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A Site Evaluation for a Wind Generator at the University of Northern Iowa

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Abstract

There is a need to develop alternative sources of energy other than our finite fossil fuel resources (Clews, 1975; Leckie, Masters, Whitehouse and Young, 1975). One possible area of great potential is the clean renewable energy in the wind. The World Meteorological Organization has estimated that there is a potential for producing 20 million megawatts of electricity from wind power (Clews, 1975). Although there are problems with cost, reliability, and its inherently intermittent nature, both government and industry are working to develop a wind technology that will help meet today's electrical energy needs.

An increased awareness by the general public of what wind generators are, their advantages, disadvantages, capabilities, and capacities, would help in the popular understanding of possible alternatives to present energy problems.

The Industrial Technology Department has an opportunity to help increase public awareness of the concept and potential of wind power by several different means.

First, department faculty and students would get "hands-on" experience with an actual wind system. Included in the experience would be the actual installation of the unit, and connection to battery banks, inverters, or existing power lines.

Second, the wind generator installation would provide a vehicle for students to conduct research related to the problems and potential of wind power. Experiments could be conducted in regular or special classes.

Third, the visibility of the wind generator to both the UNI campus and general public would indicate that the Industrial Technology Department was engaged in wind power use and study.

A SITE EVALUATION
FOR A WIND GENERATOR
AT THE UNIVERSITY OF NORTHERN IOWA

A Research Paper for Presentation
to the Graduate Faculty
of the Department of Industrial
Technology
University of Northern Iowa

In Partial Fulfillment of the Requirements for
the Non-Thesis Master of Arts Degree

by

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Introduction

Background

In 1977 a Dunlite 2 kw generator and various accessory components were donated to the College of Natural Sciences at the University of Northern Iowa by the Clinton Culver Company. Initially the equipment was to be used in a solar home project (UNISOL) that was proposed by the Industrial Technology Department. This project has been indefinitely postponed, resulting in the temporary storage of the wind generating equipment in the Industrial Technology Building (ITC) power laboratory. At the present time, September 1980, there are no plans for the installation of the wind generator.

Significance of the Problem

There is a need to develop alternative sources of energy other than our finite fossil fuel resources (Clews, 1975; Leckie, Masters, Whitehouse and Young, 1975). One possible area of great potential is the clean renewable energy in the wind. The World Meteorological Organization has estimated that there is a potential for producing 20 million megawatts of electricity from wind power (Clews, 1975). Although there are problems with cost, reliability, and its inherently intermittent nature, both government and industry are working to develop a wind technology that will help meet today's electrical energy needs.

An increased awareness by the general public of what wind generators are, their advantages, disadvantages, capabilities, and capacities, would help in the popular understanding of possible alternatives to present energy problems.

The Industrial Technology Department has an opportunity to help increase public awareness of the concept and potential of wind power by several different means.

First, department faculty and students would get "hands-on" experience with an actual wind system. Included in the experience would be the actual installation of the unit, and connection to battery banks, inverters, or existing power lines.

Second, the wind generator installation would provide a vehicle for students to conduct research related to the problems and potential of wind power. Experiments could be conducted in regular or special classes.

Third, the visibility of the wind generator to both the UNI campus and general public would indicate that the Industrial Technology Department was engaged in wind power use and study.

Statement of the Problem

What is the most appropriate location for installation of the Dunlite 2 kw generator?

Statement of Research Questions

What is the most appropriate site for the erection of a wind generator, given the following research question parameters:

1. What are the faculty suggestions for possible installation sites of the wind generator?
2. What will be the cost of installation at each site?
3. What possible research or teaching service uses can be made at each site?
4. For what practical use will the generator be used at each site?
5. What are the comparable wind speeds at each site?

Limitations of the Study

This study is the evaluation of possible site selections only, and is based upon various constraints. The lack of time to make comprehensive wind speed measurements over an extended period of time is a major constraint. Related to this factor is the lack of available wind speed measuring devices at UNI to generate accurate and meaningful wind speed comparisons. There is also a constraint in possible site locations for the wind generator, since only sites suggested by the Industrial Technology Faculty will be evaluated.

Definition of Terms

Average Wind Speed: The mean wind speed over a specified period of time.

Cube Law: The energy in the wind is proportional to the cube of the wind speed.

Cut-In Speed: The wind speed at which the wind machine is activated as the wind speed increases.

ERDA: Energy Research and Development Administration

Instantaneous Wind Speed: The wind speed at a specific moment in time.

kW: Kilowatt, a measure of power equal to 1000 watts.

Leeward: In the direction toward which the wind blows.

Magnetic Reed Switch: An electrical switch which is actuated by a magnetic field.

Octahedron-Segment Tower: A tower constructed of segments consisting of eight sides per segment.

PERT: Programmed Evaluation and Review Technique; a method for scheduling project activities and estimating time requirements.

Ohm's Law: A formula defining the relationship between voltage, current and resistance.

Rated Output Capacity: The output power of a wind generator operating at the constant speed and output power corresponding to the rated wind speed.

Rated Wind Speed: The lowest wind speed at which the rated output power of the wind generator is produced.

Relative Ratio Technique: A method used to rank items by comparing objective measurements.

Venturi: A constriction or throatlike passage that increases the velocity of a fluid passing through it.

Wind Rose: The pattern formed by a diagram showing vectors representing wind velocities.

Windward: The direction or side from which the wind blows.

Review of Related Literature

Site Selection

A windplant can be an efficient and reliable source of electric power, but only if it is positioned in a clear, turbulence-free airstream with frequent high winds. According to the Enertech Corporation (1977) the U.S. Weather Bureau divides the wind into two categories: the planetary winds and local winds.

Planetary or prevailing winds are the movements that occur over whole areas and have a constant directional characteristic. This direction varies only with the movement of high or low pressure systems, and with the seasons of the year. In most locations these are the dominant winds, and good wind generator sites take advantage of this. Such sites would include: exposed hilltops, open plains, valley floors, and the windward side of gently sloping hills.

Local winds are caused by temperature differences created by local terrain. Land-sea, and mountain-valley winds are good examples. An excellent location for a wind plant is one where local winds reinforce the prevailing winds (Enertech, 1977).

The Enertech Corporation (1977) stresses the importance of knowing that wind speed measurements made at ground level can be very misleading. Wind speeds are affected by ground level obstacles and by the friction or drag of the earth's surface. Winds speeds above ground level are always greater than surface speeds (Clews, 1975; Enertech, 1977, Hackleman, 1975; Leckie, Masters, Whitehouse, and Young, 1975). This difference can vary from 20 to 50 percent depending on the height above ground.

Leckie et.al. (1975) and the Noyes Data Corporation (1979) cite a generally recognized "rule of thumb" that the wind speed increases as the one-seventh power of the height above ground. For example, if the wind was blowing at 15 mph at 5 feet the wind speed at 40 feet could be predicted as:

$\sqrt[7]{5} = 1.258$ and $\sqrt[7]{40} = 1.694$

At 5 feet: 15mph/1.258 = 11.924

At 40 feet: 11.924 x 1.694 = 20.199 mph predicted wind speed

Table 1 uses this formula to provide predicted wind speeds up to 90 feet above ground.

Since energy in the wind is proportional to the cube of the wind speed (McGuigan, 1978, pg. 8), the amount of energy available increases dramatically as the height increases, as shown in Table 1. These figures are theoretical values, and while they do apply to the real world, there may be some variations from actual measured values at different sites.

Another example of the advantage of high wind speeds is the output of the Dunlite 2000 watt generator at different wind speeds. At 10 mph the output is 280 watts

Table 1

Height-Wind Speed-Energy Relationships*

Height Above Ground Level	Wind Speed	Available Energy
5 feet	1.00	1
30 feet	1.29	2.15
40 feet	1.35	2.44
50 feet	1.39	2.68
60 feet	1.43	2.92
70 feet	1.46	3.11
80 feet	1.49	3.31
90 feet	1.51	3.44

*Calculated for a wind speed of 1 mph at 5 feet.

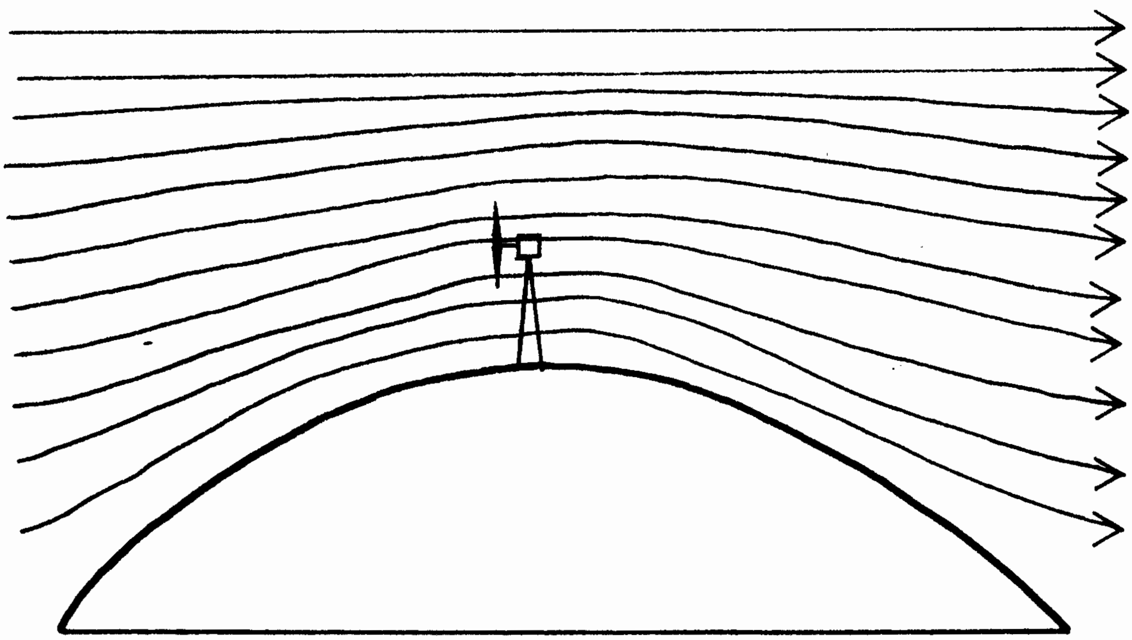
while at 15 mph the generator produces 1000 watts or 4 times as much power with an increase of only one-half in wind speed.

Wind generators generally perform best at or near their rated wind speed (Enertech, 1977; Sullivan, 1978). As a safety measure, generators usually include governors to protect against stronger winds. Unfortunately, windplants are highly vulnerable to turbulence. At most sites, turbulence is caused by wind obstacles such as trees or buildings; or by some land contours such as a sharply rising hillside to windward or leeward (Enertech, 1977). This can be avoided by using the general rule (Clews, 1975; Enertech, 1977; Hackleman, 1975; Leckie et.al., 1975) that a wind generator should be placed 10 to 30 feet higher than any obstructions within 300 to 500 feet. The cost of the additional wiring and added tower height this might require will be more than offset by the savings in replacement blades and maintenance costs.

The Enertech Corporation (1977) and Eldridge (1975) explain the effect of hills on wind speeds. As shown in Figure 1, a relatively smooth hill will cause the wind to accelerate over the top. This is very similar to the effect caused by a venturi or restriction in a wind tunnel.

Figure 1

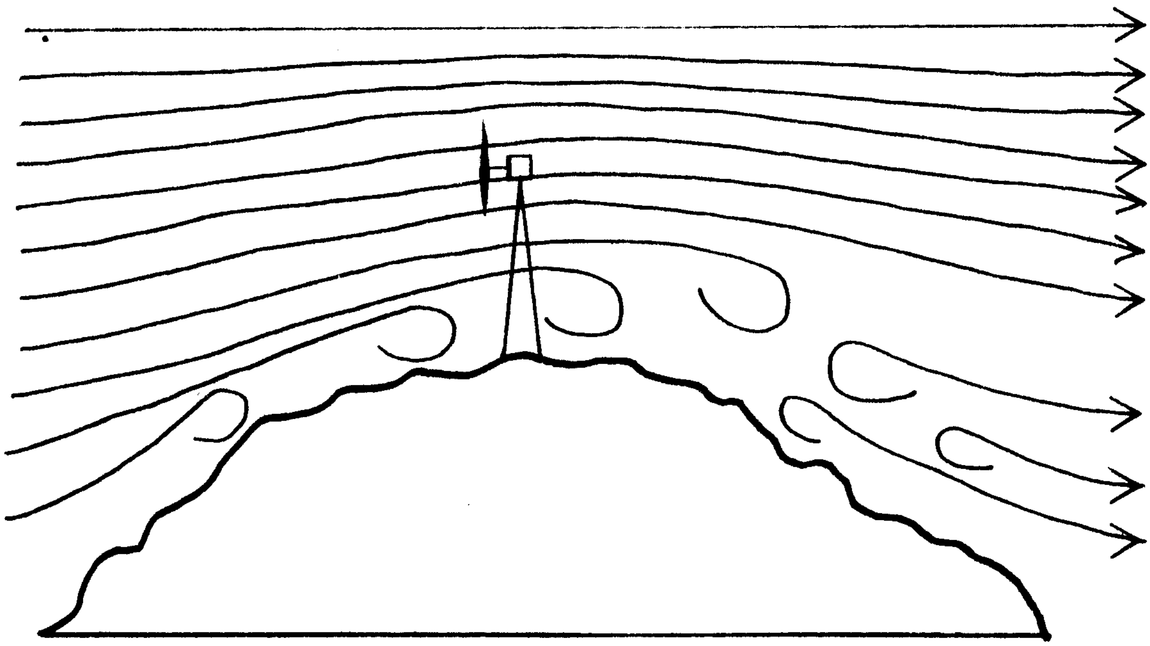
Increased Wind Speed Over A Hill



If the surface of the hill is rough, however, then turbulence results close to the ground and the tower must be placed at a greater height to reach a clear airstream as shown in Figure 2.

Figure 2

Turbulence Caused By Uneven Ground



In summary, a suitable site should include some or all of the following features:

1. The wind generator should be located as high as possible to take advantage of the increased wind speeds.

2. The site location is one where the local winds reinforce the prevailing winds.

3. Turbulence caused by wind obstacles should be avoided.

4. The wind generator should be located in an area of high average annual wind speeds.

Wind Speed Measurements

One of the first steps in site selection is to eliminate the clearly inadequate sites. These would include turbulent areas, or areas where the wind speeds at ground level average less than 8 mph (Clews, 1975, pg. 19). To make preliminary wind speed estimates, it is enough to observe and record wind speeds once or twice a day for a two week period, using any inexpensive wind meter, then calculate the average (Enertech, 1977). Wind speeds are notoriously variable. Inevitably, there will be several weeks when wind speeds will range far below or above normal.

Once the inadequate sites have been eliminated, it is important to get accurate wind speed measurements from the remaining locations. Accuracy is important, since a small difference in wind speed can produce a large difference in the wind generator output because of the Cube Law. According to Langa (1980), there is some controversy over how long to monitor wind speeds. Suggestions range from 90 days to 1 year. The longer the monitor period, the more accurate the results.

There is one solution to the problem of obtaining accurate wind speed measurements wihtout taking readings for a year or more. Wind speeds are measured at the selected site sufficiently often to establish a rough correlation between the wind speeds at the site and those at a nearby weather station. The historical data from the weather station is then taken and adjusted for the difference in wind speeds to give a close approximation for the historical wind speed data at the proposed site (Hand, 1977; Langa, 1980). The historical data from weather stations around the country can be found in the Climatic Atlas of the U.S., a publication of the National Climatic Center, (Appendix A). This summary includes average wind speeds and wind directions for each month of the year at the weather station location.

Anemometers

The actual devices used to measure the wind speed can range from the very simple to the very elaborate. Table 2 is a commonly-used method to estimate wind speeds (Hand, 1977; Leckie et.al., 1975). A popular wind velocity meter or anemometer is the Dwyer Hand Held Wind Meter distributed by the Dwyer Instruments Corporation. It has two ranges which measure wind speeds from 0 to 10 or 60 mph. A simple home made wind gauge is shown in Figure 3. The ping pong ball swings in the breeze and the angle of the string is measured on the protractor. The angle can be con-

Table 2

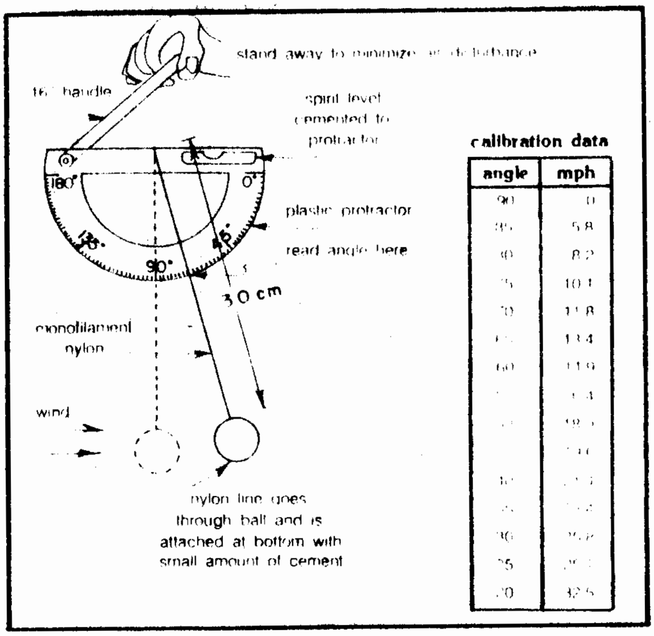
Wind Speed Indicators

Wind Speed (mph)	Wind Description
0 - 1	Calm, smoke rises vertically.
2 - 3	Direction of wind shown by smoke drift but not by wind vanes.
4 - 7	Wind felt on face, leaves rustle, ordinary vane moved by the wind.
8 - 12	Leaves and twigs in constant motion.
13 - 18	Raises dust, loose paper blown, small branches move.
19 - 24	Small trees begin to sway, wavelets form on water.
25 - 31	Large branches in motion, whistling heard in telephone wires, umbrellas used with difficulty.
32 - 38	Whole trees in motion, inconvenience felt in walking against the wind.
39 - 46	Strong gale, extreme difficulty in walking against the wind.
47 - 54	Light roofs liable to blow off houses.
55 - 63	Hurricane.

verted into the equivalent wind speed in miles-per-hour.

