AN ECONOMIC EVALUATION OF RESIDENTIAL WIND TURBINE SYSTEMS

By

BYRON ALEXANDER BLACK

Bachelor of Science in Industrial Engineering

Oklahoma State University

Stillwater, Oklahoma

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Thesis Approved:

Carl B. Estes
Thesis Adviser

Wayne C Turner

Ruth M McNeill

Norman N Durham
Dean of Graduate College

PREFACE

This study focuses on a quantitative analysis methodology that determines the actual feasibility and economics of residential wind turbine systems from an empirical data base. The primary objectives are: 1) to determine both the gross house consumption load and turbine power output, 2) calculate the net house consumption load with the wind turbine system, and 3) determine the residential wind turbine system performance measure.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The cost of energy and the cost of living have been rising at an alarming rate for the last five years. The utility companies are hard pressed to provide the energy needed by both residential and industrial customers. Some are behind schedule in constructing new plants to meet projected needs. Solar energy and solar technology are receiving serious consideration by corporations and individuals because of the potential answers they offer for United States energy problems. Unfortunately, solar energy has been advertised as the panacea for the United States energy dilemma and that claim is not true for all situations when they are economically evaluated. Residential wind turbine systems require investigation and economic analysis so that the public will be able to make informed decisions regarding investments in their fight against the rising cost of energy.

Wind power, an area of solar energy, is one of the specific technologies that is being investigated and implemented by both the industrial and public sectors. However, what quantitative analysis methodology is being used to determine the actual feasibility and economics of a wind turbine power system? Can a properly installed residential wind turbine system supply enough power to a typical house during the year to be a good economic investment? What method is available to determine the feasibility of any such system?

This research will address these questions. It involves the analysis of commercially available residential wind turbine systems. The investigation of residential wind turbine systems utilizing a detented metering scheme for measuring power generation is a relatively untouched subject. The detented meter system is a set of two racheted meters in series which run in opposite directions; one meter indicates energy being consumed and the other measures the excess energy sold back to the utility. Studies have been made for utilities on grid interconnected wind turbine systems [1-9], but very few have been made from the residential perspective [13]. This thesis provides a model for synchronizing the net turbine power output in any given wind profile with a residential house load (consumption). An economic performance measure is calculated from the model's turbine power production and the turbine's cost.

This research will not include siting techniques for wind turbines since that in itself is another thesis topic. Also, the design of the wind turbine components and the electronics required to insure safe operation and correct electric voltage and frequency parameters will not be investigated for the same reason.

CHAPTER II

LITERATURE REVIEW

The literature search for residential wind turbine systems information was by nature confined to about the last five years because of the infancy of the industry. Most of the research that has been done in this area has been published in trade journals or in the proceedings of either wind energy conferences or various society meetings. Another important source of information were the several performance summary sheets of various small wind turbines tested at the Rocky Flats Small Wind Turbine Test Station.

Several studies have been written about wind turbine integration or application with public utilities. A small sample of these reports [1-10] discuss planning, development, and the economics of utility grid turbine assisted power generation. Two articles concerning large turbine integration with utilities were of interest because of the way they approached wind velocity/wind power relationships and the modeling of a utility grid that was supplemented with turbine generated power. Janssen [11] demonstrates the use of a frequency and duration method to determine wind turbine power generation. Diesendorf and Martin [12] show how simulation modeling can be applied to describe the dynamic interactions of wind turbine generated power with a utility grid system.

A smaller number of reports have been written concerning the evaluation of small wind turbine systems for residential or rural use. Darvish [13], one report of several in rural wind energy heating, discusses a method to economically evaluate and size turbine systems for heating farm buildings. Nelson, Clark, and Barieau [14] discuss another traditional and still popular use of wind turbines, the irrigation turbine. Their paper arrives at annual turbine power generation by multiplying monthly average wind speed data with the power curves (power vs. wind speed) for various turbines. Both Bogel [15] and Mankauskas and Assarabowski [16] present a modeling or simulation procedure for residential wind turbine systems based on hourly wind speed averages.

At least three papers approached the problem of assessing the feasibility and economic justification of residential wind turbine systems. Krawiec [17] determined the cost of electric energy produced by wind turbines in the residential area and performed a breakeven cost analysis of turbine power versus utility power. The analysis was based on mean annual wind speed data and mean annual energy production compared to a theoretical all electric house that consumed an average of 15,000 KWH/yr. Haack [18] built a simulation model of a residential wind turbine system. His simulation model described a turbine that could feed directly into the house load or store energy in batteries until needed. The backup source of electric power was the utility grid. The house load or consumption was based on a study sample of 117 houses by a Michigan utility company which integrated house demand over 30-minute intervals. The power generated by a wind turbine was calculated by multiplying the average wind speeds (taken at one minute intervals, every 3 hours, for a year) by the theoretical power curves of various wind turbines. The power curves are based on rated power, swept area, cut-in speed, and rated speed. The simulation outputs included available wind energy, real generator output, backup utilization, and excess energy production. In a later paper, Haack [19] uses this simulation model to evaluate a 3KW wind turbine system and compare turbine power costs to four typical utility power generating schemes. Obermeier and Townes [20] performed a similar economic evaluation of a residential wind turbine system.

