# ANALYSIS OF ELECTRIC LOADS AND WIND- DIESEL ENERGY OPTIONS FOR REMOTE POWER STATIONS IN ALASKA

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## ABSTRACT

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This report addresses the potential of utilizing wind energy in remote communities of Alaska. About 175 villages in Alaska are located beyond the reach of the central power grids serving the major urban areas. Instead, they are powered by diesel mini-grids. Along with the high cost of fuel delivery and bulk fuel storage tanks, these communities are exposed to environmental hazards associated with diesel generators, including the potential for fuel spills and the emission of greenhouse gases and particulates. To address these issues, Alaska energy representatives are looking to renewable energy technologies, particularly wind-diesel hybrid power systems.

In order to determine the economic and technical feasibility of a wind-diesel system, computer modeling of the different power system options must be done. Two primary pieces of information are essential in accurately modeling the expected performance of a wind-diesel hybrid system: the village electric use patterns and the local wind resource. For many Alaskan villages, this information is not readily available. The purpose of this report is to present methods used to obtain both wind resource and electric load data in villages. The Alaska Village Electric Load Calculator, a simple spreadsheet, was created to assist in estimating hourly load data and is available for public use. Case studies are presented to illustrate how this information is used in modeling hybrid wind-diesel options for remote Alaskan villages.

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# INTRODUCTION

Alaska is the nation's largest state, covering almost 572,000 square miles, but has one of the smallest populations with less than 627,000 inhabitants. Half of the population lives in Anchorage and surrounding area. Another quarter live in one of the five "railbelt" boroughs connected by the Alaska railroad. The remaining quarter live in isolated villages scattered across the state. These remote communities are the focus of this report. The economy in these remote villages is heavily dependent on fishing and subsistence activities. Most employment in the villages is seasonal, with the majority of jobs provided in the summer by fish processing, construction, mining, tourism, and fire fighting. Year-round jobs are provided by the school, city government, health clinic and Village Corporation. Many families supplement their income with trapping or native crafts, and often travel to fish camps during the summer. Growing economic sectors include tourism, construction, transportation, communications, and retail trade. The average unemployment rate in the AVEC villages is 24%. The average median household income is $29,400 (Dept of Community and Economic Development, May 2004). Transportation to most villages is restricted to boat or airplane. Snowmobiles, all-terrain vehicles, and riverboats are used for local transportation.

## Background on Energy Use in Alaskan Villages

More than 118 independent utilities provide electricity to an estimated 620,000 people in Alaska, covering a geographically, economically, and culturally diverse range of communities (Alaska Energy Authority, Sept 2003). Due to the rugged terrain and lack of a roadway system, supplying rural Alaskan communities with affordable electricity is a challenge. Many of the ports along the coast and interior rivers are only accessible a few months out of the year. Over 200 villages are beyond the reach of the power grids serving the major urban areas (Drouihet, 2002). Instead, many rural villages are powered by diesel mini-grids of up to 3 MW in capacity.

Most of the electric utility data used in this study was provided the Alaska Village Electric Cooperative (AVEC), a non-profit rural electric utility based in Anchorage. This report is based on the 51 member communities that AVEC serves. The AVEC member communities range in size from 100 to 1100 residents and total about 20,000 people. The villages span the central and western part of the state, from Kivalina in the North to Old Harbor in the South, with temperature extremes ranging from –65° to 93°F.

Each village maintains its own isolated electric mini-grid powered by three to five diesel generators. In some cases a village power plant supplies electricity to a neighboring village. For example, Kasigluk receives most of its electricity from the Nunapitchuk plant but maintains a smaller generator for peak usage and would like to install its own power plant in the future. Each village power plant employs a number of local certified diesel operators. Table 1 lists characteristics of the AVEC power stations. Feasibility studies will be presented for the villages highlighted in **bold**.

**Table 1. Characteristics of AVEC Power Stations**

| Village Name | Village Population | 2002 Energy Use (MWh) | Ave kWh/day | Ave Load (kW) | Peak Load (kW) | Fuel Storage Capacity (gal) |
|---|---|---|---|---|---|---|
| St. Mary's/ Andreafsky | 782 | 2,838 | 7,774 | 324 | 586 | 132,000 |
| Mt. Village | 757 | 2,592 | 7,101 | 296 | 531 | 195,400 |
| Selawik | 778 | 2,521 | 6,906 | 288 | 531 | 76,600 |
| Emmonak | 745 | 2,515 | 6,892 | 287 | 492 | 167,300 |
| Nunapitchuk/ Kasigluk | 1,039 | 2,442 | 6,691 | 279 | 495 | 174,900 |
| Togiak | 804 | 2,398 | 6,571 | 274 | 479 | 149,500 |
| **Hooper Bay** | **1,075** | **2,382** | **6,525** | **272** | **519** | **156,700** |
| **Chevak** | **854** | **2,184** | **5,984** | **249** | **501** | **134,700** |
| Noorvik | 677 | 2,130 | 5,836 | 243 | 455 | 138,800 |
| **Gambell** | **639** | **1,984** | **5,435** | **226** | **424** | **148,400** |
| **Savoonga** | **686** | **1,880** | **5,152** | **215** | **366** | **125,700** |
| Pilot Station | 546 | 1,698 | 4,651 | 194 | 371 | 91,100 |
| Shishmaref | 589 | 1,655 | 4,534 | 189 | 354 | 209,100 |
| Alakanuk | 659 | 1,653 | 4,530 | 189 | 354 | 121,800 |
| Quinhagak | 572 | 1,551 | 4,248 | 177 | 367 | 102,000 |
| **Kiana** | **399** | **1,502** | **4,116** | **171** | **333** | **112,500** |
| Noatak | 455 | 1,471 | 4,031 | 168 | 336 | 92,000 |
| Shungnak/ Kobuk | 358 | 1,468 | 4,023 | 168 | 327 | 72,300 |
| Stebbins | 586 | 1,378 | 3,776 | 157 | 328 | 104,900 |
| Elim | 339 | 1,249 | 3,422 | 143 | 269 | 66,000 |
| **Toksook Bay/Tununak** | **872** | **2,088** | **5,720** | **238** | **461** | **169,300** |
| St. Michael | 390 | 1,234 | 3,382 | 141 | 259 | 97,100 |
| Lower & Upper Kalskag | 508 | 1,220 | 3,342 | 139 | 261 | 94,500 |
| New Stuyahok | 479 | 1,193 | 3,267 | 136 | 281 | 82,400 |
| Ambler | 295 | 1,181 | 3,234 | 135 | 298 | 98,600 |
| Kivalina | 383 | 1,174 | 3,217 | 134 | 263 | 92,400 |
| Koyuk | 329 | 1,164 | 3,188 | 133 | 260 | 69,700 |
| Nulato | 345 | 1,140 | 3,123 | 130 | 235 | 112,100 |
| Marshall | 364 | 1,083 | 2,968 | 124 | 224 | 76,300 |
| Scammon Bay | 491 | 1,033 | 2,829 | 118 | 234 | 52,400 |
| Huslia | 285 | 899 | 2,463 | 103 | 208 | 64,800 |
| Shaktoolik | 218 | 866 | 2,373 | 99 | 207 | 113,400 |
| **Mekoryuk** | **204** | **848** | **2,322** | **97** | **179** | **81,500** |
| Russian Mission | 328 | 800 | 2,192 | 91 | 194 | 56,000 |
| Brevig Mission | 307 | 784 | 2,147 | 89 | 172 | 47,200 |
| Old Harbor | 229 | 750 | 2,055 | 86 | 155 | 39,800 |
| Holy Cross | 232 | 732 | 2,006 | 84 | 169 | 75,600 |
| Kaltag | 223 | 715 | 1,958 | 82 | 163 | 91,800 |
| Goodnews Bay | 234 | 699 | 1,915 | 80 | 160 | 62,900 |
| Eek | 291 | 684 | 1,873 | 78 | 159 | 65,700 |
| Minto | 229 | 681 | 1,866 | 78 | 172 | 41,200 |
| Nightmute | 224 | 561 | 1,537 | 64 | 164 | 42,600 |
| Wales | 159 | 524 | 1,436 | 60 | 139 | 51,000 |
| Grayling | 192 | 510 | 1,399 | 58 | 125 | 64,700 |
| Anvik | 109 | 437 | 1,198 | 50 | 104 | 51,800 |
| Shageluk | 145 | 410 | 1,124 | 47 | 82 | 109,300 |

As services increase in rural areas of Alaska, the need for electric power also increases. To meet these needs, the companies and organizations that provide service to rural communities must expand generation capacity. The expansion of these services result in two clear difficulties for energy suppliers: energy cost and diesel fuel availability.

Rural areas of Alaska already experience high energy costs, part of which is met with subsidies from the state government. The average residential electric rate for AVEC customers is 39.9 cents per kWh. The state offers a Power Cost Equalization (PCE) subsidy for rural communities, which averages 17.5 cents per kWh for the first 500 kWh per month. The effective average residential rate for AVEC communities is 22.4 cents per kWh. The goal of the PCE is to equalize the cost of electricity statewide; however, even with the PCE subsidy, rural electric costs are often two or three times higher than in urban areas (Alaska Energy Authority, Sept 2003).

Fuel access is the second driver to consider alternative sources of generating electricity. The delivery of fuel is limited to 1 to 4 shipments by barge per year and is dependent upon favorable environmental conditions. In 2002, the average delivered diesel fuel price ranged from $1.02 to $2.88 per gallon. In addition, a 9 to 13 month supply of fuel must be stored on site in tank farms, which are subject to leaks and spills. Many of the plant complexes and storage tanks are aging and in need of major upgrades and expansion as energy needs increase. With limited storage capacity, increasing demand and limited fuel deliveries, alternative methods must be determined to reduce or limit fuel consumption.

### Historic Use of Wind Energy in Alaska

Of the 175 remote villages in Alaska, it is estimated that 90 are located in potentially windy regions (Meiners, 2002). The wind resource map in Figure 1 shows that wind speeds of up to Class 7 occur along the Alaskan coastal and islands areas where many of the villages are located (U.S. DOE Renewable Resource Data Center, 2003).

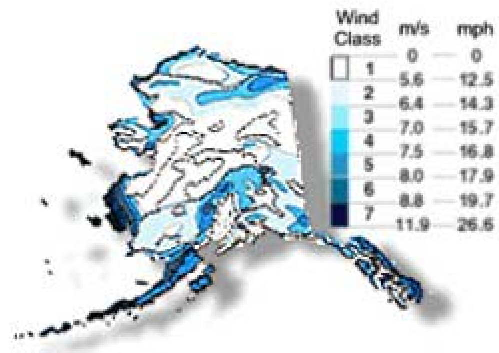



**Figure 1. Wind Resource Map of Alaska**

The wind resource tends to be greater in the winter than in the summer, which corresponds to the seasonal electric use pattern in many of the villages. This match between wind resource and electric demand makes the use of wind energy systems attractive.

In the early 1980's about 140 wind turbines were installed across Alaska with the use of state and federal funding; however, within a year, many of the systems were no longer in operation. There was a lack of community and local utility involvement in the projects, the equipment was not well suited for Alaska's rugged environment, and there was no supporting infrastructure for operating and maintaining the systems. As a result, wind energy was viewed as unreliable, and interest in the technology declined (Reeve, 2002). With fuel prices continuing to rise and recent advancements in the technology, wind energy is gaining acceptance as a serious option in reducing the use of diesel fuel and the exposure to fuel price volatility. Wind-diesel hybrid systems are currently operating in the Alaskan villages of Wales, Kotzebue, Selawik, and St. Paul. These systems provide valuable field demonstrations of the technology.

Wales is located on the western tip of the Seward Peninsula just south of the Arctic Circle. A high-penetration wind-diesel system consisting of two 50 kW Atlantic Orient Corporation AOC15/50 wind turbines, 411 kW of diesel generators, and a 130 Ah battery bank was commissioned in 2002. Lessons learned from the implementation have been well documented (Drouilhet, 2002).

The Kotzebue Electric Association (KEA) has installed eleven wind turbines in Kotzebue. Three AOC15/50 turbines were installed in 1997, seven more were added in 1999, and one NW100 was installed in 2002. The AOC turbines have reported availability of 98% and a capacity factor of 38%. The wind turbines have generated more electricity than expected due to the higher air density during the winters (Atlantic Orient Corporation, July 2004.) KEA plans to compare the performance and costs of the different types of wind machines. In addition to installing wind-diesel systems in other member communities, KEA hopes to establish a cold weather technology center in Kotzebue and develop training programs for installers and operators of wind-diesel systems. Eventually KEA hopes to install up to 4 MW of wind capacity in Kotzebue (Kotzebue Electric Association, 2004).

In 1999 a 225-kW Vestas wind turbine was installed at an airport/ industrial complex on the island of St. Paul in the Bering Sea. The St. Paul system is unique in that it is a high-penetration system that does not utilize energy storage. The installed capacity of the wind turbine is much larger than the village load requirements, which average 85 kW. When the wind turbine is generating well over the village requirements, the diesels are shut off. To maintain system stability without the diesels, a fast-acting dump load, synchronous condenser, and advanced controls are used. The dump load consists of a 6,000-gallon hot water tank, which provides heat to the facilities. When the wind power drops below the set safety margin, a diesel generator is started (Baring-Gould, et al, 2003).

Alaska's most recent wind-diesel system was installed in the village of Selawik in 2004. It is a low-penetration system consisting of four AOC15/50 wind turbines, three diesel generators, and a 160 kW electric boiler. The electric boiler serves as a dump load for excess electricity from the wind turbines and supplies heat to the power plant and village water treatment plant (Alaska Village Electric Cooperative, 2003).

Wind-diesel systems have been installed in other remote arctic communities as well as in Alaska. Ten 60 kW Vergnet wind turbines were installed in Miquelon on St. John's Island, Canada, in 2000 (Vergnet Canada Ltd, 2002). Several wind-diesel systems have been installed in the Northern Territories of Russia since 1997, funded by the Russian Ministry of Fuel and Energy, the U.S. Department of Energy, and the U.S. Agency for International Development. The systems consist of either 1.5 kW or 10 kW Bergey wind turbines, Trace inverters, batteries, and diesel generators (Office of Technology Access, 2004). Five AOC15/50 wind turbines were installed in Siberia, Russia to generate power to pump oil. The system also consists of two diesel generators, a dump load, and a central controller that monitors the wind turbine and allows for remote control of the system by the operator (Atlantic Orient Corporation, July 2004.)

Although much experience has been gained from these systems, the wind-diesel industry in Alaska is still fairly new. Much research is being done to develop better controls, especially for high-penetration systems without energy storage. There is a developing technical support infrastructure and knowledge base to support the growing market (Baring-Gould, 2003). With the availability of state and federal funding, as well as funding from native or private corporations, there is significant opportunity for wind-diesel projects in Alaska.

## REPORT PURPOSE AND METHODOLOGY

The purpose of this report is to address the potential of utilizing wind energy in remote communities of Alaska. In order to determine the economic and technical feasibility of a wind energy system, computer modeling of the different options must be done. One of the primary pieces of information essential in accurately modeling the expected performance of wind-diesel systems is the village electric use pattern. For many Alaskan villages, this information is not readily available. Chapter 1 will present a method for calculating the hourly electric load data in a village based on basic information about the community. Chapter 2 will provide a summary of the various design aspects of wind-diesel power systems and explain the assumptions used in modeling these systems. Chapter 3 provides seven feasibility studies that illustrate the methods described in Chapters 1 and 2.

# CHAPTER 1

# ANALYSIS OF VILLAGE ELECTRIC LOADS

As part of designing a village electric power system, the current and anticipated long-term electric loads must be defined, including both seasonal and daily usage patterns. However, in many cases, detailed electric load information is not readily available. The purpose of this chapter is to perform an analysis of community electric loads, including the effect on load growth as additional services are provided. This will allow for an assessment of long term load growth predictions that can be used in planning of future plant expansion and fuel needs.

A detailed investigation of villages of different sizes was used to determine typical daily and seasonal load profiles for rural communities. A number of general load profiles were created based on the size of the community and types of services that are available. These profiles were then incorporated into the Alaska Village Electric Load Calculator, a tool that generates hourly electric load data based on basic information about the community. This chapter explains how the Electric Load Calculator was developed and provide instructions on its use.

The Alaska Village Electric Cooperative (AVEC) operates about 50 power stations serving remote villages ranging in size from 100 to 1,100 residents. Much of the data used in this analysis was provided by AVEC and this report uses those villages as examples. However, it is felt that the Alaska Village Electric Load Calculator can also be applied to non-AVEC villages in Alaska and possibly other similar remote arctic communities.

## 1.1 Historical Growth in Energy Use

From 1969 to 2002 the total energy provided by AVEC to its member communities has increased dramatically from an initial production of 29 MWh/year in 1969 to 58,872 MWh/year in 2002, primarily through the incorporation of new villages and increases in consumption. Figure 2 shows the percent of total electricity used by each customer sector: residential, commercial, and public/municipal.

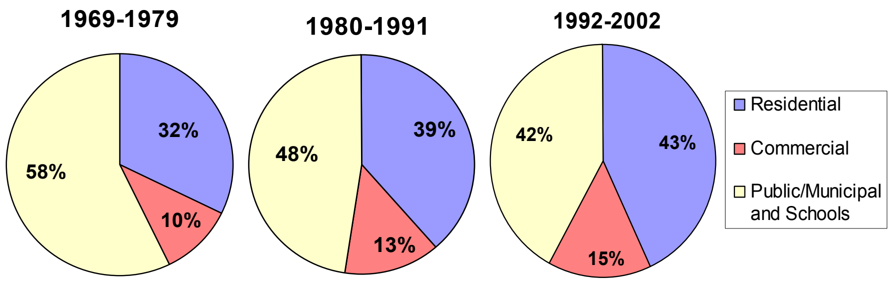



**Figure 2. Growth in Village Electric Use Sectors**

The residential sector has been growing steadily and is now the largest consumer group, followed by the public sector. Facilities in the public/municipal sector include a school, public water system, post office, airport, and city offices. The commercial sector makes up about 15% of the village electric consumption and typically includes a general store, hardware store, and a number of restaurants. Figure 3 shows in more detail the growth in energy demand from each sector that makes up AVEC's customer base. This data is valuable as it provides insight into the primary load growth areas within a community.

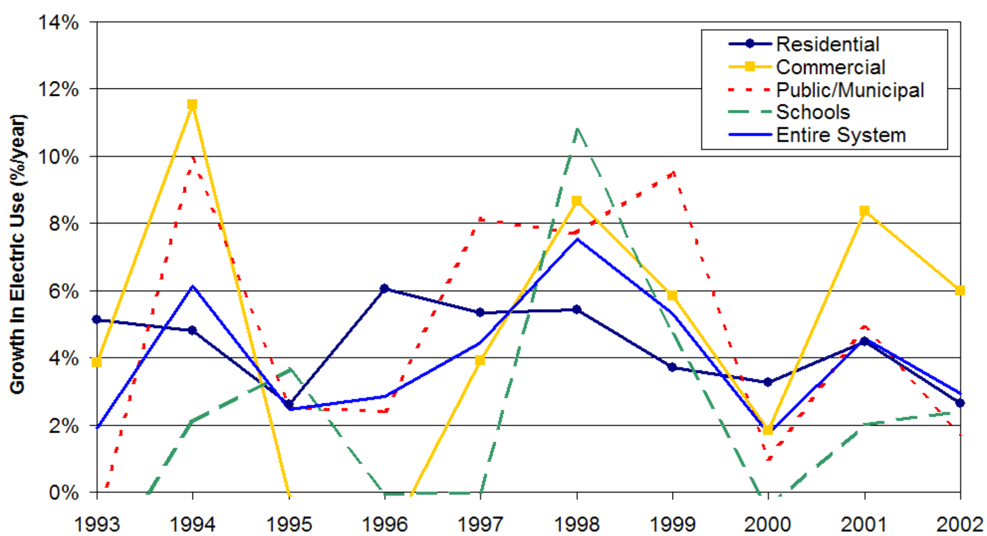



**Figure 3. Annual Change in Village Electric Usage**

The residential sector, generally the largest load sector, increases at a gradual rate of about 4% per year through general consumption increases and new housing connections. The expansion of municipal services, schools and commercial applications provide large and highly variable load increases to a community. Due to the funding process, both municipal and school expansions are widely known and can be planned into power systems needs accordingly, thus limiting its surprise impact.  Expansion of commercial loads is not easy to plan for and could quickly change the energy needs of a community.  However, commercial loads generally make up less then 20% of a community's total load, and thus large increases will have limited impact compared to the larger residential and municipal loads that make up the remaining 80% of a community's electric needs.

### 1.2 Effects of the Climate

The energy consumption of a community can be influenced by the local climate. According to the Alaska Climate Research Center, the state can be divided into four main climate regions: arctic, maritime, continental, and transitional.  The arctic region consists of villages in the northern latitudes, which receive extreme seasonal variation in solar radiation.  The maritime region is influenced by the moderate temperature of the ocean, which results in less seasonal variation in temperature but high humidity.  The inland villages of the continental region experience a wider range of seasonal and daily temperatures and low humidity.  Many villages in the northwestern region of the state experience a transitional climate characterized by long winters and mild summers.

The heating requirements of different regions can be defined with the use of heating degree-days.  These are the cumulative number of degrees in a month by which the average daily temperature falls below 65°F.  Figure 4 shows the monthly heating degree-days as measured from airport weather stations in various climate regions (BinMaker Pro, 2003).  As shown, the continental regions have the widest range of heating requirements from winter to summer.

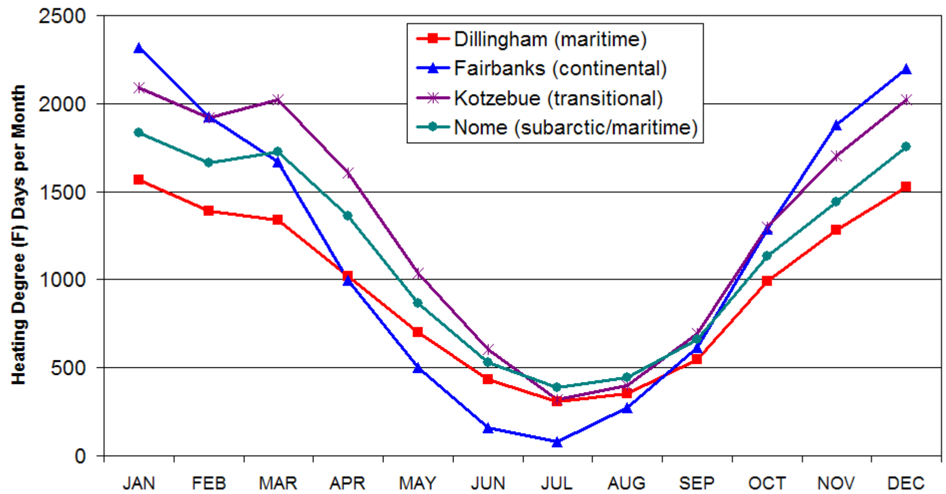



**Figure 4. Average Monthly Heating Degree Days in Each Climate Region**

If electricity is used for heating in a village, the seasonal variation in heating degree-days will have more of an impact on the monthly electricity consumption than in villages that use another fuel for heat.

### 1.3 Alaska Village Electric Load Calculator

To begin the load analysis, the electric consumption from a number of communities was broken down into its primary components: public water system, school, health clinic, communications facilities, government/ community buildings, residential sector, and commercial sector. Figure 5 shows the relative size of each of those sectors within a village.

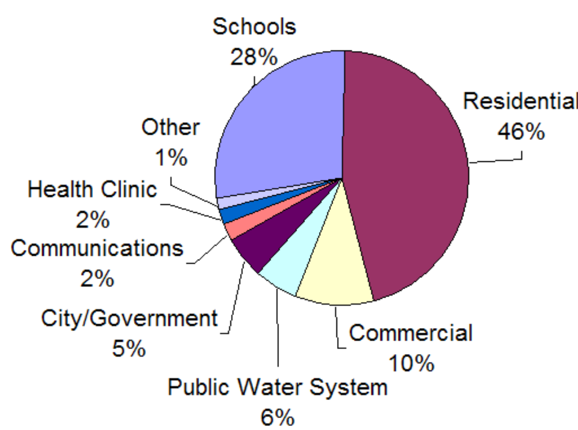



**Figure 5. Relative Load Consumption by Facility Type in a Typical Village**

For each sector, a typical seasonal load profile was created. The consumption patterns were then incorporated into the Alaska Village Electric Load Calculator, which adds up the various load profiles within a village in a building-block approach. The method used to create the building-blocks for each consumer sector is described in the following sections. A procedure for using the Electric Load Calculator to determine hourly electric load data will then be presented.

Throughout this analysis the energy consumption of certain loads was normalized by the population within each community. This allows easy comparisons between communities of various sizes. Other normalization techniques were investigated; however, normalization by total community population provided the most promising results. Some loads, such as the communication sector, which is not dependent on the size of a community, were not normalized.

### 1.3.1 Residential Sector Loads

The residential sector typically makes up about 45% of a village's total electric consumption. Electric loads that can be found in a typical home include lighting, a color TV, electric stove, refrigerator, forced air fan, and a clock radio. Homes with piped water may have electric heat tape to prevent pipes from freezing. More modern homes will have a computer, washer and dryer, satellite dish, microwave, and additional lights and television sets (Vallee, 2003). Some residents use as much as 1,000 kWh a month or more. However, the majority of village homes use 200 to 400 kWh per month.

It is difficult to characterize the monthly electric consumption of the residential sector since billing information for individual consumers is not readily available and the consumption patterns can vary drastically from consumer to consumer. However, the energy consumption of all individual households in six different villages was obtained for the months of November 2002, April 2003, and July 2003, and the results are shown in Figure 6. The data points for the other nine months were estimated based on the seasonal shape of the total village load profile. The resulting average seasonal electric load profile is shown in Figure 6.

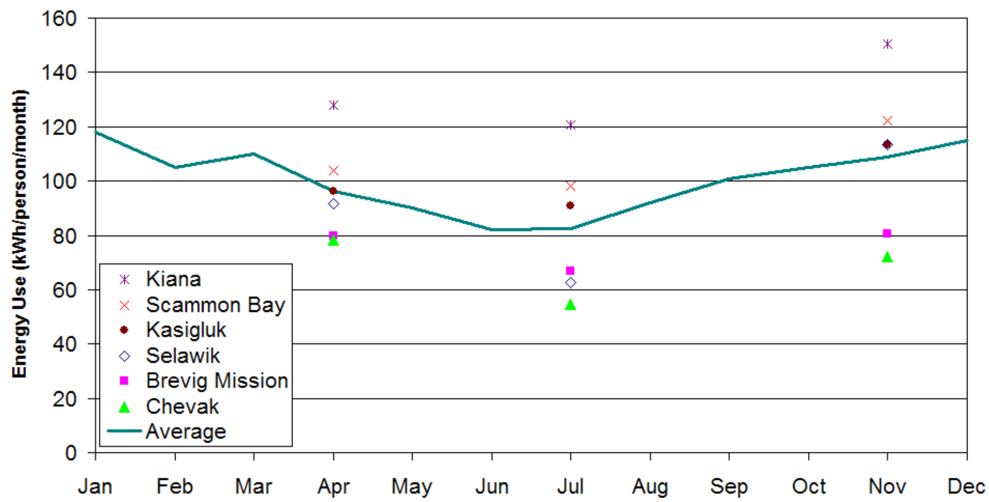



**Figure 6. Electric Consumption of Residential Sector in Sample Villages**

To determine why some villages have a higher per capita residential electric consumption than other villages, characteristics relating to the residential sector in each village were gathered. Statistics from the 2000 U.S. Census, such as people per household, unemployment rate, percent of population below poverty, and per capita income, were chosen because they are readily available and can easily be used to compare with other villages. Comparing the community statistics to the per capita energy consumption of each village, it seemed that the median household income most closely correlated to the level of energy use. This assumption coincides with reports concluding that economic growth is directly related to an increase in household energy consumption. As the level of household income increases, residents often purchase larger housing units and additional appliances, leading to increased energy consumption (Energy Information Administration, 2004).

The average median household income for remote villages in AVEC's service territory is about $31,500. Therefore, the residential sector was divided into three categories, as described in Table 2.

**Table 2. Electric Consumption of Residential Sector**

| Category: | Low | Medium | High |
|---|---|---|---|
| Median Household Income: | Less than $25,000 | $25,000 to $35,000 | More than $35,000 |
| Monthly Consumption | (kWh/person/mo.) | (kWh/person/mo.) | (kWh/person/mo.) |
| Jan | 89 | 118 | 159 |
| Feb | 84 | 105 | 142 |
| Mar | 88 | 110 | 146 |
| Apr | 78 | 96 | 128 |
| May | 65 | 90 | 123 |
| June | 58 | 84 | 121 |
| July | 55 | 82 | 121 |
| Aug | 62 | 92 | 129 |
| Sept | 68 | 101 | 141 |
| Oct | 70 | 105 | 147 |
| Nov | 72 | 109 | 150 |
| Dec | 81 | 115 | 155 |

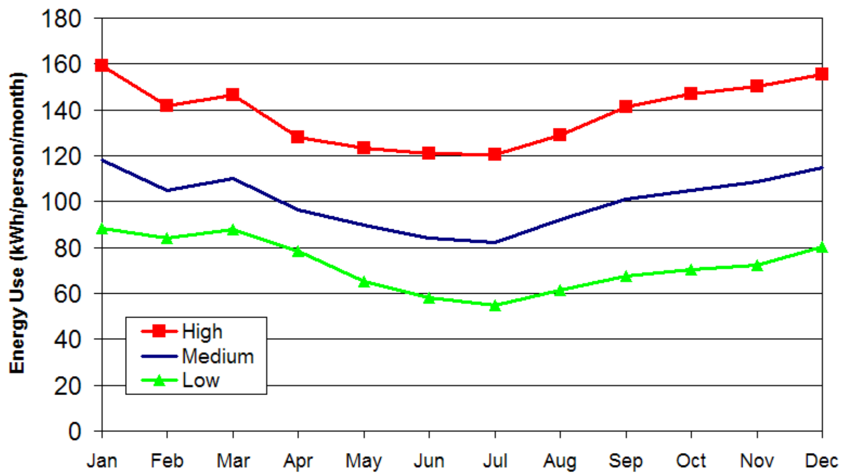



**Figure 7. Electric Consumption Model for Residential Sector**

The values listed in Table 2 and shown in Figure 7 serve as the building block for the residential sector to be included in the Village Electric Load Calculator.

### 1.3.2 Schools

As the largest individual consumer of electricity in a village, the local school has a great impact on the total village load profile. The electric consumption of eight village schools from 1998 through June 2003 was observed to have a similar seasonal load pattern. An average year of per capita electric consumption of each school is shown in Figure 8.

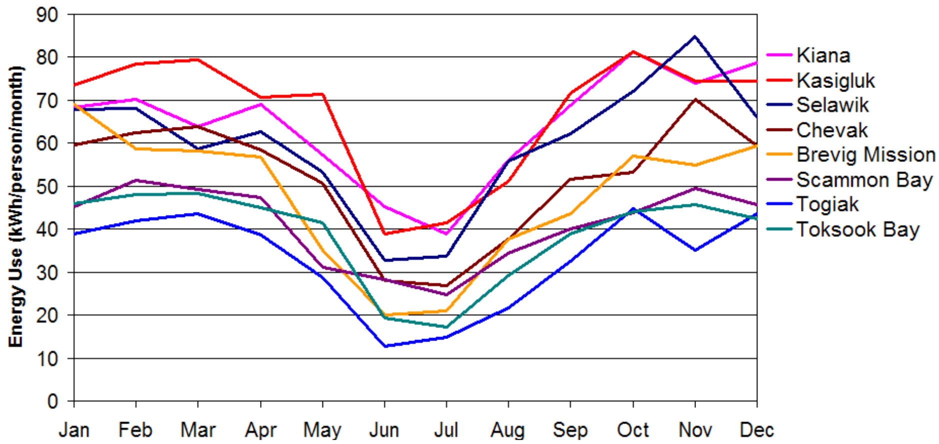



**Figure 8. Electric Consumption of Sample Village Schools**

The variation in electric consumption between schools is due to a number of factors. Kasigluk has two school buildings, and combining their electric usage, they use more electricity per capita than the other villages. The Brevig Mission school is in the mid range of electric consumption per capita. Major loads within the school include air handling units, an electric dryer, water pumps for the hot water radiator system, and kitchen appliances. Heat is provided by oil-fired furnaces. The building, particularly the gym and library, is used in the evenings and weekends for after school programs and community meetings but is used very little in the summer (Davis, 2003). The Scammon Bay, Togiak, and Toksook Bay schools are all located in maritime climates with limited electric heating loads. To distinguish among the range of electric use between schools, these facilities were divided into three categories, as described in Table 3.

**Table 3. Electric Consumption of K-12 Schools**

| Category: | Low | Medium | High |
|---|---|---|---|
| Characteristics: | Located in southern/ maritime climate region, uses propane or gas for heating and cooking. | Average school with air handling units and some electrical appliances. | Located in the arctic climate region, has its own septic system, uses electric heaters and stoves, or more than one building. |
| Monthly Consumption | (kWh/person/month) | (kWh/person/month) | (kWh/person/month) |
| Jan | 38.8 | 58.5 | 73.4 |
| Feb | 42.0 | 59.9 | 78.6 |
| Mar | 43.6 | 58.2 | 79.4 |
| Apr | 38.6 | 56.1 | 70.8 |
| May | 28.7 | 46.1 | 71.3 |
| June | 12.7 | 28.2 | 45.3 |
| July | 14.8 | 27.4 | 41.5 |
| Aug | 21.6 | 40.5 | 56.2 |
| Sept | 32.5 | 51.2 | 71.5 |
| Oct | 43.9 | 59.7 | 81.4 |
| Nov | 42.0 | 61.1 | 84.8 |
| Dec | 42.3 | 58.7 | 78.8 |

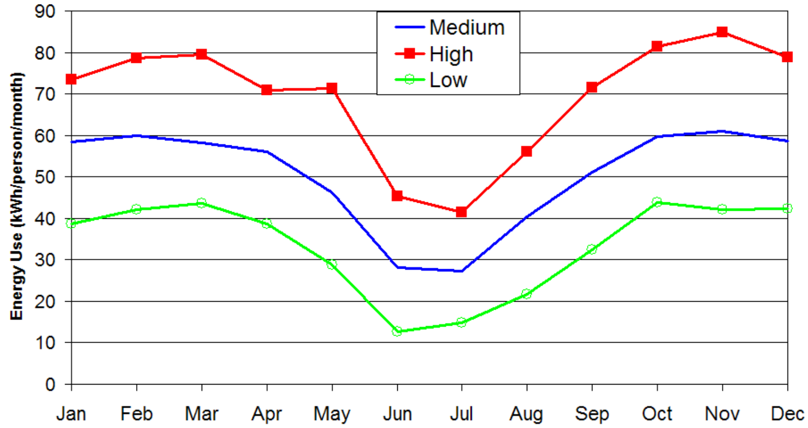



**Figure 9. Electric Consumption Model for Village K-12 Schools**

The monthly energy consumption of the different categories of schools is listed in Table 3 and shown in Figure 9. These values serve as the building block for the school sector in the Village Electric Load Calculator.

### 1.3.3 Public Water System

Village public water systems include any facilities that supply water to a community and that dispose of wastewater. There are many factors influencing the electric consumption of a public water system, including the size of the population served, the level of treatment of the water and wastewater, the method of distribution, and the climate. For the purposes of this report, village public water systems are split into two groups – those that have the capacity to provide complete plumbing to all or most residents, and those that do not.

Level I public water systems provide piped water and sewer to all city buildings and most homes. These systems usually have above-ground water mains, which need to be protected from freezing. Options include heating the water mains with electric heat tape, using a boiler to heat a glycol loop that runs through the water distribution system, or continuously pumping the water through a closed-loop distribution system. Figure 10 shows sample seasonal electric load profiles of Level I public water systems in seven different villages, normalized by village population.

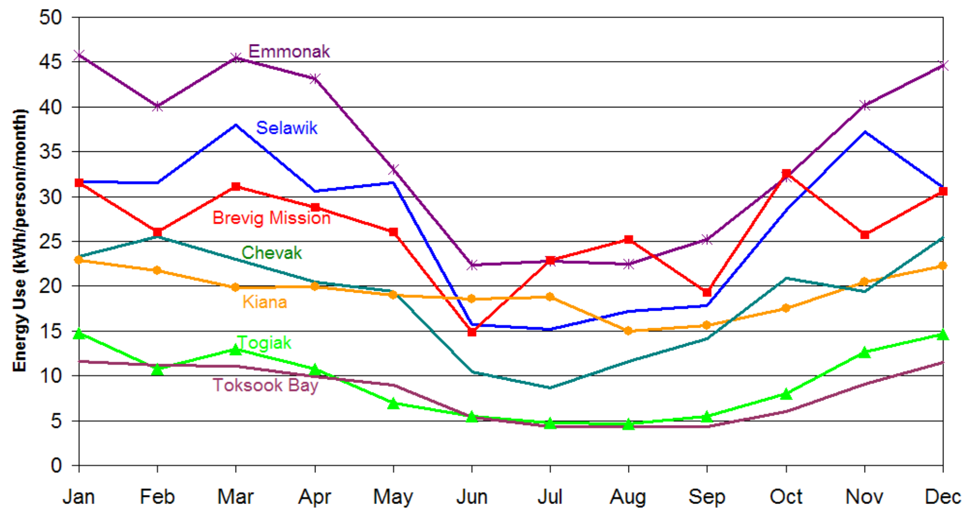



**Figure 10. Electric Usage of Sample Level I Piped Water Systems**

Within this grouping, there is a significant amount of variation in electric usage throughout the year due to the use of electricity to provide heat, the pumping requirements of the facility, and the number of buildings served. Facilities that consume the most electricity per capita (Emmonak, Selawik, and Brevig Mission) use electricity for heating water mains. Chevak uses a gas-fired glycol loop, and Kiana has buried water mains. Togiak and Toksook Bay are the southernmost facilities, which do not have a threat of freezing pipes. Toksook Bay also has a gravity piped system with limited pump requirements. To distinguish among the range of Level I public water systems, these facilities were divided into three categories, as described in Table 4.

**Table 4. Electric Consumption of Level I Public Water Systems**

| Category: | Low | Medium | High |
|---|---|---|---|
| Typical Characteristics: | Not all buildings or homes are connected. Gravity sewer system or surface water source (less pumping load). No electric heat. | Most buildings and homes are connected to piped water and sewer. No electric heat. | Circulating water and vacuum sewer system. All buildings and homes serviced. Arctic climate/ electric heat tape on pipes. |
| Monthly Consumption | (kWh /person/month) | (kWh/person/month) | (kWh/person/month) |
| Jan | 13.2 | 23.1 | 36.3 |
| Feb | 11.0 | 23.6 | 32.6 |
| Mar | 12.0 | 21.4 | 38.2 |
| Apr | 10.3 | 20.2 | 34.2 |
| May | 7.9 | 19.2 | 30.2 |
| June | 5.4 | 14.5 | 17.7 |
| July | 4.5 | 13.7 | 20.3 |
| Aug | 4.4 | 13.3 | 21.6 |
| Sept | 4.9 | 14.9 | 20.8 |
| Oct | 7.0 | 19.2 | 31.1 |
| Nov | 10.8 | 20.0 | 34.4 |
| Dec | 13.1 | 23.8 | 35.4 |

The monthly electric consumption of each category of Level I public water system is listed in Table 4 and illustrated in Figure 11.

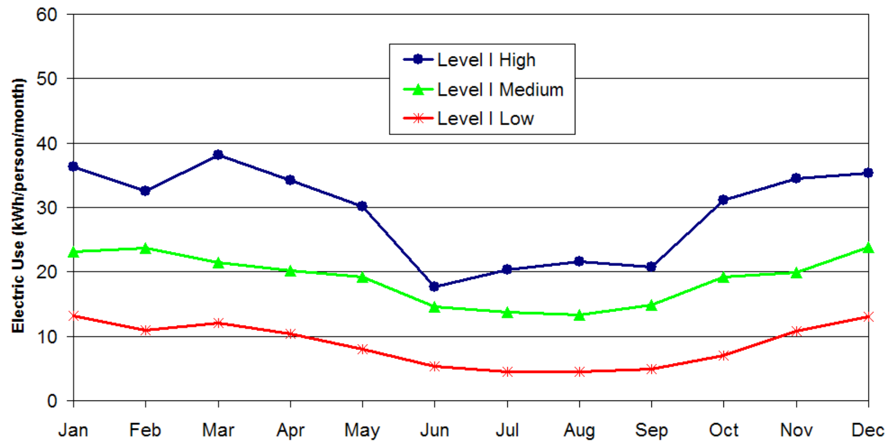



**Figure 11. Electric Consumption Model for Level I Public Water Systems**

In Level II public water systems, water is pumped from a well or surface source, treated, and stored in an insulated tank. The water is supplied to a central washeteria where residents can collect water, bathe, and do laundry. Electric loads at these Level II facilities include pumps, washing machines and dryers, and lights. In some villages, piped water is provided only to the school or health clinic. Level II systems do not treat wastewater; instead, each resident collects his or her wastewater in five-gallon “honey buckets” and hauls them to a sewage lagoon to be dumped. Almost half of Alaska’s 200 native villages have this type of system where residents do not have running water or flush toilets in their homes (Rural Alaska Sanitation Coalition website, 2003). Figure 12 shows seasonal electric load profiles of several sample Level II systems.

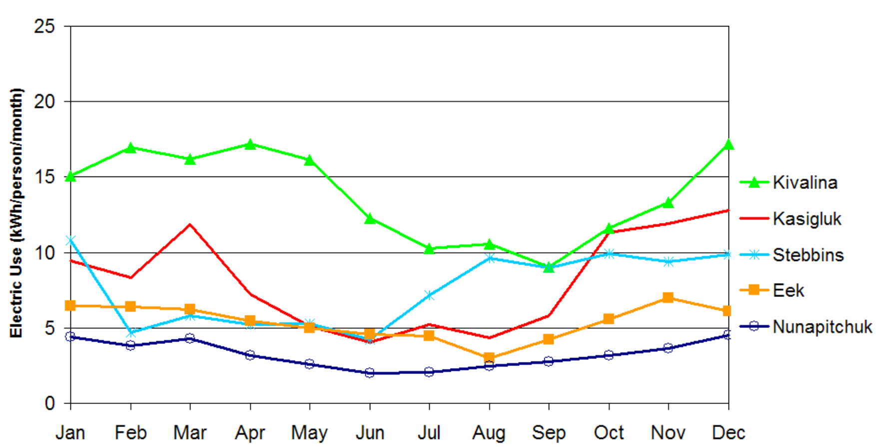



**Figure 12. Electric Consumption of Sample Level II Public Water Systems**

The range in electric use among Level II systems is influenced primarily by the types services available in the washeteria and by the climate. For example, Stebbins is the most modern facility, offering electric saunas in addition to electric washers, propane dryers, and showers. Kivalina provides piped water to the health clinic, which accounts for its increased consumption per capita. It is also the northernmost facility and requires electric heat tape to keep pipes from freezing. Eek, Nunapitchuk, and Toksook Bay are all located in the southwestern area of the state, which rarely reaches below freezing temperatures and thus these facilities have minimal heating requirements. To distinguish among the range of Level II public water systems, these facilities were further divided into two categories, as described in Table 5.

**Table 5. Electric Consumption of Level II Public Water Systems**

| Category: | Low | High |
|---|---|---|
| Typical Characteristics: | Water comes from surface source. Limited washeteria facilities. Maritime climate. | Water pumped from well or from a long distance surface source. Washeteria has electric saunas, electric dryers, or extended hours of operation. Arctic climate. |
| Monthly Consumption | (kWh/person/month) | (kWh/person/month) |
| Jan | 7.2 | 11.8 |
| Feb | 5.0 | 10.0 |
| Mar | 5.4 | 11.3 |
| Apr | 4.6 | 9.9 |
| May | 4.3 | 8.8 |
| June | 3.6 | 6.8 |
| July | 4.6 | 7.6 |
| Aug | 5.0 | 8.2 |
| Sept | 5.3 | 8.0 |
| Oct | 6.2 | 11.0 |
| Nov | 6.7 | 11.5 |
| Dec | 6.8 | 13.3 |

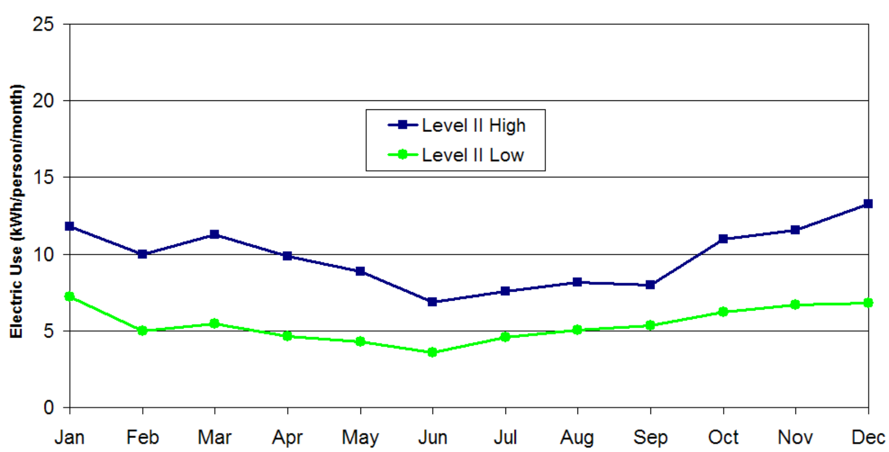



**Figure 13. Electric Consumption Model for Level II Public Water Systems**

Figure 12 illustrates the energy consumption of the two categories of Level II public water systems. The electric consumption of public water systems can vary drastically from village to village. Most villages begin with a basic Level II system and gradually move towards a high Level I system, as funding is available. The monthly electric use values listed in Table 4 and Table 5 serve as the building block for the public water systems in the Village Electric Load Calculator.

### 1.3.4 Health Clinics

Each village typically operates its own local health clinic, staffed by community health aids. Regional clinics are located in St. Mary's, Emmonak, Kiana, and Unalakeet. These clinics serve surrounding communities with a physician assistant or nurse practitioner. Patients requiring special care are flown to Anchorage or hospitals located in the hub cities of Kotzebue, Bethel, Nome, and Dillingham. The per capita electric consumption of eight sample clinics is shown in Figure 14.

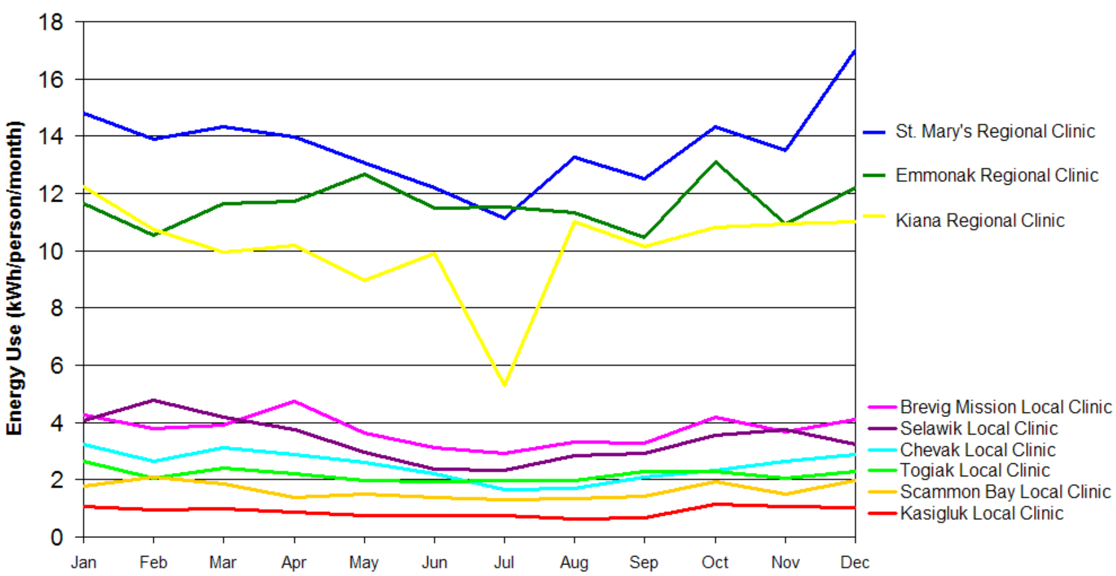



**Figure 14. Electric Consumption of Sample Village Health Clinics**

The distinction between electrical requirements in regional and local health clinics is clear, with regional clinics consuming nearly six times as much electricity as local clinics. It should be noted that only one year of data was available from the Kiana regional clinic so it is unknown if the drop in consumption during July is typical. It was assumed that the actual consumption is closer to 9 kWh per person during July. The health clinic sector was divided into two categories, as described in Table 6.

**Table 6. Electric Consumption of Village Health Clinics**

| Category: | Local clinic | Regional clinic |
|---|---|---|
| Monthly Consumption | (kWh/person/month) | (kWh/person/month) |
| Jan | 1.9 | 12.9 |
| Feb | 1.7 | 11.7 |
| Mar | 1.9 | 12.0 |
| Apr | 1.7 | 12.0 |
| May | 1.5 | 11.6 |
| June | 1.4 | 11.2 |
| July | 1.3 | 10.6 |
| Aug | 1.3 | 11.9 |
| Sept | 1.4 | 11.0 |
| Oct | 1.7 | 12.8 |
| Nov | 1.7 | 11.8 |
| Dec | 1.8 | 13.4 |

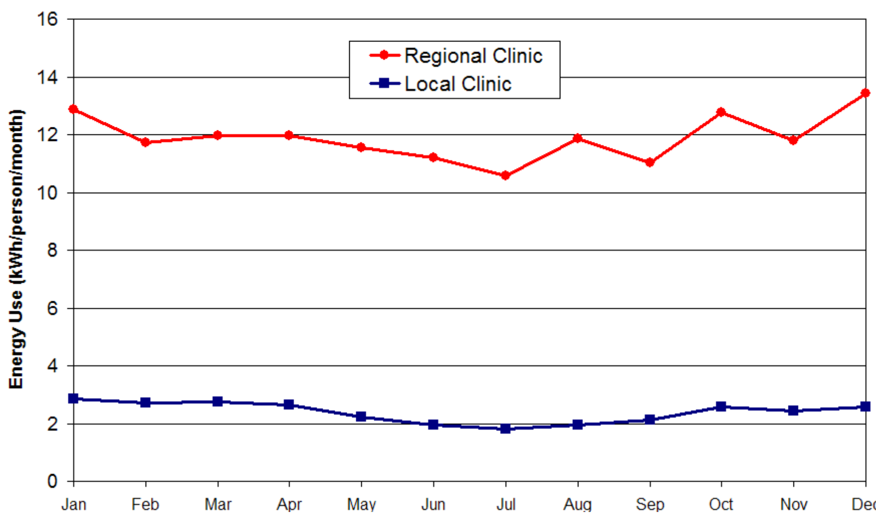



**Figure 15. Electric Consumption Model for Village Health Clinics**

The monthly electric consumption of the local and regional health clinics is listed in Table 6 and illustrated in Figure 15. These values serve as the building block for the health clinic sector that is used in the Alaska Village Electric Load Calculator.

### 1.3.5 City and Government Sector Loads

The city and government sector, which includes city offices, post offices, native tribal offices, and community centers, makes up about 20% of a village's electric use. Seasonal electric load profiles of sample city/government loads are shown in Figure 16.

