costs and gas rates. Note that the reference case assumed a system cost of $52/sf and an energy rate of $11.17/MMBtu.

Table 8. Transpired Solar Collector Economic Feasibility Sensitivity Analysis

		Natural Gas ($/MMBtu)						
		8	**10**	**12**	**14**	**16**	**18**	**20**
System Cost ($/sf)	**$10**	1.49	1.88	2.27	2.67	3.06	3.46	3.85
	$20	0.87	1.10	1.34	1.58	1.82	2.06	2.18
	$30	0.60	0.77	0.94	1.11	1.28	1.45	1.62
	$40	0.45	0.58	0.72	0.85	0.98	1.11	1.25
	$50	0.36	0.46	0.57	0.68	0.79	0.90	1.01
	$60	0.29	0.38	0.47	0.57	0.66	0.75	0.84
	$70	0.24	0.32	0.40	0.48	0.56	0.64	0.72
	$80	0.20	0.27	0.34	0.42	0.49	0.56	0.63

As can be seen, system prices generally need to be between $10 and $40 per-sf, and gas rates need to be more expensive than the current rate of $11/MMBtu, for these systems to have an SIR greater than one at Altus AFB. The addition of production- and investment-based incentives may positively affect the projects economics, which would allow for a wider range of cost-effective projects. Moreover, Oklahoma does not have a RPS, although it does have a noncompulsory RPG. A RPS that includes thermal technologies may encourage utilities and other developers to seek out the most cost-effective location for renewable energy systems.

Potential Greenhouse Gas Reductions and Job Creation

The implementation of these renewable energy projects would help reduce the nation's greenhouse gas emissions in addition to creating jobs. Table 9 documents the greenhouse gas reduction estimates and full-time employment (FTE) opportunities that would be generated if the PV projects were implemented.

Table 9. Estimates of Greenhouse Gas Reduction and Job Creation for PV Projects

Building Integrated PV (CdTe Modules)				
Building Number	**Total Investment ($)**	**Renewable Energy Delivered (kWh)**	**Greenhouse Gas Emission Reduction (lbs of CO_2e)**	**FTE Opportunities Created**
53	$268,424	85,180	141,872	2.92
76	$205,252	66,418	110,623	2.23
156	$293,784	74,279	123,716	3.19
213	$214,971	66,920	111,459	2.34
331	$180,955	56,273	93,726	1.97
Building Integrated PV (Si Modules)				
Building Number	**Total Investment ($)**	**Renewable Energy Delivered (kWh)**	**Greenhouse Gas Emission Reduction (lbs of CO_2e)**	**FTE Opportunities Created**
53	$525,972	145,847	242,917	5.72
76	$341,200	111,683	186,015	3.71
156	$561,507	127,190	211,843	6.10
213	$411,169	111,925	186,418	4.47
331	$356,501	97,002	161,563	3.88
53	$525,972	145,847	242,917	5.72

This analysis assumed the Environmental Protection Agency's eGrid emission factor for the Southwest Power Pool (SPP) South (SPSO) eGrid subregion for CO_2, CH_4, and N_2O (EPA 2008). In addition, this analysis assumed that the global warming potential of CH_4 and N_2O was 21 and 310, respectively, as per the guidance of the Federal Greenhouse Gas Accounting and Reporting Guidance (White House 2010). In addition, per the guidance of the Council of Economic Advisers (CEA), the number of FTE opportunities was estimated by taking the ratio of the investment to $92,136, which is the calculated estimate of Government spending needed to create one job-year.

Table 10 documents the greenhouse gas reduction estimates and FTE opportunities that would be generated if the solar hot water and solar air heating projects were implemented.

This analysis assumed the AP-42 (EPA 1997) emission factors for the external combustion of natural gas. In addition, this analysis assumed that the global warming potential of CH_4 and N_2O was 21 and 310, respectively, per the guidance of the Federal Greenhouse Gas Accounting and Reporting Guidance. In addition, as per the guidance of the CEA, the number of FTE opportunities was estimated by taking the ratio of the investment to $92,136, which is the calculated estimate of Government spending needed to create one job-year.

