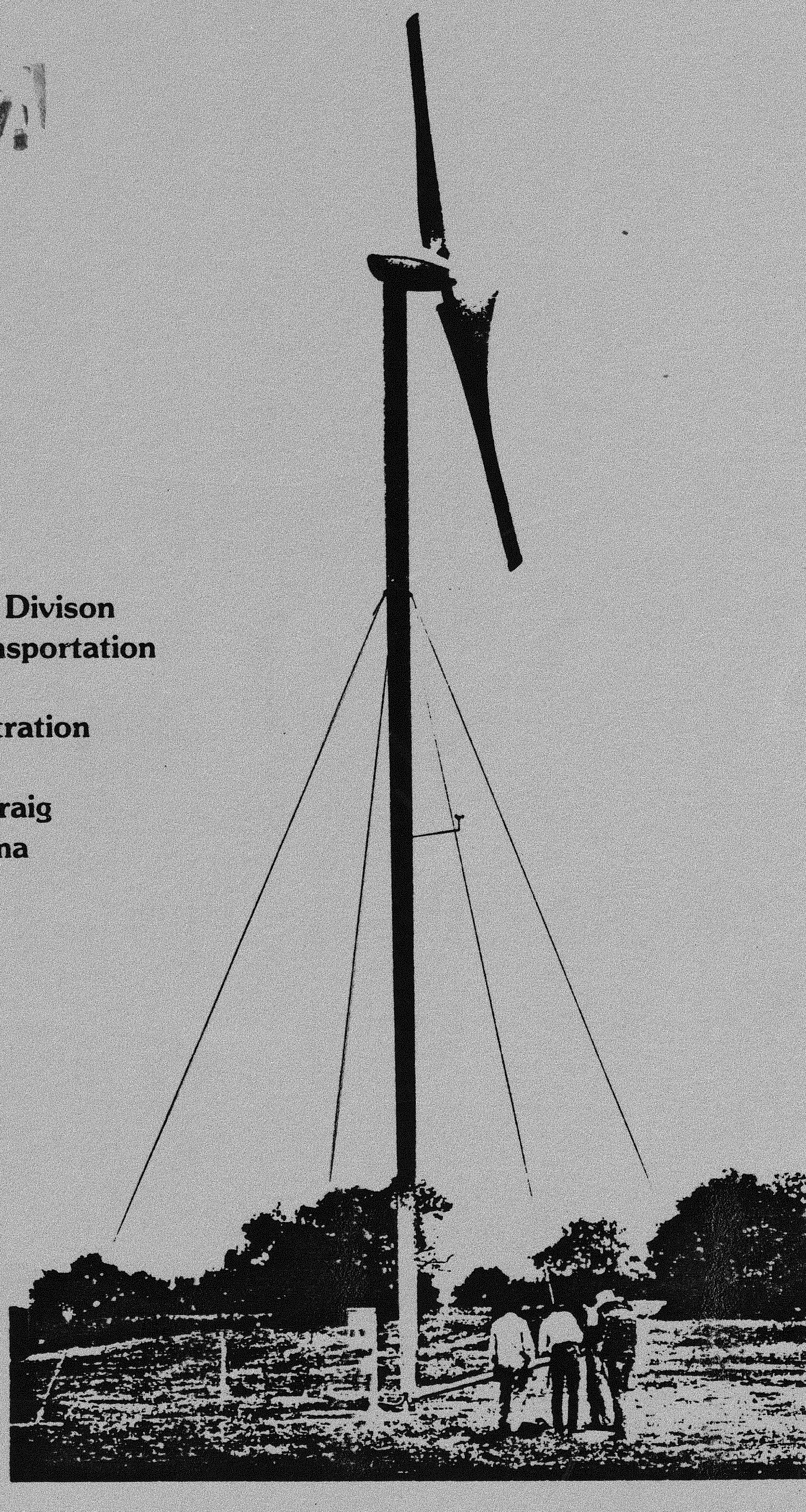
WIND POWERED GENERATOR

Erick, Oklahoma

Demonstration Project No. 52



for
Research and Development Divison
Oklahoma Department of Transportation
and
Federal Highway Administration
by

Karl Bergey and Ken Craig
University of Oklahoma

June, 1984

FINAL REPORT

WINDPOWER DEMONSTRATION PROJECT

For

Research and Development Division
DEPARTMENT OF TRANSPORTATION
State of Oklahoma
200 N.E. 21st St.
Oklahoma City, OK 73105

By

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June 1984

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16. Abstract

A windpower demonstration program was carried out to assess the potential of windpower energy for highway uses in Oklahoma. A secondary purpose of the program was to provide information for the public on the use of windpower for more general applications.

Windspeed measuring equipment was installed at the Erick Information Center along I-40 in Western Oklahoma and at the Oklahoma DOT Maintenance Yard at Hydro, west of Oklahoma City, A windpower generator with a nominal rating of 25 kw was installed on a 60-ft tower at the Erick site.

From a reliability standpoint, the windpower generator performed satisfactorily. Its availability for the one-year test period was 94%. Its annual energy output, however, was less than expected, primarily due to the lower than expected wind speed at the Erick site.

The measured windspeed was approximately 25% lower than predicted on the basis of long-term recorded data from the Department of Commerce. Further testing and analysis will be required to determine whether the low average windspeeds represent an anomaly or a long-term trend that differs significantly from earlier Department of Commerce data.

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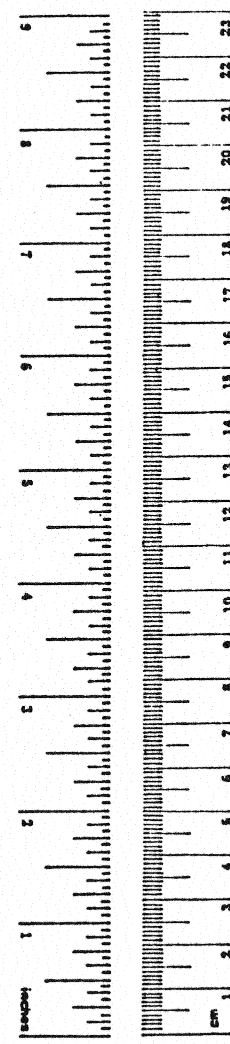
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

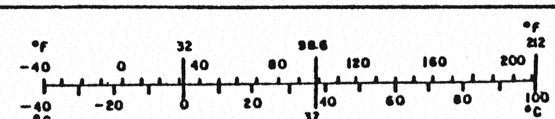
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



INTRODUCTION

Oklahoma is in the center of one of the windiest regions in the United States. It also has an abundant solar potential. At the time this program was undertaken, the actual extent to which these rich solar and wind resources could be utilized had yet to be determined with any degree of accuracy. In a state where sunshine and wind are so readily available, little had been done to take advantage of their potential. Solar collectors for heat or domestic hot water were rare, and even the faithful old water-pumping windmill had become a relic of the pioneer days. In an era of inexpensive and abundant oil and gas supplies, there had been no need to develop the state's renewable energy resources.

All that ended in 1973 with the mideastern oil embargo and the organization of the OPEC consortium. Even so, the perceived need for alternative energy sources was not matched by wide public acceptance of alternate energy technology. In the case of windpower, for example, individual homeowners were unsure of its dependability, discouraged by the high initial cost and intimidated by its technology. Utilities were dubious of windpower economics, the quality of the power produced and its effect on peak demand or base loading.

Throughout the 1970's, many of the technical and economic questions were resolved through the development of second and third generation windpower units and by detailed economic studies. In 1978, the PURPA regulations provided the legal basis for utility interconnect and for the purchase of excess power by the utilities. This Congressional action, combined with tax credits at the state and federal level, paved the way for wider public use of windpower in both residential and commercial applications.

The project described in this report was undertaken by the Oklahoma Department of Transportation to assess the local wind resource and to demonstrate the use of alternate energy for public facilities. Accurate, long-term data concerning available windpower was gathered at two sites. In particular, diurnal variation of windpower, with its consequent effect on peak-power demand, was measured. More importantly, an operating, state-of-the-art, wind-electric system was installed at a site with high-wind potential and maximum public exposure. In this way, utilities would be able to assess the dependability of wind-powered generating systems, and Oklahoma residents would become more familiar with modern windpower technology.

SITE SELECTION

There were several criteria for selection of a site (or sites) for installation of data logging and power-generating equipment for this project. Since it was to be a demonstration project, a primary requirement was visibility. In particular, the wind-powered generator was to be installed at a site that was accessible to the maximum number of Oklahoma residents. The two other major requirements, which apply to every site to be utilized for a wind system, were (1) availability of consistent strong winds and (2) sufficient unobstructed area for erection of the generator and tower. Finally, all the equipment for the project was to be located in areas regularly maintained by the funding agency, the Oklahoma Department of Transportation. Two types of state-maintained sites were considered for placement of project equipment - tourist information centers on interstate highways and DOT maintenance yards bordering the highways.

The public access requirement dictated that the wind-powered generating equipment be placed at one of the Information Centers. The locations considered were: Blackwell in the north on I-35; Miami in the northeast on I-44; Sallisaw in the east on I-40; Thackerville in the south on I-35; Erick in the west on I-40; and Guymon in the northwest on U.S. Route 54.

The only consistent information in windspeed for Oklahoma at the time this project was undertaken was the U.S. Weather Bureau information shown in Figure 1. These data are of limited use in the prediction of

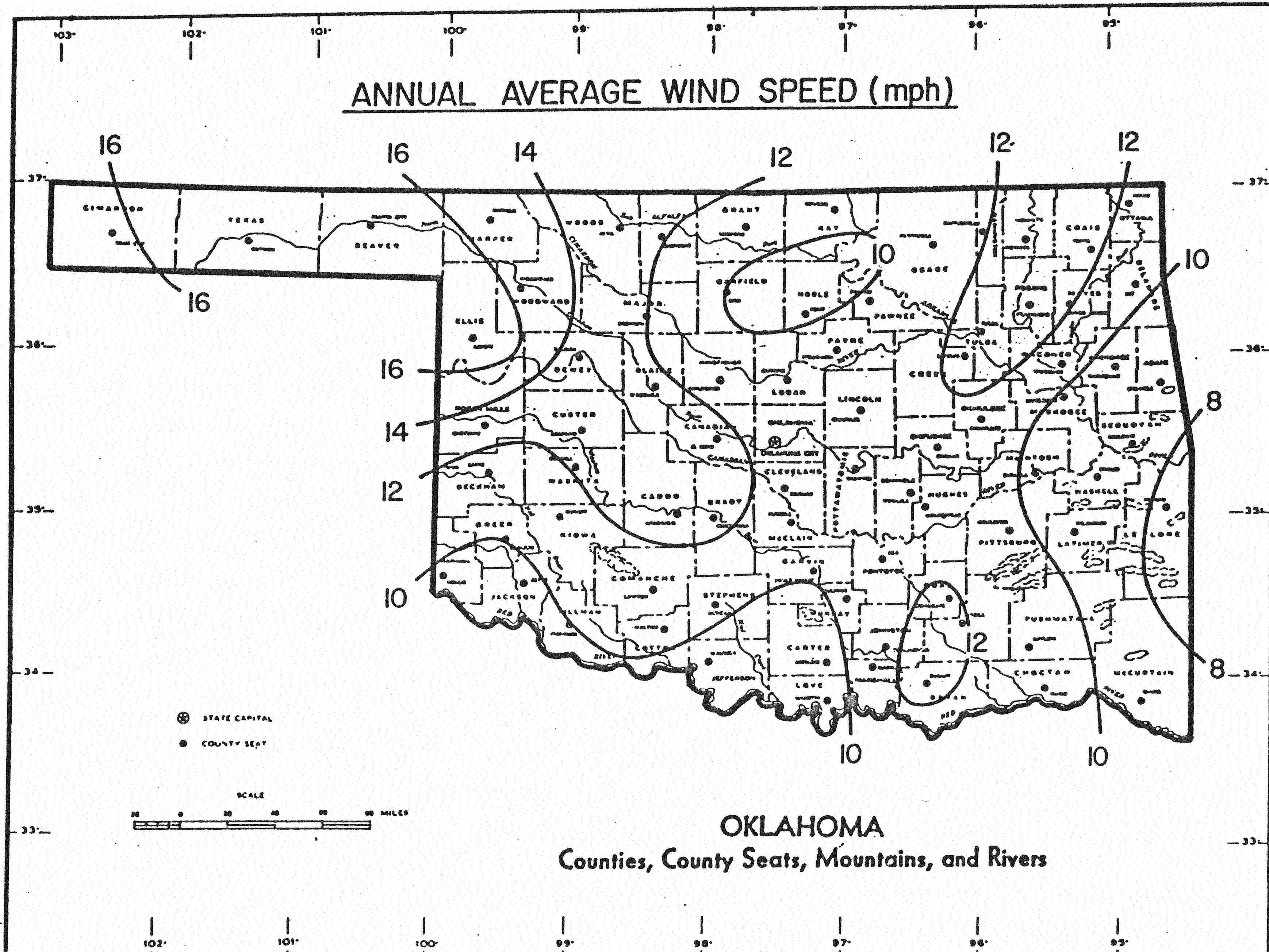


Figure 1. Weather Bureau Wind Data for Oklahoma

wind-generator performance, since they are normally measured at heights of 30 ft, and are not necessarily taken at favorable windpower sites. Because windspeed increases with elevation above ground level, wind generators are usually placed on towers which are at least 60 ft high. Nevertheless, the map shows general trends in windpower availability throughout the state, and was the basis for eliminating the sites at Sallisaw, Thackerville, and Blackwell. Weather Bureau map aside, it has been the general perception that Oklahoma winds are highest in the western part of the state. The data obtained from this project raise some questions about this commonly held view.

The Miami rest area did not have a suitable location for the generator. The two remaining sites were Erick and Guymon. Site surveys at both of these locations indicated that each had sufficient area for placement of a wind generator. The information center at Erick, where the average windspeed was thought to be 12 mph, is one of the busiest in the state while the Guymon Center receives comparatively little traffic. Although the Weather Bureau data showed the Guymon area to be a somewhat windier region, the Erick Tourist Center was chosen as the site which would maximize public exposure to the windpower system and provide the most widely useable wind and performance information.

A wind turbine was installed near the picnic area adjacent to the Tourist Information Center building on the south side of I-40 as shown in Figure 2. In order to assess the relationship between windspeed and power production, a data logging system to record windspeed and direction was installed at the same site.

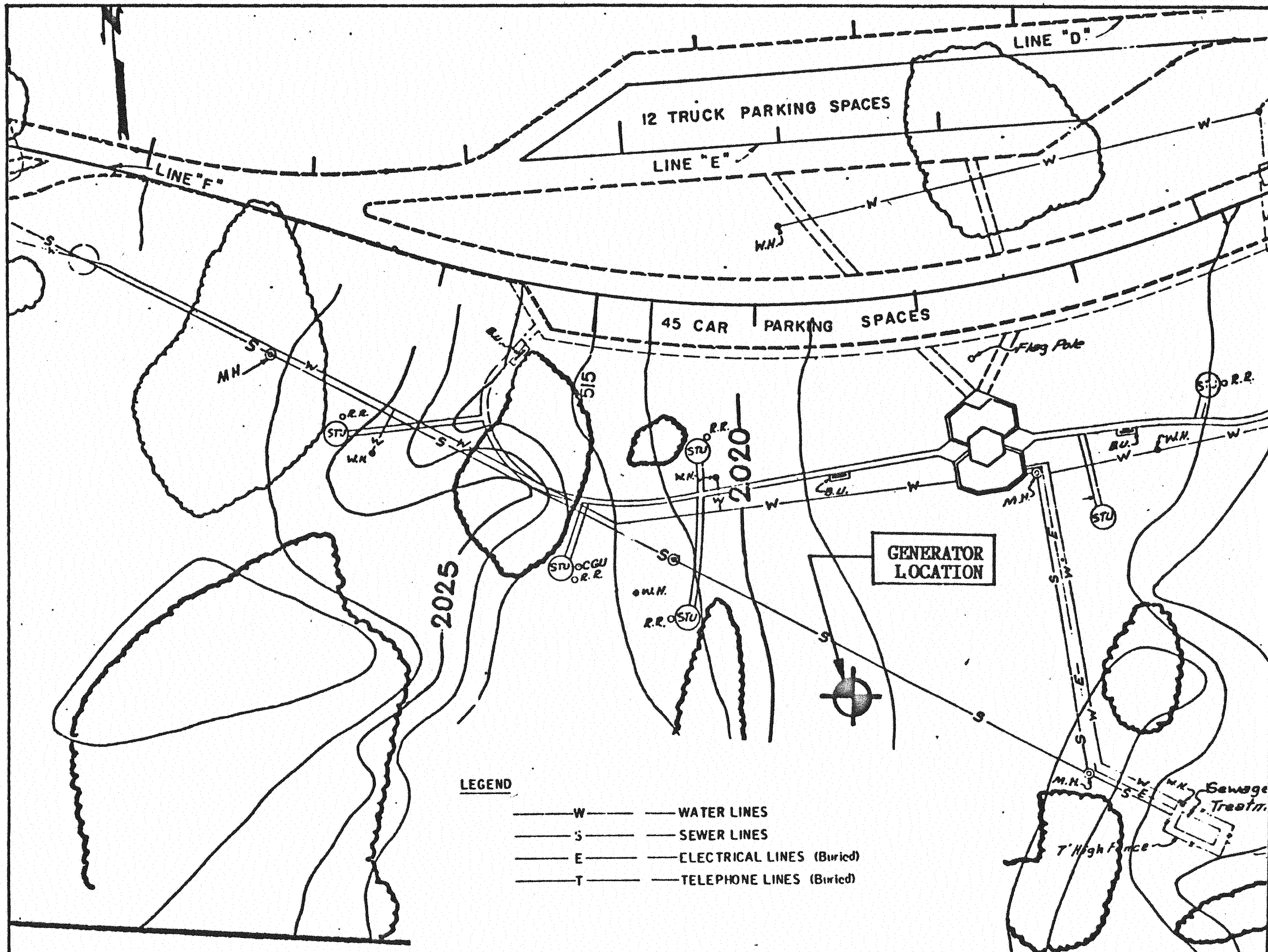


Figure 2. Location of Windpower Generator at Erick Information Center.

It was also decided to install a second set of recording anemometry equipment at a site closer to Oklahoma City. This would permit some degree of assessment of variation in windspeed with geography. It would also furnish information on windpower potential in the more heavily populated central region of the state. The DOT maintenance yard at Hydro was selected because of its excellent location on an unobstructed ridge and its visibility from I-40. A site even closer to Oklahoma City, at Yukon, was rejected because it already contained a solar hot-water heating demonstration unit.

EQUIPMENT SELECTION

WIND GENERATOR

The wind-powered generator to be installed at Erick was expected to supply a significant portion of the power required at the rest facility. Department of Transportation records were available for the period from October 1978 to October 1980. Analysis showed that electricity consumption at the site averaged 10,700 KWH per month, with peak consumption occurring in the period December - March. The maximum demand of 18,000 KWH occurred in March 1979. Minimum use of 7750 KWH occurred in June 1979.

Wind velocity increases with height above the ground. The most generally accepted method for estimating the magnitude of this increase is the power relationship:

$$V_2 = V_1\left(\frac{h_2}{h_1}\right)^n$$

where V_1 is the measured velocity at height h_1, and V_2 is the velocity to be calculated at height h_2. The exponent, n, is a function of the local terrain, including buildings, trees, and the like. In the absence of specific information, the exponent is generally assumed to be somewhere between 1/4 and 1/7.

Based on the Weather Bureau data shown in Figure 1, the average windspeed at the Erick site at an elevation of 30 ft is approximately 12 mph. Using an exponent of 1/7, for the power relationship, the average windspeed at an elevation of 60 ft was expected to be 13.5 mph.

At this windspeed, a moderately efficient windpower generator can be expected to operate at an average capacity factor of 25%, which means that it will generate an average of 25% of its rated output over an extended period of time. This estimate is based on a Rayleigh distribution of wind velocities throughout the year (the standard recommended by the American Wind Energy Association) and output versus wind velocity data for typical windpower generators.

A goal of supplying approximately 50% of the Erick electrical requirements had been established early in the program. For a monthly usage of 10,700 KWH and a capacity factor of 25%, a generator with a power rating on the order of 28 kw was required to provide this level of output.

The generator chosen was the Jay Carter Enterprises Model 25 (JCE 25), the then-available windpower generator that most closely matched the requirement. It is a horizontal axis, two-blade machine with a 32-ft rotor diameter, and is mounted on a 60-ft tower. The rotor remains downwind from the tower at all times, and overspeed protection is provided by a damped-blade pitching mechanism. The generating system consists of an induction motor/generator driven by the rotor through a step-up gearbox. The motor/generator operates in synchronization with the utility power line, so that the generated power is compatible with all electrical systems at the Erick facility. Excess generated power can be sold back to the supplying utility, Northfork REC. Figure 3 shows the configuration of the JCE Model 25 generator. The characteristics of the JCE Model 25 are described in detail in Appendix A.

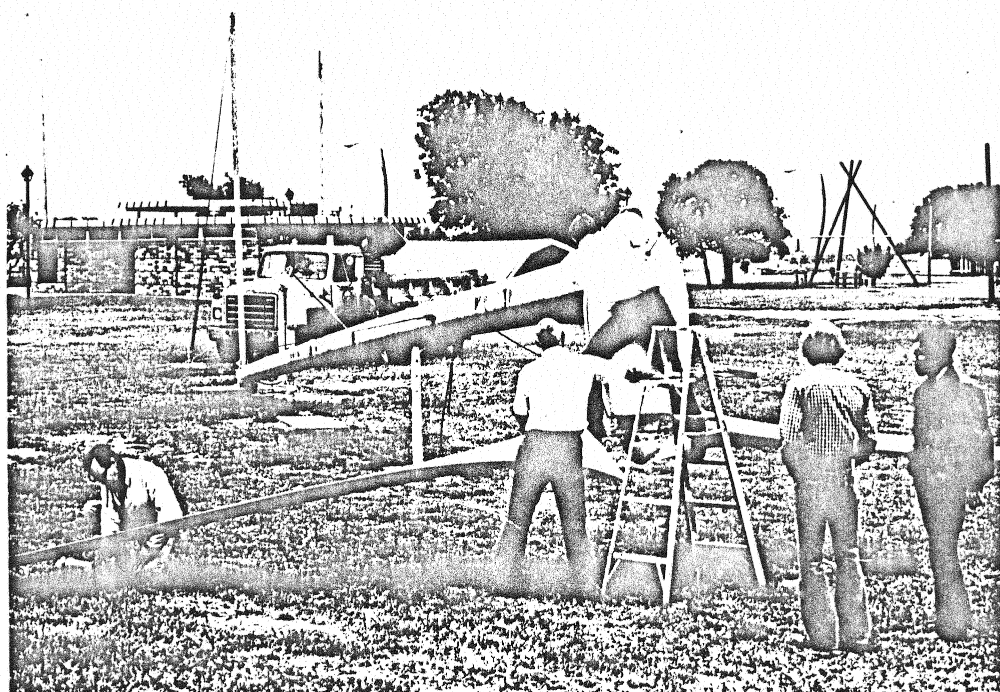


Figure 3a. Windpower Generator Installed on Tilt-up Tower

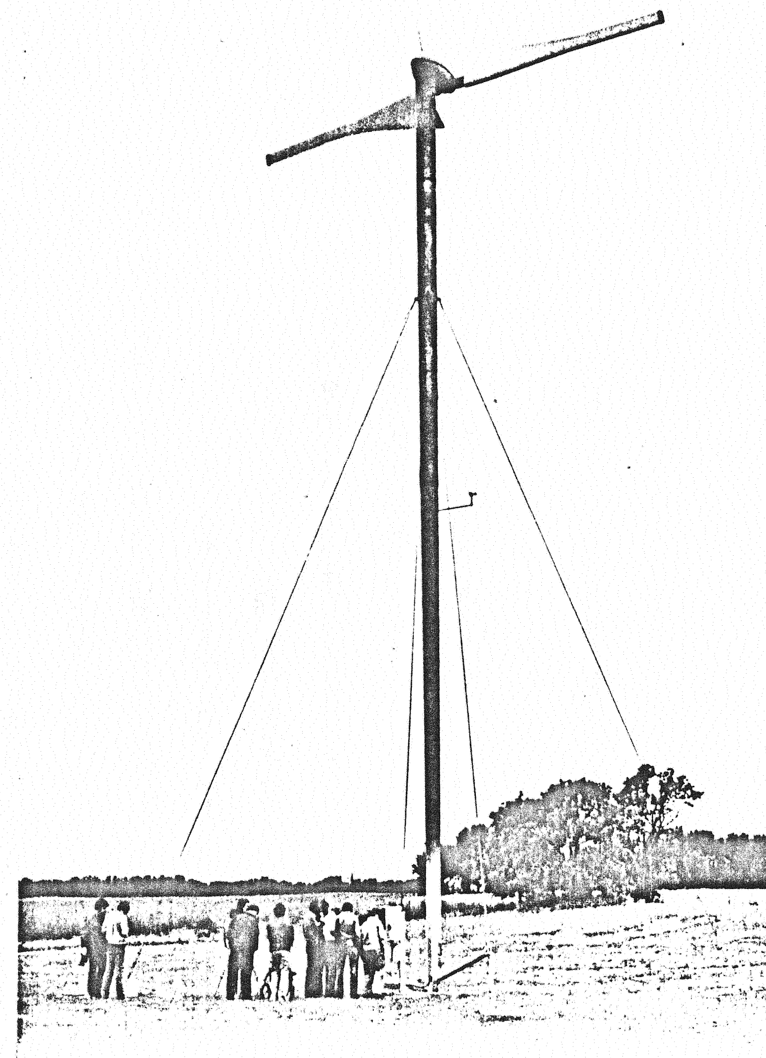


Figure 3b. Windpower Generator in Place

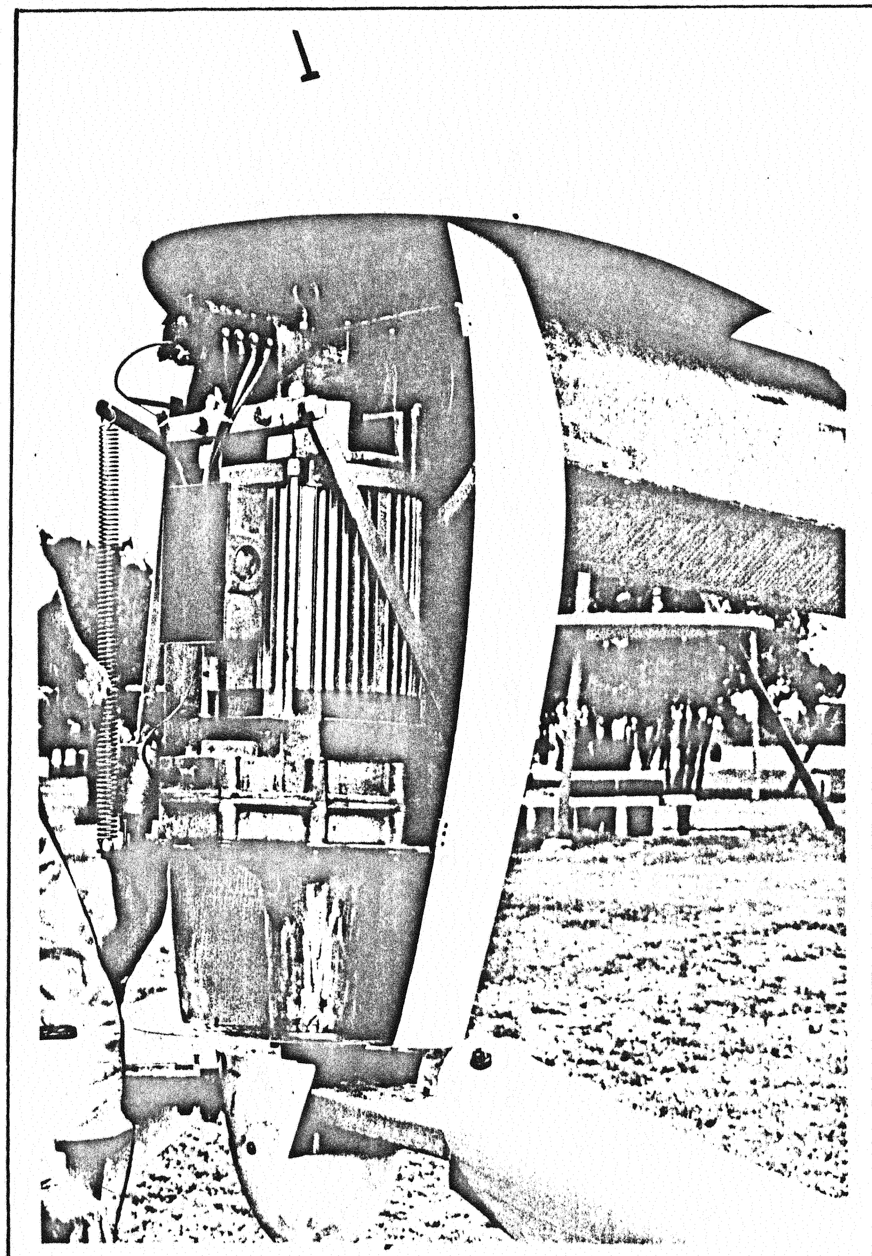


Figure 3c. Powerhead and Inboard Blade of Windpower Generator

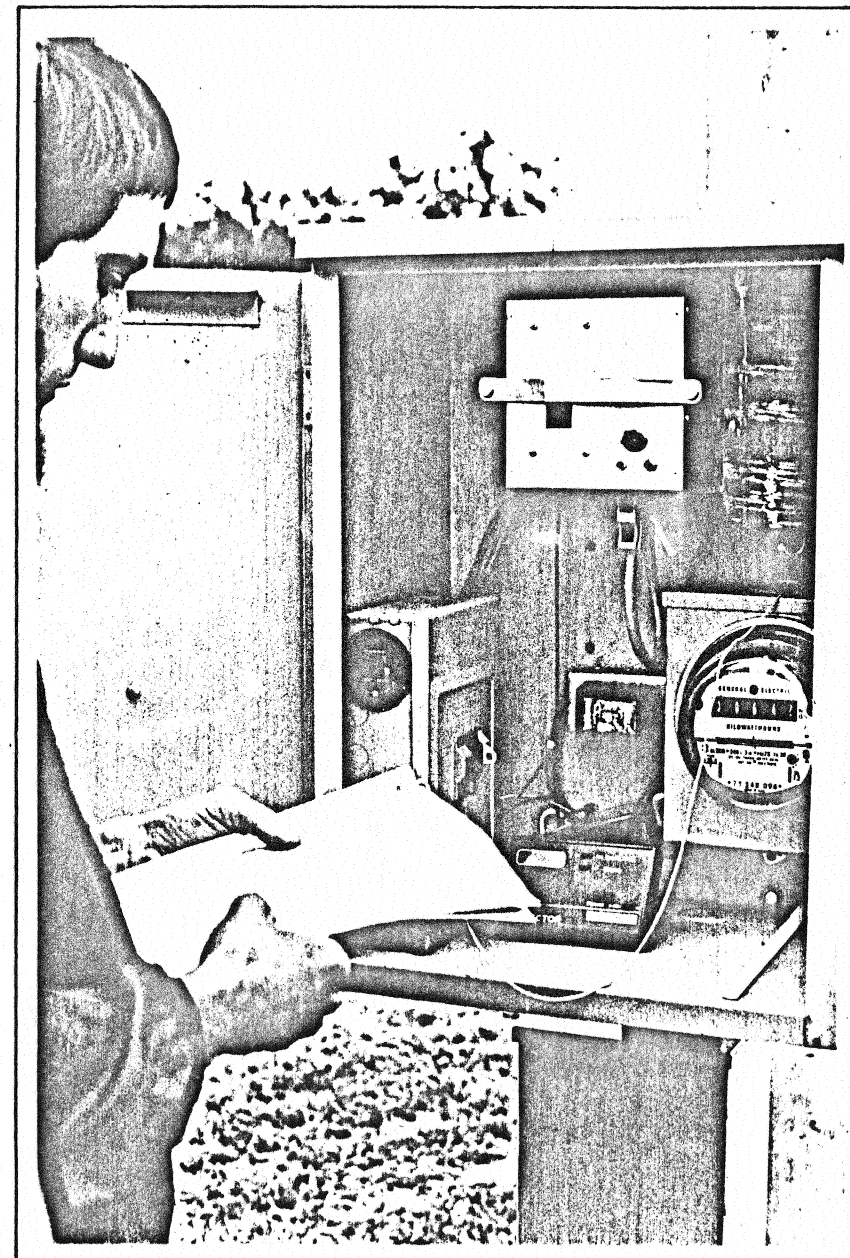


Figure 3d. Electrical Control Box at Base of Tower

Although the Carter 25 windpower generator is advertised as having a maximum output of 25 kw at a windspeed of 25 mph, the peak measured output at the Erick site was 18.7 kw. In discussing this discrepancy with the manufacturer, it was learned that the 25 kw rating applied only to the three-phase version of the machine. The single-phase unit, as installed at the Erick site, has a maximum output rating of 20 kw. The single-phase unit was chosen because three-phase utility power is not available at Erick.