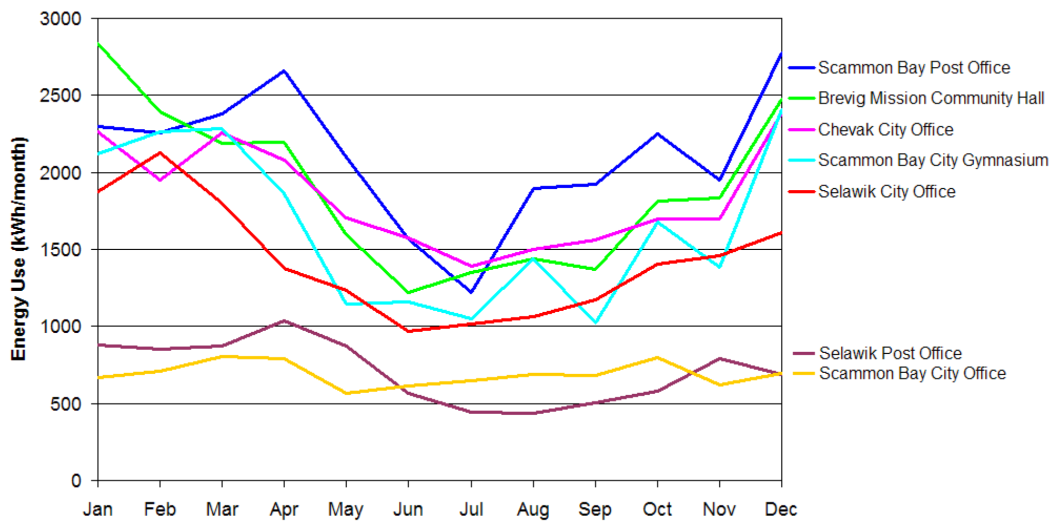



**Figure 16. Electric Consumption of Sample City/Government Buildings**

To distinguish among the range of electric use between city facilities, these loads were divided into two categories, as described in Table 7. The total city/government load can be made up of a number of buildings from each category. Note that the monthly consumption of each facility is not normalized by city population as with other sectors.

**Table 7. Electric Consumption of City and Government Buildings**

| Category: | Small | Large |
|---|---|---|
| Examples: | Post office, city office, native office, FAA, DOT | Gymnasium, community center, large city office |
| Monthly Consumption | (kWh/month) | (kWh/month) |
| Jan | 774 | 2,279 |
| Feb | 781 | 2,198 |
| Mar | 837 | 2,183 |
| Apr | 913 | 2,035 |
| May | 720 | 1,556 |
| June | 592 | 1,299 |
| July | 544 | 1,205 |
| Aug | 564 | 1,468 |
| Sept | 595 | 1,410 |
| Oct | 686 | 1,768 |
| Nov | 706 | 1,664 |
| Dec | 692 | 2,330 |

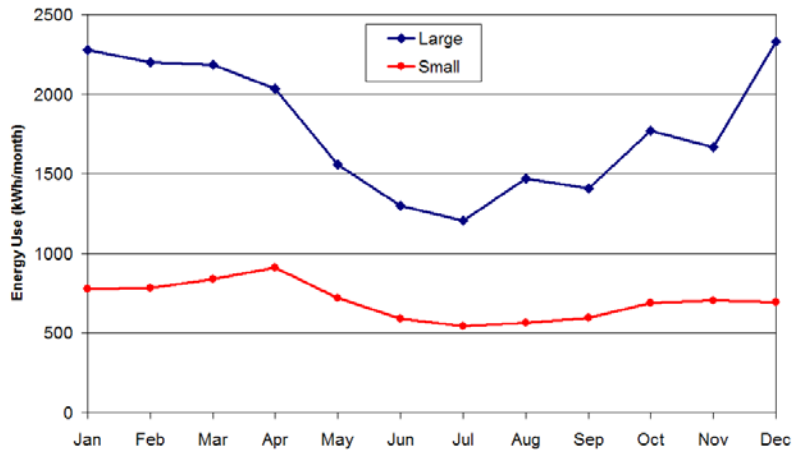



**Figure 17. Electric Consumption Model for City Buildings**

The monthly electric consumption of typical city facilities is listed in Table 7 and illustrated in Figure 17. These values make up the building block for each city/government building in the Village Electric Load Calculator.

### 1.3.6 Commercial Sector Loads

The commercial sector makes up about 15% of village electric consumption. Most villages have one general store, while larger villages have up to four different stores. The commercial sector also consists of various business offices and warehouses. The per capita electric load profile for six sample commercial facilities is shown in Figure 18.

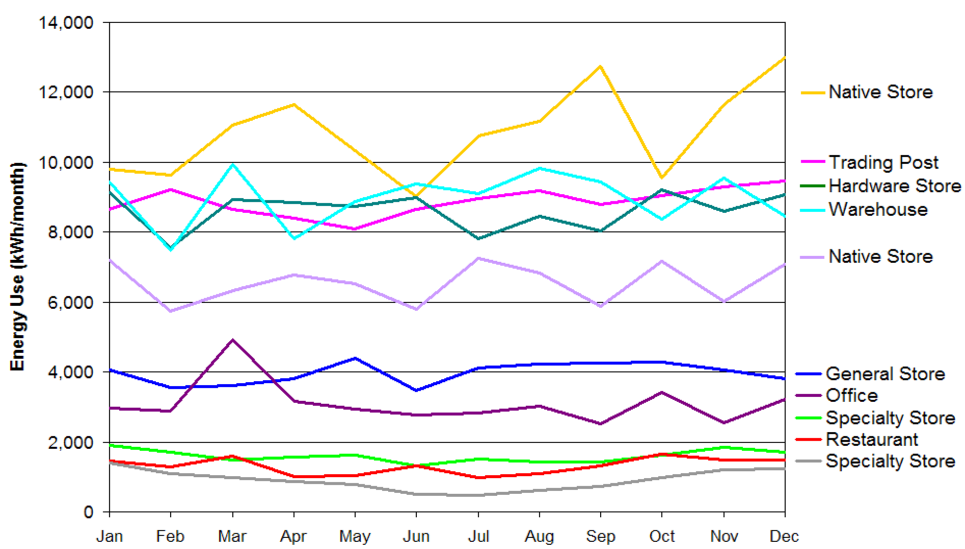



**Figure 18. Electric Consumption of Sample Commercial Facilities**

To distinguish among the range of electric use between city facilities, these loads were divided into two categories, as described in Table 8. The total commercial sector load can be made up of a number of buildings from each category. Note that the monthly electric consumption was not normalized by population as with the other sectors.

**Table 8. Electric Consumption of Commercial Facilities**

| Category: | Small Business | Large Commercial |
|---|---|---|
| Examples: | Office, restaurant, specialty store | Hardware store, native store, general store, warehouse, construction company |
| Monthly Consumption | (kWh/month) | (kWh/month) |
| Jan | 2,363 | 9,653 |
| Feb | 2,108 | 9,022 |
| Mar | 2,520 | 9,473 |
| Apr | 2,083 | 8,875 |
| May | 2,151 | 8,579 |
| June | 1,875 | 8,070 |
| July | 1,988 | 8,533 |
| Aug | 2,081 | 8,925 |
| Sept | 2,053 | 9,150 |
| Oct | 2,394 | 10,581 |
| Nov | 2,226 | 10,208 |
| Dec | 2,291 | 10,732 |

The monthly electric consumption of typical commercial facilities is summarized in Table 8 and illustrated in Figure 19. One of these load profiles is added for each commercial facility in a village to make up the building block for the commercial sector that is used in the Alaska Village Electric Load Calculator.

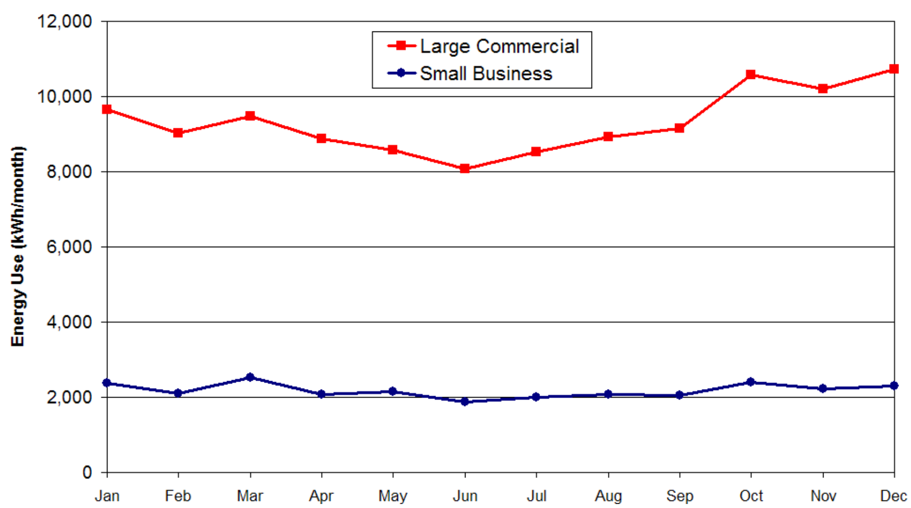



**Figure 19. Electric Consumption Model for Commercial Buildings**

It is important to note that the seasonal profile for these commercial facilities is fairly steady. Most, but not all, commercial facilities seem to follow this pattern. For example, fish-processing plants have their peak use in the summer and use considerably less electricity in the winter. As data from these facilities was not available, the electric use of unique commercial facilities such as this would need to be added to the Village Electric Load Calculator separately.

### 1.3.7 Communications Facilities

Most villages have phone, cable, and internet service, although not all homes are connected. The monthly electric consumption of sample communication service providers in six different villages is shown in Figure 20.

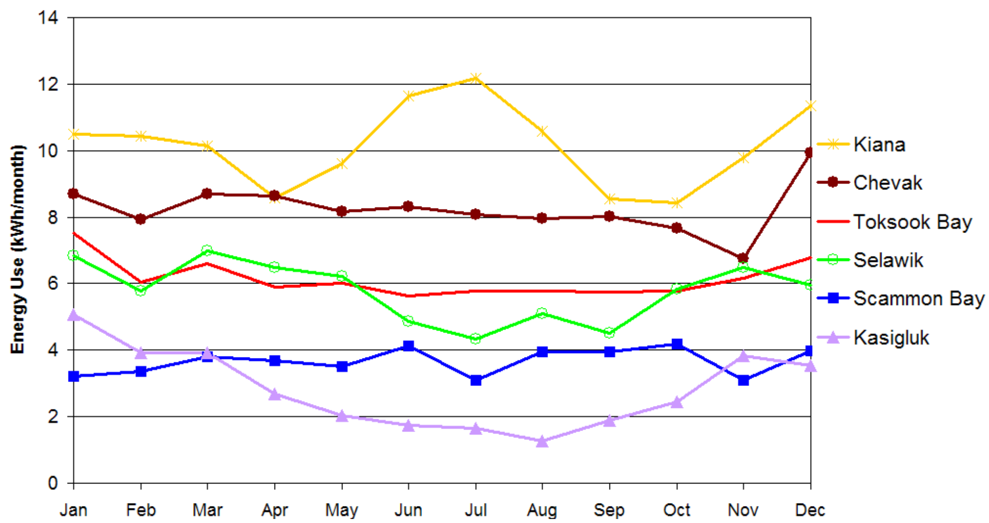



**Figure 20. Electric Consumption of Sample Communications Facilities**

The electric load of the communications service providers is relatively steady throughout the year. The communications sector was divided into two categories: basic and advanced, as detailed in Table 9. Note that the energy consumption was not normalized by population. The monthly energy consumption of the different types of communications loads is listed in Table 9 and illustrated in Figure 21. These values serve as the building block for the communications sector that is used in the Village Electric Load Calculator.

**Table 9. Electric Consumption of Communications Sector**

| Category: | Basic | Advanced |
|---|---|---|
| Characteristics: | Internet and/or cable | Internet, cable, radio tower |
| Monthly Consumption | (kWh/month) | (kWh/month) |
| Jan | 2,303 | 6,870 |
| Feb | 2,060 | 5,996 |
| Mar | 2,202 | 6,870 |
| Apr | 1,975 | 6,502 |
| May | 1,919 | 6,373 |
| June | 1,860 | 6,698 |
| July | 1,807 | 6,231 |
| Aug | 1,800 | 6,371 |
| Sept | 1,707 | 6,204 |
| Oct | 1,882 | 5,927 |
| Nov | 2,032 | 5,363 |
| Dec | 2,204 | 7,552 |

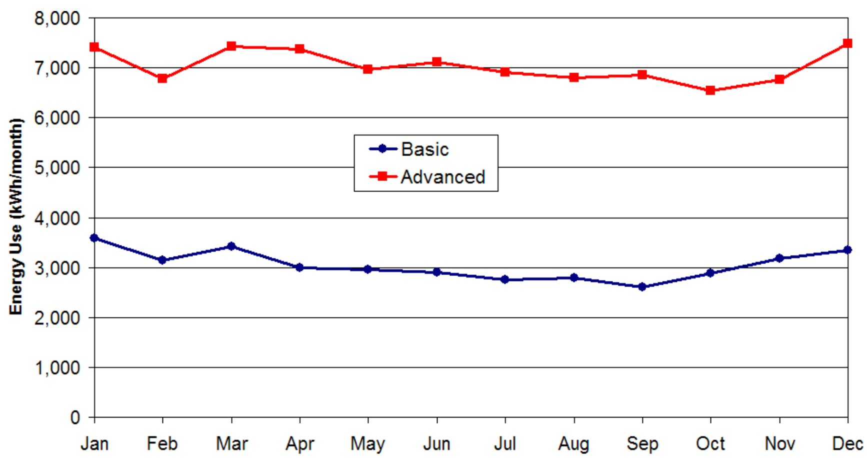



**Figure 21. Electric Consumption Model for Communications Sector Loads**

### 1.3.8 Other Loads

Other loads within a village may include an armory, street lights, and churches. These electric loads are estimated to add about 3-7% to the total village load. An option for specifying the amount of other loads is included in the Village Electric Load Calculator. The value that is input depends on the number of additional facilities in the village that is not accounted for in the community sectors described previously.

### 1.4 Daily Village Load Profiles

Similar to the process described above, a daily load profile analysis can be performed that separates the primary loads and looks at the daily changes in those loads. At the time of this writing, time series data was not available for specific consumers of electricity. Instead, what follows is an analysis of the daily electric load profiles for eight different villages where high quality data was available. The villages are: Selawik, Chevak, Kiana, Gambell, Ambler, Noorvik, Scammon Bay, and New Stuyahok. Each of these communities represents a different size of village and different levels of community services. The goal was to use this information, along with knowledge of the seasonal load profiles described in the previous sections, to make general estimates as to the electric usage in a typical Alaskan village. This information was then incorporated into the Alaska Village Electric Load Calculator to obtain an hourly load data set.

The data used in this analysis was obtained from power stations where AVEC recorded the instantaneous electric load once every 15 minutes. The four data points within each hour were averaged to create an hourly electric load profile for each year. Figure 22 displays the daily electric load profiles of an average day in each month for the village of Selawik. These daily profiles were created by averaging each hour over every day of the month.

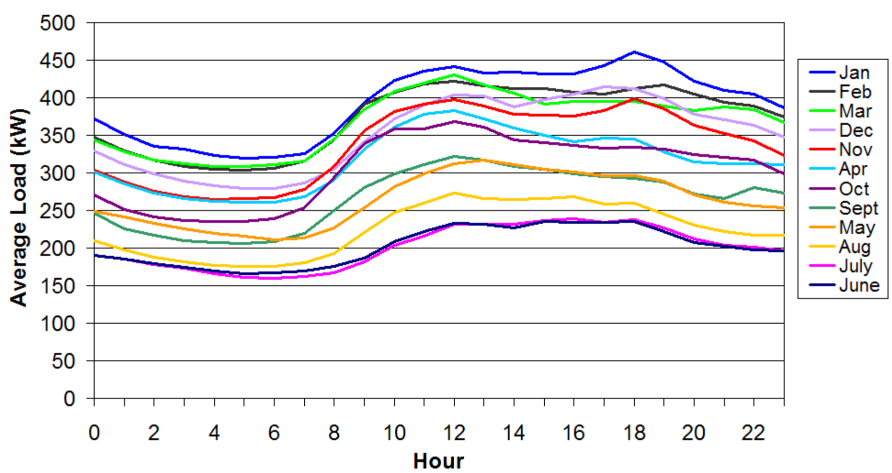



**Figure 22. Daily Electric Load Profiles for Each Month in Selawik, Alaska**

As one would expect, the daily load profile for the community depends on the season. Villages consume more electricity per capita throughout the day during the winter months than in the summer months, due primarily to increased lighting and electric heating loads. However, while the magnitude of the load fluctuates from summer to winter, the shape of the profile changes little. The difference is that on winter days, there tends to be two peaks – one around 11:00AM and the other around 6:00PM, while on the summer days, the load remains fairly constant between those hours. Also, the range between the minimum and peak load of the day is shallower during the summer months than the winter months.

Comparing the shape of the daily profiles between villages results in clear similarities. To demonstrate this, the hourly electric load values for the eight villages are normalized by village population. Then each hourly value was divided by the peak load of the day so that each load profile peaks at a value of 1. Figure 23 compares the January daily load profiles for the eight communities, and Figure 24 compares the July daily load profiles. It is important to note that the shape of the profile in each month is similar between villages. The villages represent a range of size, location, and community characteristics, yet the pattern of electric usage throughout the day is comparable.

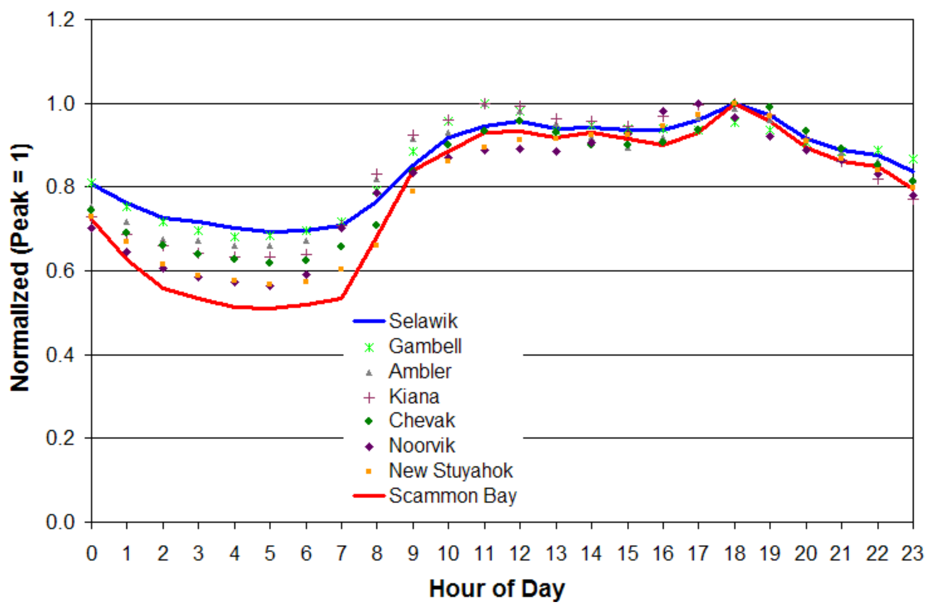



**Figure 23. January Daily Load Profile for Sample Villages**

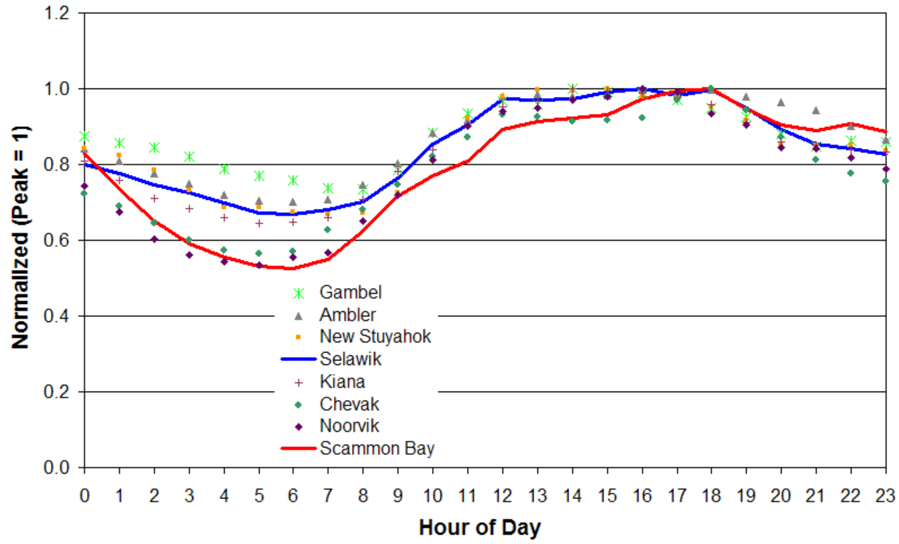



**Figure 24. July Daily Load Profiles for Sample Villages**

In each graph there is a divergence in energy usage during the early hours of the day. This is most likely due to the level of street lighting in the village and the use of electric heat tape on water mains. Selawik is located in the northernmost part of Alaska and is representative of a village that has a higher demand for early morning heating and lighting loads, even during summer months. Scammon Bay is located along the southern coast of Alaska and is representative of a village that would have less of a demand for heating and lighting in the early morning hours. The hourly electric use patterns from these two representative villages can be used to create a reasonable estimate of hourly load data for other villages. The magnitude of the daily profiles are adjusted by scaling the profile up or down depending on the monthly electric consumption determined from the seasonal load profile described in the previous section.

### 1.5 How to Use the Village Electric Load Calculator Method

The electric load calculator method consists of two steps: 1) estimate the total seasonal electric load profile for the village and 2) use the seasonal profile to adjust each month of hourly electric load data from a representative village to create a year of hourly data. An example of using such an approach is shown below for the village of Brevig Mission.

Step 1 is to estimate the village seasonal load profile by adding the profiles of each of the individual consumers described previously. Table 10 summarizes the village characteristics that determine which category of each consumer sector the Village Electric Load Calculator uses.

**Table 10. Electric Load Calculator Inputs for Brevig Mission**

| Village Characteristics | Value |
|---|---|
| Population | 314 |
| # of Small Businesses | 2 |
| # of Large Commercial Businesses | 0 |
| # of Community Buildings | 2 |
| # of Government Offices | 1 |
| Median Household Income | Low |
| K-12 School | High |
| Public Water System | Level 1 High |
| Health Clinic | Local |
| Communications | Basic |
| Other Loads | 5% |

The monthly electric consumption of each sector that makes up the total village load profile for Brevig Mission is shown in Figure 25.

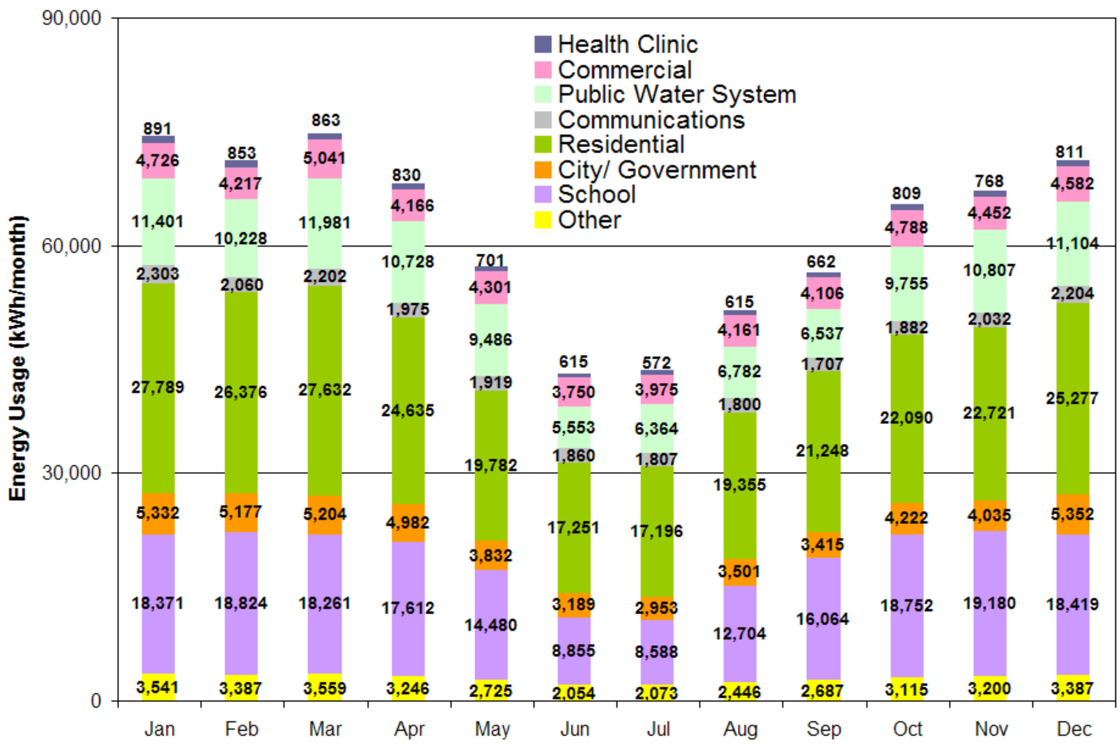



**Figure 25. Example Results of Village Electric Load Calculator Method for Brevig Mission**

Step 2 in the Alaska Village Electric Load Calculator method is to create the hourly electric load data set. A year of hourly data measured from the village of Selawik was used as a baseline. The hourly values were then scaled up or down so that the total energy use for each month matched the values estimated from the Village Electric Load Calculator in Step 1. The resulting hourly data set is shown in Figure 26.

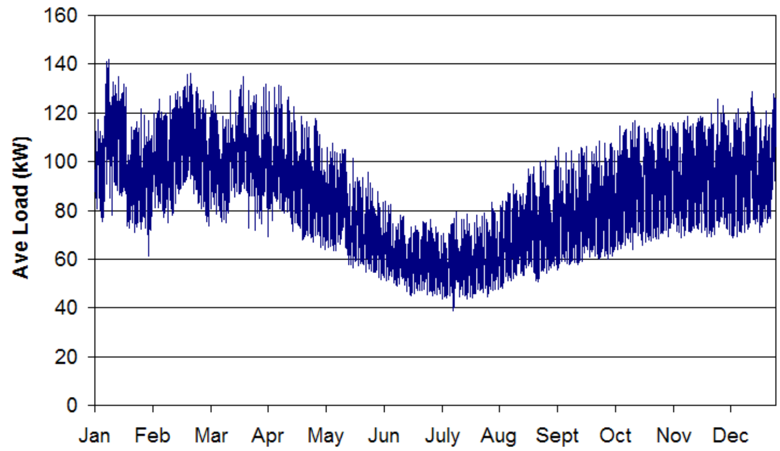



**Figure 26. Estimated Hourly Electric Load in Brevig Mission**

### 1.6 Verification of Village Electric Load Calculator Method

Figure 27 shows the estimated electric load profile determined from the Load Calculator method versus the actual load profile from billing records for Brevig Mission. On average, the Village Electric Load Calculator underestimates the actual consumption by 9%. Other examples comparing the estimated load with actual data for a number of other villages can be found in Appendix 1.

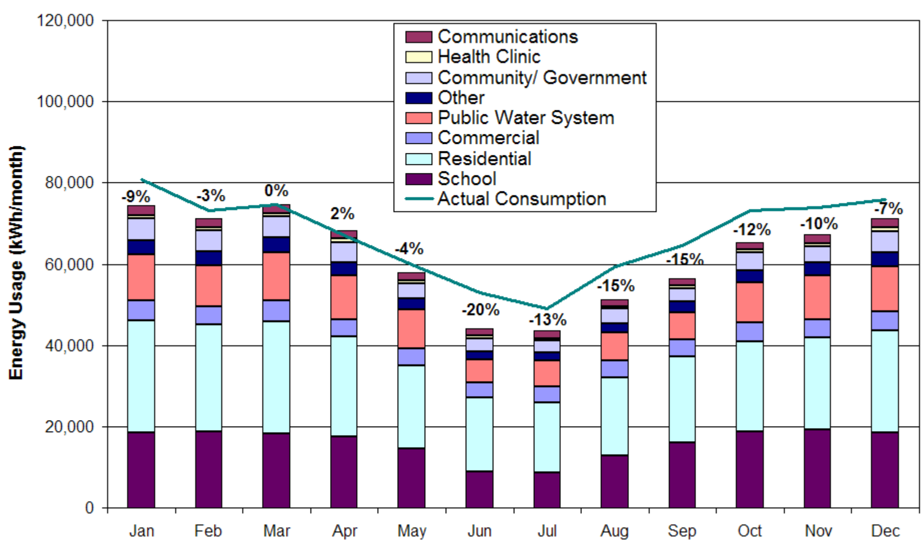



**Figure 27. Brevig Mission 2003 Estimate versus Actual Consumption**

In order to evaluate the ability of the Village Electric Load Calculator method in predicting an increase in energy consumption due to the addition of a facility in a community, the village of Selawik was used. Selawik has undergone a series of construction projects between 1996 and 2001: a piped water and sewer system project was begun in 1997 and completed in 2000, a village health clinic was constructed in 1997, and a new K-12 school came online in 2000. The Village Electric Load Calculator is used to estimate both the 1996 and the 2001 seasonal load profiles, given the facilities that were available in Selawik at those times. The inputs that were used in the Load Calculator for each year are shown in Table 11.

**Table 11. Electric Load Calculator Inputs for Selawik**

| Village Characteristics | 1996 | 2001 |
|---|---|---|
| Population | 665 | 772 |
| # of Small Businesses | 3 | 4 |
| # of Large Commercial Businesses | 2 | 2 |
| # of Community Buildings | 1 | 1 |
| # of Government Offices | 3 | 4 |
| Median Household Income | Medium | Medium |
| K-12 School | Medium | High |
| Public Water System | Level II Low | Level I High |
| Health Clinic | Local | Local |
| Communications | Basic | Basic |
| Other Loads | 3% | 5% |

The estimated results are graphed in Figure 28 along with the actual consumption.

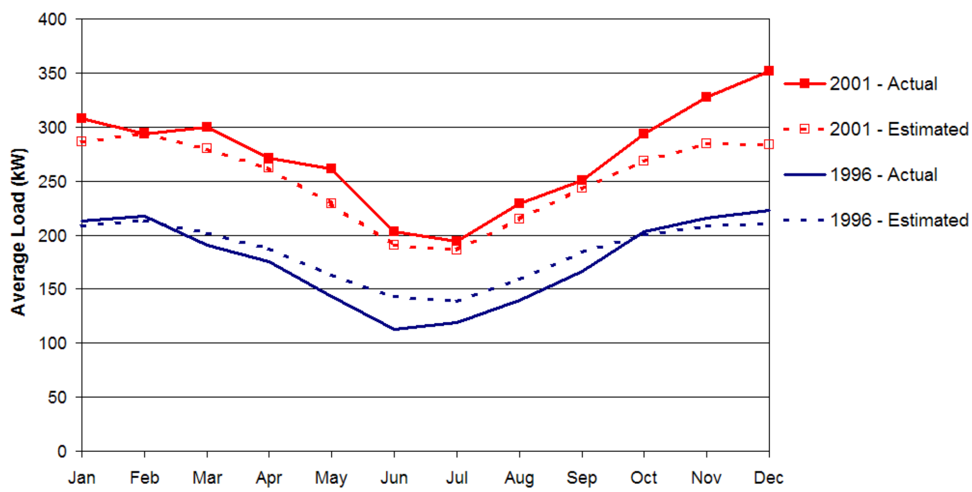



**Figure 28. Model Verification Example – Village of Selawik**

The estimation method is typically within 8% of the actual electric use for both years. The largest discrepancy occurs in December of 2001, when the actual usage was 24% more than what was estimated.

Based on an analysis of electrical use in a number of rural Alaskan communities, this chapter presented a method to estimate the hourly electrical usage in a village -- one of the key pieces of information required to conduct any detailed power system analysis. Using the Alaska Village Electric Load Calculator method, one can build upon existing knowledge of expansion plans for different communities or estimate the energy usage of non-electrified communities by simply adding the different expected electric loads in a building block approach. Several examples were given, which result in estimations within an average of 10% accuracy. The Village Electric Load Calculator method of estimating village electric loads can serve as a useful guideline for power system designers and utility planners.

# CHAPTER 2
# DESIGN OF WIND-DIESEL HYBRID POWER STATIONS

The purpose of this chapter is to introduce various design aspects of wind-diesel hybrid power systems. The costs of the different components are given, as well as the modeling assumptions and the method of evaluating system options.

## 2.1 Background on the Technical Aspects of Wind-Diesel Systems

A wind-diesel hybrid power system may include any combination of wind generators, batteries, an AC/DC power converter, and existing diesel generators. The wind turbines are connected directly to the grid and operate in parallel with the diesel generators, adding wind-generated electricity to the grid when available. A sample schematic of a wind-diesel system is shown in Figure 29 (Baring-Gould, 2003).

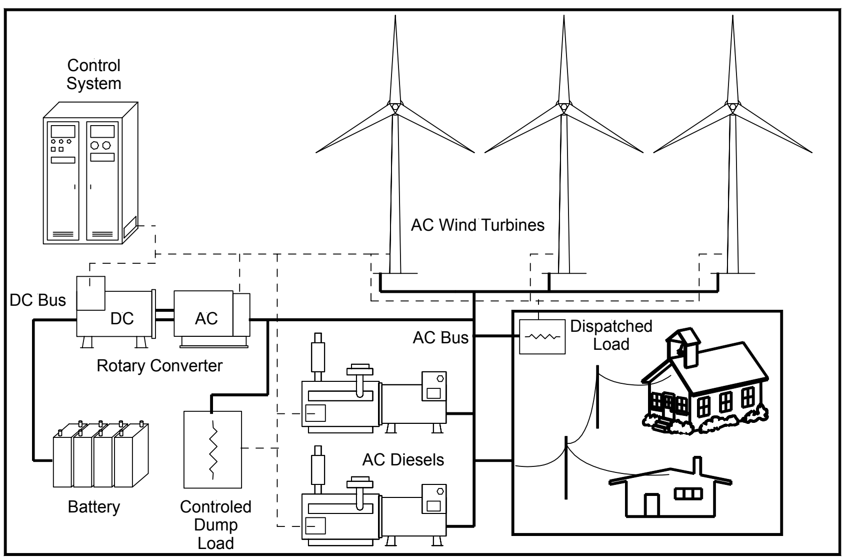



**Figure 29. Schematic of a Wind-Diesel Hybrid Power System with Battery Storage**

Wind-diesel hybrid systems can vary from simple designs in which one or more turbines are connected directly to the diesel grid with limited additional features to more complex systems with various levels of energy storage and power controls. The two main design considerations are: 1) the amount of wind energy generated in relation to the village load (system penetration) and 2) the level and type of energy storage device.

Various levels (penetrations) of wind energy can be included in the system. Wind penetration is defined here as the ratio of the wind-generated electricity to the primary system load. Average wind penetration is the annual wind energy generated (kWh) divided by the annual electric consumption of the village (kWh), while instantaneous penetration is the power being produced by the wind turbine (kW) divided by the electric demand (kW) at any given instant. This report will use average wind penetration when referring to system design.

The level of wind penetration dictates the type of components that are required and the complexity of the system. In low-penetration systems, the wind turbine(s) are simply an additional generation source, requiring a trivial amount of controls. In medium-penetration systems, the average wind turbine output is up to 50% of the average electric load, allowing some diesel generators to be shut off or allowing smaller diesels to be used. Additional controls are required to ensure an adequate power balance and to maintain system voltage and frequency. High-penetration systems allow all of the diesels to be shut off for longer periods of time, but require more sophisticated controls and system integration (Baring-Gould, 2003). Table 12 summarizes the characteristics of the three penetration classes (Drouihett, 2002).

**Table 12. Description of Wind Penetration Levels**

| Penetration Class | Operating Characteristics | Instantaneous Penetration (%) | Average Penetration (%) |
|---|---|---|---|
| **Low** | Diesel runs full-time; wind power reduces net load on diesel; all wind energy goes to primary load; no supervisory control system | < 50 | < 20 |
| **Medium** | Diesel runs full-time; at high wind power levels, secondary loads are dispatched to ensure sufficient diesel loading or wind generation is curtailed; requires relatively simple control system | 50 – 100 | 20 – 50 |
| **High** | Diesels may be shut down during high wind availability; auxiliary components required to regulate voltage and frequency; requires sophisticated control system | 100 - 400 | 50 – 150 |

The second design consideration for hybrid power systems is the use of energy storage devices. The addition of energy storage into a high-penetration wind-diesel system can increase the fuel savings and reduce the diesel generator operating hours and number of starts. These factors affect the wear on the diesel machines and resulting maintenance and overhaul costs. However, the storage equipment is expensive and difficult to ship, install and maintain, and their useful lifetime is generally limited to 5-15 years (Hunter, 1994).

The amount of storage influences the system's ability to cover short-term fluctuations in wind energy and/or village load. In a system without energy storage, a dispatchable energy source (the diesel engine in this case) must be used to cover the difference between the power required by the community (the village load) and power being supplied by the wind turbine. This difference is usually called the instantaneous net load. The net load fluctuates because of changes in the village load and changes in power from the wind turbine due to changes in the wind speed. The no-storage system includes a dump load to absorb any excess electricity generated and to maintain system frequency. Systems may also include active load control to shut off non-critical loads in time of power shortage. In low and medium-penetration systems, at least one diesel is always in operation to provide reactive power and maintain system voltage.

There are no standard guidelines as to the appropriate amount of energy storage in a wind-diesel system. The amount of storage could range from enough to supply power just during the time it takes a diesel generator to start or long enough to supply the entire village load until the diesels could operate at full load. In low penetration systems, storage is not required and is usually not worth the additional expense since the wind does not provide enough power to allow the diesels to be shut off. Storage is also not required in medium and high-penetration systems if an adequate dump load and synchronous condenser are provided to maintain voltage and frequency stability. In order to economically justify the use of energy storage, an average wind penetration of at least 50% and an instantaneous penetration of 80% should be maintained (Shirazi, 2001).

An additional benefit of a high-penetration wind-diesel system is that the excess wind energy generated could supply power to an optional load. Alaska's climate supports this concept of higher-penetration systems because any excess energy can be used year-round for heating. Currently, some villages use heat recovered from the diesel power plant to provide space heating or hot water to the community. This use of recovered heat must be considered in the installation of any alternative generation source that may reduce the use of the diesel engine.

### 2.2 Method of Analysis

In order to perform an analysis of the wind-diesel hybrid power options for any remote system, four specific pieces of information are required:

1. Detailed understanding of the community load including overall magnitude, level of service, daily and seasonal load profiles and any expected long-term growth potential. In the case of northern Alaska communities, the thermal loads supplied by the diesel plant must also be considered.
2. Available renewable resource at or in close proximity to the community. The resource must be identified with good detail and accuracy including daily and seasonal variances.
3. Specification of the existing diesel power station including number, size and make of each diesel engine as well as their expected fuel consumption.
4. Cost of different electrification, operation and maintenance options for the existing and potential power system.

To allow for this type of analysis, the National Renewable Energy Laboratory (NREL) has assisted in the developement of two computer simulation models: the Hybrid Optimization Model for Electric Renewables (HOMER) and Hybrid2. HOMER is an optimization tool that uses hourly electric load data and hourly wind speed data to compare the ability of a number of different types and quantities of wind turbines to meet the village load given the local wind resource (National Renewable Energy Laboratory, 2003). Although HOMER is a useful modeling tool in narrowing down a wide range of power system configurations, it assumes that the wind speed and load are constant throughout each hour, thus smoothing out the fluctuations that occur within the hour. Hybrid2 is an engineering tool that uses a statistical analysis to simulate system performance between timesteps and can more accurately evaluate the dynamic interaction of the batteries, village load, diesel generators and wind power than HOMER (University of Massachusetts Renewable Energy Research Lab, 2003).

The method used in this analysis was to first use HOMER to narrow down the possible combinations of wind turbines and diesel generators based on the lowest life-cycle cost. Hybrid2 was then used to perform a more accurate and detailed simulation to further refine the option chosen through HOMER.

The primary performance indicator by which the power system options were ranked was the amount of fuel savings of the wind-diesel system relative to the existing system. Other performance benefits include a reduction in total diesel run time, a reduction in the number of diesel starts, and the amount of excess wind energy generated that could meet resistive heating loads (dump loads). Both the diesel run time and the number of starts and stops affect the wear on the machine and resulting maintenance and overhaul costs.

The primary economic indicator by which the power system options were ranked was the levelized cost of energy of the wind-diesel system compared to the existing system. The economic benefits result from fuel savings, a reduction in diesel O&M and overhaul costs, and the potential monetary value of the excess wind energy that could be used for heat.

### 2.3 Modeling Inputs and Assumptions

Inputs into HOMER and Hybrid2 include wind resource data, electric load data, power equipment specifications, and economic parameters. Each of these inputs is described below.

#### 2.3.1 Wind Resource

Although the Alaska wind resource map suggests general areas where the use of wind power might be feasible, more detailed information on the wind resource at each village is needed. To address this need, AVEC, AEA, True Wind Solutions, and NREL are developing a high-resolution wind resource map, and a number of wind resource assessment programs are being implemented in various rural communities. In this report, the hourly wind resource measurements from local airports was used.

Airports are typically located in areas sheltered from the wind; therefore, the wind resource used in this report is a conservative estimate of what the actual wind resource might be in an unobstructed location where the wind turbines would be sited. A sensitivity analysis was conducted to account for the uncertainty of this wind resource. The actual wind resource should be monitored at the proposed wind turbine location before the system design is finalized.

Since the standard deviation of the hourly wind data was not recorded, a constant variability of 0.15 was assumed for modeling purposes. This allows for the variation in power output due to wind speed fluctuations that occur within each hour. In order to calculate the wind speed at the various wind turbine hub heights, the standard logarithmic wind profile was used (Manwell, et al., 2002). This calculation is based on the estimation that the landscape resembles a rough pasture with surface roughness length of 0.010 meters.

### 2.3.2 Solar Resource

As shown in Figure 30, the majority of Alaska has a poor solar resource for photovoltaics or solar heating (US DOE Office of Energy Efficiency and Renewable Energy, 2003).

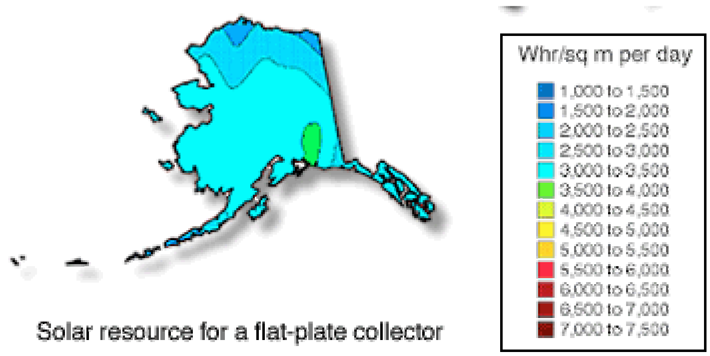



**Figure 30. Solar Resource Map of Alaska**

The best solar resource in Alaska is in the southeastern region; however, a preliminary regional analysis of the solar resource in Alaska suggests that solar electricity is not economically feasible on a village-wide scale (Cameron, 2004). Photovoltaic systems have been successful in providing power to much smaller, remote loads, such as communication stations, seismic monitoring sites, and runway lighting (Northern Power Systems, July 2004). Since this analysis focuses on central power systems that can supply a significant portion of the entire village load, the use of solar energy was not considered at this time.

### 2.3.3 Load Data

The electric load data used in this analysis was obtained by the Alaska Village Electric Cooperative (AVEC). Fifteen-minute data was collected for June 2002 to May 2003 and converted to hourly data. The data was then scaled to 2003 values using monthly load averages from June to December 2003. Since the standard deviation was not recorded with the load data, a constant load variability of 0.10 was assumed when necessary. Load variability is an indicator of how much the electric load fluctuates within the hour. It is mathematically defined as the standard deviation of the load divided by the average load in each time step.

### 2.3.4 Energy Storage

In order to compare different amounts of energy storage, the nominal energy capacity in kWh of the battery bank is used. It is determined from the rated amp-hour capacity times the nominal battery bank voltage. Storage size can also be expressed as the amount of time that the total energy capacity of the battery bank could supply the average system load. A previous study done on Deering, Alaska indicates that the optimal amount of storage in a high-penetration wind-diesel system is one that is rated to cover peaks in the net load for up to 18 minutes. Beyond that, the rate of increased energy savings diminishes relative to the increased cost of storage equipment (Shrazi, et al. 2001). Therefore, in this report, only short-term storage options were considered.

The fluctuations in power needs of wind-diesel systems require robust, deep-cycle batteries capable of many cycles of charging and discharging. The most common types of batteries for power applications are lead acid and nickel-cadmium. Lead acid batteries are widely available in a range of sizes and capacities and are relatively inexpensive. However, their lifetime is typically limited to up to 1200 cycles, depending on the level and rate of discharge (Hunter, 1994) and the quality of maintenance. Nickel-cadmium (NiCad) batteries are able to survive more than 2,000 cycles and are able to be discharged to a lower level and at a faster rate than lead acid batteries. NiCads are also less sensitive to temperature; however, NiCad batteries are more expensive. The batteries used in this analysis were Alcad M340P Nicad batteries, which are included in the Hybrid2 library. The delivered cost was estimated to be $250 each. Battery specifications can be found in Appendix 3. A nominal battery lifetime of 15 years was specified, and the minimum battery state of charge below which the batteries will not be allowed to discharge was set at 20%.

The efficiency of a battery system is less than 80%, which decreases when coupled with the rotary converter unit. Other methods of energy storage, such as flywheels, compressed air, or hydro storage were not considered. Batteries were used in this analysis because they are currently the most cost-effective and field-proven industrial storage technology available with sufficient capacity and power delivery capability.

### 2.3.5 Wind Turbines

Cold weather climates, the lack of developed infrastructure, and the general small size of remote villages impose significant restrictions on the choice of wind turbine for a power system in Alaska. Turbine design considerations include the potential icing of sensors and blades, increased fatigue on components, and changes in material properties at lower temperatures, particularly with the gearbox oil and rubber seals. The installation and maintenance of wind turbines is also affected by extreme weather conditions. Deep snowfall can limit access to wind turbines, and sub-zero temperatures create additional safety issues. The physical size of the turbine components is restricted to their ability to fit on a plane or barge for shipment and the limited installation infrastructure in remote areas.

Another selection limitation is the small market for mid-sized wind turbines. Only a few manufacturers of mid-sized wind turbines have a presence in the U.S. and Canada. The modern wind turbines currently installed in Alaska include the 50 kW Atlantic Orient AOC15/50, the 100 kW Northern Power NW100/19, and the 225 kW Vestas V27. The Vestas V27 is no longer in commercial production; however, about 30 used machines are available for the Alaska market (Petrie,2004). The Fuhrländer Wind Turbine Company, which has a North American distributor, also makes wind turbines within the size range of interest, although none have yet been installed in Alaska (Lorax Energy Systems LLC, 2004).

All turbine power curves were adjusted to account for the higher air densities in cold climates. For example, an annual average temperature of –4°C leads to an air density of 1.31 kg/m$^3$. Therefore, a power curve scaling factor of 1.069 was used. The power curves for all wind turbines used in this analysis can be found in Appendix 2.

Due to the unique conditions of Alaska, particular costs are incurred during the installation of a wind energy system. For example, the wind turbine foundations are designed to have minimal impact on the frozen tundra, and often the installation must take place during the winter to ensure that the frozen ground will support the weight of the cranes, pile drivers, and fork lifts. Based on manufacturer or dealer estimates and data from previous installations in Alaska, Table 13 summarizes these costs. The Fuhrländer cost information is based on an exchange rate of 1 Euro = US $1.24 (July 19,2004).

**Table 13. Cost of Wind Turbines**

| Turbine Model | AOC 15/50 | NW100 | FL250 | FL100 | FL30 | V27 |
|---|---|---|---|---|---|---|
| Turbine & Tower | $ 90,000 | $ 230,000 | $451,000 | $232,000 | $90,000 | $230,000 |
| Shipping | $ 25,000 | $ 35,000 | $71,000 | $38,500 | $20,000 | $75,000 |
| Installation | $ 50,000 | $ 75,000 | $111,000 | $54,500 | $40,000 | $120,000 |
| Foundation | $100,000 | $100,000 | $132,000 | $90,000 | $37,500 | $150,000 |
| **Total (each)** | **$265,000** | **$ 440,000** | **$765,000** | **$415,000** | **$187,500** | **$575,000** |
| Total ($/kW) | $5,300 | $4,400 | $3,060 | $4,150 | $6,250 | $2,560 |
| Annual O&M | $3,000 | $4,500 | $7,000 | $5,000 | $4,000 | $7,000 |

The wind turbine operation and maintenance cost was based on one day of labor ($25/hr) plus a $300 air charter once every three months for a specialized mechanic from Anchorage, plus one day of labor ($12/hr) every month for a local mechanic. The cost includes a contingency of $850 to $3,850 per year depending on the turbine to cover any supplies. These numbers result in approximately $0.005 to $0.025 per kWh generated, depending on the turbine. According to the manufacturers, overhauls of the wind machines are not necessary for the life of the system (assumed to be 25 years); therefore, overhaul costs were not included in the analysis.

### 2.3.6 Balance of System Components

The balance of system cost can vary depending on the level of wind penetration. The higher the penetration, the more difficult it is to regulate system voltage and maintain an adequate power balance. In no-storage cases where diesels are allowed to shut off, an AC synchronous condenser is used to provide reactive power. The standing no-load loss of this machine was set at 2.5 kW. In systems with battery storage, a converter is needed to connect the AC and DC components. It converts the DC electricity from the batteries to the AC electricity used by the village loads and converts the AC electricity generated by the wind turbines into DC electricity that can be stored in the batteries. The efficiency of the conversion was set at 85%.

The figures listed in Table 14 represent the estimated cost of the equipment for the different levels of wind penetration. In the high-penetration case, either an AC synchronous condenser or batteries and a rotary converter can be installed. The cost listed for these components is an average value and was adjusted if necessary in the specific case studies.

**Table 14. Balance of System Component Costs**

| Description | Low-Penetration | Medium-Penetration | High-Penetration |
|---|---|---|---|
| Diesel Controls | $20,000 | $45,000 | $45,000 |
| Line Extensions | $40,000 | $40,000 | $40,000 |
| Insulated Container Shelter | $25,000 | $25,000 | $25,000 |
| Dump Load with Controller | - | $20,000 | $30,000 |
| Supervisory Controller | - | - | $50,000 |
| Battery Bank & Rotary Converter or AC Synchronous Condenser | - | - | $95,000 |
| Installation & Shipping | $25,000 | $35,000 | $45,000 |
| Total | $110,000 | $165,000 | $330,000 |

Depending on the complexity of the system, the total cost for a wind-diesel system can be up to $7,000/kW of rated wind power. These costs are expected to decrease as more experience is gained with the installation of wind turbines in arctic conditions.

### 2.3.7 Diesel Generators

Diesel generator efficiency and cost information was obtained either from AVEC records or from manufacturers. Fuel curves for diesels used in this analysis are included in Appendix 4. The benefits of a wind-diesel system include a potential reduction in diesel operation, maintenance, and overhaul costs. Approximate values for these costs are shown in Table 15.

**Table 15. Estimated Diesel Generator System Costs**

| Diesel Model | Rating (kW) | Capital Cost | O&M Cost ($/hour of operation) | Overhaul Cost ($/10,000 hours) |
|---|---|---|---|---|
| Generic | 125 | $75,000 | $3 | $20,000 |
| Cummins LTA10G1 | 175 | $110,000 | $4 | $20,000 |
| Cummins LTA10G1 | 203 | $125,000 | $5 | $20,000 |
| Detroit Diesel Series 60 | 207 | $125,000 | $5 | $20,000 |
| Caterpillar 3412 | 350 | $210,000 | $8 | $25,000 |
| Cummins LTA10G1 | 397 | $240,000 | $10 | $25,000 |
| Cummins K19G4 | 499 | $300,000 | $12 | $30,000 |
| Cummins VTA28G5 | 557 | $320,000 | $13 | $30,000 |
| Cummins VTA28G5 | 811 | $400,000 | $13 | $30,000 |

Annual operation and maintenance costs for the diesel generators were based on costs incurred by AVEC at several representative villages, which have ranged from $3 to $10 per operating hour. Operation and maintenance costs include labor and supplies for regular oil changes and inspections or any unexpected repairs. It does not include the regular operator wages, which would not be affected by reduced diesel run time. Since wind turbine components will be added to the existing diesel facility or implemented as part of a major plant overhaul, the diesel generator capital and installation costs were not included in the analysis.