If all projects were implemented, a total of 5,013 MMBtu of energy would be saved at a cost of $4.4 million dollars with an annual cost savings of $59,732. The total project investment would create 47.9 full-time employment opportunities and would reduce greenhouse gas emissions by 808.8 MT of CO_2e.

Table 10. Estimates of Greenhouse Gas Reduction and Job Creation for Solar Thermal Projects

Solar Hot Water Projects				
Building Number	**Total Investment ($)**	**Gas Consumption Reduction (MMBtu)**	**Greenhouse Gas Emission Reduction (lbs of CO_2e)**	**FTE Opportunities Created**
47	$36,445	48	5,677	0.40
53	$36,445	69	8,144	0.40
81	$40,704	58	6,829	0.44
83	$40,704	58	6,829	0.44
84	$40,704	58	6,813	0.44
85	$40,704	58	6,813	0.44
213	$128,949	190	22,438	1.40
317	$109,334	234	27,690	1.19
331	$95,029	95	11,225	1.03
333	$95,029	95	11,225	1.03
335	$95,029	95	11,225	1.03
Solar Air Heating Projects				
Building Number	**Total Investment ($)**	**Gas Consumption Reduction (MMBtu)**	**Greenhouse Gas Emission Reduction (lbs of CO_2e)**	**FTE Opportunities Created**
187	$64,799	110	12,988	0.70
189	$61,674	105	12,422	0.67
424	$158,731	527	62,421	1.73

Action Plan for Implementation of ECMs

At this time, none of the projects identified proved to be cost-effective because of system costs and the current value of the displaced energy. Consequently, the development of solar projects should be given a low priority. In addition, the sensitivity analysis suggests that energy prices and system costs are not predicted to change sufficiently to result in cost-effective projects in the near future.

If there is interest in developing these projects for energy security or greenhouse gas emissions reduction, alternative sources of financing beyond the ECIP should be considered because ECIP projects must be cost-effective. Occasionally, calls for demonstration projects are announced, and this would be a suitable approach to seek funding. In addition, third-party financing, while unlikely, might be an option because these entities frequently consider alterative economic parameters, such as different fuel escalation and inflation rates, and potential changes in government policy, which might allow these projects to become cost-effective. If these funding sources are secured, the site should first consider solar air heating technologies because these projects had the best SIRs. Secondly, the site should consider solar hot water projects at building 317 (the dining facility) and building 53 (the child development center). Lastly, if the site wants to consider PV, buildings 76, 213, 53, and 331 should be considered first because they have ideal roof surfaces and relatively optimal orientation compared to the other buildings on post.

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Appendix A

Solar Energy Screening Assessments at Altus AFB

Appendix A - Solar Energy Screening Assessments at Altus AFB

Three different solar energy technologies were evaluated for the Air Force: photovoltaics (PV), domestic solar hot water heating, and solar air heating. Although these technologies all convert solar energy into electrical or thermal energy, they each operate on fundamentally different principles and therefore, have different screening methodologies.

Photovoltaic Methodology

To determine the solar photovoltaic resource availability, PNNL used publicly available information from NASA's Surface Meteorology and Solar Energy (SSE) (NASA 2010) database and RETScreen® International (MNRC 2010), a project analysis software package developed by Natural Resources Canada. This tool allows a user to simulate the performance of several PV systems configurations.

After recording the resource potential, RETscreen was used to determine the electrical output of a PV array fixed to the roof of the various buildings. The panels were tilted to match the slope of the roof and rotated to account for the azimuth of the building. In the case of building 156, which has a flat roof, panels were tilted at the site's latitude and rotated to face perfectly south. Each building was evaluated for two different PV technologies, Si modules and CdTe modules, which are usually cheaper than silicon cells, but less efficient. Although these modules are not based on any single supplier's module, modules with the following specifications are common from many suppliers. The mounting technique, module specifications, and the system price per kW can be found in Table A.1.

Table A.1. PV Module and System Specifications

Parameter	PV System	
Module Mounting	Roof-Mounted	Roof-Mounted
Module Material	Monocrystalline Silicone	Cadmium Telluride
Module Efficiency	18.7%	10.8%
Temperature Coefficient	0.40%/°C	0.24%/°C
Inverter Efficiency	90%	90%
System Cost	$4,500/kW	$4,000/kW

Solar Air Heating Methodology

To determine the solar air heating resource availability, PNNL used publicly available information from NASA's SSE database and RETScreen® International, a project analysis software package developed by Natural Resources Canada. This tool allows a user to simulate the performance of solar air heating systems. RETScreen® provided an estimate of the amount of energy harvested from a solar wall at each installation in addition to calculating the energy saved from improvements in building envelope and de-stratification, if applicable.

