Denali Commission
Emerging Energy Technology Grant

An Investigation of Solar Thermal Technology in Arctic Environments

A Project by Kotzebue Electric Association
Emerging Energy Technology Grant

Emerging energy technology is a critical phase in the development process of energy technology, linking research and development to the commercialization of energy solutions. Although the Arctic possesses bountiful energy resources, the Arctic also faces unique conditions in terms of climate, environment, population density, energy costs, logistics, and the isolated nature of electrical generation and transmission systems. These conditions, challenging under the best of circumstances, making the Arctic an ideal test bed for energy technology. Emerging energy technology provides a unique opportunity to meet Arctic energy needs, develop energy resources, and create global expertise.

In 2009 the Denali Commission, an independent federal agency in Alaska, released a public solicitation entitled the Emerging Energy Technology Grant (EETG). The EETG targeted (1) research, development, or demonstration projects designed to (a) test new energy technologies or methods of conserving energy or (b) improve an existing energy technology; and (2) applied research projects that employ energy technology with a reasonable expectation that the technology will be commercially viable in Alaska in not more than five years.

The following are the 9 projects funded under this solicitation:

- Alaska SeaLife Center, Seawater Heat Pump Demonstration Project
- Cordova Electric Cooperative, Psychrophiles for Generating Heating Gas
- Kotzebue Electric Association, Feasibility of Solar Hot Water Systems
- ORPC Alaska, Nenana Hydrokinetic Turbine
- Sealaska Corporation, Commercial Scale Wood Pellet Boiler
- Kotzebue Electric Association, Flow Battery Energy Storage Systems
- Tanana Chiefs Conference, Organic Rankine Cycle Heat Recovery System
- University of Alaska, Fairbanks, High Penetration Hybrid Power System
- Kotzebue Electric Association, Wales Diesel-Off High Penetration Wind System

For further information, please visit the EETG program website at:

http://energy-alaska.wikidot.com/emerging-energy-technology-grant

Kotzebue Electric Association

Kotzebue Electric Association (KEA) is a rural electric utility cooperative, based in Kotzebue, Alaska. KEA has 840 members, and generates over 18 million kilowatt hours per year. For this project, KEA explored the use of solar thermal systems to provide domestic hot water and space heating for six residential homes in the community. KEA submitted this project to the Denali Commission for consideration under the EETG program. KEA is the primary stakeholder in this project.

About the Author

The Alaska Center for Energy and Power (ACEP) is an applied energy research group housed under the Institute of Northern Engineering at the University of Alaska Fairbanks. ACEP is serving as the program manager of the EETG program on behalf of the Denali Commission.

A key deliverable for each EETG project is a lessons learned report by ACEP. As the projects deal with emerging energy technology, providing lessons learned and recommendations is critical for understanding the future of the technology in Alaska, and the next steps needed in developing energy solutions for Alaska.

ACEP's technical knowledge and objective academic management of the projects, specifically for data collection, analysis, and reporting, are vital components to the intent of the solicitation.
An Investigation of Solar Thermal Technology in Arctic Environments

A Project by Kotzebue Electric Association

Recipient:
Kotzebue Electric Association
EETG Funding: $127,000
Total Project Funding: $144,000
Project Timeline:
May 2010—December 2011

Report Overview

Solar thermal technology, mature and widely used throughout many parts of the world, has had limited application in the Arctic. This report investigates a number of solar thermal systems for use in Alaska and above latitude 60° N, focusing on a recent project in Kotzebue funded by the Denali Commission Emerging Energy Technology Grant (EETG) program. The report includes an analysis of performance data, a summary of the lessons learned from the systems investigated, conclusions, and recommendations for potential future applications of solar thermal systems in the Arctic.

For comprehensive project information, data, and report appendices, please visit the EETG program website at http://energy-alaska.wikidot.com/emerging-energy-technology-grant

Project Introduction

The goal of this project was to help mitigate the rising costs of home heating in rural Alaska by assessing the feasibility of solar thermal technology in an arctic environment.

The proposed project tasks included:

1. Installation of six solar thermal systems on homes in Kotzebue and monitoring of these systems for one year to assess energy production.
2. Evaluation of the feasibility, operation, and maintenance requirements of the six systems.
3. Analysis of payback periods to assess the economic viability of solar thermal systems in rural Alaska.

Project activities commenced in May 2010, with the final system installed in November 2010. The project underwent active performance monitoring through August 2012.

The following organizations were involved in this project:

Kotzebue Electric Association

Kotzebue Electric Association (KEA) submitted the solar thermal project to the Denali Commission for consideration under the EETG program. KEA is the primary stakeholder in this project.

Susitna Energy Systems

Susitna Energy Systems is a vendor and installer of renewable energy systems in Alaska. This vendor installed three solar thermal systems, manufactured by Viessmann, in Kotzebue.

ABS Alaskan

ABS Alaskan is a vendor and installer of renewable energy systems in Alaska. This vendor installed three solar thermal systems, manufactured by Heliodyne, in Kotzebue.

Alaska Center for Energy and Power

The Alaska Center for Energy and Power (ACEP), an applied energy research program based at the University of Alaska Fairbanks (UAF), provided technical support for data collection. In addition, ACEP provided independent project and performance analysis and reporting. This report is the final product of that effort.

Technology Overview

Heating with the sun is not new. Dwellings have been designed to passively heat since ancient times. Native Americans in the Southwest oriented dwellings so that the low winter sun provided direct solar radiation, while cliffs and overhangs provided shade, reducing heat during the hot summer months (Ramlow & Nusz, 2009). Solar thermal technology, the use of technology to capture solar energy and convert it to thermal energy, has been commercially available for over one hundred years, with systems primarily installed in locations with abundant solar resource and minimal freezing tempera-
tures, such as Florida and California (Ramlow & Nusz, 2009).

Northern Alaska and the Arctic, however, are a land of extremes. Winters consist of long periods of darkness, when the sun barely (if ever) emerges above the horizon, and summer days bring 24 hours of daylight (Figure 1). The seasonality of the resource combined with other factors such as harsh climate, cold temperatures, extreme fluctuations in sun azimuth, and remote location, in addition to historically low fossil fuel prices, has limited the application of solar thermal systems in arctic environments to date.

**Cold Weather Application**

We investigated the potential to harness solar energy for producing space heating and domestic hot water (DHW) in northern Alaska and the Arctic. Many modern solar thermal systems have recently had a number of advancements in technology, design, and materials incorporated in them, making systems more robust for colder applications. For instance, freeze protection measures using a heat transfer fluid (HTF) such as glycol allow systems to withstand freezing; HTF designed for use in solar thermal systems has a low freezing point, a high boiling point, and additives to inhibit corrosion and acidification.

There is compelling economic opportunity for offsetting energy use through production of space heating and DHW in Alaska, taking advantage of these recent advancements. Over 80% of Alaska home energy use goes toward production of space heat and DHW (WH Pacific et al., 2012). In most remote regions of the state, heating oil is the primary source of home space heating and DHW. In rural areas, this fuel can range in price from $6–$10/gallon (Division of Community and Regional Affairs, 2012). Based on simple RETScreen modeling, a solar fraction of at least 40% can be expected in most regions of Alaska depending on system size and hot-water demand. A 2012 Alaska Energy Authority (AEA) study concluded that in Railbelt and southeastern Alaska communities, DHW accounts for 12% of residential energy use. In the western Alaska community of Bethel (which was selected to represent rural hub communities), 18% of home energy use is for the production of hot water, accounting for an average of 33.8 MMBtu (million British thermal units) of energy per home (WH Pacific et al., 2012).

According to these data, on an annual basis, correctly sized solar hot-water systems in rural Alaska can be expected to offset about 7% of total home energy use if used for DHW production only. The same study estimated average home energy use in Bethel at 193 MMBtu/yr, 7% (13.5 MMBtu) of which is equivalent to 96 gallons of fuel per year. At $6/gallon for heating oil, this savings equates to $576/year, up to $960/year at $10/gallon.

**Categories of Solar Thermal Application**

Solar thermal applications are typically divided into three categories based on the temperatures generated, that is, low, medium, and high. Pool heating is the most common example of a low-temperature solar thermal application. The collectors in low-temperature applications typically are not glazed and are designed for temperatures below 100°F (Raichle, 2012a). Medium-temperature solar thermal applications are most frequent worldwide, with typical use for DHW and space heating at temperatures between 100°F and 200°F (Raichle, 2012a; International Energy Association, 2009).
High-temperature solar thermal applications, used for absorption cooling and in commercial settings for electric power generation, are designed to generate temperatures over 200°F. These systems generally concentrate the sun's energy to boil water for steam that spins some type of turbine to produce electricity. These systems must track the sun's movement, which makes them prohibitively expensive for small-scale application (Raichle, 2012b).

