COLD CLIMATE HOUSING RESEARCH CENTER
CCHRC

Final Report to
The Denali Commission

Combined Residential Wind and Solar Energy Project at the Anaktuvuk Pass Prototype House

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Combined Residential Wind and Solar Energy Project at the Anaktuvuk Pass Prototype House

Cold Climate Housing Research Center

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Disclaimer: The research conducted or products tested used the methodologies described in this report. CCHRC cautions that different results might be obtained using different test methodologies. CCHRC suggests caution in drawing inferences regarding the research or products beyond the circumstances described in this report.

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Combined Residential Wind and Solar Energy Project

The Cold Climate Housing Research Center (CCHRC) created the Sustainable Northern Communities program in 2008 to help develop sustainable rural housing in northern climates. CCHRC designers work with local residents and housing authorities to develop homes that reflect the culture, environment, and local resources of individual communities. The designs emphasize energy efficiency, affordability, and durability. CCHRC has developed several prototype homes that can be easily built and affordably reproduced within each community to provide much-needed housing.

The first prototype home, built in Anaktuvuk Pass in 2009, has a small combined solar and wind power system. The construction of the house was a collaboration between CCHRC, Tagiugmiullu Nunamiullu Housing Authority (TNHA), the Village of Anaktuvuk Pass, and Ilisagvik College. The combined solar and wind power system was installed after construction by the Yukon River Inter-Tribal Watershed Council (YRITWC) as part of its multi-year renewable energy grant from the Administration for Native Americans. YRITWC designed the combined solar and wind power system to supplement the power to the house, it was not intended to provide the full load of the house. "Both the PV and wind system were sized with the goal of collecting good data, and producing meaningful power, without overbuilding either in lieu of having accurate data for the site" (M. Worthington, personal communication, October 12, 2011). The system was set up as a preliminary study into the feasibility of rural residential renewable power systems in remote northern locations in the state.

Figure 1. The Anaktuvuk Pass prototype house. The house built in 2009 has both solar and wind power generation systems installed.

Anaktuvuk Pass

General Location and Conditions

Anaktuvuk Pass is a Nunamiut community of 325 located in the Brooks Range, accessible only by plane. It is located above the Arctic Circle at 68° N. This is a very cold location with an average winter temperature of −14°F (-25°C) and an average summer temperature of 50°F (10°C) (State of Alaska, 2011).

Solar Radiation

From early December to early January the sun does not rise above the horizon in Anaktuvuk Pass; for several weeks on either side of this period, the sun is obscured by mountains. The extremely short days from late November to February also diminish the potential solar radiation. However, from late May until early July the sun does not dip below the horizon. The on-site measured yearly solar radiation shows these extremes (Figure 2). The solar radiation in Figure 2 only accounts for the direct radiation on the fixed-azimuth (south-facing) solar radiation sensor. According to PVWatts, a National Renewable Energy Lab (NREL) analysis tool for the performance of solar PV systems, Anaktuvuk Pass averages 3.4 kWh/m^2/day (sun-hours per day) compared to 6.57 kWh/m^2/day for Phoenix, AZ (PVWatts, 2012).

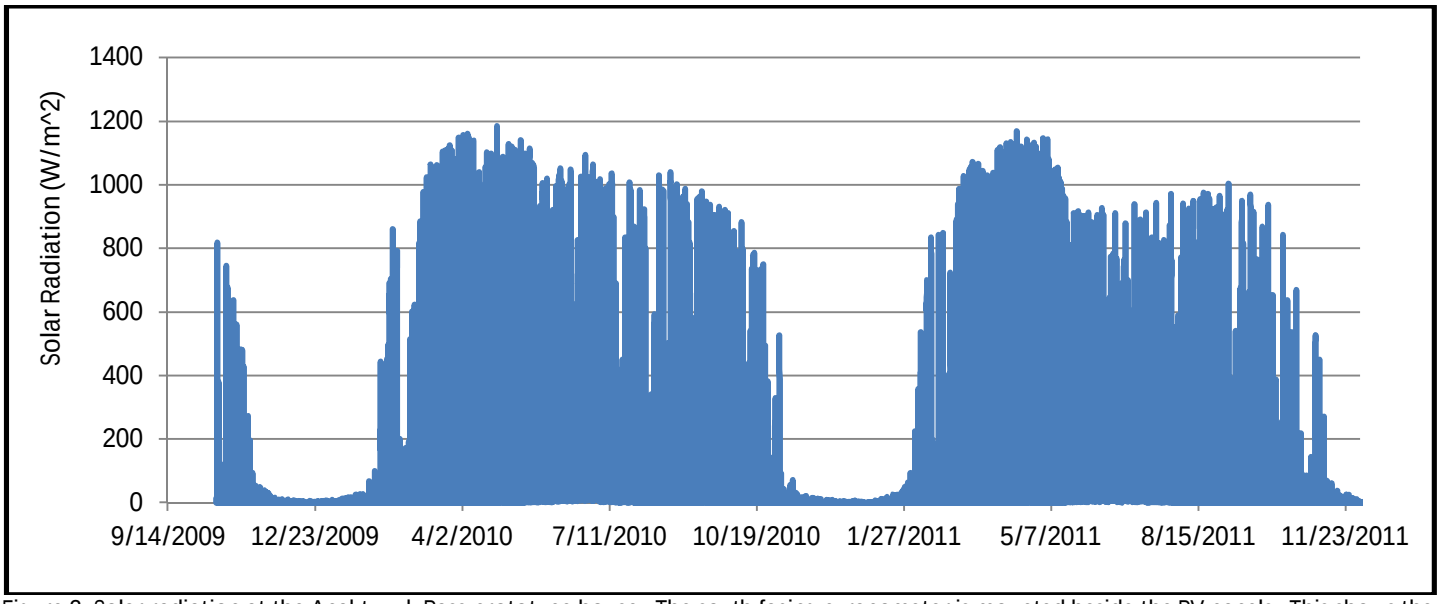

Figure 2. Solar radiation at the Anaktuvuk Pass prototype house. The south facing pyranometer is mounted beside the PV panels. This shows the solar radiation incident on the panels on the prototype house since they were installed.

Wind Potential

Prior to 2010, no wind data was available for Anaktuvuk Pass beyond the weather data from the airport. The average annual wind speed at the airport was listed as 8.6 miles per hour (mph) (3.8 meters/second (m/s)) (Western Regional Climate Center, 2012), however, the tower used to measure wind speed is low and the airport is protected from the wind by low hills (M. Worthington, personal communication, October 12, 2011). A 2010 report by the Alaska Energy Authority and V3 Energy LCC lists the average annual wind speed in Anaktuvuk Pass at 30 meters (98 ft) above the ground as 5.15 m/s (11.5 mph), a marginal wind source (Vaught, 2010). The meteorological station used to gather this data was located on a prominent hill above the power plant and southwest of the school.

At the prototype house an anemometer was installed on the wind turbine tower 15 m (49 ft) above the ground to measure the wind speed. Figure 3 shows the average wind speed for a one-year period on the tower behind the prototype house. The average measured wind speed from October 2010 through February 2012 was 4.2 m/s (9.4 mph). This is considerably less than the wind speed on the research tower that was double in height; this highlights the necessity of accessing the wind speed as close to the final turbine installation location as possible.

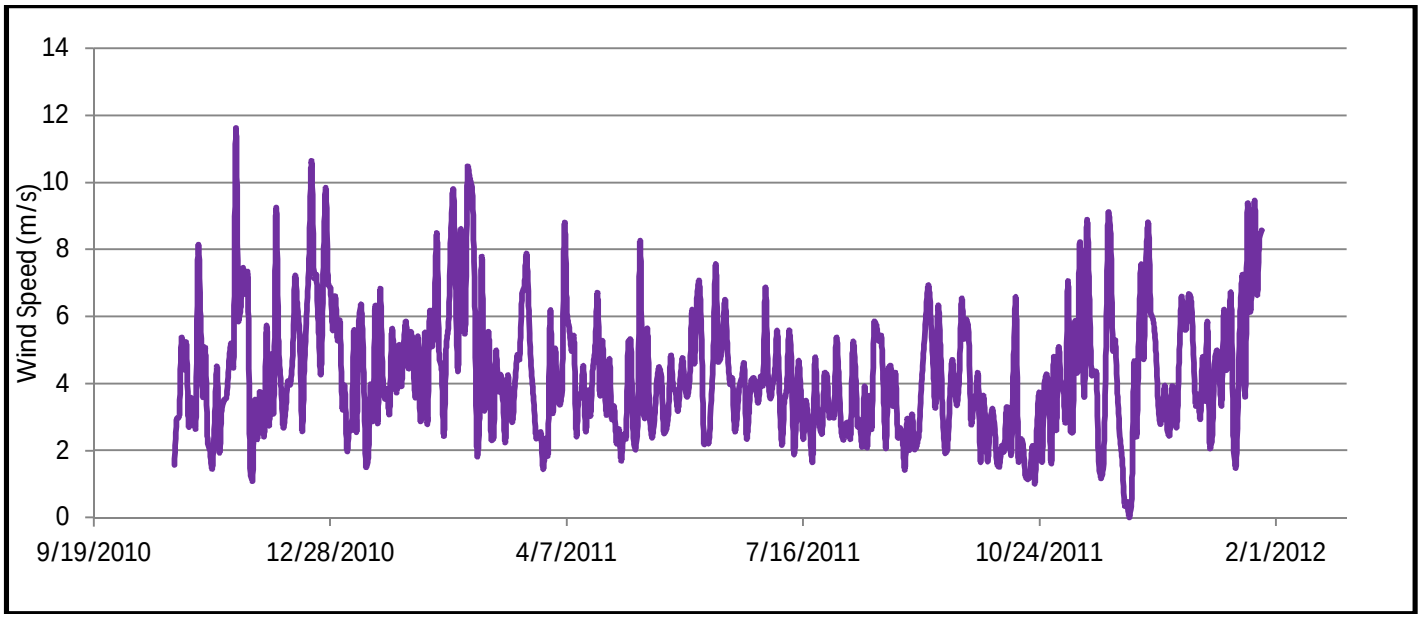

Figure 3. Wind speed at the Anaktuvuk Pass prototype house. This shows daily average wind speed, which remains fairly steady; the maximum gust was 23.1 m/s on February 25, 2011 around 11:00 pm.

Prototype House Design

In early 2008, CCHRC held a design charette in Anaktuvuk Pass to gather ideas from the community about what kind of housing suited its needs. The CCHRC design team developed a building site and floor plan based on these criteria. The design incorporated innovative building technologies, a traditional *qingok* (passive venting system), a roof truss system designed to hold solar panels, and spray polyurethane foam insulation sealed on the exterior with a spray-applied elastomeric liner.

The 800-square-foot Anaktuvuk Pass prototype house is partially bermed with soil for insulation and wind buffering, as well as reflecting the design of the traditional sod houses of the area. The foundation sits on two feet of gravel fill topped with a synthetic waterproof membrane. The house frame is made of metal studs that support half-inch sheets of plywood sheathing. Polyurethane foam insulation was sprayed onto the plywood from the outside (unlike typical construction where insulation goes on the inside) to a depth of nine inches, for an approximate R-value of 50 $ft^2 \cdot °F \cdot hr/Btu$. All insulation was covered with an elastomeric coating for weatherproofing. The roof was also covered with nine inches of foam, topped with sod, and vegetated.

General Electrical Demand

The electrical appliances and fixtures were designed to be as energy efficient as target construction costs and available technologies would allow. Of the regularly used electrical appliances, the refrigerator and the water heater draw the most electricity, although the washer and dryer can get heavy use as well. The prototype house also has an outside sewage treatment plant (STP) that requires a constant electric draw for its UV lamps and blower to both keep the effluent warm and to treat it; while it is not a large electrical draw it is a constant 230 W. The combined lighting for the house only uses 675 W when all lights are on. The electrical appliances, fixtures, and lighting installed in the house are identified in Tables 1 and 2. This list does not take into account the additional electrical appliances that the occupants may have added (occupant electrical demand is addressed later in this report).

Table 1. Electrical appliances.