ANEMOMETRY

Windpower data to be compiled at the Erick and Hydro sites, for each month, included:

1. Peak windspeed and maximum lull time,
2. Average windspeed,
3. Windspeed/duration information,
4. Diurnal windspeed, and
5. Wind direction

The distance to the anemometry sites dictated that information be stored for considerable periods of time. Thus, battery life and storage capacity of the wind-data logger were important. Obviously, dependability was another important factor. For the Erick site, two Second Wind Model AL-2000 data-logging systems were chosen. Windspeed and direction sensors for the systems were mounted at heights of 25 and 45 ft. The AL-2000 loggers can store up to 13 months of data, and the specification battery life was 13 months for the lithium batteries supplied with the unit.

The sensors supplied with the AL-2000 logger were a Maximum Model 40, 3-cup, windspeed unit, and a Downeaster wind-direction vane. The windspeed sensor is actually a small, wind-powered alternator which produces an AC signal with a frequency determined by the rotational speed of the sensor. The windspeed-frequency relationship is carefully calibrated over the windspeed range of 0-140 mph. The wind-direction sensor relies on a small, constant DC power source (in this case, the batteries in the logger). The direction vane is actually a variable resistor so that movement in the vane causes a change in the voltage drop across the resistive load.

The AL-2000 logger is calibrated to convert the frequency and voltage input data every two seconds to windspeed and direction, respectively. A programmed read-only memory chip (PROM) controls the operations which sort the data into bins corresponding to monthly, diurnal, and velocity distributions. Sorted data are stored on an erasable chip (EPROM), from which the data can be read by queries entered on a key pad in the logger. Alternatively, the EPROM chip may be removed and the data read via computer interrogation. The EPROM chip may be "erased" and reused.

For the Hydro site, a Second Wind Model AL-2002 logging system was selected. This unit stores data from two sets of speed/direction sensors for up to 13 months. Specification battery life was 9 months. Sensor pairs were mounted at 30 and 45 ft. The former height, although different from the lower sensor height at Erick, was chosen because of the proximity of a building with a height of 20 ft.

Specifications for the AL-2000 and AL-2002 are given in Appendix B, while sample data pages are shown in Appendix C. All loggers incorporated an automatic changeover to/from daylight savings time, and this is reflected in the diurnal distributions.

IMPLEMENTATION

DATA LOGGING: ERICK

The loggers at Erick were installed on January 14, 1982. Windspeed and direction data, at heights of 25 and 45 ft, were obtained for the months through July, but premature battery failure caused the loss of data for August. On September 9, 1982, the logging of wind data from the upper (45 ft) sensor pair was resumed and continued uninterrupted through August 1983.

The second logger at the Erick site was converted to record the power output from the JCE Model 25 generator. An Ohio Semitronics Model PC5-35-C, AC watt transducer, installed on the output line from the generator, monitored the output current from the generator. The linear, 0-10 VDC output of the transducer was then converted, via a solid-state circuit, to a frequency signal which would be read by the logger as a "windspeed" signal. For reasons of reliability and accuracy, a background frequency was present at all times. This 2.35 Hz background corresponds to a 4 mph windspeed, which must be subtracted from the indicated windspeed on the logger readout. Each mph increment in windspeed then corresponds to 0.735 kw of generator output power. The equation for converting from mph to kw is:

$$\text{Power Output (kw)} = [\text{windspeed (mph)} - 4] \times 0.735$$

The bin distributions for output power in the logger were 0-1.47, 1.47-2.94, 2.94-4.41, ..., 23.52-24.99 kw. Diurnal distribution was unaffected, except that indicated output distributions were to be converted according to the above equation. The wind-direction circuitry on the power logger was inactive. A schematic for the power output monitoring circuit is shown in Figure 4, along with a photograph of the Erick installation.

Logging of generator power production at Erick was initiated on September 9, 1982 and continued through August 1983.

DATA LOGGING: HYDRO

The AL-2002 at Hydro was put into operation on January 13, 1983. Data were recorded for the sensor pairs at 30 and 45 ft through August 1983. Data for May and June 1983 were lost, again due to premature battery failure.

SUMMARY OF DATA

Monthly windspeeds at Erick and Hydro are plotted in Figure 5. Monthly diurnal distributions, as well as monthly histograms showing distribution of windspeed versus duration, are shown in Appendix D, Figures D1 through D25. In the histograms, 200 hours represent an overflow (time $\geq$ 200 hrs) and 39 mph represents an overflow (all velocities $\geq$ 39 mph). A comparison of windspeeds at the various heights and locations is shown in Table 1. Overall average windspeeds, for the total number of days logged at each site are shown in Table 2.

Monthly power production from the generator at Erick is plotted in Figure 6 and is tabulated along with monthly average windspeed (at 45 ft) in Table 3. Diurnal distributions of power production for each month are shown in Appendix E, Figures E1 through E11.

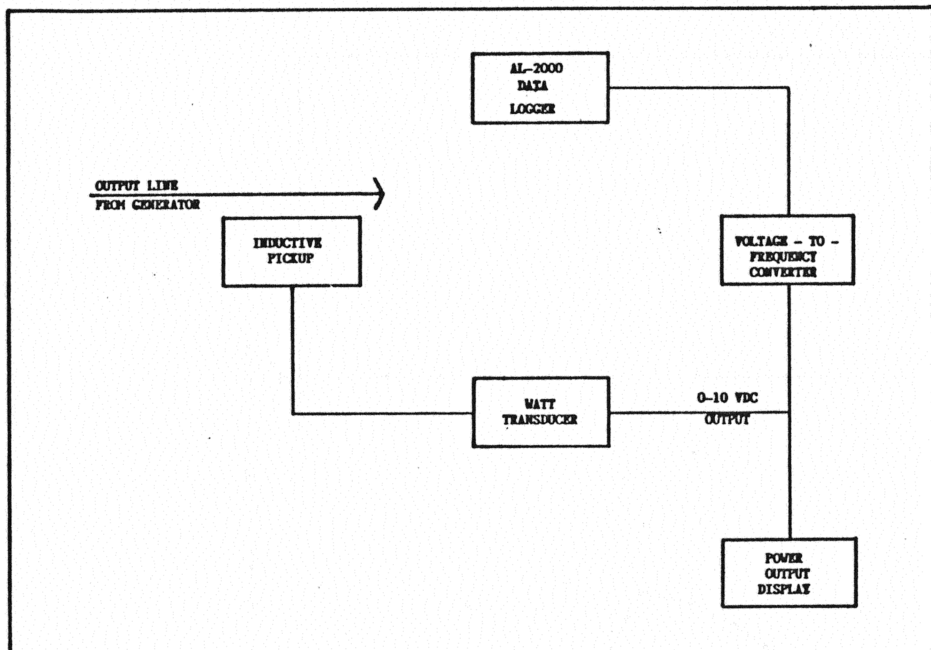


Figure 4a. Power Monitoring Circuit at Erick Information Center

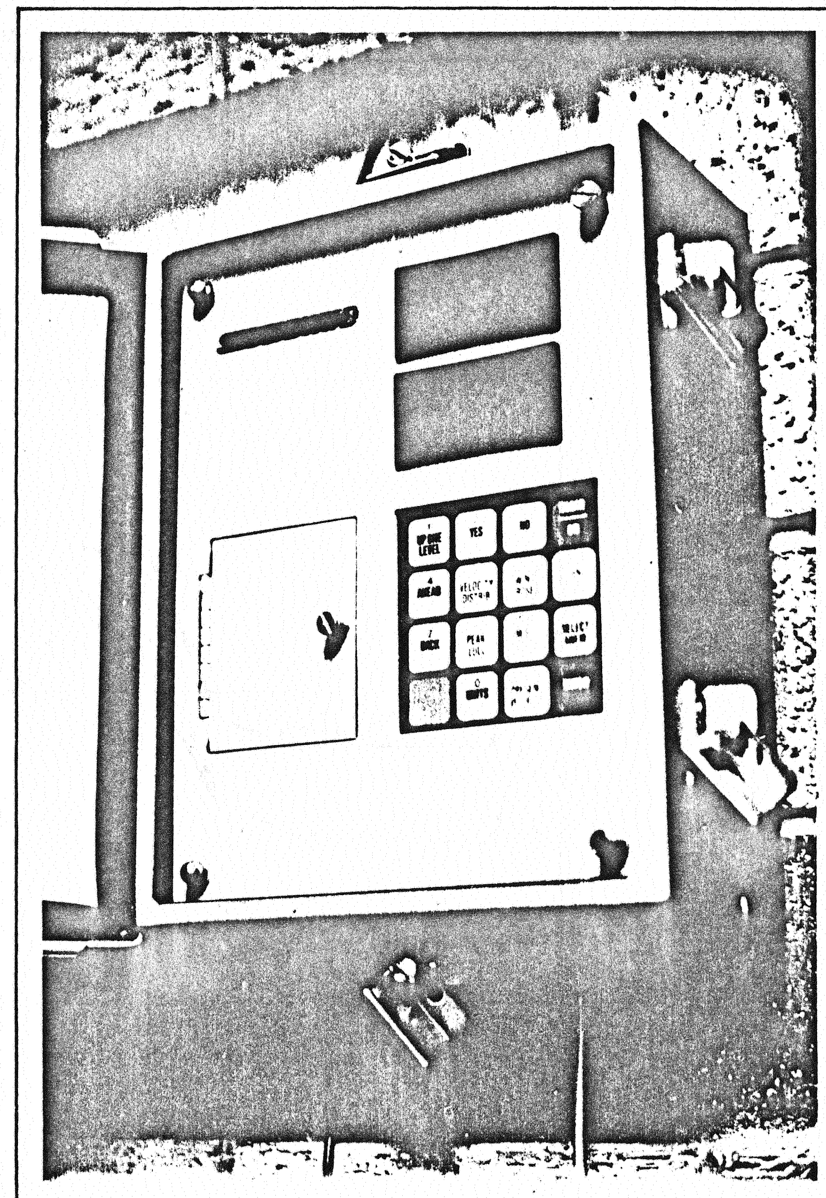


Figure 4b. AL-2000 Installation at Erick Site

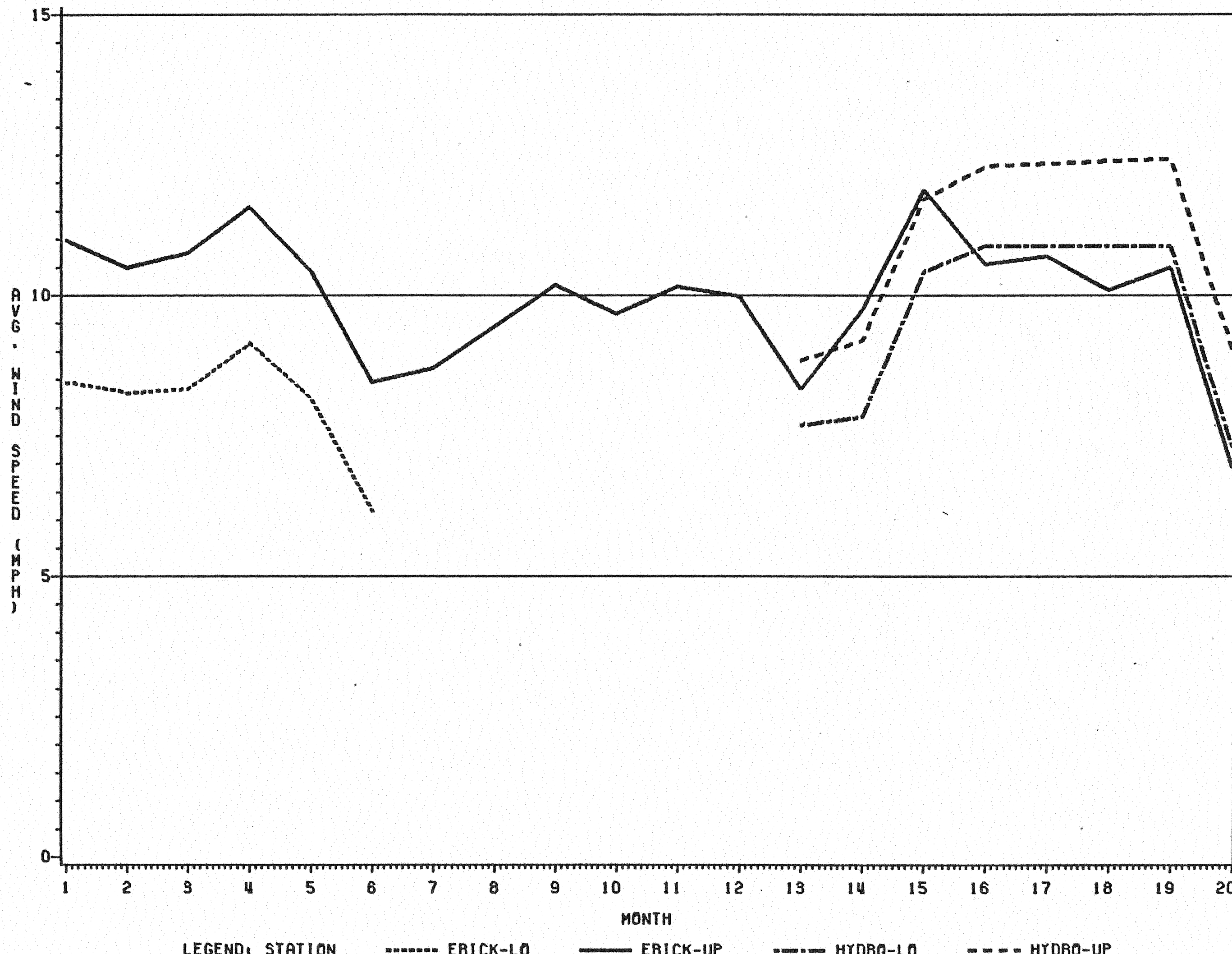


Figure 5. Monthly Wind Speeds at Erick and Hydro

Table 1. Average Monthly Wind Speeds at Erick and Hydro

	45 ft		25-30 ft	
	Erick	Hydro	Erick	Hydro
1982				
January	10.99	--	8.44	--
February	10.49	--	8.26	--
March	10.76	--	8.34	--
April	11.58	--	9.15	--
May	10.43	--	8.16	--
June	8.46	--	6.15	--
July	8.71	--	(a)	--
August	(a)	--	(a)	--
September	10.18	--	(b)	--
October	9.68	--	(b)	--
November	10.15	--	(b)	--
December	9.98	--	(b)	--
1983				
January	8.33	8.84	(b)	7.69
February	9.76	9.19	(b)	7.84
March	11.89	11.72	(b)	10.42
April	10.55	12.30	(b)	10.88
May	10.70	(a)	(b)	(a)
June	10.09	(a)	(b)	(a)
July	10.49	12.43	(b)	10.88
August	6.94	9.05	(b)	7.29

(a) Loggers down due to battery failure
(b) Logging discontinued

Table 2. Overall Average Wind Speed at Erick and Hydro (hours of operation)

	Erick		Hydro	
	45'	25'	45'	30'
Overall Avg Speed	9.99(568)	8.06(172)	10.72(170)	9.29(170)
Avg for 1/83-4/83; 7/83-8/83	9.75	---	10.72	9.29

Table 3. Power Production and Wind Speed at Erick

	Power (KWH)	Avg Wind Speed (mph)
1982		
September	3520	10.18
October	2069	9.68
November	2452	10.15
December	2324	9.98
1983		
January	1777	8.33
February	1749	9.76
March	3249	11.89
April	498(a)	10.55
May	(b)	10.70
June	1733	10.09
July	1988	10.49
August	720	6.94

(a) Generator inactive 4/1 - 4/19
(b) Transducer down due to circuit breaker malfunction

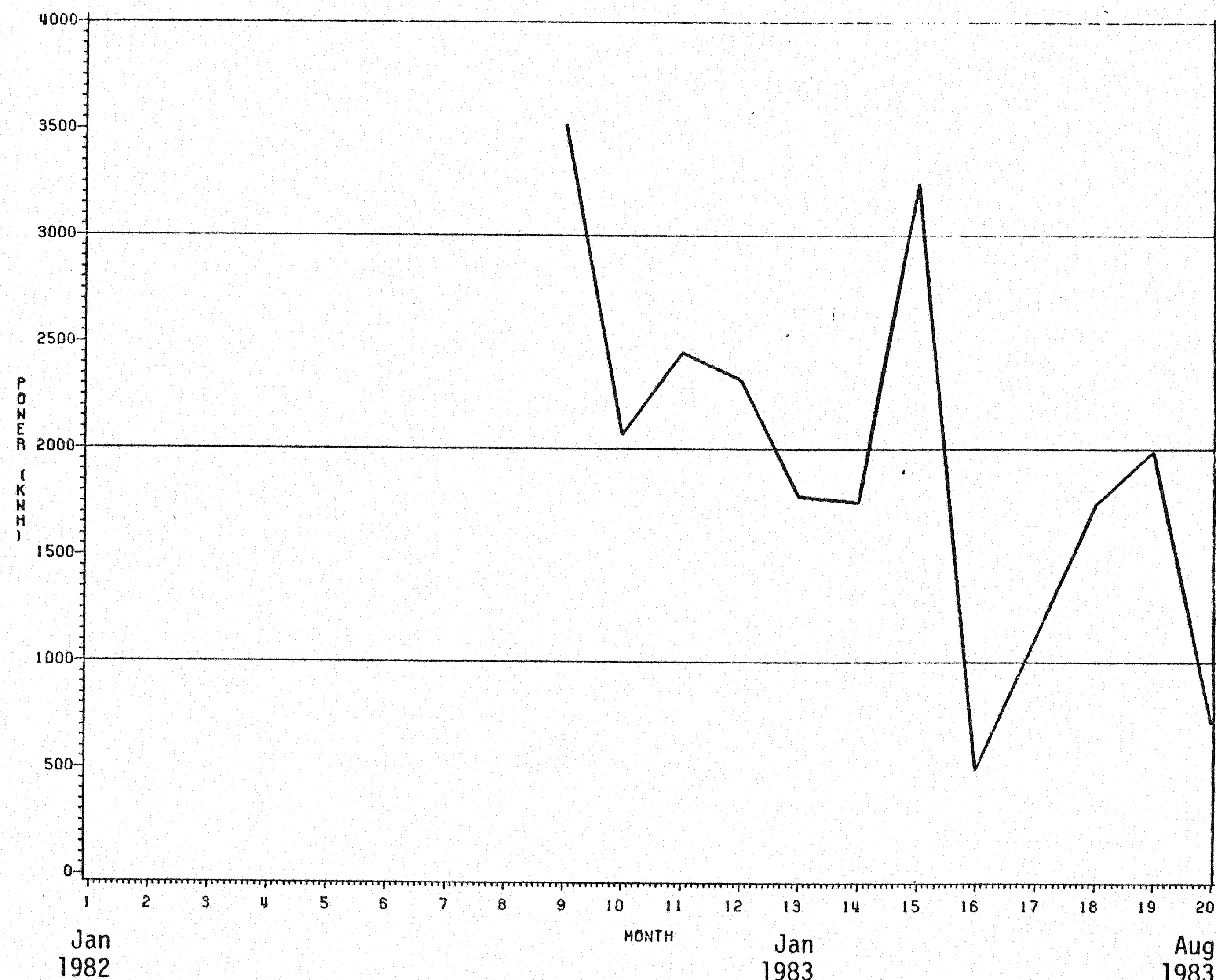


Figure 6. Monthly Power Production - Erick Site - SEPTEMBER, 1982 through AUGUST, 1983

Monthly peak windspeed and power production are shown in Table 4 while maximum lull (inactive) time is shown in Table 5.

Table 4. Monthly Peak Wind Speed (mph) and Power Output (KW)

	45 ft		25-30 ft		
	Erick	Hydro	Erick	Hydro	Power
1982					
January	45.5	--	41.5	--	--
February	41.5	--	37.5	--	--
March	53.0	--	46.0	--	--
April	68.5	--	62.0	--	--
May	58.5	--	53.0	--	--
June	51.5	--	44.5	--	--
July	45.5	--	(a)	--	--
August	(a)	--	--	--	--
September	(b)	--	--	--	16.5
October	(b)	--	--	--	16.5
November	(b)	--	--	--	18.7
December	(b)	--	--	--	18.4
1983					
January	(b)	41.0	--	38.0	18.0
February	(b)	41.0	--	40.5	18.4
March	51.5	52.0	--	49.0	18.4
April	42.0	63.5	--	59.0	16.9
May	56.0	(a)	--	(a)	17.3
June	50.0	(a)	--	(a)	16.5
July	54.0	38.5	--	38.5	15.1
August	37.5	82.0	--	72.0	15.8

(a) Logger down due to battery failure
(b) Data lost

Table 5. Maximum Lull Times for Wind and Power Production

	45 ft		25-30 ft		
	Erick	Hydro	Erick	Hydro	Power
1982					
January	14		20		
February	17		20		
March	16		25		
April	9		35		
May	30		39		
June	33		40		
July	29		(a)		
August	(a)		(a)		
September	(b)		--		43
October	(b)		--		92
November	(b)		--		68
December	(b)		--		48
1983					
January	(b)	103	--	103	119
February	(b)	21	--	31	73
March	17	20	--	34	46
April	11	15	--	17	(c)
May	14	(a)	--	(a)	(c)
June	19	(a)	--	(a)	51
July	12	13	--	14	46
August	20	17	--	18	53

(a) Logger down due to battery failure
(b) Data not recorded
(c) Transducer circuit down due to building renovations

DISCUSSION OF RESULTS

GENERATOR

The major piece of equipment, the generator, performed dependably although its output was lower than expected. Part of this low output is due to the derating of the Model 25 when operating in a single-phase electrical system. The generator did not, however, reach the 20 kw maximum which had been specified for the single-phase version. Table 4 shows that the maximum recorded output from the generator was 18.7 KWH, despite the frequency presence of high winds at the Erick site. The only significant downtime for the wind turbine occurred during the period April 1 - April 19, 1983 when the out-of-balance brake tripped during a violent thunderstorm. The generator was deactivated until it could be lowered and the brake reset. Short (5-12 hr) downtimes occurred three times when the unit was lowered for periodic service. Two factory maintenance calls were required, both under warranty. In one case, the generator yaw tube was replaced because of defective material in the casting. In the second case, the entire generator and gearbox were replaced by the manufacturer in order to investigate the noisy operation of the system.

The availability of the windpower generator for the one-year test period was 94%.

DATA LOGGERS

The AL-series loggers performed dependably, as expected, except for one serious problem. The lifetime of the lithium batteries was much shorter than anticipated. In the case of the AL-2002, the lifetime was less than half of the design life. This premature battery failure led to losses of several months of data. For a logger which is designed to function unattended for over one year, this requirement for battery replacement at five- or six-month intervals is unacceptable. For this reason, the AL-series logger in its present state of development is recommended for anemometry at remote sites only if battery life is improved. Where frequency service or monitoring is possible, the AL-series loggers should be quite satisfactory.

Aside from the battery problem, the loggers functioned well. The initialization procedure was simple and well explained, interaction between the logger and user was logical and concise, and the procedure for reading stored data was simple and direct.

One final comment should be made concerning the "directional turbulence" feature incorporated in the logger. Each of the windspeed bins is further subdivided into "slow", "medium", and "fast" directional change bins. These offer an excellent opportunity to quantify the extent of turbulence at a site, a factor which could have profound effects on the windpower available. Unfortunately, the original criteria for classification of directional change programmed into the data logger resulted in almost all wind being grouped into the "slow" category, so that little comparison of sites could be made. Field reports to the manufacturer of the data logger and numerous telephone discussions with the manufacturer's engineers resulted in a design change in the logger to revise the criteria for wind turbulence classification. The data logger at the Hydro site incorporated this change. As a consequence, this feature should provide useful information in the future.

WINDSPEED

The outstanding feature of the data logging phase of the project was the observation of average windspeeds far below those which were expected on the basis of regional distribution data from earlier surveys by the Department of Commerce. As seen from Table 1, there were only two months during the study when average windspeed exceeded 11 mph. The average for August 1983 at Erick is lower than any monthly mean which has been found for Oklahoma City, where the anemometer height is only 20 ft. The overall average windspeeds at both Hydro and Erick, as shown in Table 2, are well below those recorded at Oklahoma City for the years 1970-79 (anemometer height) [Refs. 1, 2, 3] and even further below the average recorded during the period 1946-51 at Oklahoma City, when the average windspeed was 14.9 mph [Ref. 4]. It seems clear that the study period for this project was one in which the windspeed was remarkably low. Both Erick and Hydro are located in regions of Oklahoma which traditionally experience higher winds than Oklahoma City. Both anemometer towers were located in good sites for wind optimization. The data presented should serve, therefore, as an indication of the low end of the range of wind energy available in the western regions of the state. More accurate assessment of the normal windpower available at the Erick site will require continuation of the monitoring program through a more typical period of wind activity.

An examination of the data presented in Table 1 shows that the Hydro site is apparently superior to the Erick location for windpower utilization. The observed difference of one mph could be due, however, to variations in local terrain and should not be considered significant at this time. Rather it appears that the entire west-central region of the state receives winds of similar velocity.