### 2.3.8 Dispatch Strategies

In HOMER, the diesel generator control is set at "load following," which means that the diesel(s) provide just enough power to meet the load when needed. Hybrid2 allows for a wide range of dispatch strategies. In cases consisting of only diesel generators and wind turbines, the "diesel/renewable system control" strategy was used. In cases where batteries were added to the system, the "short-term power smoothing" strategy was specified, which uses the battery bank to cover short fluctuations in the net load so the diesels can be shut down, until the batteries reach a 20% state of charge. When the diesels are needed, they produce just enough to meet the load. Only excess wind power is used to charge the batteries.

Since the Hybrid2 and HOMER simulation codes "know" what the future maximum net load will be, they can assure that the minimum amount of diesel is dispatched to meet this load. An actual wind-diesel system cannot predict how much diesel will be needed and therefore must maintain enough spinning reserve to cover any sudden spikes in the net load. The operating reserve is particularly important in high-penetration systems since the diesel generators are allowed to shut down and require several minutes to start up. There are many factors that can influence the operating reserve setting, such as the ability of the wind turbine to respond to gusts or sudden changes in wind direction, the variability of the local wind resource, the short-term variability of the village load, the level of sophistication of the power converter, controls, and energy storage devices, and the community tolerance for power outages. In systems with batteries, it is assumed that the battery bank will be sized to provide this operating reserve. In order to model the operating reserve for no-storage systems in Hybrid2, an offset of 10% of the rated wind power of the system is added to the maximum net load.

The operating reserve is defined in HOMER as the "surplus generating capacity that allows the system to absorb sudden increases in load or decreases in renewable power output." Although energy storage devices were not directly modeled in HOMER, a fixed cost was added for high-penetration systems to allow for the installation of this equipment. Assuming that the batteries would provide some amount of back-up power allows a lower value to be set for the operating reserve. Therefore, the operating reserve is set at 10% of the total load and 15% of the available wind energy. The optimal system configuration is highly influenced by the amount of operating reserve that is specified; therefore, a sensitivity analysis is performed around this parameter.

### 2.3.9 Economics

The installation or upgrade of any power system in Alaska is often dependent on government funding sources and the availability of low-interest loans. State and federal funding, as well as funding from native or private corporations is available for projects in Alaska. Economic parameters based on figures that AVEC typically uses for project cost analysis are shown in Table 16.

**Table 16. Economic Parameters**

| | |
|---|---|
| Fuel Cost | $0.53/liter ($2.00/gal) |
| General Inflation Rate | 3% |
| Fuel Inflation Rate | 3% |
| Loan Interest Rate/ Discount Rate | 6% |
| Real Interest Rate | 3% |
| Project Lifetime | 25 years |

The current cost of diesel fuel is capped at $1.92 per gallon but is expected to rise (Vallee, July 2004). This report assumes a cost of $2.00 per gallon, and a sensitivity analysis is performed around this parameter. The annual real interest rate, which is used in HOMER, takes into account the general inflation rate and loan interest rate to allow for the conversion between one-time costs and annualized costs.

# CHAPTER 3

# FEASIBILITY STUDIES

The purpose of this section is to evaluate possibilities for incorporating renewable energy technologies into existing diesel power plants in seven Alaskan villages. The economic and technical feasibility of various types of wind energy systems will be considered, and initial recommendations will be made on system configuration.

Each feasibility study follows the same format. A brief introduction to each village is given, followed by the methodology and assumptions used in obtaining hourly electric load and wind speed data. The HOMER software tool was used to narrow down the possible power system design options, and these results are presented. The Hybrid2 software tool was then used to further refine the system design and to get a more accurate representation of the system's performance. The final system design and conclusions are given.

**Feasibility Study 1: Hooper Bay, Alaska**

Hooper Bay is a village of 1,115 people located 20 miles south of Cape Romanzof in the Yukon-Kuskokwim Delta, as shown in Figure 31 (Department of Community and Economic Development, May 2004). The climate is maritime, with temperatures ranging from –25º to 79ºF.


**Figure 31. Location of Hooper Bay, Alaska**

A large Yu'pik Eskimo community lives in Hooper Bay, with 96% of the total population being Alaska Native or part Native. According to the 2000 U.S. Census, the unemployment rate was 37%, the median household income was $26,667, and per capita income was $7,841. About 28% of the population was living below the poverty level. The primary means of support include commercial fishing and subsistence activities, such as harvesting salmon, walrus, beluga whale, and waterfowl. Ivory handicrafts and grass baskets are also produced. Seasonal employment is available in fish processing and fire fighting. Transportation services include a 3300-foot paved airstrip. Barge shipments are available when the Bering Sea is ice-free, usually from late June through October. Local transportation includes skiffs and all-terrain vehicles, and winter trails exist to the nearby villages of Scammon Bay, Chevak, and Paimiut (Department of Community and Economic Development, 2003).

Hooper Bay receives its electricity from a diesel power plant operated by the Alaska Village Electric Cooperative (AVEC). In 2002 the cost of diesel fuel delivered to Hooper Bay was $1.19 per gallon ($0.314/ liter), or about $0.094 per kWh. The average residential electric rate was $0.395 per kWh, which was reduced to $0.223 per kWh after the Power Cost Equalization program, an Alaska state subsidy.

**Energy Use in Hooper Bay**

Data obtained from the Alaska Village Electric Cooperative for the Hooper Bay power station and its customers was analyzed to determine energy use trends in the community. Like most Alaskan villages, the residential sector is the largest consumer of electricity, followed by the school and the public/municipal sector. Public buildings include city offices, a health clinic and a water treatment plant. According to the 2000 census, there are 240 housing units in Hooper Bay, with an average of 4.5 people per household. Most homes use fuel oil or kerosene for heat. The school in Hooper Bay is attended by about 390 students. Along with other electric loads typical in a school, the Hooper Bay school operates its own water and septic system.

As the second largest individual consumer of electricity, the energy requirements of the public water system are important. The public water system in Hooper Bay consists of a water treatment facility and several public watering points. Water is currently pumped from several wells, treated, and stored in tanks at the washeteria. Residents haul treated water from the washeteria or other public watering points and dump honeybuckets at wastewater collection points. Homes are currently not plumbed; however, major renovations are in progress, including a piped water and vacuum sewer system and a new water treatment/ washeteria facility (Department of Community and Economic Development, July 2004). The first connection will be the school, which is expected to occur at the end of 2005. All homes and buildings will be connected to the piped water and sewer system by 2010 (Coward, 2004). A summary of the electric and diesel fuel usage in Hooper Bay since 1996 is shown in Table 17. This information is also shown graphically in Figure 32.

**Table 17. Summary of Energy Use in Hooper Bay from 1996 – 2002**

| Year | Total kWh Generated | Average Load (kW) | Peak Load (kW) | Fuel Consumption (gal/yr) |
|---|---|---|---|---|
| 1996 | 2,566,700 | 218 | 466 | 148,000 |
| 1997 | 2,750,600 | 226 | 453 | 146,600 |
| 1998 | 2,680,600 | 244 | 492 | 176,200 |
| 1999 | 2,741,900 | 259 | 518 | 186,700 |
| 2000 | 2,969,600 | 274 | 530 | 186,800 |
| 2001 | 2,969,600 | 279 | 517 | 170,600 |
| 2002 | 2,960,900 | 272 | 519 | 170,000 |

The electric load in Hooper Bay has been increasing at an average rate of 3.8% per year since 1996. The largest increase (8%) occurred from 1997 to 1998 when new water wells and pumps were installed for the water treatment plant (Department of Community and Economic Development, June 2004).

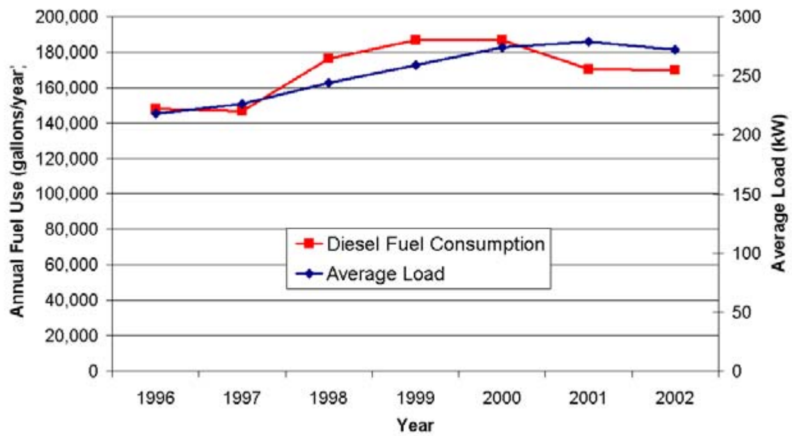



**Figure 32. Energy Use from 1996-2002 in Hooper Bay**

For modeling purposes, the expected village load in 2009 was used to evaluate the performance of a potential hybrid power system in Hooper Bay. Detailed electric load data is not currently available for Hooper Bay. Instead, an hourly data set was created based on the Alaska Village Electric Load Calculator method described in Chapter 1. A number of construction projects have been funded and are expected to be completed by 2009. These include major upgrades to the public water system, upgrades to the Satellite Building mechanical systems, additional housing, a youth/elder cultural center, and possibly a technical center (Rural Alaska Project Identification and Delivery System, 2004). The estimated electric load in Hooper Bay takes into account the addition of these facilities. The estimated data set is shown in Figure 33 and summarized in Appendix 5. A sensitivity analysis was done around this parameter.

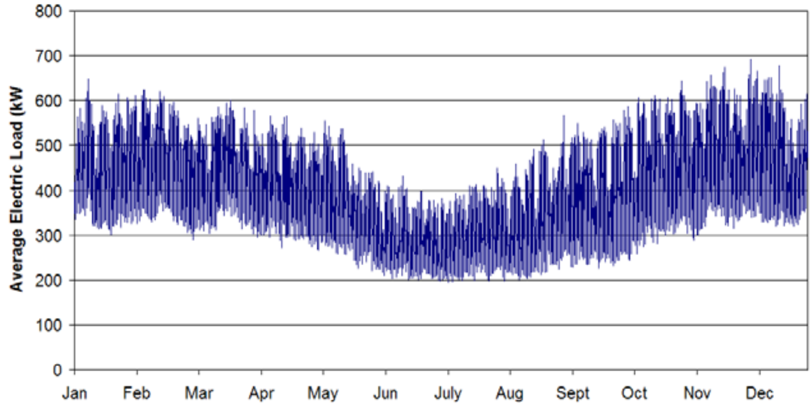



**Figure 33. Estimated 2009 Hourly Electric Load in Hooper Bay**

The electric load is expected to range from 193 to 692 kW, with an average of 400 kW. The expected diurnal load profile for each month of the year is shown in Figure 34.

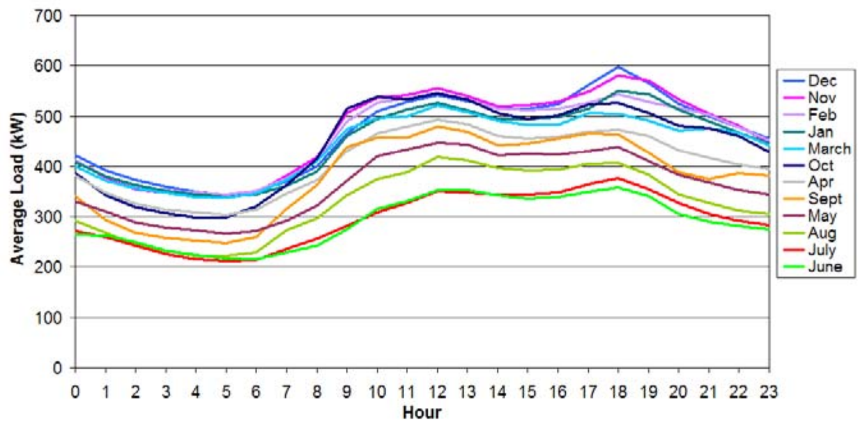



**Figure 34. Estimated 2009 Diurnal Load Profiles for Each Month in Hooper Bay**

**Existing Power Station in Hooper Bay**

The Hooper Bay power station includes four diesel generators totaling 2 MW of capacity:

1) 350 kW Caterpillar 3412
2) 350 kW Caterpillar 3412
3) 557 kW Cummins KTA2300
4) 811 kW Cummins KTA2300

The power system is manually controlled, although the plant operators currently tend to use one unit continuously for days at a time. Useable diesel storage capacity is 156,700 gallons, requiring about 3 shipments of fuel per year. The measured fuel curves for the diesel generators were obtained from AVEC and are shown in Appendix 4. For the purposes of modeling, the minimum allowed power is specified at 30% of rated power.

**Wind Resource in Hooper Bay**

Average hourly wind speeds from January 1999 through December 1999 were obtained from the Hooper Bay airport weather station (George, 2003). The data recovery rate was 88%. Any gaps in the data due to equipment or data recording failure were filled using the Hybrid2 Gapfiller program (University of Massachusetts Renewable Energy Research Lab, 2004). Most of the gaps were up to 3 hours in length; the largest gaps included an entire day in February and three consecutive days in July. Since only one year of hourly data was available, these values were scaled to meet the long-term (1994-2002) average monthly wind speeds at the same location. The adjusted wind speeds are shown in Figure 35 and Figure 36. The values that make up these graphs are tabulated in Appendix 6.

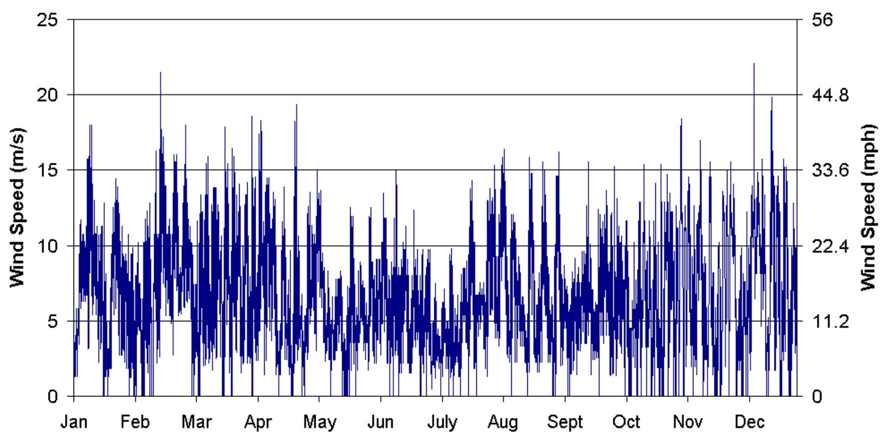



**Figure 35. Hourly Wind Speeds Measured at a 10-meter Height in Hooper Bay**

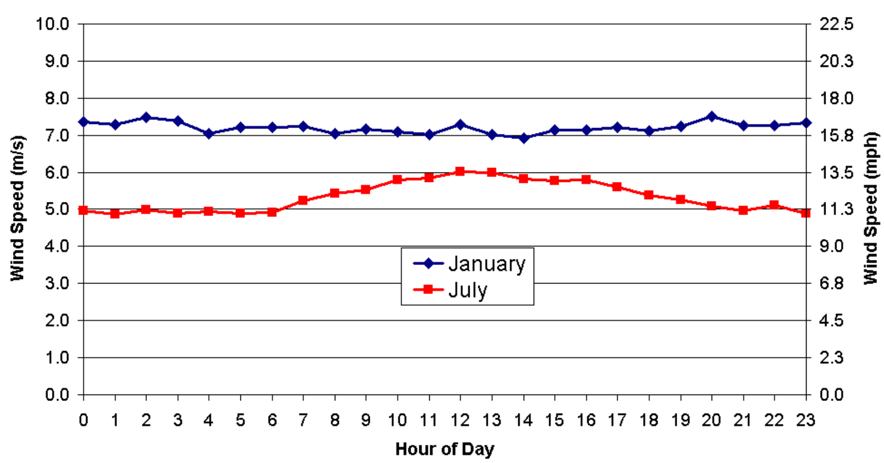



**Figure 36. Diurnal Wind Speed Profile for Hooper Bay**

The annual average wind speed for the year is 6.65 m/s (14.9 mph) at a 10-meter height, or 7.7 m/s (17.2 mph) at a typical hub height of 30-meters.  Airports are typically located in areas sheltered from the wind; therefore, the wind resource used in this report is a conservative estimate.  The draft wind resource map for Alaska suggests that Hooper Bay lies within a Class 6 wind regime with an annual average wind speed of 8.95 m/s (20 mph) at a 10-meter height (Heimiller, 2004).  A sensitivity analysis was conducted to account for the uncertainty of this data.

The wind frequency rose in Figure 37 was created by determining the percent of time that the wind comes from a particular direction.  It indicates that the prevailing wind direction is from the north and east quadrants.

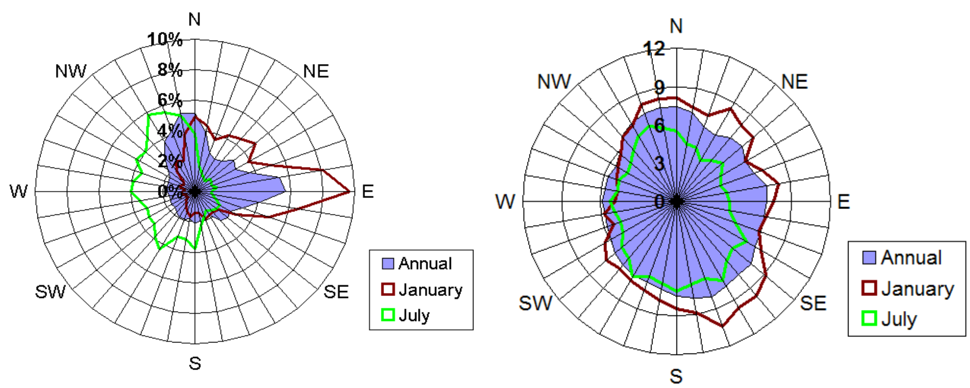



**Figure 37. Wind Frequency Rose and Wind Speed Rose for Hooper Bay**

The wind speed rose in Figure 37 was created by determining the average speed of the wind that comes from a particular direction.  It indicates that in general the wind has equal speed when coming from any direction.

## Power System Modeling Results for Hooper Bay

To compare the design options of a hybrid power system in Hooper Bay, the computer simulation model HOMER was used.  HOMER uses hourly electric load data and hourly wind speed data to compare the ability of different types and quantities of wind turbines to meet the village load given the local wind resource.  The existing diesel power station was modeled to determine the fuel consumption and cost of energy of the diesel-only system.  Table 18 summarizes the expected performance of the diesel-only power station, based on the year 2009 electric load data.

**Table 18. Expected 2009 Energy Requirements of Diesel-Only System in Hooper Bay**

| Total Energy Use | Peak Load | Average Load | Fuel Consumption | Net Present Cost |
|---|---|---|---|---|
| 3,496,700 kWh | 692 kW | 400 kW | 241,500 gal/yr (914,000 liters/yr) | $10,550,400 |

A sensitivity analysis was performed on the cost of diesel fuel, which has the most impact on the cost of energy in a diesel-only power system. The results are shown in Table 19.

**Table 19. Diesel-Only System Cost of Energy in Hooper Bay**

| Diesel Fuel Cost | Cost of Energy | Net Present Cost |
|---|---|---|
| $1.50/gallon ($0.40/liter) | $0.14 /kWh | $8,484,100 |
| $2.00/gallon ($0.53/liter) | $0.17 /kWh | $10,550,400 |
| $2.50/gallon ($0.66/liter) | $0.21 /kWh | $12,616,700 |
| $3.00/gallon ($0.79/liter) | $0.24 /kWh | $14,683,000 |

According to AVEC records, these diesel-related costs account for only about 40% of the total cost of electricity. The remainder includes other power generation expenses, such equipment and maintenance for the fuel tanks and transmission lines, administrative and general expenses, interest, and depreciation. However, these other expenses will still exist with a wind-diesel system. Therefore, the cost of energy listed in Table 19 is a benchmark, used to directly compare the diesel-related expenses with the wind-related expenses.

The impact of various numbers and types of wind turbines on fuel savings is shown graphically in Figure 38.

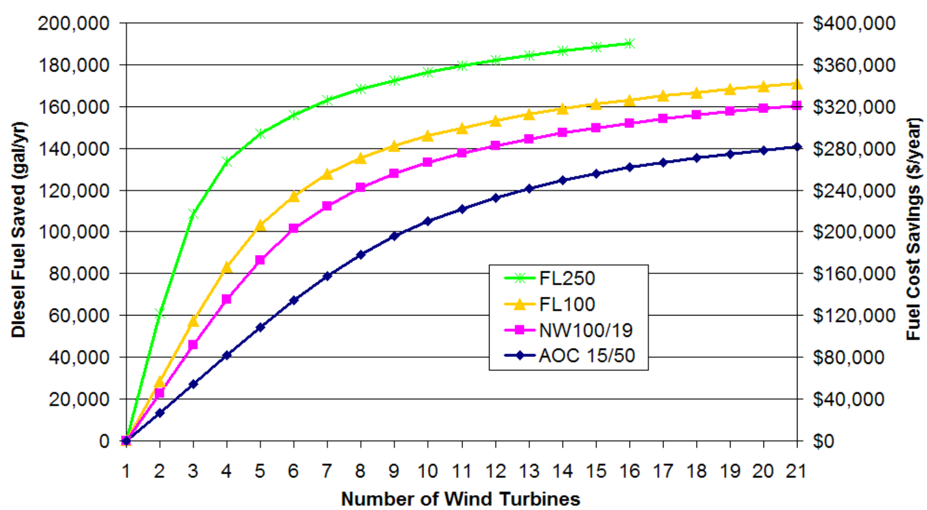



**Figure 38. Effect of Different Wind Turbines on Diesel Fuel Savings in Hooper Bay**

As the amount of wind generation increases, the fuel savings resulting from the incremental installation of a wind turbine increases, up to a point. After that, the rate of fuel savings decreases because some of the wind energy cannot be used to provide direct electrical loads. It should be noted, however, that different power system configurations require the installation of different balance of system and control equipment. The resulting comparison of performance indicators, such as fuel savings, must be held against the cost to achieve that savings.

Wind-diesel systems can be divided into three main levels, depending on the amount of wind capacity relative to diesel capacity. Low-penetration systems (up to 20% of the annual village load) are the most simple and require the least amount of initial investment for balance of system equipment. Medium-penetration systems (between 20% and 50% of the annual village load) require additional controls and a dump load, while high-penetration systems (over 50% of the village load) require equipment that will allow the diesels to be shut off for extended amounts of time. The system configurations for each penetration level that result in a lower levelized cost of energy than the diesel-only system are listed in Table 20. The options are ranked based on lowest cost of energy.

**Table 20. Low-penetration System Recommendations for Hooper Bay**

| Number of Wind Turbines | | | | Initial | Total Net | Cost of Energy | Renewable | Wind | Fuel Use | Fuel Use | Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | Capital | Present Cost | ($/kWh) | Fraction | Penetration | (L) | (Gal) | (Gal) |
| | | | 1 | $525,000 | $9,993,166 | $0.164 | 13% | 13% | 805,561 | 212,830 | 28,662 |
| 3 | | | | $905,000 | $10,006,537 | $0.164 | 19% | 19% | 758,970 | 200,520 | 40,971 |
| 2 | | | | $640,000 | $10,218,815 | $0.168 | 13% | 13% | 810,980 | 214,262 | 27,230 |
| | 1 | | | $550,000 | $10,240,689 | $0.168 | 11% | 11% | 828,102 | 218,785 | 22,706 |
| 1 | | | | $375,000 | $10,447,037 | $0.172 | 6% | 6% | 862,773 | 227,945 | 13,546 |
| Diesel-only | | | | $0 | $10,550,400 | $0.173 | 0% | 0% | 914,045 | 241,491 | 0 |

The least cost recommendation for a low penetration system, given Hooper Bay's load characteristics and wind regime, is the installation of one Fuhrländer FL100 wind turbine. The wind turbine would produce an average of 463,200 kWh per year, and no excess electricity would be generated. The installed cost of the wind turbine and related components is $525,000. The net present cost of operating this wind-diesel plant over the 25-year lifetime of the system is $9,993,000, compared to $10,550,000 for the existing diesel-only system.

**Table 21. Medium-penetration System Recommendations for Hooper Bay**

| Number of Wind Turbines | | | | | Initial | Total Net | Cost of Energy | Renewable | Ave Wind | Fuel Use | Fuel Use | Fuel Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | Capital | Present Cost | ($/kWh) | Fraction | Penetration | (L) | (Gal) | (Gal) |
| | | | | 2 | $1,315,000 | $8,439,927 | $0.139 | 43% | 44% | 572,375 | 151,222 | 90,269 |
| | | | 3 | | $1,410,000 | $8,850,323 | $0.145 | 39% | 40% | 599,117 | 158,287 | 83,204 |
| | | 1 | | | $930,000 | $9,133,807 | $0.150 | 28% | 28% | 683,192 | 180,500 | 60,992 |
| | 4 | | | | $1,925,000 | $9,243,149 | $0.152 | 41% | 42% | 586,784 | 155,029 | 86,463 |
| | | | 2 | | $995,000 | $9,399,851 | $0.154 | 26% | 27% | 696,808 | 184,097 | 57,394 |
| 7 | | | | | $2,020,000 | $9,425,495 | $0.155 | 42% | 44% | 576,169 | 152,224 | 89,267 |
| | | | | 1 | $740,000 | $9,472,979 | $0.156 | 22% | 22% | 732,458 | 193,516 | 47,975 |
| | 3 | | | | $1,485,000 | $9,499,712 | $0.156 | 31% | 32% | 657,524 | 173,718 | 67,773 |
| 6 | | | | | $1,755,000 | $9,528,437 | $0.156 | 37% | 38% | 615,339 | 162,573 | 78,918 |
| 5 | | | | | $1,490,000 | $9,657,842 | $0.159 | 31% | 32% | 658,625 | 174,009 | 67,482 |
| | 2 | | | | $1,045,000 | $9,888,643 | $0.162 | 21% | 21% | 741,225 | 195,832 | 45,659 |
| 4 | | | | | $1,225,000 | $9,847,904 | $0.162 | 25% | 25% | 707,724 | 186,981 | 54,510 |
| Diesel-only | | | | | $0 | $10,550,400 | $0.173 | 0% | 0% | 914,045 | 241,491 | 0 |

There are a number of medium-penetration system configurations that result in a lower cost of energy compared to the diesel-only case, as shown in Table 21. If the used Vestas V27 wind turbine is available, two of them should be installed to minimize the system cost of energy. If a used V27 is not available, the recommendation for a medium-penetration system, based on the lowest life-cycle cost of energy, is three Fuhrländer FL100 wind turbines. The wind turbines would produce an average of 1,390 MWh per year, and about 69 MWh per year of excess electricity would be available for a secondary or heating load. The installed cost of the wind turbine and related components is $1,410,000. The net present cost of operating this wind-diesel plant over the next 25 years is $8,850,000, compared to $10,550,000 for the diesel-only system.

**Table 22. High-penetration System Recommendations for Hooper Bay**

| Number of Wind Turbines | | | | | Initial | Total Net | Cost of Energy | Renewable | Wind | Fuel Use | Fuel Use | Fuel Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | Capital | Present Cost | ($/kWh) | Fraction | Penetration | (L) | (Gal) | (Gal) |
| | | 3 | | | $2,625,000 | $7,894,634 | $0.130 | 67% | 85% | 408,892 | 108,030 | 133,462 |
| | | | | 4 | $2,630,000 | $8,064,658 | $0.132 | 67% | 88% | 414,415 | 109,489 | 132,003 |
| | | | | 3 | $2,055,000 | $8,121,605 | $0.133 | 57% | 66% | 474,018 | 125,236 | 116,255 |
| | | 4 | | | $3,390,000 | $8,155,993 | $0.134 | 75% | 113% | 357,901 | 94,558 | 146,934 |
| | | 2 | | | $1,860,000 | $8,196,366 | $0.135 | 52% | 56% | 503,291 | 132,970 | 108,522 |
| | | | | 5 | $3,205,000 | $8,316,855 | $0.137 | 74% | 111% | 377,736 | 99,798 | 141,693 |
| | | | 5 | | $2,405,000 | $8,508,192 | $0.140 | 58% | 66% | 470,110 | 124,203 | 117,288 |
| | | | 6 | | $2,820,000 | $8,495,497 | $0.140 | 64% | 80% | 429,801 | 113,554 | 127,938 |
| | | | 4 | | $1,990,000 | $8,649,675 | $0.142 | 50% | 53% | 522,515 | 138,049 | 103,443 |
| | | | 7 | | $3,235,000 | $8,632,809 | $0.142 | 69% | 93% | 401,013 | 105,948 | 135,543 |
| Diesel-only | | | | | $0 | $10,550,400 | $0.173 | 0% | 0% | 914,045 | 241,491 | 0 |

There are a number of high-penetration system configurations that would result in a lower cost of energy compared to the diesel-only case, as shown in Table 22. The recommendation that results in the lowest life-cycle cost of energy is the installation of three Fuhrländer FL250 wind turbines. The wind turbines would produce an average of 2,955,115 kWh per year, and about 938,100 kWh of excess electricity would be available for a secondary or heating load. The installed cost of the wind turbine and related components is $2,625,000. The net present value of the costs of operating this wind-diesel plant over the lifetime of the system is $7,895,000, compared to $10,550,000 for the existing diesel-only system.

**Sensitivity Analysis for Hooper Bay System**

The system configuration with the lowest cost of energy, in this case a high-penetration system consisting of three FL250 turbines, was used as a basis for a sensitivity analysis. The sensitivity analysis was performed around the following key parameters: annual average wind speed, delivered diesel fuel price, wind turbine capital cost, wind turbine annual operation and maintenance cost, real interest rate, the average village electric load, and the level of operating reserve which is set based on the output of the wind turbine. The best estimate values for each of these parameters is listed in Table 23.

**Table 23. Best Guess Values for Baseline Sensitivity Analysis Parameters in Hooper Bay**

| Parameter | Best Guess Value |
|---|---|
| Wind Speed | 6.6 m/s (at a 10-meter height)<br>8.0 m/s (at hub height of 42-meters) |
| Diesel Price | $0.53/liter ($2.00/gallon) |
| Turbine Installed Cost | $765,000 |
| Turbine O&M Cost | $7,000/year ($0.005/kWh) |
| Operating Reserve (% of wind) | 15% |
| Real Interest Rate | 3% |
| Village Load (annual average) | 400 kW |

The best estimate values for the variables result in a cost of energy of $0.13/kWh.

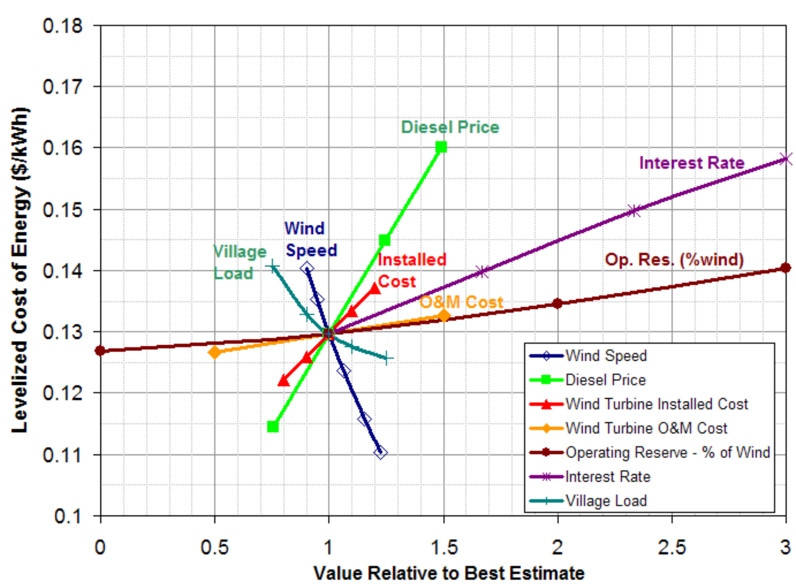



**Figure 39. Sensitivity Analysis Results for Wind-Diesel System in Hooper Bay**

As shown in Figure 39, the price of diesel fuel and the wind speed have the greatest direct impact on the cost of energy. If the diesel price increases by 25%, the cost of energy increases by $0.015/kWh. If the actual measured wind speed at the turbine location is 10% greater than the best estimate documented in this report, the cost of energy will decrease by $0.01/kWh. Since a Fuhrländer wind turbine has not yet been installed in Alaska, the actual installed cost of the system may be different from the best guess included in this report. If the actual installed cost of the FL250 machines is 20% greater than the best guess, or $918,000 each, then the levelized cost of energy would increase by less than $0.01/kWh over the best guess value of $0.13/kWh.

**Optional Loads in Hooper Bay**

An additional benefit of a high-penetration wind-diesel system is that the excess wind energy generated could supply power to an optional load. In Hooper Bay, excess energy could be used to provide space heat or hot water to the school or public water system. The school is located about 130 yards from the AVEC power station, while the water treatment facility is located about 600 yards away. The heating requirements of the school were not be quantified at this time.

The current water treatment plant uses about 15,000 gallons of #1 diesel fuel per year to provide space heat to the well houses and washeteria and to heat water for laundry services in the washeteria. The new public water facility will require that all the well water be pre-heated before being treated. Water will be distributed in a continuous loop, but it is unknown at this time whether the distribution pipes will be heated with a glycol loop or electric heat tape to keep them from freezing (Cowart, 2004). Assuming a heating value of 0.13 MMBtu per gallon for #1 diesel fuel and a boiler efficiency of 85%, the approximate monthly heating requirements of the current water treatment facility are calculated. Figure 40 compares the heating needs of the local water treatment facility with the amount of excess electricity that would be generated from a high-penetration wind-diesel system in Hooper Bay.

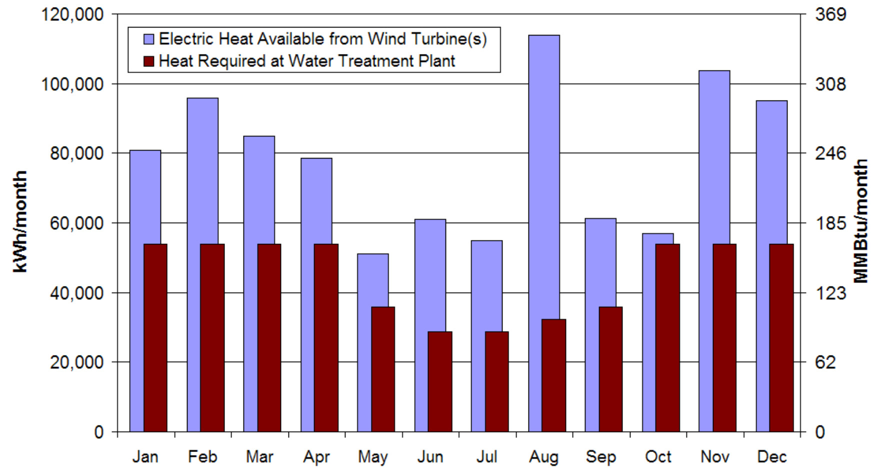



**Figure 40. Excess Electricity Available in a High Penetration System in Hooper Bay**

During most months, a heating load at the water treatment plant would absorb over half of the excess electricity from the three FL250 wind turbines. In order to absorb the remainder of the excess electricity, the school, health clinic, or power station could be added to the dump load system, or the wind turbines could be shut down when both the electric and heating loads are met. The exact size of the required dump load is not specified in this report.

### Detailed Analysis of Recommended System in Hooper Bay

The system configuration that was recommended from the HOMER analysis above was modeled in more detail using Hybrid2. Results for the diesel-only and the high-penetration wind-diesel case consisting of three FL250 wind turbines are shown in Table 24.

**Table 24. Comparison of Hybrid System Configurations to Diesel-Only Case in Hooper Bay**

| | Diesel-Only | | | Wind + Diesels | | | Wind + Diesels + Batteries | | |
|---|---|---|---|---|---|---|---|---|---|
| | 350kW | 557kW | 811kW | 350kW | 557kW | 811kW | 350kW | 557kW | 811kW |
| Diesel Run Hours | 954 | 4,343 | 3,576 | 4,206 | 2,823 | 1,427 | 4896 | 3286 | 4 |
| Diesel Starts | 219 | 561 | 415 | 976 | 1,027 | 461 | 723 | 282 | 3 |
| Fuel Consumed | 900,900 liters/yr | | | 508,400 liters/yr | | | 449,100 liters/yr | | |
| Diesel Production | 3,496,500 kWh/year | | | 1,830,200 kWh/year | | | 1,582,560 kWh/year | | |
| Cost of Energy | $0.22/kWh | | | $0.15/kWh | | | $0.13 /kWh | | |
| Simple Payback | 0 | | | 13 years | | | 11.5 years | | |
| Net Present Cost | $10,500,000 | | | $7,100,000 | | | $6,400,000 | | |

Simulations were performed to see if supplementary savings would result from the installation of a battery bank to cover short fluctuations in the net load. A battery bank size was chosen that would be able to meet the average load for about 12 minutes. The battery bank consists two rows of 120 Alcad M340P NiCad batteries wired in series for a total of 240V and 682 Ah (84 kWh) of rated capacity. In order to supply enough power for the average load, a 400 kW rotary converter is specified. The modeling results suggest that the installation of a battery bank does lead to fuel and cost savings, as shown in Table 24. The Hybrid2 output for the wind-diesel-battery simulation is included in Appendix 7. The majority of the savings between the wind-diesel system and the wind-diesel-battery system result from reduced fuel consumption as well as reduced diesel operation and maintenance costs. The battery bank displaced an additional 15,700 gallons of diesel fuel, saving $31,400 per year. The batteries also reduced total diesel run time by 270 hours per year, which is equivalent to about $2,970 in O&M costs avoided. The capital cost of the batteries and rotary converter is estimated to be $225,000.

**Conclusions for Hooper Bay Feasibility Study**

Given a diesel fuel price of $2.00 per gallon and the estimated wind resource (annual average of 6.64 m/s at a 10 meter height) in Hooper Bay, a number of hybrid power systems are feasible. The power system that results in the lowest lifecycle cost of energy is a high-penetration wind-diesel-battery hybrid system. The system consists of three Fuhrländer FL250 wind turbines, the existing diesel generators, and a 682 Ah battery bank. The cost of energy in Hooper Bay would be reduced by about $0.07 per kWh. About 103,700 gallons of diesel fuel would be saved per year, which is over half of Hooper Bay's current diesel storage capacity. The estimated installed cost of the various system components are listed in Table 25.

**Table 25. Installed Cost of Recommended System in Hooper Bay**

| Component | Installed Cost |
|---|---|
| Three FL250 Wind Turbines, including tower and foundation | $2,295,000 |
| 682 Ah Battery Bank and 400 kW Rotary Converter | $225,000 |
| Dump Load (size not specified) | $30,000 |
| Controls | $95,000 |
| Line Extensions, Insulated Container Shell | $65,000 |
| Overhead, Miscellaneous | $45,000 |
| Total | $2,755,000 |

**Feasibility Study 2: Chevak, Alaska**

Chevak is a Cup'ik Eskimo village that covers 1.1 square miles of land in the Yukon-Kuskokwim Delta on the north bank of the Niglikfak River. The climate is affected by heavy winds and rain from the Bering Sea.


**Figure 41. Location of Chevak, Alaska**

According to the 2000 census, 96% of the 850 residents are Alaska Native or part Native. Chevak is a rapidly growing community. Recently completed projects include a new landfill, washeteria upgrades, a new watering point, water treatment plant, water storage tank, sewage lagoon, and a vacuum sewer plant (Dept of Community and Economic Development, 2004).

**Energy Use in Chevak**

Chevak receives its electricity from a diesel power plant operated by the Alaska Village Electric Cooperative (AVEC). Data obtained from AVEC for the Chevak power station and its customers was analyzed to determine energy use trends. Figure 42 shows the approximate breakdown of electric use in the village.

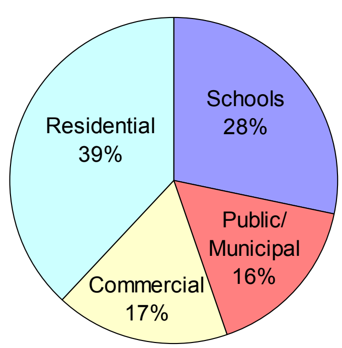



**Figure 42. Major Energy Use Sectors in Chevak**

The residential sector is the largest consumer of electricity. According to the 2000 census, there are 190 housing units in Chevak, with an average of 4.5 people per household. Nearly all of the homes are connected to the electric grid, and most homes use kerosene or fuel oil for heating. The major individual consumers of electricity in the village are the school, the water treatment plant, and a few commercial enterprises. Public facilities include a post office, armory, airport and a health clinic. In 2002, the community completed construction of a new K-12 school, which is attended by 350 students.

As the second largest individual consumer of electricity, the characteristics of the public water system are important. The village began construction of a piped water and sewer system in 1995, and nearly all of the homes and the health clinic are currently connected. Un-served residents haul water from a central source or have rain catchment systems. Well water is treated and pumped into a 150,000-gallon storage tank, which is filled daily. The water treatment plant uses four oil-fired boilers to heat a glycol loop for heating the building and above ground water mains. A washeteria is located next to the water treatment plant and is equipped with a number of electric washers and dryers. A separate public health service vacuum plant flushes sewage to the lagoon (Department of Community and Economic Development, 2004).

Based on power plant production data monitored by AVEC, a year of average hourly electric load data was collected, as shown in Figure 43.

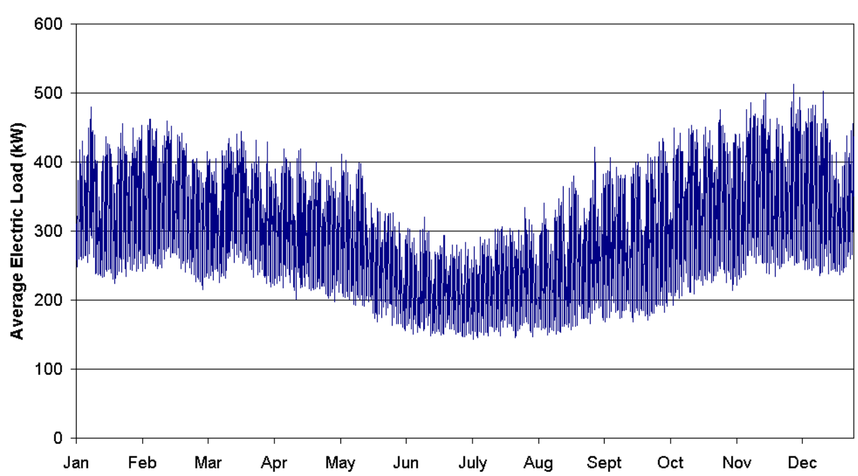



**Figure 43. Hourly Electric Load in Chevak**

Like most Alaskan villages, there is a higher consumption of electricity in the winter than in the summer in Chevak. The diurnal load profile for an average day in each month is shown in Figure 44. These profiles were created by averaging each hour of each day within the month.

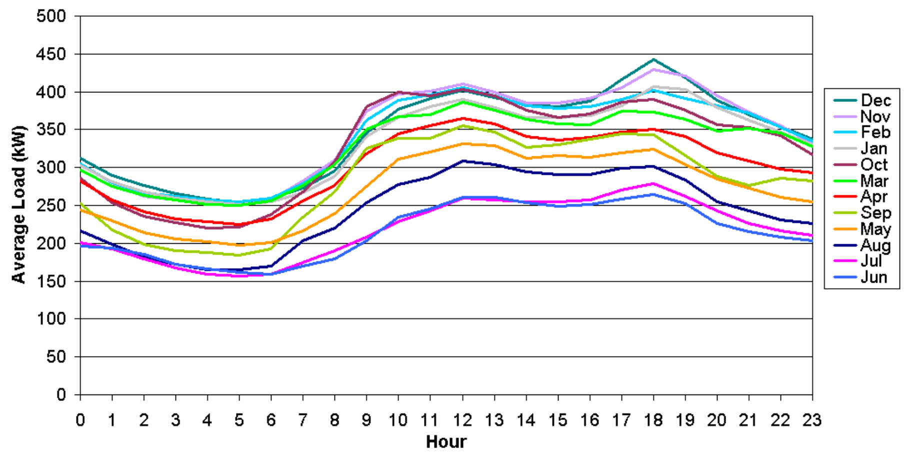



**Figure 44. Diurnal Load Profiles for Each Month in Chevak**

The winter load profiles show a sharp increase in the village load from 7:00AM to a peak around 12:00PM. The load dips slightly in mid-afternoon and peaks again in the early evening around 6:00PM. The summer profile follows the same pattern but is less pronounced. A summary of the electric and diesel fuel consumption from 1996 to 2002 is shown in Table 26.

**Table 26. Summary of Energy Use in Chevak from 1996 – 2002**

| Year | Total kWh Generated | Average Load | Peak Load | Fuel Consumption | Delivered cost of Fuel | Cost of Generation |
|---|---|---|---|---|---|---|
| 1996 | 1,410,000 | 160 kW | 336 kW | 115,670 gal/yr | $1.14/gal | 9.4 ¢/kWh |
| 1997 | 1,550,600 | 177 kW | 336 kW | 115,170 gal/yr | $1.15/gal | 8.5 ¢/kWh |
| 1998 | 1,580,900 | 181 kW | 354 kW | 125,440 gal/yr | $1.07/gal | 8.5 ¢/kWh |
| 1999 | 1,698,000 | 190 kW | 362 kW | 118,900 gal/yr | $1.03/gal | 7.4 ¢/kWh |
| 2000 | 1,700,600 | 194 kW | 371 kW | 132,070 gal/yr | $1.13/gal | 8.8 ¢/kWh |
| 2001 | 1,860,500 | 212 kW | 432 kW | 141,090 gal/yr | $1.23/gal | 9.3 ¢/kWh |
| 2002 | 2,173,400 | 249 kW | 501 kW | 160,230 gal/yr | $1.18/gal | 8.7 ¢/kWh |

The electric load in Chevak has increased at an average rate of 8% per year since 1996. The largest increase has occurred in recent years, as the village load grew 9% between 2000 and 2001 and 17% between 2001 and 2002. The recent load growth in Chevak is primarily due to the connection of nearly all homes and public buildings to the electric grid and piped water system. Figure 45 illustrates this growth.

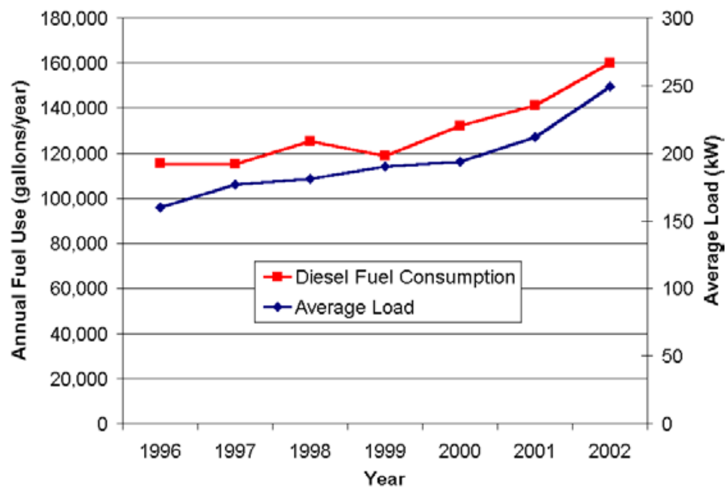



**Figure 45. Increase of Average Load and Fuel Consumption in Chevak**

For modeling purposes, the expected village load in 2009 was used to evaluate the performance of a potential hybrid power system. Although Chevak has seen rapid growth in electric consumption in recent years, it is expected that this growth will level out as the upgrade of major public facilities is nearing completion. Since the 2003 electric load data was collected, a new K-12 school came online and additional water and sewer service improvements were completed. Additional construction projects have been funded and are expected to be complete by 2009. These projects include a number of housing blocks and a potential multi-purpose building (Rural Alaska Project Identification and Delivery System, 2004). The 2003 load was scaled up based on the addition of these new facilities using the Alaska Village Electric Load Calculator method described in Chapter 1. The modified values for 2009 are listed in Appendix 5, and a sensitivity analysis was performed around this parameter.

### Existing Power Station in Chevak

The Chevak power station includes three diesel generators totaling 1.2 MW of rated capacity:

1) 499 kW Cummins KTA19G4
2) 350 kW Caterpillar 3412
3) 314 kW Detroit Diesel Series 60

The current power system is manually controlled, although the plant operators tend to use one unit continuously for days at a time. The diesels are equipped with heat exchangers to provide space heating to the plant facilities. Useable diesel storage capacity is 136,700 gallons, requiring 4 or 5 shipments of fuel per year. The actual measured fuel curves for the diesel generators were obtained from AVEC and are shown in Appendix 4. The Cummins KTA19G4 fuel curve is based on measured data from a Cummins VTA-28G5 generator. For the purposes of modeling, the minimum allowed power was specified at 30% of rated power.

**Wind Resource in Chevak**

Detailed wind speed information for Chevak is not available at this time. Therefore, the wind speed data for Hooper Bay, located 15 miles to the west, was used. Since both villages are located along the shores of the Hooper Bay and are surrounded by flat terrain, it is reasonable to assume that the wind resource is similar between the two villages. However, since Chevak is located more inland than Hooper Bay, it is expected that the wind speed will be slightly lower than in Hooper Bay. To account for this difference a lower wind shear factor is used when scaling the wind speed to the wind turbine hub height (Schwartz, 2004). A sensitivity analysis is also conducted to account for the uncertainty of this wind resource. The hourly wind resource in Hooper Bay is shown in Figure 46. The seasonal and diurnal wind speed profiles are shown in Figure 47 and Figure 48, respectively.