> The analysis compared the wind electric energy available with the home electric load in 3 hour time blocks over a 5 year period. The annual energy production was calculated using the annual frequency of occurrence of wind speeds (a 5 year data base sampled from ten locations in Montana). The home electric loads were based on an average monthly use of 270 KWH/mo and 650 KWH/mo (p. 213).

Obermeier and Townes utilized cost data and turbine performance parameters from 14 different wind turbines with the 10 weather data location wind speed averages for 12 different system configurations with the house model. No reports were found which test feasibility of wind turbine systems and justify the residential wind turbine system economically using empirical wind velocity data and empirical house load (or consumption) data. The data base for this thesis is empirical and sidesteps the statistical problems and assumption weaknesses of hourly house load data and annual ensemble averaged wind speed data.

CHAPTER III

RESIDENTIAL WIND TURBINE MODEL

This section describes a method for determining the technical feasibility of residential wind turbine systems. The model synthesizes household consumption data, wind speed measurements, and turbine performance graphs in order to determine the feasibility of each system. First, the turbine power outputs are calculated from empirical wind speed measurements and turbine power curve graphs. Then the computer program synchronizes the empirical house data and the turbine power outputs to determine household power demands and wind generated power supplies. These gross consumption levels and energy production levels are compared to determine net consumption and production levels. This data is passed on through statistical analysis and later combined with cost data for economic evaluation. The flow chart on the following page depicts the basic computer modeling process as well as the economic analysis which is the subject of the next chapter.

Background

The development of wind energy theory and related turbine information is necessary for comprehension of the

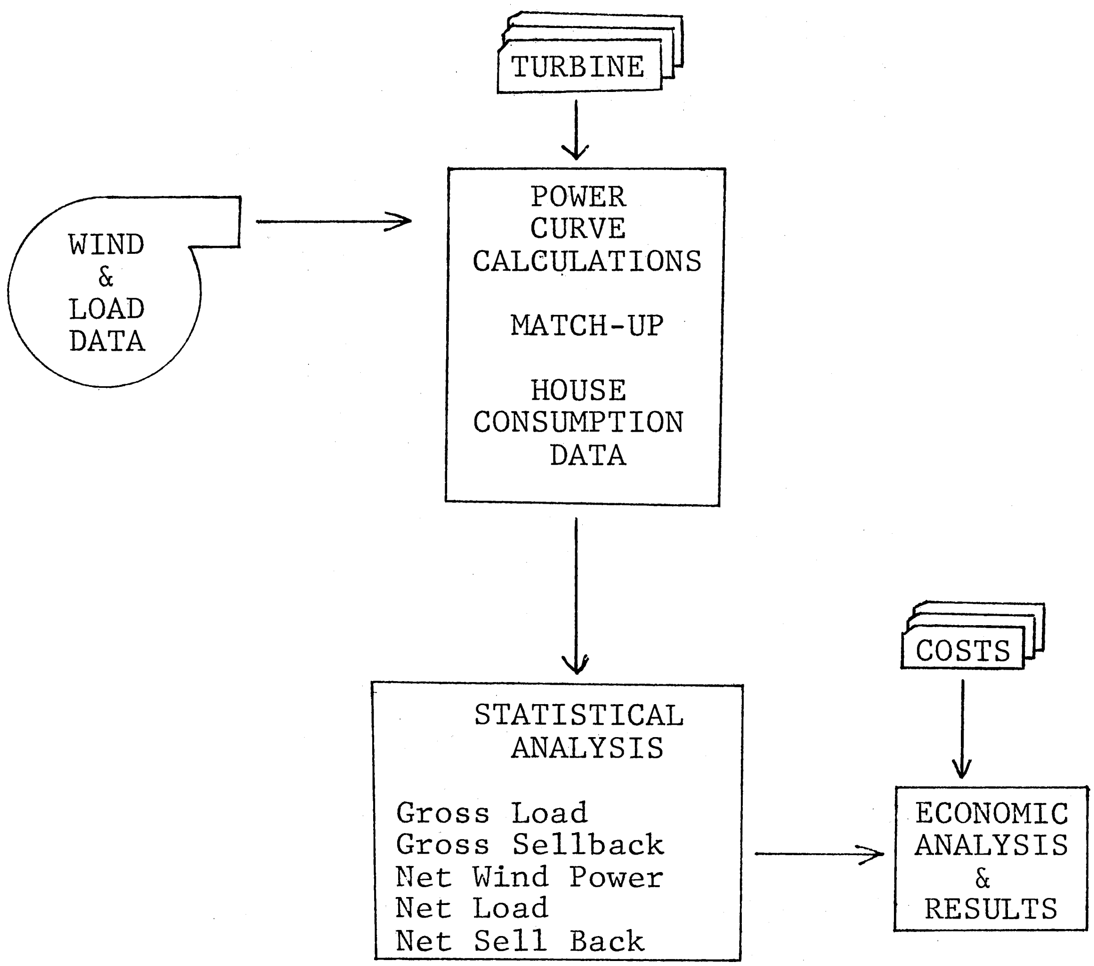

Figure 1. Model Flowchart

specific modeling steps. A wind velocity profile is a description of wind direction and wind speed for a range of heights from ground level. These wind speeds increase from zero to 30 MPH and higher at greater elevations. A snapshot of a wind profile for relatively flat land would look like one side of an exponential function. Any obstruction will produce turbulence and drag at the base of the profile and will lower the average wind speed. Therefore, the wind velocity profile over any residential area is not as well behaved as an open, flat land profile. One method to measure these wind profiles is to set up a series of tower mounted wind sensors at different heights. However, for most turbine applications, the wind speed measurements at the rotor height are the only readings needed from the wind velocity profile. The data from one wind sensor can be used to approximate the rest of the wind velocity profile or give the velocity for a specific tower height by using the 1/7 power equation.

$$A = B(T/M)^{1/7} \qquad (3\text{-}1)$$

where:

A = The "height corrected" wind speed

B = The measured wind speed

T = The tower (corrected) height

M = The measured wind speed height

Equation (3-1) can be used as a rule of thumb to correct wind speeds from zero to 100 foot elevations [21].