Figure 3

A Home Made Wind Gauge

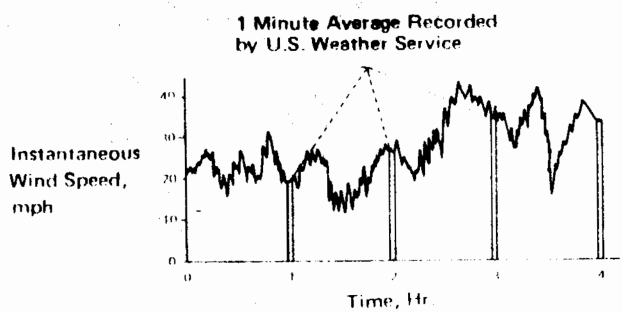


Note. From J. Leckie, G. Masters, H. Whitehouse, L. Young, <u>Other Homes and Garbage</u>, 1975, pg. 47. Copyright 1975 by Sierra Club Books. Reprinted by permission.

The gauges previously described would be difficult to utilize in calculating measurements at the height that a wind generator would typically be installed. In addition, these gauges only measure instantaneous wind speeds. At a given site the wind may vary frequently in direction, and under gusting conditions the speed may change rapidly.

Figure 4 shows a typical U.S. Weather Service graph of instantaneous wind speeds. As shown by this illustration, the one minute averages that are recorded do not always shown the complete wind patterns.

Figure 4



TYPICAL WIND SPEED RECORD

Note. From F. R. Eldridge, Wind Machines,]975. pg. 43.

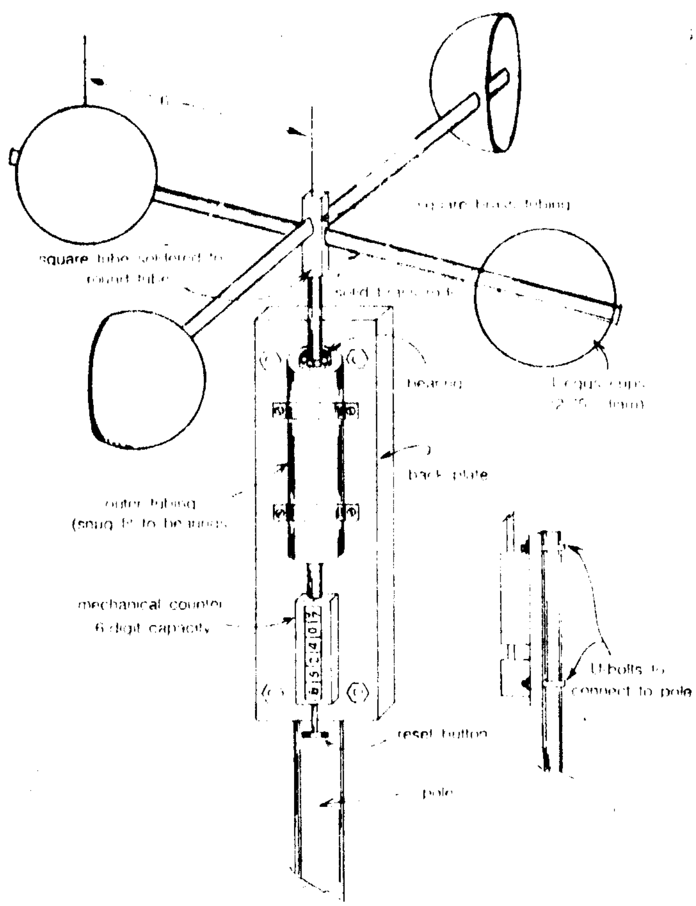
To increase the accuracy of instantaneous wind speed measurements several readings must be sampled and subsequently averaged. The more measurements taken, the more representative the average will be.

Another approach to measuring wind speeds is to use a cup-type totalizing anemometer or "wind odometer." A wind odometer counts the number of miles of wind that have blown by in a given time period. The cup anemometer output is linear and will result in an average wind speed indication.

Figure 5 is an example of a home made totalizing anemometer.

Figure 5

Totalizing Anemometer

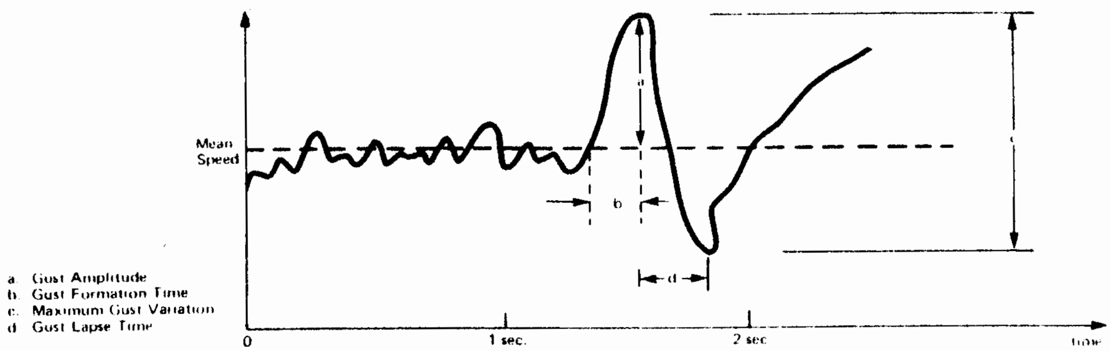


Note. From J. Leckie, G. Masters, H. Whitehouse, L. Young, Other Homes and Garbage, 1976, pg. 47. Copyright Sierra Club Books. Reprinted by permission.

The average wind speed that is found with the wind odometer will give a more accurate picture of the wind speed than an instantaneous gauge (Langa, 1980). Howver, as shown in Figure 6, Eldridge (1975) has estimated that because the wind gusts and is seldom steady, the actual wind power available at a given site can be 2 or 3 times greater than the calculated values based on average annual wind speeds.

Figure 6

An Example of Gusting



Note. From F. R. Eldridge, Wind Machines, 1975, pg. 44.

Wind Generator Towers

The purpose of the tower is to hold the generator securely in place at a height where it is in a clear windstream free from turbulence caused by nearby buildings or trees. Towers are typically made of galvanized steel to limit corrosion, and are of four designs; single-leg, three-leg, four-leg, or octahedron-segment (Hackleman, 1975, pg. 47).

The towers can be either self-supporting or guyed (Sullivan, 1978). The guyed towers are held erect by wires anchored in concrete while the self-supporting towers draw strength from a tapered design and a more secure anchoring than guyed towers. All towers must be designed to withstand the lateral force produced by high winds acting on the blades. The self-supporting towers, three-leg, four-leg, and octahedron-segment, are the most expensive. Single-leg unguyed towers made of pipe or wooden poles are prone to swaying, and Hackleman (1975) strongly advises against using such a tower. The three- and four-leg towers are the most common, and get their stability from the wide spacing of the legs. When using a guyed tower, Hackleman suggests a minimum of three guy wires and recommends using five if possible. The anchors for the guy wires should be located a distance of at least one-half the tower height from the base of the tower. All types of towers should be equipped with lightning protection kits (Hackleman, 1975; Sullivan, 1978); and in many instances, anti-climb sections or other security devices, to prevent access to the equipment by unauthorized personnel.

The two most important considerations in planning the tower height are avoidance of turbulence and excessive ground drag which lowers the wind velocity near the ground. Even over clear ground, the minimum recommended height for a tower is 30 to 40 feet (Enertech, 1977, pg. 29; Hackleman, 1975, pg. 45).

A compromise must be found which will balance the increased energy gains available at higher levels with the cost of increased tower height. Sullivan (1978) provides a cost-height comparison for typical towers (Table 3).

Table 3

Cost-Height Comparisons

Height	Self-Supporting	Guyed
30 feet	\$750-\$1000	\$500-\$600
40 feet	\$900-\$1250	\$600-\$750
50 feet	\$1250-\$1500	\$750-\$900
60 feet	\$1600-\$1700	\$900-\$1000
70 feet	\$2000-\$2400	\$1000-\$1100

Note. From G. Sullivan, Windpower For Your Home, 1978, pg. 52. Copyright 1978 by Cornerstone Library. Reprinted by permission.

Langa (1980, pg. 30) in a more recent publication estimates the cost of a wooden pole tower at \$1000 to \$2000 and a steel tower at \$3000 to \$4000 although no mention of specific height is made.

Cost is not the only consideration in choosing a tower. Vibration, wind buffeting, and rigidity are factors that must be considered when matching a tower and generator. There have been tower failures due to interactions between the generator and tower. Langa (1980) suggests using only the type of tower that is recommended by the manufacturer.

Line Losses

When locating a wind generator tower, the distance from the tower to serviced buildings must also be considered in terms of power that is lost in the resistance of the wire in the form of heat. Distances of up to 1000 feet from tower to load are acceptable if a suitable wire size is used (Clews, 1975; Leckie et.al., 1975). To estimate the line losses in the wire a variation of Ohm's Law is used:

$$I = \frac{P}{E}$$

where:

I = Maximum current output of the wind generator.

P = Power output of the generator in watts.

E = Voltage output of the generator in volts.

With the appropriate current value of the wind generator, a compromise can be found balancing the cost of the wire, voltage drop in the wire, and power loss in the wire as a function of distance of the tower from the storage batteries or buildings where the electricity will be used. For example, the line losses for a 2000 watt generator with a 200 volt output located 500 feet from the batteries and using No. 4 copper wire can be determined using Table 4 and the previous formula, where:

Table 4

Connecting Wire Voltage, Power Losses, and Rough Costs per 100-foot Separation between Generator and Batteries															
Copper		Wire Voltage Drop (Volts/100 ft)							Wire Power Loss (Watts/100 ft)						
Wire No.	2-Wire $/100 ft	I = 10 amps	20A	30A	40A	50A	60A	70A	I = 10A	20A	30A	40A	50A	60A	70A
000	360	0.12	0.24	0.38	0.5	0.62	0.74	0.86	1.2	5.0	11	20	32	44	60
00	300	0.16	0.32	0.46	0.62	0.78	0.94	1.1	1.6	6.2	14	26	40	56	76
0	220	0.2	0.4	0.6	0.8	1.0	1.2	1.4	2.0	8.0	18	32	50	72	98
2	140	0.32	0.62	0.94	1.2	1.6	1.9	2.2	3.2	12.0	28	50	78	102	144
4	95	0.5	1.0	1.5	2.0	2.5	3.0	3.5	5.0	20.0	44	80	124	180	240
6	65	0.8	1.6	2.4	3.2	4.0	4.8	—	8.0	32.0	72	128	200	288	—
8	45	1.2	2.4	3.8	5.0	—	—	—	12.0	50.0	112	200	—	—	—
10	28	2.0	4.0	6.0	—	—	—	—	20.0	80.0	180	—	—	—	—

Note. From J. Leckie, G. Masters, H. Whitehouse, L. Young, Other Homes and Garbage, 1975, pg. 48. Copyright 1975 by Sierra Club Books. Reprinted by permission.

The maximum current output of the generator would be:

$$I = \frac{P}{E} = \frac{2000 \text{ watts}}{200 \text{ volts}} = 10 \text{ amperes}$$

With No. 4 copper wire the cost would be:

$$\$95 / 100 \text{ feet} \times \frac{500 \text{ feet}}{100} = \$475 \text{ for 500 feet of wire.}$$

The voltage drop in the wire would be:

$$.5 \text{ volts} / 100 \text{ feet} \times \frac{500 \text{ feet}}{100} = 2.5 \text{ volts dropped in the wire.}$$

The power lost in the wire would be:

$$5 \text{ watts} / 100 \text{ feet} \times \frac{500 \text{ feet}}{100} = 25 \text{ watts of power lost in the wire.}$$

Using a larger diameter wire would decrease the resistance and therefore the voltage drop and power loss in the wire would also decrease, but the cost would increase. By moving the tower and generator as close to the load as possible, line losses and wire costs can be minimized.

Battery Storage and Maintenence

One of the most popular techniques for energy storage from small wind systems is the lead-acid battery (Sullivan, 1978). By connecting six volt batteries in series, the voltage output of the wind generator can be matched exactly.

For example, the Dunlite generator has an output of 120 volts (DC). By connecting 20 six volt batteries in series the generator output can be connected directly to the battery bank.

Many factors must be considered for the proper location of batteries. The Enertech Corporation (1977) gives the following recommendations for a battery system location:

1. Batteries should be in a warm, dry, well-ventilated room.

2. They should be located as conveniently as possible with respect to the electrical power source and usage point.

3. They should be located away from all sources of direct heat, flame, or spark.

The temperature of the battery storage room is very important to the operation of the batteries. The electrolyte in lead-acid batteries is dilute sulfuric acid which provides optimum performance at 77°F. Below 77°F, the capacity of the battery bank will fall off to 89% of rated capacity at 55°F; 79% at 40°F; and 73% at 32°F. At higher temperatures than 77°F, the capacity of the battery bank will be increased to 105% at 85°F; 107% at 100°F; and 111% at 120°F. Continued operation at temperatures over 80°F is not recommended since it will reduce the life expectancy of the batteries (Enertech, 1977).

Under certain conditions, the battery electrolyte can freeze and break the battery container. The freezing point of the battery is dependent upon the state of charge. A fully charged battery will not readily freeze under normal winter conditions, but a fully discharged battery can freeze at temperatures slightly less than 32°F.

Batteries should be stored in racks which are arranged to allow convenient hook-up. Figure 7 presents various types of rack arrangements. Batteries arranged in racks should never be in physical contact with each other, and should have 1/2 inch to 1 inch of space between each unit (Enertech, 1977, pg. 44).

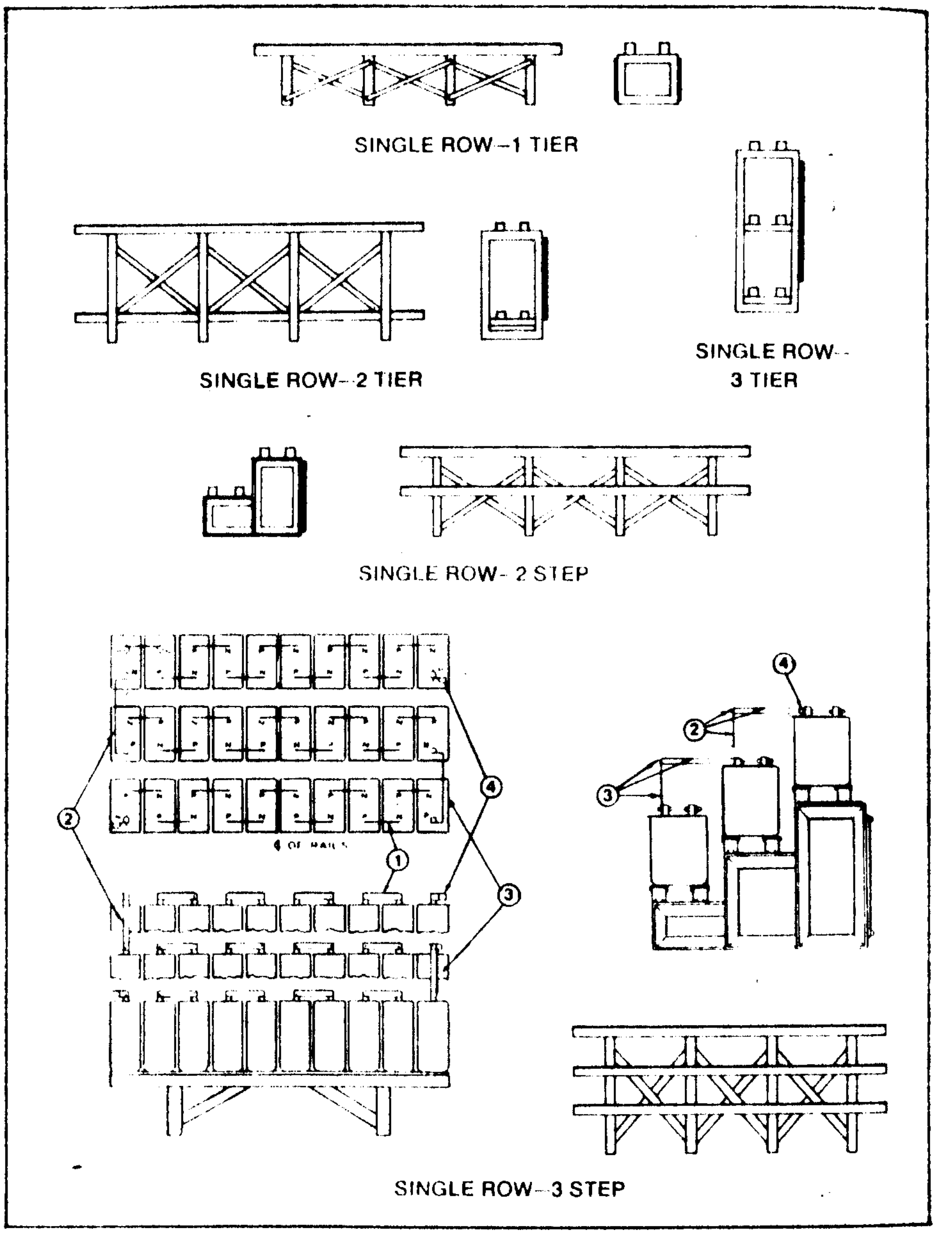
It is extremely important that adequate ventilation be provided to prevent the accumulation of hydrogen gas in the battery storage room. Hydrogen gas is produced by lead-acid batteries under charge, and since it is lighter than air it will tend to rise to the top of the battery storage room. A ventilator should be installed above the highest bank of batteries near the highest part of the room. Another ventilator should also be installed near the lowest point. The ventilation should be adequate enough to prevent the buildup of a level of 3 percent hydrogen gas by volume (Sullivan, 1978). Smoking or other sources of heat, spark or flame should not be allowed near the batteries.