Appliance	Power specification
Toyotomi OM-22 - *oil fired heater*	preheat = 275W, burning = 46W
Lifewater XSTP500UVP - *sewage treatment system*	230W
Flojet 4524-500 - *water pump*	154W @ 45 psi
Rheem Marathon 20 gallon – *water heater*	2000W
Sanibest 013 – *grinder pump*	990W
Whirlpool Duet - *clothes washer*	not specified
Whirlpool Duet – *clothes dryer*	not specified
2 Panasonic FV-40NLF1 – *air distribution fans*	132W x 2
Hotpoint - *electric range*	10,100W (@ 240V)
General Electric - *refrigerator*	1650W (Maximum)

Table 2. Light fixtures locations, types, and power consumption.

Location	No. of Fixtures	Number/Type Bulbs per Fixture	Total Power (W)
Garage	3	2/T8 LED tubes	90
Cold Storage Room	1	4/ T8 LED tubes	60
Kitchen Sink	1	1/ T8 LED tubes	15
Kitchen	1	4/ T8 LED tubes	60
Entry	1	4/ T8 LED tubes	60
Bedroom	3	3/CFL	162
Bathroom	2	2/CFL	72
Can Lights	12	1/LED	156

Wind and Solar Power Systems

The Anaktuvuk Pass prototype home includes a combined solar photovoltaic (PV) power and wind power generation system. Both the PV panels and the wind turbine are visible in the photo in Figure 1.

The solar PV and wind power generation systems provide alternating current (AC) power to the grid-connected main breaker panel. Figure 4 is a simple schematic that depicts the PV and wind electrical systems and their integration with the house and grid power. A technical wiring schematic of the integrated HMEP systems is shown in Figure 5. Electrical demand by the home's electrical systems is supplied by the renewable energy systems before power is supplied from the grid. As a result, the power demand from the grid is offset by the power produced by the renewable energy systems. When the renewable energy systems produce more electrical power than the house electrical systems demand, then power is supplied to the grid. The homeowner and the electrical utility signed a utility connection agreement that allows the homeowner to be given credit for any surplus power fed onto the grid.

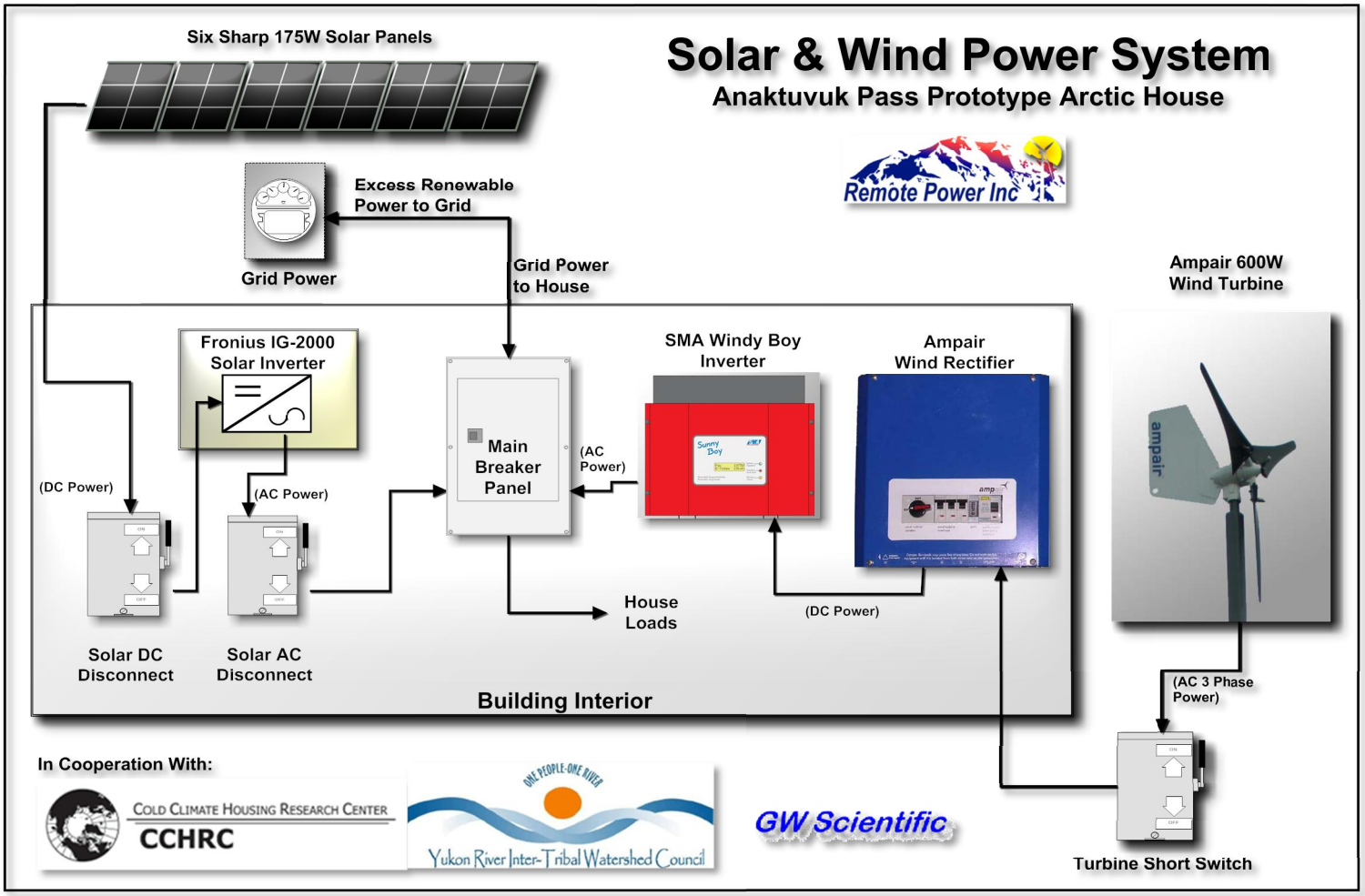

Figure 4. Schematic of the renewable energy systems installed in the Anaktuvuk Pass prototype home. The two systems were designed to work together to supply power to supplement the electrical demand from the house.

The Yukon River Inter-Tribal Watershed Council (YRITWC) received a grant to purchase and install the renewable energy systems. YRITWC personnel installed the renewable energy systems during the construction period of the prototype home; the installation costs have not been calculated. The equipment costs are estimated to be $9,000 for the solar PV system and $9,500 for the wind generator system (D. Pelunis-Messier, personal communication, September 7, 2011).

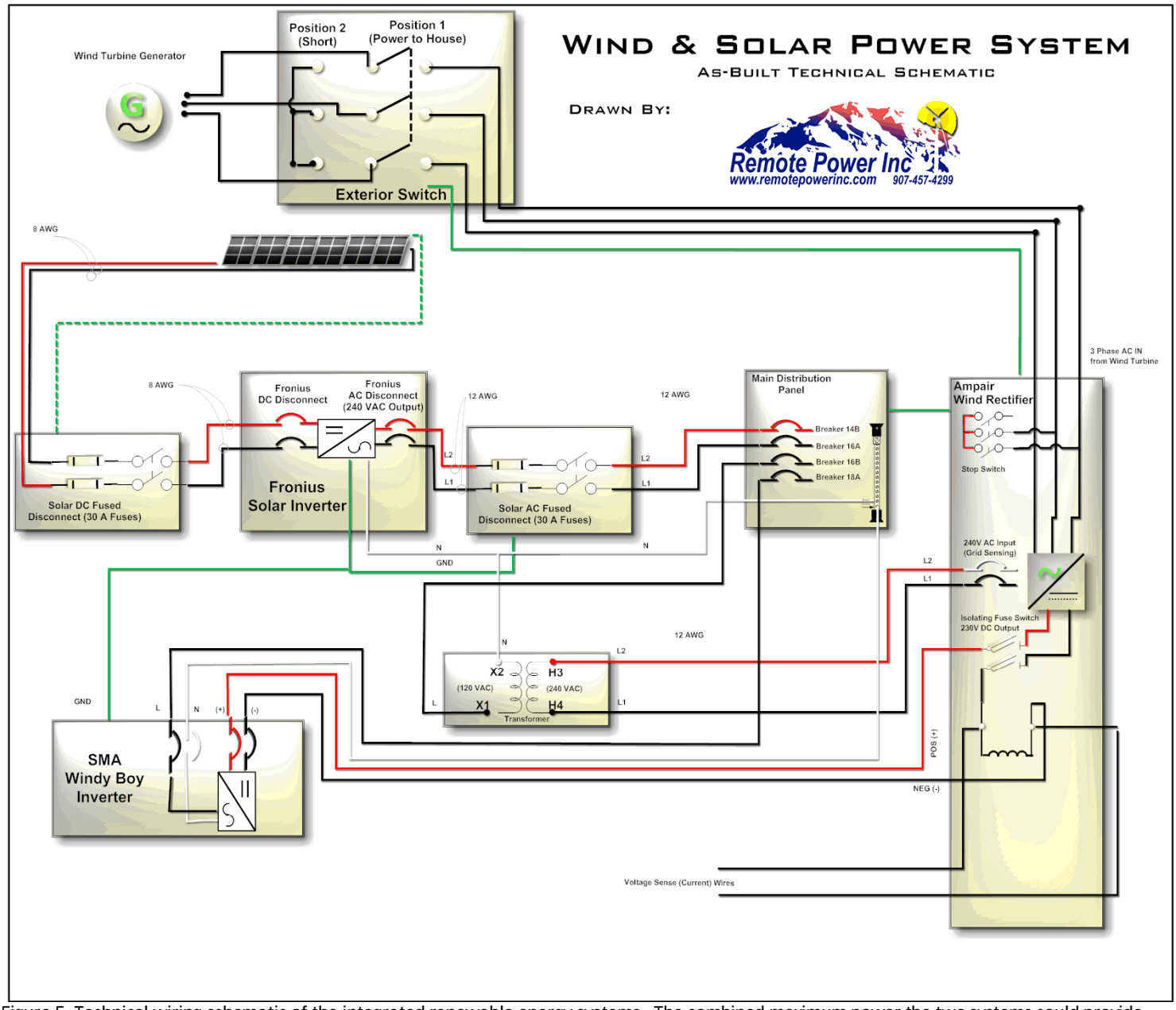

Figure 5. Technical wiring schematic of the integrated renewable energy systems. The combined maximum power the two systems could provide is 1,650 W. The schematic provides an as-built diagram of the system, produced approximately one year after the system installation.

Solar Photovoltaic System

The battery-less grid-tied solar PV system consists of six 175-watt solar panels that are wired to a 2,000-watt inverter. The inverter, an electrical device that converts direct current (DC) from the PV panels to alternating current (AC), subsequently supplies power to the main breaker panel of the house. The panels installed for the system are Sharp NT-175U1 monocrystalline panels. Each panel is 62 inches by 32.5 inches. They are mounted across the top of the wall on the south side of the house. The combined six-panel array is capable of supplying 1,050 W of power. The inverter, a Fronius IG 2000, is located in the arctic entryway of the house (Figure 6).

Figure 6. Interior components of the renewable energy system. These components are located in the arctic entryway, which is outside of the living space but still warmer than outside of the house.

The inverter (shown in Figure 6) interfaces with the user via a display and various LED lights. A quick look at the display indicates how much power, if any, is currently being generated. A sequence of push buttons enables the user to manage inverter settings and access power generation history.

Wind Generator System

The wind generator system consists of an Ampair® 600, a 600-watt wind turbine mounted on a 50-foot guyed turbine tower. The tower is comprised of 2.5-inch schedule 40 metal water pipe sections. Power generated by the wind turbine is supplied as "wild," meaning the amplitude and frequency of the voltage and current varies with wind speed. The windings in the wind turbine produces nominally 220 volt AC, however the current and voltage must be rectified to DC in order to be used by the inverter. The Ampair wind controller rectifies the 220 volt AC power to direct current (DC) power. The DC power is then inverted to AC power by a SMA Windy Boy 700-watt inverter that subsequently supplies power to the main breaker panel of the house. The inverter interfaces with the user via a display and various LED lights in a manner similar to the solar inverter.