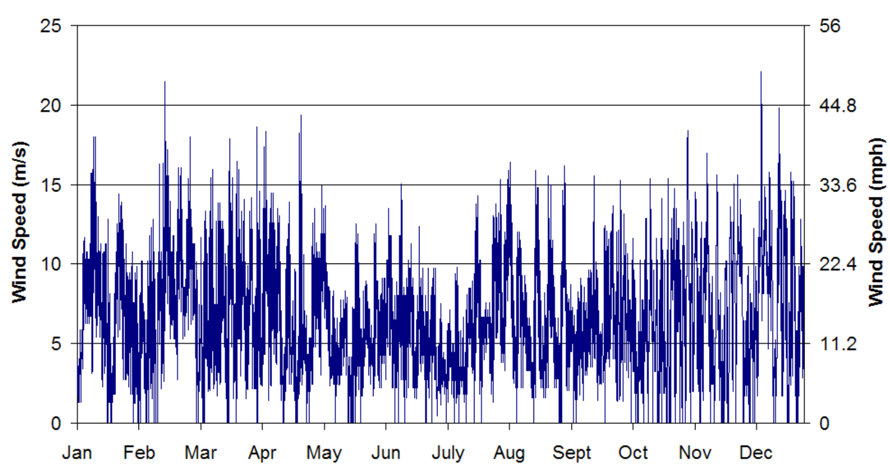



**Figure 46. Average Hourly Wind Speeds in Chevak (based on Hooper Bay)**

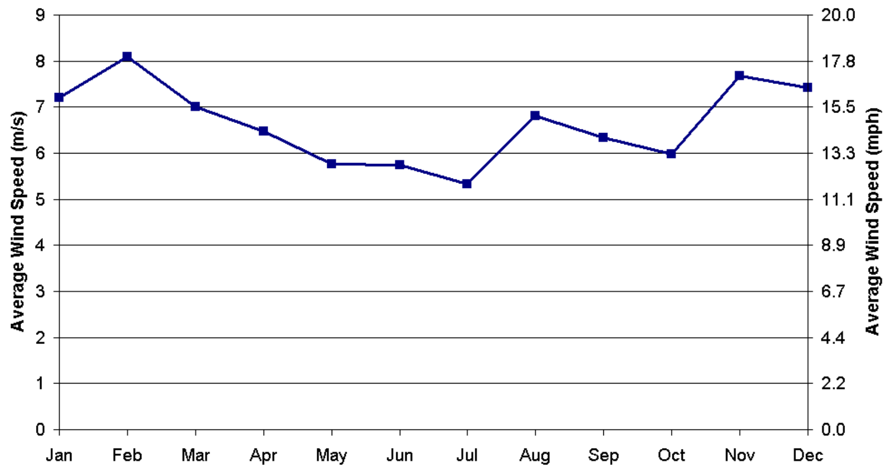



**Figure 47. Seasonal Wind Speed Profile for Chevak (based on Hooper Bay)**

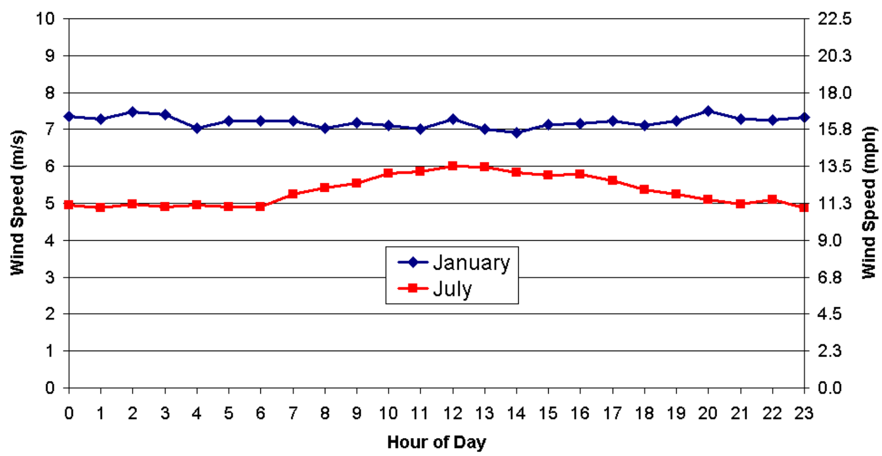



**Figure 48. Diurnal Wind Speed Profile for Chevak (based on Hooper Bay)**

The estimated annual average wind speed for the year is 6.65 m/s (14.9 mph) at a 10-meter height or 7.55 m/s (16.9 mph) at a typical hub height of 30-meters. The maximum hourly average wind speed recorded is 22.1 m/s. It is important to note that since the local wind resource has a significant effect on the power production from wind turbines, the wind speed at the proposed location should be monitored before any action is taken. This report uses the best estimate based on the assumptions described above. The draft wind resource map for Alaska suggests that Chevak lies within a Class 5 wind regime with an annual average wind speed of 8.15 m/s (18.2 mph) at a 10-meter height (Heimiller, 2004). A sensitivity analysis was conducted to account for the uncertainty of this data.

**Power System Modeling Results for Chevak**

To compare the design options of a hybrid power system in Chevak, the computer simulation model HOMER was used. HOMER uses hourly electric load data and hourly wind speed data to compare the ability of different types and quantities of wind turbines to meet the village load given the local wind resource. The existing diesel power station was modeled to determine the fuel consumption and cost of energy of the diesel-only system. Table 27 summarizes the expected performance of the diesel-only power station, based on the year 2009 electric load data.

**Table 27. Expected Energy Requirements in 2009 in Chevak**

| Energy Required | Peak Load | Average | Fuel Consumption | Net Present Cost |
|---|---|---|---|---|
| 2,889,000 kWh/yr | 576 kW | 330 kW | 197,100 gal/yr (746,200 liters/yr) | $8,873,600 |

A sensitivity analysis was performed on the cost of diesel fuel, which has the most impact on the cost of energy. The results are shown in Table 28.

**Table 28. Diesel-Only Base Case Cost of Energy in Chevak**

| Diesel Fuel Cost | Cost of Energy | Net Present Cost |
|---|---|---|
| $1.50/gallon ($0.40/liter) | $0.14 /kWh | $7,184,500 |
| $2.00/gallon ($0.53/liter) | $0.18 /kWh | $8,873,600 |
| $2.50/gallon ($0.66/liter) | $0.21 /kWh | $10,562,800 |
| $3.00/gallon ($0.79/liter) | $0.24 /kWh | $12,251,900 |

According to AVEC records, these diesel-related costs account for only about 40% of the total cost of electricity. The remainder includes other power generation expenses, such equipment and maintenance for the fuel tanks and transmission lines, administrative and general expenses, interest, and depreciation. However, these other expenses will still exist with a wind-diesel hybrid system. Therefore, the cost of energy listed in Table 28 is a benchmark, used to directly compare the diesel-related expenses with the wind-related expenses.

The impact of various numbers and types of wind turbines on fuel savings in Chevak is shown graphically in Figure 49.

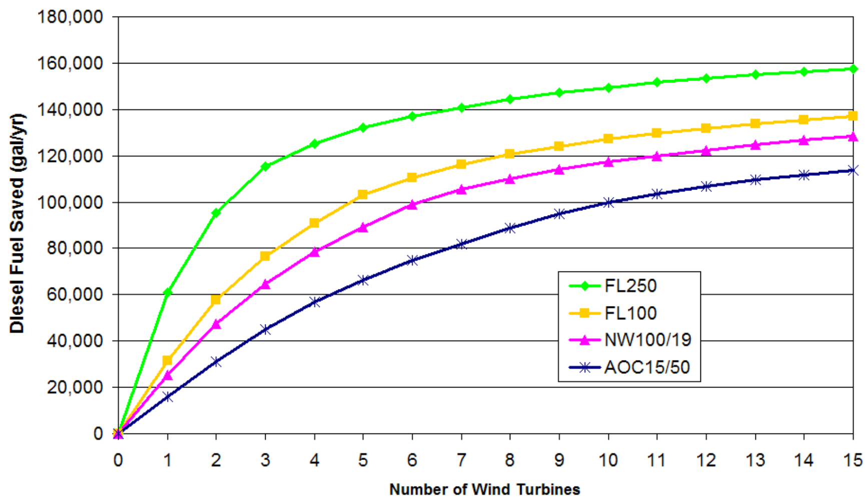



**Figure 49. Effect of Different Wind Turbines on Diesel Fuel Savings in Chevak**

The figure shows that as the amount of wind generation increases, the fuel savings resulting from the incremental installation of a wind turbine increases, up to a point. After that, the rate of fuel savings decreases because some of the wind energy cannot be used to provide direct electrical loads. It should be noted however, that different power system configurations require the installation of different balance of system components and control equipment. The resulting comparison of performance indicators, such as fuel savings, must be held against the cost to achieve that savings.

Wind-diesel systems can be divided into three main levels, depending on the amount of wind capacity relative to diesel capacity. Low-penetration systems (up to 20% of the annual village load) are the most simple and require the least amount of initial investment for balance of system equipment. Medium-penetration systems (between 20 and 50% of the annual village load) require additional controls and a dump load, while high-penetration systems (over 50% of the village load) require equipment that will allow the diesels to be shut off for extended amounts of time. The system configurations for each penetration level that result in a lower levelized cost of energy than the diesel-only system are listed below. The options are ranked based on lowest cost of energy.

**Table 29. Low-penetration System Options for Chevak**

| Number of Wind Turbines | | | | | Initial Capital | Total Net Present Cost | Cost of Energy ($/kWh) | Wind Penetration | Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | FL30 | | | | | | | |
| | | | 1 | | $525,000 | $8,236,870 | $0.164 | 16% | 627,497 | 165,785 | 31,358 |
| 2 | | | | | $640,000 | $8,421,551 | $0.167 | 16% | 629,129 | 166,216 | 30,927 |
| | 1 | | | | $550,000 | $8,484,658 | $0.169 | 13% | 650,834 | 171,951 | 25,193 |
| | | | | 4 | $860,000 | $8,516,343 | $0.169 | 19% | 603,448 | 159,431 | 37,712 |
| | | | | 3 | $672,500 | $8,604,751 | $0.171 | 15% | 637,232 | 168,357 | 28,786 |
| 1 | | | | | $375,000 | $8,668,433 | $0.172 | 8% | 685,564 | 181,127 | 16,017 |
| | | | | 2 | $485,000 | $8,709,637 | $0.173 | 10% | 672,349 | 177,635 | 19,508 |
| | | | | 1 | $297,500 | $8,834,104 | $0.176 | 5% | 708,526 | 187,193 | 9,950 |
| Diesel-only | | | | | $0 | $8,873,600 | $0.176 | 0% | 746,188 | 197,143 | 0 |

As shown in Table 29, a number of low-penetration systems result in a lower cost of energy than the diesel-only system. The option with the lowest levelized cost of energy is the installation of one Fuhrländer FL100 wind turbine. The wind turbine would produce an average of 463,200 kWh per year, and no excess electricity would be generated. The installed cost of the wind turbine and related components is $525,000. The net present cost of operating this wind-diesel plant over the 25-year lifetime of the project is $8,236,900, compared to $8,873,600 for the existing diesel-only system.

**Table 30. Medium-penetration System Options for Chevak**

| Number of Wind Turbines | | | | | Initial Capital | Total Net Present Cost | Cost of Energy ($/kWh) | Wind Penetration | Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | | | | | | | |
| | | | 3 | | $1,410,000 | $7,495,732 | $0.149 | 48% | 456,997 | 120,739 | 76,404 |
| | | 1 | | | $930,000 | $7,535,540 | $0.150 | 34% | 515,806 | 136,276 | 60,867 |
| | | | | 1 | $740,000 | $7,776,437 | $0.155 | 27% | 557,665 | 147,336 | 49,808 |
| | | | 2 | | $995,000 | $7,774,260 | $0.155 | 32% | 527,640 | 139,403 | 57,741 |
| | 3 | | | | $1,485,000 | $8,019,414 | $0.159 | 38% | 501,124 | 132,397 | 64,746 |
| 6 | | | | | $1,755,000 | $8,061,064 | $0.160 | 48% | 463,540 | 122,468 | 74,676 |
| 5 | | | | | $1,490,000 | $8,108,680 | $0.161 | 40% | 495,771 | 130,983 | 66,160 |
| 4 | | | | | $1,225,000 | $8,146,762 | $0.162 | 32% | 531,423 | 140,402 | 56,741 |
| | 2 | | | | $1,045,000 | $8,184,602 | $0.163 | 26% | 566,182 | 149,586 | 47,558 |
| 3 | | | | | $960,000 | $8,272,547 | $0.164 | 24% | 576,359 | 152,275 | 44,869 |
| Diesel-only | | | | | $0 | $8,873,600 | $0.176 | 0% | 746,188 | 197,143 | 0 |

There are a number of medium-penetration system configurations that result in a lower cost of energy compared to the diesel-only case, as shown in Table 30. The recommendation for a medium-penetration system, based on the lowest life-cycle cost of energy, is the installation of three Fuhrländer FL100 wind turbines. The wind turbines would produce an average of 1,389,600 kWh per year, and about 248,800 kWh per year of excess electricity would be available for a secondary or heating load. The installed cost of the wind turbine and related components is $1,410,000. The net present value of the costs of operating this wind-diesel plant over the next 25 years is $7,496,000, compared to $8,874,000 for the existing diesel-only system.

**Table 31. High-Penetration System Options for Chevak**

| Number of Wind Turbines | | | | | Initial | Total Net | Cost of Energy | Wind | Fuel Use | Fuel Use | Fuel Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | Capital | Present Cost | ($/kWh) | Penetration | (L) | (Gal) | (Gal) |
| | | 3 | | | $2,625,000 | $6,907,861 | $0.137 | 102% | 309,849 | 81,862 | 115,281 |
| | | | | 3 | $2,055,000 | $6,945,839 | $0.138 | 80% | 358,728 | 94,776 | 102,367 |
| | | 2 | | | $1,860,000 | $7,020,463 | $0.140 | 68% | 384,919 | 101,696 | 95,448 |
| | | | | 4 | $2,630,000 | $7,103,345 | $0.141 | 107% | 316,935 | 83,734 | 113,409 |
| | | | | 2 | $1,480,000 | $7,298,579 | $0.145 | 54% | 438,021 | 115,725 | 81,418 |
| | | 4 | | | $3,390,000 | $7,308,208 | $0.145 | 136% | 271,955 | 71,851 | 125,293 |
| | | | 5 | | $2,405,000 | $7,345,771 | $0.146 | 80% | 356,550 | 94,201 | 102,943 |
| | | | | 5 | $3,205,000 | $7,445,452 | $0.148 | 134% | 289,474 | 76,479 | 120,664 |
| | | | 4 | | $1,990,000 | $7,460,770 | $0.148 | 64% | 402,135 | 106,244 | 90,899 |
| | | | 6 | | $2,820,000 | $7,463,357 | $0.148 | 96% | 327,464 | 86,516 | 110,627 |
| Diesel-only | | | | | $0 | $8,873,600 | $0.176 | 0% | 746,188 | 197,143 | 0 |

A number of high-penetration system configurations result in a lower cost of energy than the diesel-only case, as shown in Table 31. The recommendation resulting in the lowest life-cycle cost of energy is the installation of three Fuhrländer FL250 wind turbines. The wind turbines would produce an average of 2,955 MWh per year, and about 1,253 MWh of excess electricity would be available for a heating load. The installed cost of the wind turbine and related components is $2,625,000. The net present value of the costs of operating this wind-diesel plant over the lifetime of the system is $6,908,000, compared to $8,874,000 for the diesel-only system.

**Sensitivity Analysis for Chevak System**

The system configuration with the lowest cost of energy, in this case the high-penetration system consisting of three FL250 wind turbines, was used as a basis for a sensitivity analysis. The sensitivity analysis was performed around the following key parameters: annual average wind speed, delivered diesel fuel price, wind turbine capital cost, wind turbine annual operation and maintenance cost, the village electric load, the level of operating reserve which is set based on the output of the wind turbine, and the level of operating reserve based on the village load. The best estimate values for each of these parameters is listed in Table 32.

**Table 32. Best Guess Values for Baseline Sensitivity Analysis Parameters in Chevak**

| Parameter | Best Guess Value |
|---|---|
| Wind Speed | 6.65 m/s (at a 10-meter height)<br>7.83 m/s (at hub height of 42-meters) |
| Diesel Price | $0.53/liter ($2.00/gallon) |
| Turbine Installed Cost (3 FL250's) | $2,295,000 |
| Turbine O&M Cost (total) | $21,000/year ($0.005/kWh) |
| Operating Reserve (% of load) | 10% |
| Operating Reserve (% of wind) | 15% |
| Primary Village Load (annual average) | 330 kW |

As indicated in Figure 50, the best estimate values for the variables result in a cost of energy of $0.138/kWh.

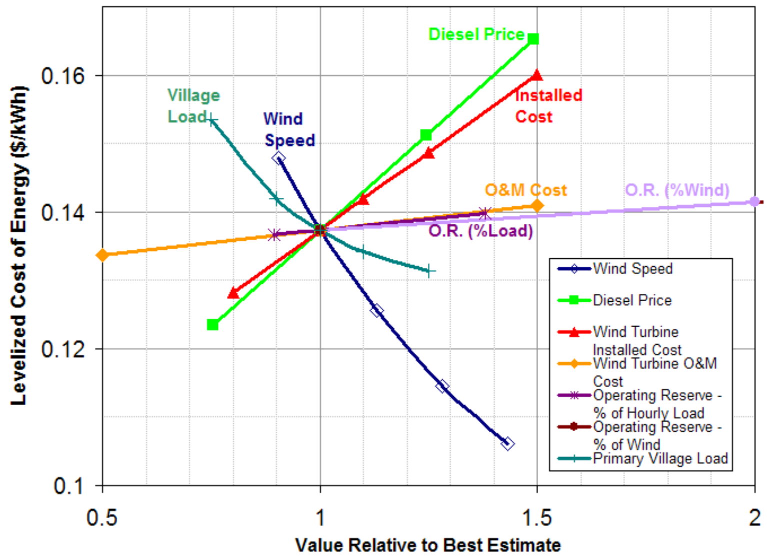



**Figure 50. Sensitivity Analysis Results for Wind-Diesel System in Chevak**

The price of diesel fuel and the wind speed have the greatest direct impact on the cost of energy. If the diesel price increases by 25%, the cost of energy increases by about $0.015/kWh. If the actual measured wind speed at the turbine location is 10% greater than the best estimate documented in this report, the cost of energy will decrease by about one cent per kWh. Since a Fuhrländer wind turbine has not yet been installed in Alaska, the actual cost of the system may be different from the best guess included in this report. If the actual installed cost of the FL250 machine is 20% greater than the best guess, or $918,000 each, then the levelized cost of energy would increase by about $0.01/kWh over the best guess value of $0.138/kWh. In order to ensure system reliability, the system may be designed to maintain a higher operating reserve. Figure 50 shows that if the operating reserve were set at 30% of the output of the wind turbine, in addition to the amount of reserve provided by the battery bank, then the cost of energy would increase by about $0.005/kWh.

### Optional Heating Loads in Chevak

Excess energy generated by the wind turbines could be used to provide heat to the village school, health clinic, or water treatment facility in Chevak. Currently, heat is recovered from the diesel generators to provide hot water to the school. Since the wind turbines are reducing the run time of the diesels, the excess electricity must also make up for the reduced heat provided by the diesels. The heating loads of the school or the power plant have not been quantified, but a wind system dump load could be incorporated into the existing heat recovery system. The water treatment plant could also be added to the system to ensure that the year-round heating requirements are large enough to absorb excess energy from the wind turbines.

The Chevak water plant, located 2 blocks from the power plant, currently uses an oil-fired furnace to provide hot water. According to plant personnel, the facility consumes 5,000 gallons of #1 fuel oil each month in the winter and 2,000 gallons per month during the summer. Assuming a heating value of 0.13 MMBtu per gallon of fuel and a boiler efficiency of 85%, the approximate monthly heating requirements were calculated. Figure 51 compares the heating needs of the local water treatment facility with the amount of excess electricity that would be generated from a high-penetration wind-diesel system in Chevak.

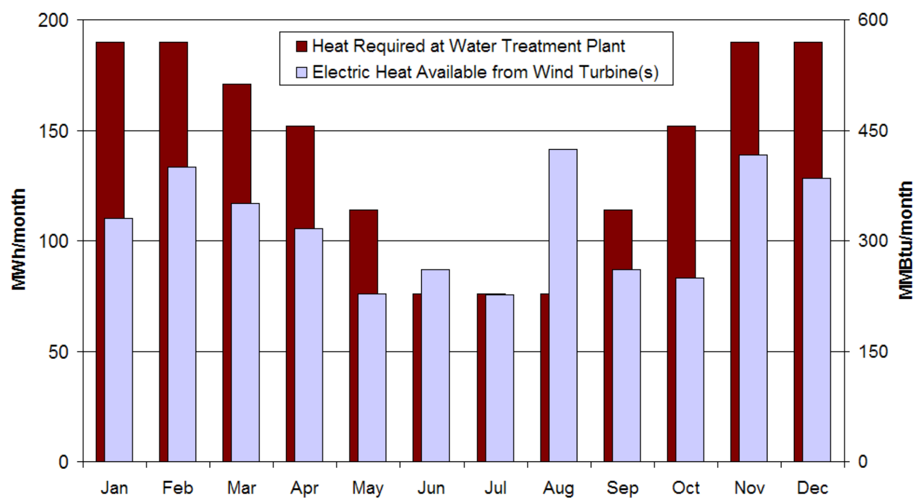



**Figure 51. Excess Electricity Available Versus Water Treatment Plant Needs in Chevak**

During most months, the demand for heat at the water treatment plant exceeds that which the wind turbines could supply. With the loads from the school and power plant, it is believed that the heating demands of the village would be more than enough to absorb any excess electricity generated by the wind turbines. The actual size of the dump load required was not specified.

**Detailed Analysis of Recommended System for Chevak**

The system configuration that was recommended from the HOMER analysis above was modeled in more detail using Hybrid2. Results for the diesel-only and the high-penetration wind-diesel case consisting of three FL250 wind turbines are shown in Table 33.

**Table 33. Comparison of Hybrid System to Diesel-Only Case in Chevak**

| | Diesel-Only | | | Wind + Diesels | | | Wind + Diesels + Batteries | | |
|---|---|---|---|---|---|---|---|---|---|
| | 314kW | 350kW | 499kW | 314kW | 350kW | 499kW | 314kW | 350kW | 499kW |
| Diesel Run Hours | 4,320 | 3,424 | 3,963 | 5,385 | 1,599 | 2,088 | 3,354 | 1,009 | 1,340 |
| Diesel Starts | 505 | 781 | 663 | 1,141 | 780 | 879 | 1,111 | 482 | 519 |
| Fuel Consumed | 206,600 gallons/yr | | | 106,400 gallons/yr | | | 83,900 gallons/yr | | |
| Diesel Production | 2,889,000 kWh/year | | | 1,453,200 kWh/year | | | 1,171,800 kWh/year | | |
| Cost of Energy | $0.12 /kWh | | | $0.09 /kWh | | | $0.07 /kWh | | |
| Net Present Cost | $4,266,000 | | | $3,044,000 | | | $2,167,000 | | |

Simulations were performed to see if supplementary savings would result from the installation of a battery bank to cover short increases in the net load. A battery bank size was chosen that would be able to meet the average load for about 15 minutes. The battery bank consists two rows of 120 Alcad M340P NiCad batteries wired in series for a total of 240V and 682 Ah (84 kWh) of rated capacity. In order to supply enough power for the average load, a 400 kW rotary converter is specified. The modeling results suggest that the installation of a battery bank does lead to fuel and cost savings, as shown in Table 33.

The majority of the savings between the wind-diesel system and the wind-diesel-battery system result from reduced fuel consumption as well as reduced diesel operation and maintenance costs. The battery bank displaced an additional 22,500 gallons of diesel fuel, saving $45,000 per year. The batteries also reduced total diesel run time by an additional 3,369 hours per year, which is equivalent to about $30,300 in O&M costs avoided. With reduced run time and less frequent starts and stops, the lives of the generators are also extended. The capital cost of the batteries and rotary converter is estimated to be $225,000.

**Conclusions for Chevak Feasibility Study**

Given a diesel fuel price of $2.00 per gallon ($0.53/liter) and the estimated wind resource (annual average of 6.65 m/s at a 10 meter height) in Chevak, a number of hybrid power systems are feasible. The power system that results in the lowest lifecycle cost of energy is a high-penetration wind-diesel-battery system. The system consists of three Fuhrländer FL250 wind turbines, the existing diesel generators, and a 682 Ah battery bank. AVEC's cost of energy in Chevak would be reduced by about $0.05 per kWh. About 122,700 gallons of diesel fuel would be saved per year. The estimated installed cost of the various system components are listed in Table 34.

**Table 34. Installed Cost of Recommended System in Chevak**

| Component | Installed Cost |
|---|---|
| Three FL250 Wind Turbines, including tower and foundation | $2,295,000 |
| 682 Ah Battery Bank and 400 kW Rotary Converter | $225,000 |
| Dump Load (size not specified) | $30,000 |
| Controls | $95,000 |
| Line Extensions, Insulated Container Shell | $65,000 |
| Overhead, Miscellaneous | $45,000 |
| Total | $2,755,000 |

**Feasibility Study 3: Gambell, Alaska**

Gambell is a village of population 650 located on the northwest cape of St. Lawrence Island in the Bering Sea, 36 miles from the Chukotsk Peninsula of Siberia. It covers an area of 11 square miles.


**Figure 52. Location of Gambell, Alaska**

The climate is maritime, with continental influences in the winter. The Bering Sea is frozen from mid-November through the end of May, limiting barge access during those times.

**Energy Use in Gambell**

Gambell receives its electricity from a diesel power plant operated by the Alaska Village Electric Cooperative (AVEC). Electrical data obtained from the AVEC power station in Gambell was analyzed to determine energy use trends. Like most Alaskan villages, the residential sector is the largest consumer of electricity. According to the 2000 U.S. Census, there are 187 housing units in Gambell, with an average of 4.8 residents per household. Nearly all homes use fuel oil or kerosene for heat. The second largest consumer of electricity is the school, which is attended by approximately 175 students. The public/municipal sector, which includes a health clinic and water treatment plant, is the third largest consumer of electricity.

As the largest individual consumer of electricity within the public/municipal sector, the patterns of energy use at the water treatment plant is important. Currently, fresh water is pumped from wells and from Troutman Lake, is treated and stored in three storage tanks. Over 100 homes are connected to the piped water and sewer system, while none of the homes in the “old town" are connected. About 40 homes continue to haul water and honeybuckets, as a new water source is needed to supply piped water to the entire community. The schools and washeteria have individual water wells and septic tank systems. A public water system master plan is underway (Department of Community and Economic Development, 2004).

A year of average hourly electric load data for Gambell is shown in Figure 53. The total village electric load varies from 112 to 382 kW throughout the year, with an annual average of 226 kW. The daily electric load profile for an average day in each month is shown in Figure 54. These profiles were created by averaging each hour of each day within the month.

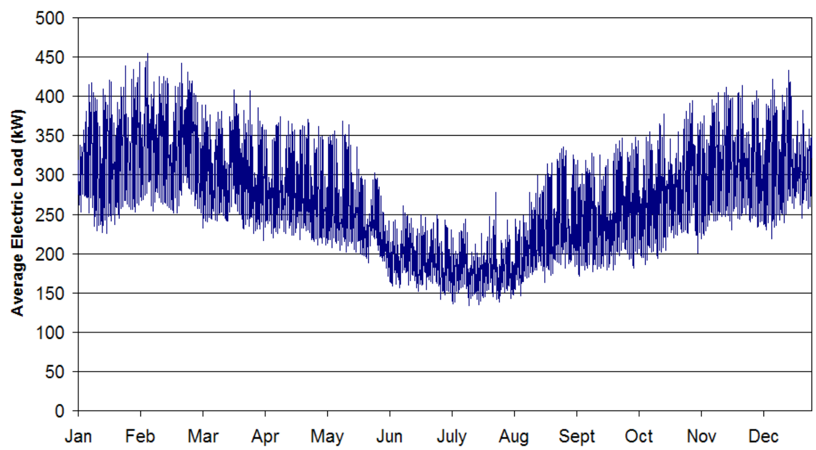



**Figure 53. Hourly Electric Load in Gambell**

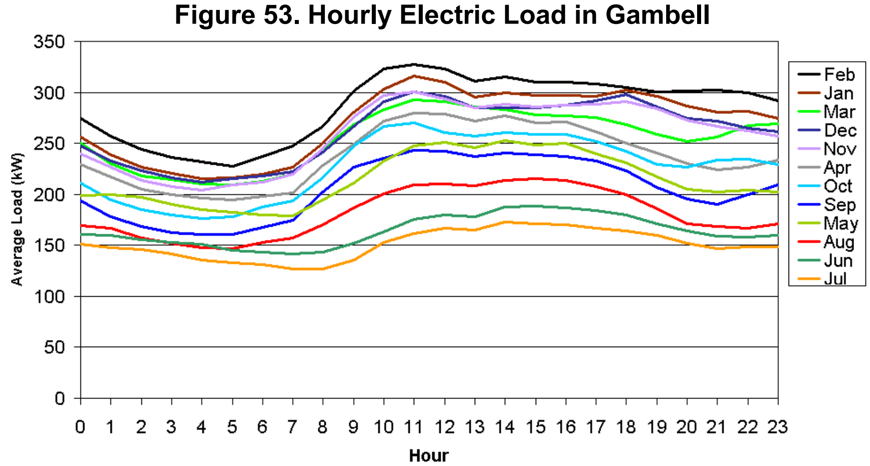



**Figure 54. Diurnal Load Profiles for Each Month in Gambell**

While the magnitude of the electric load fluctuates from summer to winter, the shape of the profile changes little. The load profile is slightly more pronounced in the winter months, with a sharp increase from 7:00AM to a peak around 11:00AM. The load then decreases slightly in mid-afternoon and peaks again in the early evening around 6:00PM. The summer load is more steady throughout the day.

For modeling purposes, the expected village load in 2009 was used to evaluate the performance of a potential hybrid power system. Table 35 summarizes the increase in electric and fuel consumption from 1996 to 2002 in Gambell. This information is also shown graphically in Figure 55.

**Table 35. Summary of Energy Use in Gambell from 1996 – 2002**

| Year | Total kWh Generated | Average Load (kW) | Peak Load (kW) | Fuel Consumption (gal/yr) | Fuel Cost ($/gal) |
|---|---|---|---|---|---|
| 1996 | 1,642,400 | 187 | 354 | 131,200 | $1.25 |
| 1997 | 1,747,800 | 200 | 380 | 139,300 | $1.19 |
| 1998 | 1,938,300 | 221 | 380 | 155,200 | $1.09 |
| 1999 | 2,049,000 | 228 | 397 | 161,200 | $1.07 |
| 2000 | 2,015,300 | 230 | 423 | 162,700 | $1.21 |
| 2001 | 1,976,600 | 226 | 406 | 148,900 | $1.21 |
| 2002 | 1,984,300 | 226 | 424 | 143,600 | $1.18 |

The electric load in Gambell has increased at an average rate of 3.3% per year since 1996. The largest increase (10.5%) occurred from 1997 to 1998 when the Gambell airport runway and safety areas were reconstructed (Rural Alaska Project Identification and Delivery System, 2004).

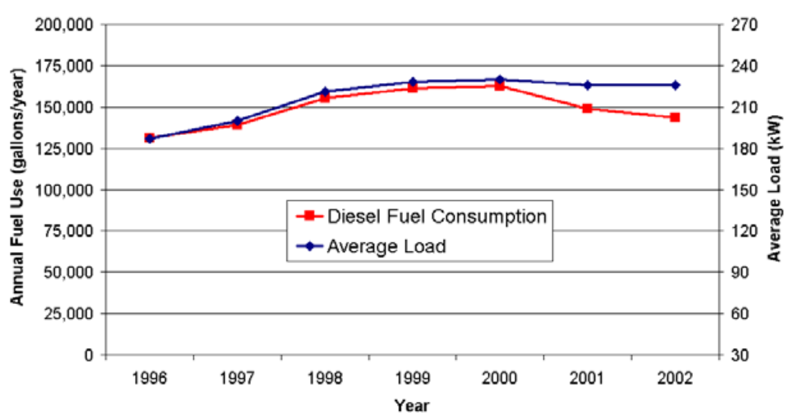



**Figure 55. Electric Load Growth in Gambell**

A number of construction projects have been funded and are expected to be completed by 2009. These projects include a new clinic, a new multi-purpose community center, additional housing units, and the expansion of the piped water and sewer system to the 40 homes in "Old Town" (Rural Alaska Project Identification and Delivery System, 2004). Therefore, the 2003 hourly data obtained from AVEC was scaled up based on the expected load that these new facilities will require according to the Alaska Village Electric Load Calculator method described in Chapter 1. The modified values for the Gambell electric load are listed in Appendix 5.

### Existing Power Station in Gambell

The Gambell power station includes three diesel generators totaling 1.1 MW of rated capacity:

1) 271 kW Cummins KTA1150
2) 350 kW Caterpillar 3412TA
3) 499 kW Cummins KTA19G4

The diesels are equipped with heat exchangers to provide space heating to the plant facilities. The actual measured fuel curves for the diesel generators were obtained from AVEC and are shown in Appendix 4. For the purposes of modeling, the minimum allowed power is specified at 30% of rated power. Useable diesel storage capacity is 148,420 gallons, which usually requires 2 shipments of fuel per year.

### Wind Resource in Gambell

Average hourly wind speeds from January 2000 through December 2000 were obtained from the Gambell airport weather station (George, 2003). The data recovery rate was 98%. Any gaps in the data due to equipment or data recording failure were filled using the Hybrid2 gapfiller program (University of Massachusetts Renewable Energy Research Lab, 2004). The hourly data set is shown in Figure 56.

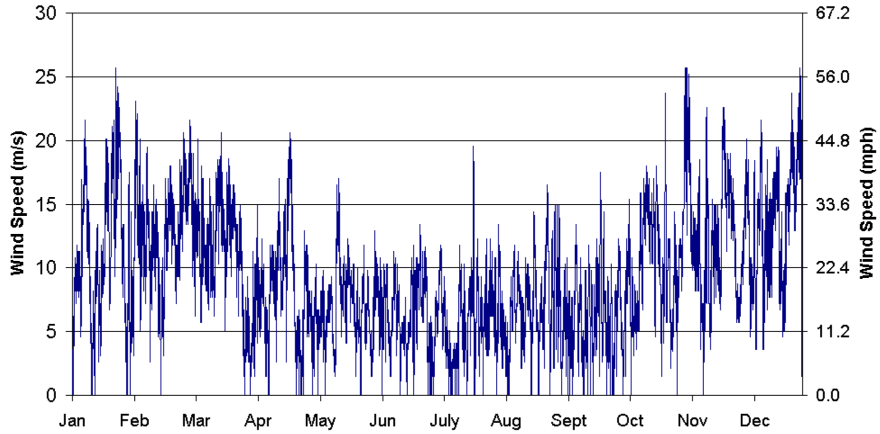



**Figure 56. Hourly Wind Speeds at a 10-meter Height in Gambell**

Since only one year of hourly data was available, these values were scaled to meet the long-term (1987-2002) average monthly wind speeds obtained from the same site. The adjusted annual average wind speed for the year is 8.3 m/s (18.6 mph) at a 10-meter height or 9.6 m/s (21.5 mph) at a typical hub height of 30-meters. A sensitivity analysis was conducted to account for the uncertainty of the wind speed data.

The seasonal and diurnal wind speed profiles, based on a 10-meter anemometer height, are shown graphically in Figure 57 and Figure 58, respectively. This information is also tabulated in Appendix 6.

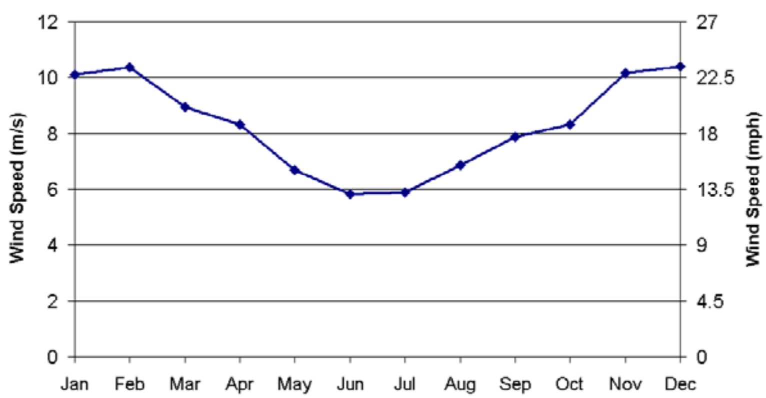



**Figure 57. Seasonal Wind Speed Profile for Gambell**

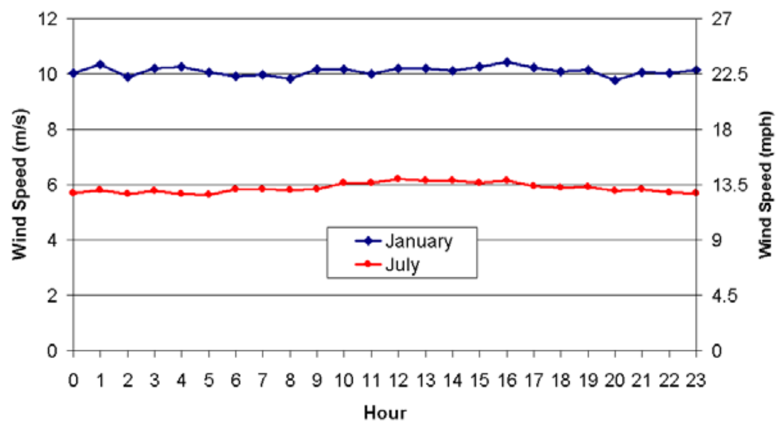



**Figure 58. Diurnal Wind Speed Profile for Gambell**

The wind frequency rose in Figure 59 was created by determining the percent of time that the wind comes from a particular direction. It indicates that the prevailing wind direction in Gambell is from the northeast quadrant in the winter and from the southwest quadrant in the summer.

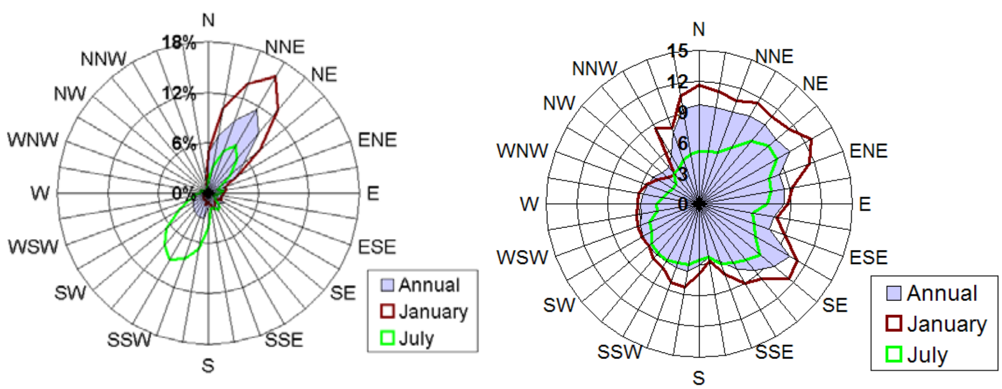



**Figure 59. Wind Frequency Rose and Wind Speed Rose for Gambell**

The wind speed rose in Figure 59 was created by determining the average speed of the wind that comes from a particular direction. It indicates that in general the speed of the wind is slightly higher from the northeast quadrant.

### Power System Modeling Results for Gambell

To compare the design options of a hybrid power system in Gambell, the computer simulation model HOMER was used. HOMER uses hourly electric load data and hourly wind speed data to compare the ability of different types and quantities of wind turbines to meet the village load given the local wind resource. The existing diesel power station was modeled to determine the fuel consumption and cost of energy of the diesel-only system. Table 36 summarizes the expected performance of the diesel-only power station.

**Table 36. Expected Energy Requirements in 2009 in Gambell**

| Total Energy Use | Peak Load | Average Load | Fuel Consumption | Net Present Cost |
|---|---|---|---|---|
| 2,352,000 kWh | 455 kW | 269 kW | 166,600 gal/yr (630,500 liters/yr) | $7,537,300 |

A sensitivity analysis was performed on the cost of diesel fuel, which has the most impact on the cost of energy. The results are shown in Table 37.

**Table 37. Diesel-Only System Cost of Energy in Gambell**

| Diesel Fuel Cost | Cost of Energy | Net Present Cost |
|---|---|---|
| $1.50/gallon ($0.40/liter) | $0.149/kWh | $6,110,100 |
| $2.00/gallon ($0.53/liter) | $0.184/kWh | $7,537,300 |
| $2.50/gallon ($0.66/liter) | $0.219/kWh | $8,964,600 |
| $3.00/gallon ($0.79/liter) | $0.254/kWh | $10,391,800 |

According to AVEC records, these diesel-related costs account for only about 40% of the total cost of electricity. The remainder includes other power generation expenses, such equipment and maintenance for the fuel tanks and transmission lines, administrative and general expenses, interest, and depreciation. However, these other expenses will still exist with a wind-diesel system. Therefore, the cost of energy listed in Table 37 is used to directly compare the diesel-related expenses with the wind-related expenses.

The impact of various numbers and types of wind turbines on fuel savings is shown graphically in Figure 60.

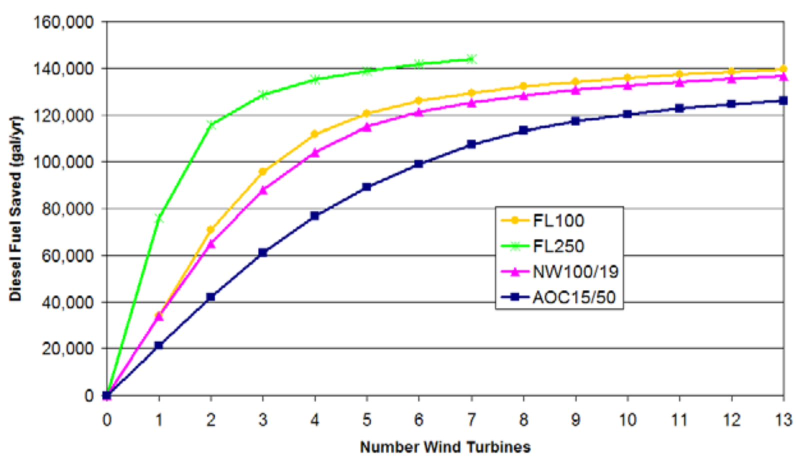



**Figure 60. Effect of Wind Turbines on Diesel Fuel Savings in Gambell**

The figure shows that as the amount of wind generation increases, the fuel savings resulting from the incremental installation of a wind turbine increases, up to a point. After that, the rate of fuel savings decreases due to the fact that some of the wind energy cannot be used to provide direct electrical loads. It should be noted however, that different power system configurations require the installation of different balance of system and control equipment. The resulting comparison of performance indicators, such as fuel savings, must be held against the cost to achieve that savings.

Wind-diesel systems can be divided into three main levels, depending on the amount of wind capacity relative to diesel capacity. Low-penetration systems (up to 20% of the annual village load) are the most simple and require the least amount of initial investment for balance of system equipment. Medium-penetration systems (between 20 and 50% of the annual village load) require additional controls and a dump load, while high-penetration systems (over 50% of the village load) require equipment that will allow the diesels to be shut off for extended amounts of time. The system configurations for each penetration level that result in a lower levelized cost of energy than the diesel-only system are listed below. The options are ranked based on lowest cost of energy.

**Table 38. Low-penetration System Options for Gambell**

| Number of Wind Turbines | | | | Initial Capital | Present Cost | COE ($/kWh) | Wind Penetration | Fuel Use (L) | Fuel Use (Gal) | Diesel Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|
| 15/50 | NW100 | FL250 | FL100 | | | | | | | |
| 1 | | | | $375,000 | $7,148,466 | $0.175 | 13% | 549,748 | 145,244 | 21,327 |
| Diesel-only | | | | $0 | $7,537,300 | $0.184 | 0% | 630,473 | 166,571 | 0 |

As shown in Table 38, the only recommendation for a low penetration system, given Gambell's low load characteristics and high wind regime, is the installation of one AOC15/50 wind turbine. The wind turbine would produce an average of 312,400 kWh per year, and no excess electricity would be generated. The installed cost of the wind turbine and related components is $375,000. The net present cost of operating this wind-diesel plant over the 25-year project lifetime is $7,149,000, compared with $7,537,000 for the existing diesel-only system.

**Table 39. Medium-penetration System Options for Gambell**

| Number of Wind Turbines | | | | | Initial Capital | Present Cost | COE ($/kWh) | Wind Penetration | Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15/50 | NW100 | FL250 | FL100 | V27 | | | | | | | |
| | | | | 1 | $740,000 | $5,854,997 | $0.143 | 46% | 370,617 | 101,491 | 65,080 |
| | 2 | | | | $1,045,000 | $6,303,095 | $0.154 | 43% | 384,149 | 101,492 | 65,079 |
| 3 | | | | | $960,000 | $6,434,322 | $0.157 | 40% | 399,569 | 105,566 | 61,005 |
| | | | 1 | | $580,000 | $6,916,973 | $0.160 | 26% | 502,509 | 132,763 | 33,808 |
| 2 | | | | | $695,000 | $6,774,184 | $0.165 | 27% | 471,753 | 124,638 | 41,934 |
| | 1 | | | | $605,000 | $6,900,658 | $0.168 | 22% | 501,599 | 132,523 | 34,049 |
| Diesel-only | | | | | $0 | $7,537,300 | $0.184 | 0% | 630,473 | 166,571 | 0 |

There are a number of medium-penetration system configurations that result in a lower cost of energy compared to the diesel-only case, as listed in Table 39. If the used Vestas V27 turbine were available, it would be the least-cost option. If a used machine is not available, the recommendation with the next lowest lifecycle cost of energy is the installation of two NW100 wind turbines. The wind turbines would produce about 1,010,200 kWh per year, and about 13,400 kWh of excess electricity would be available for a secondary or heating load. The installed cost of the wind turbines and related components is $1,045,000. The net present cost of operating this wind-diesel plant over the next 25 years is $6,303,000 compared with $7,537,000 for the existing diesel-only system.

**Table 40. High-penetration System Options for Gambell**

| Number of Wind Turbines | | | | Initial Capital | Present Cost | COE ($/kWh) | Wind Penetration | Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|
| NW100 | FL250 | FL100 | V27 | | | | | | | |
| | 2 | | | $1,860,000 | $4,735,014 | $0.110 | 111% | 191,943 | 50,711 | 115,860 |
| | | | 3 | $2,055,000 | $4,633,139 | $0.113 | 137% | 163,578 | 43,217 | 123,354 |
| | 3 | | | $2,625,000 | $4,904,239 | $0.114 | 166% | 143,360 | 37,876 | 128,696 |
| | | | 2 | $1,480,000 | $4,856,179 | $0.119 | 91% | 223,289 | 58,993 | 107,578 |
| | | 5 | | $2,405,000 | $5,173,038 | $0.120 | 128% | 173,741 | 45,903 | 120,669 |
| | | 4 | | $1,990,000 | $5,185,061 | $0.120 | 102% | 206,833 | 54,645 | 111,926 |
| | | | 4 | $2,630,000 | $4,951,847 | $0.121 | 183% | 137,281 | 36,270 | 130,302 |
| | | 6 | | $2,820,000 | $5,380,513 | $0.125 | 153% | 153,952 | 40,674 | 125,897 |
| | | 3 | | $1,575,000 | $5,635,857 | $0.131 | 77% | 267,991 | 70,803 | 95,768 |
| | | 7 | | $3,235,000 | $5,696,603 | $0.132 | 179% | 140,808 | 37,202 | 129,370 |
| 5 | | | | $2,530,000 | $5,552,997 | $0.136 | 107% | 195,386 | 51,621 | 114,950 |
| | 1 | | | $1,095,000 | $5,941,530 | $0.138 | 55% | 343,553 | 90,767 | 75,804 |
| Diesel-only | | | | $0 | $7,537,300 | $0.184 | 0% | 630,473 | 166,571 | 0 |

Many high-penetration system configurations result in a lower cost of energy compared to the diesel-only case, as listed in Table 40. The recommendation resulting in the lowest life-cycle cost of energy is the installation of two Fuhrländer FL250 wind turbines. The wind turbines would produce a total of 2,735 MWh per year, and about 909 MWh of excess electricity would be available for heating load. The installed cost of the wind turbines and related components is

$1,860,000.  The net present cost of operating this wind-diesel plant over the expected 25-year lifetime of the system is $4,735,000, compared with $7,537,000 for the diesel-only system.

**Sensitivity Analysis for Gambell System**

The system configuration with the lowest cost of energy, in this case the high-penetration system consisting of two FL250 turbines, was used as a basis for a sensitivity analysis.  The sensitivity analysis was performed around the parameters listed in Table 41.  The best estimate values for each of these parameters are also listed.

**Table 41. Best Guess Values for Base Case Sensitivity Analysis Parameters in Gambell**

| Parameter | Best Guess Value |
|---|---|
| Wind Speed | 8.3 m/s (at a 10-meter height)<br>10.0 m/s (at hub height of 42-meters) |
| Diesel Price | $0.53/liter ($2.00/gallon) |
| Turbine Installed Cost (each) | $765,000 |
| Turbine O&M Cost | $7,000/year ($0.005/kWh) |
| Operating Reserve (% of wind) | 15% |
| Operating Reserve (% of load) | 10% |
| Village Electric Load (annual average) | 269 kW |

As indicated in Figure 61, the best estimate values for the variables result in a levelized cost of energy of $0.11 per kWh.

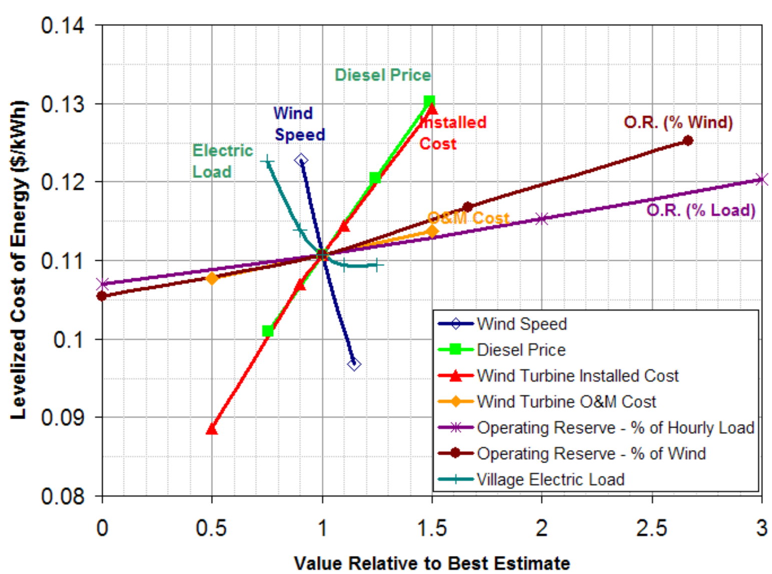



**Figure 61. Sensitivity Analysis Results for Gambell Wind-Diesel System**

The price of diesel fuel and the average wind speed have the greatest direct impact on the cost of energy.  If the diesel price increases by 25%, the cost of energy increases by

$0.015/kWh. If the actual measured wind speed at the turbine location is 10% greater than the best estimate documented in this report, the cost of energy will decrease by about $0.01/kWh. Since a Fuhrländer wind turbine has not yet been installed in Alaska, the actual installed cost may differ from the best guess listed. Figure 61 shows that if the actual installed cost is 1.25 times the best guess, or $956,250 per machine, the levelized cost of energy would increase by $0.01/kWh.

**Optional Heating Load in Gambell**

Excess electricity generated by the wind turbines could displace heating loads at the water treatment plant, school, or health clinic. Currently, heat is recovered from the diesel generators to provide heat to the power plant facility. Since the wind turbines are reducing the run time of the diesel generators, the excess electricity from the wind turbines must also make up for the reduced heat provided by the diesels. The heating loads of the power plant have not been quantified, but a wind system dump load could be incorporated into the existing heat recovery system. Other facilities could also be added to the system to ensure that the year-round heating requirements are large enough to absorb any excess energy from the wind turbines.

According to personnel at the Gambell Water Treatment Facility, three boilers are currently used to provide space heat for the building and hot water for the washeteria. The facility consumes about 1,500 gallons of #2 fuel oil during the winter months and about 1,000 gallons during the summer months (Cambell, 2004). Assuming a heating value for #2 Fuel Oil of 0.14 MMBtu per gallon and a boiler efficiency of 80%, the approximate monthly heating requirements of the water treatment facility were calculated. Figure 62 shows the amount of excess electricity that would be generated from a high-penetration wind-diesel system in Gambell, compared to the heating needs of the local water treatment facility.