The standard "power law" equation for variation of windspeed with elevation above ground was shown in the EQUIPMENT section. The value of the exponent "n" depends primarily on the topography and surface characteristics of the region. Using the data of Table 3, the value of "n" at Erick is .37, while at Hydro "n" is .35. These values are relatively high when compared to the generally accepted range of values from 1/4 (.25) to 1/7 (.14). The implication of this higher value is that the increase in windspeed with altitude is greater at these two sites than might be expected from conventional information on wind gradients.

The presence of trees at the Erick site and the buildings at Hydro were clearly major factors in this unexpected result. Nevertheless, since most recorded wind data for the United States has been obtained from standard 30 ft weather stations, further investigation of velocity gradient with height would appear to be indicated.

WIND DIRECTION

In winter months, the principal direction for power winds (windspeed $\geq$ 18 mph) is from the north with a significant contribution from the southeast. In spring, the higher-speed winds change to primarily southeast, where they remain until mid-autumn. East or west winds are not frequently observed. Table 6 summarizes the principal directional trend.

Table 6. Duration of High-Speed Winds from the Principal Directions at Erick, Oklahoma

Month	N.E. to N.W.		S.E. to S.W.	
	18-24 mph	≥ 25 mph	18-24 mph	≥ 24 mph
January	32 hr	14 hr	17 hr	9 hr
February	33	10	27	6
March	22	7	50	22
April	31	20	52	13
May	18	6	65	17
June	9	2	26	5
July	1	0	50	4
August	1	0	11	1

POWER PRODUCTION

A comparison of the electric use at the Erick site before and after the installation of the wind generator is informative. Table 7 details the electric usage at the site in the 12 months following the installation of the generator as compared to an average for the three years preceding the installation. Total usage increased 11.6%, but production from the generator resulted in an 8.2% reduction in power purchased from the utility.

The observed power production was not as high as had been expected. As noted before, two factors account for this discrepancy. The first has to do with the reduced output of the single-phase Carter 25 windpower generator. The second, and more important factor, was the lower-than-expected average windspeeds at the Erick site.

The effects of low windspeed on power production are profound,

Table 7. Electric Usage at the Erick Tourist Information Center Before and After Installation of Wind Generator (KWH)

	BEFORE WINDPOWER	AFTER WINDPOWER		
	UTILITY PURCHASE[1]	UTILITY PURCHASE	WINDPOWER GENERATED	TOTAL USED
January	10,420	13,090	1780	14,870
February	13,160	12,360	1750	14,110
March	15,940	14,800	3250	18,050
April	10,010	9,750	--	--
May	9,170	--	--	--
June	8,360	8,050	1730	9,780
July	8,660	6,720	1990	8,710
August	10,390	9,740	720	10,460
September	10,810	7,130	3520	10,650
October	9,140	8,200	2070	10,270
November	8,360	--	2450	--
December	9,370	8,200	2320	10,520
EXCLUDING APR, MAY NOV	96,250	88,290	19,130	107,420

[1] Three-year average

since the amount of power in the wind varies as the third power of the wind velocity. For example, an increase in average windspeed of only 25% can nearly double the output of a windpower generator.

At the Erick site, the power production data given in Table 3 show that the average monthly output for the JCE 25 was approximately 2000 kwh, well below the expected 4000 kwh monthly average. Furthermore, the generator produced more than 3000 kwh in only two months during the study, September 1982 and March 1983.

The average annual windspeed at Erick (measured at the 45-ft height) was 9.9 mph for the twelve-month test period. When this result is corrected for the 60-ft hub height of the JCE 25 machine, using an exponent of .35, the average windspeed available for power production is 10.9 mph. This is approximately 25% less than the expected 13.5 mph. The corresponding reduction in output using the third-power relationship, would be 47%.

This result is generally consistent with the original expectations and the goals of the program. Specifically, if the assumed 60-ft windspeed average of 13.5 mph had been attained, the average monthly output would have been approximately 3800 kwh. If, in addition, an allowance is made for the lower rating of the single-phase version of the JCE 25, the average monthly output would have been approximately 4500 kwh; or 44% of the average electrical needs of the Erick Tourist Center.

Looked at another way, the actual capacity factor (C.F.) for the windpower generator can be calculated as:

$$C.F. = \frac{2000(12)(100)}{20(8760)} = 13.7\%$$

which is considerably less than the 25% C.F. assumed during the definition phase of the study. On the other hand, when corrected for the expected average windspeed, 13.5 mph, the C.F. would be 26%, approximately the same as anticipated.

Thus, the program results, insofar as power production is concerned, lead to mixed conclusions.

1. The JCE 25 performed reliably. The average availability was 94.5%.
2. The annual output of the JCE 25 was consistent with its rated power and the measured average windspeed.
3. The actual energy output and its contribution to the electrical needs of the Erick Tourist Center were only 50% of those estimated at the start of the study.

It is clear that the sensitivity of power production to changes in average windspeed requires that accurate wind data be used for estimating the economic benefit of windpower generators at a specific site. A decision on the ultimate value of windpower generators in Oklahoma will benefit from continued monitoring of windspeed and power production at the Erick site.

WINDPOWER ECONOMICS

The cost of windpower is influenced by such a variety of technical and economic factors that there is no single (or simple) answer to the question, "Does windpower pay off?"

For business and home applications, it is generally agreed that installed costs on the order of $2000 per installed kilowatt will result in payback periods that range from less than four years to about eight years, depending on the application. These favorable pay-back periods are the result of generous federal and state tax credits, plus the rising cost of utility-generated electricity. They are also more likely to occur in those parts of the country that have better than average wind resources.

A cash flow analysis for a typical Oklahoma homeowner purchase of a 10-kw WECS with an installed cost of $20,000 is shown in Table 8. This 10-kw unit has been chosen because it represents a near optimum generator size for a typical home in Oklahoma.

An analysis for the business purchase of a 20-kw unit (the approximate size of the unit installed at the Erick site) is shown in Table 9.

Finally, an analysis for a government purchase of the JCE 25 unit is shown in Table 10. In this calculation, it is assumed that the original capital cost of the windpower generator comes from appropriations and that no interest is paid on the money involved.

Critical factors in calculating the cash flow are:

1. ANNUAL ENERGY OUTPUT. For the example cases, annual energy outputs were assumed to be 18,000 KWH/yr and 36,000 KWH/yr, respectively. This corresponds to a capacity factor of approximately 20%, which appears to be a reasonable value for the Great Plains region.
2. INITIAL COST OF ELECTRICITY. During the period 1983/1984, the average cost of electricity, including the fuel adjustment addition, in Oklahoma ranged from $0.06/KWH to $0.10/KWH. An average value of $0.08 KWH was assumed for the example calculations.
3. FUTURE COST OF ELECTRICITY. The inflation rate for electricity in Oklahoma over the past 10 years has been about 15% per year. There is some evidence that this inflation rate will moderate in the future. A rate of 12% was assumed.
4. TAX BRACKET OF OWNER. If the purchase price is borrowed, the interest expenses may be deducted from taxable income by both the business owner and the homeowner, the former as a tax credit, the latter as a cost of doing business. In the case of the business purchase, the value of the energy produced must be discounted by the amount of tax on the increased profit. In both cases, it has been assumed that the total tax bracket is 50%, including both state and federal taxes.
5. FEDERAL TAX CREDITS. The federal tax credit for homeowner purchases of windpower generators is 40% of the first $10,000 invested. The federal Business Energy Investment Credit (BEIC)

is 15% of the purchase price, without upper limit. In addition, business-related purchases may use the federal Investment Tax Credit of 10%.

6. STATE TAX CREDITS. Many states have followed the federal government in providing tax credits that may be added to the federal credits. Oklahoma, for example, provides a homeowner tax credit of 35% of the first $10,000 invested and a business tax credit of 30% of the total investment.

7. ACCELERATED DEPRECIATION. Business purchasers of WECS may depreciate their investment (minus one-half the claimed federal tax credits) over a five-year period at the rate of 15% for the first year, 22% for the second year, and 21% for each of the next three years.

8. INTEREST RATES. The assumed interest rates for borrowed money are 12% for business loans and 14% for homeowner loans.

Table 8 shows that the payback period for a homeowner purchase is just over eight years. Because of the more generous tax credits available for businesses, the payback period for a business purchase is approximately four years as shown in Table 9. It is clear that these favorable payback periods are possible largely because of the tax credits and accelerated depreciation.

Unfortunately, these tax benefits are not available to government agencies. Thus, the economics of private-sector windpower do not apply when WECS are purchased directly by government entities for their own use. Even so, with the assumptions noted previously, the payback period

CASH FLOW ANALYSIS

Table 8. Homeowner Purchase of 10-KW Windpower Generator

	Cash Flow Available for Debt Service	Outstanding Balance
YEAR 1		
Interest Expense	($2,800)	
Federal Solar Tax Credit	4,000	
State Solar Tax Credit	3,500	
Interest Tax Savings	1,400	
Energy Production	1,440	
	$7,540	$12,460
YEAR 2		
Interest Expense	($1,744)	
Interest Tax Savings	872	
Energy Production	1,613	
	$ 750	$11,719
YEAR 3		
Interest Expense	($1,640)	
Interest Tax Savings	820	
Energy Production	1,806	
	$ 986	$10,733
YEAR 4	$1,072	$9,661
YEAR 5	$1,394	$8,267
YEAR 6	$1,768	$6,499
YEAR 7	$2,199	$4,300
YEAR 8	$2,699	$1,601
YEAR 9	$3,040	$1,439

1. Assumes 3 year warranty.
2. Operation and maintenance costs are assumed to be $200 in the fourth year, increasing annually at a 5% rate.
3. Calculated for Oklahoma State Tax Credits

CASH FLOW ANALYSIS

Table 9. Business Purchase of 20-KW Windpower Generator

	Cash Flow Available for Debt Service	Outstanding Balance
YEAR 1		
Interest Expense	($ 4,080)	
Federal ITC	3,400	
Federal BEIC	5,100	
State Solar Tax Credit	10,200	
Tax Savings from Deprec	2,231	
Interest Tax Savings	2,040	
Energy Production	1,440	
	$20,331	$13,669
YEAR 2		
Interest Expense	($1,640)	
Tax Savings from Deprec	3,273	
Interest Tax Savings	820	
Energy Production	1,613	
Operation & Maintenance	(400)	
	$3,666	$10,003
YEAR 3		
Interest Expense	($1,152)	
Tax Savings from Deprec	3,124	
Interest Tax Savings	576	
Energy Production	1,806	
Operation & Maintenance	(420)	
	$3,934	$6,069
YEAR 4		
Interest Expense	($ 630)	
Tax Savings from Deprec	3,124	
Interest Tax Savings	315	
Energy Production	2,203	
Operation & Maintenance	(441)	
	$4,391	$1,678

1. Energy production is net of tax on increased production due to wind-generated power.
2. Warranty assumed to be 1 year.
3. Calculated for Oklahoma State Tax Credits

for an annual output of 36,000 KWH/yr (typical for an annual average windspeed of 12 mph) is slightly less than eight years. For a production rate consistent with the observed output at the Erick site during the test period (approximately 24,000 KWH/hr), the payback period is still less than 10 years.

To reduce utility costs even further, government agencies could contract for the purchase of wind-generated electricity from private corporations or investor groups. The benefits of tax credits available to these private investors would be passed on to the government agency as reduced utility rates.

CASH FLOW ANALYSIS

Table 10. Carter 25 Windpower Generator Installed at Erick, OK for Oklahoma Department of Transportation

Initial Cost (Installed) $26,800
Energy Production ($\bar{V}_W = 9.9$ mph) 26000 kwh/yr
Energy Production ($\bar{V}_W = 12.0$ mph) 36000 kwh/yr
No Tax Credits Available

Year	26,000 kwh/yr			36,000 kwh/yr		
	Energy Value	O & M	Outstanding Balance	Energy Value	O & M	Outstanding Balance
1	$2080	- 0 -	$(24,720)	$2880	- 0 -	$(23,920)
2	2330	$400	(22,790)	3226	$400	(21,094)
3	2609	420	(20,601)	3613	420	(17,901)
4	2922	441	(18,120)	4046	441	(14,296)
5	3273	463	(15,310)	4532	463	(10,227)
6	3666	486	(12,130)	5076	486	(5,637)
7	4106	511	(8,535)	5685	511	(463)
8	4598	536	(4,473)	6367	536	+ 5,368
9	5150	563	+ 114			
10	5768	591				

1. Warranty assumed to be 1 year.

PUBLIC AWARENESS

One of the major goals of the Windpower Demonstration Project was to provide a windpower installation with high public visibility. This purpose was served by siting the windpower generator at the Oklahoma DOT Tourist Information Center at Erick. As noted before, the Erick site was particularly attractive because of its location along the major east-west highway, I-40, and was in the extreme western part of Oklahoma, where the winds were expected to be highest. The windpower generator is visible from both approaches to the Tourist Center.

An information panel was developed and fabricated by DOT personnel and installed on an outside wall of the Tourist Center, as shown in Figure 7. In addition, an inside display shows wind direction and velocity, plus power output from the windpower generator. The inside display is shown in Figure 8.

In response to the high level of visitor interest, a printed data sheet on the machine and its installation was prepared by DOT for distribution by Center personnel. The data sheet is reproduced in Appendix F.

Over the past two years, the windpower generator has been featured on Public Television and in various newspaper articles.

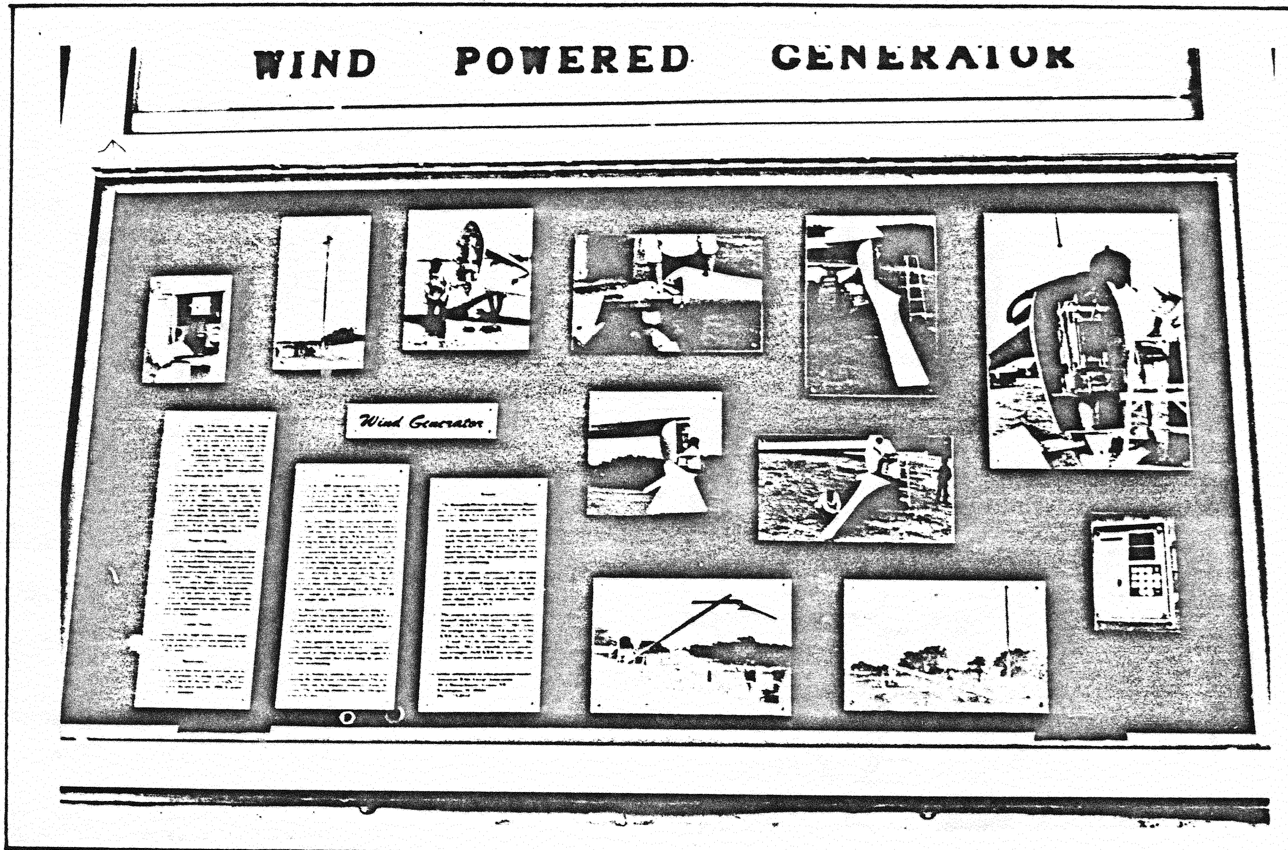


Figure 7a. Display Panel Installed at Erick Site

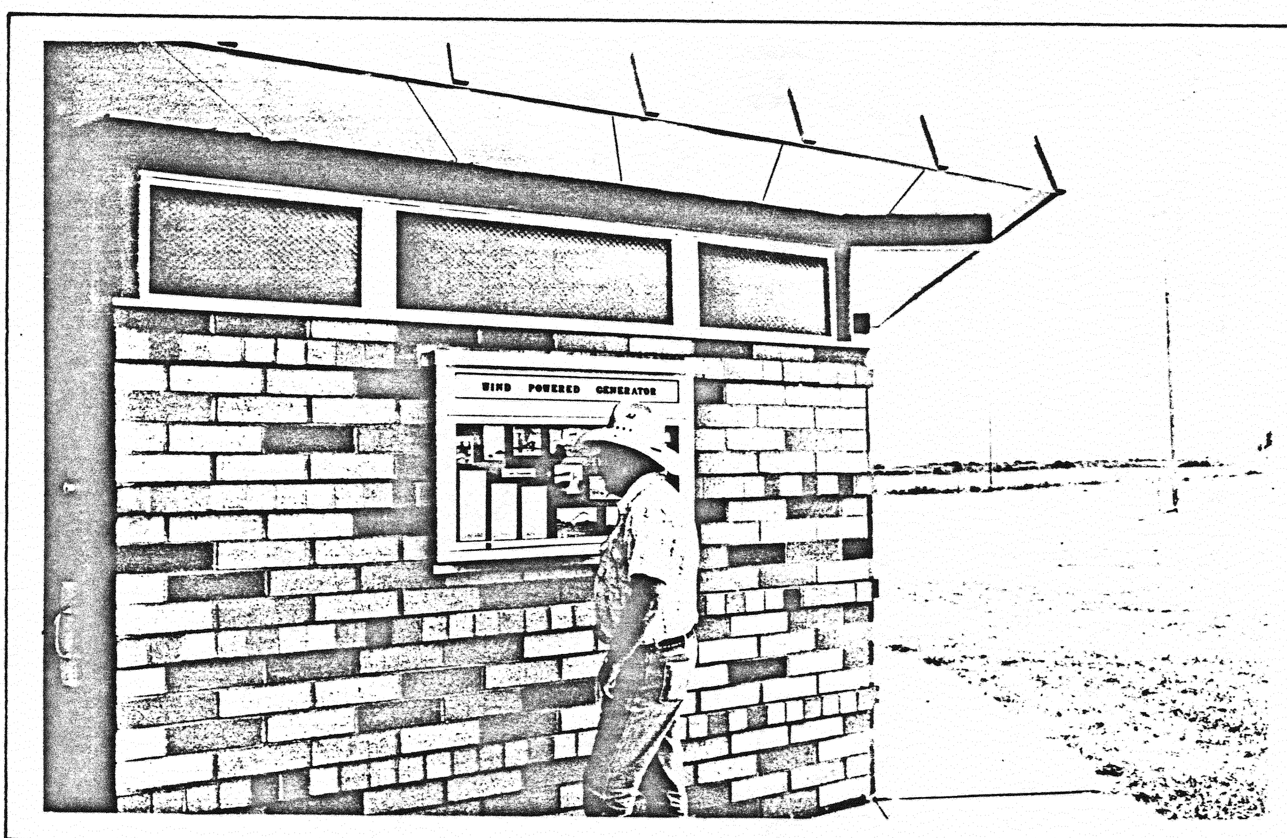


Figure 7b. Typical Visitor Interest in Display Panel

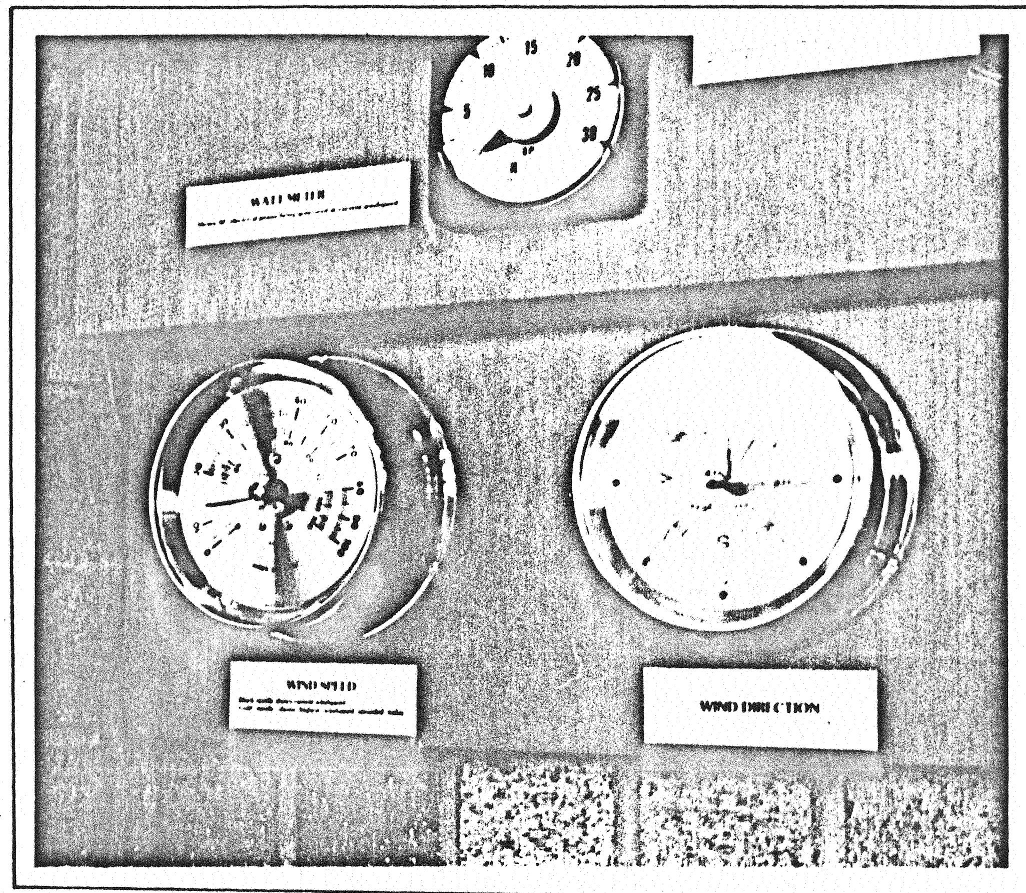


Figure 8a. Inside Display at Erick Site Showing Wind Speed, Wind Direction and Instantaneous Windpower Output.

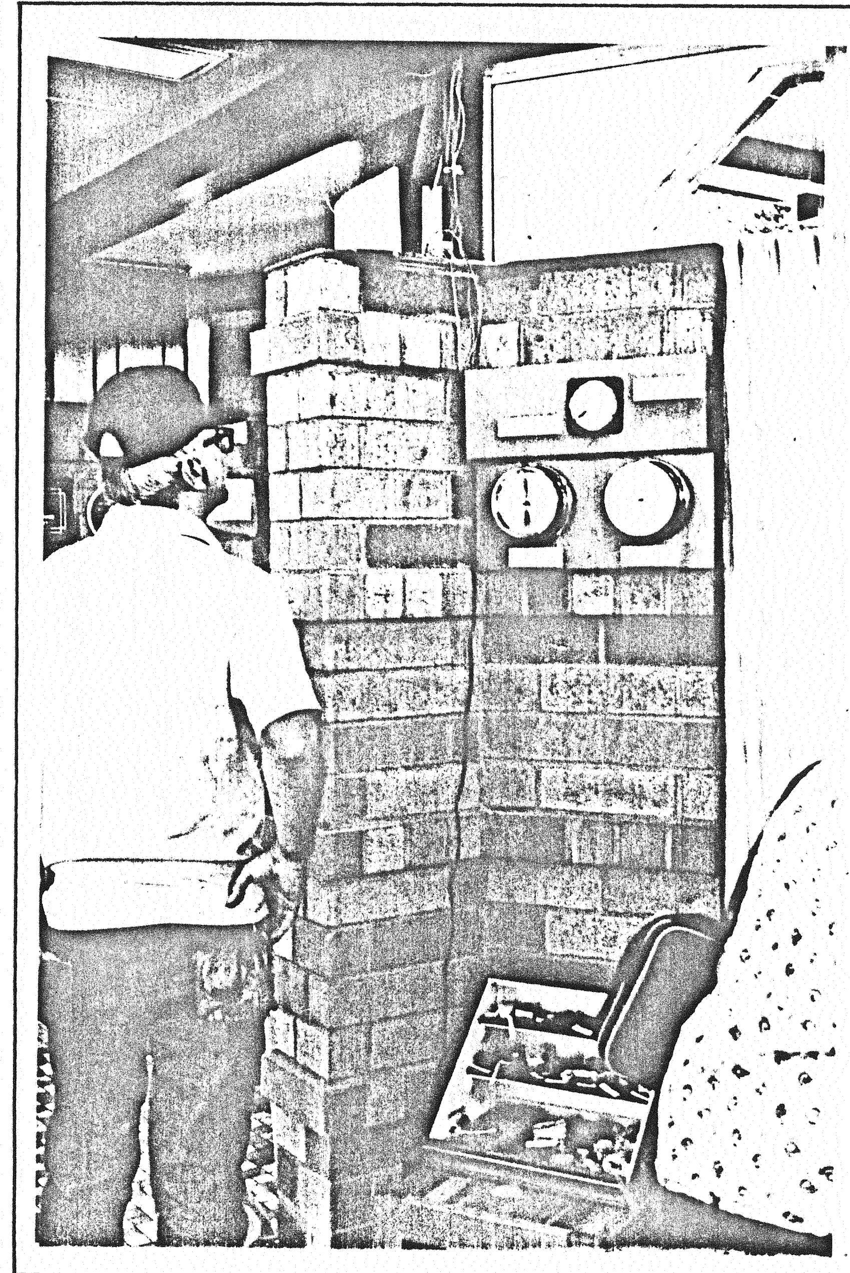


Figure 8b. Location of Inside Display Near Information Desk

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the Windpower Demonstration Project described in this report, the following Conclusions and Recommendations are presented:

CONCLUSIONS

1. Although the availability of the windpower generator was a commendable 94.5%, the capacity factor (the ratio of the actual output to the theoretical maximum output) was only 13.7%, much lower than the expected 25%.
2. A major reason for the low output was the very low average wind speed measured at the Erick site, approximately 25% less than had been predicted from long-term climatological data.
3. The output of the windpower was consistent with its power curve and the measured average wind speed.
4. The anemometry data are not adequate to establish whether the lower-than-expected average wind speed was due to site-specific terrain effects, a short term anomaly limited to the test period, or a long term trend toward lower average wind speeds than those previously recorded in western Oklahoma.
5. The sensitivity of power production to variations in average wind speed emphasizes the importance of accurate wind data when estimating the economic benefit of windpower generators at specific locations.
6. The Oklahoma Department of Transportation presently believes that

windpower generators are not a cost effective source of electric power for government agencies that cannot benefit from available tax credits.

RECOMMENDATIONS

1. Continue to monitor wind velocity, power production, availability and maintenance costs for the wind system at the Erick site. Factor the results into payback analyses for residential, business, and government users.
2. Broaden the scope of the wind monitoring program by installing anemometry equipment at other sites in western Oklahoma.
3. Compare the economics of windpower with those for the solar thermal systems installed and monitored at Yukon and Clinton.
4. Insulate the facilities at Erick to reduce the very high electric loads during the summer and winter temperature extremes. Compare electric consumption before and after insulation.

REFERENCES

1. Local Climatological Data-Annual Summary with Comparative Data, Oklahoma City, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1971.

2. Ibid., 1979.

3. Monthly and Annual Wind Distribution of Pasquill Stability Classes, January 1970 - December 1974, U.S. Department of Commerce, NOAA, Env. Data Service Asheville, NC, 1975.

4. Surface Winds, August 1946 - December 1951, Oklahoma City Will Rogers Airport Air Weather Service, Data Control Unit, New Orleans, LA.

APPENDIX A

DESCRIPTION OF
CARTER WINDPOWER GENERATOR

DESCRIPTION OF CARTER WINDPOWER GENERATOR

The windpower generator installed at the Erick Information Center site is manufactured by J. Carter Enterprises, Inc. in Burkburnett, TX. Its output is 20 kw in a 25 mph wind.