Types of Solar Thermal Collectors

The focus of this report is on residential medium-temperature solar thermal applications. The three most common types of solar collectors used in the residential solar thermal market are flat-plate collectors (FPCs), evacuated-tube collectors (ETCs), and compound parabolic concentrating collectors (CPCs). Flat-plate collectors and ETCs are used most often in residential solar thermal systems; CPCs are used less frequently, particularly in Alaska.

Flat-Plate Collectors: The oldest and most established solar thermal technology, FPCs were originally developed in the 1950s by Hottell and Willier (SOLCO, 2007). The collectors consist of an insulated box with glazing on one side and are typically 4×10 ft or 4×8 ft in size. Inside the box are a series of copper risers connected to fins that are coated with a plate material designed to absorb and retain the sun's heat (Figure 2, left). The HTF is heated as it flows through the copper risers inside the collectors.

Evacuated-Tube Collectors: A newer technology than the FPC, the ETC is designed to reduce convective and conductive heat loss. Evacuated-tube collectors have a number of designs, usually involving double tube glass construction. A smaller tube is placed inside a larger tube and then sealed together after a vacuum is drawn between the two layers of glass (similar to thermos designs). An absorber plate is typically coated on the inside layer of glass (Ramlow & Nusz, 2009). A copper pipe containing liquid is in the middle of the tubes. This copper pipe extends out the top of the evacuated tube and into a manifold where it makes contact with a HTF (Figure 2, right). As the liquid in the tubes heats up, it vaporizes and transfers energy to the HTF in the manifold.

Of significance, numerous studies have confirmed that ETCs are more efficient than FPCs in cold ambient temperatures (Ayompe et al., 2011). A National Renewable Energy Lab (NREL) report recommended ETCs when the desired heating temperatures are greater than 122°F above the ambient temperature (Taylor, 2006).

Compound Parabolic Concentrating Collectors: Though not addressed in this study, CPCs should be mentioned as a commercially available collector. Like FPCs, CPCs contain copper risers, but under the risers is a reflective material in a compound parabolic shape. This material focuses more of the sun's rays on the risers as the sun moves across the sky (Solarbook, 2009). To achieve improved performance in colder ambient temperatures, CPCs can also use evacuated tubes as risers.

Indirect Solar Thermal Systems

To prevent system freezing in cold climates, an indirect solar thermal design must be utilized so that water is not exposed to freezing temperatures. The two most common indirect solar thermal designs are pressurized glycol and drain back systems. Both drain back and pressurized glycol
systems circulate the HTF through a heat exchanger, which transfers the thermal energy to DHW or space-heating systems. Domestic hot water is not circulated through the collectors; it remains inside the building envelope. The heat exchanger is often a copper coil in the lower portion of a hot-water tank. In many designs, additional hot-water heating capability is provided by an electric heating element or another copper coil in the upper portion of the tank, which is connected to the boiler. These systems elevate DHW temperatures to desired levels when solar energy is insufficient.

Pressurized Glycol Systems: In Alaska, the solar thermal system design used most is the pressurized glycol system (Figure 3). In this type of system, a closed loop filled with propylene glycol is heated with solar collectors. The system is usually charged to a pressure that ranges from 20–40 psi. While glycol provides freeze protection in extremely low temperatures (depending on the ratio of glycol to water), its thermal capacity is lower than water (Solarbair, 2009); in other words, water is a better thermal conveyor. In addition, there are concerns about corrosion with glycol, since when glycol overheats, it becomes acidic and can shorten the life span of system components.

Drain Back Systems: Drain back systems use water or glycol under atmospheric pressures in a loop that connects to a drain back tank (Figure 4). When not being circulated by pumps, the fluid in the collectors drains into the drain back tank, which is stored in conditioned space. When the collectors heat to water-heating temperatures, the pumps circulate the water through the system. We encountered several recently installed drain back systems around Alaska; in each case, glycol was used as the HTF.

There are a few notable differences between the two systems. Static head is eliminated in pressurized glycol systems; only dynamic head must be overcome. This difference means that a smaller pump (which uses less electricity) can be used with a pressurized glycol system than with a drain back system, since drain back system pumps must be large enough to overcome both static and dynamic head.

Installers in Alaska that were interviewed for this report warned that unless a glycol solution was used, drain back systems would eventually experience freezing issues. Even when collectors are sufficiently hot, cold temperatures can cause the pipes connected to the collectors to be similarly cold. If water is used, it is likely to freeze when it contacts these cold pipes in Alaska’s freezing temperatures (Kerry Gronewold, personal communication, June 2012).

Direct Solar Thermal Systems

While not discussed in this report, it should be mentioned that in warmer climates that do not experience freezing temperatures, direct solar thermal designs are used. Domestic water travels directly through solar collectors before it enters a storage tank. Water is a more efficient HTF than glycol, and these systems eliminate heat exchangers and the associated inefficiencies, leading to higher overall system efficiencies. Direct solar thermal systems should never be installed in climates prone to freezing temperatures.

Solar Radiation

Alaska, along with other places in extreme northern and southern latitudes, receives a disproportionate amount
of sun in the summer, but on an annual basis, the entire earth receives about the same number of hours of sunlight (Dragsted, 2011). Due to weather patterns and atmospheric scattering, different areas on the Earth’s surface receive different amounts of solar radiation. In many Arctic locations, space heating is required almost all year long. Generally, however, the time of year when space heating is needed most is also the time of year when the solar resource is least available (months with a high solar resource that correspond with high space heating needs exist and are discussed in the Nome Data Analysis section of this report).

The solar irradiance outside of the earth’s atmosphere is 1367 W/m² and is known as the solar constant (Duffie & Beckman, 2006). As solar radiation travels from the sun, through Earth’s atmosphere, and ultimately to the surface of Earth, it is affected by scattering, absorption, and reflection (Horta et al., 2008). As a reference, irradiance on a sunny summer day on Earth’s surface at solar noon is about 1000 W/m², although this varies depending on atmospheric conditions and location.

To better understand the performance of solar collectors under different conditions, it is helpful to understand the solar radiation components. Radiation that reaches the outer surface of a solar collector has three components (Figure 5):

1. Beam (direct) Radiation (I): Radiation that is unaffected in its direction by atmospheric or ground effects (Horta et al., 2008).
2. Diffuse Radiation (D): Radiation affected by the scattering effects of various atmospheric conditions (Horta et al., 2008). Diffuse radiation reaches Earth’s surface from the entire dome of the sky (Andersen & Furbo, 2009).
3. Reflected Radiation (Rg): Radiation reflected off the ground before it reaches the aperture plane of the collector (Horta et al., 2008).

Global radiation is the sum of these three radiation components.

It is commonly accepted that solar systems installed in the Arctic with the collectors at a steep angle experience a shoul-
der season advantage over systems with a similar installation in more temperate areas. The advantage is due to high levels of reflected radiation from the snow cover during spring and fall. The term *albedo* is used to describe the percentage of solar radiation that is reflected by a surface. For reference:

> A perfectly black surface has an albedo of 0 (all radiation is absorbed). A perfectly white surface has an albedo of 1.0 (all radiation is reflected)” (Lightle, 2011).

The average albedo of earth is 0.3, while the albedo of snow, clouds, and ice is generally assumed to be between 0.7 and 0.9 (Lightle, 2011). More details about spring and fall snow reflection and that relationship to solar thermal system performance will be discussed in the *Nome Data Analysis* section, but the “spring bump” effect on steeply sloped surfaces can be seen in the radiation graphs of Figure 6.

In Figure 6, "Expected Average Daily Solar Radiation Levels for Varying Surface Angles by City", the bottom graph shows the amount of solar radiation that horizontal collectors in different cities in Alaska would be expected to receive throughout the year, with the highest radiation levels in May and June. In the graphs that show the collectors tilted 15° steeper than the latitude angle where they are located and tilted vertically, a strong improvement in springtime performance is seen. The graphs in Figure 6 show that Fairbanks and Kotzebue receive almost 5 kWh/m2/day in March and almost 6 kWh/m2/day in April. This early season performance improvement is attributed to more direct radiation from the low sun angles and high levels of reflected radiation from the snow-covered ground to the collectors. Significant space-heating demands coincide with this springtime arctic solar resource.

Figure 6 uses NREL data, collected between 1961 and 1990 and based on averaged values of radiation. In the NREL model, the albedo of snow was taken into account to calculate reflected radiation (National Renewable Energy Lab, 1992). Surface albedo was adjusted depending on the presence of snow cover. If there was snow on the ground, the surface albedo was set to 0.6 (albedo for snow ranges from about 0.35 for old snow to 0.95 for dry new snow). If no snow was indicated, the surface albedo was set to 0.2, a nominal value for green vegetation and some soil types (National Renewable Energy Lab, 1992).