The Wind Turbine

At the time of purchase, the wind turbine was thought to produce 600 watts at a wind speed of approximately 10 m/s (a metric often used for comparing wind turbines). However, the system had lower output than expected after being

installed. Troubleshooting and further discussions with the manufacturer revealed that the specific grid-tied model was not capable of producing the same power output as similar non-grid-tied models. Figure 7 shows the power curves of two of the three Ampair® 600 series turbines that depict the difference in performance between the grid-tied and non-grid-tied wind turbines.

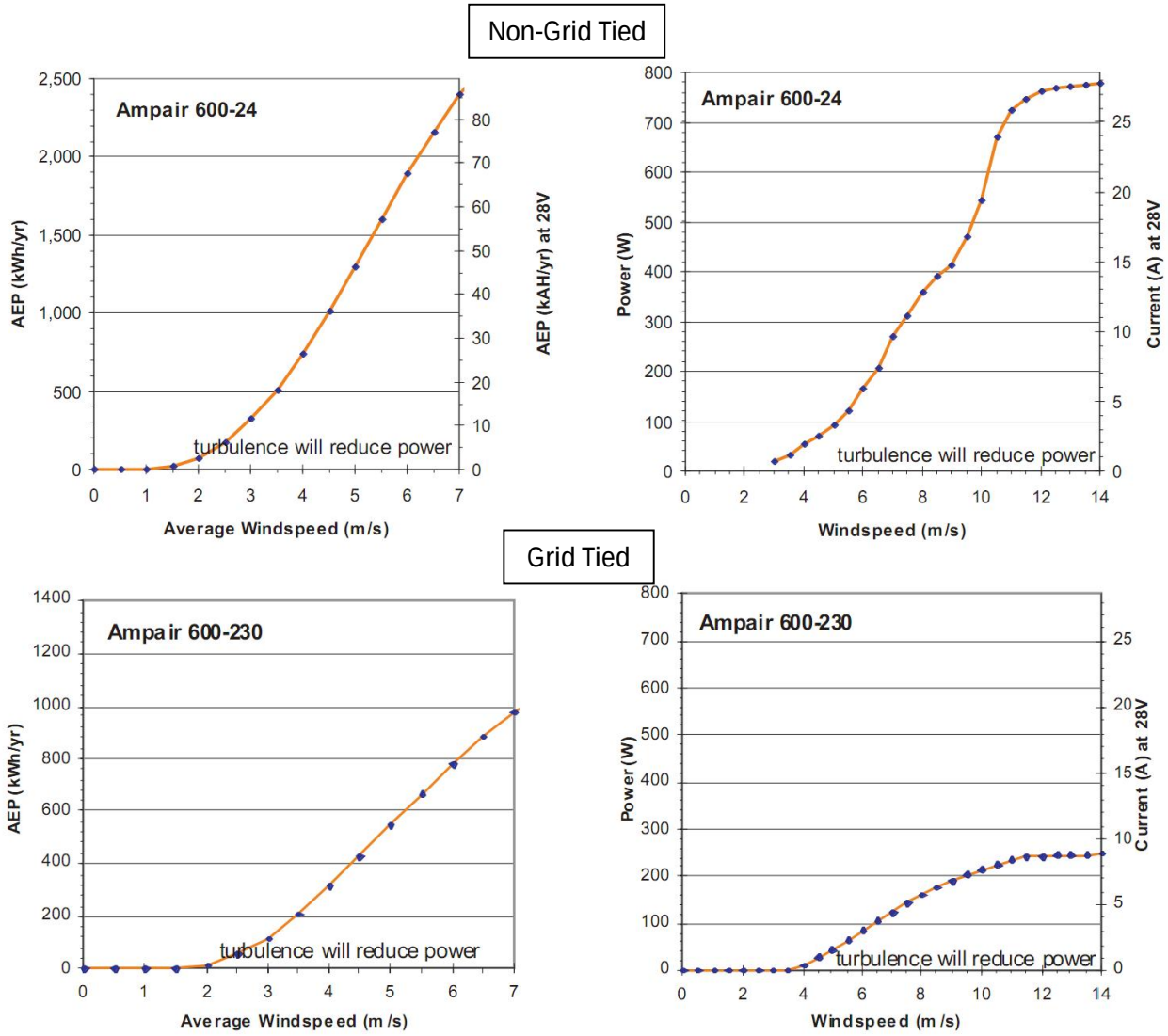

Figure 7. Power curves for two Ampair® 600 series wind turbines. The top power curves depict the non-grid-tied wind turbine performance. The lower power curves depict the grid-tied wind turbine performance. Adapted from *Ampair® wind and water power 2011 catalogue, issue 6.*

An anemometer was mounted on the wind turbine tower to record wind speed and direction. The average wind speed recorded by this anemometer for the period from October 22, 2009 through January 1, 2012 was 4.2 m/s. Based on the power curves shown in Figure 7, a 4.2 m/s average wind speed should generate about 310 kWh/year from the grid-tied version installed.

Wind Generator System Timeline

The wind system turned out to be more complex than anticipated and has required many trips to Anaktuvuk Pass to work on the system. YRITWC made seven trips to Anaktuvuk Pass to work on the system and spent a total of 20 days in Anaktuvuk Pass working on the system. Table 3 provides a brief timeline of the work done on the system. Except for a

brief period in summer 2010, the turbine has been in place but not functional and is still not functioning at the present time. Considering the wind resource available, the low projected production values of the turbine, the low end-user price of subsidized electrical energy in Anaktuvuk Pass, the high cost of trips to the village, and the absence of continued funding for troubleshooting, efforts to repair the turbine have been halted by the project partners (D. Pelunis-Messier, personal communication, February 22, 2012).

Table 3. Timeline of work on the wind generator system.

Year	Partner	Trip Summary
2009	YRITWC	Installed the turbine and did site reconnaissance, verified that all equipment had arrived, assembled the tower and installed the arrowhead anchors for the guy wires.
	YRITWC	Dug wiring trench and ran wire through house to inverter setup, attempted to start the turbine, but ran into monitoring and power issues: the data monitoring equipment was not connecting, the turbine was not sending power, the inverter did not respond.
	YRITWC	Attempted to connect turbine to the data monitoring equipment, could not connect.
2010	YRITWC	Rewired the data cables and widened operating parameters (wind speed window) on the inverter to change settings. The turbine began to produce power, though not at the expected rate.
	YRITWC	Attempted to optimize power settings on the inverter to fix power production issues. The circuit board on the rectifier shorted out and had to be brought back to Fairbanks for repairs.
	Remote Power	Remote Power went up to AKP to replace the board on the rectifier, and could not get the turbine to start. A short in the system is suspected. Inspection of the wires showed cracked insulation.
2011	YRITWC	Attempt to reconnect the turbine failed.

Monitoring

Cold Climate Housing Research Center (CCHRC) is monitoring the prototype home in Anaktuvuk Pass. The data collection systems are intended to help demonstrate operations of the prototype design, evaluate the integration of various building systems, and to recommend design improvements.

Equipment and Methods

Three Campbell Scientific (CSI) CR1000 data acquisition systems are used for data monitoring in the prototype house. The three systems are monitoring a variety of parameters in the house to develop a comprehensive understanding of the house's performance. The data is logged at two-minute, hourly, and daily intervals and is sent back to CCHRC via a wireless antenna (CSI RF450) that connects to the Nunamiut School's internet connection. An array of energy sensors (Table 4) was embedded into the prototype house following construction in October 2009. All of the sensors provide an analog signal which is converted via a CRBasic program to useable data.

Table 4. Energy sensors.

Sensor	Purpose
Solar power meter	Energy use
Wind power meter	Energy use
Electrical Utility (Grid) power meter	Energy use
Pyranometer (solar radiation sensor)	Energy potential
Anemometer (wind speed sensor)	Energy potential

CCHRC has been working closely with GW Scientific and the homeowners to monitor the house. The homeowners have been in the house for almost two years and have been actively interested in the monitoring and upgrades to the house.

Data Analysis

Electrical Demand

Home electrical usage is strongly a function of occupant behavior. The electrical usage in the house is shown in Figure 8. Prior to the family occupying the home in February 2010, the total use for the house averaged 367 kWh a month, a good metric of the baseline load of the house and the STP. Since the house has been occupied it has averaged 1,100 kWh per month. This average is well above the Alaskan monthly household average of 661 kWh/month (U.S. Energy Information Administration, 2009).

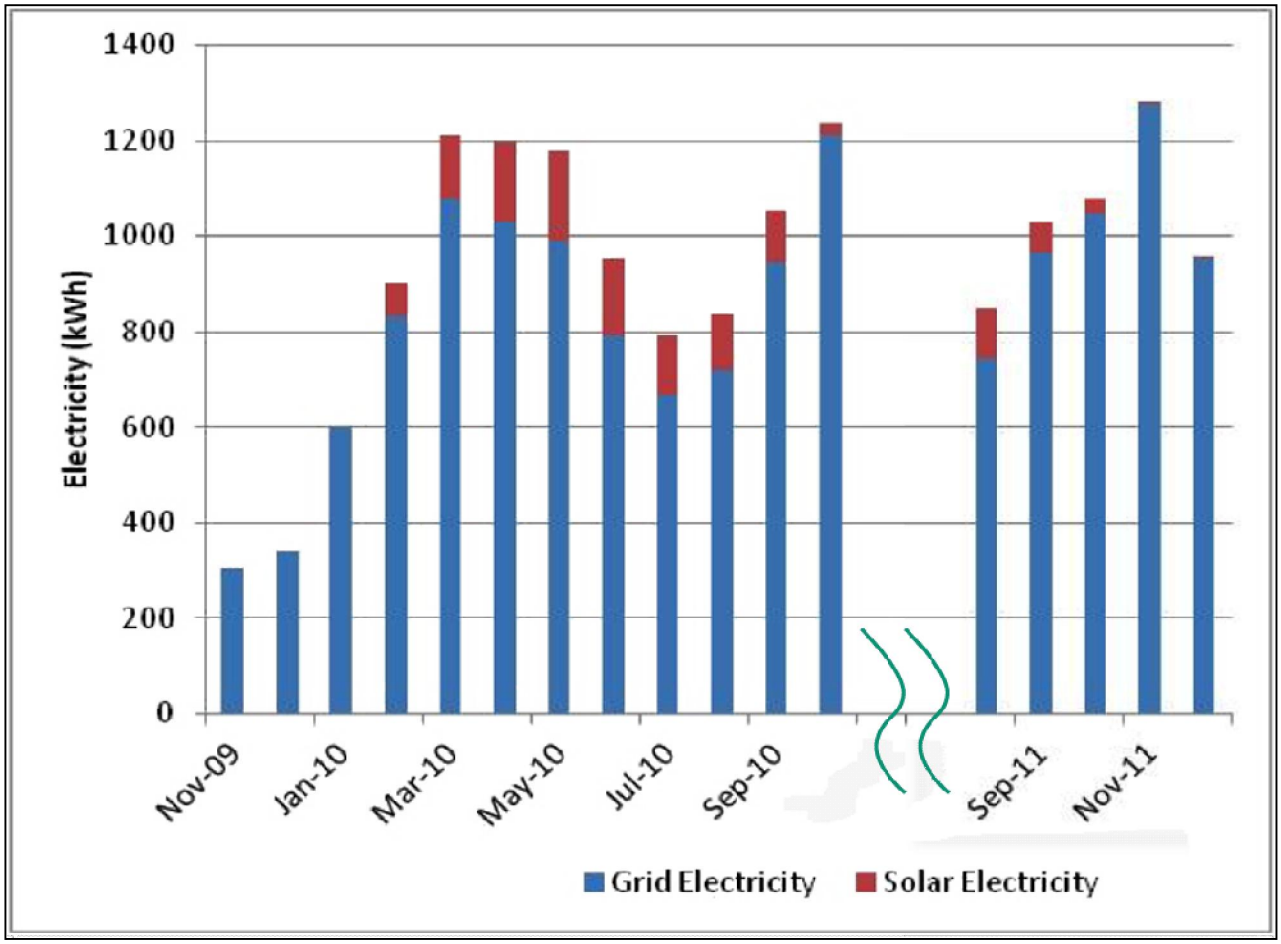

Figure 8. Electrical use for the Anaktuvuk Pass prototype house. The solar energy is included as part of the total monthly use, as it is also consumed by the house. The gap in the data is due to the switch to a new data monitoring system, which took from November 2010 until June 2011 to complete.