Any given wind velocity profile contains a certain amount of kinetic energy due to the mass of air moving over a measured distance in a given amount of time. Some of this energy can be intercepted by a wind turbine and be converted into electrical energy.

For a given area, this energy is equal to half of the cube of the velocity times the density of the air in the cross-sectional area swept by the turbine blades, or:

$$\text{Wind Power} = 1/2(\rho \cdot v^3)(A) \qquad (3\text{-}2)$$

or, by collecting constants:

$$\text{Wind Power} = (k)(v^3)(A) \qquad (3\text{-}3)$$

where:

$k = 5.08 \times 10^{-3}$ for v in MPH [22].

Theoretically, the best wind turbine could only extract 59% of this energy if it operated excellently over a range of conditions. However, in practice the measured amount of wind energy that wind turbines extract or generate is less than 59%. If the wind speed was at 14 MPH and the turbine in use had a 10 foot diameter blade sweep area, the theoretical wind energy available would be 645.6 watts. However, if the wind speed changed to 12 MPH or to 16 MPH, the v^3 term in Equation (3-3) would change the wind energy to 406.5 watts and 963.7 watts, respectively. Clearly, wind speed changes are crucial in determining the annual wind energy and annual turbine power output because of the weight or dominance of the v^3 term in Equation (3-3). Recognizing this illustrates the danger of using ensemble averaged wind data to determine power output. Instantaneous wind speed data would be much safer to use because it would show wind velocity fluctuations and give an accurate prediction for the wind turbine output. Yet, to collect and process this degree of refined data is both expensive and tedious. Compromises are required and are discussed later.

One method that is used to accurately predict a wind turbine's annual energy output is to test the turbine in the field and record the power it generates at different wind speeds. These values are plotted on a graph with power output in kilowatts versus wind speed in MPH. Such plots are called turbine power output curves. The Rocky Flats Small Wind Turbine Test Station generates these types of plots for various turbines. Plots for the turbines considered in this research are shown in the Appendix beginning on page 51. A typical power output curve is given on page 12 (Figure 2) and shows the turbine's cut in wind speed (v_{ci}), rated wind speed (v_r), and the turbine's power (P_r). These curves give accurate annual power output readings when the wind speed data is not a set of averaged points but is a set of instantaneous wind speed readings.

Data Base

The data necessary for the feasibility modeling and evaluation of a residential wind turbine system consists of four different data sets. The typical house load or

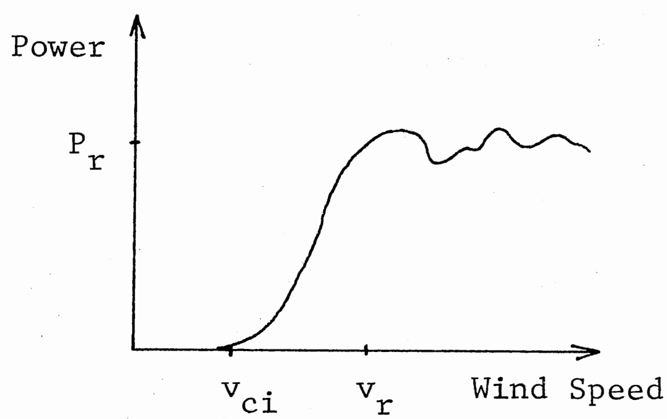

Figure 2. Typical Power Output Curve

residential consumption level is one of the required data sets. Because of the range of house constructions and the range of types and sizes of households, one method to generate the necessary data would involve simulation of household behaviors and house construction parameters in different seasonal environments. In one report:

> The typical Oklahoma home was determined by collecting data from a total of 1693 single story residential structures. Of the 1693 homes, 345 were heated with natural gas furnaces, 827 were heated with electric resistance heaters, 197 were L.P. gas furnaces, and 324 with heat pumps [23, p. 11].

In this thesis, pilot studies of actual residences with appropriate metering schemes are used to avoid the problems associated with sampling approaches. The consumption data used in this thesis was collected by metering continuous 15-minute consumption intervals for three houses in a small Oklahoma town [24]. These data points measure the house consumption level directly rather than generating them from some expected values based on a sampling survey. The data, received in electronic pulses, is interpreted and recorded on magnetic tape by a data logger. For every 15-minute interval the total watt-hours/interval is calculated based on the pulse/revolution/watt-hour factor for the meter and transferred by telephone/modem connection to a data file.