Greenland Summary

Some of the most abundant arctic solar thermal research has been carried out on projects in Greenland by students and faculty in the Department of Civil Engineering at the Technical University of Denmark. A 2011 PhD thesis titled "Solar Heating in Greenland, Resource Assessment and Potential" by Janne Dragsted provides valuable information.

Greenland territory extends from 60° to 83° N. As a reference, Anchorage is located at 61° N and Barrow, at about 71° N. During a three-year study of global radiation at four locations in Greenland between latitudes 64° and 77° N, it was found that the two locations furthest north had the highest average annual global radiation values. According to Dragsted, the increased solar radiation was due to two factors: fewer cloud formations than at other locations and high levels of reflected radiation due to proximity to inland ice and snowfields. In addition, snow cover at the northern locations lasts longer, adding to ground reflection (Dragsted, 2011).

The Greenland research found albedo levels during periods of snow cover between 0.7 and 0.8. This measurement is in line with the albedo levels that many modeling programs use. Higher albedo was observed in April (>0.8) than in March, most likely because of a thin layer of ice over the snow cover due to freeze and thaw cycles in the spring (Dragsted, 2011).

One important Arctic-specific discovery from the Greenland research regards the lack of accuracy with which present models predict radiation on a tilted surface from global radiation values. The study found that present models underestimate diffuse radiation and overestimate beam radiation, and improvements are needed to account for typical conditions at high latitudes (Dragsted, 2011).

The Greenland research included an analysis of two separate solar thermal space-heating and DHW systems. The systems were equipped with energy meters to measure energy produced, domestic water consumption, auxiliary energy supply to the hot-water tank, and solar heat sent to the space-heating radiators as well as global radiation. The lessons learned from these systems resemble the lessons learned from systems used in Alaska, which will be discussed later in this report. Production data were collected for five years. A 46% solar fraction was achieved in the town of Sissimiut at 67° N.

Proper commissioning of the Greenland systems proved to be a major hurdle. During the study, differential controller settings were set incorrectly and the maximum tank temperature setting was too low, which led to poor performance.

One of the most interesting findings is related to potential overheating of pressurized glycol systems. It was feared that occasional power outages in Greenland could lead to stagnation and overheating scenarios in the closed-loop glycol systems. If expansion tanks were sized to handle three times the fluid volume in each collector, overheating problems related to glycol acidification were eliminated. A
Figure 6. Expected Average Daily Solar Radiation Levels for Varying Surface Angles by City
controller system that turned off the circulation pump at high storage-tank temperatures along with large pressurized expansion vessels protected the HTF from critically high temperatures as long as the collectors had good emptying behaviors. Dragsted (2011) concluded, "This [design] will also secure the solar heating system from damage in sunny periods with power outages, therefore making it attractive for Greenland." These findings were based on a study conducted between July 15, 2009, and March 31, 2010. During that time, 97 stagnation periods occurred, and a glycol pH of 7 was maintained throughout the experiment (no issues with acidity).

**Steam Back Systems:** A steam back system is a method of stagnation prevention. The process is explained in a recent Home Power magazine article:

> If a pressurized system is properly designed, there is no problem if the system reaches its high limit and the circulating pump turns off. The temperature in the collectors rises rapidly above the boiling point, creating steam. It takes about a thimbleful of water to make enough steam to completely fill a large flat plate collector ... so very little water actually boils. The steam quickly expands to fill the collector and pushes the remaining heat-transfer fluid down into the expansion tank. At this point there is no fluid in the collectors so the glycol is protected from thermal breakdown. When the collectors cool at the end of the day, the steam condenses, the pressure drops, and the heat transfer fluid refills the collectors (Ramlow, 2012).

The steam back design, which has the potential to prevent glycol overheating and acidification during stagnation events, could be a good alternative to drain back systems, allowing the benefit of a pressurized glycol system without the drawbacks. In Alaska, space-heating systems sized for the spring shoulder seasons are prone to overheating during warm summer days. The steam back design could be one way to minimize system overheating and prevent the acidification of glycol.

**Nome Project Summary**

The most extensive solar thermal data set obtained in this analysis comes from Nome at latitude 64.5° N (185 miles south of Kotzebue). In 2008, the Bering Straits Development Company (BSDC) installed an ETC solar thermal system (Figure 7) on an 18-unit apartment building. The system consists of 150 Apricus evacuated tubes along a Caleffi valve station and controller, and two 119-gallon solar storage tanks that tie into a boiler-fired water tank. The tubes are installed facing south on top of the apartment building at a 70° angle. The system is tied to a dump load on the outside of the building that dissipates heat when the hot water in the storage tanks reaches a predetermined temperature. Robert Bensin is the Energy Efficiency and Renewable Energy Division Manager for BSDC and administers the system. Robert reports very few problems. At first ravens were eating the insulation off the pipes around the collectors, and a temperature sensor had to be adjusted. Otherwise, the system has been relatively maintenance-free, only requiring minor adjustment of the differential controller to maximize efficiency.

Currently, the system (Figure 8) is connected for DHW production only. Plumbing is in place to connect the system to space heating if production data suggest it is warranted. Part of this process would include the installation of controls on the boiler to lower the boiler operating temperatures in an attempt to keep them similar to the low-temperature heat produced by solar thermal.

**Nome Data Analysis**

The Nome solar thermal system data show the trends in pump operation and collector temperatures that one expects to see from a well-functioning system. The system was carefully monitored with consistent operation. The system experiences the highest production in March, April, and May. This production level appears to be the result of strong springtime sun and reflected radiation from the snow. The drop in production during summer is probably a result of the steep angle (70°) of the solar collectors, lack of snow reflection from the ground, and differential controller settings. During the three years of data studied from June 2009 through June 2012, average temperatures at the top of the solar tank were maintained above 80°F from the beginning of March until the beginning of October, and actual temperatures were much higher during part of that time (Figure 9).
While the Nome data set is the most complete set of solar thermal data that ACEP has acquired to date, note that the energy values are approximated based on estimated flows (no digital flow meter is currently installed). With this said, energy has been calculated based on several different methods, and all of these calculations support the energy values delivered by the controller. In addition, a quick RETScreen analysis shows only about a 14% difference between modeled production versus actual three-year-average annual production (with actual production being the higher value), which further substantiates the production values of the Nome system.

The Nome data set indicates that during the three years of data collection, the pump that feeds the diversion load was active between March and September, with highest activity in April and May when it was running about 40% of the time after 7 p.m. This excess spring heat is a valuable commodity that likely has many uses in rural Alaska.

Nome Economic Analysis

According to Mr. Bensin, the Nome system cost $12,000 for materials and another $9,500 for labor, and $100 for yearly operation and maintenance. Using an estimated annual production of 25 million Btu, 12.2 years of simple payback was calculated without addition of tax credits.

Over the 25-year life of the project, the system delivers a fixed energy price equivalent to $3.34/gallon of fuel oil. The payback period is dramatically influenced by the efficiency of the backup source of water heating. If a less efficient boiler is used, then payback of the solar thermal system gets shorter, and vice versa for more efficient boilers.

A RETScreen model was developed for Seattle, Washington, and Sacramento, California, to compare the Nome payback period with that of Lower 48 installations. In each example, an array of the same size and type as that installed in Nome is assumed. The arrays were assumed to cost $21,500 (just as in Nome) and to be installed at an angle equal to the location's latitude plus 6° (the same as the Nome array). In the Sacramento and Seattle models,
Figure 9. Nome System Resource and Energy Production Information
electric resistance water heaters were assumed to serve as the backup DHW heat source, with electric rates of $.15/kWh and $.11/kWh, respectively. As in the Nome analysis, no tax incentives were used to calculate payback. The Sacramento model showed a 10.5-year payback for the system, while the Seattle model showed a 22.5-year payback for the system."

Kotzebue Project Summary

Kotzebue is a town of 3,200 people on a narrow spit of land that protrudes into Kotzebue Sound in Northwest Alaska (Figure 10). The town lies north of the Arctic Circle at 66° N. Currently the town meets most of its energy needs through the combustion of diesel fuel. For this project, KEA explored the use of solar thermal systems to provide DHW and space heating for six residential homes in the community.

Project design and procurement commenced in May 2010. KEA was awarded $127,000 through the Denali Commission EETG program. Additionally, the Kotzebue Community Energy Task Force provided $12,000 of in-kind funding, primarily for project location identification, design, and monitoring, and KEA provided $5,000 in match and in-kind funding, for a total project budget of $144,000. System installation began during summer 2010, with the final system installed in November 2010.

All the solar thermal systems installed by KEA were the pressurized glycol type, manufactured by two different companies. Houses 1–3 were equipped with Viessmann systems (described in the Viessmann System Description section of this report). Although the controller and the pump station are branded as Viessmann, the differential controller is a rebranded Resol controller; the pump station is similar in design to many other brands. Houses 4–6 were equipped with Heliodyne systems. For each brand of equipment, one house was equipped with a set of ETCs and two houses were equipped with FPCs.