Solar Data

The electricity from the electrical utility (grid) and from the PV panels has been monitored by three different systems since October 2009. Monthly electrical demand and generation comparisons are summarized in Figure 9. As the chart shows, the electricity from the panels is a relatively small percentage of the electrical usage during the winter months, which corresponds to the time of highest usage. The photovoltaic panels offset the grid power by about 6% of demand on a yearly average. In the summer that percentage approaches 20% and the solar array can produce more electricity than the house consumes at certain times during the day (which is sent back to the grid).

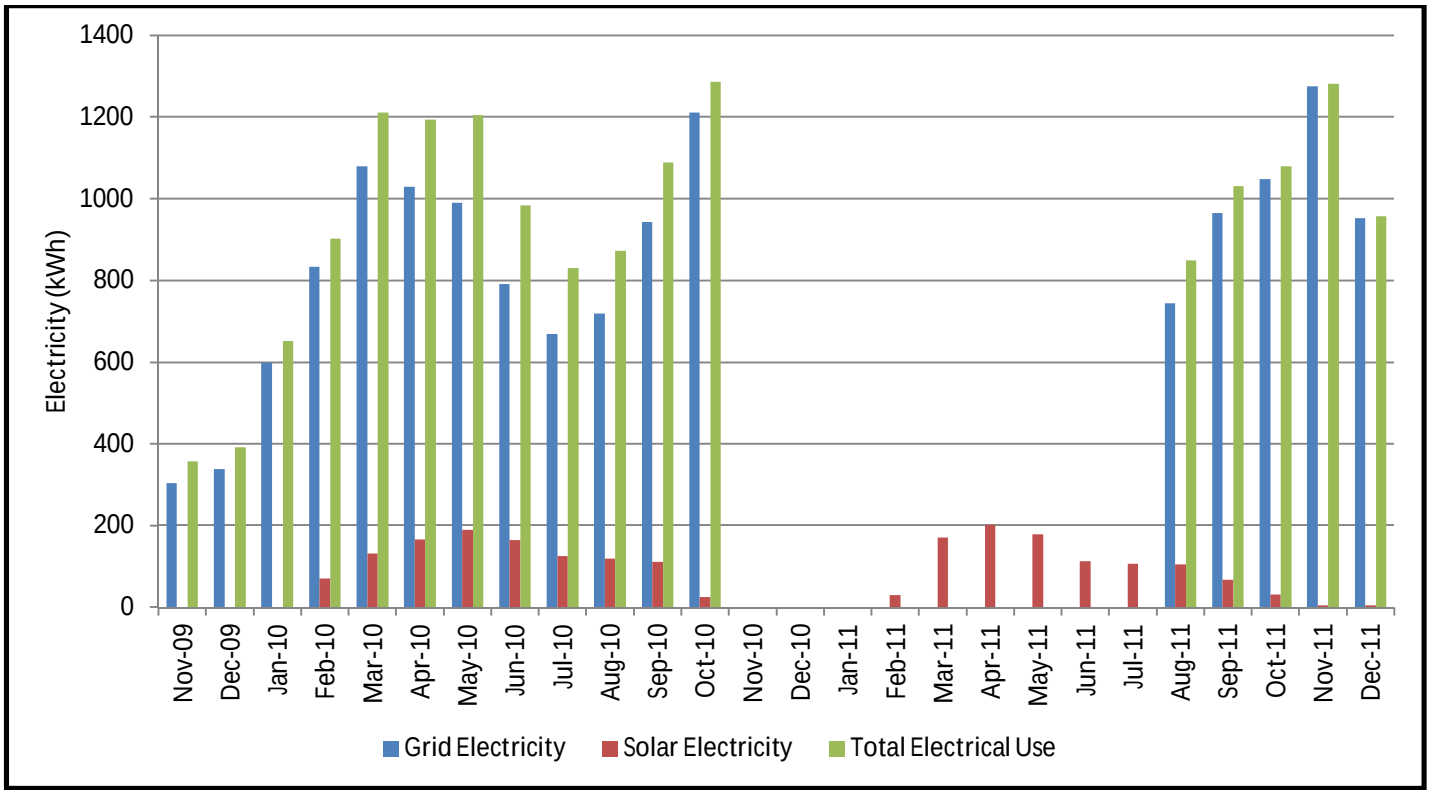

Figure 9. Electrical usage and source. The green bars represent the total amount of electricity used by the family living in the home. The blue bars are the amount of that electricity that came from the grid. The gap in grid use (Nov-10 to Aug-11) is due to a loss of data during transition to a new data monitoring system. The red bars represent the electricity from the PV panels. The accuracy of solar data prior to May 2010 is questionable due to the use of a less accurate monitoring system, which was replaced in May 2010.

Table 5 summarizes the solar electricity produced and the house electricity demand. At the current North Slope Borough electricity rates of $0.15 per kWh, the PV panels offset $189.46 in their first year (November 2009 to October 2010) and $31.97 in 4 months (August – December 2011). The PV panels have been running constantly even while they were not being monitored. Figure 10 shows the data from the Fronius inverter for some of the months that are missing from the replacement of the other datalogging system. From November 2010 through July 2011 the PV panels offset $120.05 (800 kWh). In 25 months the six panels have offset a total of $341.48 from the electrical bills at a total of 2276 kWh.

Table 5. The electricity usage for the three monitoring periods.

	November 2009 through October 2010	November 2010 though July 2011	August 2011 through December 2011
Solar Electricity Produced	1263.1 kWh	800.3 kWh	213.1 kWh
Electricity Purchased from Grid	9504.5 kWh	Not available	4984.5 kWh
Total Electricity Used	10976.4 kWh	Not available	5197.6 kWh

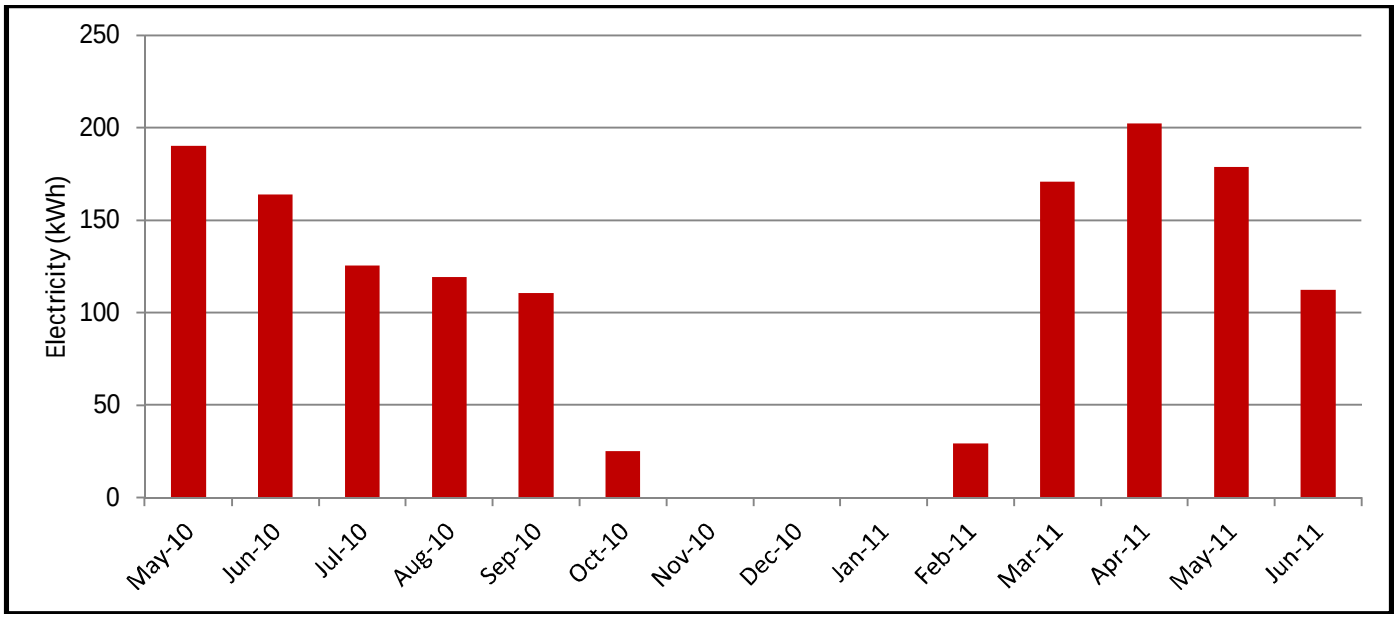

Figure 10. Solar electricity produced. The Fronius inverter also logs data on the electricity produced by the panels. This data is only available when someone is able to physically visit the site and retrieve the data.

Example Monthly Electrical Usage: September

September is the month of the fall equinox when the sun is between its maximum and minimum yearly values. In 2011, the equinox fell on September 22, meaning that the length of day and the night were approximately equal in length in Anaktuvuk Pass. Figure 11 shows the amount of electricity that was used and produced each day in September. The solar contribution during September averages 2.2 kWh per day, and the total for this month is 66.8 kWh. The solar electricity offsets the family usage slightly in September.

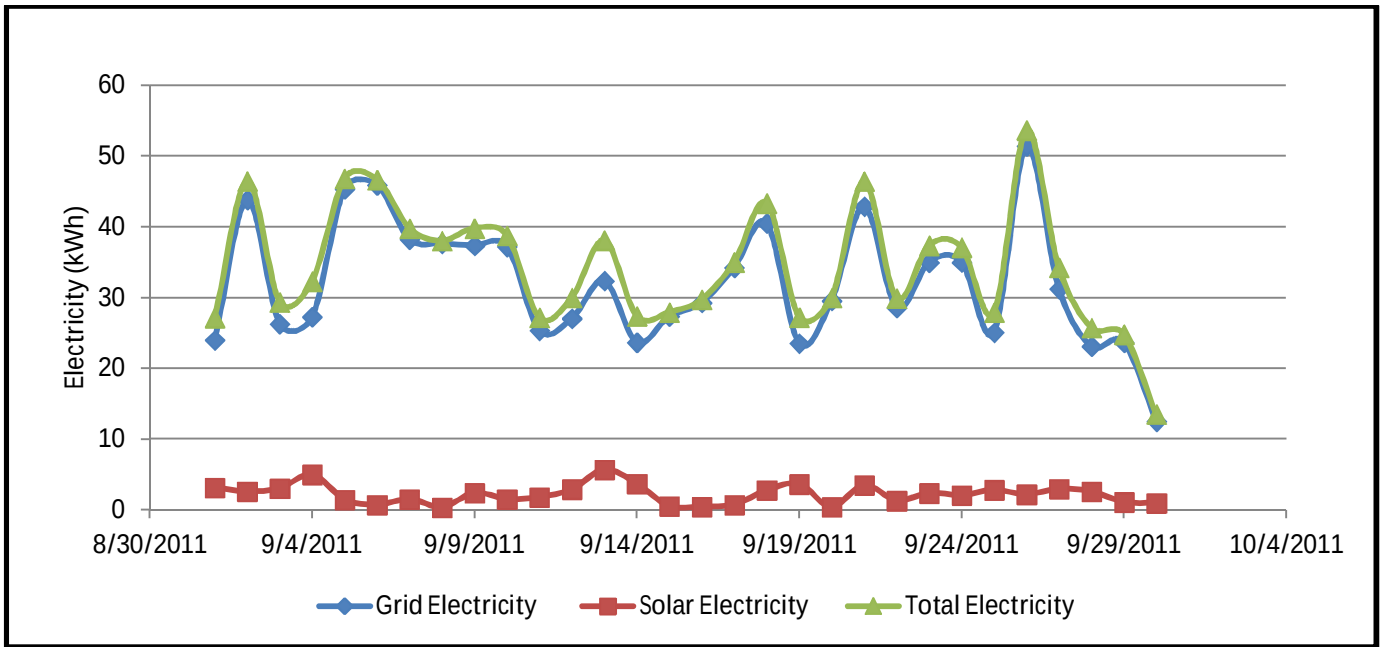

Figure 11. Daily electrical demand and production for September 2011. The red line represents the amount of electricity produced by the PV panels each day. The blue line is the electricity from the grid (that the family paid for), and the green line is the total electricity used by the family.