The households are single story dwellings with approximately 1100 square feet of floor area, excluding the garage. The walls are of face brick exterior with

TABLE I

AVERAGE SUMMARY DATA [23, p. 12]

Type of Heating System	Floor Area (Ft.^{2})	Net Wall Area (Ft.^{2})	Glass Area (Ft.^{2})	Design Heat Load (BTU/Hr.)	Design Cooling Load (BTU/Hr.)	R-Value Ceiling (hr-ft^2-°F/BTU)	R-Value (wall) (hr-ft^2-°F/BTU)
Electric Furnace	1649	1274	178	37133	17240	18.4	11.3
Natural Gas Furnace	1548	1213	179	42304	17610	15.3	8.4
L.P. Gas Furnace	1321	1067	153	40943	11747	12.4	6.2
Heat Pump	1732	1297	186	36751	17773	20.8	12.0

3 1/2 inch fiberglass batting and 1/2 inch styrofoam insulation board. The ceilings are insulated with 12 inches of rockwool and the 4 inch concrete slabs have 2 inches of styrofoam insulation one foot deep around their perimeters. Plumbing lines and air ducts are located in interior walls within the house envelope to minimize line losses and duct losses. The East house is equipped with a 1 1/2 ton air to air Carrier Heat Pump. The West house has a Commandaire Heat Pump which is assisted by a ground source heat well. In addition to the Commandaire Heat Pump and ground source heat well, the middle house utilizes a set of 5 solar collector panels. All three households were built from the same floor plan, which along with a schematic of each house HVAC system is shown on pages 55 and 56 of the Appendix.

The second necessary data set contains the residential wind speeds. As mentioned earlier, averaged wind data does not depict the fluctuations in wind speed accurately and such measurements can give erroneous turbine power output readings.

The wind speed data used in this thesis are instantaneous measurements taken every 15 minutes of each 24 hour period. The wind speed is measured by a cup anemometer which is mounted on top of a 25 foot pole at the back corners of the middle and West house lots. The pulses it sends are interpreted and recorded much the same way that the house consumption data is recorded.

The third set of data necessary to model and evaluate a residential wind turbine system contains actual turbine performance characteristics. The performance specifications in this data set are based on turbine power output curves which plot generated power versus wind speed. The source of these power curves is the Rocky Flats Small Wind Turbine Test Station in Rocky Flats, Colorado. The measured characteristics for the various turbines, such as cut in wind speed, cut out wind speed, rated power, and the actual power versus wind speed plots were all adjusted to sea level air density. Two lines can be fitted to these power output curves as shown below (Figure 3) by the heavy dashed lines superimposed over a typical power output curve.

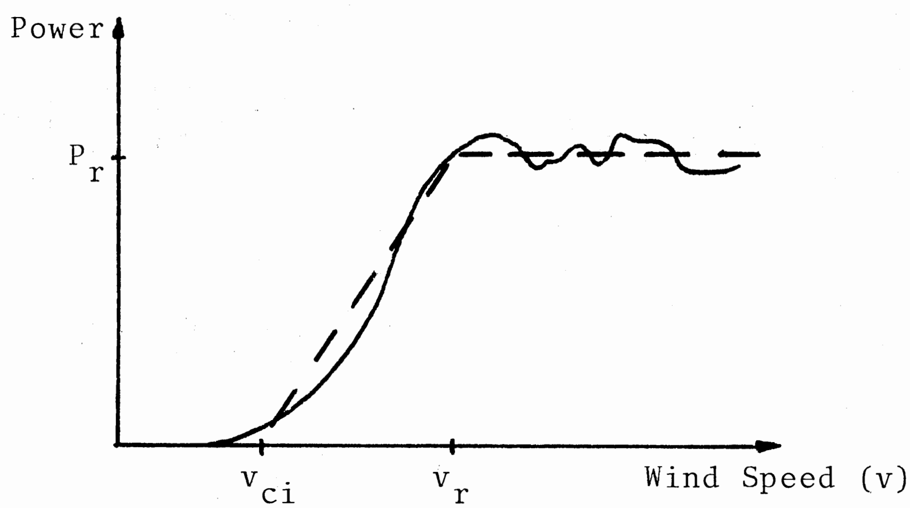

Figure 3. Fitted Power Output Curve

The horizontal line is an average of the fluctuations of generated power beyond the turbine's rated wind speed (v_r). It is often expressed as the constant rated power:

$$Y = \text{Power} = P_r \tag{3-4}$$

The other dashed line is an approximation of the data points of the power curve that shows the power generated by the turbine in the range from the cut in wind speed (v_{ci}) to the rated wind speed (v_r). The observations in this data set were generated by a group of "logical if" statements in the computer program. The equation for the power outputs along the sloped dashed line is:

$$\text{Power} = \frac{\text{Turbine Rated Power}}{(\text{rated wind speed} - \text{cut in wind speed})} \text{ X } [(\text{wind speed} - \text{cut in wind speed})]$$

$$P = \left[\frac{P_r}{(v_r - v_{ci})}\right] \text{ X } \left[(v - v_{ci})\right] \tag{3-5}$$

The final data set consists of the costs associated with data recording, and the costs to install and maintain the turbine. The costs involved with data recording are dominated by first costs since little or no maintenance is required for the data recording set-up. Since the equipment for experimental data recording could easily be reused for a similar purpose, or would most likely be provided by a private contractor or university extension group, their costs will not be assigned to the turbine system investment made by the homeowner. Since it is still of interest to expose these costs, the data logging equipment items and their costs are displayed in Table II.