Two companies were hired by KEA to complete the installations. The rationale is described in the following KEA quarterly report:

> There are several manufacturers with respectable reputations that make both types of collectors, but only two that are well represented with installation companies here in Alaska: Viessmann Manufacturing Company Inc. represented by Gensco Alaska and installed by Susitna Energy Systems (SES), and Heliodyne Inc. represented and installed by Alaska Battery Systems (ABS). KEA elected to split the 6 homes between the two manufacturing and installation companies as well as purchasing both flat plates and evacuated tubes from each (Logan, 2011).

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![Figure 10. Map of Kotzebue, Alaska](image-url)
number of inputs, one of which is critical: the groundwater temperature. The colder the water that enters the solar system, the greater the temperature differential between the water and the collector temperature and the better the system performs. In Kotzebue, water is pumped out of the ground at about 38°F. Waste heat from the diesel generators at the Kotzebue power plant is used to heat the city water to about 50°F before its delivery to residents. Many areas in rural Alaska similarly heat groundwater through various means before delivering it for residential use.

To assess system performance, KEA attempted to acquire three years of fuel consumption data from the fuel distributor in town (Crowley Maritime Corporation), and was able to obtain data for five out of the six houses (Figure 11). While these data are interesting to observe and the trends suggest areas that warrant further investigation, no solid conclusions about the performance of the systems can be made. The data are based on fuel receipts from Crowley, but no information is available on which dates fuel was delivered or how much fuel was delivered at various times. For example, if a homeowner’s tank was filled just before the New Year, then the fuel from that delivery is applied to one year, even though most of the fuel is consumed during the following calendar year. In addition, peculiarities exist in the fuel data (House 3 used the same amount of fuel in 2008 as it did in 2009), which raise questions as to the accuracy of the data. Finally, the fuel receipts only indicate fuel purchased from and delivered by the fuel distributor, and do not account for supplemental fuel deliveries. For example, fuel may be donated or gifted by a family member or friend, the amount of which will not be accounted for in fuel distributor receipts.

Due to the inconsistent nature of the system performance data and the lack of robust cost data available to ACEP, no financial analysis has been done for the KEA systems installed in Kotzebue. A financial analysis of a Nome solar thermal system will be presented later in this report.

Viessmann System Description

Susitna Energy Systems of Anchorage was chosen to install three of the solar thermal systems in the Kotzebue project. Viessmann systems (Figure 12) were chosen based on the recommendation of Susitna Energy. Each of the Viessmann systems is plumbed for DHW production only. House 1 used an ETC, while Houses 2 and 3 used FPCs. In Houses 2 and 3, the existing hot-water tanks were removed, and hot-water tanks with dual internal heat exchangers were installed. The bottom heat exchanger was plumbed into the solar thermal glycol loop, and the top heat...
exchanger was plumbed into the glycol loop, heated by the boiler. Energy gathered from the solar collectors is transported to the hot-water tank via the bottom heat exchanger. Any additional heat needed to bring the DHW to the desired temperature is delivered by the boiler to the top heat exchanger.

The Resol DL2 data logger attached to the Viessmann differential controller can store large data sets and save over a year’s worth of data on temperature and pump operation measurements at five-minute time intervals. Unfortunately, there were glitches with the date stamps on the data sets for these systems. Dates have been approximated based on when the systems began operation and when the data were downloaded. Because of this approximation, energy production cannot be tied to a specific day with complete confidence; however, the overall trends and production values are not affected.

House 1: A Viessmann 300 TPS3 evacuated-tube system was installed on House 1 (Figure 13) at an angle of 68° from the horizontal, facing true South. This system contains 30 evacuated tubes connected at a manifold, where heat from the tubes is transferred to the HTF.

Unlike the other two houses on which Viessmann systems were installed, the House 1 system contained a relatively new high-quality, on-demand hot-water heater that was not removed. A 79-gallon solar storage tank with a single internal heat exchanger was added to the system. This heat exchanger was plumbed to the solar glycol loop. Solar-heated water is stored in this tank and delivered to the on-demand hot-water heater before it is delivered for domestic use. In this scenario, if the solar-heated water is at or above the set point of the on-demand water heater, the on-demand water heater will not fire. Otherwise, the on-demand heater will make up the difference between the solar-heated water and the desired water temperature.

When ACEP analyzed the House 1 data, it observed that the normal seasonal peak-and-trough pattern that was expected was not observed until winter of 2012, after about 360 days of operation (Figure 16, top), and even after that, there seems to be an abnormality with the pump operation. Some days the pump ran all day long so that heat gained during the daytime was lost during the evening. Only data after day 360 was analyzed for energy production. It was estimated that from about February 2012 until June 2012, the system produced 2.7 MMBtu, equivalent to about 20 gallons of diesel fuel—far below its expected potential. Troubleshooting is required to remedy the situation.

House 2: The systems installed in Houses 2 and 3 were nearly identical. Both systems use dual coil solar storage hot-water tanks and two 4×8 ft FPCs. The only difference in the two systems is the boiler type. House 2 (Figure 14) contained a Toyo Oil Miser 180 boiler that was connected to the upper coil heat exchanger in the hot-water tank. Due to data logger problems, only about six months of data was collected before the logger stopped recording in August 2011. During that period, the system appears to have had limited operation. According to the data available, the collector only reached a maximum temperature of 99°F, and the pump never ran more than 80 minutes a day. These issues deserve further investigation. In addition, KEA officials suspected that this single occupancy dwelling had low hot water demand could contribute to low production (Jesse Logan, personal communication, December 2012). During the data period, the system appears to have produced only about 330,000 Btu.

House 3: With the exception of a Weil McClain boiler connected to the top coil heat exchanger in the solar storage tank, the House 3 (Figure 15) system was identical to the House 2 system. The Weil McClain boiler is larger than the Toyo boilers found in many of the other systems in the Kotzebue installations. In this study, there was no instrumentation of the boiler. During future analysis, it would be worthwhile to study the fuel consumption...
of a boiler that might run at a lower power setting due to the addition of energy from the solar thermal system.

The data set acquired from House 3 has proved to be one of the most complete data sets in this study, containing 398 days of temperature and pump operation data starting in March 2011 (Figure 16, the data were averaged by day of year and represented by one calendar year). Unfortunately, the system stopped logging data in April 2012.

House 3 generated approximately 15.5 MMBtu of energy between March 2011 and April 2012, which is equivalent to about 110 gallons of diesel fuel, even more when boiler inefficiencies are taken into account. This production rate is impressive—higher than that shown by the RETScreen modeling performed by ACEP. While this energy production is an approximation, we believe it is accurate to within 20%.

Viessmann System Observations

The Viessmann flat-plate collectors were installed parallel to the roof slope (about 30°) to minimize the risk of wind damage. Both Heliodyne flat-plate systems were installed at steeper angles...
and were more exposed to strong winds, sustaining significant wind damage during a fierce storm that occurred in November 2011. The Viessmann systems were undamaged. The disadvantage of the Viessmann installation is the reduced ability of the collectors to absorb shoulder season radiation and diffuse reflected radiation from snow cover on the ground (see Figure 5).

In Figure 16, House 3 temperatures at the collector and at the bottom of the water tank are shown by the red and green lines, while the blue bars show the percentage of the day that the pump operated. Temperatures in the bottom of the storage tank were maintained above 100°F for about 150 days. Temperatures at the top of the tank could have been even higher due to tank stratification. It is possible that, because of the low slope of the collectors, snow took longer to shed after heavy snowfall than it would have with the collectors at steeper angles.

The Viessmann differential controller is a rebranded controller manufactured by Resol, a German solar thermal company. The system displays temperature data from the sensors on the unit and can be programmed and monitored without external instruments such as a laptop computer. It takes some practice to navigate around the menu pages of the controller and to change the settings, but the instructions in the manual are fairly straightforward.

The Viessmann systems for this project use hot-water tanks with internal heat exchangers, while the Heliodyne systems use external tube and shell heat exchangers. Efficiency differences between these two designs were not taken into account in this study.

Heliodyne System Description

All of the Heliodyne systems were plumbed to provide energy for DHW and space-heating systems (Figure 17). The solar thermal priority is to heat DHW. When water in the hot-water storage tank is heated to a predetermined set point of 180°F, the system sends HTF through a flat-plate heat exchanger which preheats the return glycol space-heating loop before it reaches the boiler. All of the Heliodyne system designs are nearly identical. An external tube and shell heat exchanger is attached to the Heliodyne pump station. The pump and heat exchanger unit mounts to the outside of a solar storage tank. Glycol from the solar loop and water from the hot-water tank are pumped through the heat exchanger, where heat passes from the solar loop to the water in the solar hot-water tank. The water in the solar hot water tank flows into a second hot-water tank with a heat exchanger that is fed by the glycol boiler loop. If the water needs additional heating to reach the desired occupant set point, the boiler delivers that heat. If the water is already sufficiently heated, the boiler does not need to fire.