Envirnomental Considerations

The impact onthe environment should be examined before

Figure 7

Battery Storage Arrangements



Note. From G. Sullivan, Windpower for Your Home, 1978, pg. 60. Copyright Cornerstone Library. Reprinted by permission.

installing a wind generator and tower. An often overlooked factor of wind generator installation is the aesthetic appearance of the unit. The Energy Research and Development Administration (ERDA) (1977, pp. 3, 4) conducted a public opinion survey which found that "Old Dutch" style windmills were preferred for tower structures. ERDA suggests that the aesthetic appearance of the new generators and towers could be improved by design changes and camouflaging.

The effect of the wind generator installation on plant and animal life should be considered. If access roads must be constructed to reach the site, damage could result to plant and animal life. Birds killed by generator blades is a possibility but it has been shown (ERDA, 1977) that this is a relatively minor possibility unless the generator is located in a migratory bird route.

The noise produced by the generator blades could be annoying to some individuals, and the shadow cast by the tower may also cause a disturbance. In addition, television signals can experience interference from metal windmill blades, but most of this interference would be limited to a small area near the wind generator.

Included in the discussion of environmental impact factors are the effects of a tower structural failure or generator blade failure. The failure of a tower would affect only the area located in a radius about the tower base equal to the height of the tower. The failure of a generator blade, on the other hand, could result in the blade traveling up to 15 times the blade assembly's original diameter. This occurs only rarely, and usually to generators located in turbulent areas during a severe storm (Langa, 1980). A thrown blade will "flutter" to the ground due to the blade shape, and any damage caused by the blade would be less than the damage caused by an object of similar size and weight without the aerodynamic shape.

Intangible Considerations

Very little mention of intangible comparisons is found in literature about wind system installations. Intangible considerations are difficult to quantify, classify, or appreciate (Riggs, 1976, pp. 116, 120). Langa (1980) mentions intangibles such as "peace of mind," "satisfaction," and "visual magic" in his discussion of wind system intangibles (pg. 31). He neglects, however, to make any attempt to measure or quantify these variables. Riggs (1976) feels that intangible comparisons can be made by completing two sets of variables by an individual or group decision where one set is the ranking of possibilities under a criterion, and the other is a measurement of the relative importance of each of the criterion. Riggs (1976) lists five steps to follow in this procedure:

1. Select independent criteria by which to compare all alternatives.
2. Rate the relative importance of the criteria.

3. Determine whether there is a cutoff score for any criterion that makes an alternative unacceptable, regardless of the scores on the rest of the criteria. If so, state the cutoff ratings.

4. Assign values to the extent each alternative satisfies each criterion. An alternative is eliminated if any value falls below a criterion cutoff score.

5. For each alternative, multiply its criteria ratings by the respective importance factors, and add all the resulting products. The total scores thus obtained can be compared, to determine the most attractive alternative. (pg. 119)

A relative ratio technique can also be used in this method to rank more tangible criteria. For example, automatic ranking can be found on a scale of 1 to 10 for the cost of a battery. On this scale, the higher ranking is more desirable, therefore the lowest priced battery would be ranked the highest:

Battery 1 cost $17

Battery 2 cost $14

Battery 3 cost $12

		Ranking
Battery 1	$\frac{\$12}{\$17} \times 10 =$	7.1
Battary 2	$\frac{\$12}{\$14} \times 10 =$	8.6
Battery 3	$\frac{\$12}{\$12} \times 10 =$	10.0

The last step in this process would be to multiply the rankings of the individual batteries by the importance rating given to battery cost. Figure 8 is an example of a decision matrix for the site selection of a wind generator. The matrix makes use of tangible and intangible variables to determine the most appropriate site.

Figure 8

A Decision Matrix For

Site Selection

of A Wind Generator

CRITERIA	I*	Site 1	Rate	RxI	Site 2	Rate	RxI	Site 3	Rate	RxI
Installation Cost										
Educational Value										
Practical Use										
Efficient Wind Location										
TOTALS										

*Where I is the importance of the individual criterion ranked on a scale from 1 to 10 with 1 being low and 10 being high.

The higher the number, the greater the preference, therefore the site with the highest total would be the preferred site.

Review of Associated Equipment

Dunlite Generator Description

The Dunlite Electrical Company of Adelaide, Australia has been manufacturing wind electric systems for more than half a century (Sullivan, 1978). Distributors of their equipment in the United States include: Energy Alternatives, Greenfield, Massachusetts; Solar Wind, East Holden, Maine; and the Enertech Corporation, Norwich, Vermont. According to Sullivan (1978), the Dunlite unit is very reliable and the most popular windplant in the United States.

Quirk's of Sidney is the Australian sales agent for the Dunlite units, and is the reason that the Quirk name is found on the equipment. The Industrial Technology Department equipment includes, along with the generator, a control panel, twenty 6 volt batteries rated at 135 amp-hours each, and an inverter which changes 120 volts (DC) into 120 volts (AC). The performance specifications of the generator are:

1.	Maximum continuous output	2kW
2.	Peak output (30 mph wind speed)	3kW
3.	Cut-in wind velocity	8 mph
4.	Maximum output wind velocity	25 mph

According to the instruction manual, the generator is designed to withstand winds up to 100 mph. Automatic feathering of the blades is accomplished by centrifugal weights to prevent excessive generator speeds in strong winds.

Generator Operation

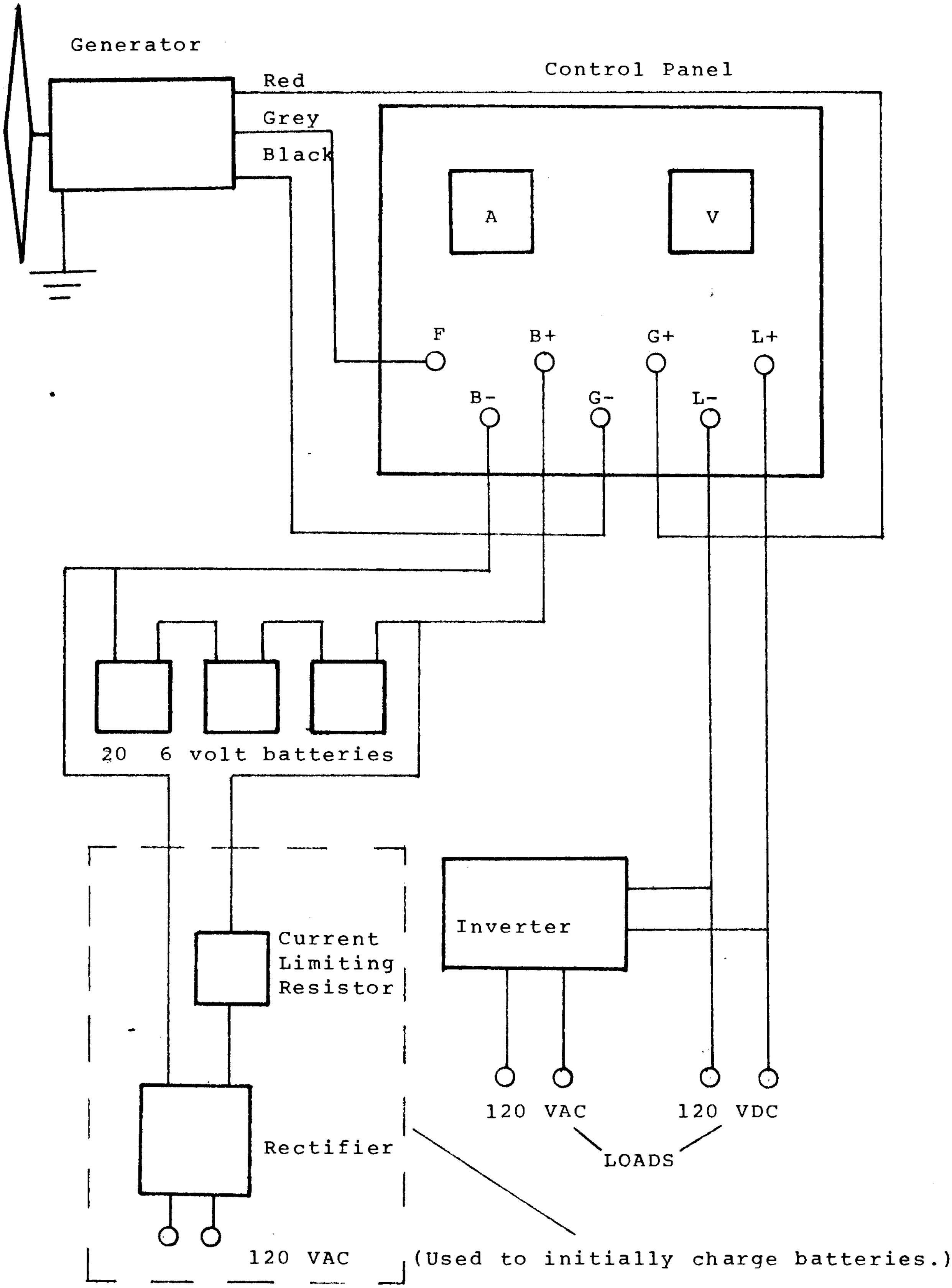
The AC current produced in the Dunlite generator is converted to DC by diodes located inside the generator housing. DC current will therefore be found at the generator output terminals. The current produced by the generator travels directly to the transistorized control panel which includes a voltmeter and ammeter for monitoring the system operation. Current is automatically directed to where it is needed, and can flow directly through the panel to any load. If there is more than enough current for the load, any extra current is automatically diverted to the batteries for storage. If the batteries are fully charged and no power is needed, the control automatically cuts off the generator output by lowering the voltage to the alternator field windings.

The net effect is that any devices connected to the system are operated directly from the generator when there is sufficient wind; but when there is not, the batteries take over and supply the extra power, or all the power when there is no wind. This is all done automatically. The batteries serve as a stabilizer for the fluctuating wind generated current, and have an average life of 15 to 20 years when used with this sytem (Clews, 1975).

An inverter is also included with the system. This device will change the 120 volts DC from the batteries or generator into 120 volts AC which is the more commonly used voltage in residential buildings. Figure 9 is a block diagram showing the connections between the components in the Dunlite system.

Figure 9

Dunlite Wind System Connections



Methods of Procedure

Survey of Equipment

The following components comprise the Industrial Technology's wind generating system as of October, 1980:

1 110v Dunlite generator; serial number 18462

3 Propeller blades with stub arms

3 Governor weights with nuts

1 Tail Assembly

1 Propeller hub assembly; serial number 2507

1 Tower cap

1 Brake assembly

1 Ten-foot tower section

20 6 volt batteries

1 Control Panel; serial number c 206-74

1 DC to AC inverter

1 Rectifier

1 Current limiting resistor

1 Instruction Manual

All components appear in excellent condition except for two items. First, the inverter was damaged in shipping, and two bakelite fuse holders on the front of the unit were broken. Since the fuses are of a European style not generally used in the United States, they should be replaced with fuse holders that would use components of a more available type.

Second, the propellers have some small dents in the blades which could cause vibration problems. The blades are carefully balanced and aligned at the factory. Attempts to repair the dents could cause the blade to be unbalanced and create vibration in the propeller assembly. However, the instruction manual states that some denting of the blades is permissible; and unless the damage is substantial, the overall performance of the machine will not be affected.

The additional electrical equipment needed for a complete installation would include wire, connectors, electrical boxes, and switches to connect the generator to the control panel, batteries, and inverter. Additional wire would be needed for any loads connected to the system.

Survey of Faculty

To determine possible locations for the wind generator installation a memorandum (Appendix C) was distributed to Industrial Technology Department Faculty. The memorandum requested suggestions, recommendations, and ideas for the installation and use of the wind generator. Seven individuals expressed an interest in the project, and each respondent was interviewed. The following suggestions for the generator location and use were obtained.

Site 1

The wind generator and tower would be located on the roof of the ITC building with the controls and batteries mounted inside the ITC building. The generator would be used to:

1. Supply electricity for lights along the parking lot and sidewalks; and

2. Supply electricity for lights on the front of the ITC building.

The proposed installation was discussed with the building architect (Grimes, Note 1) and his ideas were noted as follows:

1. The aesthetic appearance of the building would be marred by the tower.

2. The building was not designed for a tower to be mounted on the roof.

3. Reinforcement would be required in the roof structure for a roof mounted tower.

4. Vibrations caused by the generator could cause structural damage and leakage in the roof.

The architect strongly advised against mounting the tower on the ITC roof, and for this reason it was felt that Site 1 would not be suitable.

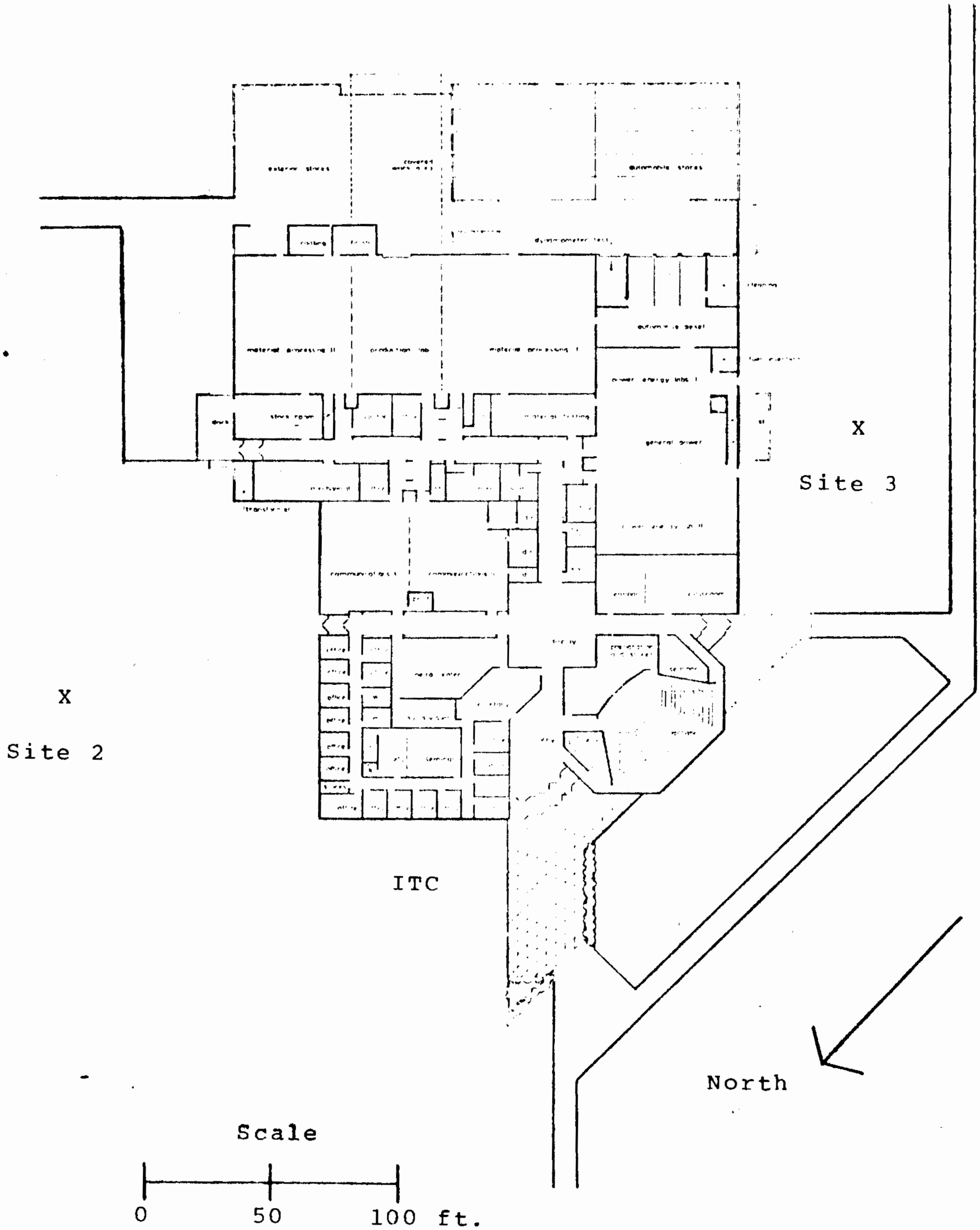
Site 2

The wind generator and tower would be located northeast of the ITC building with the controls and batteries mounted inside the ITC building. Figure 10 indicates the proposed location. The generator would be used to:

1. Supply electricity for outlets along the parking

Figure 10

Site Locations



lot for use by electrical vehicles; and

2. Supply electricity to heat the sidewalks in winter to melt snow and ice.

Site 3

The generator and tower would be located southwest of the ITC building with the controls and batteries mounted in the storage area next to the power laboratory. The proposed location is shown in Figure 10. The generator would be used to supply both AC and DC power for the power laboratory.

Site 4

The generator and tower would be located next to the UNI observatory south of the campus near married student housing, with the controls and batteries housed in a separate building. The generator would be used to:

1. Supply electricity for the UNI observatory building; and

2. Supply electricity for electrical vehicles to be used by UNI personnel.

Site 5

The generator and tower would be located on personal property owned by an Industrial Technology faculty member approximately five miles northwest of the UNI campus. The controls would be housed in existing buildings with the generator output used to:

1. Supply electricity for a small barn; and
2. Supply electricity for heating a stock tank in winter

Site Selection Criteria

The following independent criteria were selected by the researcher to further evaluate the suggested locations for the wind generator.

Installation cost. The evaluation of this criterion included the cost of a tower and base, buildings, wiring, and necessary security enclosures to protect the equipment from unauthorized personnel.

Educational value. This criterion was evaluated by the accessibility of the wind system for demonstrations, class work, and research.