PNNL examined the performance of a dominantly south-facing, vertical, transpired solar collector. PNNL's Facility Energy Decision System (FEDS), a building energy modeling tool, was used to determine many of the ventilation parameters and to examine the impact of air heating conditioning systems on buildings that are dominantly IR heated. To determine the heating season of the site, a heating-degree-day analysis was performed to determine what fraction of each month the prototype building would require heating. The TSC specifications can be found in Table A.2.

Table A.2. TSC System Specifications

Equipment	Exterior wall-mounted, black, vertical transpired solar collector
Existing Heating System	Natural gas IR heating systems
Temperature Set Point	65ºF
Hours of Operation	5 days per week from 0700–1800
Gross Collector Area	968 to 2,492-sf
Total Capital Cost	$316,790 /sf
Annual Fixed O&M Cost	0.5% of capital cost

Unlike electric heating systems that can be 100% efficient, heating systems that use boiler, furnaces, or other combustion-based heating technologies are less than 100% efficient. Although efficiencies can vary from a low of 60% for an old, unmaintained burner to over 90% for a modern, condensing system, a typical burner efficiency is approximately 80%. Burner inefficiency must be taken into account when determining the cost of energy that is displaced by a transpired solar collector. For example, if natural gas costs $20/MMBtu and a natural gas burner is 75% efficient, then 1 MMBtu of thermal energy output from the natural gas burner requires 1.33 MMBtu of fuel, which will cost $27. For this analysis, a burner efficiency of 80% was used.

Solar Water Heating Methodology

To determine the solar water heating resource availability, PNNL used publicly available information from NASA's SSE database in addition to RETScreen® International, a project analysis software package developed by Natural Resources Canada. This tool allows a user to simulate the performance of solar water heating systems. RETScreen® provided an estimate of the amount of energy harvested from a solar hot water system at each base. Lastly, PNNL's FEDS, a building energy modeling tool, and American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE 2007) tables were used to determine the total hot water energy load for each prototype building.

PNNL examined the performance of a solar hot water system for three different prototype buildings: a dining facility, a physical fitness center, and a dormitory/barracks. These buildings were selected because they are relatively large consumers of hot water and are frequently used 7 days per week. For each building, the system's panels were rotated to match the building's azimuth and tilted to match the building's roof slope. RETScreen® was then used to calculate the system's annual energy output and solar fraction. The solar fraction represents what percentage of the total hot water heating energy load is met with the solar system. To evaluate the solar thermal hot water heating potential, systems were designed to have the fewest number of panels necessary to provide at least 30% of the building's water heating demand. The 30% goal was used because the Energy Independence and Security Act of 2007 mandates that new and renovated Federal buildings must meet 30% of their hot water demand with solar hot water equipment provided it is cost-effective. The solar hot water system specifications can be found in Table A.3.

Table A.3. Solar Hot Water System Specifications

Equipment	Roof-mounted, latitude-tilted, glazed collectors, closed loop, drainback system.
Domestic Hot Water System	Recirculating system with a separate boiler and storage tank
Solar Fraction Target	30%
Capital Cost ($/ft^2 of panel)	$100
Fixed O&M Cost	1% of the capital costs

Unlike electric heating systems that can be 100% efficient, heating systems that use boiler, furnaces, or other combustion-based heating technologies are less than 100% efficient. Although efficiencies can vary from a low of 60% for an old, unmaintained burner to over 90% for a modern, condensing system, a typical burner efficiency is approximately 80%, although burner efficiencies did vary between buildings, as noted in the solar hot water section of this report. Burner inefficiency must be taken into account when determining the cost of energy that is displaced by a transpired solar collector. For example, if natural gas costs $20/MMBtu and a natural gas burner is 75% efficient, then 1 MMBtu of thermal energy output from the natural gas burner requires 1.33 MMBtu of fuel, which will cost of $27.

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