Data logging capabilities are integrated into the Heliodyne Delta T Pro Lite differential controller. In the Kotzebue installations, the data were recorded at 10-minute intervals. After 30 days, the older data were overwritten to make space for new data. In order to store long periods of data, KEA attempted to connect the controllers to the online Heliodyne data logging system via a wireless router installed at the residences. These wireless routers proved to be problematic. Two of the systems were connected sporadically, but long-term detailed data collection was not possible with these systems. As a result, the production data for the Heliodyne systems are spotty, often recording just a month of data at a time for several periods of the year, depending on when KEA officials were able to visit the home and download production data. In some cases, longer-term rough energy data were downloaded from the Heliodyne servers, but these data are approximate and lack specific temperature detail.

House 4: An evacuated-tube system that uses the Heliodyne pump station was installed in House 4 (Figure 18). As explained
earlier, the Heliodyne system has a solar storage tank that pre-heats water before it goes into a 26-gallon Amtrol hot-water tank, which is heated by a glycol loop connected to the boiler. When hot water in the solar tank is heated to a predetermined set point, the space-heating loop pump turns on and the solar loop runs through a flat-plate heat exchanger that preheats glycol in the space-heating loop before it returns to the boiler.

Limited production data are available for House 4, but overall energy production appears low. From April–September 2011 and April–June 2012, the system produced about 1.4 MMBtu according to data retrieved from the Heliodyne server. The temperature data suggest that temperatures at the top of the storage tank were often heated to 130°F and above. Even in the very early part of the year, the temperatures reached 90°F on occasion. There is speculation that the low solar production was tied to low hot-water consumption by the occupants. Water meters would have been needed to confirm this.

Figure 19 is based on data from a chart created by the Heliodyne software. Data were not downloaded during winter months, which accounts for the missing winter data (data gaps therefore do not necessarily reflect the lack of production). According to these data, energy production for this period was 1.4 MMBtu, equivalent to 10 gallons of diesel fuel when used at 100% efficiency.

Due to space constraints, the pump station and solar thermal storage in House 4 were installed in the arctic entry-way, which is adjacent to the boiler room. During a winter storm, the door blew open and froze one of the pumps next to the door. Due to the lack of a licensed plumber in Kotzebue, several months passed before the pump was replaced. Consequently, the temperatures in the manifold, which transfers heat from the tubes to the HTF, got very hot due to stagnation; the thermistor failed and had to be replaced.

**House 5:** House 5 (Figure 20) has a setup similar to House 4, the exception being that FPCs were used. After the initial solar installation, the Amtrol water tank in House 5 began leaking and was replaced with a Triangle Tube 30-gallon tank, also heated with a glycol loop from the boiler.

The data for House 5 are limited. From August to October 2011 and from March through the beginning of July 2012, the system produced about 4.3 MMBtu according to data downloaded from the Heliodyne server (Figure 21). This production rate is equivalent to 30 gallons of diesel fuel when used at 100% efficiency.

Temperature data are not available for the entire year; however, a quick review of the available data suggests that maximum daily summer temperatures at the collector outlet were sometimes above 250°F. This information is consistent with a stagnation scenario, where the pumps are not operating.
and glycol is not circulating in the solar loop. In addition, the temperature at the top of the tank never went significantly below 90°F during the first few months of operation when the pump was not operating. Apparently, a miscommunication with the homeowners occurred, and the top electric coil of the solar hot-water tank (which was not intended to connect to power) was wired and plugged in so that the top electric coil inside the solar water-storage tank was operating.

**House 6:** With the exception of two 4×10 ft FPCs instead of ETCs, House 6 (Figure 22) used the same components as House 4. House 6 has the most extensive production data for any of the Heliodyne systems. According to energy data obtained from the Heliodyne server, from March through November 2011 and from March through June 2012, 14 MMBtu were produced, equivalent to about 100 gallons of diesel fuel at 100% efficiency (Figure 23). Temperature data from House 6 suggests that maximum collector temperatures regularly reached 130°F in early March and hovered around 150°F during the summer months. Temperatures at the top of the solar storage tank were about the same. With temperatures this high, hot-water heating would require no additional energy from the boiler, which is especially meaningful during months with no space-heating demand, since the system could operate in a boiler-off status.

While these data appear to be self-consistent, data for the months of September to November 2011 raise questions about the energy production measurements during this period. Given the solar resource in Kotzebue, solar thermal production during these months should not be this high. Unfortunately, no detailed temperature data are available to help diagnose this discrepancy.

It was undetermined why the Heliodyne system in House 6 appears to have been more productive than the other Heliodyne systems. One possibility is that the demand for hot water was greater in this house, which would increase production of the solar thermal. Other possibilities include issues with the controller settings or anomalies in other parts of the hot water and heating system.

**Heliodyne System Observations**

The Heliodyne systems were installed at about a 60° angle from the horizontal. The data suggest that this angle may have improved early season performance. House 6 realized consistent maximum collector temperatures over 100°F around the beginning of March, while House 3 did not realize temperatures this high until mid to late March. Still, this data set is limited, and in order to be certain, more study is required. It is commonly accepted through experience and modeling, however, that a steeper angle will improve early season performance given...
the low winter sun angles and high reflectance of the spring-time snow-covered ground. The level to which the collector angles determine performance cannot be concluded with any type of certainty based on the data from the Kotzebue systems.

In November 2011, a severe arctic storm caused high winds in the Kotzebue area. Both Heliodyne FPC systems sustained collector damage that required replacement of the collectors. Because the maximum winds fell within levels that the collectors were rated to withstand, the warranty was honored, and Heliodyne replaced the collectors, though KEA had to pay the shipping expenses. The Heliodyne FPCs were installed at steep angles to maximize solar gain. Extra fasteners and racking were used so that the systems should have been able to withstand wind gusts over 100 mph. Indeed the racking weathered the storm without incident, but the collectors themselves sustained the damage. The glass glazing blew off the collectors, and the copper absorber material was exposed and damaged. After the panels were replaced, KEA installed banding around the collectors to prevent future damage (see Figure 22). The Viessmann systems, which were installed parallel to the roof angles, were undamaged.

The differential controllers in the Heliodyne systems are only accessible and adjustable with a computer, which is probably an advantage in situations where an installer or homeowner does not want unauthorized individuals changing the settings, but means that additional equipment is necessary when the settings need to be changed. KEA officials preferred the Heliodyne user interface, stating that in general it was easier to navigate and more user-friendly.

In the experience of the author, when off-site data monitoring is required, it is advantageous to have an external data-logging system or at least a system that does not require Internet access to store data. A system that can store data internally or on a memory card for long periods is essential in rural Alaska applications given the lack of reliability with Internet connections.

In addition, while for this study data were acquired through loggers integrated with differential controllers, future studies would benefit from using an independent data-logging system, which would increase accuracy and improve the flexibility of such systems.

Discussion of Collector Angles in Arctic Regions

Using solar modeling in RETScreen and TRNSYS, one is able to get an idea of radiation and collector angles in the region (Figure 24) for reference a summary graph of system productions is included. There is extensive discussion about the proper angle to place collectors in arctic regions. From a
Figure 24. Kotzebue Modeled Radiation by Collector Angle and System Production Summary
modeling point of view, collectors set at around the angle of latitude yield the highest annual output. Many homeowners choose to alter this angle based on the goal of the system. For example, some homeowners choose to install panels at a steep 70°–90° angle to maximize solar gain during the shoulder seasons (Figure 24, top). These steeper angles also maximize the gain from snow reflection (Figure 24, middle).

KEA installed two ETC arrays to compare the performance of ETCs with that of FPCs. Research shows that ETCs are more efficient in cold ambient temperatures (Zambolin & Del Col, 2010). In the Kotzebue study, the energy production of the ETCs was far below that of the FPCs. The lack of uniformity between the ETC and FPC systems and the homes on which these systems were installed precludes a conclusion regarding performance, but it does raise important questions. Many installers referred to the high insulation quality of the ETC as a disadvantage because the insulation causes snow, ice, and frost to cling to the collector much longer than on a FPC. KEA officials said that they observed frosty ETCs when the FPCs were clear. An ETC system in Nome, which will be discussed in the Nome Project Summary section of this report, appears to be performing well. A side-by-side scientific study specific to Arctic application is needed to make additional conclusions about the suitability of evacuated tubes in various areas around Alaska.