TABLE II

DATA LOGGING EQUIPMENT COSTS

Item	Cost
TRS-80 Model III	$ 1,500.00
CR5 Data Logger with Printer	2,250.00
CRS Telecommunication Interface	1,350.00
A235 Recorder	990.00
TEAC A-3300-SX Reel to Reel	800.00
K18 Processor Model	580.00
CT104 Pulse Counter	530.00
Watt Hour Meter	480.00
KR102W Wind Sensor	430.00
Telecommunication Modem	425.00
KRD32 Pulse Receiver	350.00
Miscellaneous Cable	250.00
Magnetic Tapes	50.00
TOTAL EQUIPMENT COST	$ 9,985.00

The investment in a residential wind turbine system consists of both first costs and maintenance costs. The first costs include the siting or tower foundation costs, the tower costs, the turbine costs with wiring and utility grid safety switches, and the two meters required for the detented metering system. These installation and material costs vary for different wind turbines. An approximation for a 20 kw turbine would total to $30,000 in first costs and $200/year for maintenance costs. A detailed breakdown of all system costs used in this thesis are in the Appendix on page 57. Other information related to these costs are the economic parameters necessary for economic analysis and evaluation. These parameters are discussed in Chapter IV.

The first three data sets are used as inputs to the computer program which models the residential detented metering system for wind turbine power generation. The fourth data set, dealing with system costs, will be used in the next chapter. A detailed flow chart (Figure 4) of the computer program is on the next page and a listing of the program is on pages 58 through 59 in the Appendix.