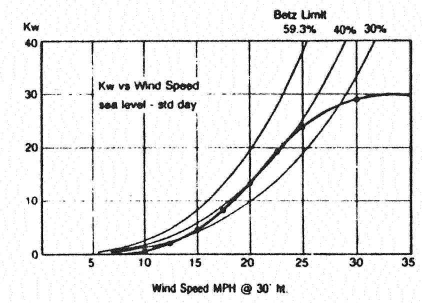
The following specifications describe the construction and performance of the Carter 25 windpower generator.

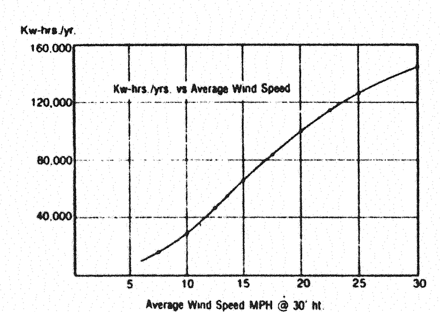
RATED OUTPUT:	20 kw @ a rated windspeed of 25 mph
OUTPUT VOLTAGE:	22 v, 60-cycle, single-phase
ROTOR DIAMETER:	32 ft
NUMBER OF BLADES:	2 (downwind)
BLADE CONSTRUCTION:	Fiberglas and PVC foam. The blade spar is a continuous filament-wound unidirectional glass structure.
STARTUP WINDSPEED:	7.5 mph
SURVIVAL WINDSPEED:	125 mph
HIGH-WIND PROTECTION:	Blade pitch/stall overspeed protection and out-of-plane blade flexibility. Disc brake for out-of-balance control.
GENERATOR:	Induction generator energized by the utility power connection.
TOWER:	Single 56-ft galvanized pole restrained by four guy wires.
SERVICE LIFE:	25-30 years
PRICE:	$22,000 $26,800 installed

MODEL 25 SPECIFICATIONS

Output

Minimum output - 7½ mph wind
Rated output - 25 kw in 26 mph wind
Max. output - 30 kw in approx. 30-40 mph wind





Voltage and current type

220 or 440 volt 60 cycle single or 3-phase AC current

Storage system

None except tie in with utility line

Power generation

Electric induction generator with control system so that excess power can be sold back to utility company

Rotor Diameter

32 feet

Blade chord

13 inches at tip, 42 inches at root

Tower

60 feet high galvanized pole supported with four guy wires, capable of being erected and serviced without a crane.

Yaw Control

Free yaw with dampening. A passive system requiring no yaw servo system or devices for monitoring and evaluating wind direction and then controlling servo system.

Overload control

Blades automatically stall in high winds to prevent overload on generator, but still generate electricity in winds of 100 mph. A passive system requiring no pitch change servo, pitch change bearings, monitoring equipment to determine operator rpm, wind speed or Kw output.

Overspeed control

Inherent design characteristics of spar and blade cause the blade to pitch up and stall in an overspeed condition to limit maximum rpm. If the overspeed was due to the utility line being down, which causes the generator to turn off, then the generator will automatically reset and come back on when power is restored to the line. This passive control also does not require a servo system that has a battery backup or a pressure accumulator, so the pitch can be changed in the event of a loss of utility line power. It requires no monitoring equipment to determine if the rotor is in an overspeed.

High wind protection

Extreme flexibility and high strength of spar enables blades to cone to 45 degrees and unload itself in a non-rotating condition in winds of 125 mph.

Out of balance control

System has a 100% mechanical control which operates a powerful disc brake capable of stopping the rotor in any wind under any rpm condition should out of balance forces ever become too high. The generator can also be manually stopped from the ground.

Blade construction

Blade is made primarily from fiberglass and PVC foam. The spar is a continuous filament wound unidirectional glass structure with a 25 to 1 safety factor.

Gear box

The gear box has double reduction gears and is made from Tenzaloy aluminum alloy with cast in place steel inserts for bearing supports. The gears are helical and hardened to insure the ultimate in long life and quietness.

Specification may be changed without notice.

Multiple Patents Pending.

GUARANTEE

The Carter Wind Generator Model 25 carries an unconditional guarantee for one year after date of installation covering materials, and workmanship. Guarantee does not cover abuse, misuse, vandalism or acts of God. Acts of God include hurricanes, tornadoes, lightning, winds in excess of 100 mph and hail greater than ½ inch diameter.

Figure A-1. Carter Model 25 Specifications

APPENDIX B

DESCRIPTION OF DATA LOGGERS FOR RECORDING WIND RESOURCE INFORMATION

DESCRIPTION OF DATA LOGGERS

The AL-2000 and AL-2002 data loggers installed at Erick and Norman, respectively, are manufactured by Second Wind, Inc. in Somerville, MA. The following specifications describe the operation of the data loggers.

NUMBER OF SENSORS:	AL-2000: One pair - one anemometer one direction vane
	AL-2002: Two pair - two anemometers two direction vanes
WINDSPEED	
Range:	0 to 255.5 mph
Accuracy:	+ 0.5, - 0 mph
WIND DIRECTION	
Accuracy:	2°
Compass Points:	8
DATA STORAGE:	AL-2000: 2516/2716 EPROM AL-2002: 2532 EPROM 13 months data storage
TIME KEEPING:	Daylight savings correction user selectable. Non-Julian calender.
BATTERY LIFE:	AL-2000: One year AL-2002: Nine months
ANEMOMETER SENSOR:	Maximum, Inc. Model 40, three-cup
WIND-DIRECTION SENSOR:	Downeaster Mfg. Co. Model TRX-WD potentiometer type

FUNCTIONS

Velocity Distribution:	Two-mph intervals subdivided into total, "fast", "medium", and "slow" yaw rates.
Wind Rose:	Four windspeed ranges per compass point (6-12, 12-18, 18-24, > 24)
Diurnal Distribution:	One average windspeed and standard deviation per 2-hour period.
Peak Windspeed:	Records speed and time of occurrence (day, hour, minute) for each month. Updated every 2 seconds.
Lull:	Moving average updated every minute. End of lull occurs when average > 6 mph. Records maximum lull duration and time lull ends (day, hour, minute) for each month.

PRICE:

AL-2000: $1,350.00
AL-2002: $2,150.00

AL-2000 DATA COLLECTION SHEET

SITE:______________________ RECORDED BY:______________________

TODAYS DATE:___/___/___ DATA FOR MONTH OF:______________, YEAR:__________

(use other side for comments)

I) PEAK/LULL:

PEAK WIND SPEED WAS ________ MPH, OCCURRING AT ________/________/________

LONGEST LULL WAS ________ HOURS LONG, ENDING AT ________/________/________

day hour minute

II) VELOCITY DISTRIBUTIONS: (in hours)

RANGE: (MPH) 00-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38->>
TOTAL:																	
SLOW ΔØ/Δt:																	
MED. ΔØ/Δt:																	
FAST ΔØ/Δt:																	

III) WIND ROSE: (in hours)

RANGE: (MPH)	06-12	12-18	18-24	24->>
NORTH:				
NOREAST:				
EAST:				
SOUEAST:				
SOUTH:				
SOUWEST:				
WEST:				
NORWEST:				

IV) DIURNAL: (in MPH)

TIME: (O'CLOCK)	00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22
AVERAGE:												
STD. DEV.												

Figure B-1. AL 2000 Data Collection Sheet

APPENDIX C

TYPICAL ANEMOMETER
DATA SHEETS

TYPICAL ANEMOMETER DATA SHEETS

The data recorded in the AL 2000/2002 memory chips may be collected either by writing the data from the front panel onto a data collection sheet or by mailing the memory chip to the manufacturer for a print-out of the data.

For the purposes of this program, it was generally more convenient to collect the data manually. Although this was done for a majority of the data points, the battery failures made direct readout impossible after the failure had occurred. On those occasions, the chips were sent back to Second Wind for readout.

Typical anemometer data sheets are shown for both the print-out and manual methods for recording the anemometry data.

AI-2000 DATA COLLECTION SHEET

SITE: ERICK-UPPER RECORDED BY: KC, KB, TN

TODAYS DATE: 8/26/83 DATA FOR MONTH OF: JUNE, YEAR: 1983

(use other side for comments)

I) PEAK/LULL:

PEAK WIND SPEED WAS 50.0 MPH, OCCURRING AT 27 / 22 / 59

LONGEST LULL WAS 19 HOURS LONG, ENDING AT 24 / 15 / 22 (day / hour / minute)

II) VELOCITY DISTRIBUTIONS: (in hours)

RANGE: (MPH)	00-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38->>
TOTAL:	186	93	91	86	74	61	47	33	21	13	7	4	2	1	0	0	0	0
SLOW ΔΦ/Δt:	90	88	82	70	57	44	31	20	12	7	4	2	1	0	0	0		
MED. ΔΦ/Δt:	2	3	3	3	3	3	2	1	1	0	0	0	0	0	0	0		
FAST ΔΦ/Δt:	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0		

III) WIND ROSE: (in hours:)

RANGE: (MPH)	06-12	12-18	18-24	24->>
NORTH:	27	21	4	1
NOREAST:	27	11	2	0
EAST:	51	16	4	1
SOUEAST:	53	51	26	7
SOUTH:	45	43	20	4
SOUWEST:	38	29	11	2
WEST:	8	1	0	0
NORWEST:	20	9	1	0

S.E. + S

IV) DIURNAL: (in MPH) 10.09 mph average

TIME: (O'CLOCK)	00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-
AVERAGE:	9.1	7.4	6.8	6.8	9.1	11.1	11.5	11.9	12.6	12.8	11.1	10.
STD. DEV.	5.0	4.5	4.0	4.0	5.0	5.0	5.0	5.0	4.5	4.5	5.5	5.

Figure C-1. Wind Data Collection Sheet - Manual Readout, June, 1983

AL-2000 DATA COLLECTION SHEET

SITE: ERICK-UPPER RECORDED BY: KC, KB, TN

TODAYS DATE: 8/26/83 DATA FOR MONTH OF: JULY, YEAR: 1983

(use other side for comments)

I) PEAK/LULL:

PEAK WIND SPEED WAS 54 MPH, OCCURRING AT 1 / 20 / 18

LONGEST LULL WAS 12 HOURS LONG, ENDING AT 31 / 15 / 48
(day / hour / minute)

II) VELOCITY DISTRIBUTIONS: (in hours)

RANGE: (MPH)	00-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38->>
TOTAL:	163	92	102	100	90	70	49	31	20	12	7	4	2	1	0	0	0	0
SLOW ΔΦ/Δt:		89	97	95	84	66	46	30	19	12	7	4	2	1	0	0	0	
MED. ΔΦ/Δt:		2	4	5	5	4	2	2	1	1	0	0	0	0	0	0	0	
FAST ΔΦ/Δt:		1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	

III) WIND ROSE: (in hours:)

RANGE: (MPH)	06-12	12-18	18-24	24->>
NORTH:	5	1	1	0
NOREAST:	13	4	3	1
EAST:	48	29	5	1
SOUEAST:	84	68	18	3
SOUTH:	65	51	18	4
SOUWEST:	61	49	19	5
WEST:	13	4	0	0
NORWEST:	6	1	0	0

S.E. + S

IV) DIURNAL: (in MPH) 10.49 mph average

TIME: (O'CLOCK)	00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-
AVERAGE:	10.9	8.5	6.9	6.0	9.4	10.9	10.9	12.4	13.4	13.4	12.2	11.0
STD. DEV.	4.0	4.0	3.5	3.5	4.5	5.0	5.0	5.5	5.0	4.0	4.5	4.0

Figure C-2. Wind Data Collection Sheet - Manual Readout, July, 1983.

AE-2000 DATA COLLECTION SHEET

SITE: FRICK - UPPER RECORDED BY: KC, KB, TN

TODAYS DATE: 8/26/83 DATA FOR MONTH OF: AUG, YEAR: 1983

(use other side for comments)

I) PEAK/LULL:

PEAK WIND SPEED WAS 37.5 MPH, OCCURRING AT 14 / 18 / 05

LONGEST LULL WAS 20 HOURS LONG, ENDING AT 14 / 16 / 58
(day / hour / minute)

II) VELOCITY DISTRIBUTIONS: (in hours)

RANGE: (MPH)	00-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38->>
TOTAL:	255	110	79	56	38	24	15	8	4	2	1	0	0	0	0	0	0	
SLOW ΔΦ/Δt:	105	74	52	36	23	14	7	4	2	1	0	0	0	0	0	0		
MED. ΔΦ/Δt:	3	3	3	2	1	1	0	0	0	0	0	0	0	0	0	0		
FAST ΔΦ/Δt:	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0		

III) WIND ROSE: (in hours:)

RANGE: (MPH)	06-12	12-18	18-24	24->>
NORTH:	5	1	0	0
NOREAST:	20	5	1	0
EAST:	69	20	2	0
SOUEAST:	66	25	6	1
SOUTH:	43	13	3	0
SOUWEST:	33	11	2	0
WEST:	7	1	0	0
NORWEST:	1	0	0	0

S.E.

IV) DIURNAL: (in MPH) 6.94 mph average

TIME: (O'CLOCK)	00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
AVERAGE:	6.4	5.0	4.1	3.6	5.5	6.4	7.1	9.0	10.0	10.1	7.9	8.2
STD. DEV.	3.5	3.0	2.0	2.5	3.5	3.5	3.0	3.5	3.0	3.5	3.5	4.5

Figure C-3. Wind Data Collection Sheet - Manual Readout, August, 1985

SITING DATA FOR: Ken Craig, University of Oklahoma

SITING LOCATION: Site "U"

DATA FOR MONTH 6/1982 FOR SENSOR A

PEAK WIND SPEED OF: 51.5 MPH ON DAY 11 AT 1:50

LONGEST ENERGY LULL OF 33 HOURS ENDING ON DAY 29 AT 10:18

VELOCITY DISTRIBUTIONS FOR THIS MONTH: (HOURS)

RANGE: (MPH)	00-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	>>38
TOTAL:	255	107	95	79	61	45	30	18	11	7	4	2	1	1	0	0	0	0
SLOW D0/DT:		106	95	78	60	44	30	18	11	7	4	2	1	1	0	0	0	
MEDIUM D0/DT:		1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
FAST D0/DT:		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Note: '255' represents an overflow.

WIND ROSE DATA: (HOURS)

RANGE: (MPH)	06-12	12-18	18-24	>>24
NORTH:	54	20	5	1
NOREAST:	37	13	2	0
EAST:	47	12	1	0
SOUEAST:	70	52	17	3
SOUTH:	32	24	8	2
SOUWEST:	13	5	1	0
WEST:	7	2	1	1
NORWEST:	23	7	2	1

DIURNAL DATA: (MPH)

TIME: (O:CLOCK)	00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
AVERAGE:	8.375	6.375	6.125	6.125	8.000	9.250	9.875	10.125	10.375	9.875	8.125	8.875
STANDARD DEVIATION:	4.5	3.5	3.5	3.5	4.0	4.5	5.0	5.0	4.5	5.0	4.5	5.0

MONTHLY AVERAGE WINDSPEED: 8.46 MPH

Second Wind Inc.
7 Davis Square
Somerville Massachusetts 02144
(617) 776-8520

Figure C-4. Wind Data Collection Sheet - Automatic Printout, June, 1982

SITING DATA FOR: Ken Craig, University of Oklahoma

SITING LOCATION: Site "U"

DATA FOR MONTH 7/1982 FOR SENSOR A

PEAK WIND SPEED OF: 45.5 MPH ON DAY 10 AT 2:21

LONGEST ENERGY LULL OF 29 HOURS ENDING ON DAY 31 AT 15:52

VELOCITY DISTRIBUTIONS FOR THIS MONTH: (HOURS)

RANGE: (MPH)	00-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	>>38
TOTAL:	255	102	87	75	65	52	39	27	16	8	4	1	0	0	0	0	0	0
SLOW D0/DT:		101	86	75	65	52	39	27	16	8	4	1	0	0	0	0	0	
MEDIUM D0/DT:		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
FAST D0/DT:		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Note: '255' represents an overflow.

WIND ROSE DATA: (HOURS)

RANGE: (MPH)	06-12	12-18	18-24	>>24
NORTH:	11	1	0	0
NOREAST:	14	3	1	0
EAST:	32	6	0	0
SOUEAST:	120	76	19	1
SOUTH:	57	64	30	3
SOUWEST:	13	4	1	0
WEST:	7	1	0	0
NORWEST:	9	2	0	0

S

DIURNAL DATA: (MPH)

TIME: (O:CLOCK)	00-02	02-04	04-06	06-08	08-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24
AVERAGE:	8.250	6.500	6.125	5.750	8.375	9.375	10.250	10.500	10.750	11.000	8.875	8.750
STANDARD DEVIATION:	4.0	3.0	3.0	3.5	5.0	5.5	4.5	5.5	5.5	5.5	4.5	4.5

MONTHLY AVERAGE WINDSPEED: 8.71 MPH

Second Wind Inc.
7 Davis Square
Somerville Massachusetts 02144
(617) 776-8520

Figure C-5. Wind Data Collection Sheet - Automatic Printout, July, 1982

APPENDIX D

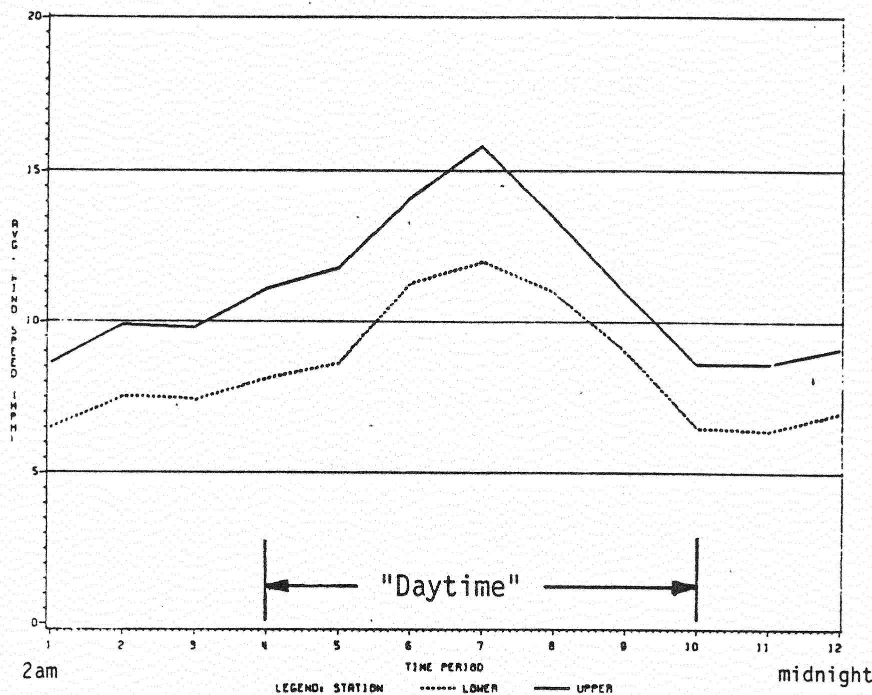
WINDSPEED DISTRIBUTIONS

WINDSPEED DISTRIBUTIONS

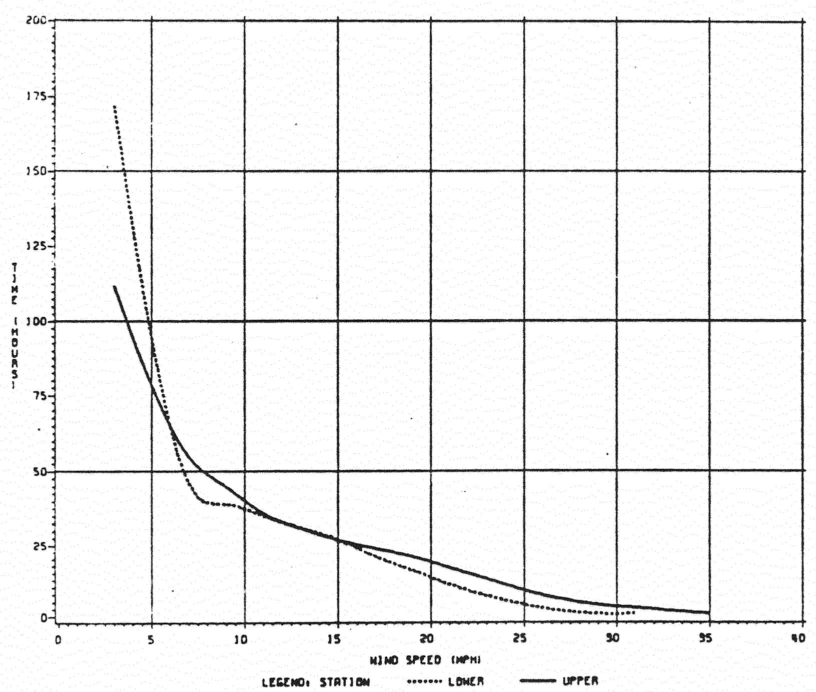
Windspeed distributions are presented in two forms, average diurnal values and histograms of windspeed versus total hours. The latter represents the number of hours during which the windspeed was within each of the velocity distribution "bins" recorded on the AL-2000 Data Collection Sheets (Appendix C).

The time scale for the diurnal values is shown in two hour intervals, with the initial (left hand) value corresponding to 2:00 AM and the final (right hand) value corresponding to midnight. Thus, the abscissa values may be multiplied by two in order to obtain the correct hour on the 24-hour clock.

Because of utility requirements for peak loading, it is sometimes valuable to distinguish between daylight (0800-2000) and night-time (2000-0800) average wind velocities. Figure D1a has been marked to show the daylight period for January, 1982. The average daytime windspeed at the upper station was 13.0 mph, while the average night-time windspeed was 9.0 mph. Based on the kinetic energy in the wind, a function of V^3, the daytime output of the windpower generator could be as much as three times that of the night-time output.