Examples for Daily Electrical Usage

Looking at the hourly average electrical usage and production each day provides examples of times when the PV panels put electricity back into the grid. For example, on August 8, 2011 electricity flows from the house back into the electrical grid at approximately 12:00 and 2:00 pm. Figure 12 shows the electricity from the PV panels (red line) rising above the amount of electricity used by the family (green line).

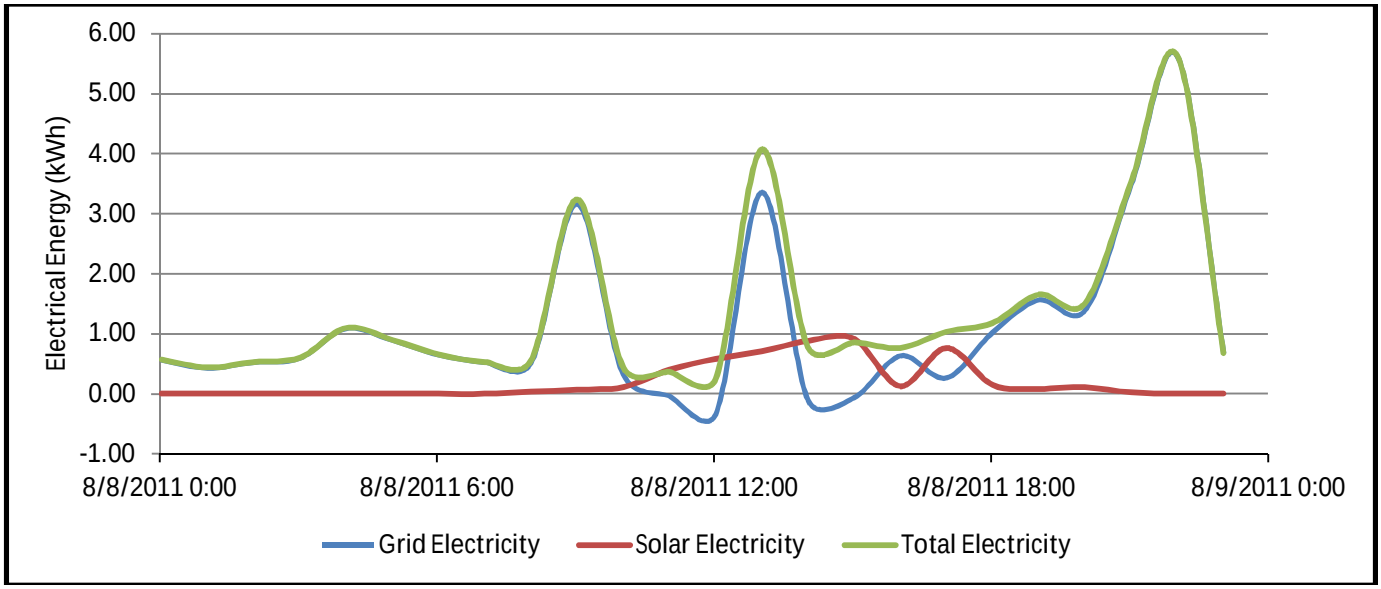

Figure 12. Electrical usage for August 8, 2011. The electricity from the PV panels (red line) rose above the total amount of electricity used by the family (green line). The blue line drops below zero because electricity is flowing into the grid from the house, instead of from the grid to the house.

Two months later, the same situation occurs, although less sunlight is available. Figure 13 shows the hourly average electricity production and usage totals for October 6, 2011. Even though this day is after the equinox, Figure 13 demonstrates that surplus solar electricity is produced during mid-day. In fact, the extra solar electricity does flow back into the grid because the family is not using that much electricity at that time.

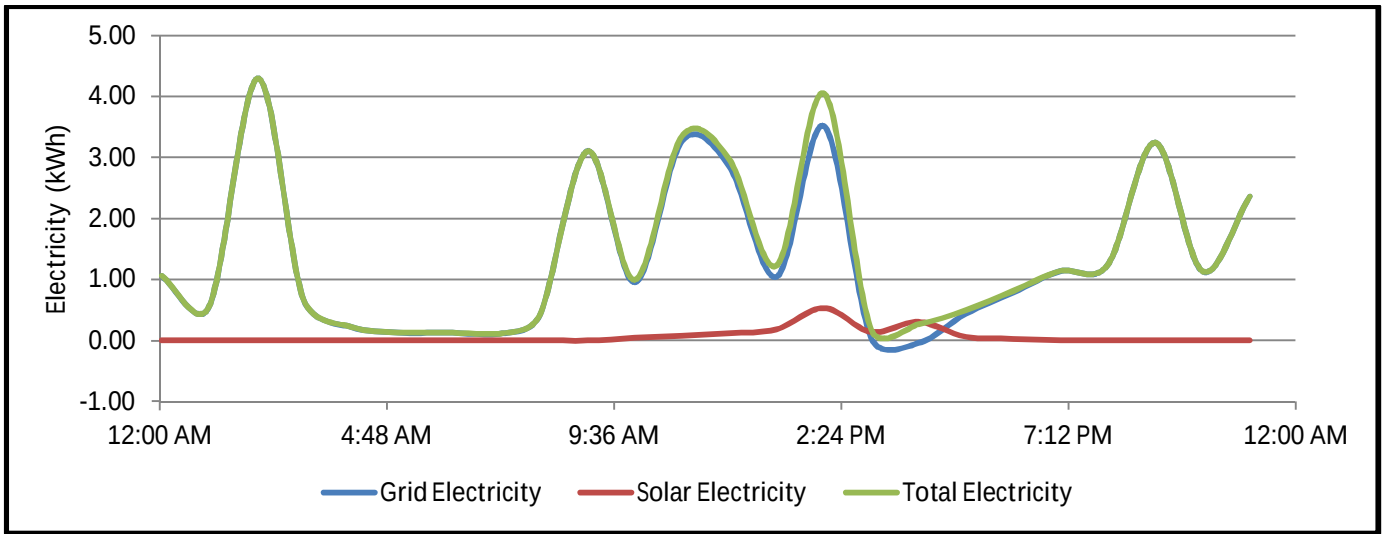

Figure 13. Electrical usage for October 6, 2011. The electricity from the PV panels (red line) rose above the total amount of electricity used by the family (green line). The blue line drops below zero because electricity is flowing into the grid from the house, instead of from the grid to the house.

Wind Data

The wind turbine only worked for a brief time. At the height of its operation it produced 42.2 kWh in July 2010. Figure 14 shows the monthly averages for electricity from the wind turbine. It was not functioning prior to April 2010 and stopped working in August 2010.

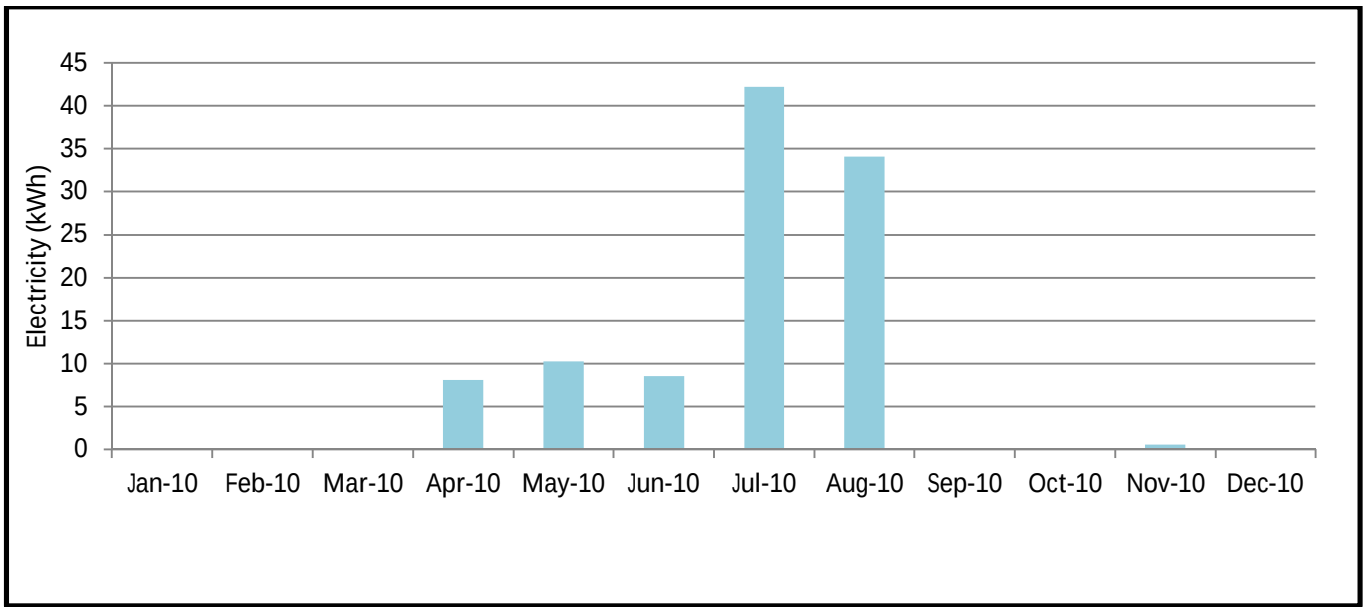

Figure 14. Electricity produced by the wind generator system. Prior to April 2010 and after August 2010 the system was not functioning due to a variety of problems (see Table 3).

The average wind speed during this window of operation was 3.8 m/s (8.5 mph) (Figure 15). At 3.8 m/s the turbine should be producing about 275 kWh per year; its amp output does not even register at this wind speed (Figure 7 bottom graphs).

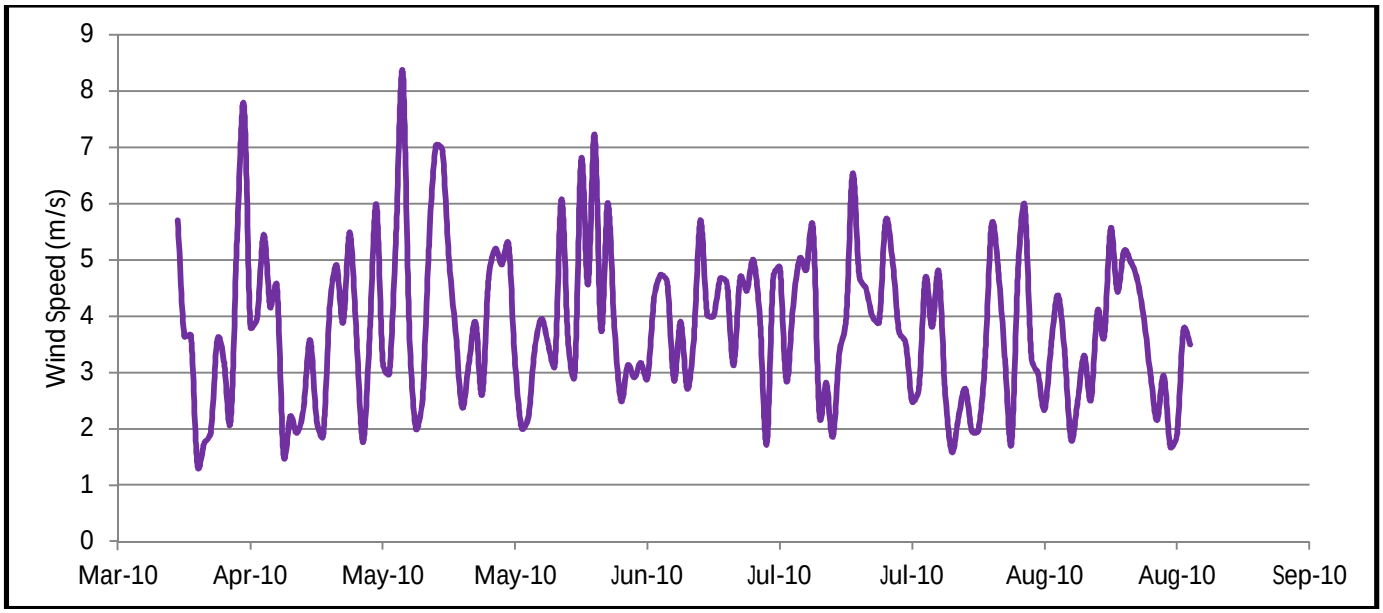

Figure 15. Wind speed while the turbine was working. The wind at the Anaktuvuk Pass prototype house consistently averages around 4 m/s, which is a marginal wind resource.