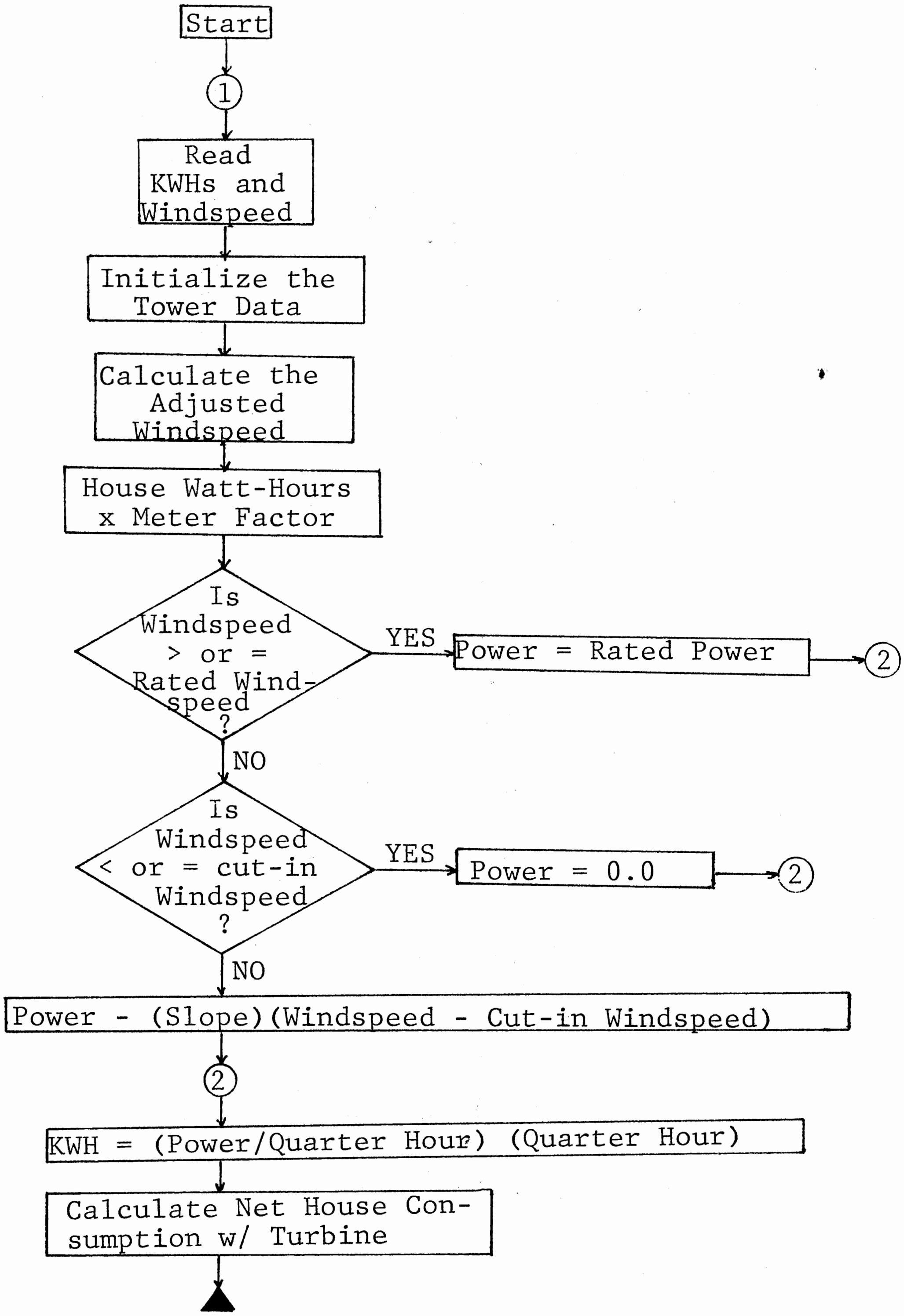

Figure 4. Detailed Flowchart

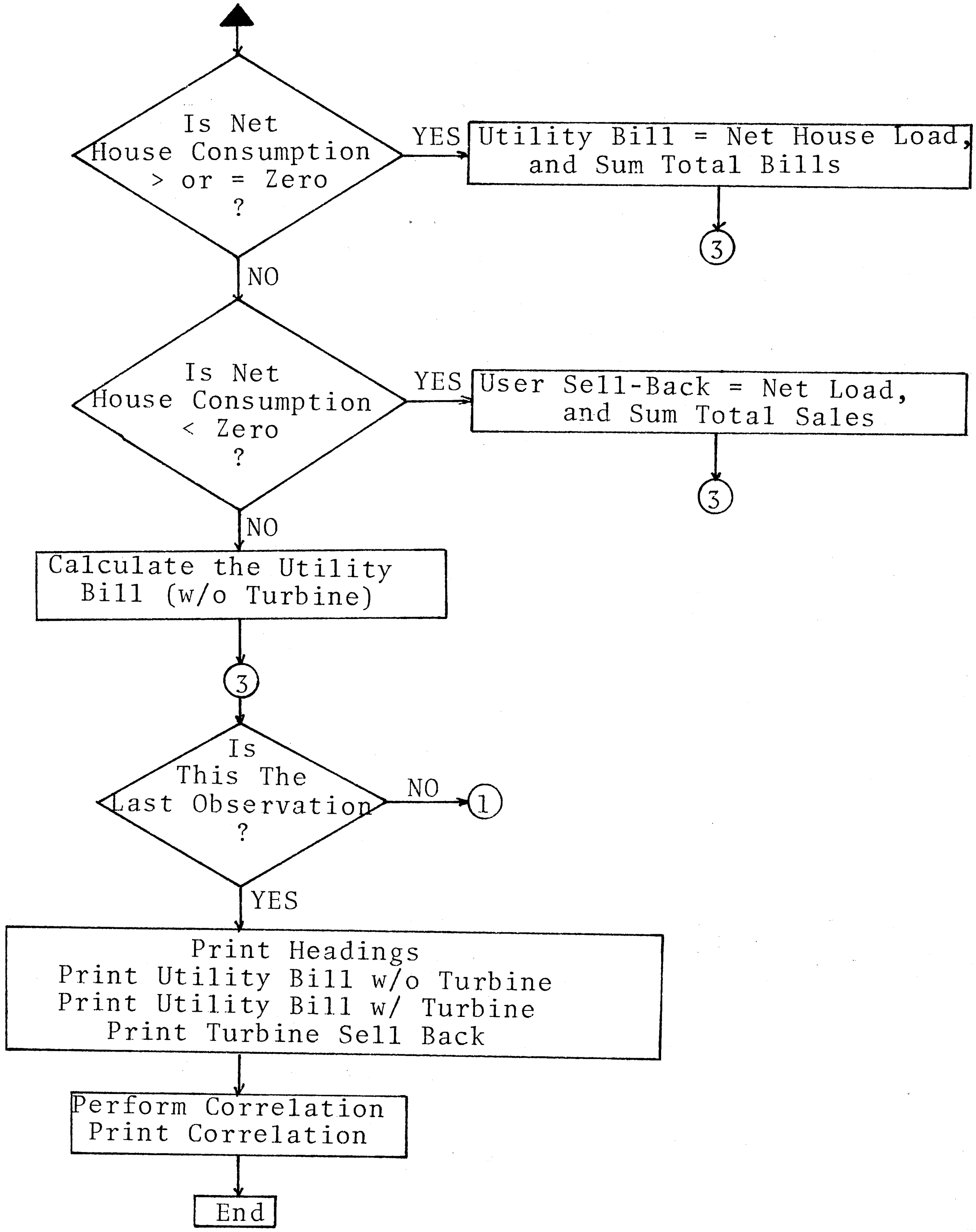

Figure 4. Continued

CHAPTER IV

ANALYSIS

A full year of data is required to properly model a system that is weather or environment dependent. However, only 10 months of data were available as input for the computer model. Fortunately, the missing months (November and December) have no impact on the cooling load nor do they amount to more than one-third of the heating load in Oklahoma. Using statistical analysis, general descriptive statistics such as the mean and standard deviation were calculated for the wind speeds, the turbine power generation, and the house consumption levels. A correlation analysis was performed on wind speed versus house consumption. An economic analysis follows the statistical analysis of the system. The outputs from the computer model and the statistical analysis were used in the economic evaluation in order to generate a measure of performance (MOP). This measure will be given in dollars per kilowatt-hour ($/KWH). This number is the quotient of the annual equivalent system cost and the annual kilowatt-hours (both those consumed and those sold back), generated by the wind turbine.

Statistical Analysis

The statistical analysis of the input data and the model generated information was performed by using the statistical analysis system (SAS) package. SAS is a powerful, all-purpose computer software system for data analysis. The SAS package was used to determine the correlation between high wind speed and peak house loads. A positive correlation between wind speed and house load would indicate that a high percent of the variation in the house load readings could be accounted for by the variation in the wind speed readings. When the correlation is zero, each variable has no linear predictive ability for the other variable.