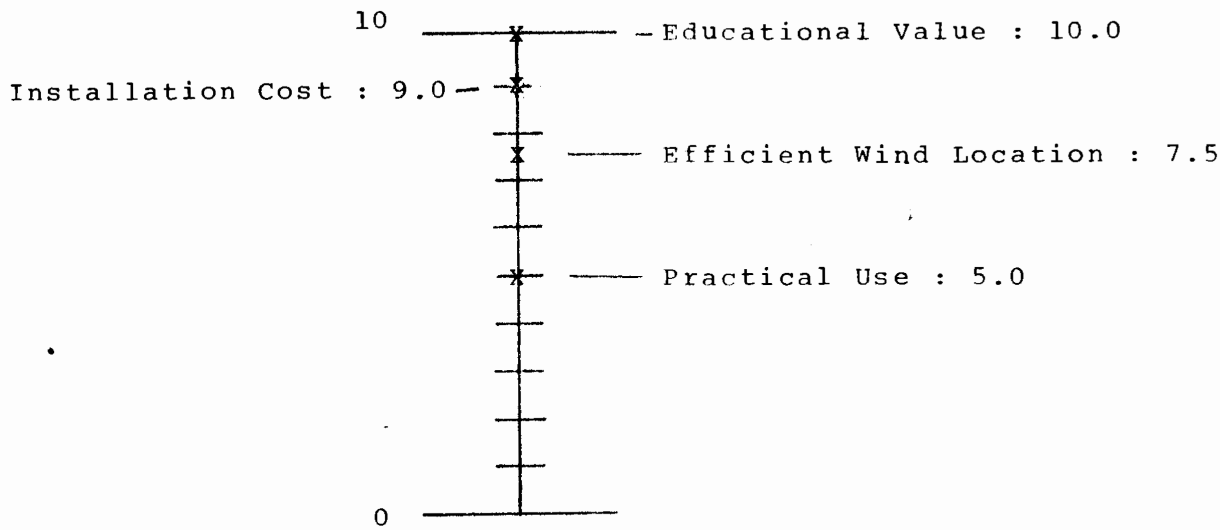
Practical use. The loads that would be connected to the wind system and their practical use were the factors used for rating the proposed sites according to this criterion.

Efficient wind location. The sites were rated by their relative wind speeds by comparing wind speed measurements made at each location.

The relative importance of the criteria were rated as shown in Figure 11, with ten representing highest importance, and zero reflecting low importance.

Figure 11

Importance Scale of Evaluation Criteria



Wind Speed Measurements

The first step in making wind speed measurements was to plot a wind rose of the average monthly wind speeds to determine the direction of the prevalent winds. Using the data in Table 5 taken from a Local Climatological Data sheet (Appendix B), a wind rose was plotted (Figure]2).

An instantaneous anemometer and a totalizing or averaging anemometer were constructed to measure the wind speeds at each site. Initially, the measurements were taken with the instantaneous meter, but because the wind speeds tended to vary widely over a short time period accurate readings were difficult to obtain with this meter. The totalizing anemometer was designed and built in order to give more representative readings (Appendix D). Figure 13 is a drawing of

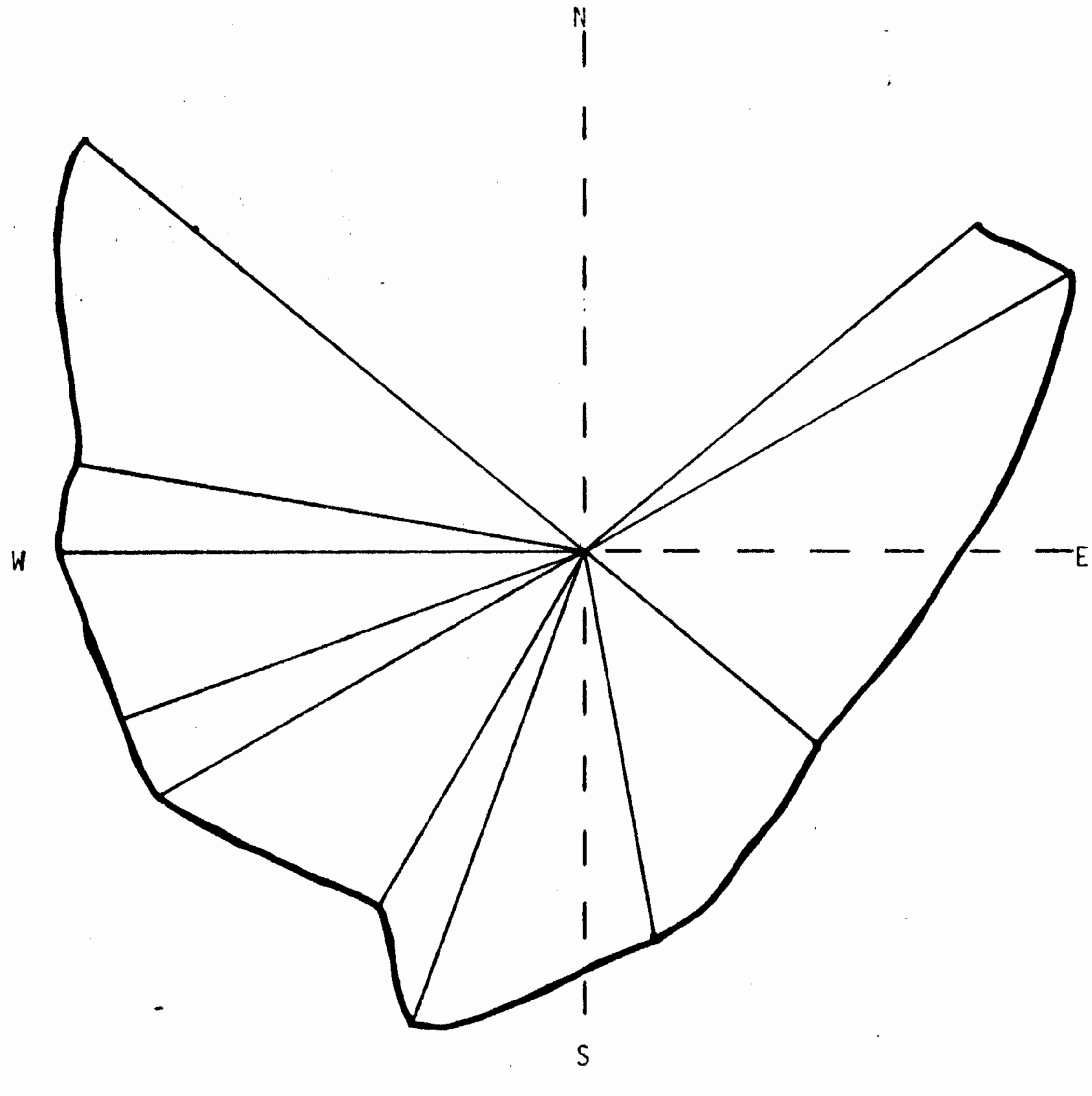
Table 5

Average Monthly Wind Speeds and Directions

Month	Average Speed (mph)	Direction (degrees x 10)
Jan.	10.9	31
Feb.	11	05
Mar.	13.6	31
Apr.	11.9	06
May	10.5	24
Jun.	10.8	20
Jul.	6.4	13
Aug.	8.4	17
Sep.	8.8	21
Oct.	11.2	27
Nov.	10.4	25
Dec.	11.0	28

Figure 12

A Wind Rose For Waterloo Iowa



the equipment used to take the wind speed measurements.

Measurements were taken daily from 3:30 to 4:00 p.m. at each site for seven days. The National Weather Service (NWS) located at the Waterloo Municipal Airport broadcasts hourly weather summaries, including wind speeds, on the weather station WXL 94 at 162.55 mhz. The NWS average wind speed measurements are taken at a height of 15 feet above ground and 15 minutes before the hour (NWS, Note 2). The NWS wind speed measurements were recorded at the same time as the site measurements to be used as a standard for comparison. Table 6 contains the wind speed data for each site along with the NWS reading. The data for sites 2 and 3 are identical since the measurements were taken at the same site, and represents the average wind speed at the ITC building. Table 7 shows the average wind speed for the seven day period of both the measured wind speeds and NWS wind speeds. Also shown is a percentage representing the measured values compared to the NWS values.

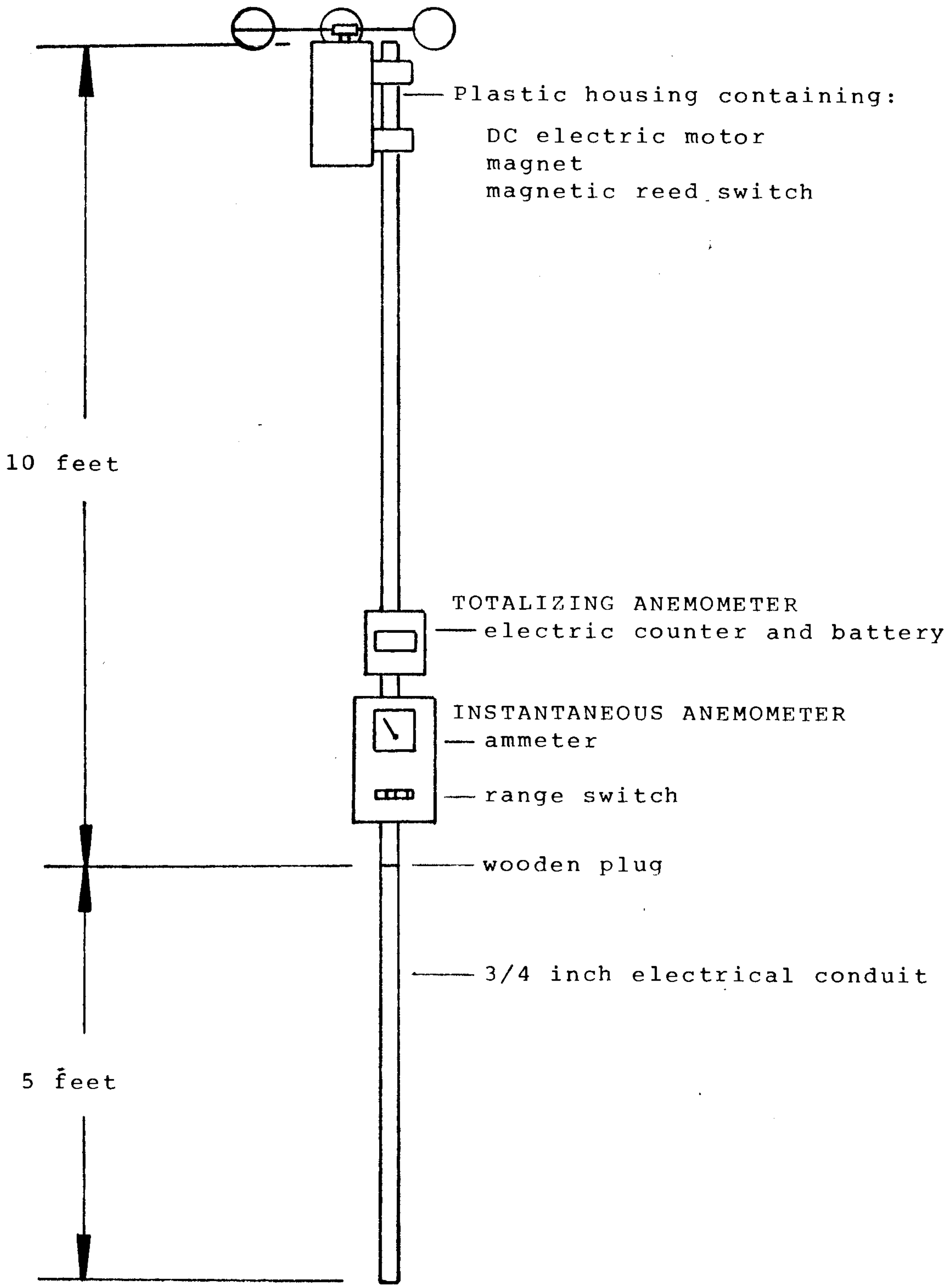
Table 7

Wind Speed Comparisons for a Seven Day Period

Values	Site 2 and 3	Site 4	Site 5
Measured Values (mph)	11.7	13.6	12.5
NWS Values (mph)	16	16	15.9
Percentage of Measured Values of NWS Values	73%	86%	79%

Figure 13

Portable Equipment for Wind Speed Measurements



(Not drawn to scale)

Table 6

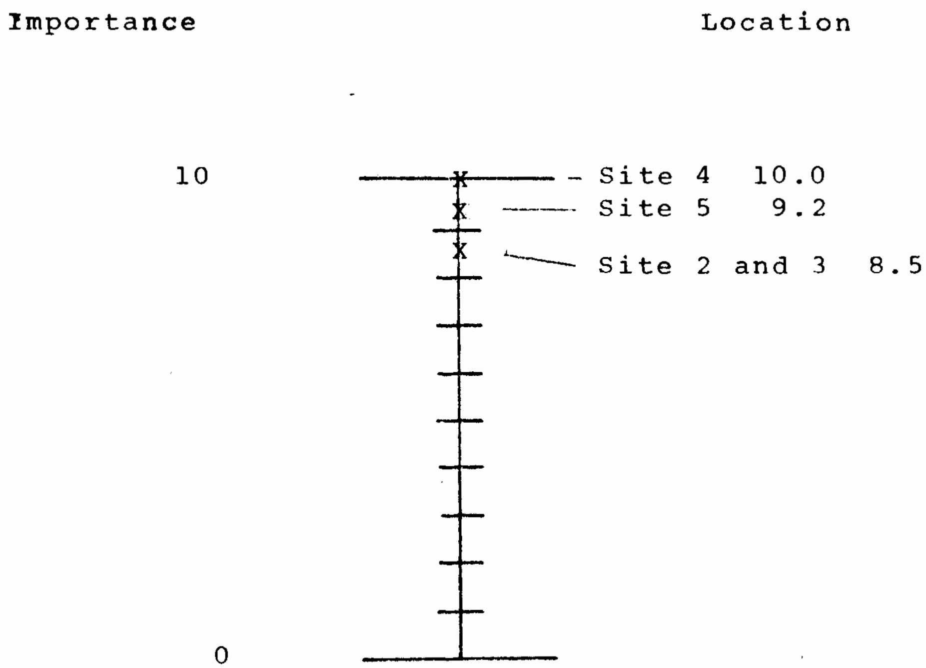
WIND SPEED DATA

Sites 2 and 3							
Measurement No.	1	2	3	4	5	6	7
Measured Average Wind Speed (mph)	11.9	11.3	8.3	14.4	10.0	16.4	10.0
NWS Average Wind Speed (mph)	17	16	13	18	14	18	16
Site 4							
Measurement No.	1	2	3	4	5	6	7
Measured Average Wind Speed (mph)	14.1	15.6	8.8	15.2	13.1	15.5	13.6
NWS Average Wind Speed (mph)	17	16	13	18	14	18	16
Site 5							
Measurement No.	1	2	3	4	5	6	7
Measured Average Wind Speed (mph)	15.6	13.4	13.6	11.2	11.9	9.1	12.8
NWS Average Wind Speed (mph)	18	17	19	14	14	13	16

The relative rankings of the average wind speeds at each site were subsequently developed, with the results shown in Figure 14.

Figure 14

Efficient Wind Location Rankings



Each of the rankings were calculated as follows:

$$\frac{86\%}{86\%} \times 10 = 10 \qquad \text{Site 4}$$

$$\frac{79\%}{86\%} \times 10 = 9.2 \qquad \text{Site 5}$$

$$\frac{73\%}{86\%} \times 10 = 8.5 \qquad \text{Site 2 and 3}$$

Height Measurements of Wind Obstructions

To determine the necessary tower height needed to place the generator above the turbulence caused by obstructions, the height of the obstructions was found. Figure 15 is a diagram indicating the method used to determine the height of the obstructions. A compass was also used to determine the direction of the obstructions from the proposed tower locations. The height, distance, and direction of the largest trees and buildings within a 300 foot radius of each site are shown in Table 8. The obstructions located in the direction of prevailing winds, as shown in Figure 12 would be the major producers of turbulence for the generator.

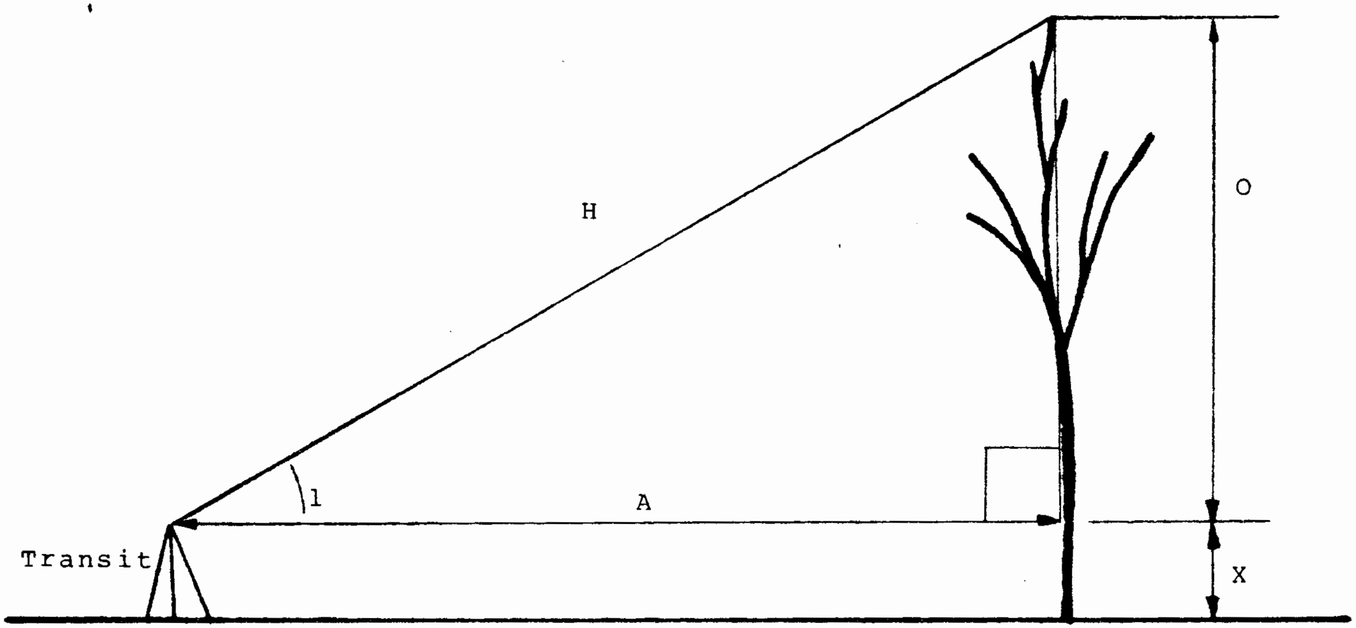
Table 8

Height and Direction of Wind Obstructions

Location	Wind Obstructions		
	Height (ft)	Direction	Distance (ft)
Site 2	77	NW	300
	55	NNW	146
	50	SE	168
	16	SW	100
Site 3	25	NE	50
	40	NW	234
Site 4	27	S	100
Site 5	40	N	110

Figure 15

Method for Measuring Wind Obstruction Heights



TAN 1 = O/4

O = (TAN 1)(A)

X = Tripod height = 5 feet

A = Distance from transit to obstruction

Obstruction height = O + X

Tower Height Selection

Using information from Table 8, the minimum recommended tower height for each site was determined as shown in Table 9. The height was determined by taking the tallest obstruction height at each site, and adding 20 feet.