Figure 16 shows the correlation between wind speed and amperage produced from April to August 2010. The system started working on April 22, 2010, when YRITWC discovered an error in the set-up for the inverter. Judging from the data, the system was not up to full power until July and August 2010. From July 2010 to the end of August 2010 the turbine was producing the amperage that meets the specifications for this turbine at those wind speeds (see Figure 7 bottom graphs). The system abruptly stopped working in August 2010, when a circuit board in the power rectifier shorted out during a maintenance visit.

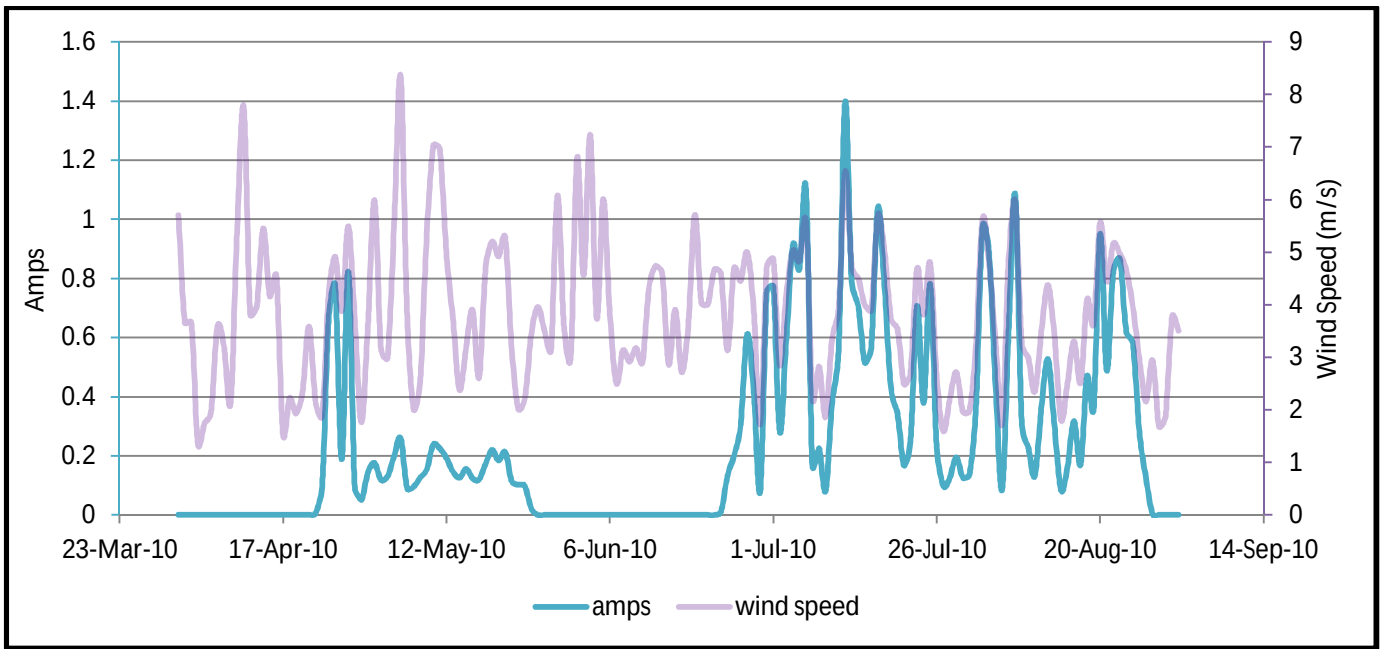

Figure 16. Wind speed and amperage for the wind generator. From March to mid-April 2010, no power was being produced by the turbine. In April 2010, the turbine started functioning following work on the operating parameters. In July and August the wind speed and amperage produced correlate well to each other and to the manufacturer specifications (Figure 7). Turbine stopped working at the end of August.

System Observations

Comparison of Power Production Based on Array Tilt

The PV panels are mounted on adjustable aluminum racking that enables the user to vary the tilt of the panels between approximately 53 and 90 degrees from horizontal. The racking is composed of Unirac SolarMount rails, 2”x2”x3/16” aluminum angle, and 1-7/8” Unistrut metal framing. The racking is easily adjusted by removing six sets of bolts from the Unistrut standoffs. Figure 17 shows the tilting positions of the solar array. Seasonally adjusting the arrays enables the homeowner to maximize solar radiation and PV power production. If the panels are tilted to 53 degrees (tilt based on latitude) from horizontal from April through September, the amount of solar radiation absorbed by the panels can be maximized. If the panels are not adjusted from this position in the winter, any snowfall would shade the panels, rendering them unable to produce power.

Figure 17. Solar array adjustable positions. The array can be tilted to 53 degrees from horizontal (as shown on left) to maximize solar radiation during the months without snow. The array can be tilted to 90 degrees from horizontal (as shown on right) to reduce snow cover on the panels and to maximize solar radiation during the months with snowfall.

If the panels are tilted to 90 degrees from horizontal during the winter, they can maximize the solar radiation from the low sun angle from October to April. Additionally, they can generate significant power by capturing the sun reflection off the snow in early spring months (Colgan, Wiltse, Lilly, LaRue & Egan, 2010). Snow accumulation on the panels is minimized in this position; however, accumulation must be removed manually using a long-handled brush or broom. The panels should be adjusted back to 53° in April in order to maximize the power generation in the summer.

The anticipated solar energy produced by the proposed system was calculated using *PVWATTS* and is summarized in Table 6 (PVWATTS, 2012). The estimated results are based on the modeled solar radiation data and assume no solar obstructions unless noted. The effect of array positioning on the potential power production is evident in Table 6. The amount of power generated depends largely on seasonal tilt and whether snow is removed from the panels by the homeowner. As Table 6 demonstrates, adjusting the array tilt twice a year and keeping it snow-free allows the system to generate about 1,006 kWh per year. Fixing the array at 90 degrees year-round and not removing the snow will reduce production to about half as much (566 kWh per year).

Table 6. Estimated annual power production of solar array (kWh) depending on array tilt and snow cover. (PVWATTS, 2012).

Array Configuration	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
90 degrees year round with snow removal	6	53	120	141	111	84	79	77	74	67	31	0	843
90 degrees year round no snow removal	0	0	0	141	111	84	79	77	74	0	0	0	566
53 degrees year round with snow removal	5	48	121	158	144	127	117	102	81	64	25	0	992
53 degrees year round no snow removal	0	0	0	158	144	127	117	102	81	0	0	0	729
53 degrees April-September 90 degrees October-March with snow removal	6	53	120	158	144	127	117	102	81	67	31	0	1006
53 degrees April-September 90 degrees October-March no snow removal	0	0	0	158	144	127	117	102	81	0	0	0	729

The PV panels are fixed facing south, if they were to track the sun there would be an increase in direct solar radiation. For single-axis (azimuth only) tracking systems, the direct solar radiation increases by about 30% compared to fixed-azimuth, fixed-tilt systems. For dual-axis tracking systems, the direct solar radiation increases by about 46% compared to fixed-azimuth, fixed-tilt systems. (PVWatts, 2012)

Wind Generator Evaluation

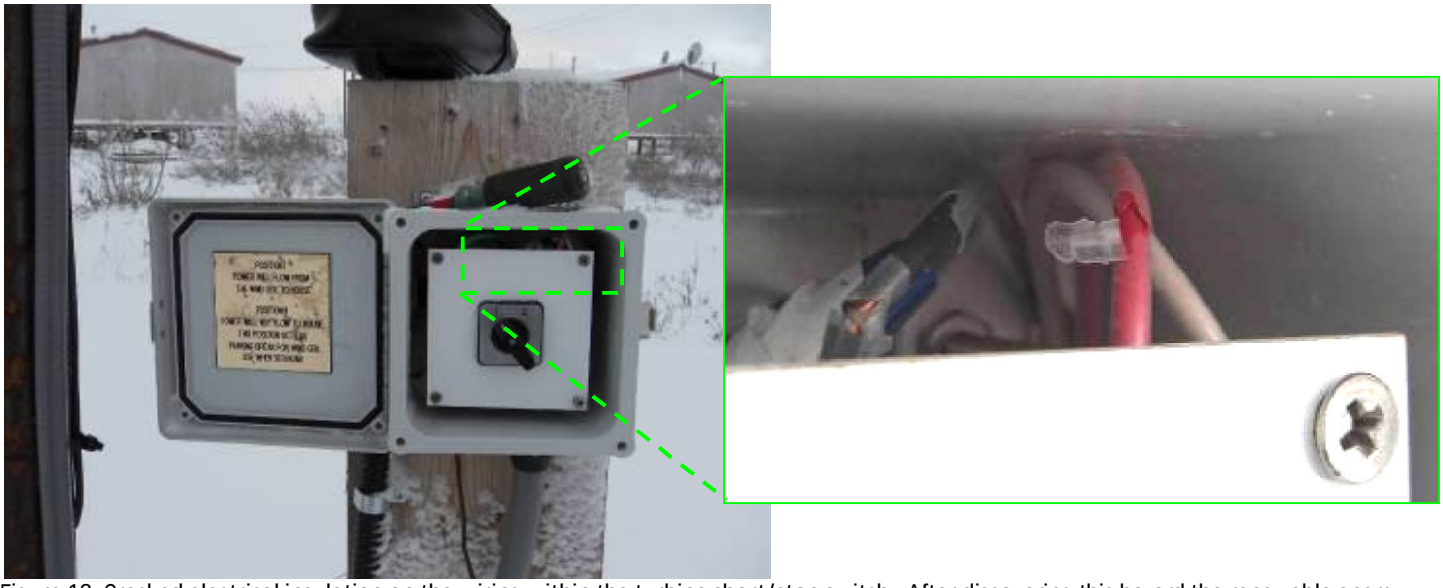

Figure 18. Cracked electrical insulation on the wiring within the turbine short/stop switch. After discovering this hazard the renewable energy professional shut down the wind turbine until the wiring and any potential short in the system could be repaired.

Remote Power Inc., a Fairbanks renewable energy systems company, inspected the installation of the wind turbine in November 2010 and suspected an electrical short somewhere in the system between the wind turbine and the short switch, most likely at the top of the tower (refer to the "Exterior Switch" in Figure 5). Additionally, they found that the electrical insulation on the wiring within the electrical short switch has cracked or fallen completely away from the

wiring. A photograph of this cracked wiring is shown in Figure 18. This condition provides an electrical hazard to those working on the system and could contribute to the detriment of the turbine power output. For safety reasons, the electrical stop switch was engaged and the turbine has been inactive ever since. Currently, the system is disabled and YRITWC has no plan in place for correcting the known problems.

Future of the Wind Installation

Wind speed data collected by CCHRC indicates the average wind speed at the prototype home is approximately 4 m/s (9 mph). Other turbines were investigated as possible alternatives to the one installed with the prototype home and a summary of these findings is presented in Table 7. This table shows the predicted annual energy output (based on manufacturers' claims). There are options for grid-tied turbines that can produce more energy than the existing turbine in Anaktuvuk Pass. However, before a different turbine would be selected for Anaktuvuk Pass further analysis of the actual site and an economic assessment of the potential payback of such a replacement should be considered. An economic analysis of the current system was not done, as there was not detailed accounting of the time and labor that went into this project. Prices are not estimated for this table either as shipping, time, and labor have not been well documented. At the present time there are no plans to install a different turbine.

Table 7. Comparison of various small-scale wind turbine options (Woofenden, 2011).

Model	600-230	600-24	XL.1	Whisper 200	1.3	e300i	Xzeres 110	Skystream 3.7	e400i	3.5	Whisper 500
Manufacturer	Ampair	Ampair	Bergey Windpower	Southwest Windpower	Raum	Kestrel	Xzeres	Southwest Windpower	Kestrel	Raum	Southwest Windpower
Swept Area (sq. ft.)	24.43	24.43	53	63.5	73	76	110	113	135	135	176
Predicted Annual Energy Output (kWh) at 9 mph average	310	750	610	1,121	1,110	1,315	2,274	1,373	2,781	3,213	2,139
Grid-tie or battery	grid-tie	battery	battery	battery	grid-tie	battery	grid-tie	grid-tie	grid-Tie	battery	battery

User Satisfaction

In December 2011 CCHRC conducted an informal interview with the Burris family, who now own and occupy the Anaktuvuk Pass prototype house. CCHRC was most interested in how the family has taken ownership of the wind and solar systems and how they interact with them.