The sample correlation coefficient for the three houses and their residential wind velocity profile are presented in Table III on the next page. The correlation coefficients were calculated from data for the period from January to October. All three correlation coefficients are fairly low positive numbers indicating no conclusive evidence for a strong correlation between house loads and wind speeds.

The descriptive statistics show that the average wind speed from January through October is 10.5 MPH. The above statistics can be used to reiterate the problems of using averaged data to model a dynamic system. The three wind turbines used in the analysis of the computer program have cut-in wind speeds of 11.4 MPH, 10.3 MPH, and 9.4 MPH. Obviously, placing two of these turbines in a model using an average wind speed of 10.5 MPH would result in zero power generation. However, the empirical time series data from January through October shows a very different picture. The turbine with the 11.4 MPH cut-in speed produced 18,900 KWH's for this period in the same wind profile. The hourly house consumption averages show the same errors in dynamic modeling that were brought out by the averaged wind speeds. For instance, the hourly average consumption level for the East house was 2.97 KWH's. Using this "worst case" average produced an expected 20,885 KWH's of consumption, yet the empirical data generated 21,125 KWH's for that same period. Averaged data is not able to represent the variations of a dynamic system. However, sampling a frequency distribution can be used to represent the same dynamic system with increased accuracy.

TABLE III

STATISTICAL ANALYSIS RESULTS

	Mean Consumption Level (KWH/hr)	Wind Speed Consumption Correlation
West House	1.48	0.0357
Middle House	2.48	0.0325
East House	2.97	0.0425

Practical problems exist with using sampling plans to develop data that represent true house consumption levels and true wind speed profiles over time. The intermittent cycling of the refrigerator compressor is a variable that is dependent on the inside house temperature, the items stored in it for cooling, and the number of times it is opened. Will a sampling plan capture the refrigerator load accurately or would continuous monitoring be better? The same problem and subsequent reasoning applies to air conditioning and heating loads, as well as other unpredictable energy consumers such as radios, stereos, and televisions. A continuous house consumption monitoring system is used in this thesis to accumulate the true house consumption levels.

A special problem exists with sampling the residential wind speed profile. The meter available for use would only take a 3 second reading every 15 minutes. If the wind speed was continuously accumulated,the wind run values would need to be integrated over time to give wind speed in miles per hour. Integration would erase the dynamic variation of the wind speed and distort the true turbine power production as mentioned earlier. Since hourly averaged data can produce major inaccuracies for dynamic minute by minute modeling, what effect does a 15-minute average have on the same minute interval model? Because the house consumption level reading is a sum over an interval of time and the wind speed reading is an instantaneous reading taken every 15 minutes to approximate turbine power generation, the comparison and justification of these two types of data were analyzed by an experiment. First, the results of the computer model were tabulated. Next, the 15 minute interval data base readings were modified so that they model hourly data. The watt-hour readings were summed over a 60 minute interval and four consecutive wind speed readings were averaged to give an hourly wind speed. This new data base was used in the computer model and these "hourly" outputs were compared to the "15 minute interval" outputs. The program listing for the hourly data program is in the Appendix on page 59. The results of this experiment for turbine system three during the month of August are shown in Table IV on the next page.

The entries for the 15 minute data base are all greater than the hourly data base. These differences were expected since the true wind speed and house load are represented more accurately by the shorter interval data base. This occurs because shorter interval sampling depicts the fluctuations of a dynamic frequency distribution more accurately than sampling with longer period intervals.

Although the 15 minute data is greater than the hourly data most of these increases are slight. The differences between the 15 minute data and the hourly data can be seen by examining the last three rows of Table IV. The sample means for the wind speed and house consumption levels change slightly (0.05% and 1.22%). The major difference between the data bases is in the sample standard deviations. The quarter hour wind speed and consumption level standard deviations show 3.35% and 14.2% more fluctuation than the hourly data. Although the hourly data base did not show the highs and lows of the 15 minute data base, it was accurate in the comparison with the quarter hour calculations for the utility consumption, both with and without the wind turbine.

TABLE IV

HOURLY DATA BASE VS. 15 MINUTE DATA BASE

Item Description	Hourly	15 Minute	% Change
Consumption Without Turbine	2880.9 KWH	2919.6 KWH	1.3%
Consumption With Turbine	2381.2	2407.4	1.1
Sell Back (Excess Energy)	306.3	336.6	9.0
Wind Speed ($\bar{x}$,s)	8.647, 4.703	8.651, 4.876	0.05, 3.35
East House Consumption ($\bar{x}$,s)	3.877, 1.698	3.925, 1.980	1.22, 14.20
Maximum Wind Speed	28.3 MPH	31.7 MPH	10.7

While a continuous data base would represent the true system performance, tradeoffs had to be made to collect sampled data. The results of Table IV are encouraging, since the user's main economic benefits over time are dependent upon the cost associated with not having to purchase power, i.e., his avoided cost. The avoided kilowatt-hour amount is calculated by subtracting the second row from the first row. The economic analysis would not have changed by using either data base since these values showed small percent changes (1.1% and 1.3%).