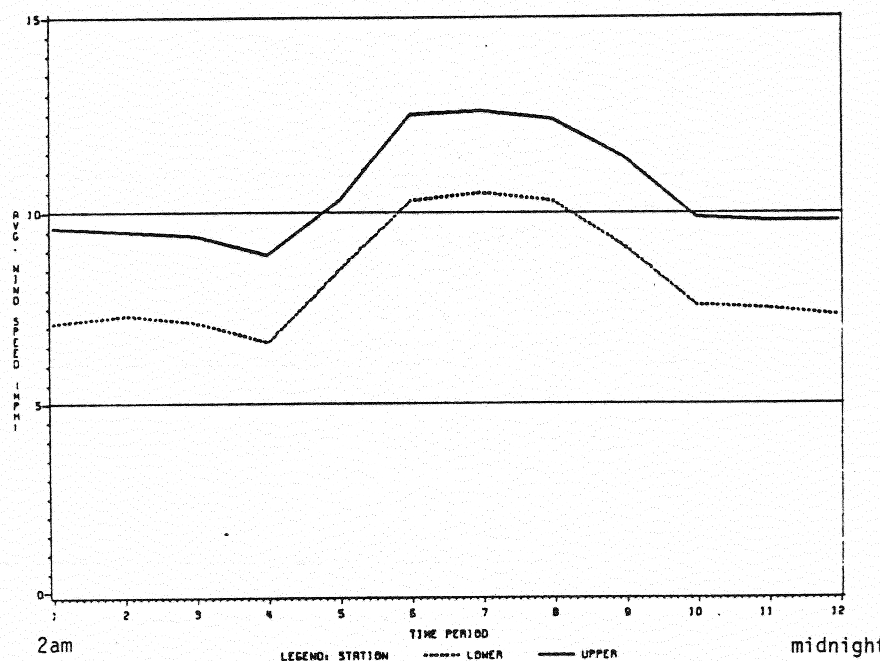


D1a. Diurnal

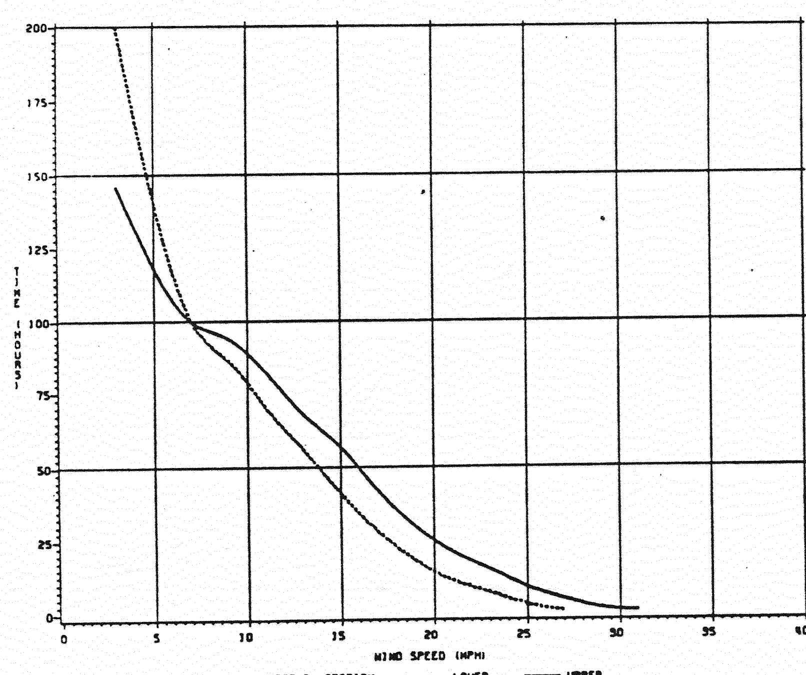


D1b. Histogram

Figure D1. Windspeed Distribution - Erick Site - JANUARY, 1982

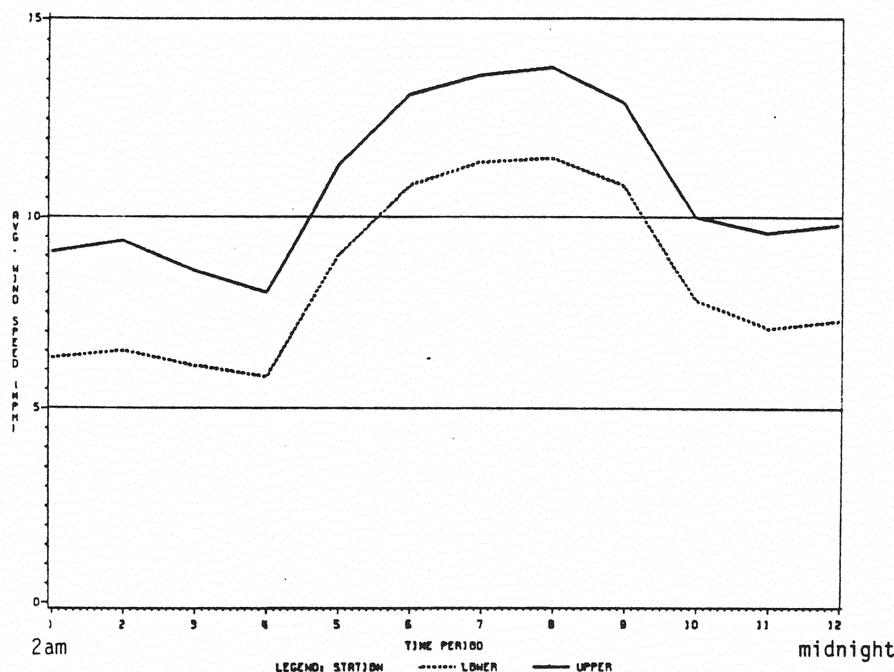


D2a. Diurnal

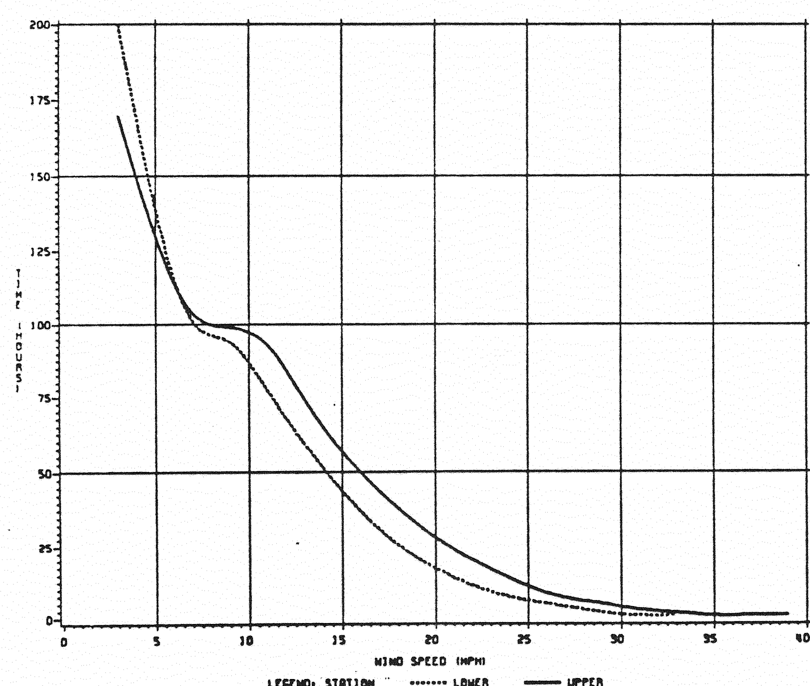


D2b. Histogram

Figure D2. Windspeed Distribution - Erick Site - FEBRUARY, 1982

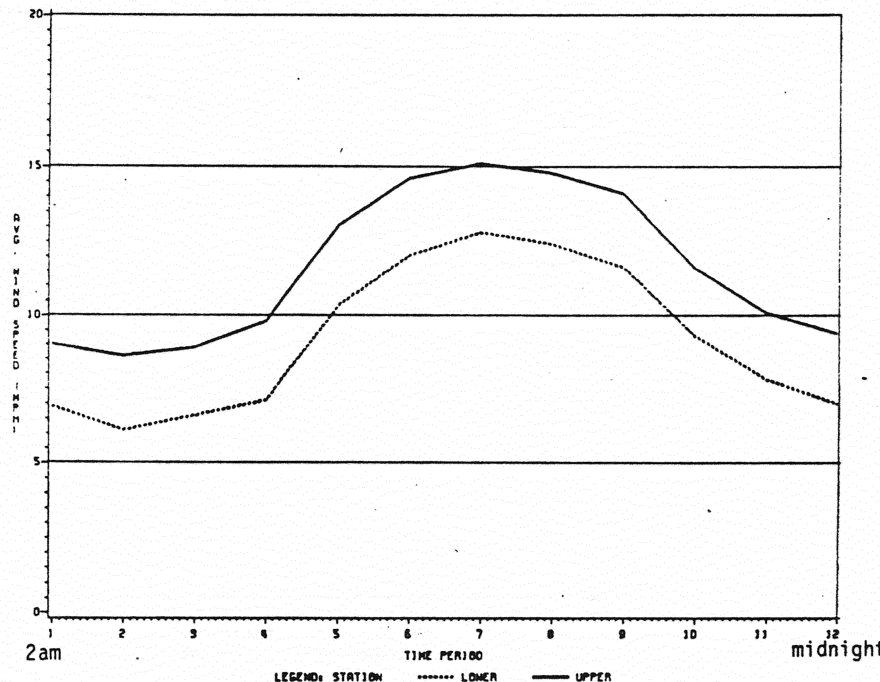


D3a. Diurnal

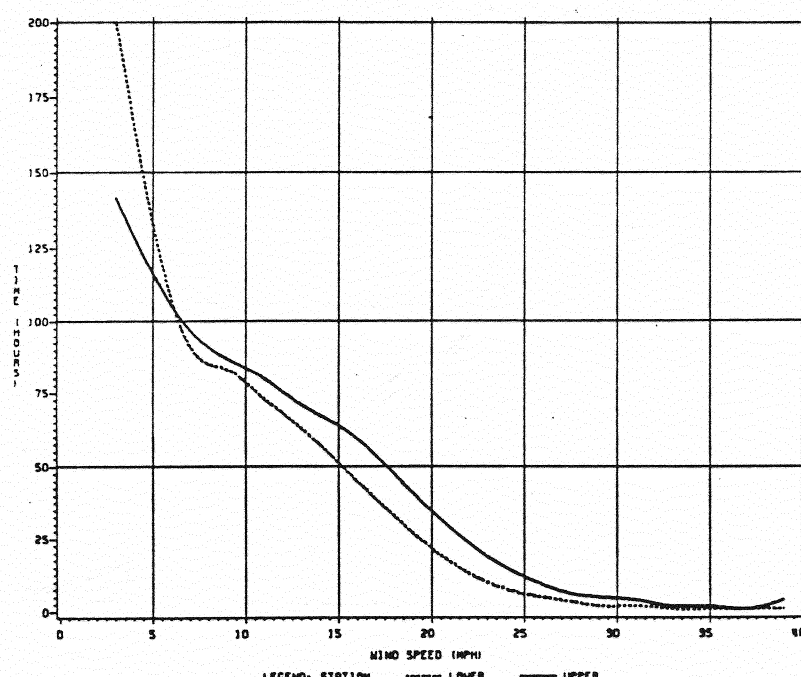


D3b. Histogram

Figure D3. Windspeed Distribution - Erick Site - MARCH, 1982

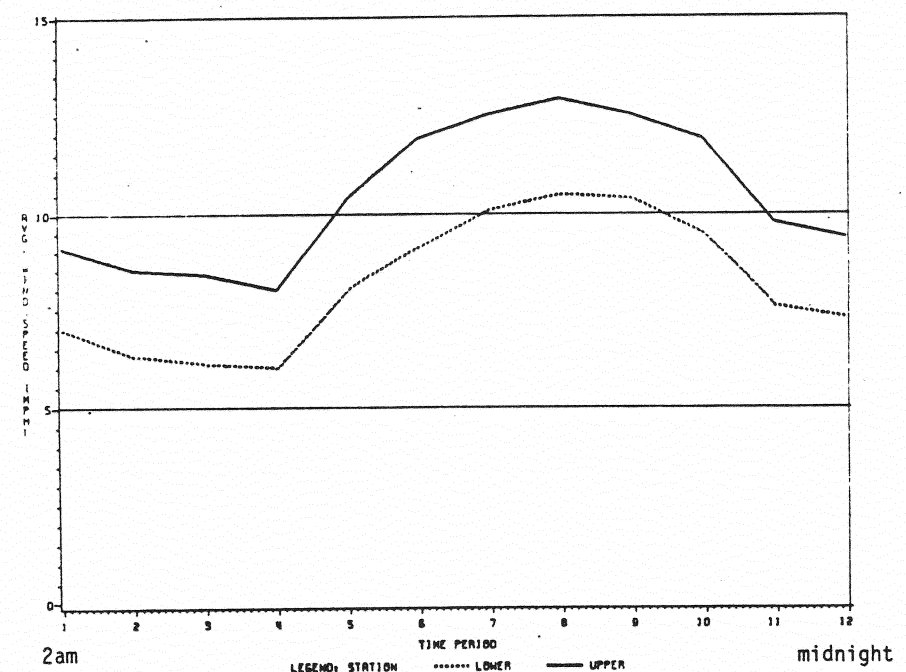


D4a. Diurnal

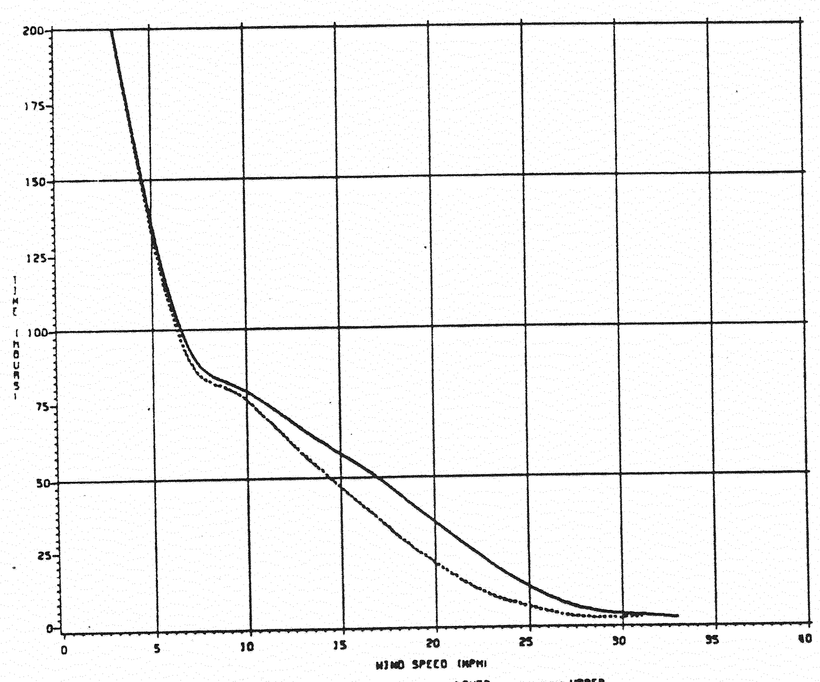


D4b. Histogram

Figure D4. Windspeed Distribution - Erick Site - APRIL, 1982

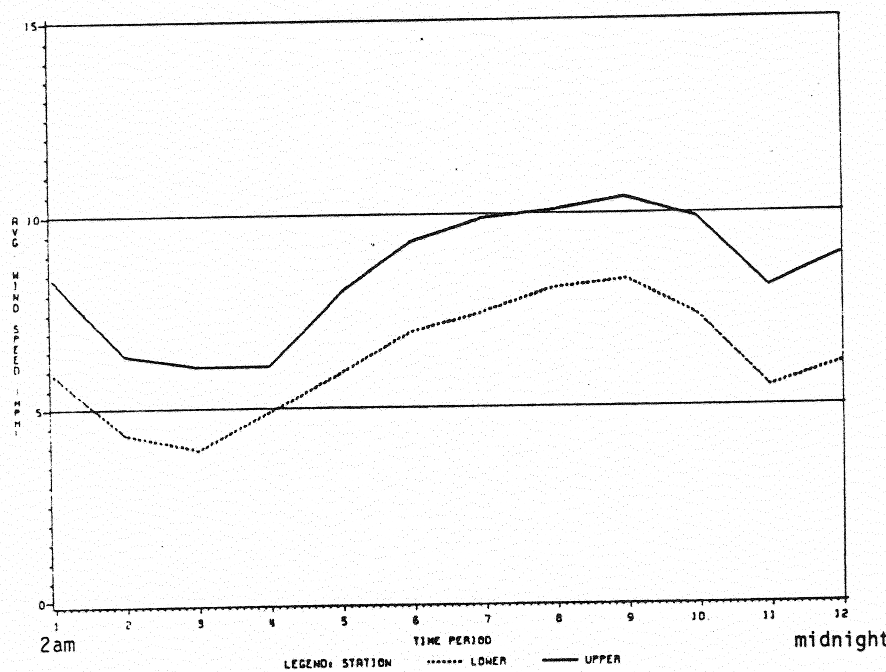


D5a. Diurnal

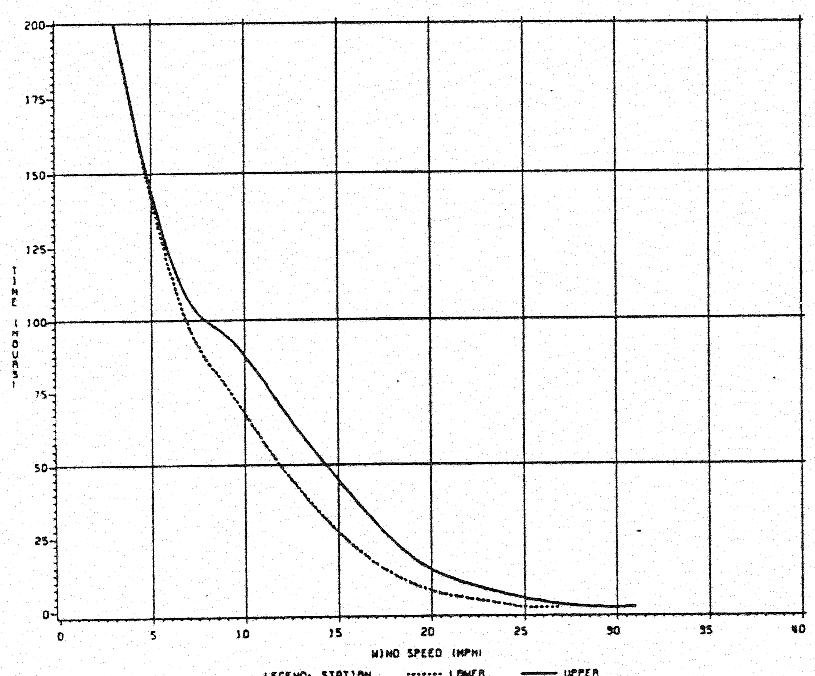


D5b. Histogram

Figure D5. Windspeed Distribution - Erick Site - MAY, 1982

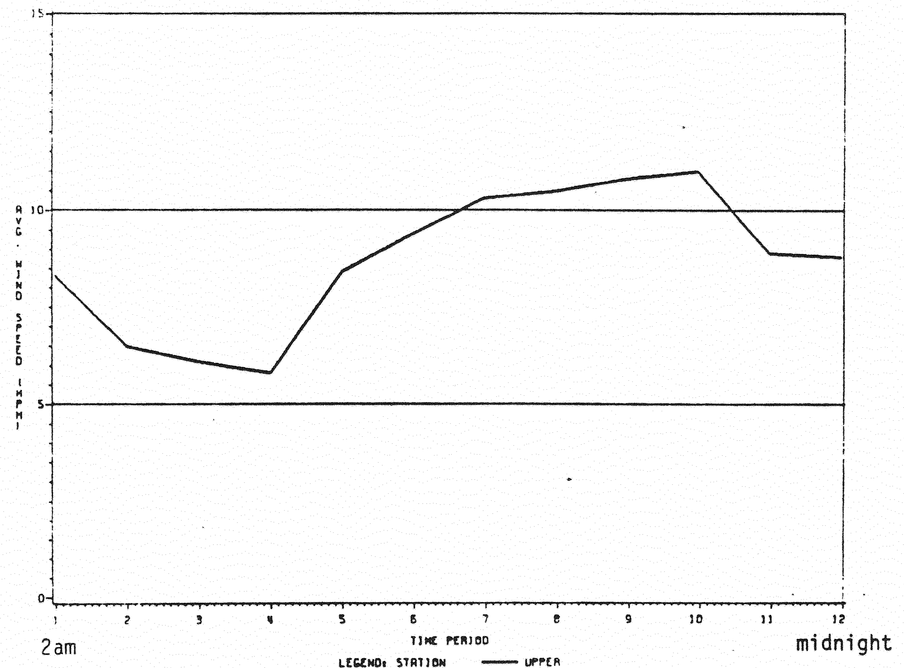


D6a. Diurnal

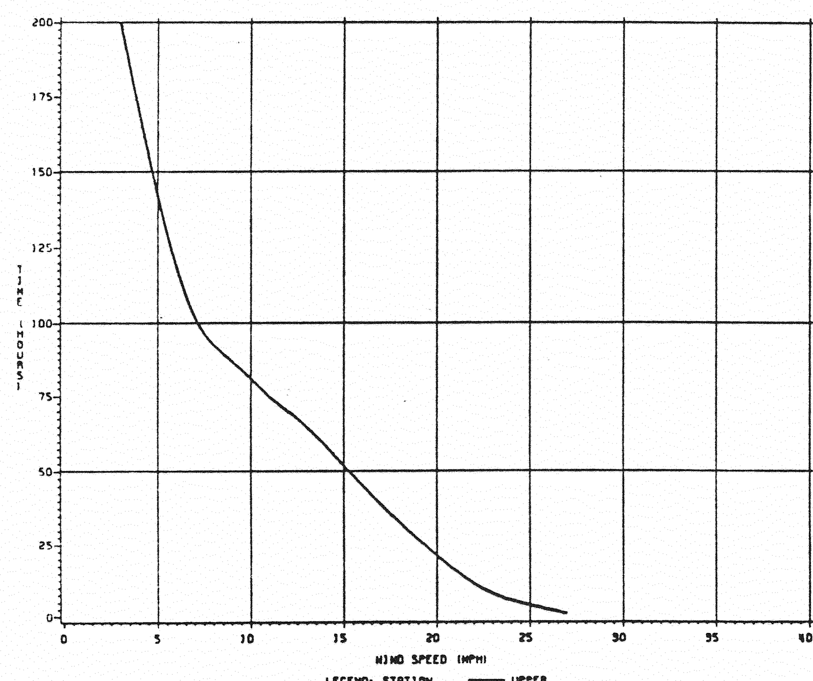


D6b. Histogram

Figure D6. Windspeed Distribution - Erick Site - JUNE, 1982

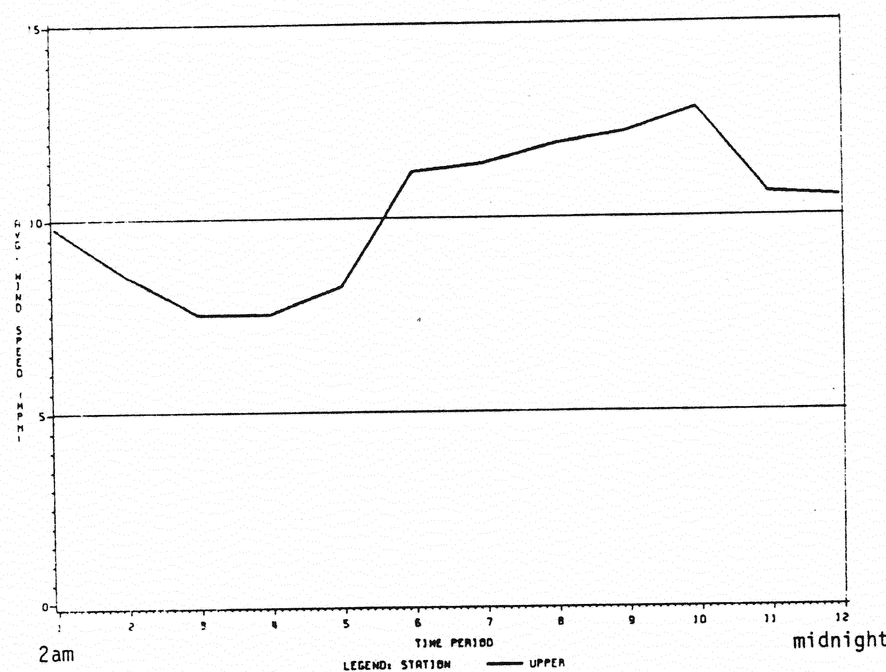


D7a. Diurnal

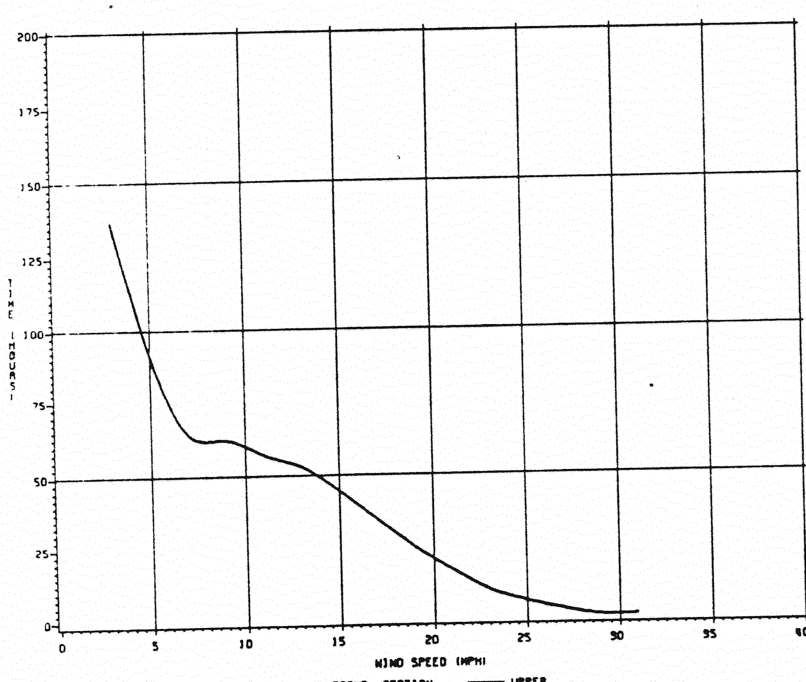


D7b. Histogram

Figure D7. Windspeed Distribution - Erick Site - JULY, 1982

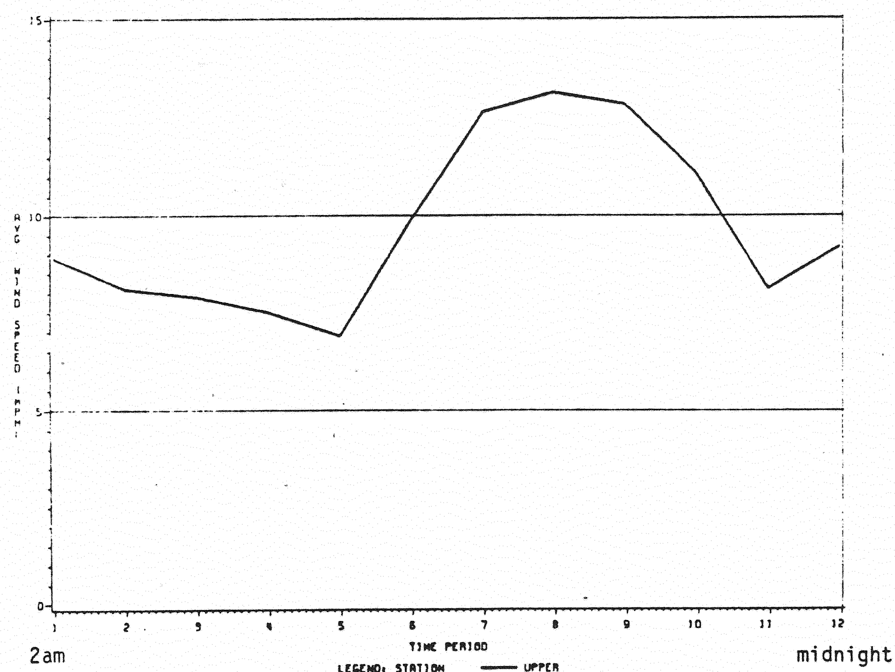


D8a. Diurnal

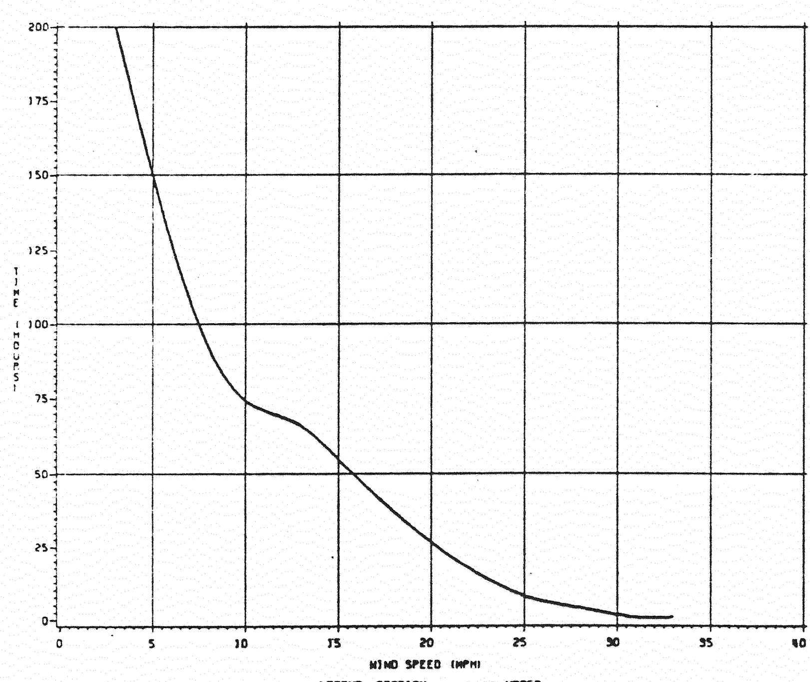


D8b. Histogram

Figure D8. Windspeed Distribution - Erick Site - SEPTEMBER, 1982

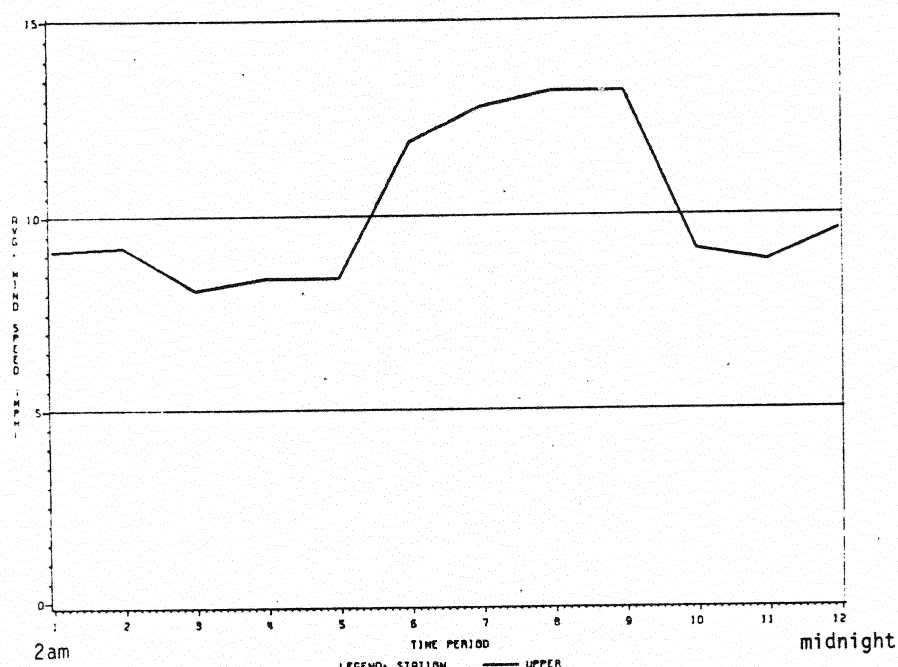


D9a. Diurnal

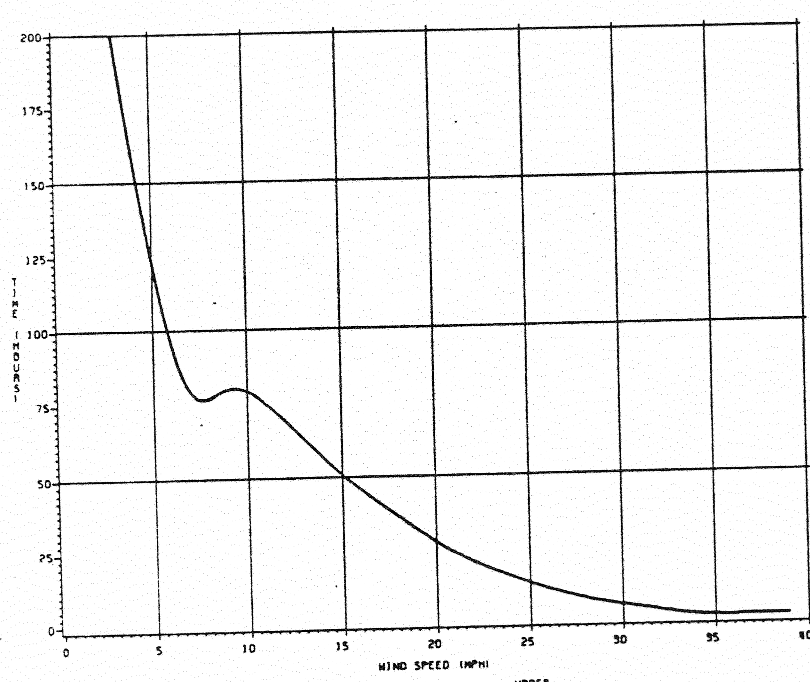


D9b. Histogram

Figure D9. Windspeed Distribution - Erick Site - OCTOBER, 1982