In addition to an ability to absorb radiation reflected off snow, there are other tangible motivations for placing collectors at steep angles. In his book, A Solar Design Manual for Alaska, Rich Seifert with the UAF Cooperative Extension Service states that he would install collectors at around 90° on a south-facing wall. This angle would eliminate the problem of snow accumulating on the collectors. Seifert’s work will be discussed in detail in the Rich Seifert section of this report. Other Fairbanks installers consulted during this study indicated that they place collectors on large racking systems to lift the bottom of the collectors higher off the roof. This minimizes the accumulation of snow at the collector base.

Snow shedding is especially important with evacuated tubes. As discussed earlier, the high efficiency of ETCs minimizes the loss of radiant heat from the collectors, preventing snow and ice from melting. Snow forming on the collectors is less of a problem in areas of high wind, such as in many parts of western Alaska (Seifert, 1981). Mounting collectors on a wall also eliminates roof penetrations. One common concern regarding wall-mounted collectors is the potential for vandalism. During the extensive research for this report, the concern about vandalism was shared by many; however, no one had actually experienced an act of vandalism against a solar thermal collector. KEA expressed concern about roof penetrations that were necessary during the installation of roof-mounted solar thermal collectors. Attics in Kotzebue are sealed and have no access for increasing efficiency during the cold and windy conditions that are frequently experienced. It was feared that roof penetrations could make buildings more susceptible to weather damage.

Springtime solar gain from snow reflection is often used to justify the expected performance of solar thermal in northern regions. To obtain Figure 24 (top and middle) we used the TRNSYS modeling program, which has the capacity to analyze historical weather data and calculate solar radiation components. For this analysis, TMY2 data were used. Ground albedo was set to 0.2 during times of year with no snow cover and 0.8 during times of year when the ground was covered by snow. In reality, these numbers varied so that albedo would often be between 0.2 and 0.8. The model does not have the capability to represent this. Also, collectors near the water or the sea ice could benefit from additional reflection from these surfaces.

Other Alaska Systems and Resources

Many solar thermal systems are used in Alaska including many residential systems in Fairbanks, Anchorage, and Homer. The oldest operational solar thermal system in Alaska that the authors are aware of exists in Fairbanks and belongs to John “Benny” Benevento (Figure 25). The system is a CPC/ETC drain back design that has been in operation since 1983. Benevento originally installed the system himself and has had to replace a few tubes over the years, but overall it appears that the system has held up well. According to Benevento, the system qualified for a $2,000 federal tax credit and cost $4,900 (including shipping) when it was purchased in 1983. He has a 120-gallon hot-water tank that sends water through a heat exchanger in the drain back tank. The following are notable systems and resources in Alaska relevant to this report:
Dillingham

Dillingham has at least two systems that were installed on U.S. Fish and Wildlife facilities: a drain back system connected to radiant floor heating in a hangar facility and a Heliodyne system installed on a residential U.S. Fish and Wildlife facility tied to DHW. Although not located at arctic latitudes, these systems are of interest due to their installation in rural Alaska. The DHW system includes a Heliodyne pump station and three 4x10 ft FPCs installed at roof pitch (Figure 26). The installed residential system was a collaboration between the U.S. Fish and Wildlife Service and the UAF Bristol Bay Campus. The system, which cost about $14,000 without labor, is instrumented for energy monitoring. The data from the first eight months (April–November 2011) of production are erroneous due to inaccurate measurements from one of the temperature sensors. The sensor was replaced with a high accuracy immersion well type sensor. For verification purposes, the energy data collection is being performed on both the glycol side and the water side of the system. The data from this improved data collection system is planned to be evaluated in December 2012.

Denali Education Center

The solar thermal system at the Denali Education Center was installed in 2009. Though administered by the Center, the system is owned by the Golden Valley Electric Association (GVEA). The system, which was the result of a $190,000 award to GVEA by AEA, is a pressurized glycol design; it is installed at a 60° angle and has a 2,700-gallon solar storage tank filled with water. The system (Figure 27) uses 36 Heliodyne FPCs and a Heliodyne differential controller. The solar thermal system preheats hot water before it flows to about 16 bathrooms in individual cabins as well as a busy communal kitchen. This solar-heated water is delivered to electric and propane water heaters in the individual buildings, which heat the water additionally if required. The system only operates during the summer season. The solar loop is charged by staff members in the spring and drained in the fall. The system was designed and installed by ABS Alaskan. After construction, the production data supplied by the Heliodyne controller were unsatisfactory to GVEA officials, and the system was robustly instrumented for energy production monitoring by ABS Alaskan at the request of GVEA.

The system was initially expected to produce 32–36 MWh of energy annually. According to Denali Education Center staff, production thus far has been below initial expectations. During summer 2011, pressure differentiations caused fluctuations in hot-water temperatures during guest showers, forcing staff to make system modifications and shut off the solar thermal system for part of the summer. New high-quality mixing valves were installed, and during a June 2012 site visit by ACEP, the system was operational. Staff members are optimistic about improved future performance.

According to a grant report obtained from AEA, in 2011 the system offset electricity and propane equal to $7,000 (Rich Stromberg, personal communication, August 2012). This amount was obtained by subtracting the electricity and propane consumed during 2011 from a 2008 measured base year. This energy is equal to about 39 MWh, providing an estimated payback of 27 years.

GVEA officials as well as Denali Education Center staff are optimistic that, after a successful summer of operation in 2012, production data from the data logging system can be analyzed to get an accurate picture of the solar thermal system production.

Rich Seifert

A discussion of solar energy in Alaska would not be complete without mention of Professor Rich Seifert and his findings on solar thermal. Seifert worked for the UAF Cooperative Extension Service and authored a book titled *A Solar Design Manual*.
for Alaska, first published in 1981 and now in its fourth edition. Seifert, who has been experimenting with passive solar, PV (photovoltaics), and solar thermal in Alaska for years, is known around the state as a rich source of information on solar energy.

Seifert discusses the solar thermal system installed on his own house (Figure 28) in the fourth addition of his Alaska solar design book. In 2006, Seifert observed that between May 1 and September 14, he used 178 gallons of heating oil at his home. As this was during the summer in Fairbanks, he assumed that most of this energy was going toward hot-water heating. Tripling this roughly four-month figure gave him an idea of how much oil goes toward water heating each year. He spent $8,000 and installed a pressurized glycol system with two 4×10 ft collectors. Seifert estimates that he gets 16 MMBtu/yr from his system, equivalent to about 115 gallons of heating oil. During the design phase, Seifert expected to achieve a 50–60% solar fraction and estimates that he realizes this amount (Seifert, 1981).

The main advice Seifert gives for northern areas with little to no wind (such as Fairbanks) is to mount the collectors vertically (90°) on a south wall to avoid having to clear snow off the collectors. Seifert recommends some type of a heat dump when using pressurized glycol systems to prevent overheating. Before installing ETCs vertically, consult the manufacturer’s recommendations. Some types of tubes are designed for installation at a maximum slope of 70°–80°.

Seifert encourages people to focus on solar hot water first when designing a solar thermal system. According to Seifert, hydronic baseboard heating requires too high of temperatures for use with solar thermal, but radiant floor/radiant wall heating is ideal because of the cooler temperatures required. Seifert echoes what has been heard many times during this investigation: Super insulation is an important first step during the home weatherization process; how one heats is secondary (Rich Seifert, personal communication, June 2012).

Thorsten Chlupp

Many Alaska residents are using solar thermal to help meet their space-heating needs. Thorsten Chlupp and his Fairbanks company Reina LLC design and build homes to the Passive House standard, using solar thermal for space and water heating. Chlupp lives in a 2,300 square foot house that he built. The house is heated by a solar thermal system supplemented by a wood-burning masonry heater. The solar thermal system (Figure 29) contains 12 SunEarth 4×10 ft FPCs, a Resol differential controller and data logger, two 48 watt Grundfos pumps, and multiple heat exchangers. Chlupp reports that he chooses FPCs over ETCs because of problems that he has observed with the tubes frosting up and failing to shed snow during the shoulder seasons. Chlupp stresses that to use solar energy for space heating in Alaska, one must effectively use the shoulder seasons (see Figure 24). Chlupp reports that he starts capturing solar energy around the end of January and enjoys solar production until mid-November. This leaves about 2.5 months with virtually no production by his large solar thermal system. During this time of winter in 2011/2012, he burned about 1.5 cords of wood in his custom-built masonry heater to heat his home. Chlupp indicates that he has data to substantiate the performance of his solar system, but ACEP was unable to obtain the data during this study. Chlupp believes that inadequate storage is the largest impediment to solar thermal heating in Alaska. He states, “Two panels and 120 gallons of storage are inadequate for significant space heating.” Chlupp’s designs generally involve 1,500–2,000-gallon storage tanks wrapped with R-70 insulation, using a bladder tank system and cellulose insulation. Chlupp prefers to install these thermal storage tanks in
the middle of a house so that any tank loss heats living space. If the solar storage tanks cannot be installed in the interior of a house, Chlupp puts them under it.