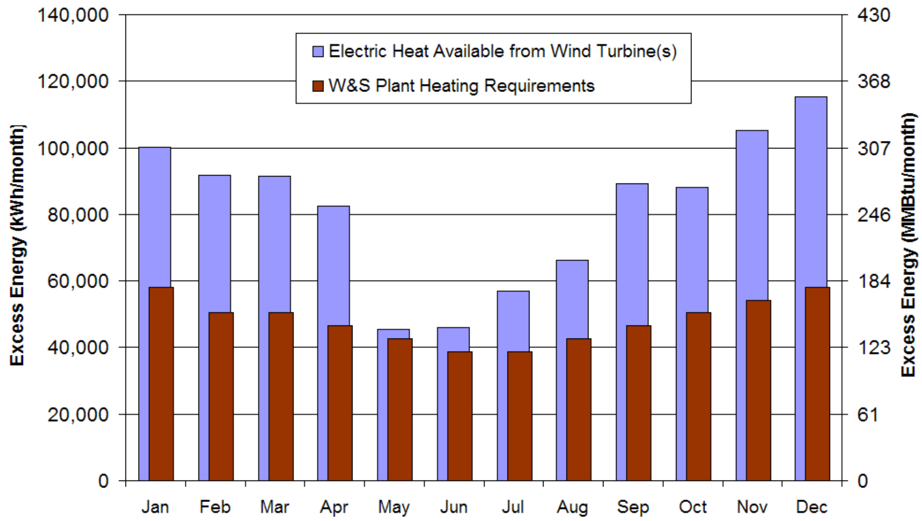



**Figure 62. Excess Electricity Available from a High-Penetration System in Gambell**

During most months, the water treatment plant would absorb over half of the excess electricity from the two FL250 wind turbines. In order to absorb the remainder of the excess electricity, the power station, school, or health clinic could be added to the dump load system. Alternatively, the wind turbines could be shut down when both the electric and heating loads are met. The exact size of the required dump load is not specified in this report.

### Detailed Analysis of Recommended System in Gambell

The system configuration that was recommended from the HOMER analysis above was modeled in more detail using Hybrid2. Results for the diesel-only and the high-penetration wind-diesel case consisting of two FL250 wind turbines are shown in Table 42.

**Table 42. Comparison of Hybrid System Configurations to Diesel-Only Case in Gambell**

| | Diesel-Only | | | Wind + Diesels | | | Wind + Diesels + Batteries | | |
|---|---|---|---|---|---|---|---|---|---|
| | 499kW | 350kW | 271kW | 499kW | 350kW | 271kW | 499kW | 350kW | 271kW |
| Diesel Run Hours | 4290 | 3221 | 2224 | 1,175 | 1,833 | 5,924 | 667 | 906 | 2,459 |
| Diesel Starts | 480 | 642 | 480 | 367 | 771 | 585 | 184 | 378 | 663 |
| Fuel Consumed | 181,300 gallons/yr | | | 84,100 gallons/yr | | | 50,900 gallons/yr | | |
| Diesel Production | 2,475,900 kWh/year | | | 1,074,800 kWh/year | | | 679,800 kWh/year | | |
| Levelized Cost of Energy | $0.12 /kWh | | | $0.09/kWh | | | $0.05 /kWh | | |
| Net Present Cost | $3,819,000 | | | $2,951,000 | | | $1,563,000 | | |

Simulations were also performed to see if supplementary savings would result from the installation of a battery bank to cover short fluctuations in the net load. A battery bank size was chosen to be able to meet the average load for about 12-15 minutes. The result is a battery bank consisting of 120 Alcad NiCad batteries wired in series for a total of 240V and 341 Ah (81.8 kWh) of rated capacity. In order to cover the average load of 280 kW, a 300 kW rotary converter is specified. The estimated capital cost is $80,000 for the converter and $30,000 for the battery bank. The modeling results suggest that the installation of a battery bank does lead to significant fuel and cost savings, as shown in Table 42.

The majority of the savings between the wind-diesel system and the wind-diesel-battery system result from reduced fuel consumption as well as reduced diesel operation and maintenance costs. The battery bank displaced an additional 33,200 gallons of diesel fuel over the no-storage wind-diesel system, saving an additional $66,400 per year. The batteries also reduced total diesel run time by 4,900 hours, which is equivalent to about $49,900 in O&M costs avoided. With reduced run time, the lives of the diesel generators are also extended.

With high penetration systems, a small diesel generator can be installed to cover the minor fluctuations in load or wind and reduce the number of times the larger generators are required to start. A number of small diesels ranging from 60 to 113 kW were modeled along with the existing 271 kW, 350 kW, and 499 kW generators and without battery storage. However, none of the small diesels had a significant impact on fuel savings or the cost of energy. Any minor savings were not worth the additional capital expense of the diesel.

**Conclusions for Gambell Feasibility Study**

Given a diesel fuel price of $2.00 per gallon ($0.53/liter) and the estimated wind resource (annual average of 8.3 m/s at a 10 meter height) in Gambell, a number of wind-diesel hybrid systems are feasible. The power system that results in the lowest lifecycle cost of energy for Gambell is a high-penetration wind-diesel-battery system. The system consists of two Fuhrländer FL250 wind turbines, the existing diesel generators, and a 341 Ah battery bank. AVEC's cost of energy in Gambell would be reduced by about $0.03 per kWh, while fuel consumption would be reduced by more than half.  The estimated installed cost of the various system components are listed in Table 43.

**Table 43. Installed Cost of Recommended System in Gambell**

| Component | Installed Cost |
|---|---|
| Two FL250 Wind Turbines, including tower and foundation | $1,530,000 |
| 341 Ah Battery Bank and 300 kW Rotary Converter | $110,000 |
| Dump Load (size not specified) | $30,000 |
| Controls | $95,000 |
| Line Extensions, Insulated Container Shell | $65,000 |
| Overhead, Miscellaneous | $45,000 |
| Total | $1,875,000 |

**Feasibility Study 4: Mekoryuk**

Mekoryuk is a village of 205 people located on 7 square miles of land on the north shore of Nunivak Island. The island is 30 miles off the western coast of Alaska and is home to the Yukon Delta National Wildlife Refuge. The climate is strongly influenced by the Bering Sea, and foggy and stormy weather are common. Temperatures have ranged from -48 to 76°F.


**Figure 63. Location of Mekoryuk, Alaska**

Mekoryuk is a Cup'ik Eskimo village that maintains reindeer and musk ox herds. Employment is provided by the school, city offices, village corporation, processing of halibut and salmon, and construction. Additional sources of income include trapping and native crafts. According to the 2000 U.S. Census, the median household income is $30,833, unemployment is 20%, and 22% live below the poverty level. The 3,070-foot gravel runway in Mekoryuk provides the primary means of transporting passengers, mail, and cargo year-round, while boats, snowmobiles, and all-terrain vehicles are used for local transportation. Goods are delivered by barge from Bethel during the summer.

**Energy Use in Mekoryuk**

Electricity in Mekoryuk is provided by a diesel power plant operated by the Alaska Village Electric Cooperative (AVEC). Data obtained from AVEC for the Mekoryuk power station was analyzed to determine energy usage trends. Like most Alaskan villages, the residential sector is the largest consumer of electricity, followed by the school and the public/municipal sector. Public buildings include a health clinic and a water treatment plant.

As the second largest individual consumer of electricity, the characteristics of the public water system are important. At the facility, water is pumped from a well, is treated and stored. A flush/haul sewer system serves nearly all homes. The K-12 school, which serves 40 students, operates its own well and water treatment system. The health clinic hauls water and uses a pail toilet. Upgrade and expansion of water distribution lines are planned. A summary of the electric and diesel fuel use since 1996 is listed in Table 44 and shown graphically in Figure 64.

**Table 44. Summary of Energy Use in Mekoryuk from 1996 – 2002**

| Year | Total kWh Generated | Average Load | Peak Load | Fuel Consumption |
|---|---|---|---|---|
| 1996 | 740,200 | 84 kW | 169 kW | 51,500 gal/yr |
| 1997 | 719,300 | 82 kW | 181 kW | 55,400 gal/yr |
| 1998 | 773,400 | 88 kW | 168 kW | 55,700 gal/yr |
| 1999 | 844,400 | 94 kW | 182 kW | 59,400 gal/yr |
| 2000 | 794,900 | 91 kW | 174 kW | 56,800 gal/yr |
| 2001 | 834,800 | 95 kW | 174 kW | 64,300 gal/yr |
| 2002 | 846,900 | 97 kW | 179 kW | 59,800 gal/yr |

There was a 7% annual increase in average load from 1997 to 1999 due to the construction of about 20 housing units and upgrades to the public water system. After a decrease in consumption from 1999 to 2000 for unknown reasons, the electric load has been increasing at a rate of about 3% per year.

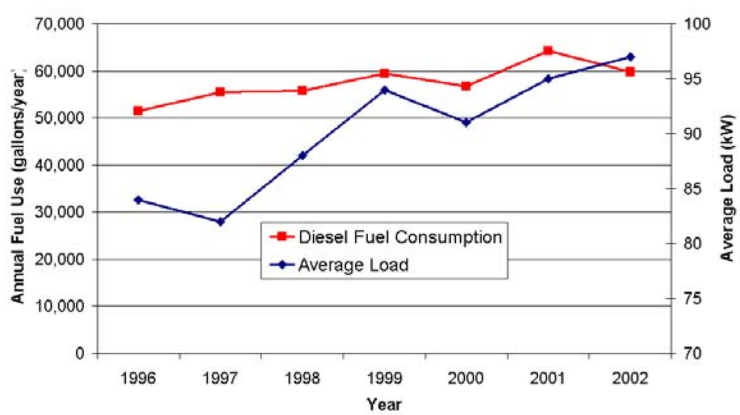



**Figure 64. Energy Use from 1996-2002 in Mekoryuk**

The detailed electric load data necessary for modeling a hybrid power system is not currently available for Mekoryuk. Therefore, an hourly electric load data set is created based on measured data from the village of Gambell, as described by the Alaska Village Electric Load Calculator method from Chapter 1. Gambell was chosen because it is also an island community with the same median household income level as Mekoryuk. For modeling purposes, the expected village load in 2009 was used to evaluate the performance of a potential hybrid power system in Mekoryuk. A number of construction projects have been funded and are expected to be completed by 2009. These projects include installing flush tank and haul systems to additional homes, upgrading the water distribution infrastructure and wastewater pump stations, and constructing additional housing units (Rural Alaska Project Identification and Delivery System, 2004). The estimated electric load in Mekoryuk takes into account the addition of these facilities. The resulting hourly electric load is shown in Figure 65. The diurnal load profile for an average day in January and July is shown in Figure 66. A summary of the daily load profiles for all months can be found in Appendix 5.

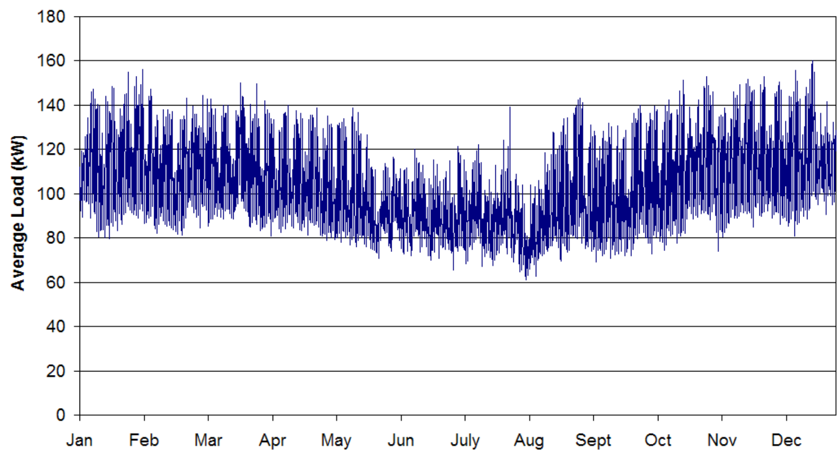



**Figure 65. Expected 2009 Hourly Electric Load in Mekoryuk**

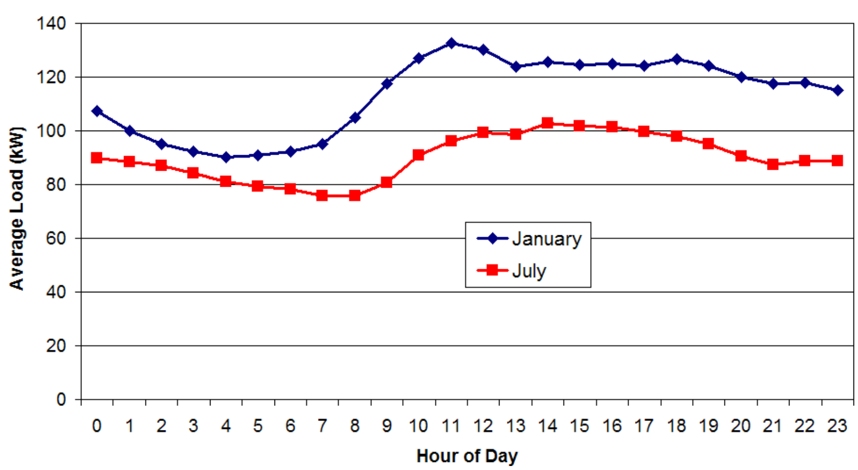



**Figure 66. Estimated Diurnal Load Profiles in Mekoryuk**

### Existing Power Station in Mekoryuk

The Mekoryuk power plant includes four diesel generators totaling 585 kW of rated capacity:

1) 207 Detroit Diesel Series 60 DDEC2
2) 175 kW Allis-Chalmers 6851
3) 203 kW Cummins LTA10

The power system is manually controlled, although currently the plant operators tend to use one unit continuously for days at a time. Diesel storage capacity is 81,500 gallons and Mekoryuk usually receives 2 shipments of diesel fuel per year. The measured fuel curves for the diesel generators were obtained from AVEC and are shown in Appendix 4. The actual Allis-Chalmers fuel curve is not available; therefore a curve is based on that of the Cummins LTA10. The minimum allowed power is specified at 30% of rated power.

**Wind Resource in Mekoryuk**

Average hourly wind speed data from January 2001 through December 2001 were obtained from the Mekoryuk airport weather station and are shown in Figure 67 (George, 2003). The data recovery rate was 95%. Any gaps in the data due to equipment or data recording failure were filled using the Hybrid2 Gapfiller program (University of Massachusetts Renewable Energy Research Lab, 2004).

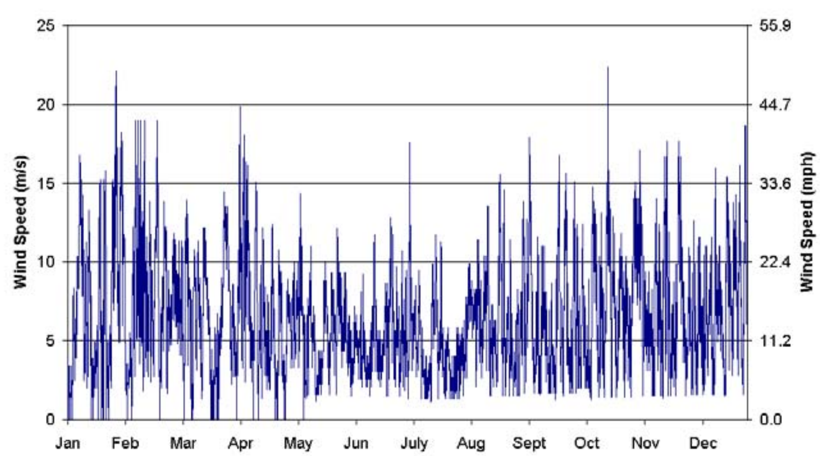



**Figure 67. Average Hourly Wind Speeds Measured at a 10-meter Height in Mekoryuk**

Since only one year of hourly data was available, these values were scaled to meet the long-term (1994-2002) average monthly wind speeds at the same location. The adjusted wind speeds are tabulated in Appendix 6. The annual average wind speed for the year is 6.46 m/s

(14.5 mph) at a 10-meter height, or 7.49 m/s (16.75 mph) at a typical hub height of 30-meters. The draft wind resource map for Alaska suggests that Mekoryuk lies within a Class 6 wind regime with an annual average wind speed of 8.95 m/s (20 mph) at a 10-meter height (Heimiller, 2004). A sensitivity analysis was conducted to account for the uncertainty of this data. The seasonal and diurnal wind speed profiles are shown in Figure 68 and Figure 69, respectively.

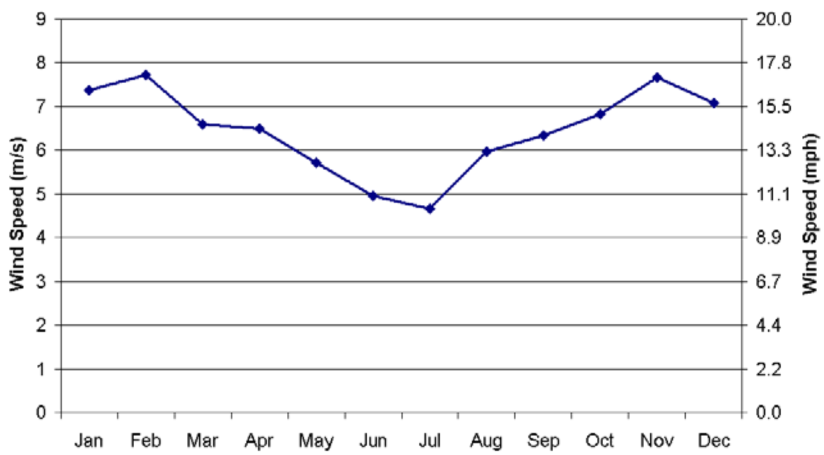



**Figure 68. Seasonal Wind Speed Profile for Mekoryuk**

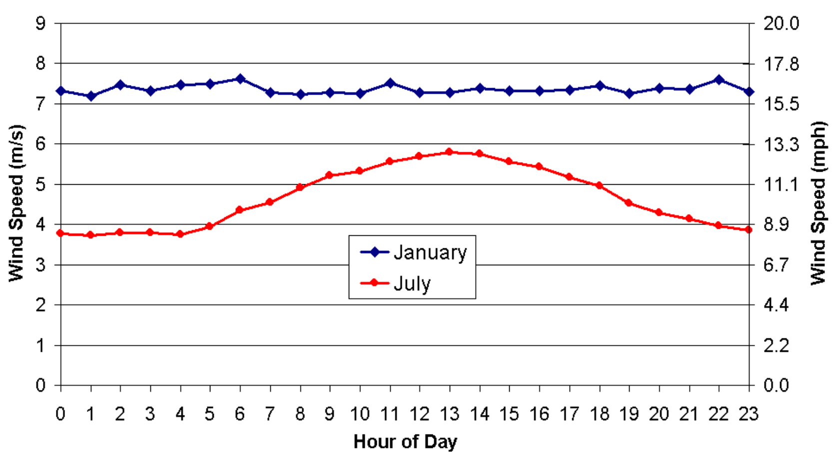



**Figure 69. Diurnal Wind Speed Profile for Mekoryuk**

The wind frequency rose in Figure 70 was created by determining the percent of time that the wind comes from a particular direction. It indicates that the wind tends to come from the north but there is no clear prevailing wind direction.

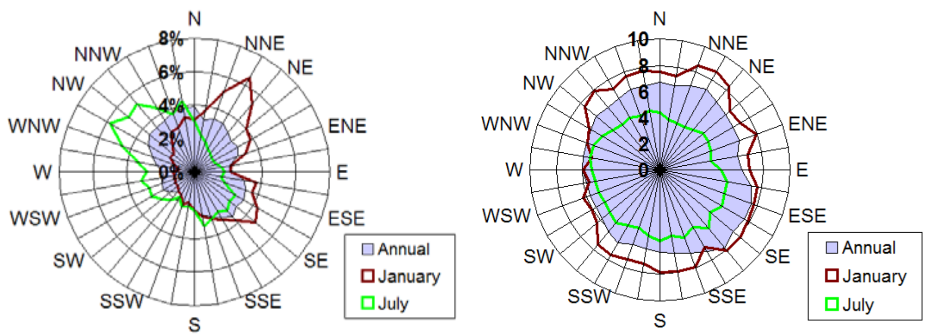



**Figure 70. Wind Frequency Rose and Wind Speed Rose for Mekoryuk**

The wind speed rose in Figure 70 was created by determining the average speed of the wind that comes from a particular direction. It indicates that in general the speed of the wind is about equal in magnitude when coming from any direction.

### Power System Modeling Results for Mekoryuk

To compare the design options of a hybrid power system in Mekoryuk, the computer simulation model HOMER was used. HOMER uses hourly electric load data and hourly wind speed data to compare the ability of different types and quantities of wind turbines to meet the village load given the local wind resource. The existing diesel power station was modeled to determine the fuel consumption and cost of energy of the diesel-only system. Table 45 summarizes the expected performance of the diesel-only power station, based on the year 2009 electric load data.

**Table 45. Expected 2009 Energy Requirements of Diesel-Only System in Mekoryuk**

| Total Energy Use | Peak Load | Average Load | Fuel Consumption | Net Present Cost |
|---|---|---|---|---|
| 908,100 kWh/yr | 160 kW | 104 kW | 64,400 gal/yr (243,800 liters/yr) | $3,284,600 |

A sensitivity analysis was performed on the cost of diesel fuel, which has the most impact on the cost of energy. The resulting cost of energy values are shown in Table 46.

**Table 46. Cost of Energy for Diesel-Only System in Mekoryoryuk**

| Diesel Fuel Cost | Cost of Energy | Net Present Cost |
|---|---|---|
| $1.50/gallon ($0.40/liter) | $0.17 /kWh | $2,732,700 |
| $2.00/gallon ($0.53/liter) | $0.21 /kWh | $3,284,600 |
| $2.50/gallon ($0.66/liter) | $0.24 /kWh | $3,836,400 |
| $3.00/gallon ($0.79/liter) | $0.28 /kWh | $4,388,300 |

According to AVEC records, these diesel-related costs account for only about 40% of the total cost of electricity. The remainder includes other power generation expenses, such equipment and maintenance for the fuel tanks and transmission lines, administrative and general expenses, interest, and depreciation. However, these other expenses will still exist with a wind-diesel system. Therefore, the cost of energy listed in Table 46 is used to directly compare the diesel-related expenses with the wind-related expenses.

The impact of various numbers and types of wind turbines on fuel savings is shown graphically in Figure 71.

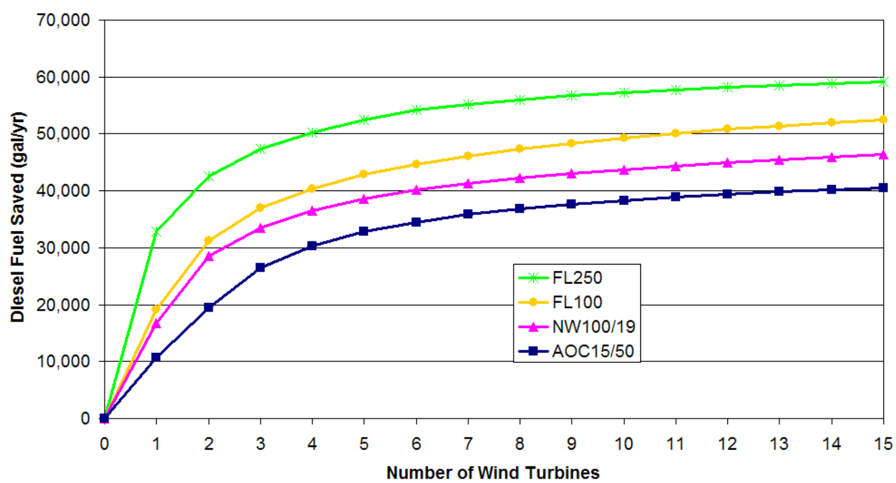



**Figure 71. Effect of Different Wind Turbines on Diesel Fuel Savings in Mekoryuk**

The figures show that as the amount of wind generation increases, the fuel savings resulting from the incremental installation of a wind turbine increases, up to a point. After that, the rate of fuel savings decreases due to the fact that some of the wind energy cannot be used to provide direct electrical loads. It should be noted however, that different power system configurations require the installation of different balance of system and control equipment. The resulting comparison of performance indicators, such as fuel savings, must be held against the cost to achieve that savings.

Wind-diesel systems can be divided into three main levels, depending on the amount of wind capacity relative to diesel capacity. Low-penetration systems (up to 20% of the annual village load) are the most simple and require the least amount of initial investment for balance of system equipment. Medium-penetration systems (between 20 and 50% of the annual village load) require additional controls and a dump load, while high-penetration systems (over 50% of the village load) require equipment that will allow the diesels to be shut off for extended amounts of time. The system configurations for each penetration level that result in a cost of energy less than or close to the cost of the diesel-only system are listed in Table 47 - Table 49. The options are ranked based on lowest cost of energy.

**Table 47. Low-penetration System Options for Mekoryuk**

| Number of Wind Turbines | | | | | Initial | Total Net | Cost of Energy | Wind | Fuel Use | Fuel Use | Fuel Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | FL30 | Capital | Present Cost | ($/kWh) | Penetration | (L) | (Gal) | (Gal) |
| Diesel-only | | | | | 0 | $3,284,600 | $0.208 | 0 | 243,782 | 64,407 | 0 |
| | | | | 1 | $297,500 | $3,436,469 | $0.217 | 13% | 220,600 | 58,283 | 6,125 |

As shown in Table 47, there are no low-penetration systems that would result in a lower cost of energy than the diesel-only system. The installation of one FL30 wind turbine would lead to a system with about the same cost of energy as the existing system.

**Table 48. Medium-penetration System Options for Mekoryuk**

| Number of Wind Turbines | | | | Initial | Total Net | Cost of Energy | Wind | Fuel Use | Fuel Use | Fuel Savings |
|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | Capital | Present Cost | ($/kWh) | Penetration | (L) | (Gal) | (Gal) |
| Diesel-only | | | | 0 | $3,284,600 | $0.208 | 0 | 243,782 | 64,407 | 0 |
| | | | 1 | $580,000 | $3,289,774 | $0.208 | 40% | 176,489 | 46,629 | 17,779 |
| 2 | | | | $695,000 | $3,378,476 | $0.214 | 45% | 170,071 | 44,933 | 19,475 |
| | 1 | | | $605,000 | $3,364,053 | $0.213 | 37% | 180,258 | 47,624 | 16,783 |
| 1 | | | | $430,000 | $3,410,054 | $0.216 | 22% | 203,387 | 53,735 | 10,672 |

There is one configuration for a medium-penetration system that would result in a similar cost of energy than the diesel-only case, as shown in Table 48. The installation of one Fuhrländer FL100 wind turbine would produce an average of 363 MWh per year. About 46 MWh per year of excess electricity would be available for a secondary or heating load. The installed cost of the wind turbine and related components is $580,000. The net present cost of operating this wind-diesel plant over the next 25 years is $3,290,000, compared with $3,285,000 for the existing diesel-only system.

**Table 49. High-penetration System Options for Mekoryuk**

| Number of Wind Turbines | | | | | Initial | Total Net | Cost of Energy | Wind | Fuel Use | Fuel Use | Fuel Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | Capital | Present Cost | ($/kWh) | Penetration | (L) | (Gal) | (Gal) |
| | | 1 | | | $1,095,000 | $3,132,089 | $0.20 | 86% | 129,460 | 34,203 | 30,204 |
| | | | | 1 | $905,000 | $3,181,304 | $0.20 | 66% | 146,320 | 38,658 | 25,750 |
| Diesel-only | | | | | 0 | $3,284,600 | $0.21 | 0 | 243,782 | 64,407 | 0 |
| | | | 2 | | $1,160,000 | $3,324,278 | $0.21 | 80% | 135,371 | 35,765 | 28,642 |
| | 2 | | | | $1,210,000 | $3,349,202 | $0.21 | 74% | 135,689 | 35,849 | 28,558 |
| | | | | 2 | $1,480,000 | $3,398,120 | $0.22 | 133% | 114,370 | 30,217 | 34,191 |
| 3 | | | | | $1,125,000 | $3,448,829 | $0.22 | 67% | 143,538 | 37,923 | 26,485 |
| | | | 3 | | $1,575,000 | $3,549,878 | $0.22 | 120% | 117,161 | 30,954 | 33,453 |
| 4 | | | | | $1,390,000 | $3,545,338 | $0.22 | 89% | 128,846 | 34,041 | 30,366 |
| | | 2 | | | $1,860,000 | $3,562,714 | $0.23 | 172% | 98,197 | 25,944 | 38,464 |
| | 3 | | | | $1,650,000 | $3,571,940 | $0.23 | 111% | 116,983 | 30,907 | 33,500 |

There are two high-penetration system configurations that result in a lower cost of energy compared to the diesel-only case, as listed in Table 49. It is recommended that either one Fuhrländer FL250 or one used Vestas V27 wind turbine be installed. The FL250 wind turbine would produce an average of 780 MWh per year, and about 304 MWh of excess electricity would be available for a secondary or heating load. The installed cost of the wind turbine and related components is $1,095,000. The net present cost of operating this wind-diesel plant over the 25-year project lifetime is $3,132,000, compared with $3,285,000 for the existing diesel-only system. There are also a number of configurations that would lead to a slightly higher cost of energy than the diesel-only system. If the installed cost of the wind components is lower or if the actual measured wind speed is higher than estimated in this report, the other configurations may be feasible.

**Optional Heating Load in Mekoryuk**

Excess energy generated by the wind turbine could be used to provide space heat or hot water for the school, health clinic, or public water system. According to personnel at the washeteria, the facility uses about 200 gallons of #1 fuel oil per month for heating at a price of $1.93 per gallon (Patterson, 2004). Assuming a heating value for #1 Fuel Oil of 0.14 MMBtu per gallon and a boiler efficiency of 80%, the approximate monthly heating requirements of the water treatment facility were calculated. Figure 72 shows the amount of excess electricity that would be generated from one FL250 wind turbine in Mekoryuk, compared to the heating needs of the local water treatment facility.

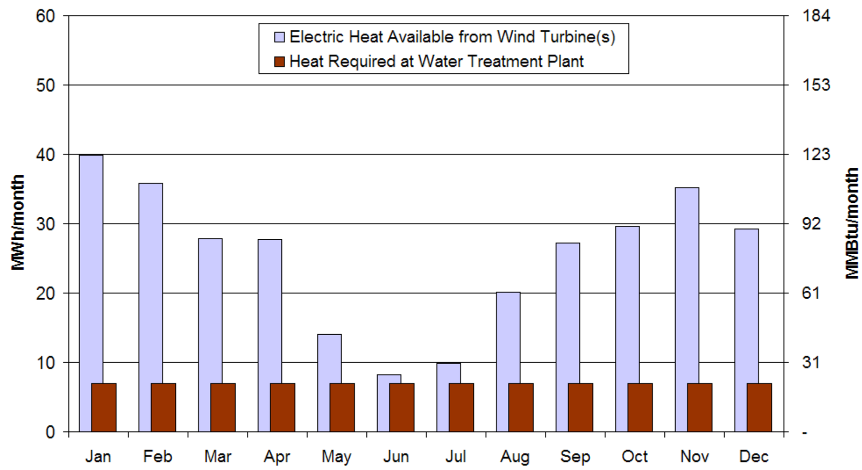



**Figure 72. Excess Electricity Available Compared to Village Needs in Mekoryuk**

A heating load at the water treatment plant would absorb almost all of the excess electricity during the summer months but less than one-third of the electricity during the other months. In order to absorb the remainder of the excess electricity, the school or power station could be added to the system, or the wind turbines could be shut down when both the electric and heating loads are met. The size of the required dump load is not specified in this report.

### Sensitivity Analysis for the Mekoryuk System

The system with the lowest life-cycle cost of energy was used as a basis for a sensitivity analysis. Since it is unknown whether or not the used V27 is available, the high-penetration case consisting of one FL250 was used. The sensitivity analysis was performed around the parameters listed in Table 50. The best guess values for each of these parameters is also listed.

**Table 50. Best Guess Values for Base Case Sensitivity Analysis Parameters in Mekoryuk**

| Parameter | Best Guess Value |
|---|---|
| Wind Speed | 6.46 m/s (at a 10-meter height)<br>7.8 m/s (at hub height of 42-meters) |
| Diesel Price | $0.53/liter ($2.00/gallon) |
| Turbine Installed Cost | $765,000 |
| Turbine O&M Cost | $7,000/year ($0.005/kWh) |
| Operating Reserve (% of wind) | 15% |
| Operating Reserve (% of load) | 10% |
| Village Electric Load (annual average) | 104 kW |

As indicated in Figure 73, the best estimate values for the variables result in a cost of energy of about $0.20 per kWh.

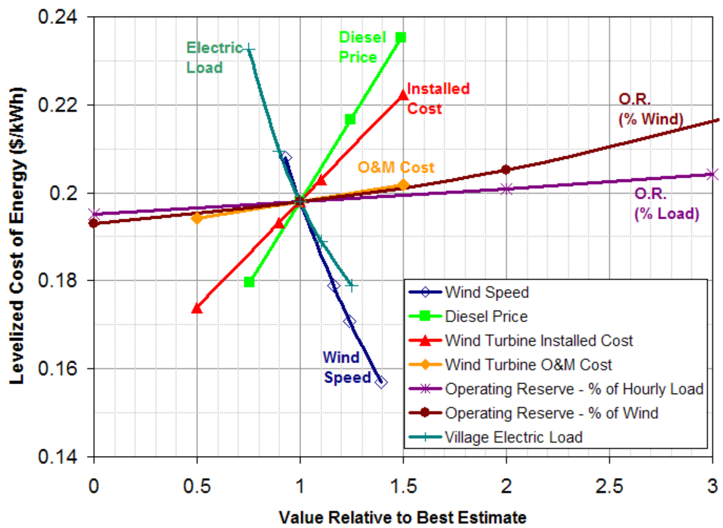



**Figure 73. Sensitivity Analysis Results for Wind-Diesel System in Mekoryuk**

The price of diesel fuel, the average wind speed, and the average village electric load have the greatest impact on the cost of energy. If the diesel price increases by 25%, the cost of energy increases by $0.017/kWh. If the actual measured wind speed at the turbine location is 10% greater than the best estimate documented in this report, the cost of energy will decrease by about $0.015 per kWh. If the actual 2009 electric load is 20% less than the estimation, the cost of energy will be about $0.01/kWh greater than the estimate.

### Detailed Analysis of Recommended System in Mekoryuk

The system configuration that was recommended from the HOMER analysis above was modeled in more detail using Hybrid2. Results for the diesel-only and the high-penetration wind-diesel case consisting of one FL250 wind turbine are shown in Table 51.

**Table 51. Comparison of Hybrid System Configurations to Diesel-Only Case in Mekoryuk**

| | Diesel-Only | | | Wind + Diesels | | | Wind + Diesels + Batteries | | |
|---|---|---|---|---|---|---|---|---|---|
| | 203kW | 207kW | 175kW | 203kW | 207kW | 175kW | 203kW | 207kW | 175kW |
| Diesel Run Hours | 0 | 809 | 7,958 | 0 | 3,310 | 6,003 | 0 | 276 | 4,820 |
| Diesel Starts | 0 | 233 | 239 | 0 | 481 | 664 | 0 | 86 | 411 |
| Fuel Consumed | 240,500 liters/yr | | | 179,200 liters/yr | | | 119,600 liters/yr | | |
| Diesel Production | 908,200 kWh/year | | | 611,100 kWh/year | | | 429,200 kWh/year | | |
| Cost of Energy | $0.31/kWh | | | $0.27/kWh | | | $0.19 /kWh | | |
| Net Present Cost | $3,575,000 | | | $3,150,000 | | | $2,082,000 | | |

As shown, the 203 kW diesel is unnecessary as the 207 kW generator can meet the load just as efficiently. Also, the addition of a wind turbine does not significantly reduce diesel run time or the number of diesel starts, but it does reduce fuel consumption and the cost of energy.

Simulations were performed to see if supplementary savings would result from the installation of a battery bank to cover short fluctuations in the net load. A battery bank size was specified that would be able to meet the average load for about 30 minutes or the peak load for about 20 minutes. The battery bank consists of 120 Alcad M340P NiCad batteries wired in series for a total of 240V and 341 Ah (81.8 kWh) of rated capacity. In order to cover the peak load of 160 kW, a 200 kW rotary converter is specified. The modeling results suggest that the installation of a battery bank does lead to significant fuel and cost savings, as shown in Table 51.

**Conclusions for Mekoryuk Feasibility Study**

Given a diesel fuel price of $2.00 per gallon, the average village electric load of 104 kW, and the estimated wind resource of 6.46 m/s at a 10-meter height, a few hybrid power options are feasible. The power system that results in the lowest lifecycle cost of energy is a high-penetration wind-diesel-battery system. The system consists of one Fuhrländer FL250 wind turbine, the existing diesel generators, and a 341-Ah battery bank. AVEC's cost of energy in Mekoryuk would be reduced by about $0.12 per kWh. The estimated installed cost of the various system components are listed in Table 52.

**Table 52. Installed Cost of Recommended System in Mekoryuk**

| Component | Installed Cost |
|---|---|
| One FL250 Wind Turbine, including tower and foundation | $765,000 |
| 341Ah Battery Bank and 200 kW Rotary Converter | $95,000 |
| Dump Load (size not specified) | $30,000 |
| Controls | $95,000 |
| Line Extensions, Insulated Container Shell | $65,000 |
| Overhead, Miscellaneous | $45,000 |
| Total | $1,095,000 |

**Feasibility Study 5: Savoonga**

Savoonga is a village of 705 residents, encompassing 6 square miles on the northern coast of St. Lawrence Island in the Bering Sea. The climate region is maritime with some continental influences during the winter. Temperatures range from –34 to 67ºF.


**Figure 74. Location of Savoonga, Alaska**

The population is primarily Siberian Yup'ik who maintain a traditional subsistence lifestyle. Savoonga is hailed as the "Walrus Capital of the World" with walrus, whale, seal, and reindeer comprising 80% of the local diet. The local economy is heavily based on subsistence activities and some cash income from seafood processing, fox trapping, ivory carvings, and tourism. According to the 2000 U.S. Census, the median household income is $23,438, unemployment is 37%, and 29% of the population live below the poverty level. Savoonga is dependent on air transportation due to the lack of a seaport and iced-in conditions during the winter. The state operates a 4,400-foot gravel airstrip, which is undergoing improvements (Department of Community and Economic Development, 2003).

**Energy Use in Savoonga**

Savoonga receives its electricity from a diesel power plant operated by the Alaska Village Electric Cooperative (AVEC). Data obtained from AVEC for the Savoonga power station was analyzed to determine energy usage trends. Like most Alaskan villages, the residential sector is the largest consumer of electricity. According to the 2000 U.S. Census, there are 160 housing units in Savoonga, with an average of 4.4 people per household. Nearly all homes use fuel oil or kerosene for heat, while a few use natural gas.

As a large individual consumer of electricity within a village, the characteristics of the water treatment plant are important. At the water plant, well water is treated and stored in a 100,000-gallon tank. In 1999, a circulating water and sewer system came online, providing piped water to over half of the homes. In 2000 and 2001, another round of upgrades was made to provide plumbing to additional homes. The remainder of residents continues to haul water and honeybuckets. The school operates an independent septic system. The energy use in Savoonga from 1996 to 2002 is summarized in Table 53 and illustrated in Figure 75.

**Table 53. Summary of Energy Use in Savoonga from 1996 – 2002**

| Year | Total kWh Generated | Average Load (kW) | Peak Load (kW) | Fuel Consumption (gal/yr) | Delivered Cost of Fuel ($/gal) |
|---|---|---|---|---|---|
| 1996 | 1,214,400 | 138 | 245 | 99,400 | 1.16 |
| 1997 | 1,311,100 | 150 | 264 | 104,600 | 1.16 |
| 1998 | 1,509,200 | 172 | 331 | 120,000 | 1.08 |
| 1999 | 1,688,600 | 188 | 318 | 165,500 | 1.07 |
| 2000 | 1,730,400 | 198 | 326 | 141,000 | 1.23 |
| 2001 | 1,860,100 | 212 | 361 | 153,600 | 1.30 |
| 2002 | 1,885,900 | 215 | 366 | 147,300 | 1.23 |

The electric load in Savoonga has been growing at an average rate of 7.7% per year since 1996, due mainly to continual upgrades to the public water system. The largest increase (14.7%) occurred from 1997 to 1998 when water and sewer lines were extended and about 40 homes, the health clinic, and 4 other public buildings were connected (Rural Alaska Project Identification and Delivery System, 2004).

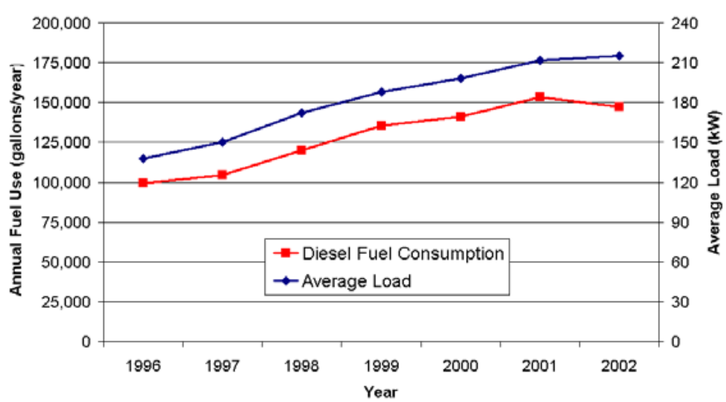



**Figure 75. Energy Use in Savoonga**

The detailed electric load data necessary for modeling a hybrid power system is not currently available for Savoonga. Therefore, an hourly electric load data set was created based on measured data from the nearby village of Gambell using the Alaska Village Electric Load Calculator method described in Chapter 1. For modeling purposes, the expected village load in 2009 was used to evaluate the performance of a potential hybrid power system in Savoonga. A number of construction projects are planned and expected to be completed by 2009. These include a sub-regional clinic, a multi-purpose community center, expansion of the water and sewer lines to about 50 homes, and additional housing (Rural Alaska Project Identification and Delivery System, 2004). Improvements to the K-12 school are also proposed. The estimated 2009 electric load in Savoonga takes into account the addition of these facilities. The adjusted seasonal and daily load profiles are shown in Figure 77 and Figure 76, respectively. The complete data set of daily load profiles can be found in Appendix 5.

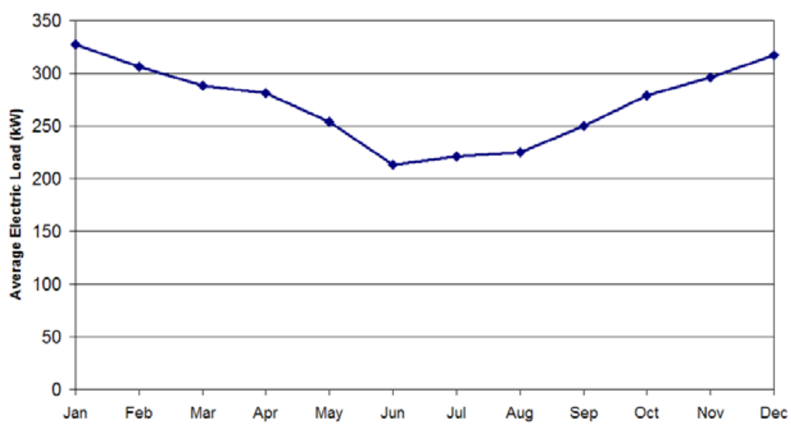



**Figure 76. Estimated 2009 Seasonal Electric Load Profile for Savoonga**

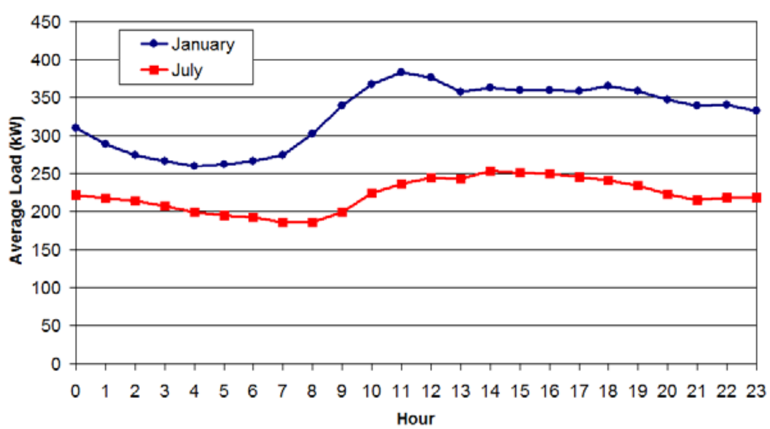



**Figure 77. Estimated 2009 Daily Electric Load Profiles for Savoonga**

**Existing Power Station in Savoonga**

The Savoonga power plant includes four diesel generators totaling 1.6 MW of rated capacity:

1) 397 kW Cummins KTA 1150
2) 499 kW Cummins KTA19G4
3) 314 kW Detroit Diesel Series 60 DDEC4
4) 350 kW Cummins KTA 1150

The power system is currently manually controlled, although the plant operators tend to use one unit continuously for days at a time. Diesel fuel storage capacity is about 125,700 gallons, usually requiring 2 shipments of diesel fuel per year. The measured fuel curves for the diesel generators were obtained from AVEC and are shown in Appendix 4. The Cummins KTA1150 397 kW fuel curve is based on a Cummins LTA-10G1 model, and the Cummins KTA1150 350 kW fuel curve is based on a Cummins VTA-28G5 model. According to diesel manufacturers, the minimum allowed power is specified at 30% of rated power.

**Wind Resource in Savoonga**

Average hourly wind speed data from January 2000 through December 2000 were obtained from the Savoonga airport weather station and are shown in Figure 78 (George, 2003). The data recovery rate was 98%. Any gaps in the data due to equipment or data recording failure were filled using the Hybrid2 Gapfiller program (University of Massachusetts Renewable Energy Research Lab, 2004).

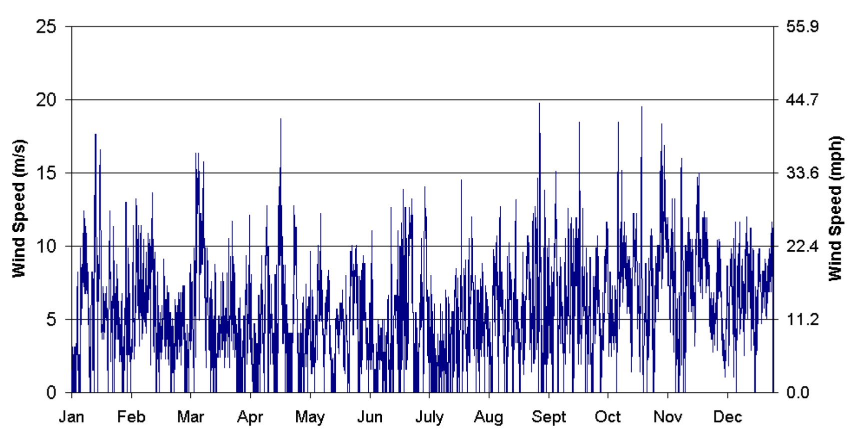



**Figure 78. Average Hourly Wind Speeds Measured at 10-meter Height in Savoonga**

Since only one year of hourly data was available, these values were scaled to meet the long-term (1994-2002) average monthly wind speeds at the same location. The estimated annual average wind speed is 5.7 m/s (12.8 mph) at a 10-meter height, or 6.6 m/s (14.8 mph) at a typical wind turbine hub height of 30-meters. The maximum average hourly wind speed recorded was 19.7 m/s (44 mph). Airports are typically located in areas sheltered from the wind; therefore, the wind resource used in this report is a conservative estimate. A sensitivity analysis is conducted to account for the uncertainty of this wind resource. The seasonal and diurnal wind speed profiles are shown in Figure 79 and Figure 80, respectively. The wind speed data is tabulated in Appendix 6.

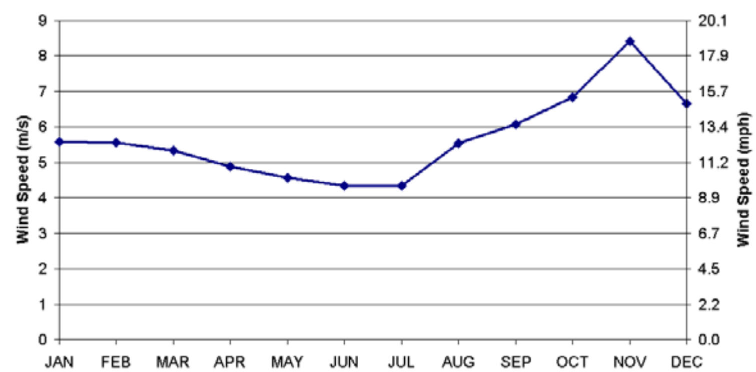



**Figure 79. Seasonal Wind Speed Profile at a 10-meter Height in Savoonga**

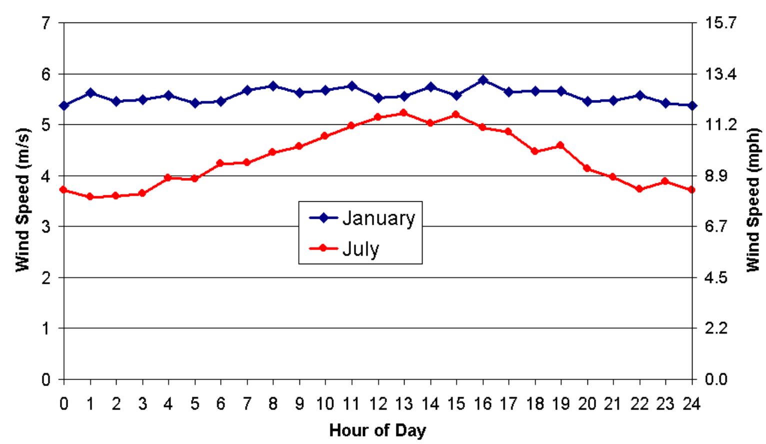



**Figure 80. Diurnal Wind Speed Profiles at a 10-meter Height in Savoonga**

The wind frequency rose in Figure 81 was created by determining the percent of time that the wind comes from a particular direction. It indicates that the prevailing wind direction is from the northeast and southwest quadrants. The wind speed rose in Figure 81 was created by determining the average speed of the wind that comes from a particular direction. It indicates that in general the speed of the wind has equal magnitude when coming from any direction.

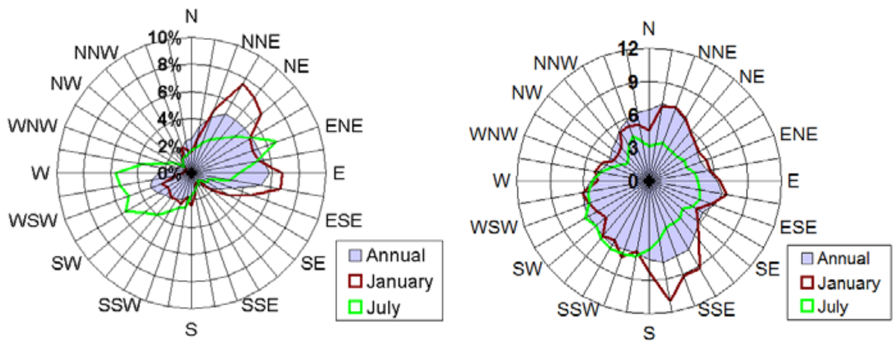



**Figure 81. Wind Frequency Rose and Wind Speed Rose for Savoonga**

**Power System Modeling Results for Savoonga**

To compare the design options of a hybrid power system in Savoonga, the computer simulation model HOMER was used. HOMER uses hourly electric load data and hourly wind speed data to compare the ability of different types and quantities of wind turbines to meet the village load given the local wind resource. The existing diesel power station was modeled to determine the fuel consumption and cost of energy of the diesel-only system. Table 54 summarizes the expected performance of the diesel-only power station, based on the year 2009 electric load data.

**Table 54. Expected 2009 Energy Requirements of Diesel-Only System in Savoonga**

| Total Energy Use | Peak Load | Average Load | Fuel Consumption | Net Present Cost |
|---|---|---|---|---|
| 2,377,600 kWh/yr | 450 kW | 272 kW | 152,000 gal/year<br>(575,400 liters/year) | $7,001,900 |

A sensitivity analysis was performed on the cost of diesel fuel, which has the most impact on the cost of energy. The resulting cost of energy values are shown in Table 55.