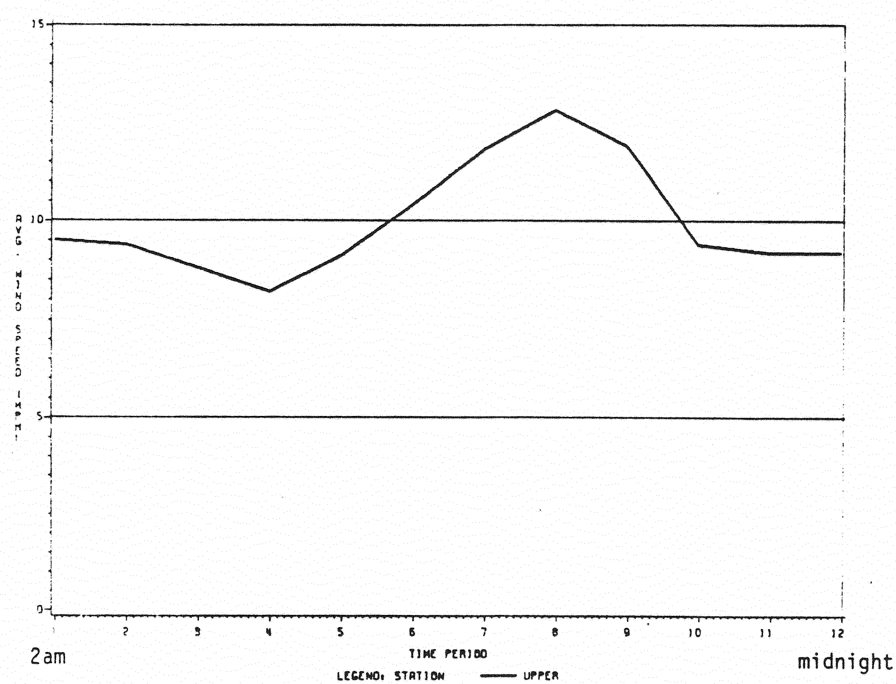


D10a. Diurnal

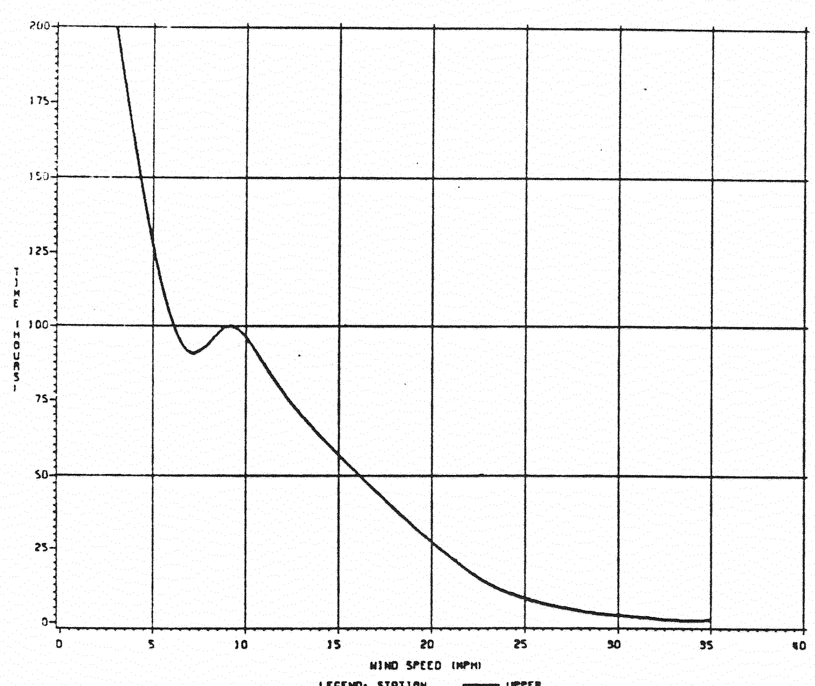


D10b. Histogram

Figure D10. Windspeed Distribution - Erick Site - NOVEMBER,1982

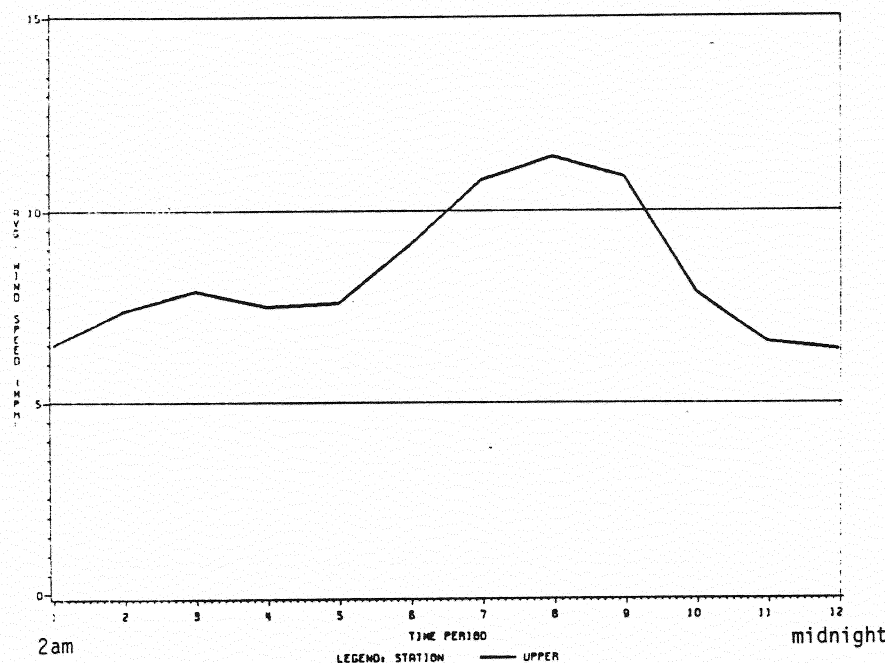


D11a. Diurnal

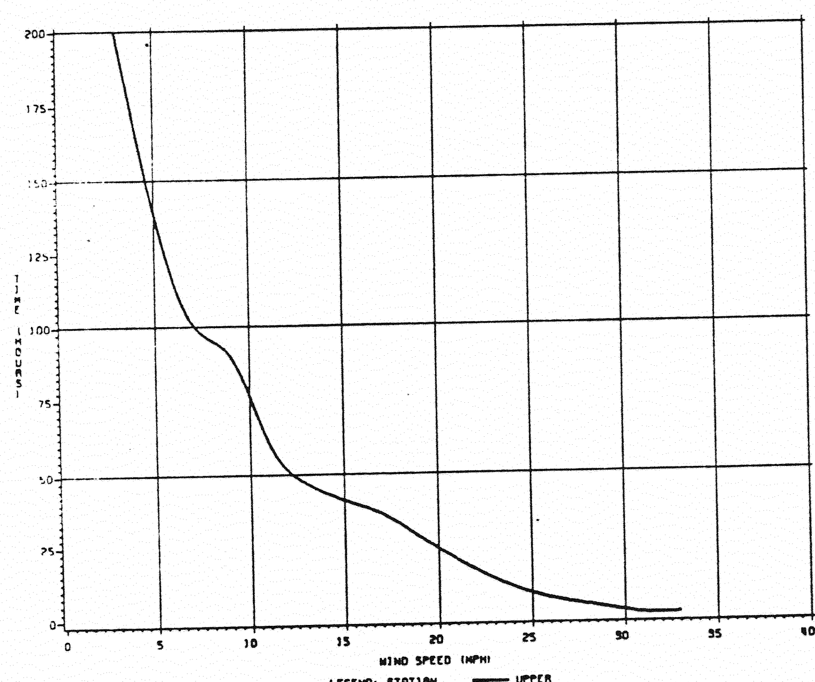


D11b. Histogram

Figure D11. Windspeed Distribution - Erick Site - DECEMBER, 1982

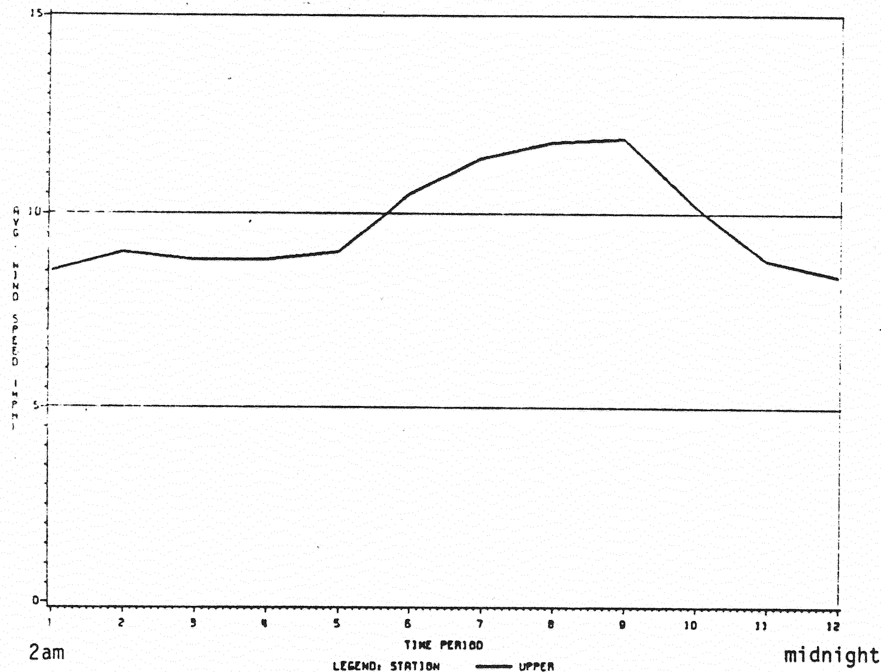


D12a. Diurnal

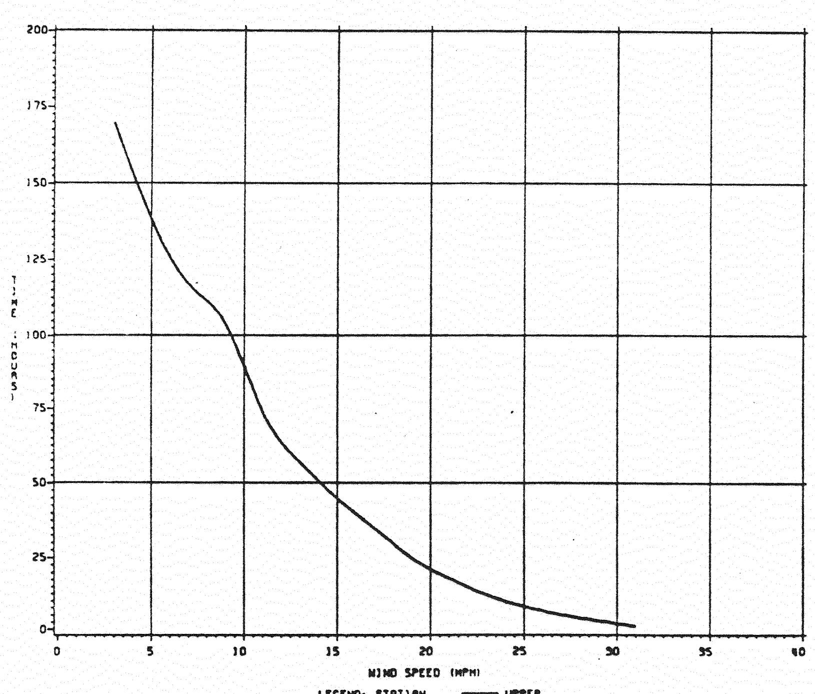


D12b. Histogram

Figure D12. Windspeed Distribution - Erick Site - JANUARY, 1983

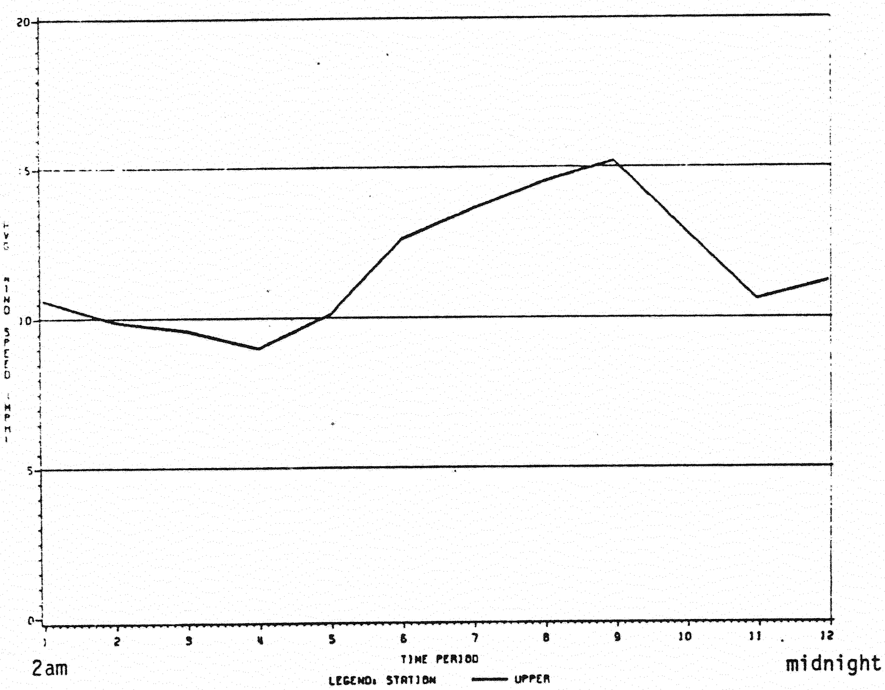


D13a. Diurnal

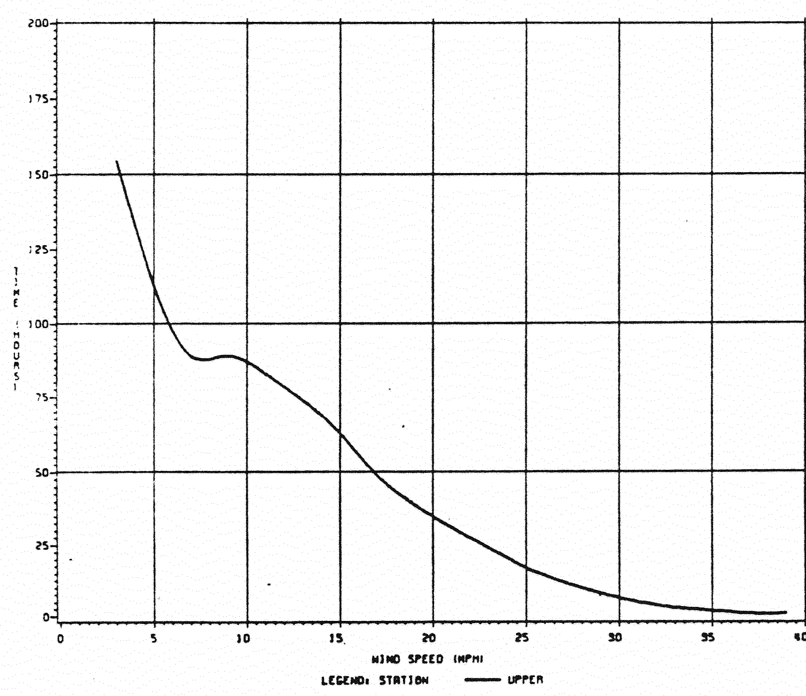


D13b. Histogram

Figure D13. Windspeed Distribution - Erick Site - FEBRUARY, 1983

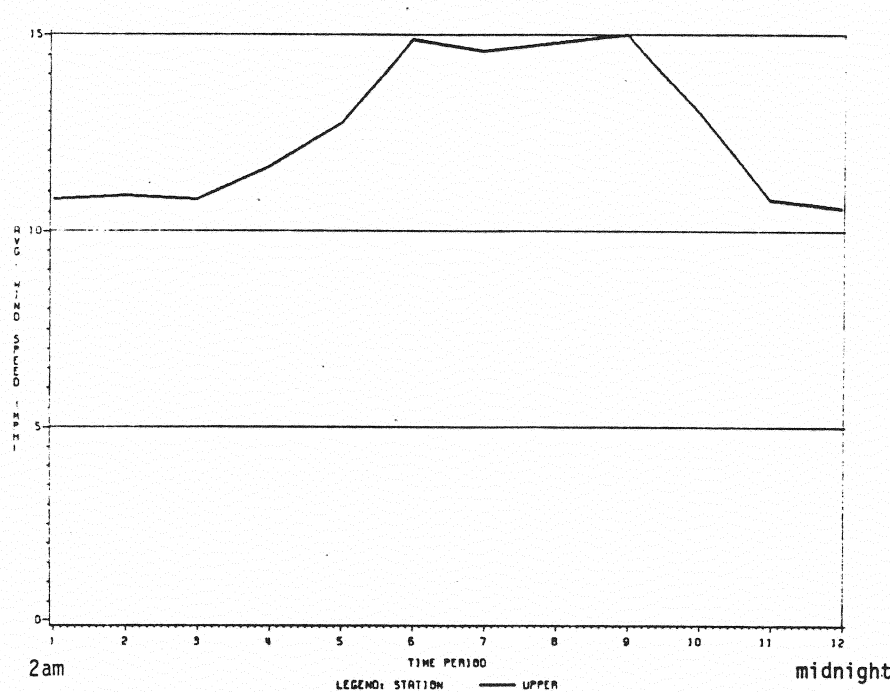


D14a. Diurnal

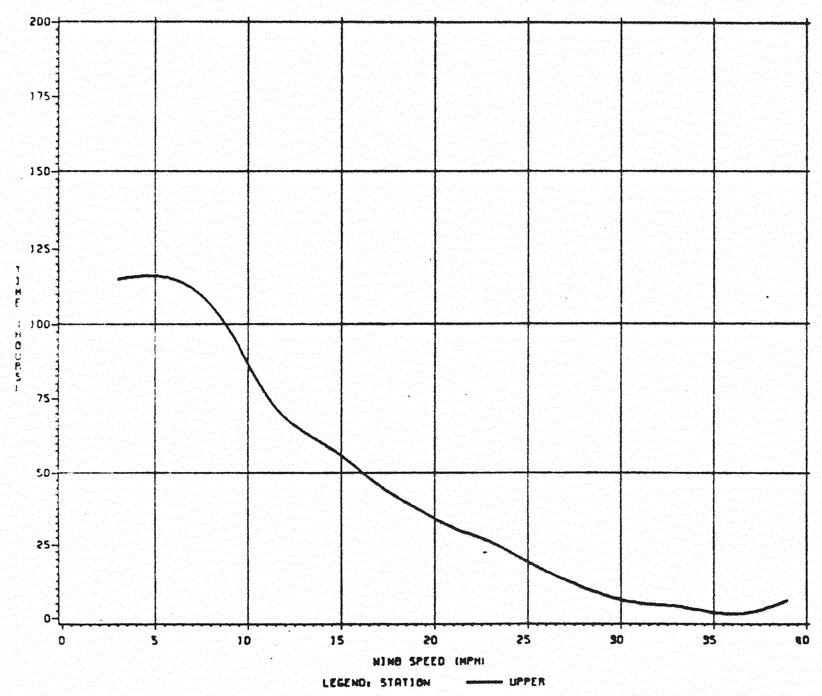


D14b. Histogram

Figure D14. Windspeed Distribution - Erick Site - MARCH, 1983

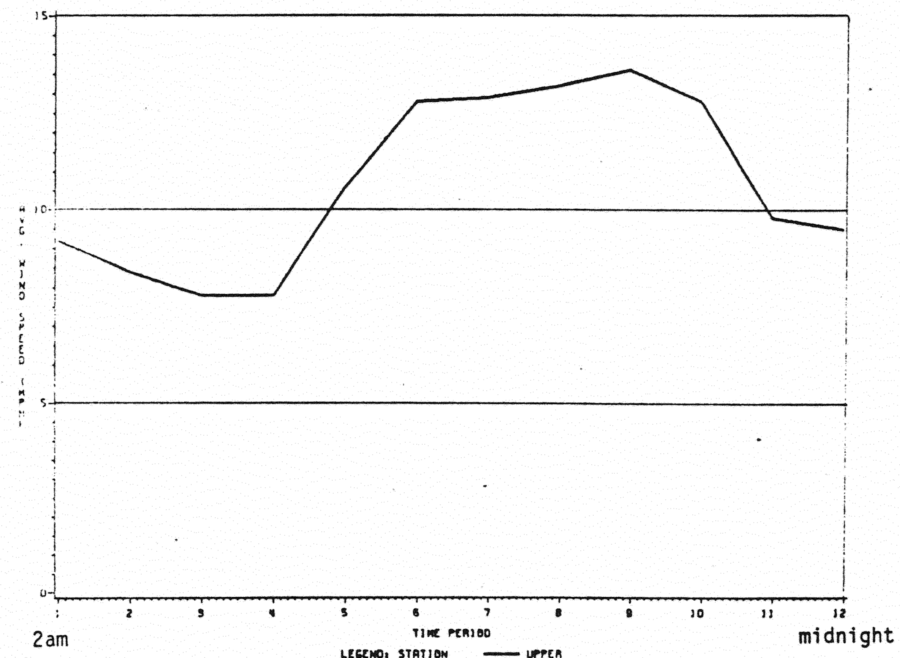


D15a. Diurnal

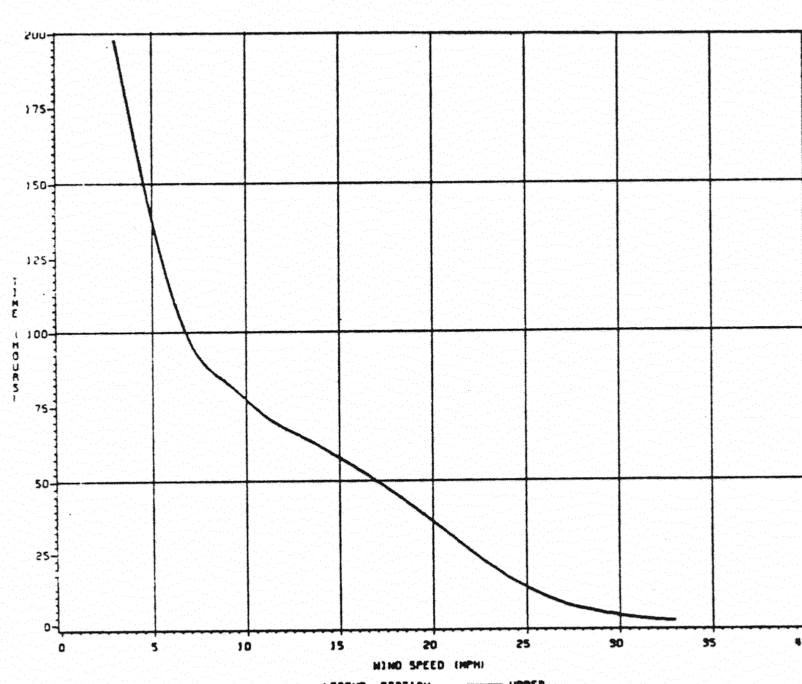


D15b. Histogram

Figure D15. Windspeed Distribution - Erick Site - APRIL, 1983

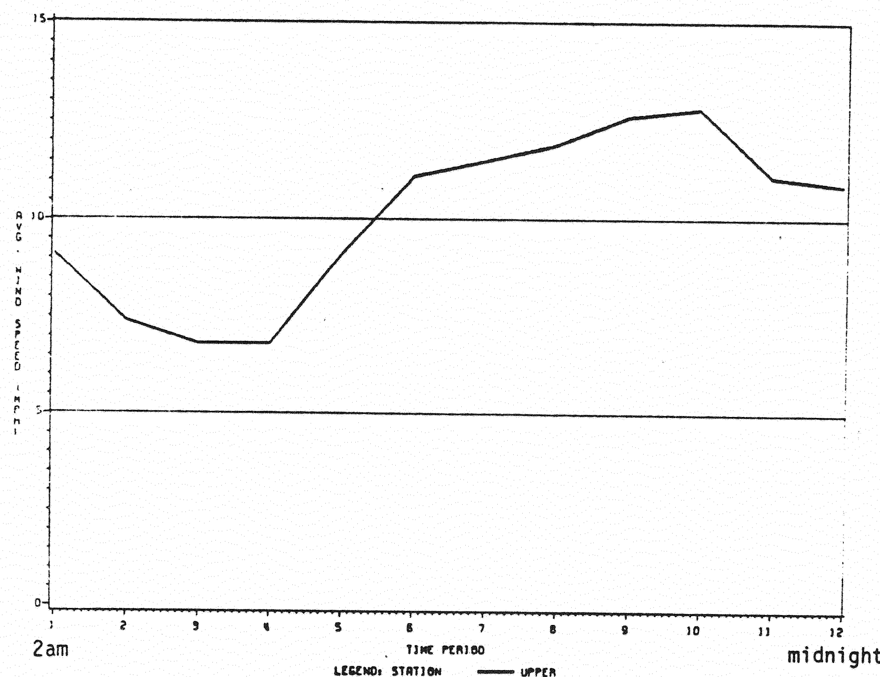


D16a. Diurnal



D16b. Histogram

Figure D16. Windspeed Distribution - Erick Site - MAY, 1983



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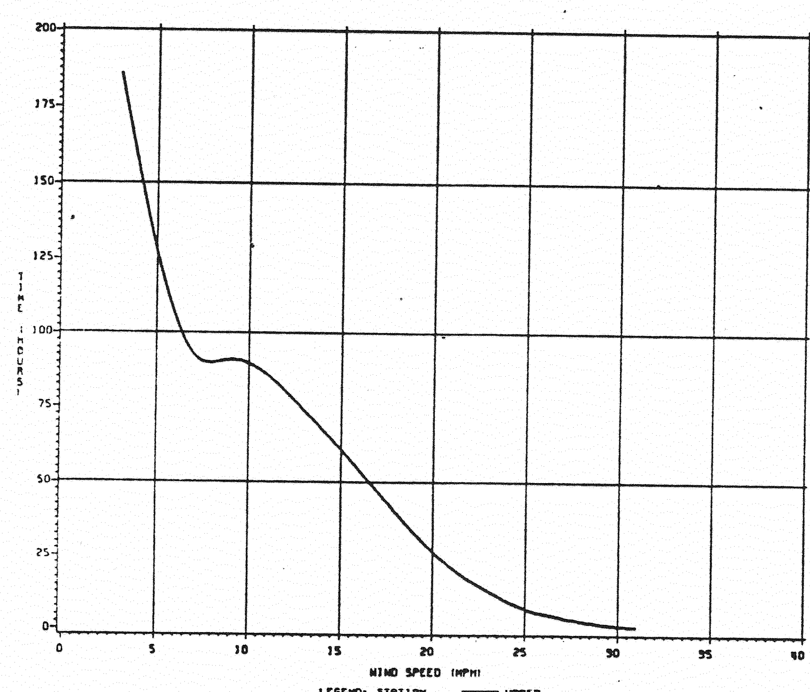
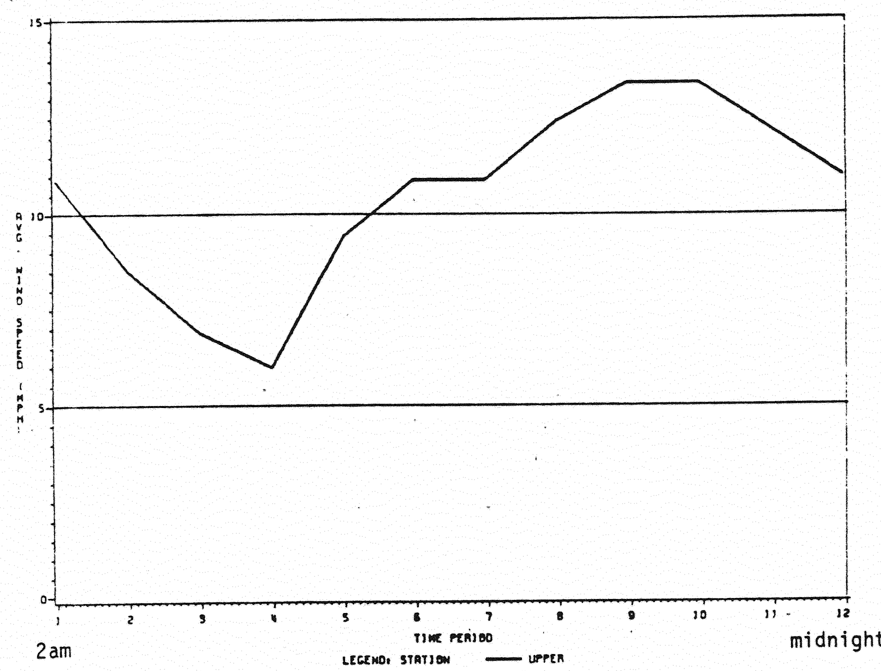


D17b. Histogram

Figure D17. Windspeed Distribution - Erick Site - JUNE, 1983



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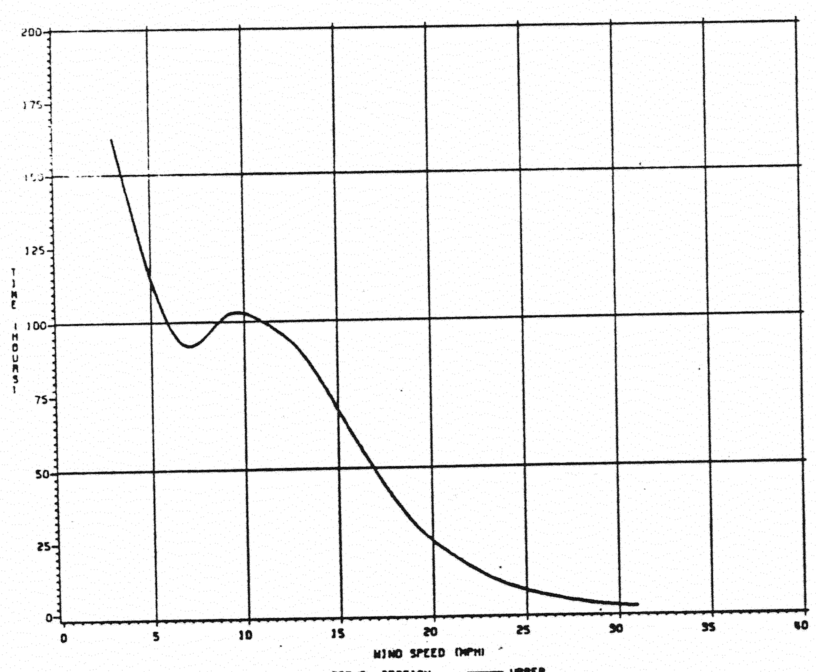
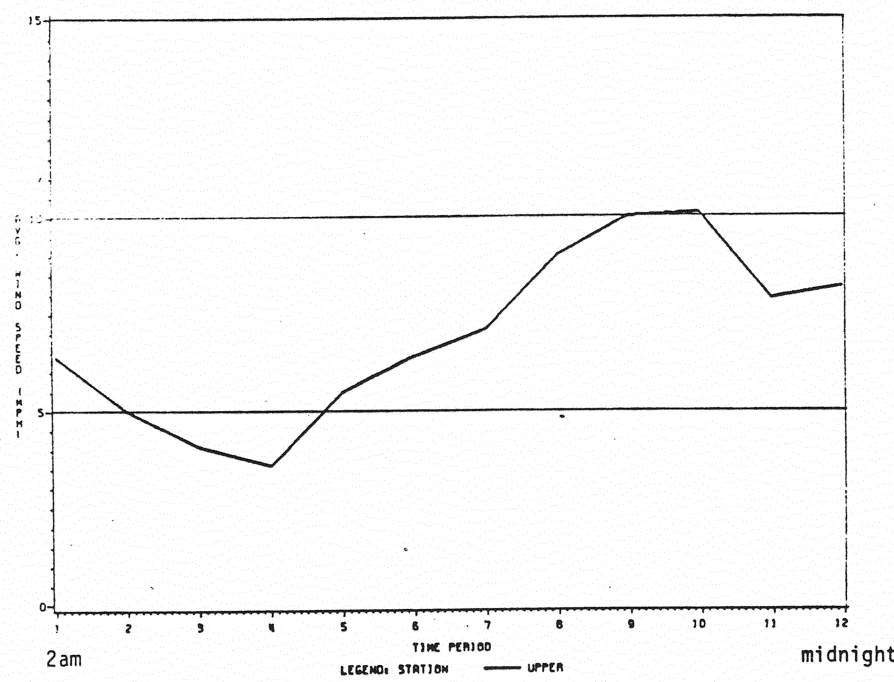