Originally, the system that Chlupp installed on his home used pressurized glycol. After multiple overheating occurrences, he converted the system to a drain back system, using glycol as the HTF. As discussed above, the downside of a drain back system is that it takes a larger pump to overcome the static and dynamic head (a pressurized glycol system pump only has to overcome dynamic head). Newer pumps can vary the power output to reduce parasitic loads after static head has been overcome in drain back systems. Chlupp currently favors the drain back design because it allows a system that he “can walk away from.” If something goes wrong, stagnation is avoided, because when pumps shut off HTF drains from the collectors. This feature creates a simple and fail-safe system (Thorsten Chlupp personal communication, June 2012). Many experts are of the opinion that an effective space heating solar thermal system must be drain back (Raichle, 2012b). This information is important because space-heating systems are sized for the shoulder seasons, meaning they are oversized for the summer season. Overheating could occur if glycol stagnates in the collectors.

Another design that prevents stagnation, a steam back system, was discussed earlier in the section on solar thermal research in Greenland. Essentially, a steam back system is a pressurized glycol system with an expansion tank (or tanks) large enough to store all of the glycol. When stagnation occurs, a very small amount of fluid boils in each collector, forcing HTF out of the collectors and into the expansion tank, where it (the HTF) is protected from overheating damage. The controller is set to turn the pump off when the high-temperature limit is reached in the storage tank. According to the research presented about the system in Greenland, the system worked well and prevented acidification of the glycol (Dragsted, 2011). Glycol is rated for specific temperatures, and when those temperatures are exceeded in collectors, the fluid breaks down and becomes acidic. Acidic glycol causes premature wearing of many system components.

While the solar thermal system and wood-burning masonry heater in Chlupp’s home provide an efficient and fossil fuel-free way to heat his house, the superinsulated building envelope makes the system work. The slab is rated at R-63, the walls at R-75, and the attic at R-115. In addition, the house achieved an air-tightness rating of 0.48 ACH @ 50 Pa during blower door testing. A superefficient, well-insulated building is the most important part of a successful solar thermal space-heating system. A whole-building approach is necessary to get maximum efficiency out of the different building components.

Chlupp plans to include a 5 kW photovoltaic system and a water-sourced heat pump that draws heat from the thermal storage tank to take advantage of temperatures between 33° and 90°F, which presently are not fully used.

In general, three main building components contribute to Chlupp’s success, the first being that he uses radiant floor heat. Radiant floors use a low-temperature HTF, generally about 125°F, to heat a house. This temperature is similar to that produced by a solar thermal system. Baseboard heating, used in most rural Alaska homes, requires temperatures of at least 160°F (Guardian Water and Power, 2012). To take full advantage of solar thermal in Alaska, a low-temperature heating method should be used (Rich Seifert, personal communication, June 2012). The second building component is the storage tank that Chlupp uses, which is unique in many ways. He built it out of scrap materials and installed a high-density polyethylene (HDPE) liner. At 5,000 gallons in volume, the tank is 8 feet in diameter and 14 feet tall. A tank stratification device is the third building component for successful use of solar thermal. Chlupp built a tank stratification device (Figure 30) that takes full advantage of stratification that occurs in his tall tank. The hot-water return to the solar tank is not just a single pipe delivering water to the top of the tank. Instead, it contains a series of tees and lies inside another perforated pipe. This arrangement allows hot water that has been heated by the solar thermal system to return to the proper tank height according to its temperature. This improved stratification means that the coldest water in the tank will flow through the solar thermal system to collect heat, which maximizes the efficiency of the system.

Researchers have long known that a highly stratified hot-water tank maximizes production of solar thermal systems (Furbo, 2003). Research is currently focusing on ways to return heated water to tanks so that stratification continues to be maintained. In this study, we saw other designs similar...
to the one used by Chlupp, but also saw designs that use fabric wrapped around a manifold. Some of these designs are currently being introduced into solar hot-water tanks, especially those coming out of Europe. Whichever design is chosen, maximizing tank stratification is a simple and important way of maximizing solar thermal performance.

Cold Climate Housing Research Center

The Cold Climate Housing Research Center (CCHRC), located in Fairbanks, has been conducting research and data collection on two systems—FPCs and ETCs—installed on their research facility. Although no comprehensive performance data are available to date, CCHRC has reported numerous findings and recommendations specific to installing and integrating solar thermal technology in an arctic home, which we have incorporated in this study. In its new building addition, CCHRC is planning to install a solar thermal heating system that incorporates a 15,000-gallon water storage tank and about 15 collectors. CCHRC estimates that this system will meet 30% of its heating needs (Bruno Grunau, personal communication, May 2012).

Weatherization

To demonstrate the relationship between space heating, hot-water heating, and solar thermal production, an analysis was done based on data provided in the Alaska End Use Energy Study 2012 by AEA. This study uses the western Alaska town of Bethel as a demonstration site to gather data about space heating and water heating energy use in rural Alaska. According to this study, the average Bethel home uses 139 MMBtu annually for space heating. Bethel averages 12,923 heating degree-days (HDD) each year; therefore, the aver-
age Bethel home uses 10,755 Btu/HDD. For hot-water heating needs, the average home uses 33.8 MMBtu each year. The top graph of Figure 31 shows the estimated output of a 320 square foot solar thermal system (eight 4×10 ft panels), installed at a 60° angle operating at 35% efficiency in relation to the average home energy demands. This graph also shows that even a large solar thermal system fails to meet the basic space-heating needs of the average home.

The bottom graph of Figure 31 shows the relationship between the same solar thermal system as shown in the top graph and a more efficient house. Instead of consuming 10,755 Btu/HDD as the average home does, the more efficient house consumes only 5,000 Btu/HDD because of weatherization upgrades. This basic demonstration shows how a larger portion of heating needs can be met by a solar thermal space-heating system in a well-insulated home. This finding echoes earlier statements in this report by Rich Seifert and others who stress the importance of insulation and weatherization when considering a solar thermal space-heating system.

Findings

In northwestern Alaska, properly designed solar thermal systems that function as designed have generally followed the production patterns predicted in simple modeling programs such as RETScreen. Our findings indicate that operation of solar thermal systems in other regions of Alaska would follow the production figures predicted by similar models.

The most-detailed production data exist for the Nome solar thermal system. Using this data as well as cost figures provided by BSDC, payback of 12.2 years was calculated using fuel prices of $6/gallon, increasing at 3% annually. For comparison, using energy costs in Seattle, Washington, and Sacramento, California, the same system has been modeled to pay back in 22 and 10 years, respectively.

Production data from the Nome system demonstrate that in that region the most concentrated solar radiation is received during the spring months. Figure 32 shows a four-year production graph of a solar electric system mounted vertically on the south side of a building in Nome. The figure indicates that the highest energy production occurs in late March and early April. Large space-heating demands still exist during this spring season. Adequate storage is necessary to maximize the potential of solar thermal systems so that energy from solar radiation during spring afternoons can be stored and distributed throughout the day.

Based on the performance of the solar thermal systems reviewed during this study, it is evident that solar thermal equipment is robust enough to endure harsh arctic weather, with some exceptions. The Kotzebue systems withstood an arctic storm of unusual strength. All ETCs and those FPCs installed flush with the roof pitches were undamaged; the FPCs installed at steep angles had severe wind damage. This difference in outcome supports the conclusion shared by many people interviewed during this study, that collector installation should be steeply angled on south-facing walls where possible. This angle of installation not only provides additional protection from wind loading, but also eliminates the need for roof penetrations and allows snow to shed easily.

Data from the Kotzebue solar thermal systems used for space heating are not sufficient to make any generalizations about the effectiveness of solar thermal systems tied to high-temperature

![Daily Energy Production from a 16.8kW PV Array](image.jpg)
hydronic heating systems. Given the temperatures required for these types of heating systems, the benefits would be limited without boiler modifications that enable lower-temperature operation. The greatest solar thermal space-heating potential occurs when radiant heating systems are tied to solar thermal, since these heating systems operate at much lower temperatures.

A system designed for space heating must maximize the potential of the shoulder seasons when high HDDs and high solar radiation exist, which means the system will likely be oversized for summer months. An oversized system necessitates robust stagnation countermeasures such as a drain back system, adequate heat dumps, or a steam back system. Some Alaskans have recommended using solar thermal to heat greenhouses and flower boxes as a way to take advantage of excess heat capacity. While such an application was not studied in this report, the peak solar thermal season could correlate well with heating needs in greenhouses and similar types of buildings.

In Alaskan homes, most energy is consumed for space heating, but the importance of a simple solar thermal system used for DHW only should not be underestimated. Nome provides a good example of the savings potential available in a DHW-only system. For most retrofits, Rich Seifert recommends focusing on DHW first and then determining whether space heating is realistic given the needs of the household and the kind of heating infrastructure already installed in the home.