Table 9

Recommended Tower Height

Location	Height (ft)
Site 2	90
Site 3	60
Site 4	50
Site 5	60**

** a 30 ft. tower is already installed at that site.

Installation Cost

This criterion was evaluated by finding the estimated costs at each site for the following items:

1. Generator tower;
2. Generator tower base;
3. An enclosure for the controls and batteries;
4. Security enclosures for protection of the equipment; and
5. Wiring for connecting the controls and batteries to the generator.

The least expensive method of obtaining a suitable tower would be the utilization of the existing ten foot section of tower, and the fabrication of the remaining sections by the Industrial Technology Department. The costs (Weissman, Note 3) of the materials used in the existing section of tower are shown in Table 10.

Table 10

Material Costs for Tower Fabrication

Material	Cost
2 1/4 x 2 1/4 x 3/16 angle cold rolled steel	$1.12 per linear ft.
1 3/4 x 1 3/4 x 1/8 angle cold rolled steel	$0.55 per linear ft.
1 x 1 1/8 angle cold rolled steel	$0.31 per linear ft.
1 1/4 x 3/16 flat mild steel	$0.38 per linear ft.

Table 11 is an estimation of the material costs for constructing towers up to a height of 90 feet using the materials given in Table 10.

The recommended size for concrete tower footings is three cubic feet for each leg (Sullivan, 1978). The estimated cost (November, 1980) for a concrete base is $149.45 (Shirey, Note 4).

Table 11

Estimated Tower Costs

Height	Costs
20	$ 66
30	$157
40	$283
50	$457
60	$698
70	$1029
80	$1361
90	$1692

Some proposed sites will need a building to house the batteries and controls. The estimated cost (Payless, Note 5) is $837 for a 8 ft x 10 ft building (Appendix E). Some sites will need security fences to protect the equipment. The estimated costs for two sizes of enclosures (Miller, Note 6) are:

$891 for a 26' x 19' x 6' high fence

$688 for a 12' x 12' x 6' high fence

All proposed sites will need electrical wire to connect the generator to the controls and battery bank. Table 12 contains the cost (November, 1980) of appropriate size wire (Crescent, Note 7).

Table 12

Wire Costs

Wire Size	Price per 1000 ft.	
	NM (indoor)	UF (underground)
14 - 3	$154.20	$169.96
12 - 3	$224.43	$241.64
10 - 3	$333.56	$352.17

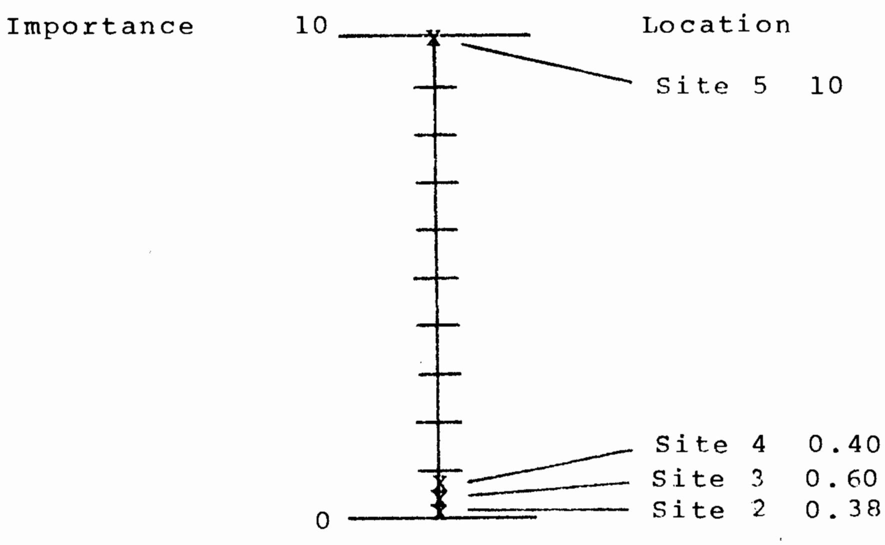
The estimated installation cost for each site was determined as follows:

Site 2	tower and base		$1841
	security		$ 688
	wiring		$ 75
		TOTAL	$2604
Site 3	tower and base		$ 843
	security		$ 688
	wiring		$ 25
		TOTAL	$1556
Site 4	tower and base		$ 602
	building		$ 837
	security		$ 891
	wiring		$ 25
		TOTAL	$2355
Site 5	wiring		$ 100
		TOTAL	$ 100

The estimated installation costs included only the items where cost was affected by location. For example, the cost of switches, connectors, and circuit breakers was not included in the wiring estimates since these items will be found in all of the proposed sites. However, the amount of wire used varied from site to site; therefore, the cost of wire was included in the estimates.

Figure 16

Estimated Installation Cost Rankings



The estimated installation costs were ranked as shown in Figure 16. The rankings were calculated as follows:

$$\frac{\$100}{\$100} \times 10 = 10 \quad \text{Site 5}$$

$$\frac{\$100}{\$2355} \times 10 = 0.4 \quad \text{Site 4}$$

$$\frac{\$100}{\$1556} \times 10 = 0.6 \quad \text{Site 3}$$

$$\frac{\$100}{\$2604} \times 10 = 0.38 \quad \text{Site 2}$$

Educational Value

Each site was evaluated according to the accessibility of the wind generating equipment for faculty and student use. The sites were ranked as shown in Figure 17 according to the distance, in miles, from the ITC building to the wind generating system. The rankings were calculated as follows:

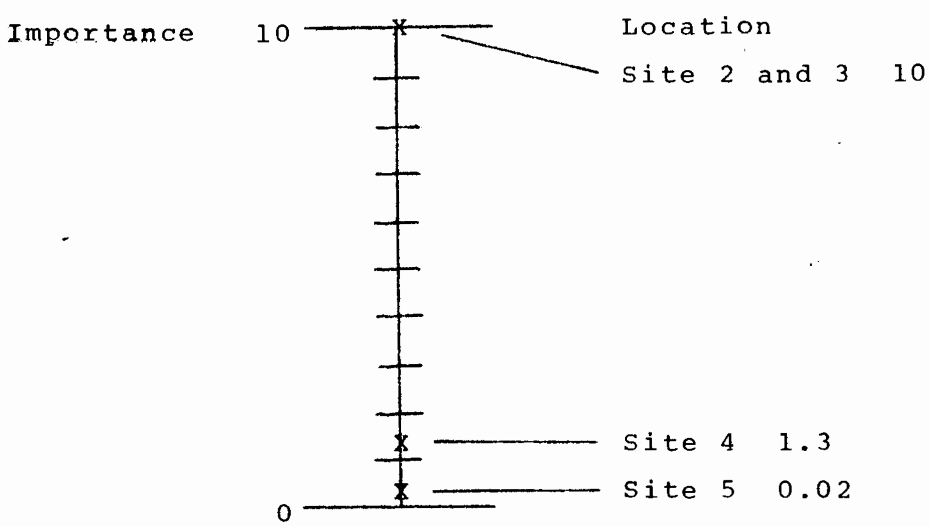
$\frac{.1}{.1} \times 10 = 10$ Site 2 and 3

$\frac{.1}{.75} \times 10 = 1.3$ Site 4

$\frac{.1}{5} \times 10 = 0.02$ Site 5

Figure 17

Educational Value Rankings



Practical Use

Practical use was a difficult criterion to evaluate. The sites were considered by the author according to the loads that would be connected to the wind generator, and the practical value of the loads. The sites were arbitrarily ranked as shown in Figure 18.

Site Selection

By using the importance ratings of the four criteria, and the rankings of each site according to the criteria, the most appropriate site was selected as shown in Figure 19. The site with the highest point total on the decision matrix is #3. This site locates the tower southwest of the ITC building with the controls and battery bank mounted in the storage area next to the power laboratory. Based upon all of the factors previously discussed, Site 3 is the recommended installation site for the wind system.

Figure 18

Practical Use Rankings

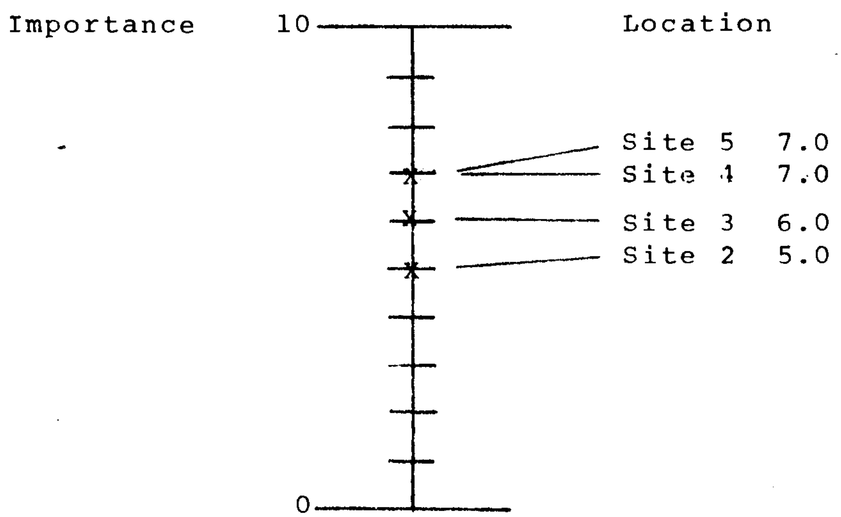


Figure 19

DECISION MATRIX FOR SITE SELECTION

CRITERIA	LOCATION										
		Site 1		Site 2		Site 3		Site 4		Site 5	
	I	RATE	RATE X I	RATE	RATE X I	RATE	RATE X I	RATE	RATE X I	RATE	RATE X I
Installation Cost	9.0	NA	NA	.38	3.42	0.6	5.4	0.4	3.6	10	90
Educational Value	10	NA	NA	10	100	10	100	1.3	13	.02	2
Practical Use	5.0	NA	NA	5	25	6	30	7	35	7	35
Efficient Wind Location	7.5	NA	NA	8.5	63.75	8.5	63.75	10	75	9.2	69
TOTALS			NA		192.17		199.15		126.6		196.0

Approval Needed for Installation

Before the proposed installation can be attempted, the necessary approval must be obtained from the appropriate sources. Any construction projects on the UNI academic campus are subject to approve from the following groups or individuals:

1. Every proposed project is classifed as either an individual or department proposal by the Facilities Planning Office. The wind generator installation is an Industrial Technology Department project, and would therefore need the approval of the Head of the Industrial Technology Department.

2. Project proposals are reviewed by the Campus Planning and Advisory Committee. The committee approval is needed before a project can be undertaken. The wind generator installation would be presented to the committee by the Industrial Technology Department representative, Dr. Clifford McCollum.

3. Plans for a project must be checked and approved by a licensed engineer. The wind generator plans, including the generator tower structure, will need to be approved by a structural engineer since the Facilities Planning Office does not have an engineer familiar with tower design.

4. Although the UNI campus is exempt from Cedar Falls zoning laws, the wind generator installation is still

required to meet the standards set forth by the *National Electrical Code*.

5. A construction permit will be issued by the City of Cedar Falls for the actual construction work. The work can be done by either the Industrial Technology Department or an outside contractor. In the latter case the UNI Physical Plant will handle the competitive bids.

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this paper was an attempt to answer the question: What is the most appropriate site for the erection of a wind generator using suggestions for possible sites from Industrial Technology faculty; and evaluating installation cost, education value, practical use, and wind speeds at each site?

Five possible sites for the generator were suggested by Industrial Technology faculty. The variable costs of installing the generator at each proposed site, the distance of the generator from the ITC building, the practical use of the proposed loads connected to the generator output, and average wind speeds for a seven day period were evaluated and ranked for each site. Site 1 was eliminated as a possibility on the recommendation of the ITC building architect. In his opinion the building could be damaged by mounting a tower and generator on the ITC building roof as proposed by Site 1. The remaining site rankings were compared by using a decision or selection matrix and the appropriate site was selected. The recommended site for the wind generator was southwest of the ITC building near the power laboratory. The minimum suggested tower height was 60 feet. The controls and batteries for the wind system would be located in the power laboratory storage area. The estimated installation cost was approximately $1556.

There are several areas that should be discussed about the selected site. This paper was a preliminary research into the possibility of installing the wind generator. A more detailed analysis should be undertaken of the site that was selected. This analysis should include the design of the complete electrical system that will be used including a suitable rack arrangement for the battery bank, and the type and number of loads, switches, and wiring that will be needed. Detailed working drawings of the wiring must be developed for the complete system to enable contractors, if they are used, to make appropriate bids; and for presentation to the committees and individuals responsible for approving the project. For the same reasons, working drawings and specifications are also required for the tower and base construction.

The tower height which was selected for the site is an optimum value. It is entirely possible that a shorter tower could be used if the equipment was not expected to operate continually. The reduction in operation would be necessary since the generator would be subjected to turbulence when the wind was blowing from the direction of the wind obstructions if the tower was lower than the obstruction. The purpose of the installation is primarily for education utilization and would not require continuous operation. Therefore, the reduction in tower height is one way to reduce the installation cost. A study of wind speed and turbulence at various heights at the proposed site would assist in selection of an appropriate tower height if this approach were used.

Mention should also be made of the estimated installation costs used in this report. The installation cost for the selected site is an approximate value based on variable costs that were affected by the location. All of the costs involved in the actual erection of the wind generator were not evaluated. A more complete analysis of the installation cost should be made if and when a decision to install the generator is made.

Finally, the installation of the wind generator will require the coordination of many people and resources. In order to provide an aid for future study of the wind system installation, a PERT diagram was developed as shown in Figure 20. The diagram outlines the activities and the time required for the activities in the wind generator installation. Table 13 is the activity list for the PERT diagram.

Figure 20.

PERT Diagram for a Wind System Installation at UNI

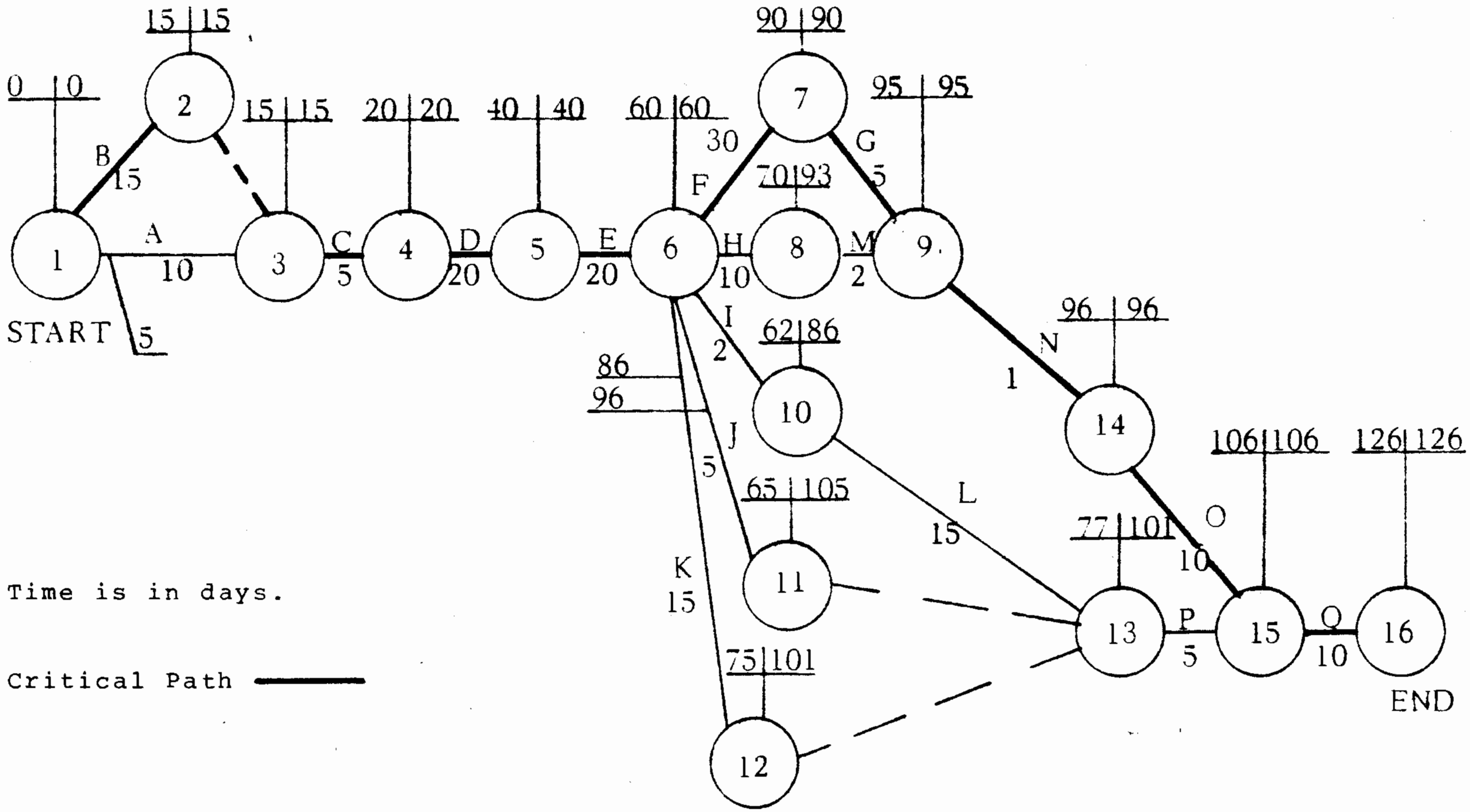


Table 13

Activity List for PERT Diagram

Description	Symbol
Develop wiring diagrams	A
Develop structural drawings	B
Obtain department approval	C
Obtain Campus Planning and Advisory Committee Approval	D
Acquire funding	E
Construct tower	F
Paint tower	G
Construct base	H
Assemble generator	I
Mount controls	J
Construct battery racks	K
Wire loads, controls, and batteries	L
Erect tower	M
Mount generator	N
Construct security fence	O
Wire generator to batteries and controls	P
Test system	Q

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Appendix A

Climatic Atlas of the U.S. information

The Climatic Atlas of the U.S. is printed by the Government Printing Office for the:

U.S. Department of Commerce
National Climatic Center
Federal Building
Asheville, North Carolina
28801

The atlas includes information about temperature means and extremes, precipitation amounts, sunshine average, cloud cover, and wind directions and speeds.