**Table 55. Cost of Energy of Diesel-only System in Savoonga**

| Diesel Fuel Cost | Cost of Energy | Net Present Cost |
|---|---|---|
| $1.50/gallon ($0.40/liter) | $0.14/kWh | $5,699,400 |
| $2.00/gallon ($0.53/liter) | $0.17 /kWh | $7,001,900 |
| $2.50/gallon ($0.66/liter) | $0.20 /kWh | $8,304,400 |
| $3.00/gallon ($0.79/liter) | $0.23 /kWh | $9,606,900 |

According to AVEC records, these diesel-related costs account for only about 40% of the total cost of electricity. The remainder includes other power generation expenses, such equipment and maintenance for the fuel tanks and transmission lines, administrative and general expenses, interest, and depreciation. However, these other expenses will still exist with a wind-diesel system. Therefore, the cost of energy listed in Table 55 is used to directly compare the diesel-related expenses with the wind-related expenses.

The impact of various numbers and types of wind turbines on fuel savings is shown graphically in Figure 82.

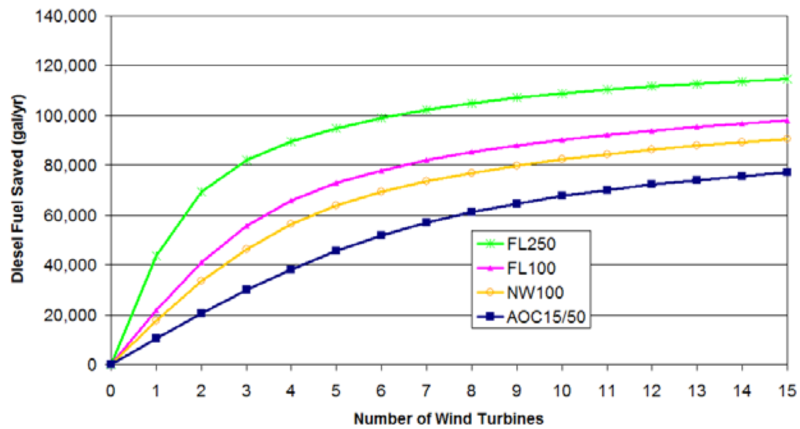



**Figure 82. Effect of Different Wind Turbines on Diesel Fuel Savings in Savoonga**

The figure shows that as the amount of wind generation increases, the fuel savings resulting from the incremental installation of a wind turbine increases, up to a point. After that, the rate of fuel savings decreases due to the fact that some of the wind energy cannot be used to provide direct electrical loads. It should be noted however, that different power system configurations require the installation of different balance of system and control equipment. The resulting comparison of performance indicators, such as fuel savings, must be held against the cost to achieve that savings.

Wind-diesel systems can be divided into three main levels, depending on the amount of wind capacity relative to diesel capacity. Low-penetration systems (up to 20% of the annual village load) are the most simple and require the least amount of initial investment for balance of system equipment. Medium-penetration systems (between 20 and 50% of the annual village load) require additional controls and a dump load, while high-penetration systems (over 50% of the village load) require equipment that will allow the diesels to be shut off for extended amounts of time. The system configurations for each penetration level that result in a cost of energy less than the cost of the diesel-only system are listed in Table 56 – Table 58. The options are ranked based on lowest cost of energy.

**Table 56. Low-penetration System Options for Savoonga**

| Number of Wind Turbines | | | | Initial Capital | Total Net Present Cost | Cost of Energy ($/kWh) | Wind Penetration | Diesel Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | | | | | | | |
| | | | 1 | $525,000 | $6,788,756 | $0.164 | 15% | 492,455 | 130,107 | 21,910 |
| | 1 | | | $550,000 | $6,959,990 | $0.168 | 12% | 509,313 | 134,561 | 17,456 |
| 2 | | | | $640,000 | $7,011,793 | $0.169 | 14% | 498,176 | 131,618 | 20,398 |
| Diesel-only | | | | $0 | $7,001,900 | $0.169 | 0% | 575,384 | 152,017 | 0 |

With the given assumptions, the installation of one FL100 wind turbine would lead to the lowest lifecycle cost of energy for a low-penetration system. The wind turbine would generate approximately 364,500 kWh per year with no excess electricity. The net present cost of the system over the 25-year life of the project is $6,789,000 compared to $7,002,000 for the existing diesel-only case.

**Table 57. Medium-penetration System Options for Savoonga**

| Number of Wind Turbines | | | | | Initial Capital | Total Net Present Cost | Cost of Energy ($/kWh) | Wind Penetration | Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | | | | | | | |
| | | | | 2 | $1,315,000 | $6,216,909 | $0.150 | 51% | 353,002 | 93,263 | 58,754 |
| | | 1 | | | $930,000 | $6,432,352 | $0.155 | 33% | 410,019 | 108,327 | 43,690 |
| | | | 3 | | $1,410,000 | $6,508,055 | $0.157 | 46% | 365,067 | 96,451 | 55,566 |
| | | | | 1 | $740,000 | $6,565,650 | $0.159 | 25% | 442,832 | 116,997 | 35,020 |
| | | | 2 | | $995,000 | $6,646,661 | $0.161 | 31% | 419,749 | 110,898 | 41,119 |
| | 3 | | | | $1,485,000 | $6,940,604 | $0.168 | 36% | 399,845 | 105,639 | 46,378 |
| | 2 | | | | $1,045,000 | $6,947,231 | $0.168 | 24% | 448,973 | 118,619 | 33,398 |
| | 4 | | | | $1,925,000 | $6,967,334 | $0.168 | 48% | 362,062 | 95,657 | 56,360 |
| 3 | | | | | $905,000 | $7,003,991 | $0.169 | 21% | 462,374 | 122,160 | 29,857 |
| Diesel-only | | | | | $0 | $7,001,900 | $0.169 | 0% | 575,384 | 152,017 | 0 |

If the used Vestas V27 wind turbine were available, its installation would lead to the lowest lifecycle cost of energy for a medium-penetration system. If it is not available, it is recommended that one Fuhrländer FL250 wind turbine be installed. The FL250 would produce an average of 780 MWh per year, and about 33 MWh per year of excess electricity would be available to supply a secondary or heating load. The net present cost of the system over the 25-year life of the project is $6,217,000 compared to $7,002,000 for the existing diesel-only case.

Table 58. High-penetration System Options for Savoonga

| Number of Wind Turbines | | | | | Initial Capital | Total Net Present Cost | Cost of Energy ($/kWh) | Wind Penetration | Diesel Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | | | | | | | |
| | | 2 | | | $1,860,000 | $6,248,553 | $0.151 | 66% | 312,794 | 82,640 | 69,376 |
| | | | | 3 | $2,055,000 | $6,402,598 | $0.155 | 76% | 303,094 | 80,078 | 71,939 |
| | | 3 | | | $2,625,000 | $6,491,296 | $0.157 | 98% | 265,422 | 70,125 | 81,892 |
| | | | 4 | | $1,990,000 | $6,641,129 | $0.160 | 61% | 326,092 | 86,154 | 65,863 |
| | | | | 4 | $2,630,000 | $6,695,194 | $0.162 | 102% | 272,992 | 72,125 | 79,892 |
| | | | 5 | | $2,405,000 | $6,773,338 | $0.164 | 77% | 299,419 | 79,107 | 72,910 |
| | | 4 | | | $3,390,000 | $7,006,102 | $0.169 | 131% | 236,724 | 62,543 | 89,474 |
| Diesel-only | | | | | 0 | $7,001,900 | $0.169 | 0% | 575,384 | 152,017 | 0 |

There are a number of high-penetration system configurations that result in a lower cost of energy compared to the diesel-only case. A system consisting of two FL250 wind turbines would produce approximately 1,560 MWh per year. About 417 MWh of excess electricity would be available to supply power to a secondary or heating load. The net present cost of the system over the 25-year life of the project is $6,249,000 compared to $7,001,900 for the diesel-only case.

**Sensitivity Analysis for Savoonga System**

The system with the lowest life-cycle cost of energy, in this case the installation of two FL250 wind turbines, was used as a basis for a sensitivity analysis. The sensitivity analysis was performed around the parameters listed in Table 59. The best guess values for each of the parameters is also listed.

Table 59. Best Guess Values for Base Case Sensitivity Analysis Parameters in Savoonga

| Parameter | Best Guess Value |
|---|---|
| Wind Speed | 5.7 m/s (at a 10-meter height)<br>6.9 m/s (at hub height of 42-meters) |
| Diesel Price | $0.53/liter ($2.00/gallon) |
| Turbine Installed Cost (each) | $765,000 |
| Turbine O&M Cost | $7,000/year ($0.005/kWh) |
| Operating Reserve (% of wind) | 15% |
| Operating Reserve (% of load) | 10% |
| Village Electric Load (annual average) | 272 kW |

As indicated in Figure 83, the best estimate values for the variables result in a cost of energy of about $0.15 per kWh.

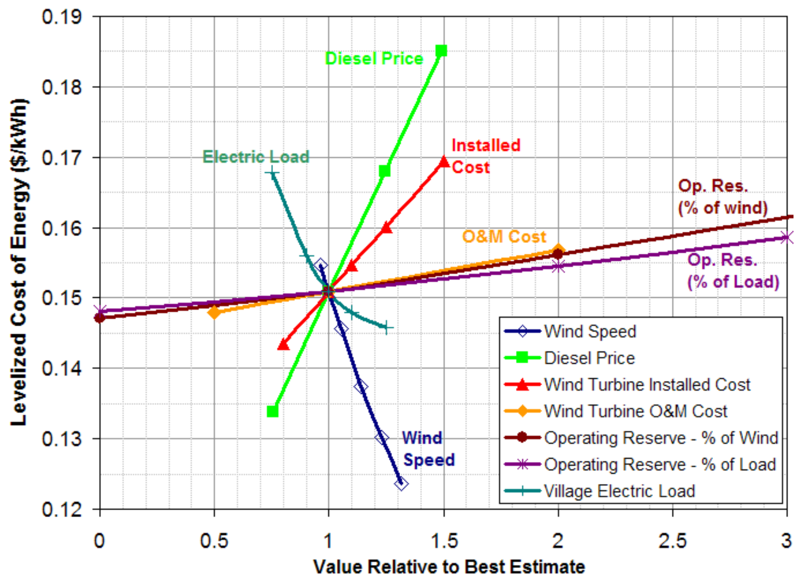



**Figure 83. Sensitivity Analysis Results for Wind-Diesel System in Savoonga**

The price of diesel fuel, the average wind speed, and the average electric load have the greatest direct impact on the cost of energy. If the diesel price increases by 25%, the cost of energy increases by about $0.02/kWh. If the actual measured wind speed at the turbine location is 10% greater than the best estimate documented in this report, the cost of energy will be about $0.01/kWh lower. If the actual 2009 electric load in Savoonga is 10% less than the estimate, then the actual cost of energy would be about $0.005/kWh greater than the estimate. Since a Fuhrländer wind turbine has not yet been installed in Alaska, the actual installed cost may differ from the best guess value listed. Figure 83 shows that if the actual installed cost is 1.25 times the best guess, or $956,250 per machine, the cost of energy would increase by about $0.01/kWh.

### Detailed Analysis of Recommended System in Savoonga

The system configuration that was recommended from the HOMER analysis above was modeled in more detail using Hybrid2. Results for the diesel-only and the high-penetration wind-diesel case consisting of two FL250 wind turbines are shown in Table 60.

**Table 60. Comparison of Hybrid System Configurations to Diesel-Only Case in Savoonga**

| | Diesel-Only | | | Wind + Diesels | | | Wind + Diesels + Batteries | | |
|---|---|---|---|---|---|---|---|---|---|
| | 314kW | 397kW | 499kW | 314kW | 397kW | 499kW | 314kW | 397kW | 499kW |
| Diesel Run Hours | 2,872 | 3,639 | 2,596 | 4,299 | 3,151 | 1,591 | 3,760 | 1,875 | 871 |
| Diesel Starts | 421 | 751 | 436 | 673 | 1,010 | 498 | 770 | 599 | 245 |
| Fuel Consumed | 155,400 gallons | | | 103,400 gallons | | | 86,100 gallons | | |
| Diesel Production | 2,377,700 kWh/year | | | 1,507,500 kWh/year | | | 1,302,700 kWh/year | | |
| Cost of Energy | $0.11/kWh | | | $0.09 /kWh | | | $0.08 | | |
| Net Present Cost | $3,448,000 | | | $2,936,000 | | | $2,360,000 | | |

Simulations were performed to see if supplementary savings would result from the installation of a battery bank to cover short increases in the net load. A battery bank size was specified that would be able to meet the average load for about 18 minutes. The battery bank consists of 120 Alcad M340P NiCad batteries wired in series for a total of 240V and 341 Ah (82 kWh) of rated capacity. In order to cover the average load of 272 kW, a 300 kW rotary converter is specified. The modeling results suggest that the installation of a battery bank does lead to additional fuel and cost savings, as shown in Table 60.

### Conclusions for Savoonga Feasibility Study

Given a diesel fuel price of $2.00 per gallon and the estimated wind resource of 5.7 m/s at a 10-meter height in Savoonga, a number of hybrid power systems are feasible. The power system that results in the lowest lifecycle cost of energy is a high-penetration wind-diesel-battery system. The system consists of two Fuhrländer FL250 wind turbines, the existing diesel generators, and a 341-Ah battery bank. AVEC's cost of energy in Savoonga would be reduced by about $0.03 per kWh. About 69,300 gallons of diesel fuel would be saved per year, which is over half of Savoonga's current diesel storage capacity. The estimated installed cost of the various system components are listed in Table 61.

**Table 61. Installed Cost of Recommended System in Savoonga**

| Component | Installed Cost |
|---|---|
| Two FL250 Wind Turbines, including tower and foundation | $1,530,000 |
| 341 Ah Battery Bank and 300 kW Rotary Converter | $110,000 |
| Dump Load (size not specified) | $30,000 |
| Controls | $95,000 |
| Line Extensions, Insulated Container Shell | $65,000 |
| Overhead, Miscellaneous | $45,000 |
| Total | $1,875,000 |

### Feasibility Study 6: Toksook Bay/ Tununak

Toksook Bay is a village of 572 people encompassing 33 square miles of Nelson Island on the western coast of Alaska. Toksook Bay receives its electricity from a diesel power station managed by the Alaska Village Electric Cooperative (AVEC). AVEC recently acquired the power station in the nearby village of Tununak (population 304) and is planning to construct a grid intertie between the villages and serve both with a single power station.


**Figure 84. Location of Toksook Bay and Tununak, Alaska**

Toksook Bay and Tununak are traditional Yup'ik Eskimo communities. Major employers include the commercial fishing industry, the school district, city offices, and the Tribal Council. The economy is also heavily dependent on subsistence activities. The State-owned gravel airstrip in each village provides service year-round, while barges deliver goods during the summer. Local transportation consists of fishing boats, snow mobiles, and all-terrain vehicles. Toksook Bay and Tununak are located in the maritime climate region, with temperatures ranging from 2º to 59º F (Department of Community and Economic Development, 2004).

### Energy Use in Toksook Bay and Tununak

Major energy consumers in Toksook Bay include a K-12 school, a health clinic, two general stores, a cultural center, the Traditional Council Hall, a number of city offices, and a water treatment facility. At the water treatment facility, well water is treated and stored in a 212,000-gallon tank at the washeteria, then piped throughout the community. Most buildings and homes have complete plumbing, including a gravity piped sewer system. As temperatures rarely fall below freezing, a minimal amount of electric heat tape is required to prevent the pipes from freezing. The residential sector makes up about 55% of the total village load. According to the 2000 U.S. Census, there are 110 housing units in Toksook Bay, all of which use fuel oil or kerosene for heat. The median household income is $30,200.

Major energy consumers in Tununak include a K-12 school, health clinic, two large stores, one small store, a community hall, a fish processing plant, and a number of city and tribal offices (Vallee, 2004). A flush/haul public water system was constructed in 1992, and most residents currently haul water from six watering points. A public washeteria is used for laundry and bathing. The school operates its own piped water and sewer system (Department of Community and Economic Development, 2004).

The detailed electric load data necessary for modeling a hybrid power system is not currently available for Toksook Bay or Tununak. Therefore, an hourly electric load data set was created based on the types of energy consumers located in each village according to the Alaska Village Electric Load Calculator procedure described in Chapter 1. For modeling purposes, the expected village load in 2009 was used to evaluate the performance of potential a hybrid power system. A number of projects are expected to be completed by 2009. The projects in Toksook Bay include the construction of a sub-regional clinic in, expansion of the halibut processing plant, additional housing units, and upgrades to the school. Planned projects in Tununak include the construction of additional housing units and the installation of flush/haul water system units in additional homes. The expected 2009 electric load profile for each village, along with the combined seasonal electric load profile is shown in Figure 85. The combined daily electric load profile is shown in Figure 86 and tabulated in Appendix 5.

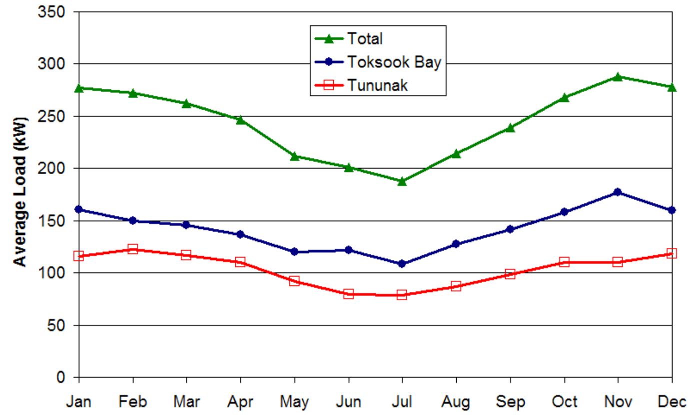



**Figure 85. Estimated 2009 Seasonal Electric Load Profile for Toksook Bay/Tununak**

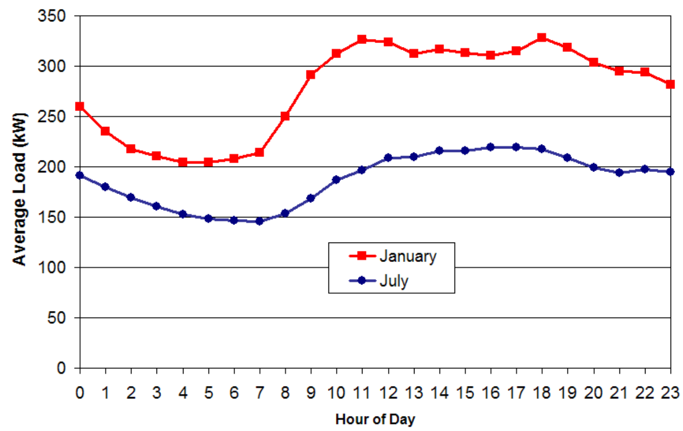



**Figure 86. Estimated 2009 Daily Electric Load Profile for Toksook Bay/Tununak**

### Diesel Power Station in Toksook Bay/Tununak

A new power plant will be constructed to serve both Toksook Bay and Tununak. Based on the diesels that are used in villages of similar size, the following generator capacities were assumed for modeling purposes:

1. 125 kW Generic Diesel
2. 250 kW Cummins LTA10
3. 350 kW Caterpillar 3412

The fuel curves for the diesel generators are based on data obtained from AVEC and are shown in Appendix 4. The minimum allowed power is specified at 30% of rated power.

### Wind Resource in Toksook Bay/Tununak

Detailed wind speed information for Toksook Bay or Tununak is not available at this time. Therefore, the wind speed data from the Mekoryuk airport, located on an island about 35 miles west of Toksook Bay, is used. Since both villages are located along the coast and are separated only by the Etolin Strait, it is reasonable to assume that the wind resource is similar between the two villages (Schwartz, 2004). Mekoryuk is located at the tip of a peninsula, and the surrounding area is relatively flat. The Kitnik and Nealruk mountains lie to the west of Toksook Bay and may cause the wind speed in Toksook Bay to differ from that in Mekoryuk at times. It is unknown how much of an impact the mountains will have; therefore, the actual wind resource should be monitored at the proposed wind turbine location before the system design is finalized. The average hourly wind speed data set is shown in Figure 87, and the daily wind speed profiles are tabulated in Appendix 6.

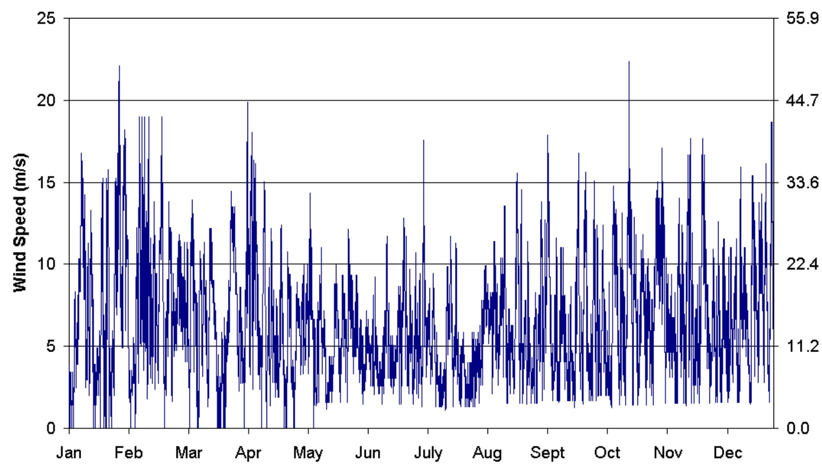



**Figure 87. Average Hourly Wind Speeds in Toksook Bay/ Tununak (based on Mekoryuk)**

The annual average wind speed for the year is 6.46 m/s (14.5 mph) at a 10-meter height and 7.5 m/s (16.8 mph) at a typical wind turbine hub height of 30-meters. The maximum average hourly wind speed recorded was 22.4 m/s (50 mph). The draft wind resource map for Alaska suggests that both Savoonga and Mekoryuk lie within a Class 6 wind regime with an annual average wind speed of 8.95 m/s (20 mph) at a 10-meter height (Heimiller, 2004). A sensitivity analysis was conducted to account for the uncertainty of this data.

### Power System Modeling Results for Toksook Bay/ Tununak

To compare the design options of a hybrid power system in Toksook Bay/ Tununak, the computer simulation model HOMER was used. HOMER uses hourly electric load data and hourly wind speed data to compare the ability of different types and quantities of wind turbines to meet the village load given the local wind resource. The characteristics of the diesel power station were modeled to determine the fuel consumption and cost of energy of the diesel-only system. Table 62 summarizes the expected performance of the new power station.

**Table 62. Expected 2009 Energy Requirements in Toksook Bay and Tununak**

| Total Energy Use | Peak Load | Average Load | Fuel Consumption | Net Present Cost |
|---|---|---|---|---|
| 2,525,800 kWh/year | 438 kW | 288 kW | 179,500 gal/year (679,200 l/year) | $7,773,700 |

A sensitivity analysis was performed on the cost of diesel fuel, which has the most impact on the cost of energy. The resulting cost of energy and the net present value of the system costs over the lifetime of the project are shown in Table 63.

**Table 63. Cost of Diesel-only System in Toksook Bay and Tununak**

| Diesel Fuel Cost | Cost of Energy | Net Present Cost |
|---|---|---|
| $1.50/gallon ($0.40/liter) | $0.14/kWh | $6,237,600 |
| $2.00/gallon ($0.53/liter) | $0.18 /kWh | $7,773,700 |
| $2.50/gallon ($0.66/liter) | $0.22 /kWh | $9,309,800 |
| $3.00/gallon ($0.79/liter) | $0.25 /kWh | $10,845,900 |

According to AVEC records, these diesel-related costs account for only about 40% of the total cost of electricity. The remainder includes other power generation expenses, such equipment and maintenance for the fuel tanks and transmission lines, administrative and general expenses, interest, and depreciation. However, these other expenses will still exist with a wind-diesel system. Therefore, the cost of energy listed in Table 63 is used to directly compare the diesel-related expenses with the wind-related expenses. The impact of various numbers and types of wind turbines on fuel savings is shown graphically in Figure 88.

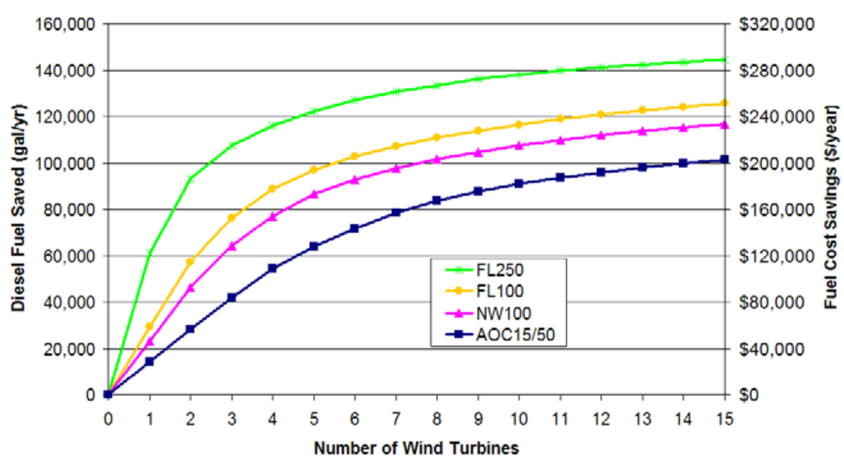



**Figure 88. Effect of Different Wind Turbines on Fuel Savings in Toksook Bay/Tununak**

The figure shows that as the amount of wind generation increases, the fuel savings resulting from the incremental installation of a wind turbine increases, up to a point. After that, the rate of fuel savings decreases due to the fact that some of the wind energy cannot be used to provide direct electrical loads. It should be noted however, that different power system configurations require the installation of different balance of system components and control equipment. The resulting comparison of performance indicators, such as fuel savings, must be held against the cost to achieve that savings.

In general, wind-diesel systems can be divided into three main levels, depending on the amount of wind capacity relative to diesel capacity. Low-penetration systems (the wind supplies up to 20% of the annual village load) are the most simple and require the least amount of initial investment for balance of system equipment. Medium-penetration systems (between 20% and 50% of the annual village load) require additional controls and a dump load, while high-penetration systems (over 50% of the village load) require equipment that will allow the diesels to be shut off for extended amounts of time. The system configurations for each penetration level that result in a cost of energy less than the diesel-only system are listed in Table 64. The options are ranked based on lowest cost of energy.

**Table 64. Low-penetration System Options for Toksook Bay/Tununak**

| Number of Wind Turbines | | | | | Initial Capital | Total Net Present Cost | Cost of Energy ($/kWh) | Wind Penetration | Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | FL30 | | | | | | | |
| | | | 1 | | $525,000 | $7,223,697 | $0.164 | 17% | 567,702 | 149,987 | 29,467 |
| 2 | | | | | $640,000 | $7,445,531 | $0.169 | 16% | 572,966 | 151,378 | 28,076 |
| | 1 | | | | $550,000 | $7,465,110 | $0.170 | 13% | 591,139 | 156,179 | 23,275 |
| 1 | | | | | $375,000 | $7,648,693 | $0.174 | 8% | 625,522 | 165,263 | 14,191 |
| | | | | 3 | $672,500 | $7,571,795 | $0.172 | 16% | 576,055 | 152,194 | 27,260 |
| | | | | 2 | $485,000 | $7,664,768 | $0.174 | 10% | 609,738 | 161,093 | 18,361 |
| | | | | 1 | $297,500 | $7,778,496 | $0.177 | 5% | 644,497 | 170,277 | 9,178 |
| Diesel-only | | | | | $0 | $7,773,700 | $0.180 | 0% | 679,234 | 179,454 | 0 |

With the given assumptions, the installation of one FL100 wind turbine would lead to the lowest lifecycle cost of energy for a low-penetration system. The wind turbine would generate approximately 424,200 kWh per year with no excess electricity. The net present cost of the system over the 25-year life of the project is $7,224,000 compared to $7,774,000 for the existing diesel-only system.

**Table 65. Medium-penetration System Options for Toksook Bay/Tununak**

| Number of Wind Turbines | | | | | Initial | Total Net | Cost of Energy | Wind | Fuel Use | Fuel Use | Fuel Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | Capital | Present Cost | ($/kWh) | Penetration | (L) | (Gal) | (Gal) |
| | | | 3 | | $1,410,000 | $6,386,676 | $0.145 | 50% | 390,972 | 103,295 | 76,159 |
| | | 1 | | | $930,000 | $6,438,108 | $0.146 | 36% | 448,191 | 118,412 | 61,042 |
| | | | 2 | | $995,000 | $6,705,198 | $0.152 | 34% | 462,314 | 122,144 | 57,310 |
| | 3 | | | | $1,485,000 | $6,933,075 | $0.158 | 40% | 435,799 | 115,138 | 64,316 |
| 5 | | | | | $1,490,000 | $7,080,078 | $0.161 | 40% | 437,078 | 115,476 | 63,978 |
| 6 | | | | | $1,755,000 | $7,060,745 | $0.161 | 48% | 407,687 | 107,711 | 71,743 |
| | 2 | | | | $1,045,000 | $7,159,266 | $0.163 | 27% | 504,407 | 133,265 | 46,189 |
| 4 | | | | | $1,225,000 | $7,158,325 | $0.163 | 32% | 473,963 | 125,221 | 54,233 |
| 3 | | | | | $960,000 | $7,309,000 | $0.166 | 24% | 520,491 | 137,514 | 41,940 |
| | | | | 1 | $740,000 | $6,728,770 | $0.153 | 28% | 493,837 | 130,472 | 48,982 |
| Diesel-only | | | | | $0 | $7,773,700 | $0.180 | 0% | 679,234 | 179,454 | 0 |

The medium-penetration system configuration with the lowest lifecycle cost of energy consists of three Fuhrländer FL100 wind turbines. An average of 1,273 MWh of electricity would be generated per year, and about 177 MWh per year of excess electricity would be available to supply a secondary or heating load. The net present cost of the system over the 25-year life of the project is $6,387,000 compared to $7,774,000 for the existing diesel-only system.

**Table 66. High-penetration System Options for Toksook Bay/Tununak**

| Number of Wind Turbines | | | | | Initial | Total Net | Cost of Energy | Wind | Fuel Use | Fuel Use | Fuel Savings |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AOC | NW100 | FL250 | FL100 | V27 | Capital | Present Cost | ($/kWh) | Penetration | (L) | (Gal) | (Gal) |
| | | 2 | | | $1,860,000 | $6,017,204 | $0.137 | 73% | 326,281 | 86,204 | 93,250 |
| | | | | 3 | $2,055,000 | $6,187,982 | $0.141 | 85% | 315,917 | 83,466 | 95,989 |
| | | | | 2 | $1,480,000 | $6,232,029 | $0.142 | 56% | 375,322 | 99,160 | 80,294 |
| | | 3 | | | $2,625,000 | $6,254,309 | $0.142 | 109% | 272,790 | 72,071 | 107,383 |
| | | | 4 | | $1,990,000 | $6,439,137 | $0.146 | 67% | 342,444 | 90,474 | 88,980 |
| | | | | 4 | $2,630,000 | $6,477,663 | $0.147 | 113% | 282,253 | 74,571 | 104,883 |
| | | | 5 | | $2,405,000 | $6,559,540 | $0.149 | 84% | 311,871 | 82,397 | 97,058 |
| | | 4 | | | $3,390,000 | $6,751,802 | $0.154 | 145% | 240,145 | 63,446 | 116,008 |
| | | | 6 | | $2,820,000 | $6,792,758 | $0.154 | 101% | 289,918 | 76,597 | 102,858 |
| | | | | 5 | $3,205,000 | $6,890,360 | $0.157 | 141% | 258,691 | 68,346 | 111,108 |
| | 4 | | | | $2,090,000 | $7,018,047 | $0.160 | 53% | 387,331 | 102,333 | 77,121 |
| | 5 | | | | $2,530,000 | $7,070,524 | $0.161 | 66% | 351,351 | 92,827 | 86,627 |
| | | | 7 | | $3,235,000 | $7,096,079 | $0.161 | 118% | 273,439 | 72,243 | 107,211 |
| 7 | | | | | $2,185,000 | $7,241,838 | $0.165 | 56% | 382,526 | 101,064 | 78,390 |
| | 6 | | | | $2,970,000 | $7,281,387 | $0.166 | 80% | 327,319 | 86,478 | 92,976 |
| Diesel-only | | | | | $0 | $7,773,700 | $0.180 | 0% | 679,234 | 179,454 | 0 |

A number of high-penetration system configurations result in a lower cost of energy compared to the diesel-only case. A system consisting of two FL250 wind turbines would produce approximately 1,833 MWh per year and about 504 MWh of excess electricity would be available to supply power to a heating load. The net present cost of the system over the 25-year life of the project is $6,017,000 compared to $7,774,000 for the diesel-only system.

**Sensitivity Analysis for Toksook Bay/Tununak System**

The hybrid power system with the lowest life-cycle cost of energy, in this case the high-penetration system consisting of two FL250 turbines, was used as a basis for a sensitivity analysis. The sensitivity analysis was performed around the parameters listed in Table 67. The best guess values for each of these parameters is also listed.

**Table 67. Best Guess Values for Sensitivity Analysis Parameters in Toksook Bay/Tununak**

| Parameter | Best Guess Value |
|---|---|
| Average Annual Wind Speed | 6.46 m/s (at a 10-meter height)<br>7.8 m/s (at hub height of 42-meters) |
| Diesel Price | $0.53/liter ($2.00/gallon) |
| Turbine Installed Cost (each) | $765,000 |
| Turbine O&M Cost | $7,000/year ($0.005/kWh) |
| Operating Reserve (% of wind) | 15% |
| Operating Reserve (% of load) | 10% |
| Village Electric Load (annual average) | 288 kW |

As indicated in Figure 89, the best estimate values result in a cost of energy of $0.137 per kWh.

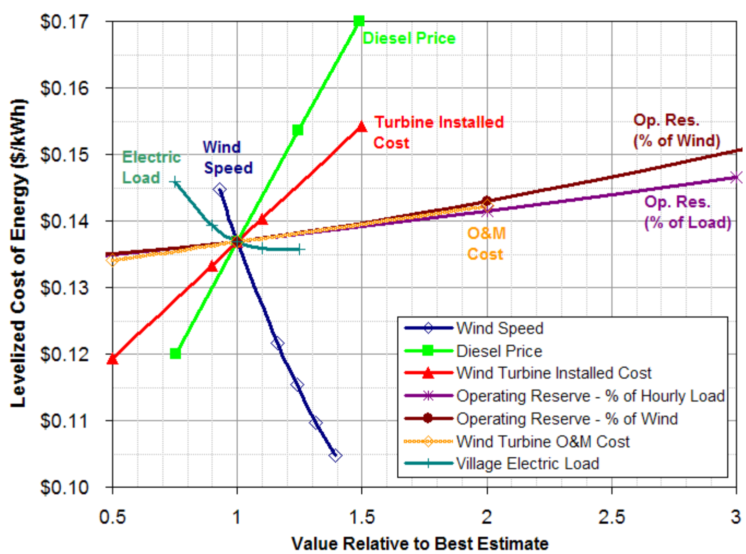



**Figure 89. Sensitivity Analysis Results of Toksook Bay/Tununak Wind-Diesel System**

The price of diesel fuel and the wind speed have the greatest impact on the cost of energy. If the diesel price increases by 25%, the cost of energy increases by about $0.02/kWh. If the actual measured wind speed at the turbine location is 15% greater than the best estimate documented in this report, the cost of energy will be about $0.015/kWh lower. The local phone company is planning to erect a microwave tower in Tununak, and there is a possibility of AVEC sharing in the cost of a crane to install the microwave tower and the wind towers (Petrie, July 2004). Figure 89 shows that if the actual installed cost of the wind turbines were 75% of the best guess value, the levelized cost of energy would decrease by about $0.01/kWh.

### Detailed Analysis of Recommended System in Savoonga

Since the exact configuration of the new diesel power station is not known, a detailed analysis of a potential wind-diesel system in Toksook Bay/Tununak was not completed at this time.

### Conclusions for Toksook Bay/Tununak Feasibility Study

Given a diesel fuel price of $2.00 per gallon and the estimated annual average wind resource of 6.46 m/s at a 10 meter height, a number of hybrid power systems are feasible. The power system that results in the lowest lifecycle cost of energy is a high-penetration wind-diesel system. The system consists of two Fuhrländer FL250 wind turbines and diesel generators. AVEC’s cost of energy would be reduced by about $0.04/kWh over the diesel-only system, and about 93,000 gallons of diesel fuel would be saved per year.

**Feasibility Study 7: Kiana**

Kiana is a village covering less than a quarter square mile of land on the north bank of the Kobuk River, 60 miles east of Kotzebue. The population is 400, 93% of which are Inupiat Eskimo. Kiana is located in the transitional climate zone with average temperatures ranging from –10° to 60°F. The state maintains a 3,400-foot lighted gravel runway in Kiana, and the Kobuk River is navigable from the end of May through early October, allowing the delivery of fuel and supplies. The primary means of local transportation include small boats, all-terrain vehicles, and snowmobiles (Department of Community and Economic Development, 2003).

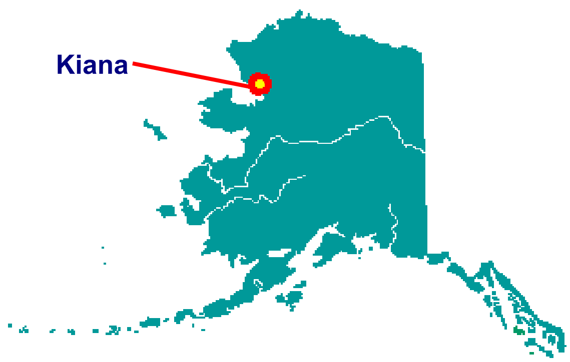



**Figure 90. Location of Kiana, Alaska**

Kiana is one of the more modern villages in the Northwest Arctic Borough. It was among the first communities in the region to construct a piped water and sewer system. The Maniilaq Association, a major year-round employer, operates a sub-regional health clinic in Kiana. Three general stores provide supplies brought upriver by boat. Seasonal employment is provided on river barges, fire-fighting, mining for jade or copper ore, and a growing tourism industry. Subsistence gathering of salmon, moose, caribou, waterfowl, and berries is also a major part of the local lifestyle and economy (Maniilaq Association, 2003). According to the 2000 U.S. Census, the unemployment rate is 12% and the median household income is $29,688.

**Energy Use in Kiana**

Kiana receives its electricity from a diesel power plant operated by the Alaska Village Electric Cooperative (AVEC). Data obtained from AVEC for the Kiana power station was analyzed to determine energy use trends.  A breakdown of the electricity usage of the major consumer sectors is shown in Figure 91.

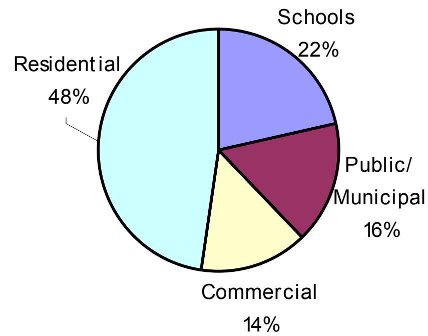



**Figure 91. Major Energy Use Sectors in Kiana**

Like most Alaskan villages, the residential sector is the largest consumer of electricity. According to the 2000 U.S. Census, there are 133 housing units in Kiana, with an average of 4.5 people per household.  Most homes use fuel oil or kerosene for heat while about 7% of homes use wood fuel.  Largest individual consumers of electricity include the school and water plant.

The characteristics of the public water system influence the amount of electricity it uses. At the Kiana water treatment facility a 200,000-gallon steel tank is filled intermittently from two water wells near the Kobuk River.  The water is chlorinated before being distributed through buried water mains.  A gravity sewer system drains to a lift station where wastewater is pumped to a sewage treatment lagoon northeast of the village.  Piped water and sewer services are provided to about 75 homes, the health clinic, the school, and community hall.  About 20 households are yet to be connected and haul water and use honeybuckets or septic tanks.  The development of a public water system master plan, a new water treatment facility, and additional service connections have been funded.

Based on power plant production data collected by AVEC, a year of average hourly electric load data from the Kiana power station is shown in Figure 92.  Like most Alaskan villages, there is a higher consumption of electricity in the winter than in the summer in Kiana.  The diurnal load profile for an average day in each month is shown in Figure 93. These profiles were created by averaging each hour of each day within the month.

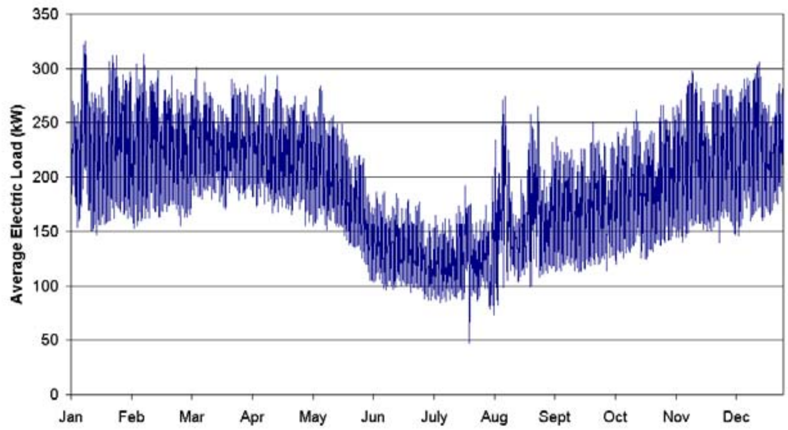



**Figure 92. 2003 Hourly Electric Load in Kiana**

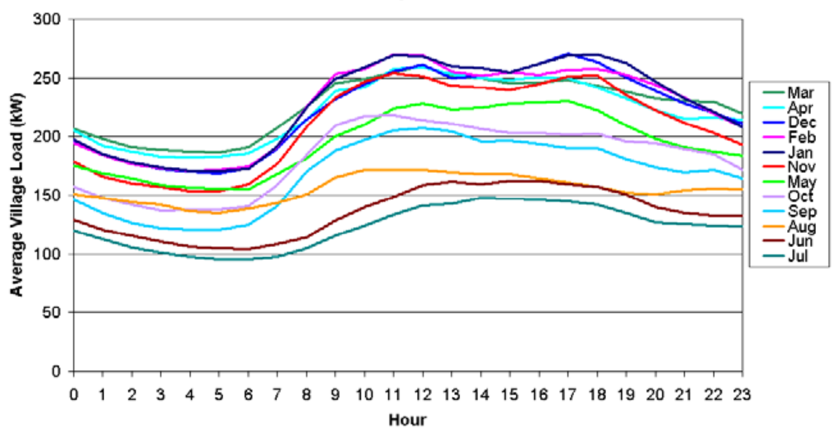



**Figure 93. Diurnal Load Profiles for Each Month in Kiana**

The load profile is more pronounced in the winter, with a sharp increase from 7:00AM to a peak around 12:00PM. The load is steady throughout mid-afternoon and peaks again in the early evening around 6PM. The electric and diesel fuel usage in Kiana since 1996 is summarized in Table 68. This information is also shown graphically in Figure 94.

**Table 68. Summary of Energy Use in Kiana from 1996 – 2002**

| Year | Total kWh Generated | Average Load (kW) | Peak Load (kW) | Fuel Consumption (gal/yr) | Delivered cost of Fuel ($/gal) |
|---|---|---|---|---|---|
| 1996 | 1,224,600 | 139 | 265 | 96,400 | $1.65 |
| 1997 | 1,279,100 | 146 | 298 | 103,400 | $1.53 |
| 1998 | 1,385,100 | 158 | 293 | 105,400 | $1.26 |
| 1999 | 1,418,900 | 159 | 294 | 104,500 | $1.33 |
| 2000 | 1,358,000 | 155 | 300 | 102,200 | $1.60 |
| 2001 | 1,411,300 | 161 | 307 | 107,900 | $1.75 |
| 2002 | 1,495,900 | 171 | 333 | 110,800 | $1.73 |

The electric load in Kiana has been increasing at an average rate of 3.6% per year since 1996. The largest increase (8.2%) occurred from 1997 to 1998 when additional single-family housing units were constructed (Department of Community and Economic Development, 2004).

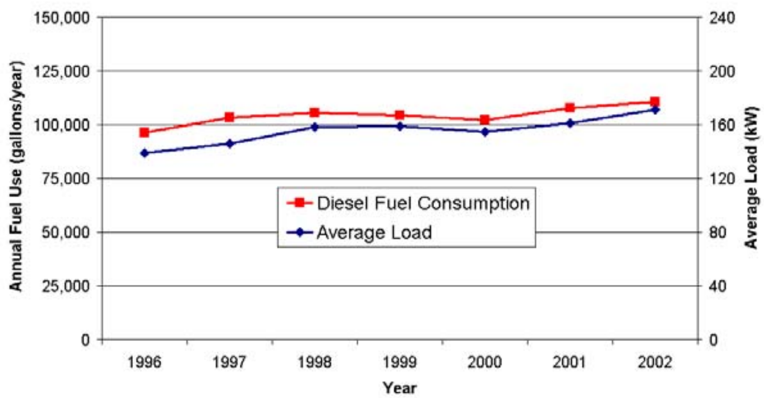



**Figure 94. Energy Use from 1996-2002 in Kiana**

For modeling purposes, the expected village load in 2009 will be used to evaluate the performance of potential a hybrid power system. A number of construction projects have been funded and are expected to be online by 2009. These projects include additional housing units, upgrades to the public water system, and possibly a multi-purpose building (Rural Alaska Project Identification and Delivery System, 2004). The 2003 electric load data in Kiana is adjusted to account for the addition of these facilities, based on the Alaska Village Electric Load Calculator method described in Chapter 1. The modified values are tabulated in Appendix 5, and a sensitivity analysis was performed around this parameter.

**Existing Power Station in Kiana**

The Kiana power plant includes four diesel generators totaling 1163 kW of rated capacity:

1) 314 Detroit Diesel Series 60 DDEC4
2) 350 kW Cummins KTA1150
3) 499 kW Cummins KTA19G4

Useable diesel storage capacity is 112,500 gallons, usually requiring 3 shipments of diesel fuel per year. The measured fuel curves for the diesel generators were obtained from AVEC and are shown in Appendix 4. The Cummins fuel curves are based on a Cummins model VTA-28G5. For modeling purposes, the minimum allowed power was specified at 30% of rated power.

**Wind Resource in Kiana**

Average hourly wind speeds from January 2003 through December 2003 were obtained from the Western Regional Climate Center online database. A Remote Automated Weather Station (RAWS) in Kiana recorded hourly wind speed information at a height of 20 feet. This station is located at the airport and is maintained by the Alaska Bureau of Land Management Fire Service Department (Shelley, 2004). The data recovery rate for the year was only 78%. Two weeks in January and most of November and December were missing. These gaps were filled using data from previous years. Shorter gaps in the data were filled using the Hybrid2 Gapfiller program (University of Massachusetts Renewable Energy Research Lab, 2004). The compiled year of hourly values was scaled to meet the long-term (1992-2003) average monthly wind speeds at the same location. The adjusted wind speed data set is shown in Figure 95 and summarized in Appendix 6.

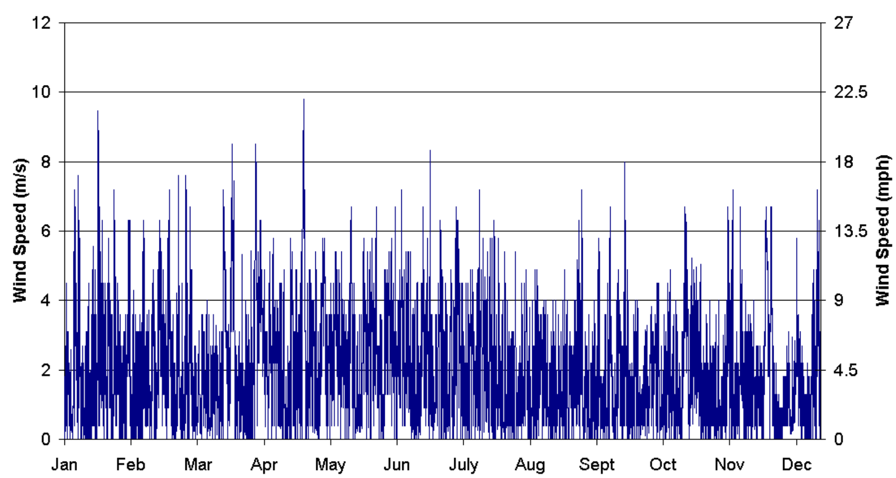



**Figure 95. Hourly Wind Speeds Measured at 6.1-meter Height in Kiana**

The annual average wind speed for the year is 2.4 m/s (5.4 mph) at a 6.1-meter height, 2.6 m/s (5.8 mph) at a 10-meter height, and 3 m/s (6.7 mph) at a typical hub height of 30-meters. The maximum average hourly wind speed recorded during the year was 10.2 m/s (22.8 mph) at a 6.1-meter height. A sensitivity analysis was conducted to account for the uncertainty of this data.

The seasonal and diurnal wind speed profiles are shown in Figure 96 and Figure 97, respectively.

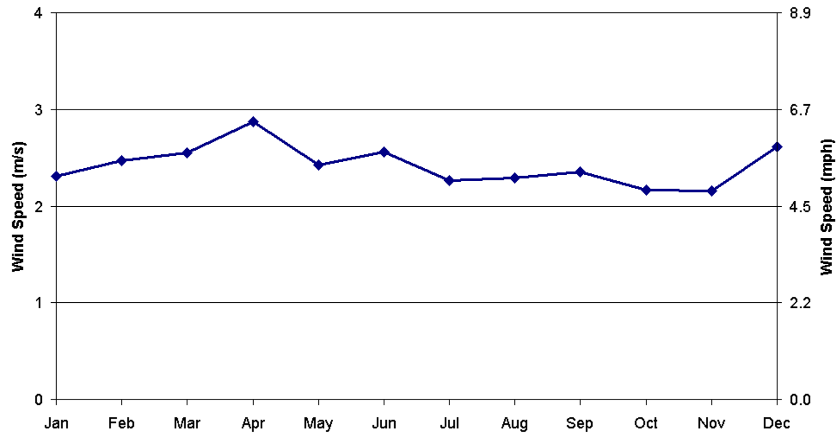



**Figure 96. Seasonal Wind Speed Profile Measured at a 6.1-meter Height in Kiana**

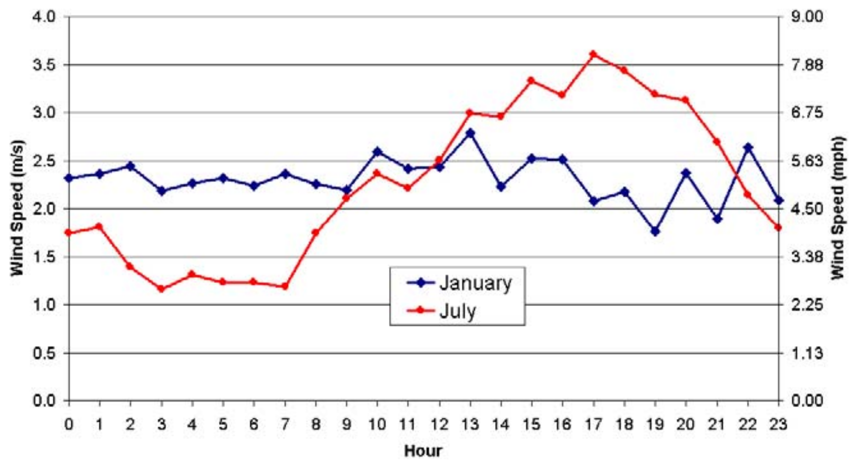



**Figure 97. Diurnal Wind Speed Profile Measured at a 6.1-meter Height in Kiana**

The wind rose in Figure 98 was created by determining the percent of time that the wind comes from a particular direction. It indicates that the prevailing wind direction is from the east and southwest quadrants.