D18b. Histogram

Figure D18. Windspeed Distribution - Erick Site - JULY, 1983



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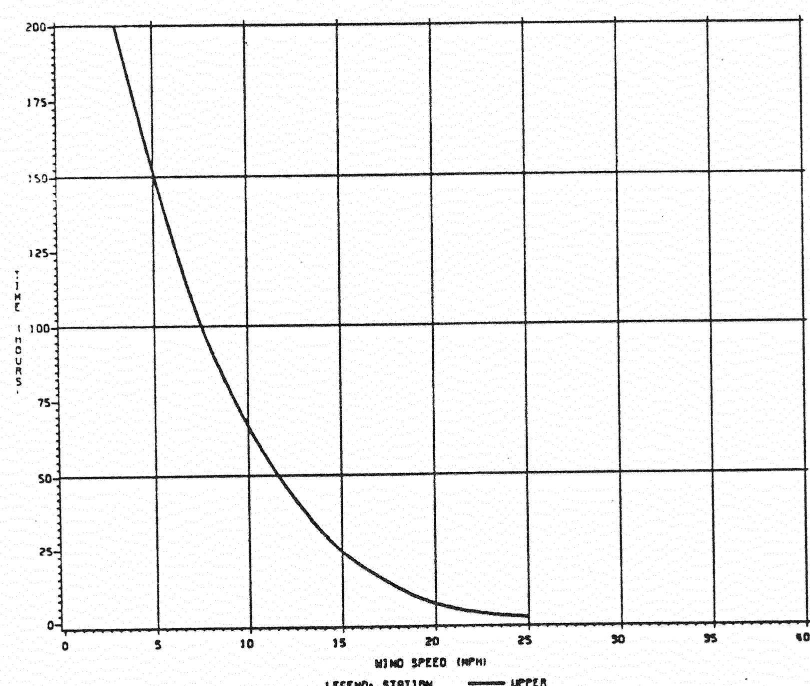
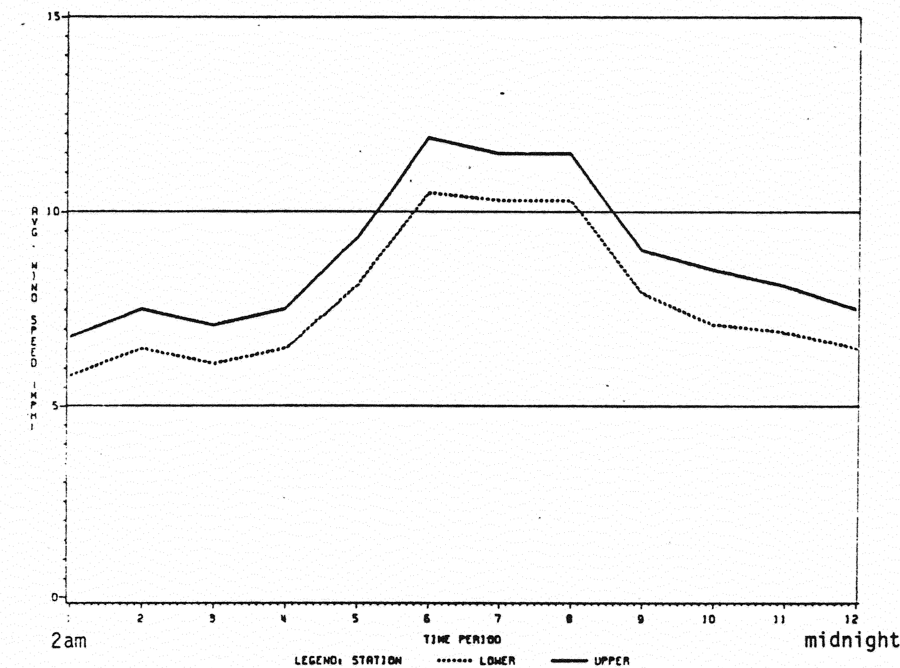


D19b. Histogram

Figure D19. Windspeed Distribution - Erick Site - AUGUST, 1983



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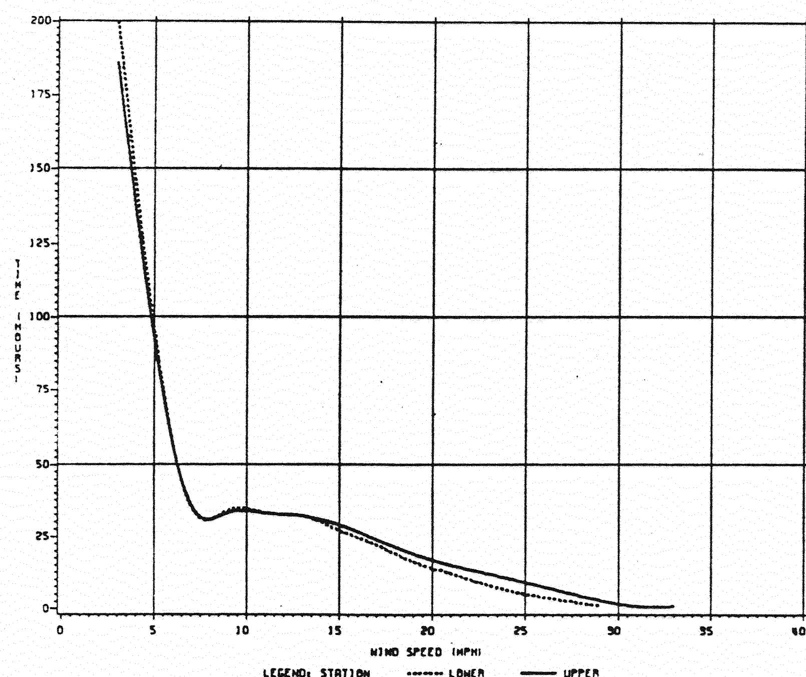
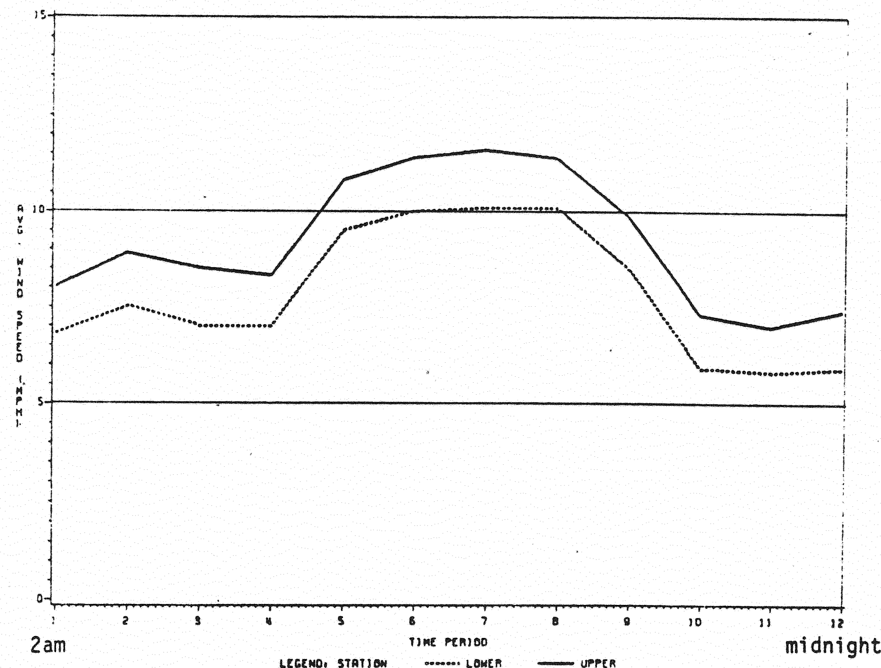
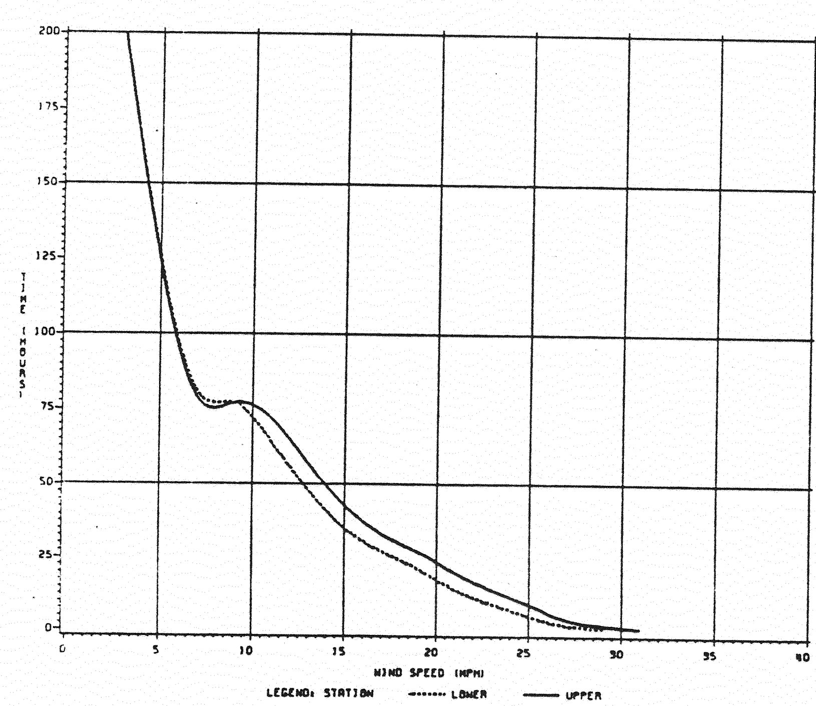


D20b. Histogram

Figure D20. Windspeed Distribution - Hydro Site - JANUARY, 1983

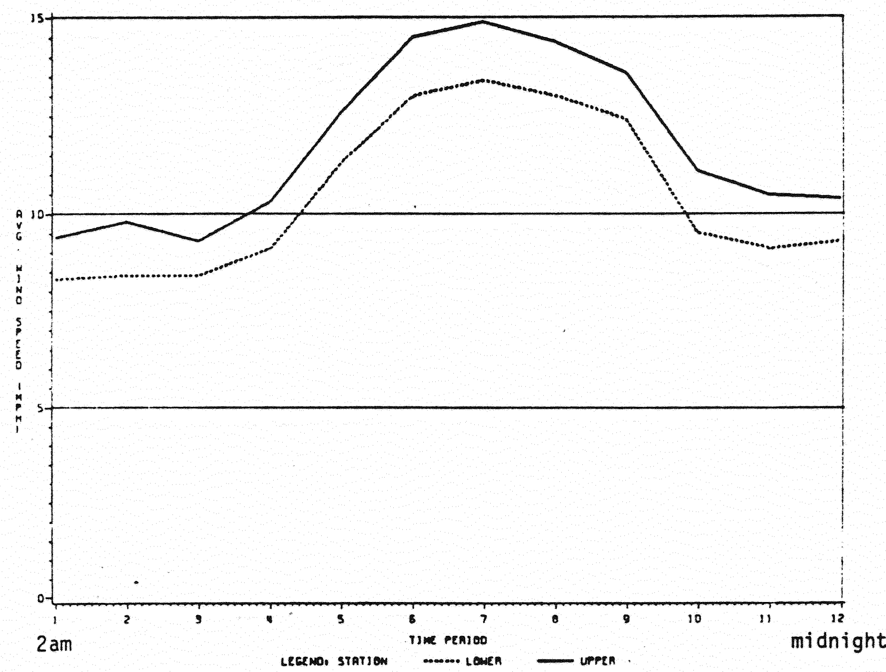


D21a. Diurnal

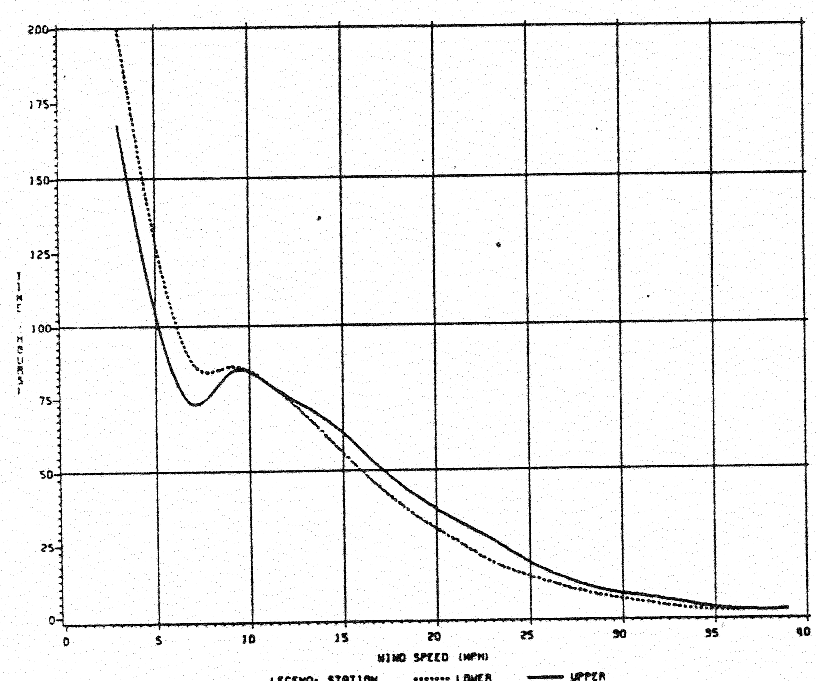


D21b. Histogram

Figure D21. Windspeed Distribution - Hydro Site - FEBRUARY, 1983

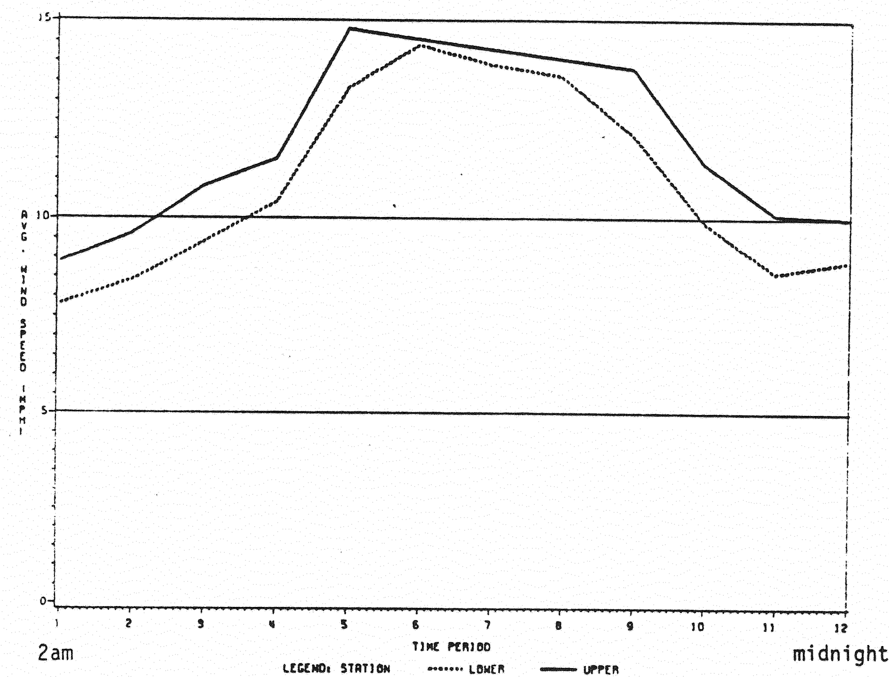


D22a. Diurnal

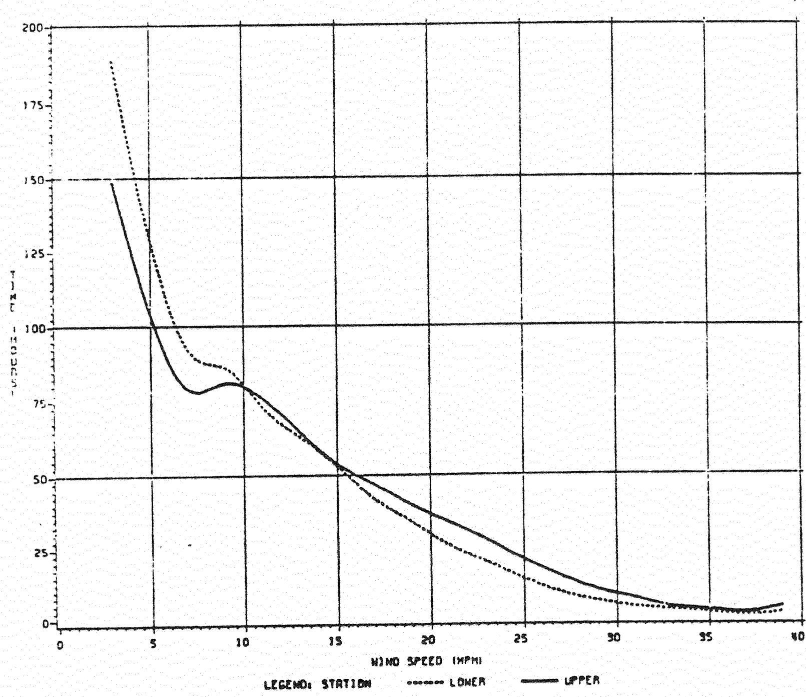


D22b. Histogram

Figure D22. Windspeed Distribution - Hydro Site - MARCH, 1983

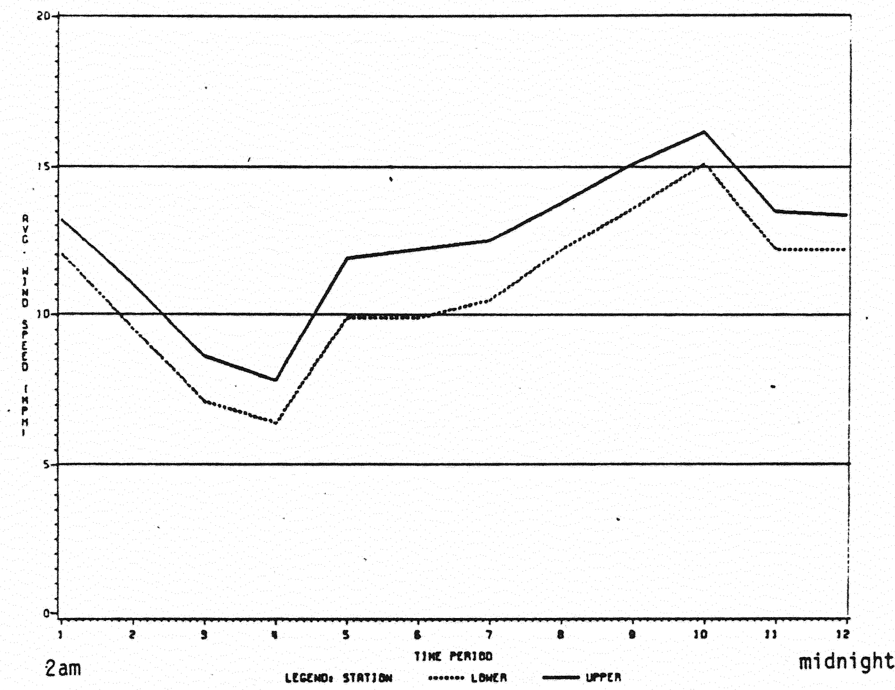


D23a. Diurnal

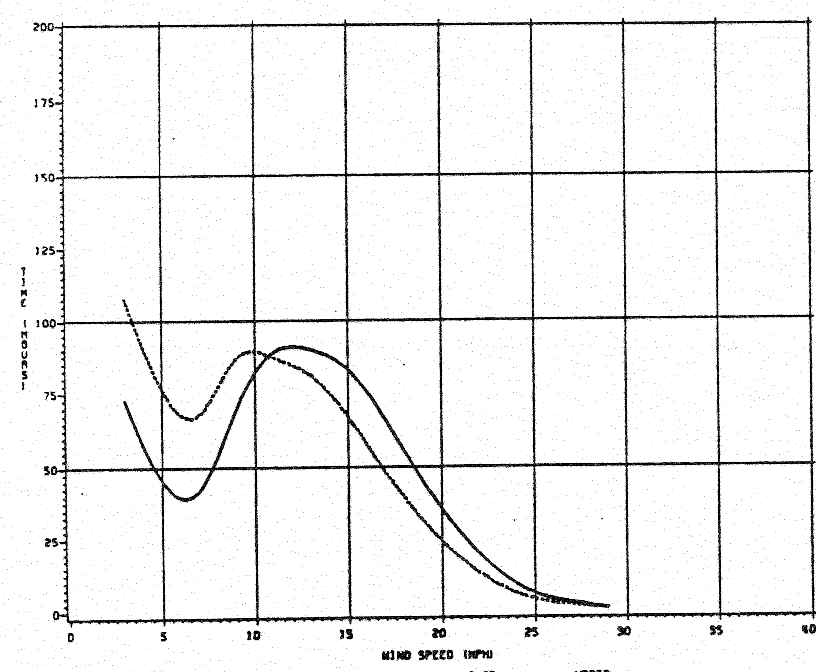


D23b. Histogram

Figure D23. Windspeed Distribution - Hydro Site - APRIL, 1983

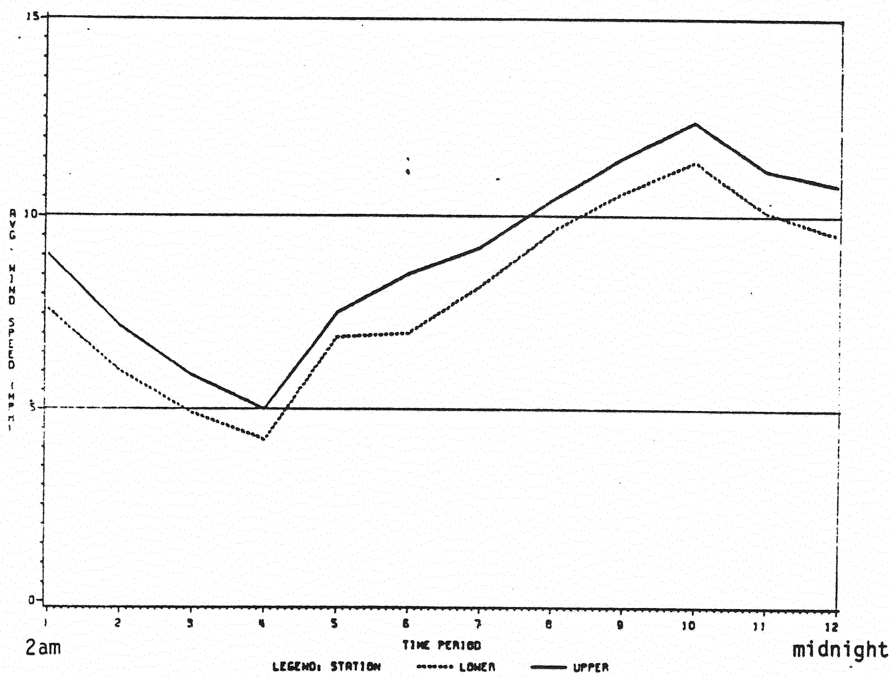


D24a. Diurnal

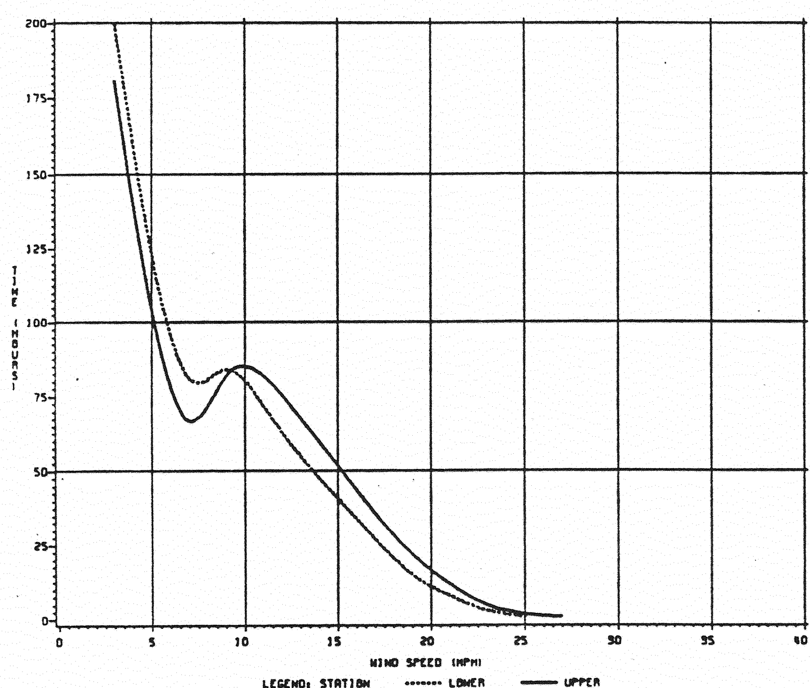


D24b. Histogram

Figure D24. Windspeed Distribution - Hydro Site - JULY, 1983



D25a. Diurnal



D25b. Histogram

Figure D25. Windspeed Distribution - Hydro Site - AUGUST, 1983

APPENDIX E

DIURNAL POWER PRODUCTION

DIURNAL POWER PRODUCTION

Diurnal power production is shown on the same time scale as the diurnal windspeed distribution of Appendix D. Thus, the abscissa values may be multiplied by two in order to obtain the correct hour on the 24-hour clock.

In general, the output of the windpower generator tracked the average windspeed very closely. Furthermore, the power output data tended to verify the power curve for the Carter Model 25 shown in Figure A-1. For example, the average daytime windspeed during November, 1982, was 11.3 mph. The average night-time windspeed was 9.0 mph. The average daytime output of the windpower generator was 4.3 kw and the average night-time output was 2.5 kw. When annualized by multiplying by 8760 (hours/year) there is good agreement between the annual output and average windspeed curve of Figure A-1.

Further analyses of the windspeed and power output data indicate that power output does not follow the same cubic relationship that describes the increase in kinetic energy of the wind with an increase in velocity. It appears that the power output exponent may vary between 2.0 and 2.5.