The cost of the atlas is approximately $7.00 (November, 1980), and can be purchased from the:

Superintendent of Documents
U.S. Government Printing Office
Washington, D.C.

Appendix B

Local Climatological Data

sheet for

Waterloo, Iowa

Local Climatological Data
Annual Summary With Comparative Data

1979

WATERLOO, IOWA

Narrative Climatological Summary

The city of Waterloo is situated on the banks of the Cedar River in northeast Iowa, and has a climate continental in character. It is far removed from the moderating influence of any large body of water, and a wide variation is experienced in both temperature and precipitation during the four distinct seasons.

The average annual precipitation for Waterloo is near 32 inches, though annual amounts have varied from 17.35 inches in 1910 to 50.79 inches in 1965. The most likely annual amount is between 28-1/2 and 35-1/2 inches. The distribution of precipitation through the year is very favorable for agriculture with an average 71 percent of the year's total falling in the April to September crop season. As befits the continental climate, the annual temperature range is large. January, the coldest month, averages near 18°F and the warmest month, July, averages about 74°. Extreme temperatures are -34°F and 112°.

It is sometimes convenient to divide the year into periods corresponding to the growing season of the staple crops of the area. Winter, corresponding to the period of dormant plant life, extends from November 7 to March 31, based on a mean daily temperature of 40°. This winter period is a season of cold, dry weather occasionally broken by storms of short duration. Precipitation during the winter is mainly in the form of snow with rain the predominant form at the beginning and at the close of the season. Like the annual rainfall, annual snowfall varies considerably from year to year, having ranged from 11.6 inches in the 1967-68 season to 59.4 inches during the winter of 1961-62. Minimum temperatures of zero or below have an average occurrence of about 28 days per year. Bitterly cold days with maximum temperatures zero or lower average about 3 days per year. Temperature records after 1959 from the hygrothermometer exposed on a field site at the airport indicate a higher frequency of temperatures of zero or below (see Normals, Means, and Extremes table on next page). During the winter, prevailing winds are from the northwest.

The spring growing season is marked by an increase in both frequency and intensity of rainfall and by a rapid increase in the seasonal temperature march. Spring extends from April 1 to May 18, based on mean daily temperatures between 40° and 59° - a range suitable for hardy crops. Average date of the last temperature of 32° is May 6.

The summer growing season extends from May 19 to September 19, based on a mean daily temperature of 60°. Precipitation, increases during the spring and reaches its maximum in June. Most summer precipitation falls in connection with thundershowers, three-fourths of which occur during the summer growing season. The prevailing summer wind is southerly, supplying moisture from the Gulf of Mexico. Daily temperatures reach their highest level in July or early August. The occurrence of maximum temperatures of 90° or above for 1895-1959 have averaged about 22 days per year and maxima of 100° or higher average about 2 days per year. Hygrothermometer data after 1959 indicate lower frequencies for maxima of 90° and 100°. Average date of the first temperature of 32° is October 3.

The fall growing season extends from September 20 to November 6, by which time the mean daily temperature has fallen to 40°. The fall is characterized by a decline in precipitation and frequent periods of warm days, cool nights, and cloudless, but hazy, skies.

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA AND INFORMATION SERVICE / NATIONAL CLIMATIC CENTER ASHEVILLE, N.C.

Meteorological Data For The Current Year

Station: WATERLOO, IOWA MUNICIPAL AIRPORT Standard time used: CENTRAL Latitude: 42° 33' N Longitude: 92° 24' W Elevation (ground): 866 feet Year: 1979

Month	Temp °F Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days Base 65 °F: Heating	Cooling	Precipitation in inches, Water equivalent: Total	Greatest in 24 hrs.	Date	Snow, Ice pellets: Total	Greatest in 24 hrs	Date	Relative humidity pct. Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind, Resultant: Direction	Speed m.p.h.	Average speed m.p.h.	Fastest mile: Speed m.p.h.	Direction	Date	Percent of possible sunshine	Average sky cover, tenths, sunrise to sunset	Number of days, Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperature °F Maximum (b): 90° and above	32° and below	Minimum: 32° and below	0° and below	Average station pressure mb, Elev. 878 feet m.s.l.
JAN	11.6	-4.6	3.6	30	23	-20	11	1903	0	1.41	0.46	18-19	17.2	5.3	12-13	71	71	65	68	31	4.8	10.9	26	34	13		6.4	9	4	16	9	6	0	1	0	31	31	22	988.5
FEB	19.4	.0	9.7	37	23	-24	5	1547	0	0.32	0.06	22-23	2.9	0.9	7-8	71	70	65	69	35	0.7	11.7	31	33	14		6.6	6	10	12	9	0	0	2	0	22	28	14	990.9
MAR	39.4	24.1	31.8	61	20	9	15	1024	0	3.06	1.12	23	4.3	3.3	23-24	82	83	76	76	31	3.1	13.6	32	35	24		8.1	4	5	22	12	2	2	7	0	7	25	0	983.7
APR	53.9	34.2	44.4	72	22	15	6	612	0	4.37	2.86	19-20	4.7	4.7	1-2	77	84	60	59	06	0.7	11.9	43	11	11		6.6	6	8	16	11	2	4	2	0	0	14	0	985.1
MAY	70.6	45.7	58.2	86	30	32	1	236	35	3.83	1.36	29	0.0	0.0		71	78	51	52	24	1.6	10.9	32	27	17		6.0	6	12	11	10	0	6	0	0	0	1	0	982.7
JUN	80.1	58.4	69.3	90	6	44	1	20	153	6.07	2.86	17-18	0.0	0.0		77	80	58	56	20	2.6	10.8	32	32	10		6.2	6	13	11	12	0	7	1	1	0	0	0	984.1
JUL	82.1	62.5	72.3	89	12	52	18	2	237	6.68	2.40	29-30	0.0	0.0		84	87	62	59	13	1.8	6.4	30	33	3		7.0	3	12	16	9	0	7	0	0	0	0	0	985.8
AUG	80.9	62.7	71.8	91	6	48	15	13	230	5.33	0.99	19	0.0	0.0		83	84	62	66	17	2.7	6.4	29	35	5		6.7	5	10	16	13	0	12	2	5	0	0	0	984.4
SEP	76.7	53.4	66.1	88	11	38	22	70	106	0.75	0.48	5	0.0	0.0		72	77	46	51	21	2.5	8.8	25	18	1		2.6	21	7	2	3	0	3	4	0	0	0	0	984.1
OCT	61.9	40.5	51.2	81	20	28	13	421	9	4.18	2.62	21-22	T	T	23	72	75	53	56	27	1.8	11.7	36	32	22		6.4	7	9	15	8	0	3	1	0	0	6	0	980.4
NOV	43.7	27.5	35.6	68	18	12	12	875	0	1.41	0.68	20-21	2.5	1.9	12	72	75	62	66	25	3.1	10.4	24	24	1		7.4	5	3	22	9	1	0	0	0	5	22	0	985.1
DEC	35.5	16.1	26.3	56	10	-3	17	1121	0	0.71	0.66	22-23	0.2	0.2	16	78	82	67	69	26	3.4	11.0	25	34	24		6.9	7	7	17	3	0	0	4	0	10	30	2	987.8
YEAR	55.1	35.3	45.2	91	AUG 6	-24	FEB 5	7667	770	38.12	2.86	JUN 17-18	31.6	5.3	JAN 12-13	76	79	61	62	26	1.3	10.4	43	11	APR 11		6.4	87	100	178	108	11	44	24	6	75	152	36	985.4

Normals, Means, And Extremes

Month	Temperatures °F Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal Degree days Base 65 °F: Heating	Cooling	Precipitation in inches, Water equivalent: Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs	Year	Snow, Ice pellets: Maximum monthly	Year	Maximum in 24 hrs	Year	Relative humidity pct. Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind: Mean speed m.p.h.	Prevailing direction	Fastest mile: Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days, Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperatures °F Max: 90° and above	32° and below	Min: 32° and below	0° and below	Average station pressure mb, Elev. 878 feet m.s.l.
(a)				31		31					31		31		31		29		24		20	20	20	20	23	3	19	19			19	19	19	19	29	26	25	24	20	20	[illegible]	[illegible]	[illegible]
J	25.7	6.6	16.2	55	1956	-31	1970	1511	0	1.00	2.78	1949	0.10	1962	1.64	1971	17.2	1979	14.6	1971	75	75	68	72	11.3	NW	46	29	1963		6.5	8	7	16	7	2	*	0	0	23	31	15	[illegible]
F	30.2	11.3	20.8	62	1976	-29	1962	1238	0	0.92	3.54	1971	0.02	1969	1.53	1976	24.3	1962	8.0	1962	77	76	67	70	11.5	NW	44	26	1971		6.6	7	6	15	6	2	*	2	0	17	26	8	[illegible]
M	40.6	22.3	31.5	84	1967	-34	1962	1039	0	2.25	5.43	1961	0.34	1956	1.93	1966	20.1	1959	12.2	1959	79	82	66	68	12.3	NW	45	30	1965		7.0	6	7	18	9	2	1	3	0	8	25	1	[illegible]
A	58.5	36.3	47.4	90	1949	4	1975	526	0	3.43	6.11	1964	0.95	1971	2.86	1979	10.3	1973	6.2	1973	76	62	56	57	13.0	NW	52	25	1963		6.9	6	8	16	10	*	4	2	0	*	17	0	985.5
M	70.0	47.5	58.8	94	1967	25	1971	229	37	4.18	7.24	1970	1.47	1977	3.15	1960	0.3	1966	T	1976	76	62	55	55	11.5	S	52	18	1962		6.4	7	10	14	11	0	7	1	1	0	2	0	981.7
J	79.4	57.6	68.5	99	1970	38	1964	35	144	5.01	8.34	1966	0.66	1955	2.86	1979	0.0		0.0		79	83	55	56	10.1	S	43	34	1963		6.0	7	12	11	10	0	8	1	3	0	0	0	982.3
J	83.6	61.5	72.6	102	1955	43	1975	7	243	4.75	12.60	1968	0.43	1954	9.31	1966	0.0		0.0		84	86	58	59	8.6	ESE	54	05	1963		5.6	9	12	10	9	0	8	1	5	0	0	0	984.4
A	82.1	59.5	70.8	97	1964	38	1967	26	206	3.50	8.07	1968	0.37	1955	5.28	1966	0.0		0.0		85	89	58	61	8.5	S	46	21	1967		5.5	10	10	11	8	0	7	2	4	0	0	0	985.1
S	73.3	49.8	61.6	98	1955	22	1967	137	35	3.63	11.38	1965	0.42	1953	3.52	1978	0.0		0.0		85	89	60	64	9.0	S	38	27	1964		5.7	10	8	12	8	0	4	2	1	0	1	0	985.6
O	63.5	39.7	51.6	95	1963	13	1952	426	10	2.36	4.97	1961	T	1952	2.65	1961	0.5	1955	0.3	1972	78	84	56	63	10.2	S	36	32	1979		5.7	10	8	13	7	0	2	1	*	0	9	0	985.6
N	44.6	25.6	35.2	79	1950	-17	1977	897	0	1.50	4.68	1961	T	1954	2.61	1959	11.7	1971	8.5	1972	79	82	65	71	11.2	S	43	33	1964		7.1	5	8	17	6	1	*	2	0	5	22	1	985.5
D	30.6	12.9	21.8	65	1973	-27	1963	1339	0	1.19	2.80	1968	0.28	1962	1.35	1964	20.1	1961	8.4	1969	79	80	71	74	11.2	NW	39	32	1969		7.0	7	6	18	7	2	*	3	0	19	30	7	985.3
YR	56.8	35.9	46.4	102	JUL 1955	-34	MAR 1962	7415	675	33.74	12.60	JUL 1968	T	NOV 1954	9.31	JUL 1966	24.3	FEB 1962	14.8	JAN 1971	79	83	61	64	10.7	NW	54	05	JUL 1963		6.3	92	102	171	99	10	42	22	14	71	159	31	984.6

94910 WATERLOO

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 112 in August 1936.

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

Average Temperature

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1940	9.4	24.5	30.2	47.4	57.8	72.4	76.3	70.0	64.4	55.8	33.4	27.2	47.6
1941	25.4	20.6	32.0	54.0	66.4	70.5	73.2	74.0	65.6	53.5	39.8	31.6	50.4
1942	19.5	21.2	38.0	53.8	59.0	68.8	73.2	70.9	60.1	51.5	37.0	18.9	47.7
1943	15.4	24.2	30.6	48.0	57.4	72.0	75.0	73.0	58.9	49.6	32.4	25.4	46.8
1944	[illegible]	25.6	29.5	44.8	64.0	71.2	71.7	71.2	63.9	52.0	41.1	19.1	47.9
1945	17.1	23.6	46.6	49.0	54.4	64.0	71.7	71.2	61.6	50.7	35.8	17.4	46.9
1946	20.7	26.4	44.8	53.6	56.0	69.0	72.4	67.4	67.1	55.2	36.8	28.2	49.4
1947	24.5	16.2	31.2	46.2	54.5	65.4	71.3	79.4	66.7	61.0	32.6	26.8	48.0
*1948	16.8	22.4	32.0	54.1	58.0	67.6	74.7	73.2	66.7	50.8	39.6	24.4	48.3
1949	18.3	18.9	32.4	48.5	62.5	71.8	75.3	72.8	58.1	54.5	39.5	25.8	48.2
1950			28.4	40.2	59.5		70.3	67.6	62.9	57.0	32.3	16.1	
1951	14.?	21.4	25.5	44.1	62.4	65.6	71.8	69.2	59.6	51.4	29.7	20.1	44.6
1952	19.0	31.1	31.8	49.6	58.7	73.3	75.6	70.1	64.7	46.0	38.0	26.1	48.7
1953	22.0	26.0	37.8	42.7	60.6	72.2	74.2	72.0	63.7	57.6	40.3	27.5	49.5
1954	17.6	35.2	31.1	51.1	55.1	72.9	76.5	71.1	65.6	51.0	40.5	26.0	49.5
1955	17.1	19.7	32.3	56.9	62.8	67.1	79.1	75.7	65.1	51.5	29.1	17.3	47.8
1956	16.?	20.4	30.1	44.6	59.4	74.0	71.7	71.3	60.1	56.9	35.3	24.6	47.1
1957	12.0	27.6	33.7	48.9	57.5	67.9	76.8	71.5	59.9	48.3	33.4	27.8	47.1
1958	21.?	14.9	32.8	47.6	60.1	64.5	69.0	70.9	62.4	53.6	37.9	18.1	46.1
*1959	13.0	17.6	32.4	47.5	62.2	70.8	71.7	75.9	63.3	47.6	27.3	32.4	46.8
1960	19.6	20.0	18.7	49.3	58.4	66.2	71.1	72.8	64.5	50.3	37.9	20.3	45.8
1961	16.0	27.3	34.8	41.8	56.1	69.3	71.7	71.7	61.7	53.8	36.9	18.5	46.6
1962	11.6	16.8	26.0	46.5	65.8	69.5	69.7	70.7	58.6	53.1	37.8	21.5	45.6
1963	6.9	15.2	37.1	50.4	59.3	72.3	73.2	69.9	63.7	61.4	40.8	10.4	46.7
1964	24.6	25.0	28.4	47.2	63.2	69.1	75.8	68.2	60.9	47.7	37.9	19.1	47.2
1965	13.9	16.5	21.9	44.3	60.2	66.2	70.3	67.8	58.6	51.8	38.3	32.6	45.2
1966	7.8	21.3	38.7	43.7	54.6	70.7	75.7	67.5	61.5	50.9	35.7	22.6	45.9
1967	20.2	16.1	36.6	47.7	54.6	67.3	68.6	65.2	58.1	46.4	32.3	25.1	44.9
1968	18.0	19.3	39.4	50.4	54.1	69.1	70.8	69.5	60.2	50.6	33.7	18.6	46.2
1969	12.9	22.0	26.1	48.5	59.0	61.9	72.6	70.6	61.1	45.9	33.6	17.3	44.3
1970	5.?	17.4	29.1	47.9	61.6	69.6	72.5	70.0	61.8	49.9	34.7	19.4	44.9
1971	7.7	16.2	29.6	46.5	53.5	71.6	66.4	66.7	63.4	54.9	34.7	23.9	44.6
1972	10.2	11.9	30.8	44.3	60.8	67.2	70.2	71.1	61.2	46.4	33.2	16.1	43.6
1973	19.8	24.4	41.8	45.2	56.5	71.3	73.9	73.8	61.8	55.0	37.2	20.3	48.3
1974	17.2	21.2	32.9	49.4	56.0	66.5	75.5	68.3	58.0	51.3	36.7	24.4	46.4
1975	19.5	17.?	24.9	42.8	63.1	71.0	73.9	72.9	57.1	52.7	39.1	25.3	46.7
1976	16.6	30.1	35.9	50.5	56.6	68.8	73.8	69.6	60.7	43.6	26.6	12.7	45.4
1977	[illegible]	23.3	40.1	51.7	65.5	68.9	74.3	65.9	60.7	46.0	34.0	16.8	45.6
1978	2.7	7.4	28.2	46.9	60.1	70.1	72.7	71.5	67.1	49.7	34.3	19.5	44.2
1979	3.6	9.7	31.8	44.4	58.7	69.3	77.3	71.8	66.1	51.2	35.6	28.1	45.2
RECORD MEAN	17.0	21.7	33.6	48.0	59.7	69.2	73.8	71.4	63.1	51.7	36.1	22.6	47.3
MAX	[illegible]	[illegible]	43.2	59.4	71.4	80.5	85.5	83.3	75.0	63.5	45.7	31.3	58.0
MIN	[illegible]	11.8	24.0	36.6	48.0	57.8	62.0	59.5	51.1	39.9	26.5	13.9	36.6