Efficient use of energy is the most effective way to reduce fossil fuel consumption in Alaska. Energy use can be reduced in several steps. For more-efficient space heating, improve the building envelope by insulating and by eliminating air leakage. Since space heating is responsible for the largest portion of residential energy consumption in Alaska, weatherization is an important first step. Another significant area of energy consumption is DHW. Solar thermal can make significant contributions, commonly covering 40% to 50% of DHW production in many areas of the state. In certain situations, solar thermal can also contribute significantly toward space heating. Since space heating and DHW production account for about 80% of the typical residential energy consumption in Alaska, reducing both of them goes a long way toward reducing fuel oil consumption and saving money.

A valuable lesson from this study has been the understanding of the importance of system commissioning. Oftentimes, system commissioning is what separates successful systems from underperforming systems, and this applies to solar thermal and most technological systems. As an example, in the LEED (Leadership in Energy and Environmental Design) model, commissioning is required to obtain certification, and extra certification points are given toward advanced status for additional commissioning procedures. In the LEED example, installing efficient and sustainable building components is one major step, but a final and key step is checking each component to confirm that it is functioning as designed and working well with all the other building components. The process of achieving the additional LEED commissioning status involves the installer returning after the system has been operating for a set period to review performance data and ensure that the system is continuing to operate as intended. A similar set of procedures is advised when installing solar thermal systems. Certain performance levels should be realized at various times of the year. For example, during springtime in Alaska, collector temperatures well over 100°F should be reached. If such temperatures are not reached, the problems could be, but are not limited to, malfunctioning sensors or excessively high flow rates. If a system is instrumented for data logging, an analysis of the temperatures, flow, and energy delivered should be conducted to analyze the system, verify performance, and correct any issues. The importance of system commissioning cannot be overstated. System commissioning can make the difference between a solar thermal system that provides a quick payback and one that performs below expectations.

Recommendations for Future Installations

- Commercial buildings such as apartments, hotels, dormitories, and hospitals use large quantities of hot water. Several factors make these facilities good candidates for solar thermal installations. These buildings use lots of energy to heat water. The combination of large hot-water demand and the associated high energy costs can equate to short payback periods for solar thermal installations. In addition, commercial buildings already have dedicated maintenance personnel who can help properly commission and maintain the solar thermal system, maximizing its performance. Operation and maintenance are typically sunk costs, since maintenance personnel are already on staff.

- Solar thermal systems tend to be low-maintenance once they are properly installed and commissioned, but they are not maintenance-free. Someone will always need to “own” the system and actively monitor it to ensure that the system is functioning as designed. Just as homeowners must routinely check fuel levels and boilers for proper operation, the owner of a solar thermal system must check it to ensure proper functioning. In homes with many inhabitants (who consume a lot of hot water), with a homeowner who is dedicated to monitoring and maintaining the solar thermal system, a solar thermal system should result in reduced
energy costs.

- Weatherized and well-insulated homes with low-temperature heating systems will benefit the most from solar thermal space-heating systems.

- The complexity of collecting data on solar thermal systems should not be underestimated. Small errors in temperature sensor outputs can result in larger errors in calculated energy output. For verification purposes, it is useful to have redundant data collection. This could include collecting data on both the glycol and water side of the system as well as the inclusion of flow meters on the fuel being fed to the boiler and measuring household DHW consumption.

Recommendations for Future Research

- During future analysis, it would be worthwhile to study the fuel consumption of a boiler, which might run at a lower power setting because of the addition of energy from the solar thermal system.

- Testing of collectors at steep angles in northern climates is warranted and would help to further establish procedures for installing collectors on south-facing walls; for example, examine the production difference between a collector oriented vertically versus a collector oriented at 60° or 70°.

- Results from a side-by-side test of evacuated tubes and flat-plate collectors in northern Alaska would provide valuable information about the performance of the two systems in northern climates and which systems perform better in various conditions.

- An examination of the effectiveness and maintenance requirements of the steam back method of overheating protection would be valuable. No steam back systems were observed in Alaska during the course of this investigation.

- An investigation of the marginal benefit of installing larger storage tanks in conjunction with solar thermal systems would be useful to aid in the design of future space-heating systems.

- Photovoltaic systems are quickly decreasing in price, and there have been suggestions that a PV system tied to a heat pump water heater could yield a quicker payback than a solar thermal system (Holladay, 2012). This suggestion deserves a case study specific to Alaska.

References and Notes


i. While KEA was responsible for installation, maintenance, operation, and instrumentation of the systems, ACEP was responsible for performance data analysis as well as independent economic and performance comparisons. While initial production modeling was done by KEA, the modeling discussed in this report was performed by ACEP unless attributed to a different organization.

ii. Azimuth is the angular distance along the horizon between North and the position of the sun measured in a clockwise direction.

iii. While electricity accounts for a small amount of energy comparatively from the end-use perspective, it takes about 3 times that amount of energy in the form of fuel for the diesel generator (assuming 33% efficiency); the amount of fuel that the generator needs to burn to provide electricity for a typical residence is not too much lower than the amount of fuel that a typical residence burns for heating (Tom Marsik, personal communication, December 2012).

iv. In this report, the terms “heating oil,” “fuel oil,” “diesel fuel,” and “stove oil” refer to the same fuel type used for heating and power generation throughout most of rural Alaska. One gallon of heating oil produces 138,690 Btu.

v. RETScreen is free Excel-based clean energy analysis software first released in 1998. Developed to help assess the technical, financial, and environmental suitability of clean energy project, it is managed by the Canadian government’s Centre for Natural Resources. For more information visit http://www.retscreen.net/.

vi. Solar fraction is the percentage of hot water demand that can be met by solar thermal production.

vii. The term “Railbelt” refers to the broad geographic area served by the Alaska Railroad from the Kenai Peninsula to Fairbanks.

viii. For initial modeling, a pressurized glycol system with two 4 x 10 flat plate collectors, an 80 gallon hot water storage tank and a daily hot water consumption of 80 gallons was assumed.

ix. Glazing is a clear covering (e.g., glass) that allows solar radiation through and helps reduce heat loss.

x. 0.8 Btu/lb-°F for a 50% glycol mixture vs. 1 Btu/lb for water.

xi. The insolation at the top of the atmosphere varies slightly (by about 3%) with the eccentricity of Earth’s solar orbit. However, compared to the effects of the optical thickness of the atmosphere and atmospheric conditions, this effect is negligible and insolation at the top of the atmosphere is generally accepted to be constant.

xii. Comprehensive project information can be found at http://energy-alaska.wikidot.com/feasibility-of-solar-hot-water-systems.

xiii. Ibid.

xiv. Other assumptions include: system output of 7,300 kWh/yr, 70% backup heater efficiency, $6.00/gallon fuel cost, 3% yearly increase in fuel cost, $12,000 system cost, $0 storage tank cost, $9,500 installation cost, $100 yearly maintenance cost, 0% federal tax credit, $0 in local and state incentives, and 3% general inflation.

xv. For reference, the NREL created a map in 2010 that uses some basic assumptions to calculate simple payback periods in different parts of the United States. For more information, visit http://www.nrel.gov/gis/emp.html.

xvi. It should be noted that during peer review of this report, several experts from around Alaska noted that the 180° set point was far too high since DHW never needs to be this hot, and residential solar thermal is not designed to regularly reach this temperature. It is possible that a lower set point could have supplied more heat to the space heating systems and improved system performance.

xvii. TRNSYS is a simulation program originally developed at the University of Wisconsin used primarily for renewable and building modeling. For more information, visit http://www.trnsys.com.

xviii. TMY stands for typical meteorological year. It is an accumulation of weather and solar radiation data from 1961 through 1990. A “typical” year is accumulated so that a weather data set can be used for building and solar modeling calculations. It is important to note that this is not an average year. The TMY data attempt to account for some extremes. For more information, visit the NREL national solar radiation data base at http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/tmy2/.

xix. For more information on the systems, CCHRC, and their recommendations, please visit http://www.cchrc.org/solar-thermal.

xx. HDD is a measurement designed to represent building heat demand. To calculate HDD, daily high and low temperatures are averaged and then subtracted from a base temperature, usually 65°F. This is done for each day of the year when the temperatures are below the base temperature. The summation of all the days is the total annual HDD. In this report HDD information was retrieved from the National Oceanic and Atmospheric Administration and expressed in terms of a 65°F base temp. Fairbanks experiences about 14,000 HDD days each year while some North Slope communities can experience over 19,000 HDD each year. As a comparison, Seattle experiences about 4,700 HDD. For more information, visit http://www.wrcc.dri.edu/htmlfiles/ak/ak-hdd.html.

xxi. Comprehensive project information can be found at http://energy-alaska.wikidot.com/feasibility-of-solar-hot-water-systems.