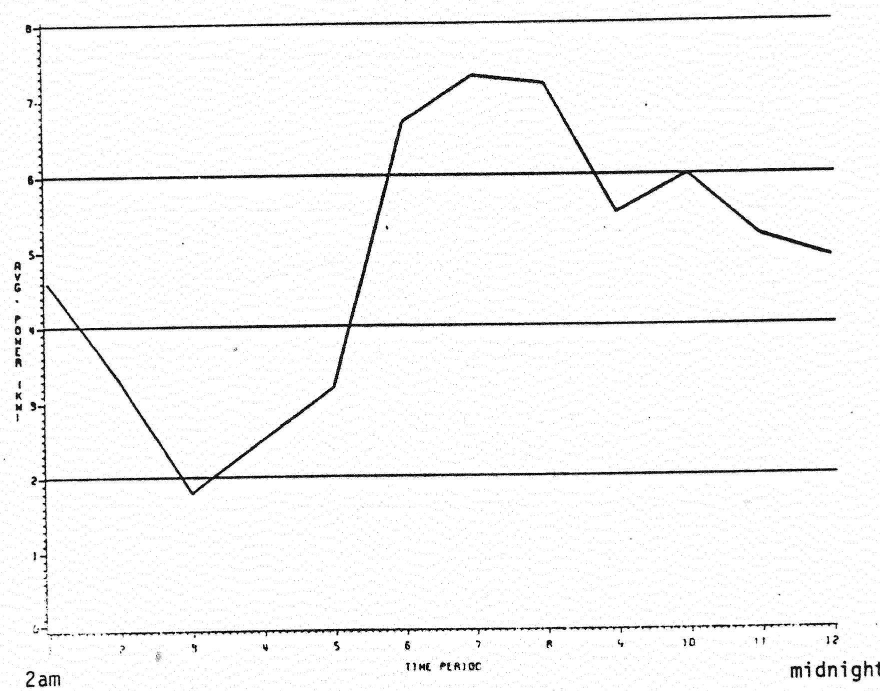


Figure E1. Diurnal Power Production - Erick Site - SEPTEMBER, 1982

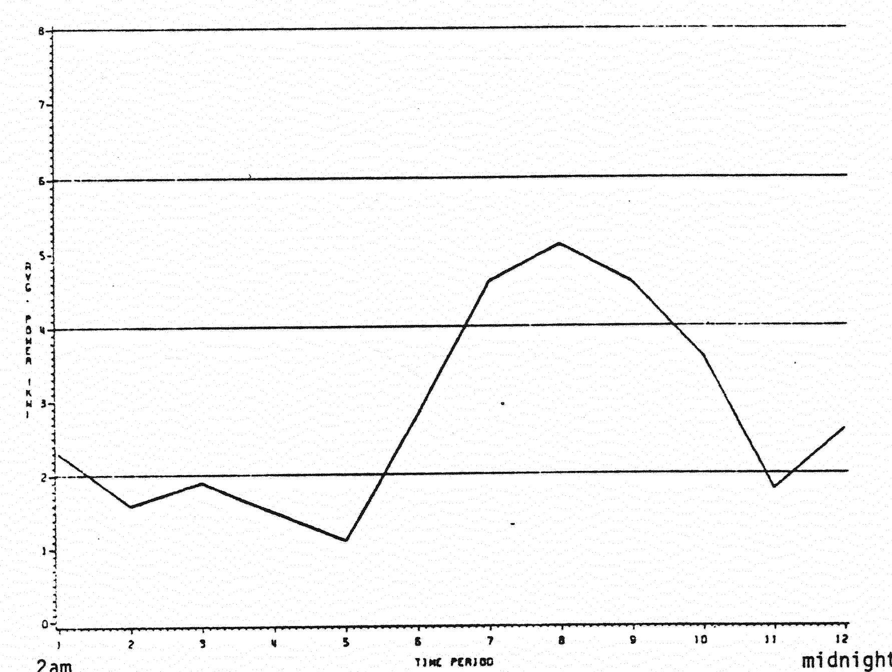


Figure E2. Diurnal Power Production - Erick Site - OCTOBER,1982

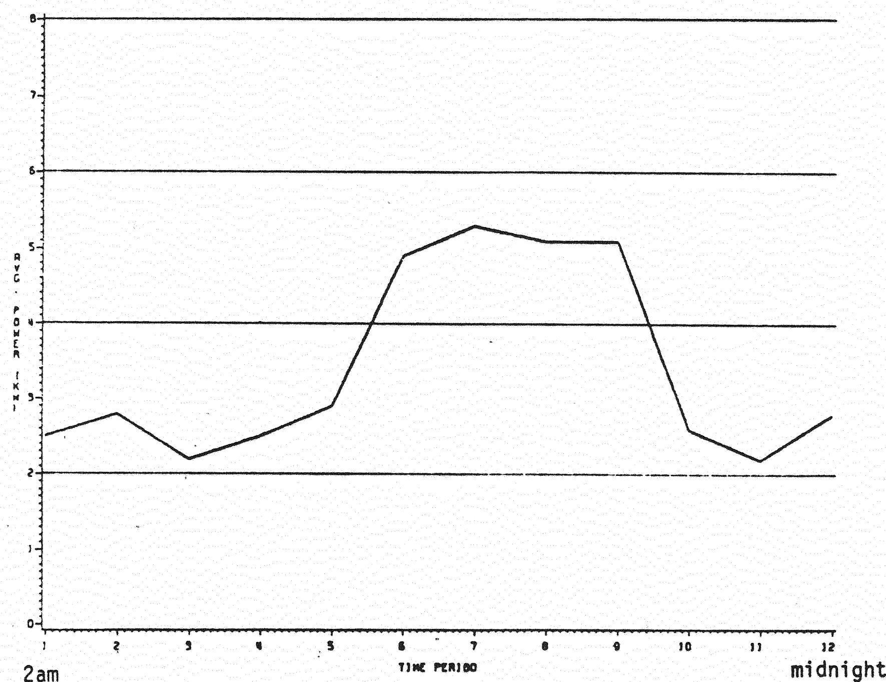


Figure E3. Diurnal Power Production - Erick Site - NOVEMBER, 1982

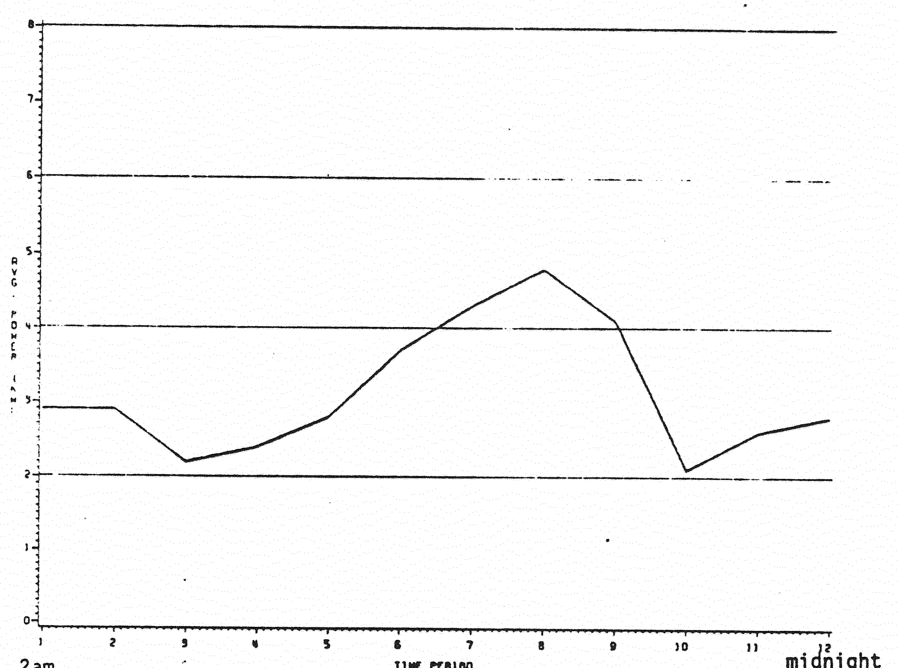


Figure E4. Diurnal Power Production - Erick Site - DECEMBER, 1982

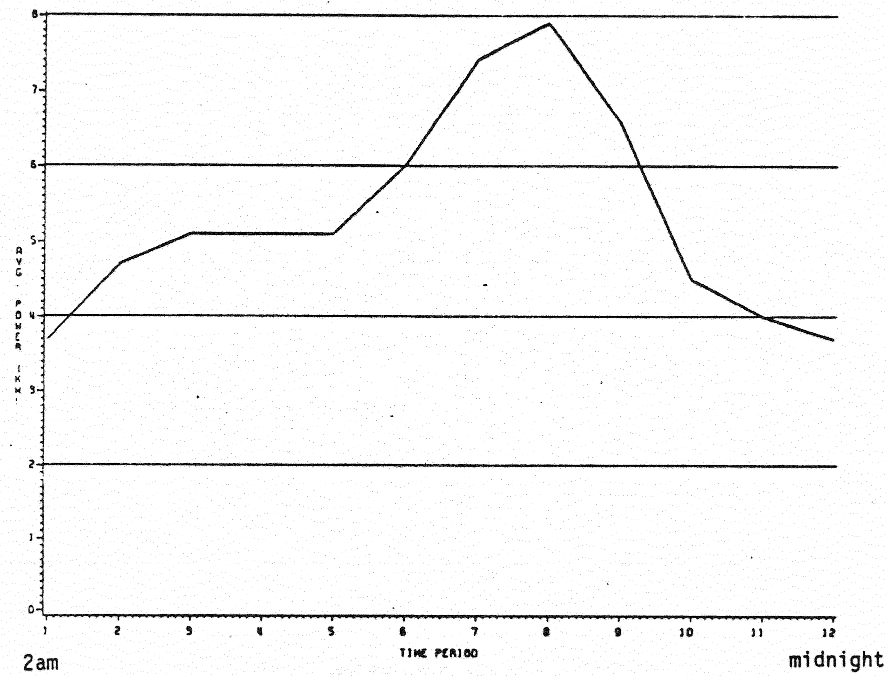


Figure E5. Diurnal Power Production - Erick Site - JANUARY, 1983

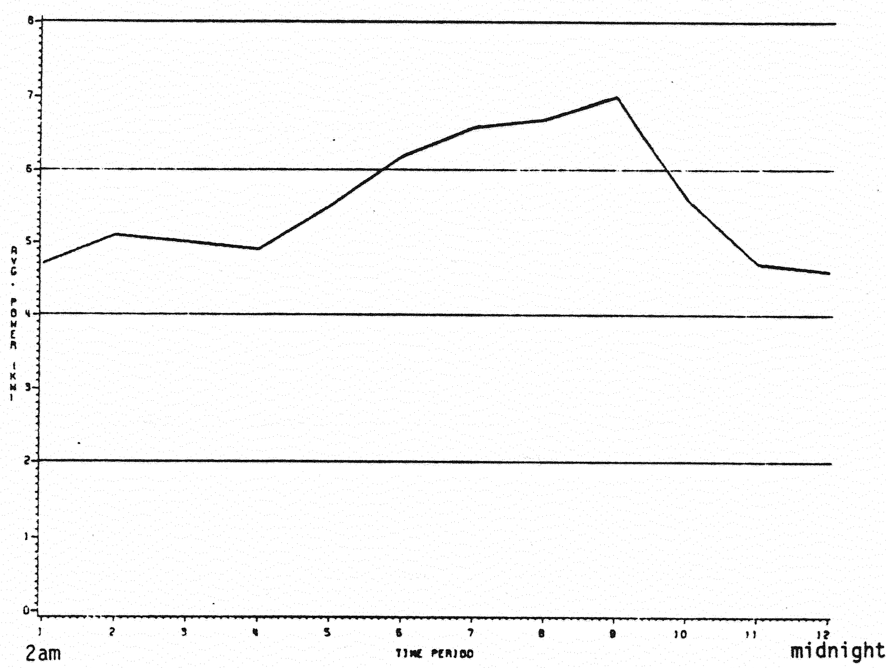
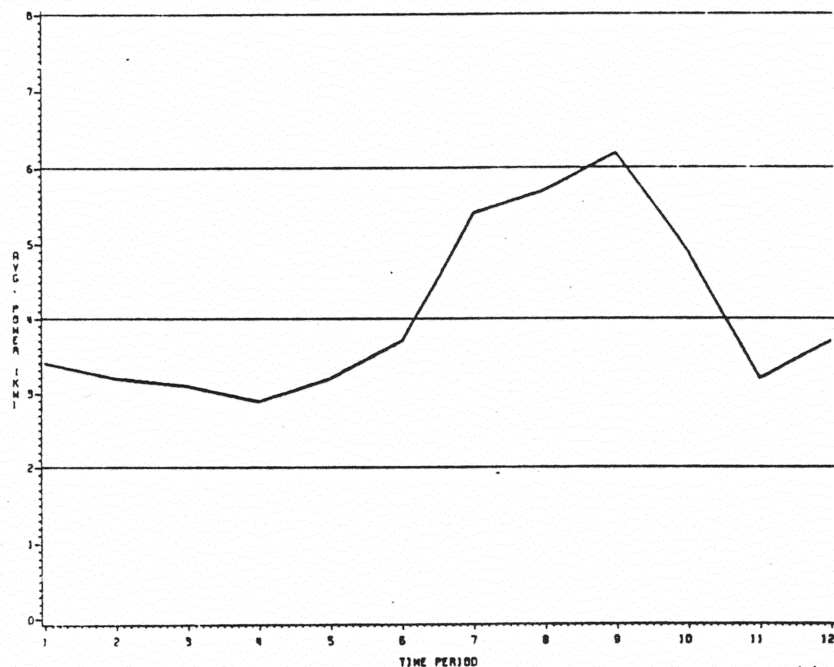
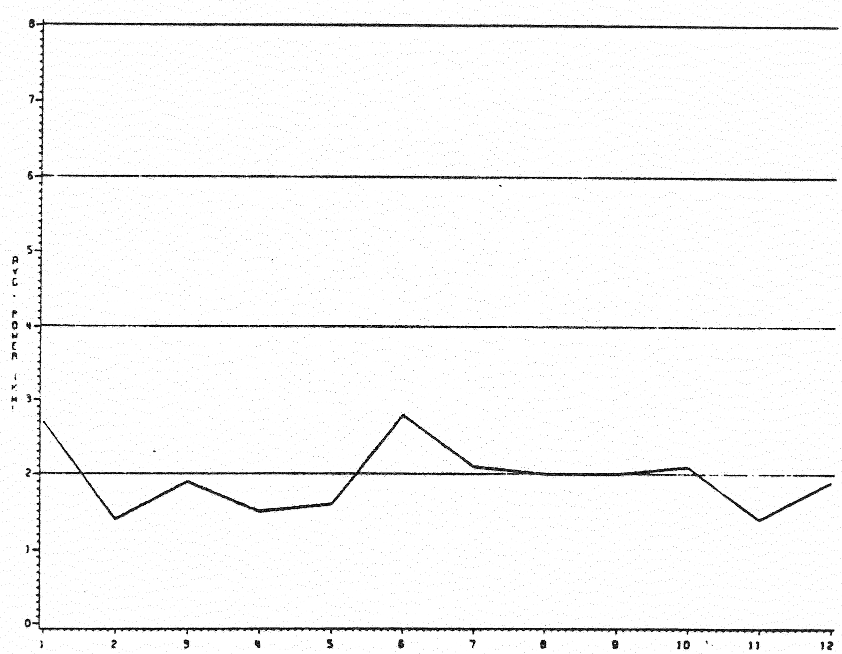


Figure E6. Diurnal Power Production - Erick Site - FEBRUARY, 1983



2am midnight

Figure E7. Diurnal Power Production - Erick Site - MARCH, 1983



2am midnight

Figure E8. Diurnal Power Production - Erick Site - APRIL, 1983

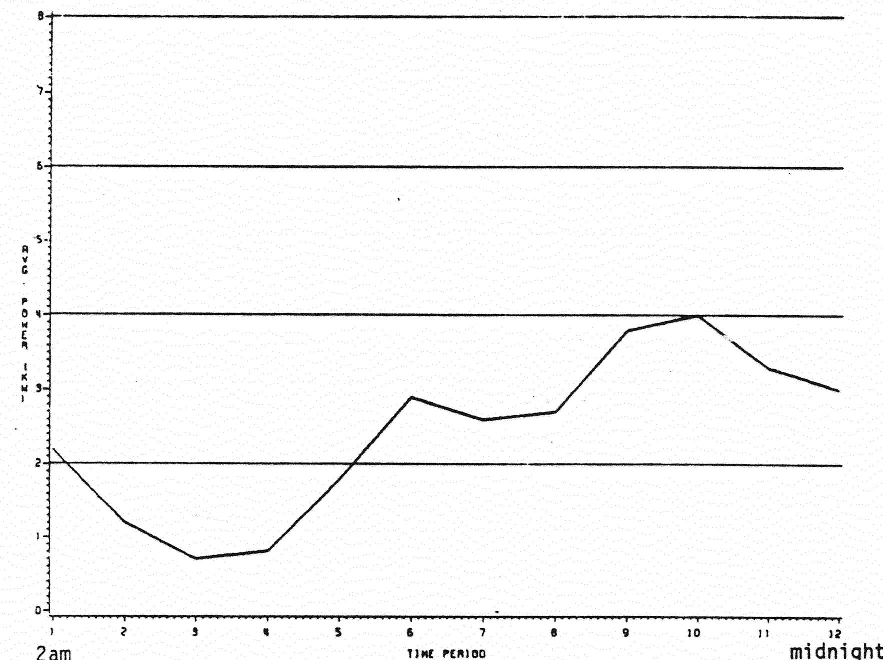


Figure E9. Diurnal Power Production - Erick Site - JUNE, 1983

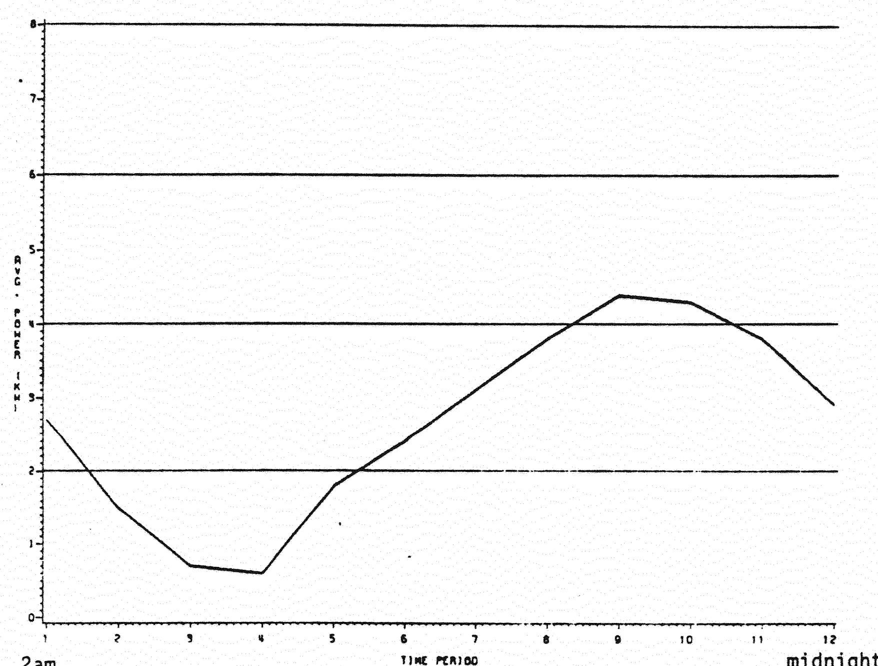


Figure E10. Diurnal Power Production - Erick Site - JULY, 1983

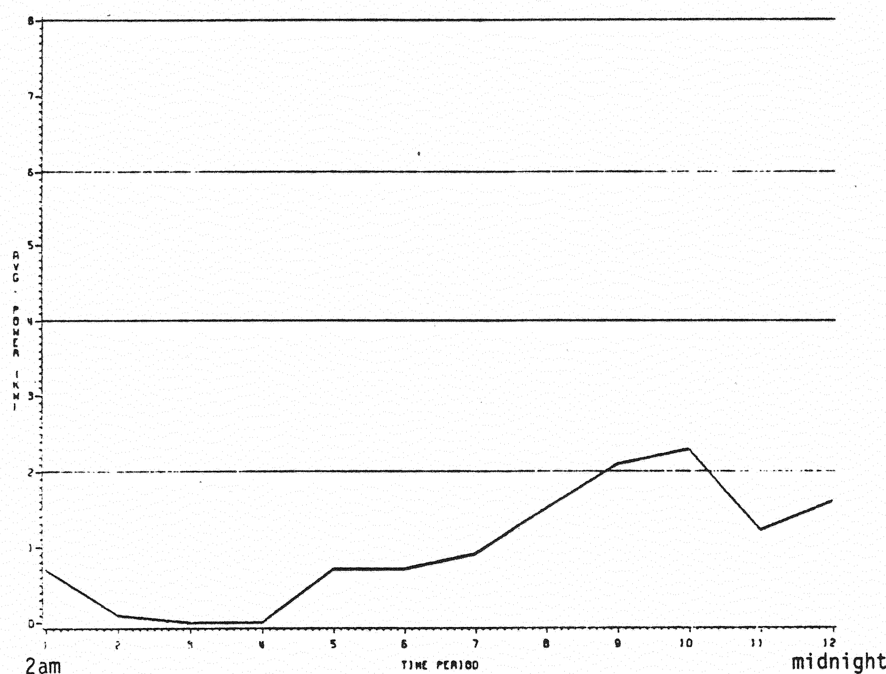


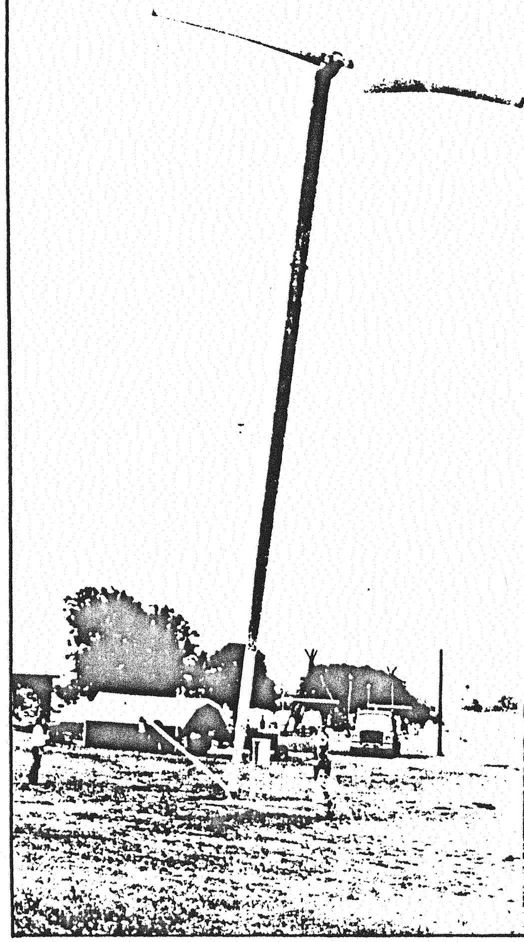
Figure E11. Diurnal Power Production - Erick Site - AUGUST, 1983

APPENDIX F

DATA SHEET PREPARED AND DISTRIBUTED
BY THE
OKLAHOMA DEPARTMENT OF TRANSPORTATION

Maintenance

The 60 foot tower has four guy wires and can be lowered for maintenance by using a pulley and gin pole system activated by the pull of a truck. Two people can lower the tower and the 1000 lb. generator in five to 10 minutes.



Results

The Research Division of the Oklahoma Department of Transportation expects the cost effectiveness study of the Erick wind generator to be completed in 1984. Early results indicate:

1. Wind speed has been lower than expected, with monthly averages between 8.3 and 11.9 mph. For the first quarter of 1983, the average wind velocity was 10 mph. For the corresponding period in 1982, the average was 10.8 mph, indicating that the abnormally low wind speeds are continuing.

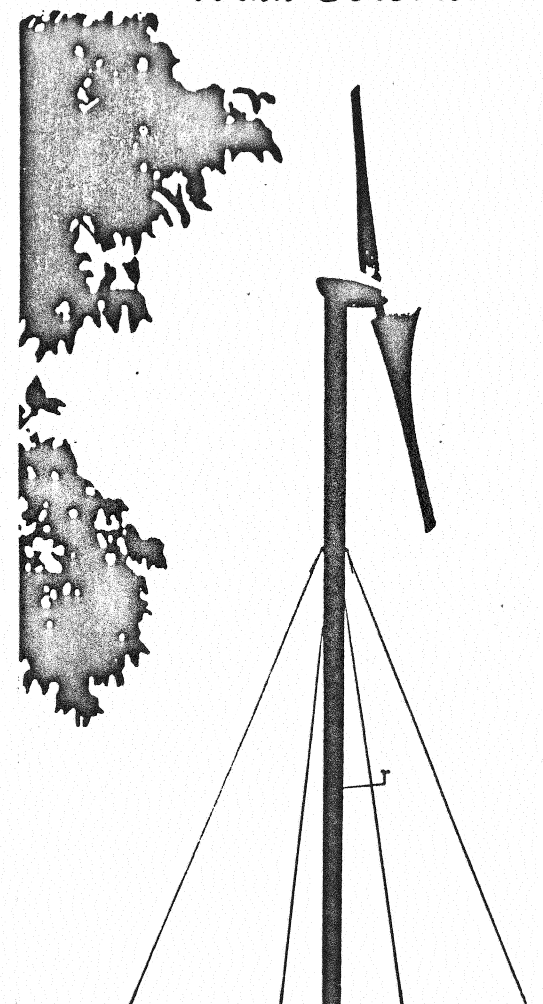
2. The wind velocity increases with elevation above the ground. For example, if the wind speed at 30 ft. is 10 mph, the speed at 60 ft. is approximately 11.5 mph. Under these conditions, a wind generator at 60 ft. would produce about fifty percent more power than a similar machine at 30 ft.

3. The output of the wind generator is sensitive to small changes in wind speed. Output ranged from 1750 KWH in February, 1983 (when the average wind speed was 9.8 mph) to 3260 KWH in March, 1983 (average wind speed 11.9 mph). For the period September, 1982 to March, 1983, the monthly power production averaged 2450 KWH and provided one fourth the electricity needed by the rest area.

For further information on wind generators contact:
American Wind Energy Association
2010 Massachusetts Avenue, NW
Washington, DC 20036
202—775-8910

Printing and distribution of this publication by the Oklahoma Department of Transportation was authorized by R. A. Ward, Director/Chief Engineer. Approximately 1,000 copies have been prepared at a cost to the taxpayers of Oklahoma of $64.50.

Wind Generator



Oklahoma Department of Transportation
Research & Development Division
200 NE 21st Street
Oklahoma City, OK 73105
405—521-2671

Figure F-1. Data Sheet Prepared and Distributed by the Oklahoma Department of Transportation.

Wind Generator

The state song, "Oklahoma" tells of the "wind sweepin' down the plain." Now Oklahoma's wind is being harnessed as a promising alternate energy source. The I-40 rest area at Erick is located in the windiest part of the state with an average wind speed of 13 mph and in 1982 was selected as the site for an Oklahoma Department of Transportation (ODOT) research study. The project explored the use of wind power as a means of reducing electric bills at rest areas and other transportation facilities throughout the state.

Wind has been used for thousands of years to mill grain, drive machinery, and power boats. Although it was displaced by cheap fossil fuels beginning in the 19th century, wind power has always been an important source of energy in remote locations. Water-pumping windmills enable ranchers throughout the world to support cattle at great distances from naturally occurring water supplies. With the soaring cost of energy, windpower is making a strong comeback.

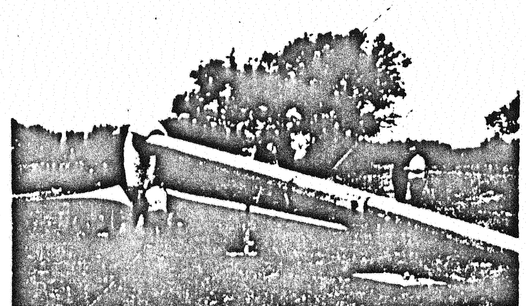
Project Monitoring

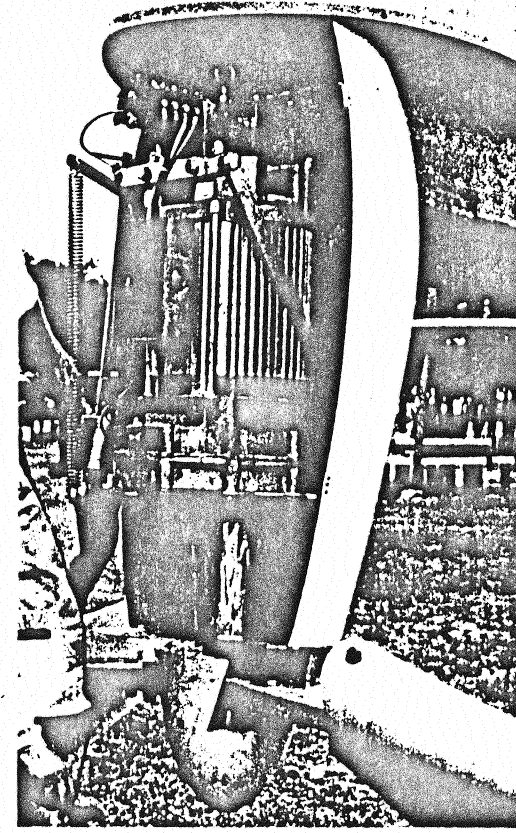
Professor Karl Bergey, of the Aerospace and Mechanical Engineering School at the University of Oklahoma, was awarded a contract by the Research and Development Division of the Oklahoma Department of Transportation to select, monitor and evaluate a 20 KW wind powered electric generator. He was assisted by Ken Craig, OU graduate student. The project received partial funding from a Federal Highway Administration grant. The monitoring program includes measurement of local wind speed at several heights and comparison with generator output. A digital data logger records the information from directional vanes and anemometers for later analysis at the University of Oklahoma.

The $27,000 wind generator was erected by the manufacturer, Jay Carter Enterprises, Inc., of Burkburnett, Texas, in May, 1982. The equipment was selected on the basis of its being able to supply approximately half of the 10,000 KWH average monthly electricity needed for the South rest area.

The Carter Model 25 uses an induction generator which produces electric power that is compatible with and can be fed into the local Northfork Electric Cooperative grid. Whenever the wind is blowing so hard that the wind generator is producing more electricity than can be consumed, the extra electricity is fed into the line and the credit is recorded by a second watt-hour meter. When the wind is not blowing hard enough to supply all the electricity needed, the rest area uses the wind generator's electricity first and only then buys the difference from the utility company. This flow of power is done automatically without any noticeable effects such as a dimming of the lights. The output voltage of the wind generator is 220 V, 60 cycle, single phase AC.

The Model 25 generator begins operating in a 7 1/2 mph wind and has a rated output of 20 KW in a 26 mph wind. The ideal location is on the top of a gentle rising hill with no trees or high buildings to disrupt the flow of air into the generator.





The wind generator has blade pitch/stall overspeed protection. If the wind rises to 125 mph the blades stall by bending to a 45 degree angle in a non-rotating position thus protecting the generator from overloading.

An out of balance control has a disc brake for stopping the rotor in any wind condition. The generator also can be stopped manually from the ground. The turning diameter of the fiberglass blades is 32 feet.

Data Sheet (Continued)