Heating Degree Days

WATERLOO, IA

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
*1959-60	1	0	146	533	1123	1001	1402	1299	1427	480	209	43	7674
1960-61	5	3	130	453	804	1383	1515	1049	931	688	295	24	7279
1961-62	0	3	189	347	836	1436	1650	1345	1203	560	105	26	7691
1962-63	16	7	217	389	839	1343	1802	1389	859	437	206	15	7479
1963-64	7	25	101	158	726	1691	1255	1154	1129	530	118	41	6929
1964-65	0	53	181	526	809	1417	1582	1353	1327	612	183	31	8074
1965-66	4	60	207	412	793	992	1776	1219	809	632	336	25	7272
1966-67	0	37	152	438	862	1306	1384	1365	878	520	357	27	7329
1967-68	47	75	204	574	976	1231	1450	1319	786	431	338	41	7476
1968-69	14	35	163	464	935	1433	1610	1196	1201	492	217	132	7889
1969-70	9	4	150	597	935	1473	1851	1330	1104	536	182	32	8201
1970-71	15	6	175	466	900	1410	1776	1364	1095	549	354	15	8125
1971-72	37	40	196	328	903	1266	1694	1516	1053	611	196	56	7866
1972-73	23	28	158	571	945	1509	1428	1130	712	589	264	2	7359
1973-74	0	1	143	313	827	1380	1480	1218	985	469	296	52	7170
1974-75	0	27	232	420	847	1251	1435	1277	1238	662	139	28	7558
1975-76	21	1	262	411	770	1224	1495	1005	897	441	263	14	6806
1976-77	2	26	178	665	1142	1615	2017	1162	764	329	86	22	8077
1977-78	2	56	144	584	923	1490	1932	1610	1133	532	224	23	8660
1978-79	2	9	78	468	914	1408	1903	1547	1024	613	238	20	8220
1979-80	2	13	70	431	875	1131							

Cooling Degree Days

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1969	0	0	0	0	41	47	250	185	40	12	0	0	575
1970	0	0	0	28	84	175	254	170	86	3	0	0	800
1971	0	0	0	2	5	217	87	100	104	21	0	0	536
1972	0	0	0	0	74	128	188	224	50	0	0	0	664
1973	0	0	0	0	8	197	268	283	60	12	0	0	828
1974	0	0	0	9	23	105	331	136	38	0	0	0	642
1975	0	0	0	0	86	215	304	253	30	21	0	0	909
1976	0	0	0	10	10	131	282	175	55	5	0	0	668
1977	0	0	0	9	107	145	297	92	23	0	0	0	673
1978	0	0	0	0	79	179	230	216	149	0	0	0	853
1979	0	0	0	0	35	153	237	230	106	9	0	0	770

Precipitation

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1940	0.99	1.10	1.15	3.19	3.23	2.57	9.70	3.29	4.07	2.19	2.62	1.48	35.58
1941	1.71	0.30	1.39	2.35	1.90	4.38	1.40	2.37	11.63	3.75	1.97	1.23	35.28
1942	1.27	1.01	1.50	0.28	3.58	7.89	10.43	4.38	4.88	2.03	2.05	1.26	40.52
1943	1.14	0.49	1.56	2.76	4.07	5.77	4.40	3.51	2.84	3.04	0.94	0.82	31.58
1944	1.30	0.97	2.37	2.58	5.03	5.09	5.59	5.78	3.07	0.68	0.98	1.36	34.76
1945	0.45	1.63	2.98	4.24	6.21	3.03	2.39	5.94	5.38	0.53	1.43	1.46	35.85
1946	1.02	0.68	1.20	1.38	4.62	8.56	2.63	1.17	6.23	3.99	1.59	0.80	38.57
1947	1.45	0.19	1.10	4.26	4.81	12.43	3.27	3.08	1.54	4.84	1.61	1.52	40.18
*1948	0.02	2.30	3.07	4.37	3.25	6.98	2.76	1.51	1.19	2.22	3.01	1.55	32.19
1949	2.79	0.72	1.85	1.13	2.04	4.92	1.40	0.45	4.09	1.13	0.47	0.59	21.55
1950				3.26	4.31		2.35	0.67	4.16	0.81	0.22		
1951			3.72	5.03	2.95	4.67	8.45	5.86	1.62	1.94	1.02	1.35	
1952	1.97	0.52	3.01	1.05	5.15	3.95	2.39	3.03	0.61	T	2.47	1.18	25.53
1953	[illegible]	1.63	3.10	3.95	1.47	4.87	4.23	1.94	0.42	0.21	1.79	1.06	25.25
1954	0.17	0.50	1.34	5.38	5.29	5.04	0.43	5.97	2.92	3.74	T	0.96	31.62
1955	0.41	0.95	0.90	3.11	3.65	0.86	5.90	0.37	2.42	1.23	0.27	0.46	20.53
1956	0.41	0.09	0.97	2.74	3.23	2.07	4.27	3.24	2.46	1.72	1.20	0.41	22.81
1957	0.42	0.29	0.86	2.71	4.14	4.03	2.87	4.94	1.18	1.15	2.56	0.68	27.82
1958	0.30	0.04	0.34	3.12	2.64	3.35	5.37	2.59	1.85	1.09	2.84	0.40	25.63
1959	0.57	1.29	4.21	1.59	4.57	7.94	3.44	3.41	4.36	2.47	3.45	1.78	38.85
1960	2.09	0.75	1.55	5.73	7.18	2.29	2.20	5.12	5.06	1.51	0.52	0.71	35.65
1961	0.11	2.50	5.43	4.27	3.12	2.59	8.56	1.51	8.13	4.97	4.68	1.29	47.16
1962	0.12	1.74	2.14	2.03	6.62	2.91	7.35	3.74	1.73	3.01	0.22	0.28	31.49
1963	0.45	0.57	3.27	3.41	2.31	4.52	8.73	3.01	2.52	1.76	2.04	0.52	32.64
1964	0.34	0.21	1.24	8.11	5.01	4.01	3.48	4.86	5.17	0.46	1.11	1.93	35.93
1965	1.11	1.16	3.48	4.81	5.24	5.09	4.41	7.08	11.39	1.93	3.07	2.12	50.79
1966	1.30	1.47	3.40	3.89	4.79	8.34	6.05	5.97	0.55	3.21	0.47	0.80	40.65
1967	1.54	0.57	2.47	4.49	3.49	5.52	2.25	3.95	1.40	2.80	1.03	0.93	28.68
1968	0.73	0.04	1.30	5.15	3.95	4.66	12.60	4.07	3.61	2.97	0.74	2.80	44.42
1969	1.56	0.02	0.97	4.47	6.76	4.82	4.90	0.58	1.35	3.04	0.17	1.25	34.52
1970	0.18	0.42	2.48	3.21	7.24	2.16	4.13	0.99	5.20	3.50	1.41	1.13	30.05
1971	1.76	1.54	1.36	0.95	5.51	3.14	3.14	0.47	2.56	2.43	2.76	1.78	29.36
1972	0.16	1.13	1.78	3.29	3.35	4.33	5.29	5.71	4.86	3.77	1.98	1.94	35.59
1973	1.15	1.49	3.22	3.45	7.23	3.07	3.29	2.12	6.88	0.94	2.75	2.26	34.46
1974	0.24	1.07	1.63	2.25	5.35	3.72	3.37	2.87	2.14	4.08	0.91	1.28	29.60
1975	0.42	1.14	2.35	3.24	1.93	4.00	1.06	4.53	0.80	0.04	3.48	0.40	24.09
1976	0.14	2.16	3.14	4.66	2.21	2.83	2.83	0.08	1.36	1.75	0.06	0.46	22.12
1977	0.17	0.68	3.04	2.26	1.47	4.11	3.23	5.45	6.09	2.94	1.82	1.73	33.96
1978	0.53	0.45	0.50	4.75	2.69	5.70	3.74	3.60	7.21	1.07	3.70	0.39	35.36
1979	1.01	0.32	3.06	4.37	3.43	6.07	6.66	5.33	0.75	4.18	1.41	0.71	38.32
RECORD MEAN	1.01	1.03	2.02	2.92	3.99	4.39	4.16	3.57	3.89	2.34	1.72	1.16	32.20

Snowfall

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
1940-41	0.0	0.0	0.0	0.0	4.2	13.8	5.3	1.3	8.8	0.0	0.0	0.0	33.4
1941-42	0.0	0.0	0.0	0.0	1.0	7.6	12.3	3.3	0.4	0.0	0.0	0.0	24.6
1942-43	0.0	0.0	T	0.0	6.7	7.1	11.6	2.6	6.5	T	0.0	0.0	34.5
1943-44	0.0	0.0	0.0	0.0	0.5	T	0.8	3.6	7.5	0.0	0.2	0.0	12.6
1944-45	0.0	0.0	0.0	0.0	4.1	10.5	4.5	12.2	0.5	T	2.0	0.0	33.8
1945-46	0.0	0.0	0.0	0.0	1.2	8.7	6.4	2.4	8.5	0.5	0.0	0.0	27.7
1946-47	0.0	0.0	0.0	0.2	0.0	2.6	14.1	1.9	1.5	2.0	2.0	0.0	24.3
1947-48	0.0	0.0	0.0	0.0	7.0	4.3	0.2	2.8	12.0	0.0	0.0	0.0	26.3
*1948-49	0.0	0.0	0.0	0.0	0.0	9.6	16.2	7.2	0.7	4.0	0.0	0.0	37.7
1949-50	0.0	0.0	0.0	0.0	1.5	3.3	7.2	11.8	0.0	T	0.0	0.0	23.6
1950-51													
1951-52	0.0	0.0	0.0	0.0		16.0	8.1	3.0		3.2	0.0	0.0	
1952-53	0.0	0.0	0.0	T									
1953-54						2.5	1.5	3.0		0.0	0.0	0.0	
1954-55	0.0	0.0	0.0	0.0	T				0.8	0.0	0.0	0.0	
1955-56	0.0	0.0	0.0	0.5	1.1	4.5	4.2	1.6	3.6	T	0.0	0.0	15.5
1956-57	0.0	0.0	0.0	0.0	2.7	7.3	9.6	1.0	2.9	T	0.0	0.0	23.5
1957-58	0.0	0.0	0.0	0.0	7.5	5.6	5.1	0.6	4.3	0.0	0.0	0.0	23.1
1958-59	0.0	0.0	0.0	0.0	0.3	6.1	7.8	10.3	20.1	0.3	0.0	0.0	44.9
1959-60	0.0	0.0	0.0	T	6.0	4.5	10.6	6.5	12.4	3.0	T	0.0	43.0
1960-61	0.0	0.0	0.0	0.0	T	4.3	5.2	4.9	10.0	2.0	0.0	0.0	26.4
1961-62	0.0	0.0	0.0	0.0	1.1	20.1	1.5	24.3	10.2	2.2	0.0	0.0	59.4
1962-63	0.0	0.0	0.0	0.3	0.7	2.5	6.8	6.3	9.9	0.0	0.0	0.0	26.5
1963-64	0.0	0.0	0.0	0.0	0.4	7.0	3.8	0.8	11.5	T	0.0	0.0	23.5
1964-65	0.0	0.0	0.0	0.0	2.1	4.8	6.6	6.6	16.1	0.0	0.0	0.0	36.2
1965-66	0.0	0.0	0.0	0.0	T	1.0	8.1	0.6	1.7	0.4	0.3	0.0	12.1
1966-67	0.0	0.0	0.0	0.0	T	6.4	2.6	7.0	3.9	0.4	0.0	0.0	20.3
1967-68	0.0	0.0	0.0	T	2.6	2.2	6.2	0.6	T	T	0.0	0.0	11.6
1968-69	0.0	0.0	0.0	T	1.4	14.5	5.2	0.3	4.4	T	0.0	0.0	25.8
1969-70	0.0	0.0	0.0	T	0.2	19.5	2.8	4.8	8.4	0.0	0.0	0.0	35.7
1970-71	0.0	0.0	0.0	T	1.0	7.3	16.7	14.1	6.5	T	0.0	0.0	45.6
1971-72	0.0	0.0	0.0	0.0	11.7	7.0	2.9	15.4	5.8	3.4	0.0	0.0	46.2
1972-73	0.0	0.0	0.0	0.3	7.6	10.6	8.0	4.8	0.1	10.3	0.0	0.0	43.7
1973-74	0.0	0.0	0.0	0.0	T	8.4	4.3	8.3	3.1	0.6	0.0	0.0	24.7
1974-75	0.0	0.0	0.0	0.0	4.1	5.3	7.0	12.5	10.5	6.6	0.0	0.0	46.0
1975-76	0.0	0.0	0.0	0.0	4.9	T	1.7	7.2	1.4	T	T	0.0	15.2
1976-77	0.0	0.0	0.0	0.1	0.7	5.3	4.9	1.8	3.1	1.5	0.0	0.0	17.4
1977-78	0.0	0.0	0.0	0.0	11.2	16.9	5.9	6.4	4.6	0.4	0.0	0.0	45.4
1978-79	0.0	0.0	0.0	0.0	9.1	8.1	17.2	7.9	4.3	4.7	0.0	0.0	46.3
1979-80	0.0	0.0	0.0	T	2.5	0.2							
RECORD MEAN	0.0	0.0	0.0	T	3.3	7.1	6.8	6.3	6.4	1.6	T	0.0	31.5

* Indicates a station move or relocation of instruments. See station location table.

Record mean values above are means through the current year for the period beginning in 1895 for temperature and precipitation, 1955 for snowfall. Data are from cooperative locations through 1958.

STATION LOCATION

WATERLOO, IOWA

Location	Occupied from	Occupied to	Airline distance and direction from previous location	Latitude North	Longitude West	Elevation above Sea level: Ground at temp. site	Elevation above Ground: Wind instruments	Extreme thermometers	Psychrometer	Sunshine Switch	Tipping bucket rain gage	Weighing rain gage	8" rain gage	Hygrothermometer	Automatic Observing Equipment *	Remarks
COOPERATIVE																
617 Mulberry Street	1/21/95	4/25/11		42° 31'	92° 20'	856										Instrument exposures unknown for cooperative stations.
302 High Street	4/25/11	6/01/15	1/2 mi. N	42° 31'	92° 20'	872										
717 Fairview Street	6/02/15	2/28/50	1 mi. NW	42° 31'	92° 20'	858										
AIRPORT																
Administration Building Waterloo Municipal AP	1/29/48	10/17/55	4 mi. NW	42° 33'	92° 24'	867		27	5				4	e		SAWRS.
Administration Building Waterloo Municipal AP	10/18/55	Present	NA	42° 33'	92° 24'	b868	20	4	4	NA	NA	5	4	a5	NA	Weather Bureau First Order Station. a - Telepsychrometer(4') 1/29/48-12/1/59. Hygro. comm. 2000' NW of tele. site 12/1/59. b - 867 feet to 12/1/59.

* Type
M = AMOS
T = AUTOB

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Daniel B. Mitchell
Director, National Climatic Center

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Appendix C

Memorandum distributed to department faculty

UNIVERSITY OF NORTHERN IOWA · Cedar Falls, Iowa 50613
Department of Industrial Technology

MEMO TO: ITD Faculty

DATE: September 12, 1980

FROM: William Rosburg

RE: Future installation of the Quirk's wind powered generator

As one component of research in my masters program, I am looking into the possible erection and use of the 2kw wind powered generator that is presently stored in our power laboratory.

If you are interested in this idea and have any suggestions, recommendations, ideas, or information that you could share with me about this project, I would like to discuss them with you.

You may contact me any time, or if you prefer, just mark the box below and return this memo to my mailbox and I will contact you.

Thank you.

☐ I would like to discuss this idea with you.

Appendix D

Anemometer description and calibration

Anemometer Description and Calibration

The instantaneous anemometer uses a DC electric motor connected to a shaft turned by four plastic cups held in the wind stream. The current output of the motor is fed through calibration potentiometers to a milliammeter. Two ranges are used to help increase the accuracy of the readings. Figure D 1 is a schematic drawing of the circuit. To calibrate the anemometer the current reading of the meter is recorded at different wind speeds using the Dwyer Hand Held Wind Meter and Scott wind tunnel. Figures D 2 and D 3 are graphs of the current output versus the measured wind speed on the high and low range settings. Since the output is linear, the relationship can be expressed by the linear equation:

$y = ax + b$

Where: y = wind speed in mph

z = slope of the line

x = meter reading in milliamps (ma.)

b = y intercept

The equation for the low range calibration is:

Instantaneous wind speed = 4.167 x meter reading in ma. + 5.8

The equation for the high range calibration is:

Instantaneous wind speed = 41.67 x meter reading in ma. + 6.75

In actual use, the range and meter reading is noted, and the reading inserted into the proper equation to calculate the wind speed.