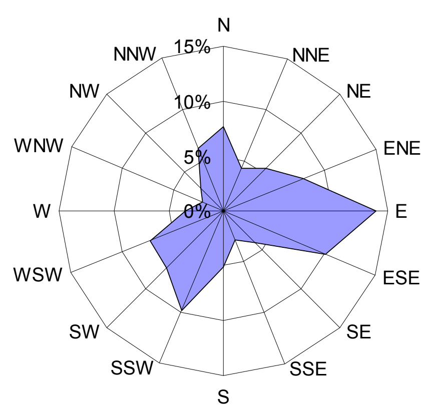



**Figure 98. Annual Wind Frequency Rose for Kiana**

The RAWS equipment is not a standard wind monitoring station for use in power production calculations; therefore, the wind resource used in this report is a conservative estimate and a sensitivity analysis is conducted to account for its uncertainty. The actual wind resource should be monitored at the proposed wind turbine location before the system design is finalized.

### Power System Modeling Results for Kiana

To compare the design options of a hybrid power system in Kiana, the computer simulation model HOMER was used. HOMER uses hourly electric load data and hourly wind speed data to compare the ability of different types and quantities of wind turbines to meet the village load given the local wind resource. The characteristics of the diesel power station were modeled to determine the fuel consumption and cost of energy of the diesel-only system. Table 69 summarizes the expected performance of the power station, based on the estimated electric load data for the year 2009.

**Table 69. Expected Energy Requirements in 2009 for Kiana**

| Total Energy Use | Peak Load | Average Load | Fuel Consumption | Net Present Cost |
|---|---|---|---|---|
| 1,721,800 kWh/yr | 411 kW | 242 kW | 140,000 gal/yr (530,000 liters/yr) | $6,273,200 |

A sensitivity analysis was performed on the cost of diesel fuel, which has the most impact on the cost of energy. The resulting cost of energy and the net present value of the system costs over the lifetime of the project are shown in Table 70.

**Table 70. Cost of Energy for Diesel-Only System in Kiana**

| Diesel Fuel Cost | Cost of Energy | Net Present Cost |
|---|---|---|
| $1.50/gallon ($0.40/liter) | $0.14 /kWh | $5,073,500 |
| $2.00/gallon ($0.53/liter) | $0.17 /kWh | $6,273,200 |
| $2.50/gallon ($0.66/liter) | $0.22 /kWh | $7,473,000 |
| $3.00/gallon ($0.79/liter) | $0.25 /kWh | $8,672,800 |

According to AVEC records, these diesel-related costs account for only about 40% of the total cost of electricity. The remainder includes other power generation expenses, such equipment and maintenance for the fuel tanks and transmission lines, administrative and general expenses, interest, and depreciation. However, these other expenses will still exist with a wind-diesel system. Therefore, the cost of energy listed in Table 70 is used to directly compare the diesel-related expenses with the wind-related expenses.

The impact of various numbers and types of wind turbines on fuel savings is shown graphically in Figure 99.

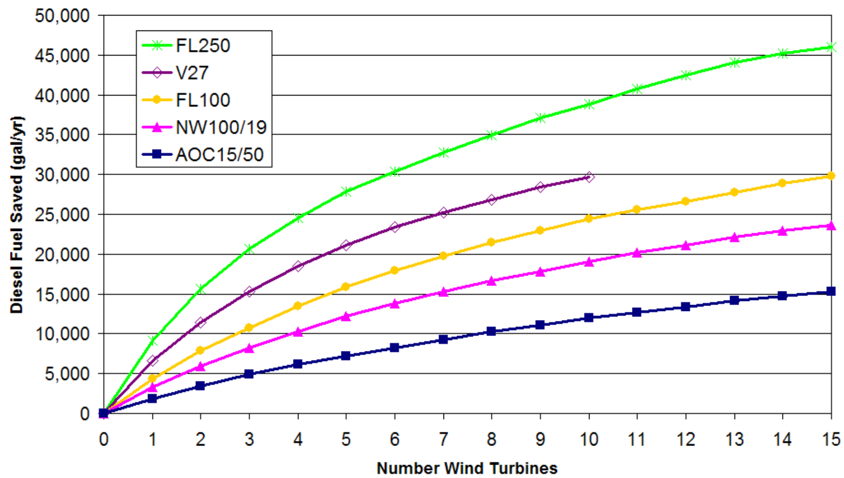



**Figure 99. Effect of Different Wind Turbines on Diesel Fuel Savings in Kiana**

Due to the poor wind resource measured in Kiana, the wind turbines do not produce as much electricity as they could if sited in a windier location. Capacity factors of the different wind turbine types, given Kiana's wind resource, are less than 25%. An economic evaluation of the different power options indicates that there are no wind-diesel systems that would result in a lower cost of energy or lower net present cost than the diesel-only system. An annual average wind speed of at least 5.4 m/s (12 mph) at a 10-meter height is needed in order to make a wind-diesel system in Kiana economically justified.

The draft wind resource map for Alaska suggests that Kiana lies within a Class 2 wind regime with an annual average wind speed of 6.3 m/s (14.1 mph) at a 10-meter height, and that there are areas near Kiana with a Class 6 wind regime (Heimiller, 2004). If a more exposed location than the airport can be found near Kiana to site the wind turbine(s), then the systems summarized in Table 71 would be recommended.

**Table 71. Recommended System Configurations Assuming a 5.4 m/s Wind Speed in Kiana**

| Penetration Level | # of Wind Turbines FL250 | AOC | NW100 | V27 | Initial Capital | Total Net Present Cost | COE ($/kWh) | Wind Penetration | Fuel Use (L) | Fuel Use (Gal) | Fuel Savings (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diesel-only | | | | | 0 | $6,273,200 | $0.170 | 0% | 530,000 | 140,026 | 0 |
| Low | | | 1 | | $550,000 | $6,293,096 | $0.171 | 13% | 470,950 | 124,425 | 15,601 |
| | | 1 | | | $375,000 | $6,319,869 | $0.172 | 8% | 491,674 | 129,901 | 10,126 |
| | | 2 | | | $640,000 | $6,357,203 | $0.173 | 15% | 460,865 | 121,761 | 18,266 |
| Medium | 1 | | | | $930,000 | $6,331,815 | $0.172 | 35% | 406315 | 107,349 | 32,678 |
| High | | | | 2 | $1,480,000 | $6,284,805 | $0.171 | 54% | 355,130 | 93,826 | 46,201 |
| | 2 | | | | $1,860,000 | $6,286,324 | $0.171 | 70% | 326043 | 86,141 | 53,886 |

### Conclusions for Kiana Feasibility Study

The available wind resource data indicates that wind energy is not an economically feasible option in Kiana. A minimum annual average wind speed of 5.4 m/s at a 10-meter height (6.2 m/s at a typical wind turbine hub height of 30-meters) is required. The draft wind resource map for Alaska suggests that there are windier sites around Kiana where a wind power system could be located. If the wind speed at a more exposed site in Kiana is measured and results in an annual average wind speed of at least 5.4 m/s, the feasibility study should be repeated with the new data.

## CONCLUSIONS

This report presented an analysis of the historical electric load growth, current and future village power needs, and wind-diesel hybrid power options for remote villages in Alaska. Based on an analysis of electrical use in a number of rural Alaskan communities, a method for estimating the hourly electric usage in a village was presented. The Alaska Village Electric Load Calculator method allows one to build upon existing knowledge of expansion plans for different communities or estimate the energy usage of non-electrified communities by simply adding the different expected electric loads in a building block approach. Several examples were given, which result in estimations within an average of 10% accuracy. The hourly electric load data produced is one of the key pieces of information required to conduct any detailed power system analysis.

The Alaska Village Electric Load Calculator was used to predict the 2009 electric needs of seven remote villages. This information, along with local hourly wind speed data, was used in computer simulations to determine the technical and economic feasibility of wind-diesel hybrid power stations in these villages.

Table 72 summarizes the results of the feasibility studies.

**Table 72. Wind-Diesel Hybrid System Feasibility Study Results**

| Village Name | Population | 2009 Ave Electric Load (kW) | Ave Wind Speed at hub height (m/s) | Recommended Wind-Diesel System | COE Savings | Ave Wind Penetration | Fuel Savings (gal/yr) | Fuel Savings |
|---|---|---|---|---|---|---|---|---|
| Gambell | 650 | 283 | 10.02 | High-Pen, 2 x FL250 | $0.07 | 111% | 130,000 | 72% |
| Chevak | 850 | 330 | 8.03 | High-Pen, 3 x FL250 | $0.05 | 102% | 123,000 | 59% |
| Hooper Bay | 1115 | 400 | 8.03 | High-Pen, 3 x FL250 | $0.09 | 85% | 119,000 | 50% |
| Mekoryuk | 205 | 104 | 7.80 | High-Pen, 1 x FL250 | $0.08 | 86% | 32,000 | 50% |
| Savoonga | 705 | 272 | 6.87 | High-Pen, 2 x FL250 | $0.03 | 66% | 69,000 | 45% |
| Kiana | 400 | 242 | 3.15 | Diesel-only | - | 0% | - | - |
| Toksook Bay/ Tununak | 876 | 288 | 7.80 | High-Pen, 2 x FL250 | $0.04 | 73% | 93,000 | 52% |

As expected, the wind resource has a major effect on the power system recommendation. For example, although Savoonga and Toksook Bay/Tununak have a nearly identical electric demand; Toksook Bay/Tununak would receive more immediate benefit from the installation of wind turbines than Savoonga due to the superior wind resource. Also, as the Kiana case illustrates, the use of wind energy is not recommended for all villages. The wind resource must be great enough to produce the amount of electricity necessary to offset the capital costs of the wind power equipment.

In most cases, a high-penetration wind-diesel system consisting of Fuhrländer wind turbines is recommended; however, it is important to note that many other system configurations including other wind turbine models also lead to cost savings. The Fuhrländer FL250 was the largest wind turbine evaluated with the lowest installed cost per kW of rated capacity. Thus, economies of scale make the installation of this machine attractive. Also, the FL250 is installed on a taller tower than the other machines, giving it access to higher wind speeds and greater generating potential. In each village where a wind-diesel system was recommended, there were a number of wind turbine options and wind penetration levels that lead to a lower cost of energy than the diesel-only system. The addition of short-term battery storage to the high-penetration system leads to increased fuel savings and decreased operation and maintenance costs of the diesel generators.

Both of the software packages HOMER and Hybrid2 are useful modeling tools for estimating the energy production and economic impacts of wind-diesel hybrid systems. In most cases, the results from both models were similar, particularly in calculating the power production from the different system components and the amount of fuel savings. The primary difference is in the calculation of the levelized cost of energy. The models give significantly different values, most likely due to the methods for calculating the salvage value of equipment; however, both models are in agreement when determining whether or not a given wind-diesel system has a lower cost of energy than the diesel-only system.

## AREAS FOR FURTHER INVESTIGATION

Following the completion of more complete wind resource assessments, including the GIS-based wind resource map currently being developed for Alaska, more accurate analysis can be conducted on these and additional communities using the results of this analysis as a baseline of study. Since the wind resource has a great impact on the performance of a wind-diesel power system, more accurate wind speed data will lead to a more efficient power system design.

The methodology developed in this document, specifically the assessment of community loads, can also be applied to non-AVEC communities in Alaska and possibly other similar remote arctic communities. The steps are outlined in this report and a CD of the Alaska Village Electric Load Calculator spreadsheet is included so that the process can be repeated for other communities.

To expand on the Alaska Village Electric Load Calculator, the hourly electric consumption of individual consumers could be monitored and analyzed. The daily load profile of a village could then be determined in the same manner as with the seasonal load profile. Also, a method for estimating the thermal loads of community facilities would be helpful in determining the ability of these loads to absorb excess electricity produced by the wind turbine(s). The thermal loads from facilities such as the village power plant, water treatment plant, school, or health clinic could be added in a building-block approach and compared with the electric output of the wind turbine(s).

## APPENDIX 1. VALIDATION OF VILLAGE ELECTRIC LOAD CALCULATOR

A number of village seasonal electric load profiles were created using the Alaska Village Electric Load Calculator method described in Chapter 1 and then compared to actual data from AVEC records for the year 2002. The model inputs and results are shown here. In each case, the graph shows the community facilities that make up the model load, a line showing the actual measured consumption, and the percent difference between the model and actual load.

**Table 73. Village Electric Load Calculator Inputs for the Village of Toksook Bay**

| Village Characteristic | Value |
|---|---|
| Population | 550 |
| # of Small Businesses | 3 |
| # of Large Commercial Businesses | 0 |
| # of Community Buildings | 2 |
| # of Government Offices | 3 |
| Median Household Income | Medium |

| Village Characteristic | Value |
|---|---|
| K-12 School | Medium |
| Public Water System | Level II Low |
| Health Clinic | Local |
| Communications | Basic |
| Other Loads | 1% |

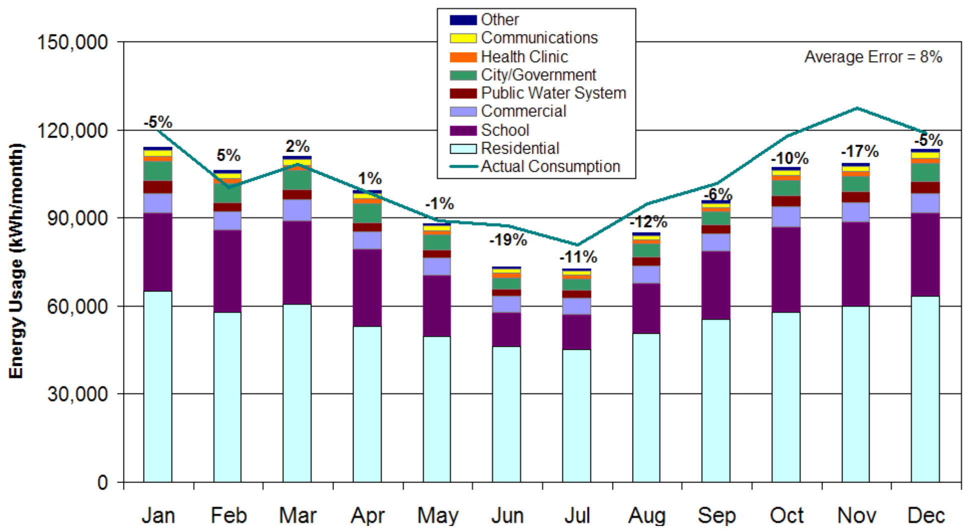



**Figure 100. Village Electric Load Calculator Results for the Village of Toksook Bay**

The average error between the estimated load and actual load is 8%.

**Table 74. Village Electric Load Calculator Inputs for the Village of Mekoryuk**

| Village Characteristic | Value |
|---|---|
| Population | 204 |
| # of Small Businesses | 3 |
| # of Large Commercial Businesses | 1 |
| # of Community Buildings | 1 |
| # of Government Offices | 5 |
| Median Household Income | Medium |

| Village Characteristic | Value |
|---|---|
| K-12 School | Medium |
| Public Water System | Level I Medium |
| Health Clinic | Local |
| Communications | Basic |
| Other Loads | 5% |

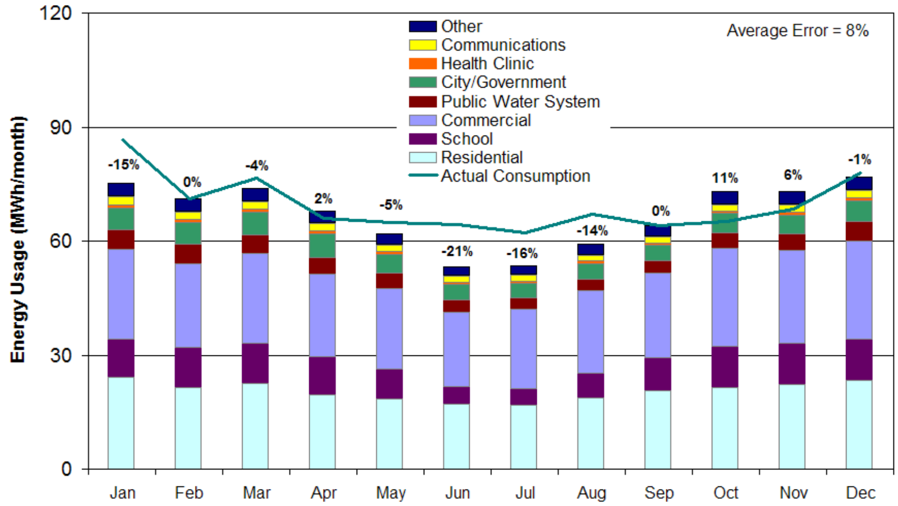



**Figure 101. Village Electric Load Calculator Results for the Village of Mekoryuk**

The average error between the estimated load and actual load is 8%.

**Table 75. Village Electric Load Calculator Inputs for the Village of Kiana**

| Village Characteristic | Value | Village Characteristic | Value |
|---|---|---|---|
| Population | 400 | K-12 School | High |
| # of Small Businesses | 4 | Public Water System | Level I High |
| # of Large Commercial Businesses | 2 | Health Clinic | Local |
| # of Community Buildings | 1 | Communications | Basic |
| # of Government Offices | 3 | Other Loads | 5% |
| Median Household Income | High | | |

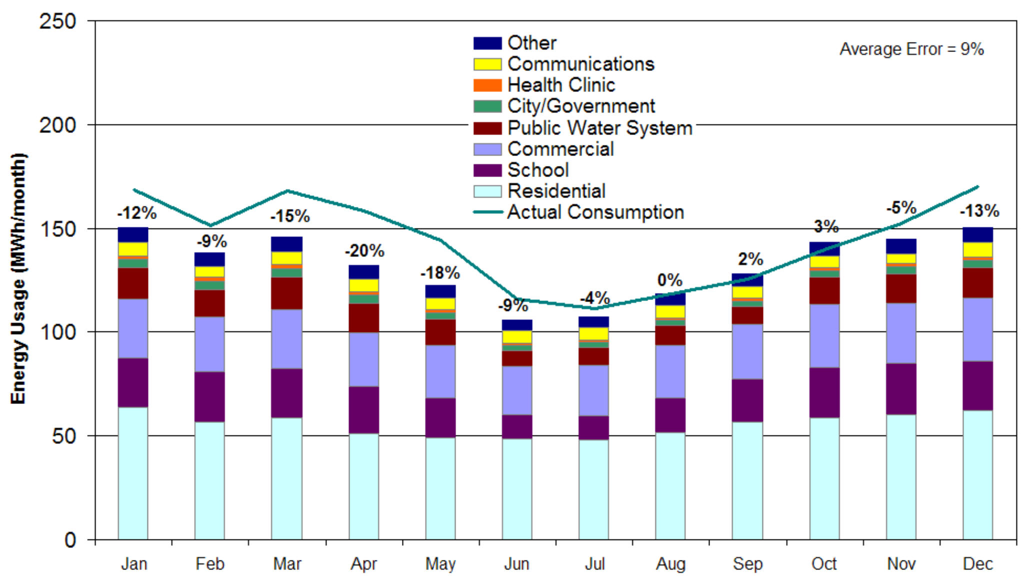
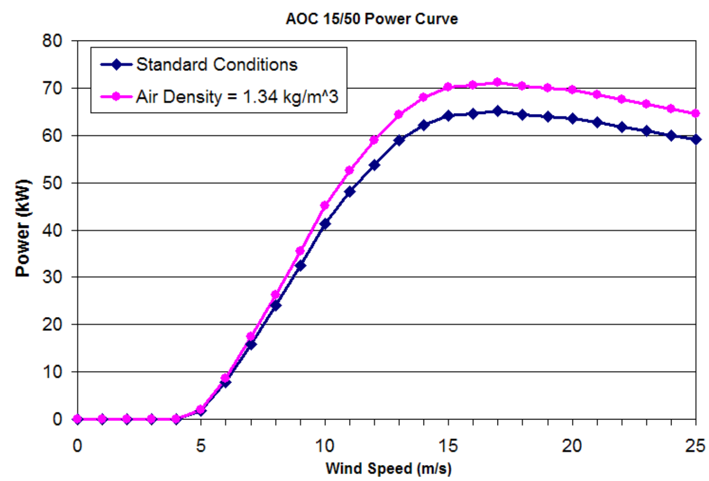



**Figure 102. Village Electric Load Calculator Results for the Village of Kiana**

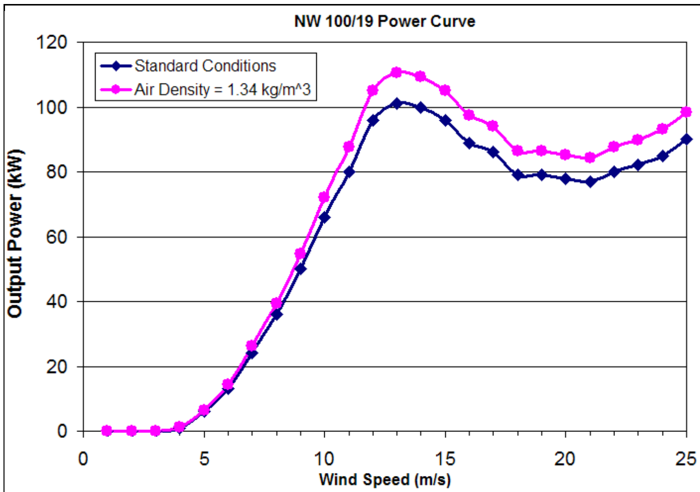
The average error between the estimated electric load and the actual electric load for the Kiana example is 9%.

## APPENDIX 2. WIND TURBINE SPECIFICATIONS



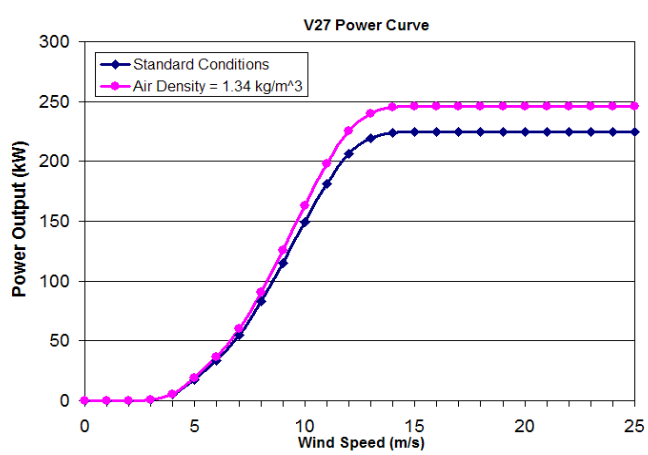

Atlantic Orient Corporation AOC15/50
PO Box 832, Charlottetown, PE
C1A 7L9, Canada
902-368-7171 www.aocwind.net

| | |
|---|---|
| Rated Power | 50 kW |
| Orientation | Downwind |
| Power Regulation | Stall |
| Rotor Diameter | 15 m |
| Tower Type | Lattice |
| Hub Height | 24.4 m (80 ft) |
| Tower Weight | 3,210 kg (7,080 lbs) |
| Rotor & Nacelle Weight | 2,420 kg (5,340 lbs) |




Northern Power Systems NW100
182 Mad River Park, Waitsfield, VT 05673
877-496-2955
www.northernpower.com

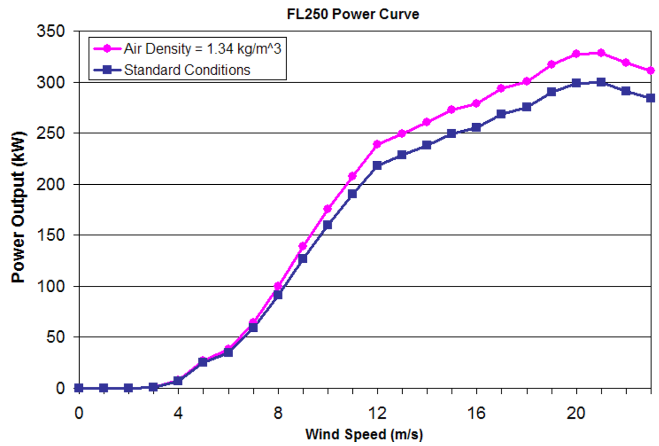
| | |
|---|---|
| Rated Power | 100 kW |
| Orientation | Upwind |
| Power Regulation | Stall |
| Rotor Diameter | 19.1 m |
| Tower Type | Tubular |
| Hub Height | 25, 30, or 35 m (82, 98, or 115 ft) |
| Temperature Operating Range | -46°C to 50°C (-50°F to 122°F) |
| Rotor & Nacelle Weight | 7086 kg (15,630 lbs) |
| Tower Weight (25m) | 6,500 kg (14,330 lbs) |



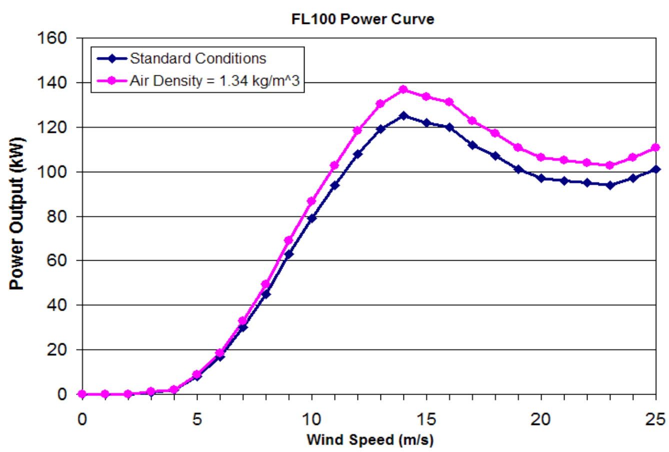

Vestas V27
111 SW Columbia St, Suite 480, Portland, OR 97201
503-327-2000
www.vestas.com

| | |
|---|---|
| Rated Power | 225 kW |
| Orientation | Upwind |
| Power Regulation | Pitch |
| Rotor Diameter | 27 m |
| Tower Type | Tubular |
| Hub Height | 30 m |

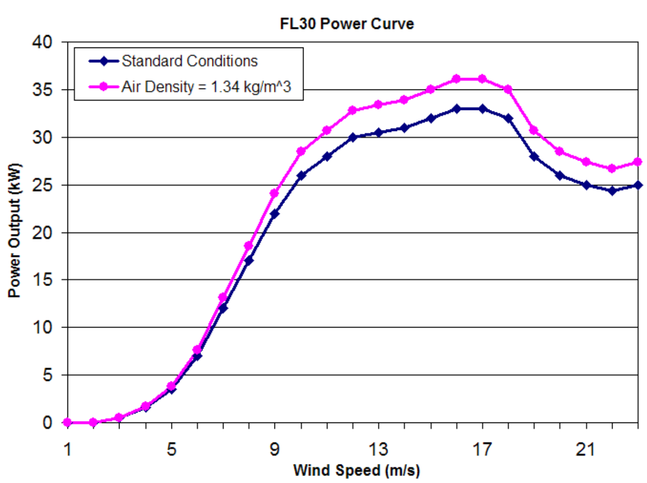
Fuhrländer
Lorax Energy Systems, LLC (North American Distributor)
4 Airport Rd, Block Island, RI 02807
www.lorax-energy.com
401-466-2883




| | |
|---|---|
| Rated Power | 250 kW |
| Orientation | Upwind |
| Power Regulation | Stall |
| Rotor Diameter | 29.5 m |
| Tower Type | Tubular |
| Hub Height | 42 m |
| Rotor & Nacelle Weight | 14,700 kg |
| Tower Weight | 26,500 kg |




| | |
|---|---|
| Rated Power | 100 kW |
| Orientation | Upwind |
| Power Regulation | Stall |
| Rotor Diameter | 21m |
| Tower Type | Tubular |
| Hub Height | 35 m |
| Rotor & Nacelle Weight | 9,000 kg |
| Tower Weight | 18,000 kg |




| | |
|---|---|
| Rated Power | 30 kW |
| Orientation | Upwind |
| Power Regulation | Fixed pitch, stall |
| Rotor Diameter | 13 m |
| Tower Type | Lattice |
| Hub Height | 27 m |
| Rotor & Nacelle Weight | 1,360 kg |
| Tower Weight | 3,000 kg |

## APPENDIX 3. BATTERY SPECIFICATIONS

The batteries used in this report are Alcad M340P Nickel-Cadmium batteries, which can by found in the Hybrid2 Library (source: Alcad Incorporated, 73 Defco Park Road, Wharton Brook Industrial Park, North Haven, CT. 06473. USA.)

| Capacity (Ah) | Current (A) |
|---|---|
| 43 | 344 |
| 112 | 336 |
| 163 | 326 |
| 196 | 294 |
| 262 | 262 |
| 402 | 201 |
| 487 | 122 |
| 594 | 49.5 |
| 742 | 12.4 |
| 984 | 0.3 |

Nominal Voltage: 2 V
Nominal Capacity: 341 Ah
Charge Rate Limit: 5 A/Ah remaining
Internal Resistance: 0.26 mOhms

Delivered Cost: $250 each
O&M Cost: 5% per year
Battery Life: 15 years

Battery Voltage

| Discharge | |
|---|---|
| DOD | Voltage |
| 20 | 1.3 |
| 80 | 1 |

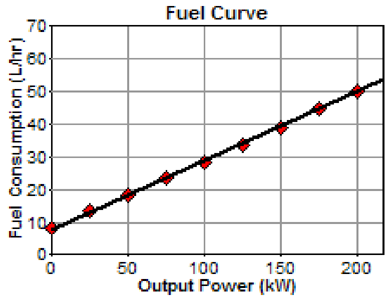
| Charge | |
|---|---|
| DOD | Voltage |
| 20 | 1.67 |
| 80 | 1.52 |

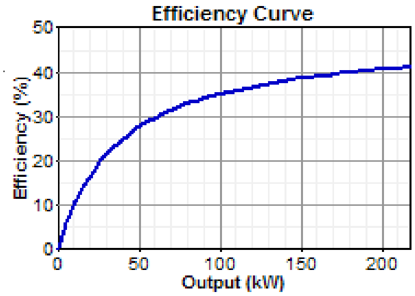
## APPENDIX 4. DIESEL FUEL EFFICIENCY DATA

271 kW Cummins KTA1150, 1200 rpm

Intercept (L/hr/kW rated) = 0.036

Slope (L/hr/kW output) = 0.21

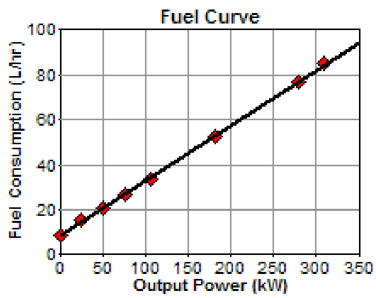


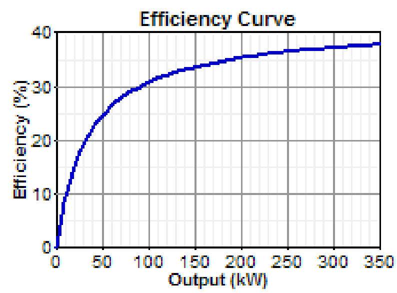




350 kW Caterpillar 3412, 1200 rpm

Intercept (L/hr/kW rated) = 0.0243

Slope (L/hr/kW output) = 0.245

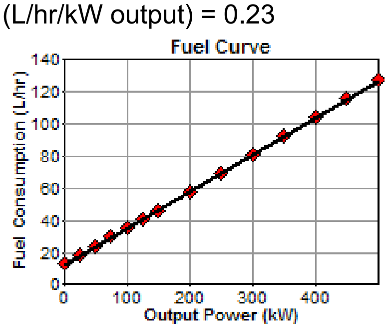


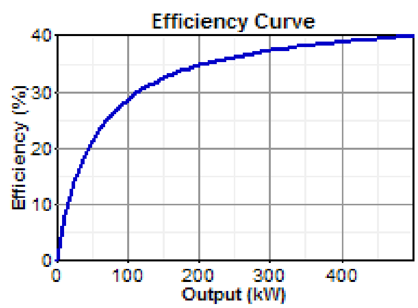




499 kW Cummins K19G2, 1800 rpm

Intercept (L/hr/kW rated) = 0.025

Slope (L/hr/kW output) = 0.23

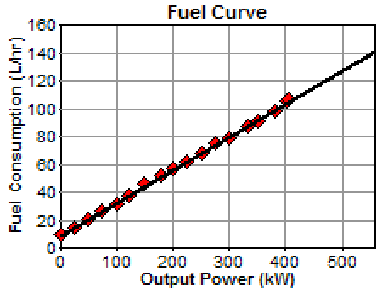


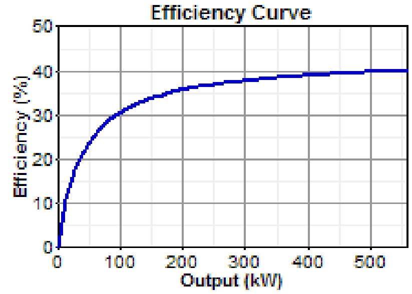




557 kW Cummins VTA28G5, 1200 rpm

Intercept (L/hr/kW rated) = 0.017

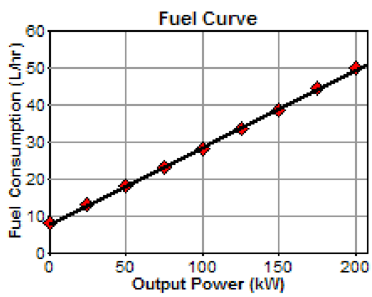
Slope (L/hr/kW output) = 0.24

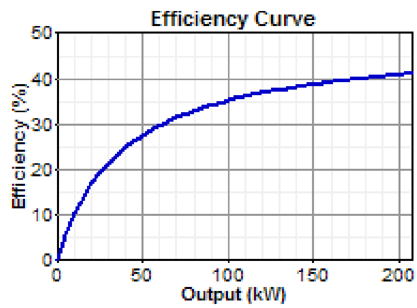


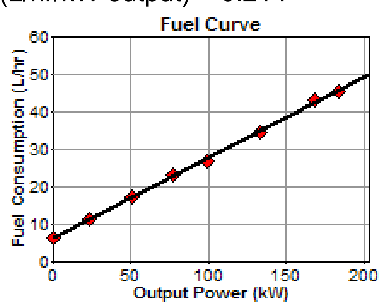

811 kW Cummins VTA28G5, 1200 rpm (based on 400 kW generator)
Intercept (L/hr/kW rated) = 0.012
Slope (L/hr/kW output) = 0.24

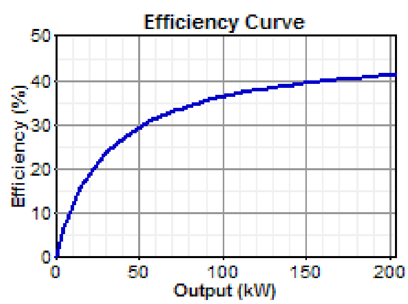
207 kW Detroit Diesel Series 60, 1200 rpm
Intercept (L/hr/kW rated) = 0.039
Slope (L/hr/kW output) = 0.21



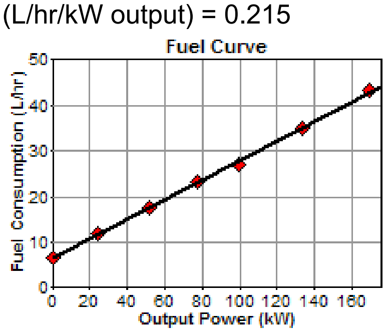



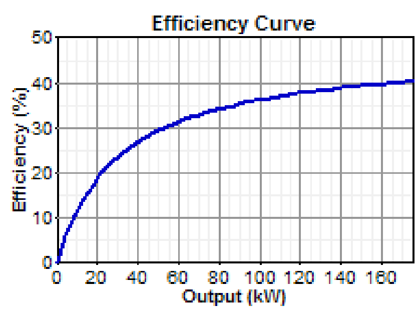

203 kW Cummins LTA10G1, 1800 rpm
Intercept (L/hr/kW rated) = 0.032
Slope (L/hr/kW output) = 0.214




175 kW Cummins LTA10G1, 1800 rpm (also used for 175 kW Allis-Chalmers 685I)
Intercept (L/hr/kW rated) = 0.037
Slope (L/hr/kW output) = 0.215

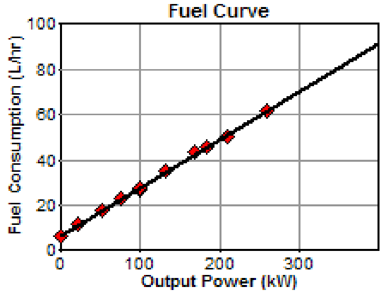


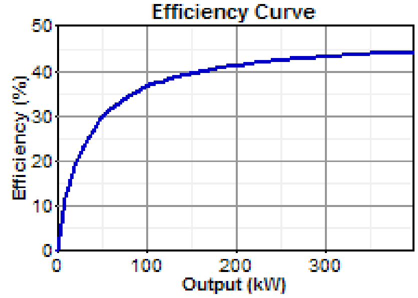



397 kW Cummins LTA10G1, 1800 rpm

Intercept (L/hr/kW rated) = 0.017

Slope (L/hr/kW output) = 0.213

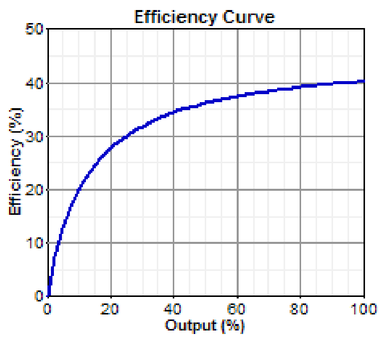



125 kW Generic Diesel

Intercept (L/hr/kW rated) = 0.028

Slope (L/hr/kW output) = 0.22



## APPENDIX 5. VILLAGE ELECTRIC LOAD DATA

Estimated 2009 Electric Load Data for Gambell, AK

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 256 | 275 | 250 | 229 | 199 | 161 | 151 | 169 | 194 | 211 | 240 | 247 | 215 |
| 1 | 239 | 257 | 230 | 217 | 199 | 160 | 148 | 167 | 178 | 194 | 227 | 233 | 204 |
| 2 | 227 | 244 | 218 | 205 | 197 | 155 | 146 | 158 | 169 | 185 | 214 | 223 | 195 |
| 3 | 220 | 236 | 214 | 199 | 191 | 153 | 141 | 152 | 163 | 180 | 208 | 216 | 189 |
| 4 | 215 | 232 | 210 | 196 | 185 | 151 | 136 | 148 | 161 | 176 | 204 | 212 | 185 |
| 5 | 217 | 228 | 209 | 194 | 182 | 145 | 133 | 147 | 161 | 178 | 210 | 215 | 185 |
| 6 | 220 | 237 | 213 | 198 | 180 | 144 | 131 | 153 | 168 | 187 | 212 | 218 | 188 |
| 7 | 227 | 247 | 220 | 202 | 179 | 142 | 127 | 157 | 174 | 194 | 219 | 223 | 192 |
| 8 | 250 | 267 | 245 | 228 | 194 | 143 | 127 | 170 | 202 | 216 | 245 | 241 | 211 |
| 9 | 280 | 301 | 269 | 250 | 211 | 152 | 135 | 187 | 227 | 248 | 276 | 267 | 233 |
| 10 | 303 | 324 | 283 | 272 | 233 | 164 | 153 | 201 | 235 | 266 | 297 | 291 | 252 |
| 11 | 316 | 327 | 292 | 280 | 247 | 176 | 161 | 209 | 243 | 270 | 301 | 301 | 260 |
| 12 | 310 | 323 | 291 | 279 | 251 | 180 | 167 | 210 | 242 | 261 | 293 | 296 | 259 |
| 13 | 295 | 311 | 285 | 272 | 246 | 178 | 165 | 208 | 237 | 257 | 285 | 285 | 252 |
| 14 | 300 | 315 | 283 | 277 | 252 | 188 | 172 | 213 | 241 | 260 | 289 | 285 | 256 |
| 15 | 297 | 310 | 278 | 270 | 249 | 189 | 171 | 215 | 239 | 259 | 286 | 285 | 254 |
| 16 | 297 | 310 | 277 | 271 | 250 | 187 | 170 | 214 | 237 | 259 | 287 | 288 | 254 |
| 17 | 296 | 308 | 275 | 262 | 240 | 184 | 167 | 207 | 233 | 252 | 289 | 291 | 250 |
| 18 | 302 | 304 | 269 | 250 | 231 | 180 | 164 | 200 | 223 | 242 | 291 | 298 | 246 |
| 19 | 296 | 301 | 259 | 240 | 217 | 171 | 159 | 186 | 207 | 229 | 284 | 285 | 236 |
| 20 | 286 | 301 | 251 | 230 | 205 | 164 | 152 | 171 | 196 | 226 | 273 | 275 | 228 |
| 21 | 280 | 302 | 256 | 224 | 202 | 159 | 146 | 168 | 190 | 233 | 266 | 272 | 225 |
| 22 | 281 | 299 | 268 | 227 | 204 | 158 | 149 | 167 | 200 | 234 | 262 | 265 | 226 |
| 23 | 275 | 292 | 269 | 234 | 202 | 159 | 148 | 171 | 209 | 229 | 257 | 261 | 226 |
| Ave | 270 | 285 | 255 | 238 | 214 | 164 | 151 | 181 | 205 | 227 | 259 | 261 | 226 |

Estimated 2009 Electric Load Data for Chevak, AK

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 358 | 344 | 331 | 312 | 267 | 213 | 218 | 237 | 278 | 317 | 340 | 351 | 297 |
| 1 | 333 | 317 | 308 | 285 | 251 | 211 | 208 | 217 | 240 | 282 | 314 | 326 | 274 |
| 2 | 317 | 301 | 295 | 267 | 234 | 200 | 194 | 199 | 220 | 262 | 294 | 311 | 258 |
| 3 | 307 | 295 | 288 | 257 | 225 | 187 | 181 | 189 | 211 | 253 | 288 | 299 | 248 |
| 4 | 301 | 290 | 281 | 253 | 221 | 180 | 172 | 181 | 207 | 245 | 283 | 290 | 242 |
| 5 | 297 | 288 | 279 | 250 | 216 | 175 | 170 | 181 | 203 | 246 | 281 | 285 | 239 |
| 6 | 301 | 294 | 286 | 257 | 220 | 173 | 172 | 186 | 212 | 264 | 289 | 291 | 245 |
| 7 | 316 | 314 | 309 | 283 | 237 | 184 | 189 | 222 | 258 | 298 | 317 | 307 | 270 |
| 8 | 341 | 344 | 339 | 306 | 261 | 194 | 205 | 241 | 296 | 341 | 348 | 333 | 296 |
| 9 | 403 | 409 | 392 | 352 | 301 | 221 | 225 | 279 | 359 | 423 | 420 | 388 | 348 |
| 10 | 433 | 439 | 410 | 382 | 340 | 254 | 247 | 304 | 373 | 444 | 446 | 423 | 375 |
| 11 | 449 | 447 | 413 | 394 | 351 | 266 | 262 | 315 | 373 | 439 | 449 | 439 | 383 |
| 12 | 461 | 457 | 432 | 404 | 363 | 283 | 281 | 339 | 392 | 448 | 461 | 451 | 398 |
| 13 | 448 | 446 | 419 | 397 | 359 | 283 | 279 | 334 | 384 | 439 | 448 | 441 | 390 |
| 14 | 433 | 430 | 406 | 378 | 342 | 275 | 275 | 322 | 361 | 417 | 432 | 430 | 375 |
| 15 | 432 | 427 | 400 | 373 | 345 | 269 | 276 | 318 | 364 | 407 | 432 | 428 | 373 |
| 16 | 436 | 430 | 399 | 377 | 343 | 272 | 278 | 319 | 372 | 412 | 438 | 436 | 376 |
| 17 | 451 | 440 | 418 | 385 | 349 | 281 | 293 | 328 | 380 | 430 | 455 | 468 | 390 |
| 18 | 481 | 453 | 417 | 388 | 355 | 287 | 301 | 330 | 380 | 433 | 482 | 497 | 400 |
| 19 | 476 | 442 | 406 | 378 | 332 | 274 | 284 | 311 | 349 | 417 | 473 | 470 | 384 |
| 20 | 449 | 431 | 389 | 354 | 311 | 246 | 263 | 280 | 318 | 396 | 443 | 436 | 359 |
| 21 | 428 | 420 | 394 | 342 | 298 | 234 | 245 | 266 | 306 | 392 | 419 | 415 | 347 |
| 22 | 409 | 398 | 387 | 330 | 285 | 226 | 234 | 253 | 315 | 380 | 399 | 398 | 335 |
| 23 | 390 | 378 | 366 | 324 | 278 | 220 | 228 | 248 | 311 | 353 | 372 | 379 | 321 |
| Ave | 394 | 385 | 365 | 334 | 295 | 234 | 237 | 267 | 311 | 364 | 388 | 387 | 330 |

### Estimated 2009 Electric Load Data for Hooper Bay

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 408 | 412 | 400 | 381 | 330 | 265 | 271 | 292 | 340 | 386 | 410 | 421 | 360 |
| 1 | 380 | 379 | 372 | 348 | 310 | 262 | 259 | 268 | 294 | 342 | 378 | 391 | 332 |
| 2 | 362 | 360 | 356 | 326 | 289 | 250 | 242 | 245 | 269 | 318 | 355 | 373 | 312 |
| 3 | 351 | 353 | 348 | 313 | 278 | 233 | 226 | 232 | 258 | 307 | 347 | 359 | 300 |
| 4 | 344 | 347 | 339 | 309 | 273 | 225 | 215 | 223 | 253 | 298 | 340 | 349 | 293 |
| 5 | 339 | 344 | 338 | 304 | 266 | 218 | 212 | 223 | 249 | 299 | 338 | 343 | 289 |
| 6 | 344 | 351 | 346 | 314 | 271 | 215 | 215 | 230 | 260 | 321 | 348 | 350 | 297 |
| 7 | 361 | 376 | 373 | 345 | 293 | 229 | 236 | 274 | 316 | 363 | 381 | 369 | 326 |
| 8 | 390 | 411 | 410 | 373 | 322 | 242 | 256 | 297 | 362 | 415 | 419 | 400 | 358 |
| 9 | 460 | 489 | 473 | 429 | 372 | 275 | 281 | 343 | 439 | 514 | 505 | 466 | 421 |
| 10 | 495 | 526 | 496 | 466 | 419 | 316 | 309 | 375 | 457 | 539 | 537 | 509 | 454 |
| 11 | 513 | 535 | 499 | 480 | 434 | 331 | 327 | 389 | 456 | 533 | 541 | 528 | 464 |
| 12 | 527 | 547 | 522 | 492 | 448 | 353 | 350 | 418 | 479 | 545 | 555 | 542 | 481 |
| 13 | 511 | 533 | 507 | 483 | 444 | 353 | 348 | 411 | 469 | 533 | 539 | 530 | 472 |
| 14 | 494 | 515 | 491 | 460 | 422 | 342 | 343 | 397 | 441 | 507 | 520 | 516 | 454 |
| 15 | 494 | 511 | 483 | 455 | 426 | 335 | 344 | 392 | 446 | 495 | 521 | 514 | 451 |
| 16 | 498 | 514 | 482 | 459 | 424 | 339 | 347 | 393 | 455 | 501 | 528 | 524 | 455 |
| 17 | 515 | 526 | 506 | 469 | 431 | 349 | 365 | 404 | 465 | 522 | 548 | 562 | 472 |
| 18 | 550 | 543 | 504 | 473 | 438 | 358 | 376 | 406 | 464 | 526 | 580 | 597 | 485 |
| 19 | 544 | 529 | 491 | 461 | 410 | 341 | 354 | 383 | 427 | 507 | 569 | 565 | 465 |
| 20 | 513 | 515 | 470 | 431 | 384 | 306 | 328 | 345 | 389 | 481 | 533 | 524 | 435 |
| 21 | 489 | 503 | 476 | 417 | 368 | 291 | 306 | 328 | 374 | 476 | 505 | 499 | 419 |
| 22 | 468 | 477 | 467 | 403 | 352 | 281 | 292 | 311 | 386 | 461 | 480 | 478 | 405 |
| 23 | 446 | 452 | 442 | 395 | 343 | 274 | 284 | 306 | 381 | 428 | 448 | 455 | 388 |
| Ave | 450 | 460 | 441 | 408 | 364 | 291 | 295 | 328 | 380 | 442 | 468 | 465 | 400 |

### Estimated 2009 Electric Load Data for Mekoryuk, AK

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 107 | 106 | 109 | 102 | 89 | 88 | 90 | 86 | 93 | 101 | 105 | 109 | 99 |
| 1 | 100 | 99 | 101 | 96 | 89 | 88 | 88 | 85 | 85 | 93 | 100 | 102 | 94 |
| 2 | 95 | 94 | 96 | 91 | 88 | 85 | 87 | 80 | 81 | 89 | 94 | 98 | 90 |
| 3 | 92 | 91 | 94 | 89 | 85 | 84 | 84 | 77 | 78 | 86 | 91 | 95 | 87 |
| 4 | 90 | 89 | 92 | 87 | 83 | 83 | 81 | 75 | 77 | 85 | 90 | 93 | 85 |
| 5 | 91 | 88 | 92 | 87 | 82 | 80 | 79 | 74 | 77 | 85 | 92 | 95 | 85 |
| 6 | 92 | 91 | 93 | 88 | 81 | 79 | 78 | 78 | 80 | 90 | 93 | 96 | 87 |
| 7 | 95 | 95 | 96 | 90 | 80 | 78 | 76 | 80 | 83 | 93 | 96 | 98 | 88 |
| 8 | 105 | 103 | 107 | 102 | 87 | 78 | 76 | 86 | 97 | 104 | 107 | 106 | 97 |
| 9 | 118 | 116 | 118 | 111 | 94 | 83 | 81 | 95 | 108 | 119 | 121 | 117 | 107 |
| 10 | 127 | 125 | 124 | 121 | 104 | 90 | 91 | 102 | 113 | 128 | 130 | 128 | 115 |
| 11 | 133 | 126 | 128 | 124 | 111 | 96 | 96 | 106 | 117 | 130 | 132 | 132 | 119 |
| 12 | 130 | 125 | 127 | 124 | 112 | 99 | 99 | 107 | 116 | 125 | 129 | 130 | 119 |
| 13 | 124 | 120 | 125 | 121 | 110 | 98 | 99 | 106 | 113 | 123 | 125 | 125 | 116 |
| 14 | 126 | 121 | 124 | 123 | 113 | 103 | 103 | 108 | 115 | 125 | 127 | 125 | 118 |
| 15 | 125 | 119 | 122 | 120 | 111 | 103 | 102 | 109 | 114 | 124 | 126 | 125 | 117 |
| 16 | 125 | 119 | 121 | 121 | 112 | 102 | 102 | 109 | 113 | 124 | 126 | 127 | 117 |
| 17 | 124 | 119 | 120 | 116 | 107 | 101 | 100 | 105 | 111 | 121 | 127 | 128 | 115 |
| 18 | 127 | 117 | 117 | 111 | 104 | 99 | 98 | 101 | 107 | 116 | 128 | 131 | 113 |
| 19 | 124 | 116 | 113 | 107 | 97 | 94 | 95 | 94 | 99 | 110 | 125 | 126 | 108 |
| 20 | 120 | 116 | 110 | 102 | 92 | 90 | 91 | 87 | 94 | 109 | 120 | 121 | 104 |
| 21 | 118 | 116 | 112 | 100 | 91 | 87 | 87 | 85 | 91 | 112 | 117 | 120 | 103 |
| 22 | 118 | 115 | 117 | 101 | 91 | 86 | 89 | 85 | 96 | 112 | 115 | 117 | 104 |
| 23 | 115 | 112 | 118 | 104 | 91 | 87 | 89 | 87 | 100 | 110 | 113 | 115 | 103 |
| Ave | 113 | 110 | 111 | 106 | 96 | 90 | 90 | 92 | 98 | 109 | 114 | 115 | 104 |