Overall, the Burris family is happy with the solar PV system. They like the "set-it-and-forget-it" approach that one can take with the PV system. They are satisfied with the interior and exterior aesthetics and are happy with its quiet performance. Any change in their utility bills is not readily noticeable since they've always had the PV system contributing to their power supply in this house.

The only work that is required of them for general use of the PV system has been to keep the panels free of snow and to maximize the solar PV production by tilting the panels on a semi-annual basis (see Appendix A, maintenance guide). The Burris family tends to keep the panels free of snow during the time when the sun shines on them. This maintenance task is not absolutely necessary for maximum power production in December and January because the valley does not see

direct sunlight for about 8 weeks. The homeowners have not performed the suggested semi-annual task of adjusting the tilt of the panels. It seems that the process of moving the panels is more difficult than desired - an additional person on an extra ladder is required to safely adjust the panels. Since the effort is not required for the functionality of the PV panels, it is considered to be a low-priority task on their maintenance list. As of November 2011, the PV panels were fixed to 90 degrees from horizontal year-round. In order to get the most electricity out of their PV panels in a fixed location the homeowners should move them to the fixed 53 degree position (see Figure 19). With the exception of occasional snow removal from the panels, minimal interaction is required of the homeowners for the operation of the system.

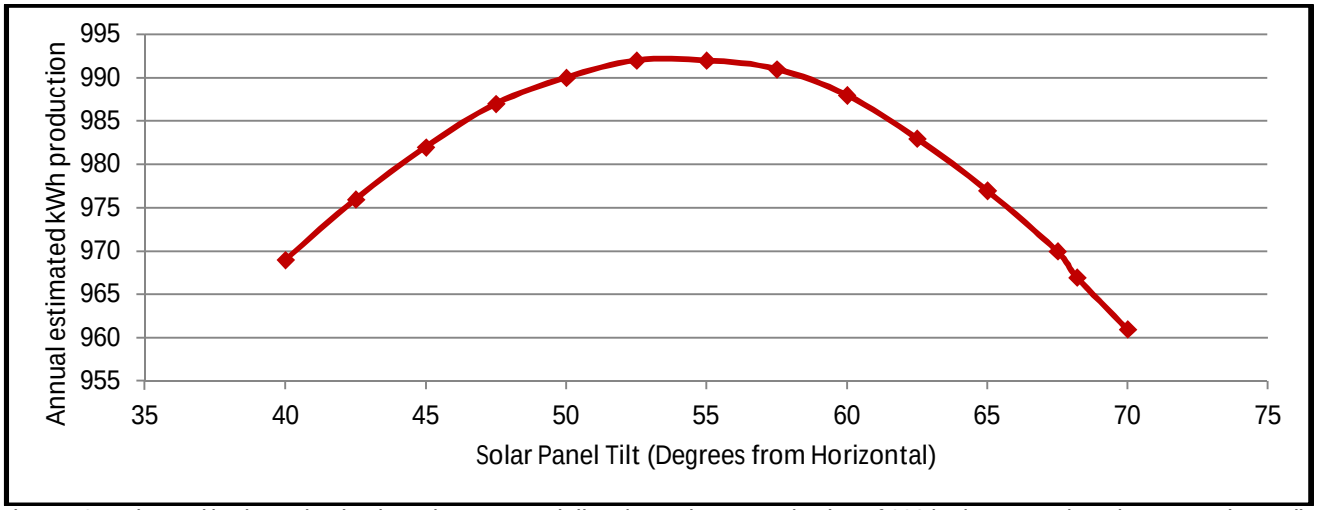

Figure 19. Estimated kWh production based on PV panel tilt. The optimum production of 992 kWh occurs when the PV panels are tilted between 52° to 55° from the horizontal.

The homeowner is aware of which electrical enclosure is the PV inverter and has a solid understanding of how the system works and how the power can be potentially fed back into the grid. They have reviewed data from the solar system both from the private website that GW Scientific set up and from the data presented to them by CCHRC that summarizes the PV production.

The Burris family would like to see a functioning wind system for the home. They are disappointed that the system does not produce power. The average wind speed appears to be around 4.2 m/s (about 9 mph). *Home Power* magazine lists the output of several small wind turbines and their corresponding manufacturers predicted annual energy output at 8 mph that ranges from 420 kWh to 2,021 kWh for turbines with a swept area of 135 sq ft or less (Woofenden et al, 2011). Knowing that several turbines are available with such electrical outputs, the Burris family would like to consider installing a turbine that functions. They have expressed a willingness to perform the necessary yearly maintenance required for proper functioning. The wind turbine requires an annual preventative maintenance of the turbine to lower the tower and inspect the turbine housing and blades for cracks, burn marks, or other wear and tear as well as to lubricate the bearings (see Appendix A, maintenance guide). This maintenance requires that the tower be lowered; however the tower has not been lowered since its initial installation.

Lessons Learned

The combined wind and solar energy system in the Anaktuvuk Pass prototype house can serve as a learning prototype just as the house itself has been an instructive prototype. The project itself was a learning opportunity for all of the partners involved. CCHRC, along with YRITWC, GW Scientific, and Remote Power have put together a comprehensive list of the lessons learned, from broad lessons on remote residential power to detailed lessons on small technical issues.

This section compiles and synthesizes the lessons project partners learned over the course of designing, installing, operating, and maintaining a combined small-scale wind generator and solar PV system at the Anaktuvuk Pass prototype home. While these lessons were derived from the actual experience on this specific project, many of the lessons will serve others well in their consideration of applying small-scale wind and solar PV systems across Alaska.

This report addresses social and technical issues related to combined residential wind and solar energy. In general the solar system in Anaktuvuk Pass is very technically feasible and appropriate for the geographic location. The technical feasibility of the wind generator is unknown and the system may not be appropriate for the geographic location. Further study on the economic feasibility of such systems is needed to provide a broader picture of the overall potential of residential-scale renewable energy systems in rural Alaska.

Combined Wind and Solar Energy System

There are several lessons that are general to residential renewable energy systems in rural Alaska. These lessons originate from both the successes and difficulties encountered over the course of this project.

Key Lesson: Thoroughly research the potential renewable energy systems before deciding on a system
Ensure that the available technology complements its use in a rural Alaskan community and that it also complements the amount of renewable resources available. Ascertain that the maintenance required for the system use agrees with the willingness of the homeowner to follow through on these tasks.

Key Lesson: Review the complete system before shipping it to a remote location
Assemble the complete system before going out to install, which will prevent the need for multiple trips. Having a renewable energy expert review the design and components before shipping them out will help ensure that all the components are present and are compatible. Purchasing all equipment through a single vendor can also help ensure the compatibility of components.

The general lessons for this project come from the large amount of time that YRITWC spent working to get the solar PV and wind systems functioning. The intent of these lessons would be to lower the time and cost of the installation of the systems.

Solar PV System

Overall, the strong performance of the Anaktuvuk Pass solar PV system and the ease of use blend well together and show potential for such a system in remote locations. Many of the key lessons originate from the successful installation and performance of the solar PV system.

Key Lesson: Evaluate the geographic setting and site location for the potential resource
The Anaktuvuk Pass prototype house is ideally situated for a solar PV system. The average annual solar resource for Anaktuvuk Pass is higher than many other parts of Alaska. Table 8 compares the annual solar radiation values for various locations throughout Alaska. The values are based on the tilt of the array (degrees from horizontal) being the same as the latitude of the geographical location. The insolation for Anaktuvuk Pass is higher than most other locations listed, due more to cloud cover than to latitude. The higher-than-average solar resource in Anaktuvuk Pass coupled with the location of the house within the village, in an area with clear southern exposure, makes the prototype house a viable location for solar PV. A well-shaded area or a location with a rainy climate is less ideal for solar PV installations.

Table 8. Average annual insolation data compared to various locations across Alaska.

Location	Latitude (Deg N)	Insolation (kWh/m2/day, sun-hours/day)
Anaktuvuk Pass	68.2	3.4
Anchorage	61.2	3.0
Annette Island	55	3.0
Barrow	71.3	2.5
Bethel	60.8	3.1
Bettles	66.9	3.2
Big Delta	64	3.4
Cold Bay	55.2	2.4
Fairbanks	64.8	3.3
Gulkana	62.2	3.6
King Salmon	58.7	3.0
Kodiak	57.8	3.1
Kotzebue	66.9	3.2
McGrath	63	3.2
Nome	64.5	3.3
St. Paul Island	57.2	2.5
Talkeetna	62.3	3.3
Yukatat	59.5	2.7

Key Lesson: Communicate with the future owners and users of the system throughout the design and install process
Understanding the motivations and objectives the future owners and users have for their energy system will help drive the design of the system. Communicating the maintenance needs of the system in advance will allow stakeholders to make informed decisions about which systems they are willing and able to maintain. The low maintenance requirements of solar PV make it attractive for rural locations that may not have access to electrical experts. While changing the tilt of the panels twice a year will increase the performance of the panels, it is not absolutely necessary for functionality of the system, as the system in Anaktuvuk Pass demonstrates.

Key Lesson: Integrate the design of the energy system into the original design of the house
Integration of the alternative energy systems into the design of the house will lead to lower cost and fewer setbacks when installing the system. Integration of wiring into the design of the prototype house would have led to less time wiring through the attic after the fact. The prototype house was designed with a sloped roof line, providing a large flat area on the south side of the house to mount the solar panels (see Figure 1).

Key Lesson: Solar PV is a technologically viable alternative in areas of rural Alaska with the potential resource
A review of the solar production data for 25 months shows that the six panels produced 2,276 kWh. At the subsidized electrical rate for the North Slope ($0.15/kWh), the savings is $341.48. The average unsubsidized rural village rate is $0.55 per kWh (AKWarm, 2011); at this typical rate the PV system would have offset $1251.80 in the 25-month period.

Wind Energy Generation System

The wind energy generation system at the Anaktuvuk Pass prototype house provided a wealth of lessons learned in residential wind systems. Even the lessons particular to the Anaktuvuk Pass project will be informative to potential users of residential wind energy generation systems.

Key Lesson: Enlist Expertise in System Design and Installation
The system design is the culmination of the strategies for addressing setting, site, beneficiary objectives, and installation. Enlisting an expert can help to optimize the system. Expert help with design and installation can minimize the need for repeated installation and maintenance trips to the site.

Key Lesson: Integrate the design of the energy system into the original house design
Ensure that the infrastructure will be in place to accept hardware for wind turbine systems. A system that returns energy to the local power grid needs to be connected to the grid correctly and the grid needs the ability to accept that energy. Integration of wiring into the design of the house would have led to less time trenching for the wire.

Key Lesson: The location of the house is an important factor in the design and installation of a system
The site of the home will be important in the choice of which systems to install and what hardware to use. The Anaktuvuk Pass prototype house is in the center of a residential area and has a small yard. Guy wires for the wind tower are not preferable in such a tight area; the guy wires at this location severely limit access and use of the backyard; a monopole tower is preferable, although the price of this option has not been evaluated. Consideration should be given to placing a tower in such close proximity to houses, power lines, and roads during the planning stages of the building construction project.

Key Lesson: Thoroughly research the potential wind resource before deciding on a system
The wind resource in Anaktuvuk Pass had not been studied prior to this installation, but a 2010 report states 5.15 m/s (11.5 mph), a marginal wind source (Vaught, 2010). Knowing the marginal average wind speed may have eliminated the wind part of the system from the start.

Key Lesson: Thoroughly research the potential wind energy systems before deciding on a system
The wind resource for Anaktuvuk Pass is adequate enough to produce 2-10 times more power than the currently installed wind turbine can produce (Table 6). At the time of installation, the models listed and data provided in Table 6 were not available. There will be better decisions on future projects of this nature with this data available. For instance, the long-term ability of the turbine to produce power is essential in order to produce power at rates that compare with current electrical utility rates. An off-grid turbine is different than a grid-tied turbine; most rural residential applications will probably be tied to the grid.