Figure D 1

Anemometer Schematic Diagram

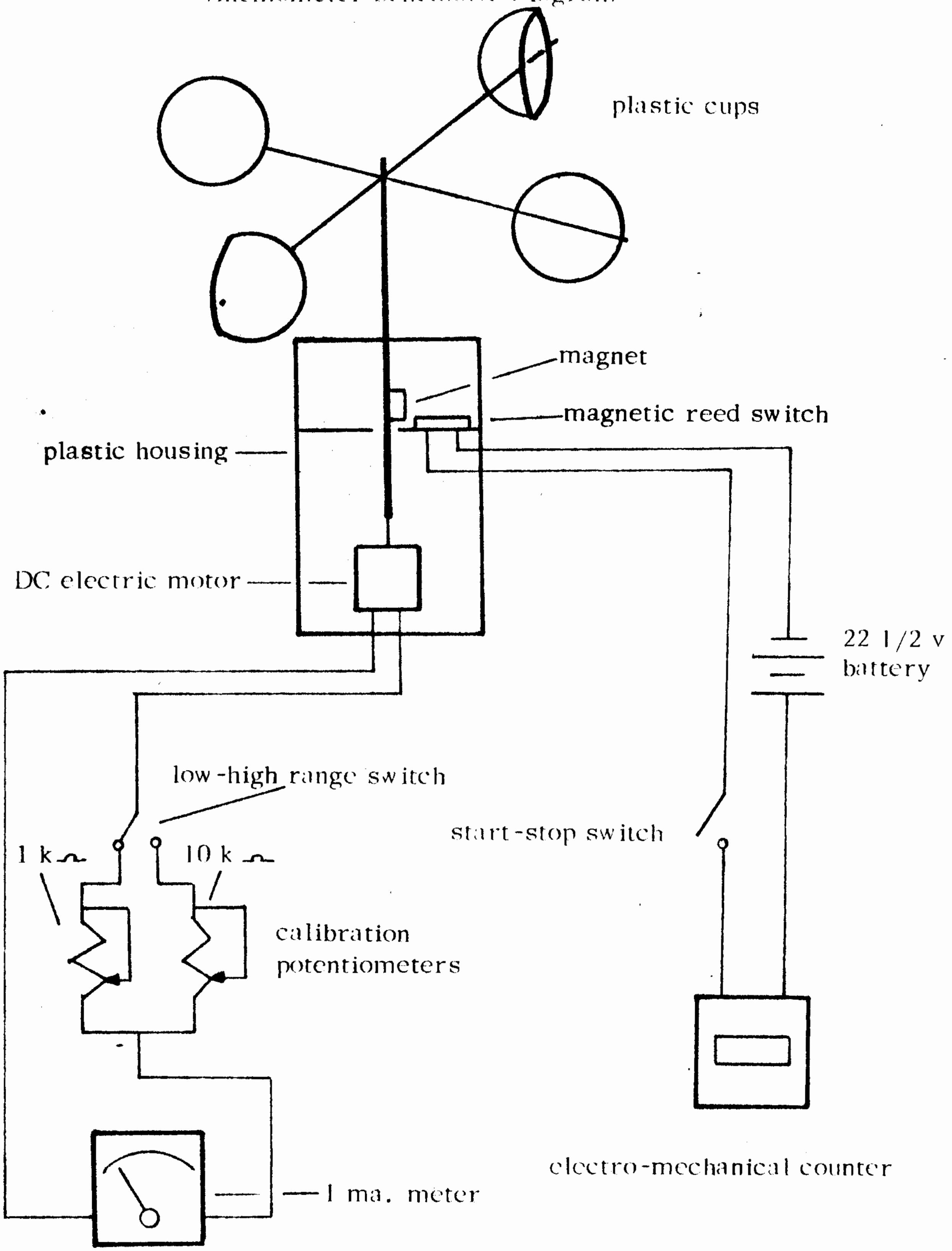
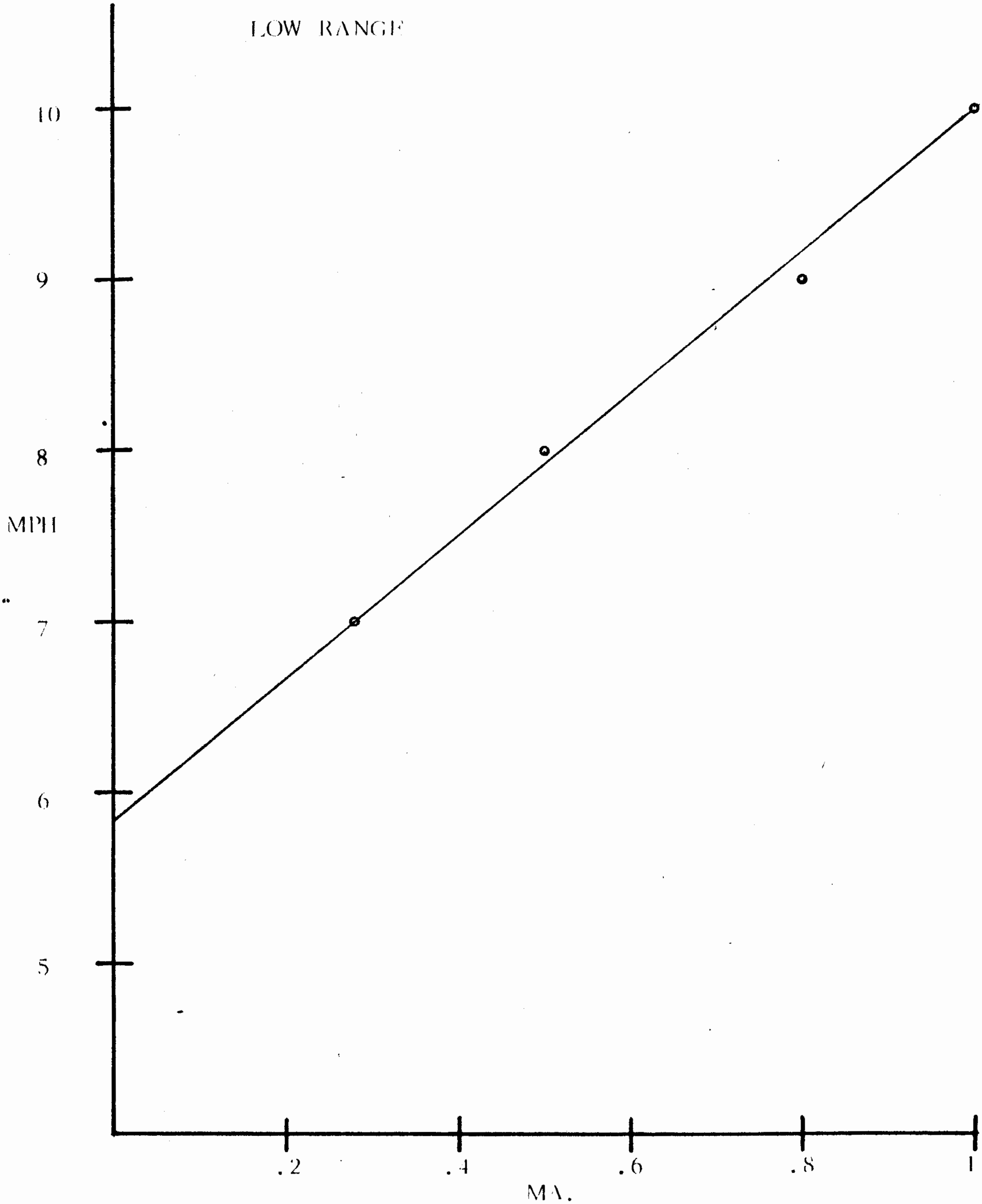
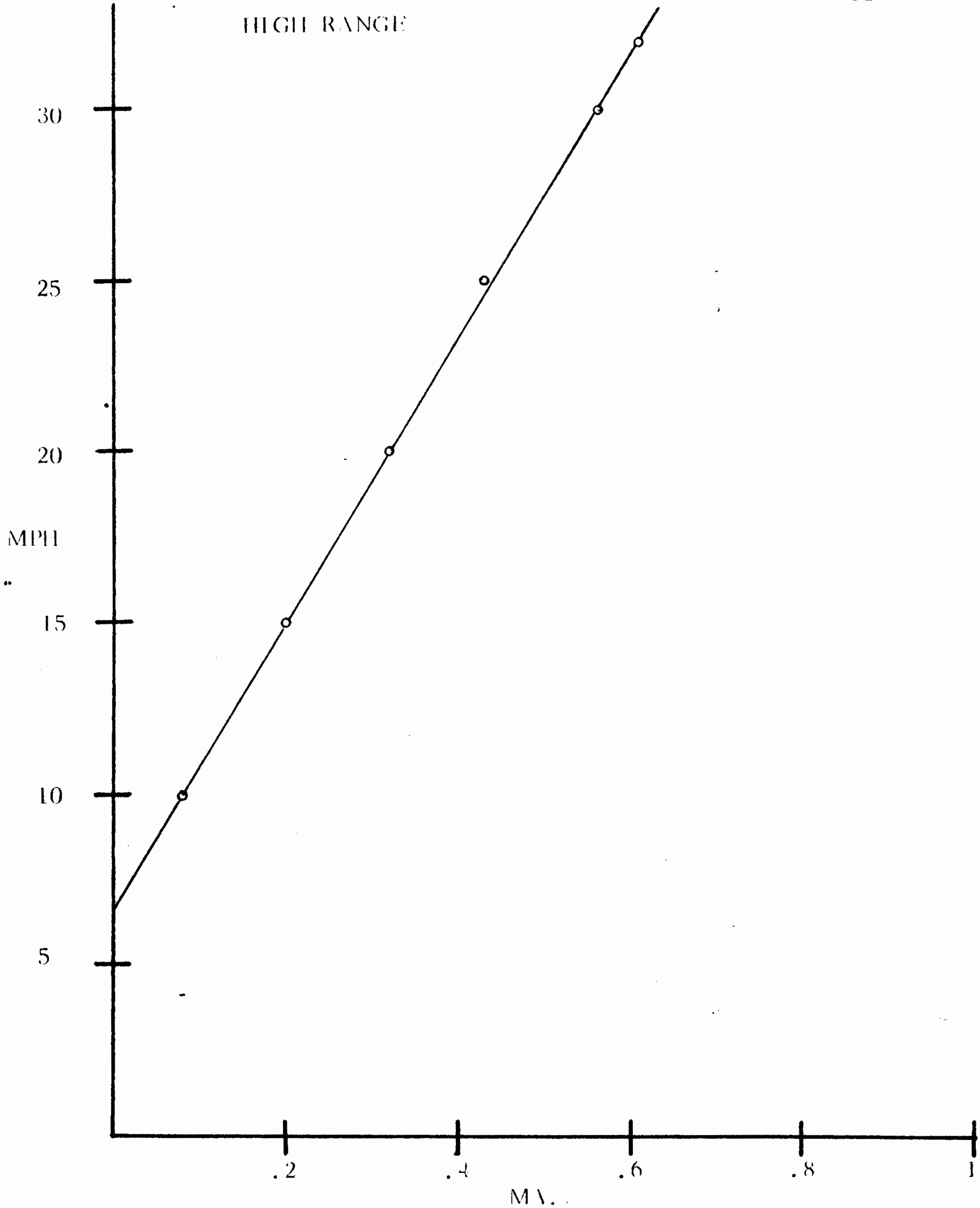


Figure D2



Anemometer Calibration Curve

Figure D3



Anemometer Calibration Curve

The totalizing anemometer uses a magnetic reed switch actuated by a magnet mounted on a shaft turned by four plastic cups held in the wind stream. The shaft and cups from the instantaneous meter are also used for the totalizing anemometer. When the magnet rotates past the switch and closes it on each revolution of the cups, the circuit is completed and the counter is advanced. Figure D 1 contains a schematic drawing of this circuit. Figure D 4 is a graph of the calibration curve of the meter. The anemometer is calibrated by counting the number of revolutions of the anemometer cups in a specific time period at a specific wind speed. The Dwyer Hand Held Wind Meter and the Scott wind tunnel were used for calibration. Since the output is linear, the linear equation can be used:

$$y = ax + b$$

Where: y = wind speed in mph

z = slope of the line

x = number of revolutions per minute

b = y intercept

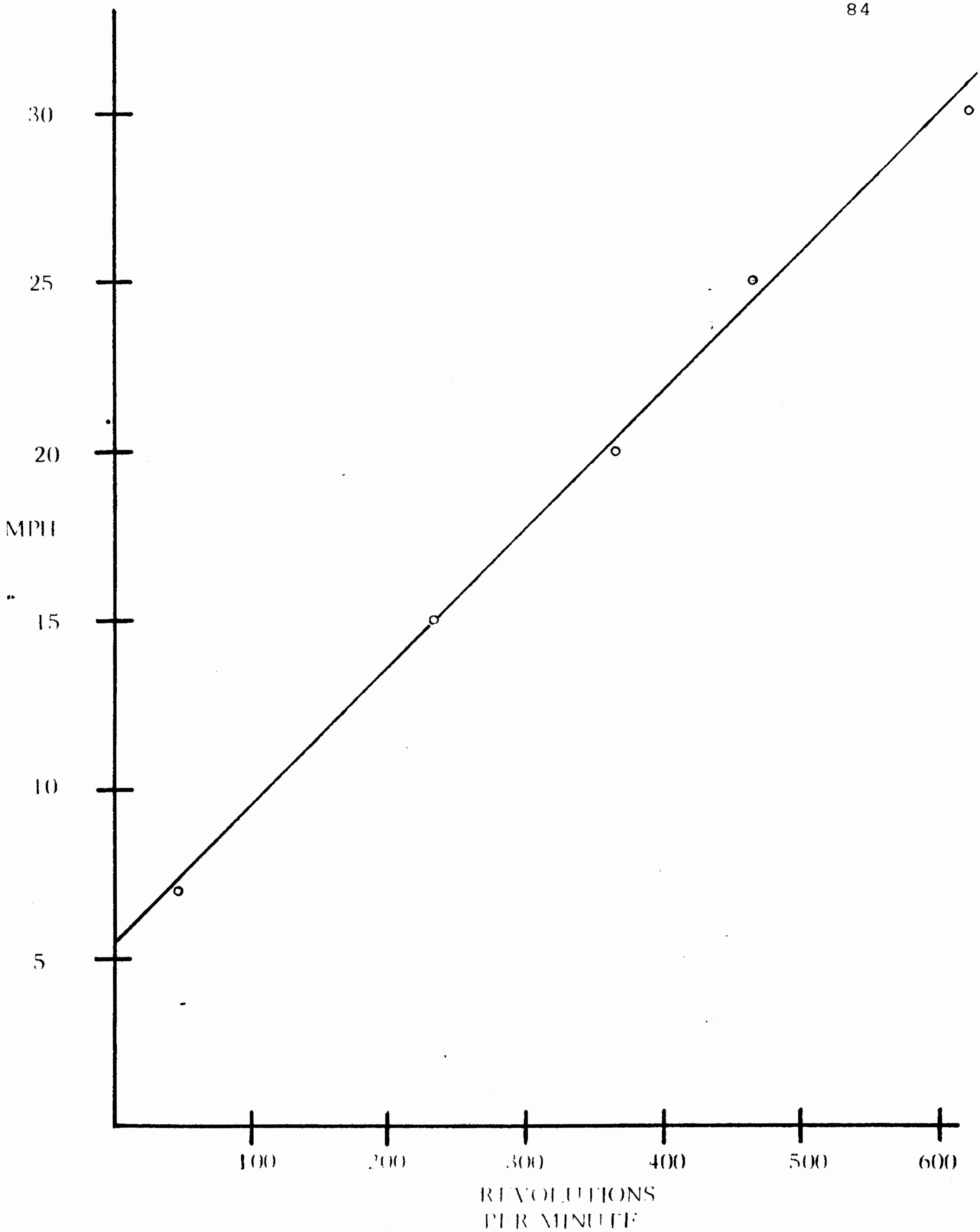
The equation for the totalizing anemometer calibration is:

Average wind speed = .040 x revolutions per minute + 5.5

In actual use the starting number of the counter is recorded, and after ten minutes the ending number recorded. The difference in the two numbers divided by ten will give the revolutions per minute of the anemometer cups. This number is then inserted into the equation, and the average wind speed is calculated.

A longer measuring period would give a more representative figure for the average wind speed, but it was felt that a ten minute period was adequate for this project.

Figure D 4



Anemometer Calibration Curve

Appendix E

Estimated cost for a 8 ft. by 10 ft. building

Payless Cashways, INC.

Everything for the Home, Farm and Ranch

ESTIMATE LIST (S-9)

86

Name: Norbert Koonie ... Date: ...

Address: ... Job: ...

[illegible]	PIECES	PRICE	CODE	AMOUNT
1/2 x 6 anchor Bolts.	12	.54		6 48
Roof Vent.	1	2.99	[illegible]	2 99
2x6 8 [illegible] Soffit	2	3 59		7 18
10	2	4 49		8 98
3" x 6" [illegible] 100 steel [illegible]	1	119.95		119 95
2x4 pre cut studs	14	1.25		17 50
2x4 8 Top plates	4	1 36		5 44
2x4 10	4	1 70		6 80
2x8 10 Roof deck 24" oc	6	4 40		[illegible] 40
14	1	6 16		6 16
Rolls Salvage edge Roofing	2	13 95		[illegible] 90
4x8 3/4 [illegible]	4	13 95		[illegible] 80
1" 10' Gravel guard	5	1 75		[illegible]
Gal lap cement.	3	3 95		11 85
1x8 10 facia	2	3 59		[illegible] 18
1x8 12	2	4 39		8 78
1x12 10 Soffit	1	5.99		5 99
12	1	7.19		7 19
1/4 3/4 qtr Rd.	36	.21		7 56
4x8 3/8 [illegible]	8	8.99		71 92
4x8 5/8 [illegible] "B"	8	16.95		135 60
4x8 1/4" [illegible]	11	9 95		109 45
Rolls 21 x 23 fiber glass Insul.	2	16 21		32 42
4x8 1/2 styrene ceiling	5	6 95		[illegible] 85
Roll 6 x 23 fiber glass ceiling	1	15.76		15 76
1" Galv. Rfg	4#	-		3 80
16d Sinker	12#	-		9 24

Please examine this list carefully. This list only sets forth the articles, quantities, grades and prices of materials listed and we do not warrant that the materials, quantities and grades listed will satisfy buyer's requirements. Buyer is responsible for determining own requirements and selecting proper materials. Prices shown will be guaranteed for ______ days from the date hereof and are subject to change thereafter without notice. Clerical errors are subject to correction.

The prices shown in this estimate are subject to change.

Salesman ______ This is an estimate only, we reserve the right to correct price changes and errors. TOTAL ______

Payless Cashways, INC.®

ESTIMATE LIST (S-9)

87

Everything for the Home, Farm and Ranch

me: ______ Date ______

dress: ______ Job ______

75 Gals Dog	75#	—		15.19
100 Com.	5#	329		3 29
2 3/4 Cove	64	21		13.44
deal Bolt	1	2195		21 95
				812.79
			tax	24 38
			Total.	837.17

ase examine this list carefully. This list only sets forth the articles, quantities, grades and prices of materials listed and we do warrant that the materials, quantites and grades listed will satisfy buyer s requirements. Buyer is responsible for determining n requirements and selecting proper materials. Prices shown will be guaranteed for ______ days from the date hereof and bject to change thereafter without notice. Clerical errors are subject to correction

sman ______

This is an estimate only, we reserve the right to correct price changes and errors.

TOTAL