Estimated 2009 Electric Load Data for Savoonga, AK

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 310 | 295 | 283 | 271 | 236 | 208 | 221 | 210 | 236 | 259 | 275 | 300 | 259 |
| 1 | 289 | 276 | 261 | 257 | 236 | 207 | 217 | 207 | 217 | 239 | 259 | 282 | 246 |
| 2 | 274 | 262 | 247 | 243 | 233 | 201 | 214 | 196 | 206 | 227 | 245 | 270 | 235 |
| 3 | 267 | 254 | 242 | 236 | 226 | 199 | 208 | 188 | 198 | 221 | 238 | 262 | 228 |
| 4 | 260 | 249 | 237 | 233 | 219 | 196 | 199 | 183 | 196 | 217 | 234 | 257 | 223 |
| 5 | 262 | 244 | 237 | 230 | 216 | 189 | 195 | 182 | 196 | 218 | 240 | 261 | 223 |
| 6 | 266 | 254 | 241 | 234 | 213 | 186 | 192 | 190 | 205 | 230 | 243 | 264 | 227 |
| 7 | 274 | 265 | 249 | 239 | 212 | 184 | 186 | 195 | 212 | 238 | 251 | 270 | 231 |
| 8 | 303 | 287 | 277 | 270 | 230 | 186 | 186 | 211 | 247 | 266 | 280 | 292 | 253 |
| 9 | 339 | 324 | 304 | 296 | 250 | 197 | 199 | 232 | 276 | 304 | 316 | 324 | 280 |
| 10 | 367 | 347 | 321 | 322 | 276 | 212 | 224 | 249 | 287 | 327 | 340 | 353 | 302 |
| 11 | 383 | 351 | 331 | 331 | 293 | 228 | 237 | 260 | 297 | 332 | 344 | 364 | 313 |
| 12 | 376 | 347 | 329 | 330 | 297 | 233 | 245 | 261 | 295 | 320 | 336 | 359 | 311 |
| 13 | 357 | 334 | 323 | 322 | 292 | 231 | 243 | 259 | 289 | 315 | 326 | 346 | 303 |
| 14 | 363 | 339 | 321 | 328 | 299 | 243 | 253 | 265 | 294 | 320 | 330 | 345 | 308 |
| 15 | 360 | 333 | 314 | 320 | 295 | 245 | 251 | 267 | 291 | 318 | 327 | 345 | 305 |
| 16 | 360 | 333 | 313 | 321 | 296 | 242 | 250 | 265 | 289 | 318 | 329 | 349 | 305 |
| 17 | 359 | 331 | 311 | 310 | 284 | 238 | 245 | 257 | 284 | 310 | 330 | 353 | 301 |
| 18 | 365 | 327 | 304 | 296 | 274 | 234 | 241 | 248 | 272 | 297 | 333 | 362 | 296 |
| 19 | 359 | 323 | 293 | 285 | 257 | 222 | 234 | 231 | 252 | 281 | 326 | 346 | 284 |
| 20 | 347 | 323 | 284 | 273 | 243 | 213 | 223 | 213 | 238 | 278 | 313 | 333 | 273 |
| 21 | 339 | 325 | 290 | 265 | 240 | 206 | 215 | 209 | 232 | 287 | 305 | 330 | 270 |
| 22 | 340 | 321 | 303 | 269 | 242 | 205 | 218 | 207 | 244 | 288 | 300 | 322 | 272 |
| 23 | 332 | 313 | 304 | 277 | 240 | 207 | 218 | 213 | 255 | 282 | 294 | 317 | 271 |
| Ave | 327 | 307 | 288 | 282 | 254 | 213 | 221 | 225 | 250 | 279 | 296 | 317 | 272 |

Estimated 2009 Electric Load Data for Toksook Bay/ Tununak, AK

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 260 | 257 | 250 | 236 | 201 | 201 | 191 | 204 | 224 | 241 | 259 | 263 | 232 |
| 1 | 235 | 231 | 226 | 216 | 195 | 194 | 179 | 188 | 197 | 215 | 238 | 239 | 213 |
| 2 | 218 | 216 | 212 | 199 | 184 | 184 | 170 | 172 | 181 | 201 | 222 | 223 | 198 |
| 3 | 210 | 208 | 205 | 193 | 175 | 174 | 160 | 164 | 173 | 195 | 216 | 214 | 191 |
| 4 | 204 | 203 | 201 | 190 | 168 | 168 | 153 | 158 | 170 | 192 | 212 | 208 | 186 |
| 5 | 205 | 199 | 200 | 188 | 165 | 162 | 149 | 156 | 170 | 193 | 215 | 209 | 184 |
| 6 | 208 | 207 | 204 | 192 | 163 | 159 | 146 | 160 | 175 | 200 | 218 | 212 | 187 |
| 7 | 214 | 214 | 210 | 200 | 165 | 157 | 146 | 170 | 184 | 212 | 231 | 218 | 193 |
| 8 | 250 | 250 | 248 | 236 | 184 | 161 | 153 | 191 | 226 | 254 | 270 | 248 | 223 |
| 9 | 292 | 296 | 286 | 271 | 209 | 177 | 169 | 213 | 264 | 302 | 313 | 282 | 256 |
| 10 | 312 | 313 | 295 | 286 | 231 | 195 | 186 | 232 | 275 | 320 | 335 | 308 | 274 |
| 11 | 327 | 317 | 305 | 295 | 243 | 212 | 197 | 244 | 284 | 324 | 340 | 321 | 284 |
| 12 | 324 | 316 | 306 | 295 | 250 | 224 | 209 | 253 | 288 | 316 | 332 | 318 | 286 |
| 13 | 312 | 309 | 302 | 290 | 252 | 229 | 210 | 253 | 284 | 312 | 325 | 313 | 282 |
| 14 | 317 | 310 | 300 | 290 | 252 | 234 | 216 | 257 | 283 | 312 | 327 | 310 | 284 |
| 15 | 313 | 306 | 293 | 285 | 250 | 235 | 215 | 260 | 284 | 309 | 323 | 307 | 282 |
| 16 | 311 | 308 | 293 | 285 | 249 | 236 | 219 | 259 | 285 | 310 | 324 | 314 | 283 |
| 17 | 315 | 306 | 292 | 276 | 243 | 240 | 219 | 259 | 285 | 311 | 333 | 325 | 284 |
| 18 | 328 | 305 | 290 | 267 | 241 | 237 | 217 | 255 | 277 | 303 | 340 | 339 | 283 |
| 19 | 319 | 298 | 275 | 258 | 226 | 222 | 209 | 236 | 259 | 286 | 329 | 321 | 270 |
| 20 | 303 | 300 | 269 | 244 | 212 | 212 | 199 | 222 | 243 | 284 | 316 | 305 | 259 |
| 21 | 295 | 296 | 277 | 238 | 207 | 206 | 194 | 215 | 237 | 287 | 305 | 297 | 254 |
| 22 | 294 | 289 | 283 | 242 | 207 | 202 | 197 | 213 | 247 | 284 | 297 | 290 | 254 |
| 23 | 282 | 277 | 276 | 247 | 206 | 203 | 195 | 215 | 251 | 273 | 283 | 281 | 249 |
| Ave | 277 | 272 | 262 | 247 | 211 | 201 | 187 | 214 | 240 | 268 | 288 | 278 | 245 |

Expected 2009 Energy Requirements in Kiana

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 249 | 246 | 261 | 259 | 221 | 163 | 152 | 190 | 186 | 199 | 226 | 248 | 217 |
| 1 | 235 | 233 | 251 | 243 | 214 | 153 | 142 | 187 | 171 | 187 | 209 | 233 | 205 |
| 2 | 225 | 223 | 241 | 237 | 208 | 146 | 133 | 182 | 160 | 180 | 203 | 225 | 197 |
| 3 | 220 | 219 | 239 | 232 | 200 | 140 | 128 | 179 | 155 | 173 | 198 | 218 | 192 |
| 4 | 216 | 216 | 237 | 231 | 198 | 134 | 124 | 173 | 153 | 174 | 194 | 215 | 189 |
| 5 | 216 | 217 | 236 | 232 | 197 | 133 | 121 | 170 | 153 | 175 | 195 | 214 | 188 |
| 6 | 218 | 220 | 242 | 235 | 196 | 132 | 121 | 175 | 158 | 178 | 201 | 219 | 191 |
| 7 | 242 | 241 | 262 | 251 | 212 | 137 | 124 | 182 | 178 | 201 | 223 | 239 | 208 |
| 8 | 284 | 285 | 286 | 271 | 230 | 144 | 132 | 191 | 215 | 233 | 263 | 272 | 234 |
| 9 | 315 | 320 | 311 | 303 | 253 | 162 | 146 | 209 | 238 | 265 | 295 | 294 | 259 |
| 10 | 328 | 326 | 315 | 306 | 266 | 177 | 157 | 217 | 250 | 275 | 313 | 310 | 270 |
| 11 | 341 | 341 | 322 | 326 | 283 | 188 | 169 | 217 | 259 | 276 | 321 | 323 | 281 |
| 12 | 340 | 341 | 329 | 328 | 289 | 201 | 179 | 217 | 263 | 271 | 318 | 330 | 284 |
| 13 | 329 | 323 | 318 | 321 | 283 | 204 | 181 | 215 | 259 | 267 | 308 | 316 | 277 |
| 14 | 327 | 319 | 316 | 316 | 284 | 202 | 187 | 213 | 248 | 262 | 306 | 319 | 275 |
| 15 | 322 | 322 | 311 | 314 | 288 | 205 | 186 | 212 | 249 | 257 | 304 | 322 | 274 |
| 16 | 331 | 320 | 312 | 317 | 289 | 205 | 185 | 208 | 245 | 257 | 309 | 331 | 276 |
| 17 | 341 | 325 | 314 | 316 | 291 | 202 | 183 | 203 | 240 | 255 | 318 | 342 | 278 |
| 18 | 342 | 326 | 308 | 306 | 282 | 199 | 179 | 199 | 241 | 256 | 319 | 334 | 274 |
| 19 | 332 | 320 | 302 | 294 | 265 | 191 | 171 | 193 | 229 | 248 | 298 | 317 | 263 |
| 20 | 312 | 309 | 294 | 282 | 251 | 177 | 161 | 191 | 219 | 246 | 282 | 302 | 252 |
| 21 | 294 | 295 | 292 | 273 | 242 | 171 | 159 | 195 | 214 | 240 | 268 | 289 | 244 |
| 22 | 279 | 278 | 291 | 273 | 237 | 168 | 157 | 197 | 217 | 234 | 257 | 279 | 239 |
| 23 | 263 | 263 | 278 | 271 | 232 | 168 | 156 | 197 | 208 | 217 | 244 | 267 | 230 |
| Ave | 288 | 285 | 286 | 281 | 246 | 171 | 156 | 196 | 213 | 230 | 266 | 282 | 242 |

## APPENDIX 6. VILLAGE WIND SPEED DATA

Average Wind Speeds in Gambell at a 10-meter Height

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 10.0 | 10.1 | 8.7 | 7.8 | 6.6 | 5.6 | 5.7 | 6.7 | 7.9 | 8.1 | 10.1 | 10.3 | 8.1 |
| 1 | 10.3 | 10.3 | 8.7 | 8.0 | 6.3 | 5.6 | 5.8 | 6.9 | 7.9 | 8.1 | 9.9 | 10.3 | 8.2 |
| 2 | 9.9 | 10.2 | 8.9 | 8.2 | 6.4 | 5.6 | 5.7 | 6.9 | 7.8 | 8.0 | 10.2 | 10.4 | 8.2 |
| 3 | 10.2 | 10.4 | 9.0 | 8.2 | 6.4 | 5.9 | 5.8 | 6.8 | 8.0 | 8.1 | 10.1 | 10.3 | 8.2 |
| 4 | 10.3 | 10.2 | 9.0 | 8.2 | 6.4 | 5.6 | 5.7 | 6.9 | 7.9 | 8.4 | 10.1 | 10.2 | 8.2 |
| 5 | 10.1 | 10.2 | 8.9 | 8.1 | 6.7 | 5.8 | 5.6 | 6.8 | 7.9 | 8.1 | 10.3 | 10.6 | 8.3 |
| 6 | 9.9 | 10.3 | 9.0 | 8.3 | 6.8 | 5.8 | 5.8 | 6.8 | 7.8 | 8.3 | 10.1 | 10.7 | 8.3 |
| 7 | 10.0 | 10.4 | 8.9 | 8.1 | 6.7 | 5.9 | 5.8 | 7.0 | 7.9 | 8.4 | 10.3 | 10.5 | 8.3 |
| 8 | 9.8 | 10.4 | 9.0 | 8.5 | 6.9 | 6.0 | 5.8 | 7.0 | 7.9 | 8.3 | 10.4 | 10.5 | 8.4 |
| 9 | 10.2 | 10.5 | 8.8 | 8.5 | 7.1 | 6.0 | 5.8 | 6.9 | 8.0 | 8.4 | 10.1 | 10.4 | 8.4 |
| 10 | 10.2 | 10.5 | 8.9 | 8.4 | 6.9 | 6.2 | 6.1 | 7.0 | 8.1 | 8.3 | 10.1 | 10.3 | 8.4 |
| 11 | 10.0 | 10.3 | 9.2 | 8.7 | 7.0 | 6.1 | 6.1 | 7.1 | 8.0 | 8.4 | 10.0 | 10.5 | 8.4 |
| 12 | 10.2 | 10.1 | 8.9 | 8.6 | 7.2 | 6.3 | 6.2 | 6.9 | 8.0 | 8.3 | 10.1 | 10.3 | 8.4 |
| 13 | 10.2 | 10.2 | 9.0 | 8.6 | 7.1 | 6.2 | 6.1 | 7.1 | 8.0 | 8.6 | 10.1 | 10.2 | 8.5 |
| 14 | 10.1 | 10.4 | 9.1 | 8.8 | 7.1 | 6.3 | 6.2 | 7.0 | 7.9 | 8.5 | 10.1 | 10.3 | 8.5 |
| 15 | 10.3 | 10.4 | 9.0 | 8.6 | 6.9 | 6.2 | 6.1 | 6.9 | 7.9 | 8.5 | 10.2 | 10.3 | 8.4 |
| 16 | 10.4 | 10.4 | 8.8 | 8.6 | 6.7 | 6.0 | 6.1 | 7.1 | 7.9 | 8.3 | 10.1 | 10.4 | 8.4 |
| 17 | 10.2 | 10.5 | 8.9 | 8.7 | 6.8 | 5.7 | 5.9 | 6.9 | 7.7 | 8.4 | 10.2 | 10.3 | 8.4 |
| 18 | 10.1 | 10.6 | 8.9 | 8.4 | 6.6 | 5.8 | 5.9 | 6.9 | 7.8 | 8.4 | 10.3 | 10.4 | 8.3 |
| 19 | 10.2 | 10.7 | 9.2 | 8.1 | 6.4 | 5.7 | 5.9 | 6.7 | 7.6 | 8.3 | 10.1 | 10.9 | 8.3 |
| 20 | 9.8 | 10.5 | 9.0 | 7.9 | 6.3 | 5.6 | 5.8 | 6.6 | 7.7 | 8.5 | 10.3 | 10.4 | 8.2 |
| 21 | 10.1 | 10.3 | 9.1 | 8.1 | 6.6 | 5.4 | 5.8 | 6.7 | 7.8 | 8.3 | 10.3 | 10.4 | 8.2 |
| 22 | 10.0 | 10.6 | 8.9 | 7.8 | 6.3 | 5.5 | 5.7 | 6.7 | 7.7 | 8.2 | 10.2 | 10.5 | 8.2 |
| 23 | 10.1 | 10.2 | 9.0 | 8.1 | 6.4 | 5.4 | 5.7 | 6.7 | 7.7 | 8.2 | 10.2 | 10.3 | 8.2 |
| Ave | 10.1 | 10.4 | 8.9 | 8.3 | 6.7 | 5.8 | 5.9 | 6.9 | 7.9 | 8.3 | 10.2 | 10.4 | 8.3 |

Weibull k: 2.25
Autocorrelation factor: 0.932
Diurnal pattern strength: 0.0231
Hour of peak windspeed: 15

Average Wind Speeds in Mekoryuk (also used for Toksook Bay) at a 10-meter Height (m/s)

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 7.3 | 8.1 | 6.4 | 6.1 | 5.0 | 4.1 | 3.8 | 5.5 | 5.9 | 6.2 | 7.6 | 6.7 | 6.1 |
| **1** | 7.2 | 7.9 | 6.5 | 5.9 | 4.9 | 4.2 | 3.7 | 5.4 | 5.7 | 6.4 | 7.6 | 6.8 | 6.0 |
| **2** | 7.5 | 7.6 | 6.4 | 6.3 | 5.0 | 4.1 | 3.8 | 5.5 | 5.8 | 6.5 | 7.6 | 7.0 | 6.1 |
| **3** | 7.3 | 7.9 | 6.3 | 6.3 | 5.0 | 3.9 | 3.8 | 5.3 | 6.0 | 6.4 | 7.6 | 7.0 | 6.1 |
| **4** | 7.5 | 7.6 | 6.6 | 6.2 | 4.9 | 4.0 | 3.8 | 5.3 | 5.8 | 6.5 | 7.6 | 6.8 | 6.1 |
| **5** | 7.5 | 7.3 | 6.4 | 6.4 | 5.3 | 4.6 | 4.0 | 5.2 | 5.9 | 6.6 | 7.7 | 7.2 | 6.2 |
| **6** | 7.6 | 7.4 | 6.4 | 6.2 | 5.6 | 4.7 | 4.4 | 5.5 | 6.0 | 6.9 | 7.6 | 7.0 | 6.3 |
| **7** | 7.3 | 7.4 | 6.3 | 6.3 | 5.8 | 5.0 | 4.6 | 5.7 | 6.3 | 6.8 | 7.6 | 7.2 | 6.4 |
| **8** | 7.2 | 7.5 | 6.3 | 6.6 | 6.0 | 5.3 | 4.9 | 6.0 | 6.5 | 6.8 | 7.6 | 7.1 | 6.5 |
| **9** | 7.3 | 7.6 | 6.4 | 6.7 | 6.3 | 5.5 | 5.2 | 6.3 | 6.7 | 7.0 | 7.7 | 7.4 | 6.7 |
| **10** | 7.3 | 7.7 | 6.8 | 6.6 | 6.2 | 5.6 | 5.3 | 6.3 | 6.8 | 7.2 | 7.7 | 7.2 | 6.7 |
| **11** | 7.5 | 7.8 | 6.7 | 7.0 | 6.5 | 5.9 | 5.6 | 6.6 | 7.1 | 7.4 | 8.1 | 7.5 | 7.0 |
| **12** | 7.3 | 7.9 | 7.0 | 7.0 | 6.8 | 6.0 | 5.7 | 6.8 | 7.1 | 7.5 | 8.2 | 7.4 | 7.1 |
| **13** | 7.3 | 7.7 | 7.2 | 7.0 | 6.6 | 6.0 | 5.8 | 6.7 | 7.2 | 7.6 | 8.0 | 7.2 | 7.0 |
| **14** | 7.4 | 7.8 | 7.1 | 7.1 | 6.7 | 6.0 | 5.8 | 7.0 | 7.2 | 7.3 | 7.6 | 7.2 | 7.0 |
| **15** | 7.3 | 7.6 | 6.9 | 6.8 | 6.6 | 6.0 | 5.6 | 6.8 | 6.9 | 7.2 | 7.7 | 7.1 | 6.9 |
| **16** | 7.3 | 7.6 | 6.8 | 6.9 | 6.5 | 5.7 | 5.4 | 6.7 | 6.8 | 6.9 | 7.4 | 7.0 | 6.7 |
| **17** | 7.4 | 7.9 | 6.7 | 6.5 | 6.2 | 5.5 | 5.2 | 6.4 | 6.4 | 7.0 | 7.6 | 7.0 | 6.6 |
| **18** | 7.5 | 8.0 | 6.6 | 6.5 | 6.0 | 5.3 | 5.0 | 6.2 | 6.2 | 6.8 | 7.4 | 7.0 | 6.5 |
| **19** | 7.3 | 7.9 | 6.6 | 6.3 | 5.2 | 4.9 | 4.5 | 5.7 | 6.1 | 6.7 | 7.7 | 7.1 | 6.3 |
| **20** | 7.4 | 7.6 | 6.5 | 6.4 | 5.3 | 4.5 | 4.3 | 5.7 | 6.0 | 6.6 | 7.4 | 6.9 | 6.2 |
| **21** | 7.4 | 8.0 | 6.5 | 6.2 | 5.2 | 4.3 | 4.1 | 5.6 | 5.9 | 6.6 | 7.6 | 7.0 | 6.2 |
| **22** | 7.6 | 7.8 | 6.4 | 6.3 | 5.0 | 4.1 | 4.0 | 5.5 | 5.9 | 6.5 | 7.5 | 7.1 | 6.1 |
| **23** | 7.3 | 7.8 | 6.4 | 6.2 | 4.8 | 4.0 | 3.9 | 5.6 | 5.8 | 6.4 | 7.5 | 6.9 | 6.1 |
| **Ave** | 7.4 | 7.7 | 6.6 | 6.5 | 5.7 | 5.0 | 4.7 | 6.0 | 6.3 | 6.8 | 7.6 | 7.1 | 6.4 |

Weibull k: 1.934
Autocorrelation factor: 0.924
Diurnal pattern strength: 0.0687
Hour of peak windspeed: 15

Average Wind Speeds in Hooper Bay (also used for Chevak) at a 10-meter Height (m/s)

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0:00 | 7.35 | 7.92 | 6.72 | 5.99 | 5.43 | 5.13 | 4.96 | 6.43 | 5.93 | 5.68 | 7.67 | 7.36 | 6.32 |
| 1:00 | 7.29 | 7.93 | 6.82 | 5.98 | 5.35 | 5.27 | 4.87 | 6.46 | 6.02 | 5.8 | 7.61 | 7.35 | 6.3 |
| 2:00 | 7.47 | 8.12 | 6.85 | 6.13 | 5.47 | 4.98 | 4.98 | 6.59 | 6.09 | 5.82 | 7.87 | 7.43 | 6.43 |
| 3:00 | 7.39 | 8.01 | 6.8 | 6.15 | 5.35 | 5.22 | 4.89 | 6.55 | 6.04 | 5.77 | 7.46 | 7.48 | 6.37 |
| 4:00 | 7.04 | 8.06 | 6.81 | 6.12 | 5.41 | 5.27 | 4.94 | 6.42 | 6.05 | 5.89 | 7.69 | 7.56 | 6.36 |
| 5:00 | 7.22 | 8.17 | 6.71 | 6.36 | 5.62 | 5.31 | 4.89 | 6.5 | 6.04 | 5.89 | 7.87 | 7.46 | 6.45 |
| 6:00 | 7.22 | 8.17 | 6.86 | 6.41 | 5.77 | 5.55 | 4.91 | 6.71 | 6.1 | 5.89 | 7.86 | 7.49 | 6.53 |
| 7:00 | 7.24 | 8.14 | 6.95 | 6.35 | 5.92 | 5.7 | 5.24 | 6.76 | 6.15 | 5.64 | 7.77 | 7.16 | 6.52 |
| 8:00 | 7.03 | 8.07 | 6.79 | 6.43 | 6.05 | 5.75 | 5.42 | 6.81 | 6.5 | 5.75 | 8.01 | 7.47 | 6.65 |
| 9:00 | 7.17 | 8.24 | 7.05 | 6.65 | 6.18 | 5.87 | 5.53 | 7.02 | 6.71 | 6.1 | 7.79 | 7.55 | 6.78 |
| 10:00 | 7.1 | 8.18 | 7.05 | 6.65 | 6.18 | 5.9 | 5.8 | 6.92 | 6.73 | 6.13 | 7.42 | 7.11 | 6.72 |
| 11:00 | 7.02 | 8.22 | 7.13 | 6.95 | 6.17 | 6.23 | 5.85 | 7.16 | 6.9 | 6.33 | 7.61 | 7.55 | 6.91 |
| 12:00 | 7.28 | 8.39 | 7.38 | 6.74 | 6.2 | 6.44 | 6.01 | 7.06 | 6.97 | 6.31 | 7.61 | 7.5 | 6.96 |
| 13:00 | 7.01 | 8.12 | 7.48 | 6.76 | 6.07 | 6.37 | 5.98 | 7.33 | 6.93 | 6.59 | 7.63 | 7.25 | 6.9 |
| 14:00 | 6.92 | 8.23 | 7.27 | 6.9 | 6.1 | 6.42 | 5.83 | 7.38 | 6.89 | 6.56 | 7.55 | 7.66 | 6.95 |
| 15:00 | 7.13 | 8.07 | 7.23 | 6.91 | 6.08 | 6.49 | 5.76 | 7.06 | 6.81 | 6.26 | 7.62 | 7.74 | 6.9 |
| 16:00 | 7.15 | 8.02 | 7.21 | 6.59 | 5.97 | 6.31 | 5.79 | 7.27 | 6.75 | 6.04 | 7.58 | 7.57 | 6.8 |
| 17:00 | 7.22 | 8.02 | 7.05 | 6.71 | 5.97 | 6.22 | 5.61 | 7.04 | 6.58 | 6.01 | 7.38 | 7.59 | 6.75 |
| 18:00 | 7.11 | 8 | 7.13 | 6.57 | 5.87 | 6.01 | 5.37 | 6.98 | 6.05 | 5.92 | 7.61 | 7.53 | 6.63 |
| 19:00 | 7.24 | 7.99 | 6.97 | 6.41 | 5.6 | 5.93 | 5.25 | 6.65 | 6.19 | 6.02 | 7.73 | 7.23 | 6.54 |
| 20:00 | 7.51 | 7.99 | 7.03 | 6.52 | 5.48 | 5.65 | 5.09 | 6.51 | 6 | 5.91 | 7.47 | 7.29 | 6.5 |
| 21:00 | 7.27 | 8.11 | 7.04 | 6.35 | 5.33 | 5.51 | 4.97 | 6.73 | 5.96 | 5.9 | 7.83 | 7.35 | 6.47 |
| 22:00 | 7.26 | 7.93 | 6.98 | 6.24 | 5.25 | 5.31 | 5.11 | 6.59 | 5.78 | 5.63 | 7.81 | 7.21 | 6.34 |
| 23:00 | 7.34 | 7.89 | 6.71 | 6.33 | 5.39 | 5.16 | 4.88 | 6.54 | 6.05 | 5.91 | 7.75 | 7.33 | 6.39 |
| Average | 7.21 | 8.08 | 7 | 6.47 | 5.76 | 5.75 | 5.33 | 6.81 | 6.34 | 5.99 | 7.68 | 7.43 | 6.65 |

Weibull k: 2
Autocorrelation factor: 0.733
Diurnal pattern strength: 0.0534
Hour of peak windspeed: 16

Average Wind Speeds in Savoonga at a 10-meter Height (m/s)

| Hour | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | AVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 5.4 | 5.4 | 5.3 | 4.3 | 4.2 | 3.9 | 3.7 | 5.3 | 5.9 | 6.8 | 8.4 | 6.6 | 5.4 |
| 1 | 5.6 | 5.5 | 5.2 | 4.1 | 4.2 | 3.8 | 3.6 | 5.1 | 6.0 | 6.8 | 8.2 | 6.7 | 5.4 |
| 2 | 5.5 | 5.1 | 5.2 | 4.5 | 4.4 | 4.2 | 3.6 | 5.0 | 5.8 | 6.6 | 8.4 | 6.6 | 5.4 |
| 3 | 5.5 | 5.5 | 5.2 | 4.4 | 4.2 | 4.2 | 3.7 | 5.2 | 6.0 | 6.7 | 8.1 | 6.9 | 5.5 |
| 4 | 5.6 | 5.2 | 5.1 | 4.8 | 4.3 | 4.1 | 4.0 | 5.2 | 5.8 | 6.7 | 8.2 | 6.8 | 5.5 |
| 5 | 5.4 | 5.2 | 5.4 | 4.7 | 4.6 | 4.2 | 3.9 | 5.2 | 6.1 | 6.9 | 8.6 | 6.8 | 5.6 |
| 6 | 5.5 | 5.5 | 5.2 | 5.0 | 4.5 | 4.4 | 4.2 | 5.3 | 6.2 | 6.9 | 8.4 | 6.7 | 5.6 |
| 7 | 5.7 | 5.8 | 5.2 | 4.6 | 4.7 | 4.4 | 4.2 | 5.4 | 6.2 | 7.0 | 8.6 | 6.5 | 5.7 |
| 8 | 5.8 | 5.5 | 5.1 | 5.0 | 4.7 | 4.6 | 4.5 | 5.4 | 6.1 | 7.1 | 8.7 | 6.6 | 5.7 |
| 9 | 5.6 | 5.6 | 5.3 | 4.9 | 5.0 | 4.7 | 4.6 | 5.7 | 6.4 | 6.9 | 8.6 | 6.6 | 5.8 |
| 10 | 5.7 | 5.8 | 5.4 | 5.3 | 4.9 | 4.8 | 4.8 | 5.9 | 6.6 | 7.1 | 8.7 | 6.6 | 6.0 |
| 11 | 5.8 | 5.4 | 5.5 | 5.4 | 4.9 | 4.8 | 5.0 | 5.9 | 6.6 | 7.0 | 8.6 | 6.8 | 6.0 |
| 12 | 5.5 | 5.9 | 5.5 | 5.3 | 4.9 | 5.0 | 5.1 | 6.0 | 6.5 | 7.1 | 8.7 | 6.7 | 6.0 |
| 13 | 5.6 | 5.8 | 5.4 | 5.6 | 5.2 | 4.7 | 5.2 | 6.0 | 6.7 | 7.1 | 8.5 | 6.6 | 6.0 |
| 14 | 5.7 | 5.9 | 5.5 | 5.4 | 5.2 | 4.8 | 5.0 | 6.0 | 6.6 | 6.8 | 8.5 | 6.3 | 6.0 |
| 15 | 5.6 | 5.8 | 5.7 | 5.5 | 5.1 | 4.9 | 5.2 | 6.1 | 6.5 | 7.1 | 8.4 | 6.5 | 6.0 |
| 16 | 5.9 | 6.3 | 5.5 | 5.5 | 4.8 | 4.8 | 4.9 | 6.0 | 6.1 | 6.9 | 8.4 | 6.5 | 6.0 |
| 17 | 5.6 | 5.5 | 5.5 | 5.1 | 4.6 | 4.6 | 4.9 | 5.8 | 5.9 | 7.0 | 8.3 | 6.7 | 5.8 |
| 18 | 5.7 | 5.6 | 5.5 | 5.2 | 4.4 | 4.3 | 4.5 | 5.7 | 5.7 | 6.8 | 8.4 | 6.6 | 5.7 |
| 19 | 5.7 | 5.6 | 5.4 | 5.1 | 4.4 | 4.3 | 4.6 | 5.6 | 5.6 | 6.6 | 8.3 | 6.9 | 5.7 |
| 20 | 5.5 | 5.7 | 5.3 | 4.8 | 4.3 | 4.1 | 4.1 | 5.5 | 5.8 | 6.9 | 8.5 | 6.5 | 5.6 |
| 21 | 5.5 | 5.3 | 5.3 | 4.6 | 4.2 | 3.9 | 4.0 | 5.4 | 5.7 | 6.8 | 8.3 | 6.7 | 5.5 |
| 22 | 5.6 | 5.5 | 5.1 | 4.3 | 4.3 | 3.8 | 3.7 | 5.2 | 5.8 | 6.5 | 8.3 | 6.7 | 5.4 |
| 23 | 5.4 | 5.0 | 5.2 | 4.3 | 4.3 | 3.8 | 3.9 | 5.3 | 5.7 | 6.8 | 8.3 | 6.8 | 5.4 |
| 24 | 5.4 | 5.4 | 5.3 | 4.3 | 4.2 | 3.9 | 3.7 | 5.3 | 5.9 | 6.8 | 8.4 | 6.6 | 5.4 |
| AVE | 5.6 | 5.6 | 5.3 | 4.9 | 4.6 | 4.3 | 4.3 | 5.5 | 6.1 | 6.9 | 8.4 | 6.7 | 5.7 |

Weibull k: 1.827
Autocorrelation factor: 0.889
Diurnal pattern strength: 0.0573
Hour of peak windspeed: 15

Average Wind Speeds in Kiana at a 6.1-meter Height (m/s)

| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 2.32 | 2.62 | 2.43 | 2.31 | 1.83 | 1.87 | 1.74 | 1.60 | 2.13 | 1.88 | 2.05 | 3.00 | 2.15 |
| 1 | 2.36 | 2.11 | 2.49 | 2.21 | 1.70 | 1.78 | 1.80 | 1.42 | 1.74 | 1.91 | 2.31 | 2.55 | 2.03 |
| 2 | 2.44 | 2.30 | 3.00 | 2.51 | 1.67 | 1.74 | 1.39 | 1.80 | 1.84 | 1.80 | 2.09 | 2.75 | 2.11 |
| 3 | 2.18 | 2.27 | 2.71 | 2.26 | 1.64 | 1.37 | 1.16 | 1.79 | 1.84 | 1.64 | 1.72 | 2.33 | 1.91 |
| 4 | 2.26 | 2.46 | 2.08 | 2.28 | 1.73 | 1.63 | 1.31 | 1.51 | 1.76 | 1.45 | 1.89 | 2.32 | 1.89 |
| 5 | 2.32 | 2.52 | 2.15 | 2.48 | 1.71 | 1.89 | 1.23 | 1.35 | 1.86 | 1.80 | 1.90 | 2.69 | 1.99 |
| 6 | 2.24 | 2.36 | 2.34 | 2.51 | 1.86 | 2.00 | 1.23 | 1.70 | 1.84 | 2.00 | 2.00 | 2.17 | 2.02 |
| 7 | 2.36 | 2.54 | 2.48 | 2.44 | 1.63 | 1.98 | 1.19 | 1.60 | 1.87 | 1.82 | 2.27 | 2.20 | 2.03 |
| 8 | 2.26 | 2.06 | 1.85 | 2.55 | 2.17 | 2.10 | 1.75 | 1.82 | 1.91 | 2.17 | 2.39 | 2.51 | 2.13 |
| 9 | 2.19 | 1.84 | 2.39 | 2.84 | 2.05 | 2.24 | 2.11 | 1.84 | 1.74 | 2.32 | 2.27 | 2.36 | 2.18 |
| 10 | 2.59 | 2.33 | 2.31 | 2.80 | 2.57 | 2.47 | 2.36 | 1.73 | 2.20 | 2.12 | 1.85 | 2.30 | 2.30 |
| 11 | 2.41 | 2.54 | 2.15 | 3.17 | 2.91 | 2.63 | 2.21 | 2.23 | 2.00 | 2.44 | 1.88 | 2.35 | 2.41 |
| 12 | 2.44 | 2.32 | 2.32 | 3.34 | 2.99 | 2.67 | 2.50 | 2.42 | 2.40 | 2.65 | 2.19 | 2.65 | 2.57 |
| 13 | 2.78 | 2.96 | 2.55 | 3.49 | 3.02 | 2.82 | 2.99 | 2.50 | 2.73 | 2.34 | 2.29 | 2.61 | 2.76 |
| 14 | 2.23 | 2.65 | 2.75 | 3.68 | 2.93 | 3.12 | 2.96 | 2.65 | 2.82 | 2.41 | 2.39 | 2.78 | 2.78 |
| 15 | 2.52 | 2.45 | 2.85 | 3.71 | 3.12 | 3.51 | 3.33 | 3.05 | 3.36 | 2.62 | 2.22 | 3.00 | 2.98 |
| 16 | 2.51 | 2.88 | 3.10 | 3.85 | 3.21 | 3.56 | 3.17 | 3.22 | 2.96 | 2.40 | 2.63 | 2.83 | 3.03 |
| 17 | 2.08 | 3.01 | 3.24 | 3.52 | 3.34 | 3.81 | 3.60 | 3.91 | 3.25 | 2.42 | 2.52 | 2.87 | 3.13 |
| 18 | 2.18 | 2.59 | 3.31 | 3.76 | 3.02 | 4.12 | 3.43 | 4.01 | 3.25 | 2.40 | 2.31 | 2.82 | 3.10 |
| 19 | 1.76 | 2.68 | 2.74 | 3.42 | 3.10 | 3.46 | 3.19 | 3.48 | 2.86 | 2.39 | 2.13 | 2.82 | 2.84 |
| 20 | 2.37 | 2.38 | 2.58 | 2.82 | 3.04 | 3.22 | 3.13 | 3.05 | 2.75 | 2.46 | 2.10 | 2.49 | 2.70 |
| 21 | 1.89 | 2.32 | 2.54 | 2.49 | 2.83 | 2.78 | 2.69 | 2.68 | 2.48 | 2.18 | 2.05 | 2.85 | 2.48 |
| 22 | 2.64 | 2.48 | 2.60 | 2.38 | 2.22 | 2.40 | 2.14 | 1.94 | 2.48 | 2.31 | 2.59 | 2.47 | 2.39 |
| 23 | 2.09 | 2.61 | 2.26 | 2.06 | 1.95 | 2.21 | 1.80 | 1.72 | 2.28 | 2.06 | 1.79 | 2.96 | 2.15 |
| Ave | 2.31 | 2.47 | 2.55 | 2.87 | 2.43 | 2.56 | 2.27 | 2.29 | 2.35 | 2.17 | 2.16 | 2.61 | 2.42 |

Weibull k: 1.211
Autocorrelation factor: 0.741
Diurnal pattern strength: 0.224
Hour of peak windspeed: 17

## Appendix 7. Hybrid2 Simulation Inputs and Results
## Example: Hooper Bay

**************************************************
*    HOOPER BAY OVERALL PERFORMANCE RESULTS   *
**************************************************

Summary File created with Hybrid2 Version 1.3c R3
Executable Software Date: June 2004
Simulation run on:  Monday, September 13, 2004   at  11:19:56 AM

* Run specifications
- start value of the simulation period (h)    1
- duration of the simulation period (h)    8760
- simulation time step (min)    60

* COMPARISON OF HYBRID AND BASE CASE (DIESEL ONLY) SYSTEMS
- Fuel saved by hybrid system (liters)    451794
- Percent fuel savings by hybrid system    50.2

* HYBRID SYSTEM  ENERGY FLOWS

| | kWh demand | % load | | kWh demand | % load |
|---|---|---|---|---|---|
| Total production | 4641601 | 132.7 | Total sinks | 4641638 | 132.7 |
| Load demand | 3496548 | 100 | Load coverage | 3496548 | 100 |
| AC primary load | 3496548 | 100 | AC primary load | 3496548 | 100 |
| AC deferrable load | 0 | 0 | AC deferrable load | 0 | 0 |
| DC primary load | 0 | 0 | DC primary load | 0 | 0 |
| DC deferrable load | 0 | 0 | DC deferrable load | 0 | 0 |
| Unmet load | 0 | 0 | Optional load | 0 | 0 |
| Production | | | | | |
| - from wind (AC) | 3013749 | 86.2 | - AC optional load | 0 | 0 |
| - from wind (DC) | 0 | 0 | - DC optional load | 0 | 0 |
| - from diesel (AC/DC) | 1582560 | 45.3 | - Excess energy | 978034 | 28 |
| Storage | | | | | |
| - into storage | 45278.5 | 1.3 | - spilled | 0 | 0 |
| - from storage | 45291.7 | 1.3 | - dump load | 0 | 0 |
| Energy losses | 121778 | 3.5 | - excess dump load | 978034 | 28 |

Fuel consumed (liters) 449082

* BASE CASE (DIESEL ONLY) SYSTEM ENERGY FLOWS

| | kWh demand | % load | | kWh demand | % load |
|---|---|---|---|---|---|
| Load demand | 3496548 | 100 | Load coverage | 3496548 | 100 |
| AC primary load | 3496548 | 100 | AC primary load | 3496548 | 100 |
| AC deferrable load | 0 | 0 | AC deferrable load | 0 | 0 |
| DC primary load | 0 | 0 | DC primary load | 0 | 0 |
| DC deferrable load | 0 | 0 | DC deferrable load | 0 | 0 |
| Unmet load | 0 | 0 | Excess energy | 0.3 | 0 |

Fuel consumed (liters) 900876

* RESULTS OF THE SIMULATION: PERFORMANCE PER COMPONENT

* AC primary load (scale factor of 1 included)
  - average (kW) 399.1
  - standard deviation (kW) 102.1
  - minimum (kW) 198.3
  - maximum (kW) 697.4

* Wind speed (scale factor of 1 not included)
- air density correction 1.09

| | anemometer | hub turbine 1 |
|---|---|---|
| - height (m) | 10 | 42 |
| - hub height correction | - | 1.228 |
| - average (m/s) | 6.64 | 8.15392 |
| - standard deviation (m/s) | 3.53 | 4.33484 |
| - minimum (m/s) | 0 | 0 |
| - maximum (m/s) | 22.11 | 27.15108 |

* Ambient temperature
- average day temp ( C) 0

* HYBRID SYSTEM
* AC diesel
diesel # 1 ( 557 kW)
  - on time (h) 3286
  - number of starts 282
diesel # 2 ( 811 kW)
  - on time (h) 4
  - number of starts 3
diesel # 3 ( 350 kW)
  - on time (h) 4896
  - number of starts 723

* BASE CASE (DIESEL ONLY)
* Base case diesel
diesel # 1 ( 557 kW)
  - on time (h) 4343
  - number of starts 561
diesel # 2 ( 811 kW)
  - on time (h) 3576
  - number of starts 415
diesel # 3 ( 350 kW)
  - on time (h) 954
  - number of starts 219

PROJECT: OVERVIEW ***********************************************************
AC wind turbines Total power: 750 kW
- number and type of specified wind turbines
  3 Fuhrlaender FL250 wind turbine ( 250 kw)

AC diesel Total power: 1718 kW
- number and type of specified diesels:
  1 557 kW Cummins VTA-28G5 generator ( 557 kW)
  1 811 kW Cummins VTA-28G5 generator ( 811 kW)
  1 Caterpillar3412 350kW (Metric units) generator ( 350 kW)

Battery bank
Battery notes: Alcad M Range M340P NiCad Battery (simple model). Alcad Incorporated, 73 Defco Park Road,
Wharton Brook Industrial Park, North Haven, CT. 06473. USA.
- total capacity (scaled) 163.2 kWh (accessible capacity 65.3 kWh)
- number and type of batteries 240 Alcad M340P NiCad Battery
- battery bank scale factor 1
- nominal voltage 2 V

Rotary convertor: Hooper Bay
- rated power (inverting): 400 kW
- rated power (rectifying): 400 kW

Dispatch strategy : Traditional Power Smoothing
This strategy is used for small battery banks, on the order of a few hours capacity at average load, where renewables are assumed to charge the battery bank periodically. This allows the diesel to be shut down during times of reasonable winds. Dispatch Strategy B.1.1 in Users Manual.

| | |
|---|---|
| Operating Power level: | load following, minimum battery usage |
| Diesel starts: | to meet load |
| Diesel stops: | when renewables can meet load |

* BASE CASE (DIESEL ONLY)
Base case diesels Total power: 1718 kW
number and type of specified diesels:
1 557 kW Cummins VTA-28G5 generator ( 557 kW)
1 811 kW Cummins VTA-28G5 generator ( 811 kW)
1 Caterpillar3412 350kW (Metric units) generator ( 350 kW)

Dispatch strategy
- minimum run time (h): 1
- allowed shutdown: all but one
- Dispatch order: minimum fuel use

* PROJECT: DETAIL***************************************************
* RESOURCE/SITE
Wind speed
- power law exponent 0.143
- turbulence length scale (m) 100
- reference wind velocity for
  turbulence calculations (m/s) 10
- nominal turbulence intensity 0.15
- air density model: density ratio
- nominal ambient temperature ( C) 0

* POWER SYSTEM
AC wind turbines
- spacing between AC wind turbines (m) 100
- AC wind farm power fluctuation reduc. factor 0.644
- AC wind power response factor 1.5

Battery bank
- number of batteries in series: 120
- number of battery banks in parallel: 2
- initial capacity of battery bank (kWh): 122.4
- battery bank installation cost ($): 60000

General system cost

| | |
|---|---|
| - balance of system capital cost ($): | 0 |
| - system O&M Cost (fraction/y): | 0 |
| - administrative Cost (fraction/y): | 0 |
| - wind turbine O&M Cost (fraction/y): | 0.005 |
| - diesel O&M Cost (fraction/y): | 11 |

**********************************

HOOPER BAY HYBRID2 ECONOMIC ANALYSIS

**********************************

ECONOMIC FIGURES OF MERIT

Calculations Are For A Retrofit Diesel System:

Basic Project Feasibility Indicators For Hybrid System:

| | | |
|---|---|---|
| Simple Payback Period | Years | 11.67 |
| Discounted Payback Period | Years | 0 |

| System Economic Indicators: | | Hybrid | Diesel Only |
|---|---|---|---|
| Net Present Value of Retrofit System Cost Savings | | $4100012 | N/A |
| Net Present Value of Retrofit | | $3877307 | N/A |
| Annualized Worth | | $303309 | N/A |
| Internal Rate of Return of Project | % | Not Calculated | N/A |
| Levelized Cost of Energy Savings, Primary | $/kWh | 0.0867 | N/A |
| Levelized Cost of Energy Savings, Total | $/kWh | 0.0867 | N/A |
| Net Present Value of Optional Load | $ | 0 | N/A |

| Levelized Annual Economic Figures: | | Hybrid | Diesel Only |
|---|---|---|---|
| Capital Costs, inc. Loan, | $ | 0 | 0 |
| Fuel Costs, | $ | 327395 | 656767 |
| O & M Costs, | $ | 99549 | 85436 |
| System Replacement & Overhaul Costs, | $ | 26536 | 32007 |
| Gross Revenue, | $ | 0 | 0 |
| Additional Net Revenue/Gross Income, | $ | 303309 | N/A |
| Additional Net After Tax Income, | $ | 303309 | N/A |

HYBRID2 PERFORMANCE PREDICTIONS

| Power System: | | Hybrid | Diesel Only |
|---|---|---|---|
| Total energy produced, | kWh | 3496545 | 3496554 |
| Primary energy delivered, | kWh | 3496545 | 3496545 |
| Deferrable energy delivered, | kWh | 0 | Inc. in Primary |
| Optional energy delivered, | kWh | 0 | Not Included |
| Heating energy delivered, | kWh | 0 | Not Included |
| Annual fuel consumed, | Fuel Units | 449082.4 | 900875.8 |

SYSTEM LEVELIZED COSTS

| Power System: | | Hybrid | Diesel Only |
|---|---|---|---|
| Total installed system capacity, | kW | 3031 | 1718 |
| Total system installed cost, | $ | 2755000 | 0 |
| Equipment capital cost, | $ | 2295000 | 0 |
| System installation cost, | $ | 0 | 0 |
| Balance of installation cost, | $ | 460000 | 0 |
| System installation overhead, | $ | 0 | 0 |
| System cost down payment, | $ | 0 | 0 |
| System cost yearly payment, | $ | 0 | 0 |

| | | | |
|---|---|---|---|
| First year administration cost, | $ | 0 | 0 |
| First year system O&M cost, | $ | 74542 | 63974 |
| First year system income, $ | | 0 | 0 |
| Equipment salvage value, $ | | 0 | 0 |

INPUTS ECONOMIC ANALYSIS PARAMETERS

| | |
|---|---|
| Fuel Cost, $/unit | 0.53 |
| Installation overhead, % | 0 |
| Total cost of optional load, $ | 0 |
| Useful system life, Years | 25 |
| Salvage value of project equipment, % | 0 |
| General inflation rate, % | 3 |
| Discount rate, % | 6 |
| Fuel inflation rate, % | 3 |
| Loan Interest rate, % | 0 |
| Loan period, Years | 0 |
| Grace period for loan payback, Years | 0 |
| Down payment fraction, % | 0 |
| Price of regular power, $/kWh | 0 |
| Price of deferrable power, $/kWh | 0 |
| Price of optional power, $/kWh | 0 |
| Price of heating power, $/kWh | 0 |
| Corporate tax rate, % | 0 |
| Renewable energy tax incentive, $/kWh | 0 |
| Equipment deprecation life, Years | 1 |

SYSTEM SPECIFICATIONS

| | | |
|---|---|---|
| Balance of system cost (Hybrid Only), $ | | 460000 |
| Capital cost of optional load equipment (Hybrid only), $ | | 0 |
| Capital Cost of the Grid Extension to Consumer, $ | | 0 |
| Total Importation tariffs (Hybrid only), | $ | 0 |
| Total shipping costs (Hybrid only), $ | | 0 |
| System administration cost (Hybrid), | $ | 0 |
| System general O&M cost (Hybrid), | $ | 0 |
| System administration cost (Diesel), | $ | 0 |
| System general O&M cost (Diesel),$ | | 0 |

EQUIPMENT SPECIFICATIONS

Wind turbine(s):

| | |
|---|---|
| Total capacity on AC bus, kW | 750 |
| Total capacity on DC bus, kW | 0 |
| AC turbine scale factor used, | 1 |
| DC turbine scale factor used, | 1 |
| Capital cost, $ | 2295000 |
| Total installation cost, $ | 0 |
| Wind turbine O&M rate, $/kWh | 0.005 |

Wind turbine overhaul specifications:

| | Cost; $ | Time; Years |
|---|---|---|
| Wind turbine 1 | 0 | 25 |
| Wind turbine 2 | 0 | 25 |
| Wind turbine 3 | 0 | 25 |

Diesel(s):

| | | |
|---|---|---|
| Hybrid system total diesel rated capacity, | kW | 1718 |
| Base case system total diesel rated capacity, | kW | 1718 |
| Capital cost of hybrid system diesels, | $ | 0 |
| Hybrid system diesel installation cost, | $ | 0 |

| | | |
|---|---|---|
| Capital cost of all diesel system, | $ | 0 |
| Diesel system diesel installation cost, | $ | 0 |
| Diesel O&M rate, | $/hr | 7 |
| Diesel overhaul specifications: | Cost, $ | Time, hours |
| Hybrid Diesel 1 | 30000 | 10000 |
| Hybrid Diesel 2 | 30000 | 10000 |
| Hybrid Diesel 3 | 25000 | 10000 |
| Base Diesel 1 | 30000 | 10000 |
| Base Diesel 2 | 30000 | 10000 |
| Base Diesel 3 | 25000 | 10000 |

Battery:

| | |
|---|---|
| Rated capacity, kWh | 163.2342 |
| Storage scale factor used, | 1 |
| Capital cost (including scale factor),$ | 0 |
| Installation cost, $ | 0 |
| O&M rate, % of initial capital cost per year, | 0 |
| Life of batteries, Years | 15 |

Converter:

| | |
|---|---|
| Rated capacity, kW | 400 |
| Capital cost, $ | 0 |
| Installation cost, $ | 0 |
| Life of power converter, Years | 0 |

SYSTEM CASH FLOW

| Year | Hybrid | Diesel only |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 243148 | 0 |
| 3 | 288688 | 0 |
| 4 | 224191 | 0 |
| 5 | 271491 | 0 |
| 6 | 309487 | 0 |
| 7 | 251128 | 0 |
| 8 | 290332 | 0 |
| 9 | 305565 | 0 |
| 10 | 308013 | 0 |
| 11 | 317253 | 0 |
| 12 | 412316 | 0 |
| 13 | 255805 | 0 |
| 14 | 437427 | 0 |
| 15 | 318122 | 0 |
| 16 | 319642 | 0 |
| 17 | 436667 | 0 |
| 18 | 390182 | 0 |
| 19 | 358049 | 0 |
| 20 | 468127 | 0 |
| 21 | 482171 | 0 |
| 22 | 381670 | 0 |
| 23 | 462195 | 0 |
| 24 | 526881 | 0 |
| 25 | 479874 | 0 |

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