Key Lesson: Wind generator systems are complex and require more maintenance and troubleshooting
Most of the seven trips that YRITWC made to Anaktuvuk Pass were to troubleshoot the wind generator system. The energy specialist who visited the site was able to pinpoint several problems and fix a few items, but the system is still not functioning due to the complexity and cost of troubleshooting the problem in a remote location. A turbine also needs annual maintenance, which is more complicated than simply keeping the panels snow free, and involves lowering the 50 foot tower to access the turbine.

Key Lesson: Communicate with the stakeholders throughout the design and install process
The wind system is complex and requires some technical knowledge and willingness to maintain the system. It is important to be certain that the system is something that the stakeholders are committed to and are willing to maintain. Be sure it is something that makes sense at the location; for example, a family with small children may prefer to have a

backyard free of towers and wires. Ensure that the maintenance required for the system use complements the willingness of the homeowner to follow through on maintenance tasks.

.

Partners

The following organizations collaborated to help design, build, and study the Anaktuvuk Pass prototype house:

- Alaska Housing Finance Corporation (AHFC)
- Alaska State Museum
- Burris Family, House Residents
- Campbell Scientific, Inc. (CSI)
- Canada Mortgage and Housing Corporation (CMHC)
- Cold Climate Housing Research Center (CCHRC)
- Denali Commission
- EE Internet
- Geo-Watersheds Scientific (GWS)
- Ilisagvik College
- Lifewater Engineering Company (LEC)
- Nunamiut School, North Slope Borough
- Remote Power, Inc. (RPI)
- Tagiugmiullu Nunamiullu Housing Authority (TNHA)
- US Department of Energy, National Renewable Energy Laboratory (NREL)
- Village of Anaktuvuk Pass
- Yukon River Inter-Tribal Watershed Council (YRITWC)

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Colgan, R., Wiltse, N., Lilly, M., LaRue, B., Egan, G. (2010). Performance of photovoltaic arrays. Cold Climate Housing Research Center. Retrieved from http://cchrc.org/docs/snapshots/RS_2010-01_Solar_Photovoltaics.pdf

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For more information on the Anaktuvuk Pass prototype house visit

http://www.cchrc.org/anaktuvuk-pass-prototype-home

Appendix A

Home Maintenance Guide

The renewable energy system in Anaktuvuk Pass provides electricity using solar and wind energy. The system consists of four parts:

1) Solar photovoltaic (PV) panel array: The solar array consists of six panels mounted on the south-facing side of the house. Each panel is 62 inches by 32.5 inches and is capable of producing 175 Watts in standard test conditions.
2) Wind turbine: The wind turbine is located on the north side of the house. It has 3 blades and a swept diameter of 5.5 feet.
3) Inverters: Inverters for the solar array and wind turbine convert the direct current (DC) electricity from the solar panels and wind turbine to alternating current (AC) to be used by the house or sent to the Anaktuvuk Pass electrical grid.
4) System wiring: Wires are used to connect the PV panels and wind turbine to the inverters, and to connect the inverters to the house electrical system and the grid.

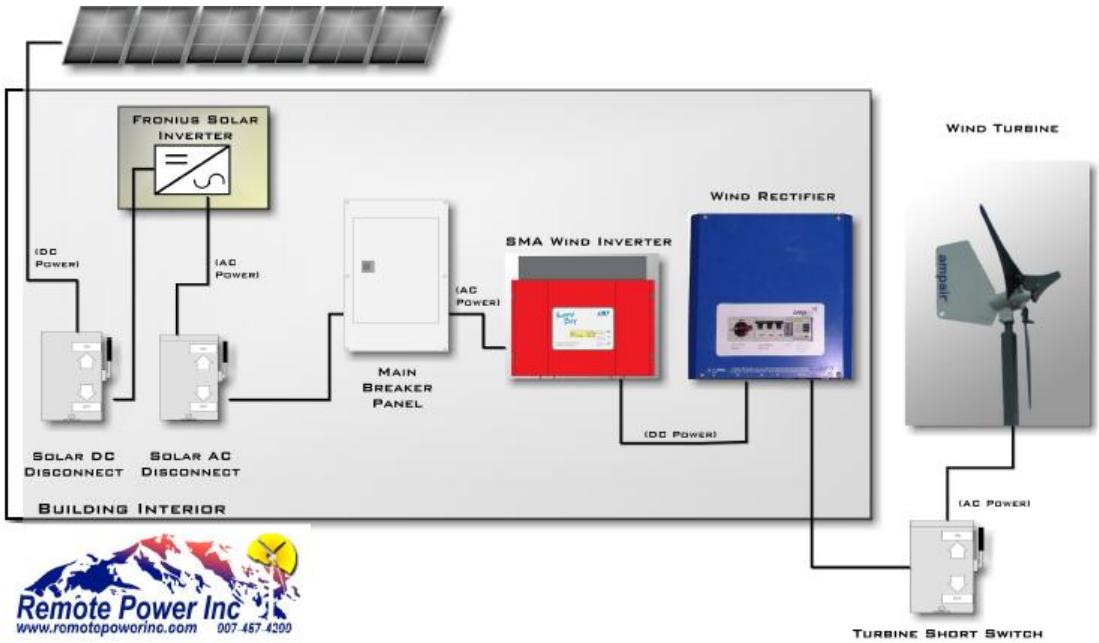

Figure 1. Schematic of the renewable power system in Anaktuvuk Pass

Proper system and component maintenance is important to keep a system functional and safe. Maintenance prevents breakdowns, keeps the system working at its highest efficiency, and helps homeowners become familiar with the system.

First and foremost, safety precautions should always be followed. Always read the manual for the system components before performing maintenance, and follow all safety advice. If any part of the maintenance instructions is unclear, the homeowner should consult a technician. Technicians and engineers that install and work on renewable systems are great resources. They can demonstrate proper safety technique and also advise the homeowner on how to perform maintenance.

This section contains some general safety tips and maintenance tasks for the system. Residents are encouraged to read this and also to consult appliance manuals and technicians.

Solar Panel Array

The PV panels are mounted on the front of the house, and do not contain any moving parts.

Figure 2. Solar panels before and after snow removal.

Safety: PV panels can be secured to a wall, roof, or mounted on a tall pole. If you need to ascend to a height to maintain them, take proper precautions to avoid falling. For instance, if you need to use a ladder to reach the panels, make sure the ladder is sturdy and properly balanced.
Maintenance Tasks: Maintenance for PV panels consists mostly of keeping the panels clean. If the PV panels are covered in dirt or snow, they will have very low electrical output. If they are covered in debris, snow, or dust, use a brush to wipe them off. During the summer, you can also use a water hose to spray them off or wash them with mildly soapy water.

Visual inspection each week:	• Check for snow, dirt or debris on the PV panels and brush off, if necessary
Each summer:	• Hose off the solar panel or clean with mildly soapy water if there is a prolonged period with no rain
Regular inspection once a year:	• Check that all cables and connections are secure • Check that the electrical meter is operating correctly • Check for rust in the panel mounting framework • Check for loose connections on solar panel mounting framework • Check for cracks, chips or discoloration in the panels

Wind Turbine

The wind turbine consists of the turbine blades and a tail atop a long mast that is anchored to the ground with guy wires. When performing maintenance on the wind turbine, it is important to follow safety guidelines because the moving parts of the wind turbine can injure people or break objects. Be sure to read the maintenance guide for the wind turbine before trying to take it down or repair it.

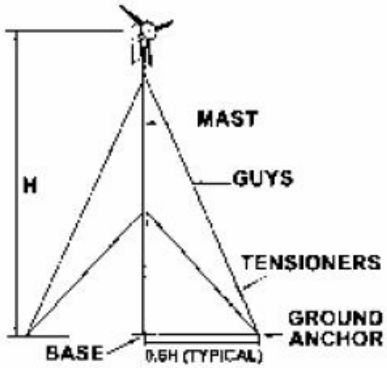

Figure 3. Parts of the wind system. Diagram courtesy of Ampair 600 manual.

Safety: It is very important to never touch the rotor blades or the tail while

they are moving. Also, do not use your hands to stop them from moving. Even at low speeds, the blades have the potential to seriously injure humans as they are very sharp, or they can throw debris from objects that have entered the rotating blades. When the rotor is stopped, always use gloves to touch the blades, as they are very sharp. Tying the blade off will prevent it from beginning to move while you are working on it.

If you are going to perform any work on the wind turbines, they should first be disconnected from the electric grid. Should they need maintenance, it is important to use caution in lowering the turbine from the mast and follow guidelines in the appliance manual on how to lower the turbine. If the blades or tail needs repair work, it is a good idea to call a technician to fix them, as they can show you proper safety techniques.

Maintenance Tasks: The maintenance guidelines include regular inspection and also investigation of unusual noise. Binoculars can be used to inspect components so that you can avoid taking the turbine down. If you find components are damaged, consult a technician to learn how to repair them.

Regular inspection each year (must be performed by lowering turbine tower):	• All blade fasteners • Center screw • Wind turbine blades for cracking or damage • Tail vane and fasteners • Pole mounting screws
After a storm or unusually windy weather:	• Blade fasteners • Wind turbine blades • Listen for vibration that may indicate the turbine is running out of balance

Inverters

The inverters do not require much maintenance but they should still be checked when maintenance is performed on other parts of the system. They should be installed in a clean, dry and ventilated area out of direct sunlight. Inverters can make a small noise when operating, so usually they are not installed in a living area.

Figure 4. Inverters should be kept clean and dry.

Safety: Do not take apart or disconnect the inverter without the installer or a technician present. The wires connected to the inverter carry electric current and can be dangerous to disconnect if not done properly.
Maintenance: The inverter should be kept clean. This mostly involves removing dust, which can be done using a dry cloth.

Every 6 months:	• Wipe off the inverter box with a dry cloth to remove dust • Visually inspect ventilation grills for signs of insects that might have gotten into the inverter • Check any LED indicators or displays on the inverter to make sure they are functioning correctly

System Wiring

The system wiring carries currents of 50 Amps and voltages of up to 60 Volts. The wiring carries electricity generated by the wind turbine and PV panels to the inverter. From the inverter, the electricity enters the electric grid to be used by the home or somewhere else in Anaktuvuk Pass.

Figure 5. Cracked wiring should be replaced by an electrician.

Safety: The wiring connections and any disconnected wires should only be handled by an electrician. Residents should not touch wires that become disconnected as they can cause electric shock. If wires have signs of corrosion or burning upon inspection, contact an electrician to identify and fix the problem.
Maintenance Tasks: The system wiring should not require any maintenance. However, it is a good idea to visually inspect the wiring when you check the rest of the system. This includes the wiring from the PV panels and wind turbine to the inverter and the wiring from the inverter to the house and the grid.

Every 6 months:	• Visually inspect wires to ensure they have no signs of corrosion, burning, breaks or deterioration

Sample Logbook

We also recommend keeping a maintenance logbook. A logbook should contain records of the type and frequency of maintenance performed, and who performed it. It can also contain records of system performance – dates for when the system was performing well, and when it is not. This type of logbook will provide a history of your system, which can be used to evaluate performance and to diagnose breakdowns or problems. It will also be useful if you need to use the

warranty for the system components. A sample log sheet appears below. Look in your maintenance manuals, as they may have one you can use, or feel free to make your own logbook with a computer spreadsheet or loose-leaf notebook to suit your system.

Date	Name	Maintenance Completed	System Performance Notes

Manufacturer Manuals

The Fronius Solar Inverter:
http://www.fronius.com/cps/rde/xbcr/SID-F3301004-7CBB28E4/fronius_usa/fronius_ig_usa_pre_IEEE1547_199194_snapshot.pdf

Ampair 600 Wind Turbine:
http://www.ampair.com/downloads/Ampair_600_manual_rev_July_2007.pdf

SMA Windy Boy 700-Watt Inverter:
http://www.sma-america.com/en_US/products/grid-tied-inverters/sunny-boy/sunny-boy-700-us.html

Sharp NT-175U1 Monocrystalline Panels:
http://www.sharpusa.com/SolarElectricity/SolarProducts/LiteratureDownloads_Archive.aspx