The most significant variation of the experiment is in the sell back quantity. But, the sell back quantity's economic benefit is reduced by the price differential between the utility's consumption and sell back rates. The overall results of this experiment indicate that the use of a 15 minute data base does not significantly bias a proper economic analysis.

Economic Analysis

Intelligent economic decisions should consider the time value of money. Economic analysis has been a major Industrial Engineering decision tool for a long time. Inflation was not originally accounted for in the developing years of economic analysis techniques. It has often been ignored in the last decade because it was either considered to have an offsetting effect on the project's cash flow or because of controversy over its introduction. However, inflation was included in this economic evaluation since it is an important factor in energy field financing. When the inflation rate for an energy price is considered to remain higher than the general rate of inflation, it has been shown that a single rate can be used as follows [25]:

$$k' = \frac{(1 + k)}{(1 + j)} - 1.0 \qquad (4\text{-}1)$$

where: k' = the equivalent single inflation rate,

k = the energy price inflation rate, and

j = the general economy inflation rate.

This single inflation rate was used along with the investor's minimum attractive rate of return to determine the cost of investing in a wind turbine system. The economic components are the initial investment and the salvage value (capital costs), the annual maintenance, the change in the utility bill due to the wind turbine, the first year energy tax credit, and the net income to the customer for excess power generation. Using the net present value (NPV) technique the cost equation can be expressed as:

$$NPV = (-P) + (F)(^{P/F}\ _{i,n}) + FYC - (M)(^{P/A}\ _{i,n})$$
$$+ \sum_{L=1}^{n} U(1+k')^{L}(^{P/F}\ _{i,L})$$
$$+ \sum_{L=1}^{n} C(1+k')^{L}(^{P/F}\ _{i,L}) \qquad (4\text{-}2)$$

where: NPV = net present value,

P = system installed cost,

F = system salvage value,

i = investor's minimum attractive rate of return (MARR),

n = system life,

M = annual maintenance,

U = utility bill without turbine - utility bill with turbine,

C = customer sell back, and

FYC = first year credits.

The net present value (NPV) of each turbine system was converted into an annual equivalent cost (AEC) by Equation (4-3).

$$AEC = (NPV)(^{A/P\ i,n}) \qquad (4\text{-}3)$$

Equation (4-3) was needed in order to calculate the performance measure ($/KWH). All economic calculations were performed by a computer program which is listed in the Appendix on pages 60 through 62.

The data used for economic analysis covers the period from January through October of 1982. The net present value for three wind turbine systems was calculated for the East house and the residential wind speed profile. The East house was used to represent the "worst case" because it had the highest consumption level of the three houses. The East house consumption level and the power outputs for the three wind turbine systems are shown in Table V on page 31.

Equation (4-2) assumed a uniform rate schedule without an on-peak, off-peak feature or an energy demand charge. The consumption charge for residences was assumed to be $0.05/KWH, and the customer sell back rate was assumed to be $0.025/KWH. For the initial case, the investor's MARR, the general economy inflation rate, and the specific energy price inflation rates were set at 10%, 8%, and 8% respectively. These values give an equivalent single inflation rate (k') of 0% from Equation (4-1). The general economy inflation rate and the specific energy price inflation rate will be varied to perform sensitivity analysis in the next section.

TABLE V

HOUSE CONSUMPTION AND TURBINE PRODUCTION FOR THE PERIOD FROM JANUARY THROUGH OCTOBER

East House Consumption	21,125	KWH
Monthly Average	2,112	KWH/MO
Consumption With Turbine 1	19,230	KWH
Monthly Average	1,923	KWH/MO
Excess Energy - Turbine 1	190	KWH
Monthly Average	19	KWH/MO
Consumption With Turbine 2	19,860	KWH
Monthly Average	1,986	KWH/MO
Excess Energy - Turbine 2	42	KWH
Monthly Average	4.2	KWH/MO
Consumption With Turbine 3	14,805	KWH
Monthly Average	1,480	KWH/MO
Excess Energy - Turbine 3	12,590	KWH
Monthly Average	1,259	KWH/MO

However, before the economic analysis could be performed on the wind turbine systems the two missing months had to be approximated. The values for November and December were approximated by the following linear relationships:

$$Y_{NOV} = Y_{OCT} + (1)[(Y_{JAN} - Y_{OCT})/3] \qquad (4\text{-}4)$$

$$Y_{DEC} = Y_{OCT} + (2)[(Y_{JAN} - Y_{OCT})/3] \qquad (4\text{-}5)$$

Then the economic analysis could be based upon both the annual house consumption and wind turbine production levels. The variables that are required to calculate the net consumption and production levels are the utility bill without the turbine, the utility bill with the turbine, and the excess energy produced by the turbine. These three variables, for turbine system three and the empirical 10 month data base, are plotted in Figures 5 and 6 on pages 33 and 34. The graphs for turbine systems one and two are in the Appendix on pages 63 and 66.

Figure 5 shows the monthly consumption levels of the East house, both without and with turbine #3. Wind turbine #3 was chosen for examination since it supplied the most power to the East house of the three turbines examined. The peak consumption level for the East house is in August and the next highest consumption level is in January. Calculations based on data from Table V show that the turbine produced a total of 18,910 KWH's and that the house consumed 6320 of the turbine produced KWH's, or approximately 30% of the total consumption needs were satisfied by the

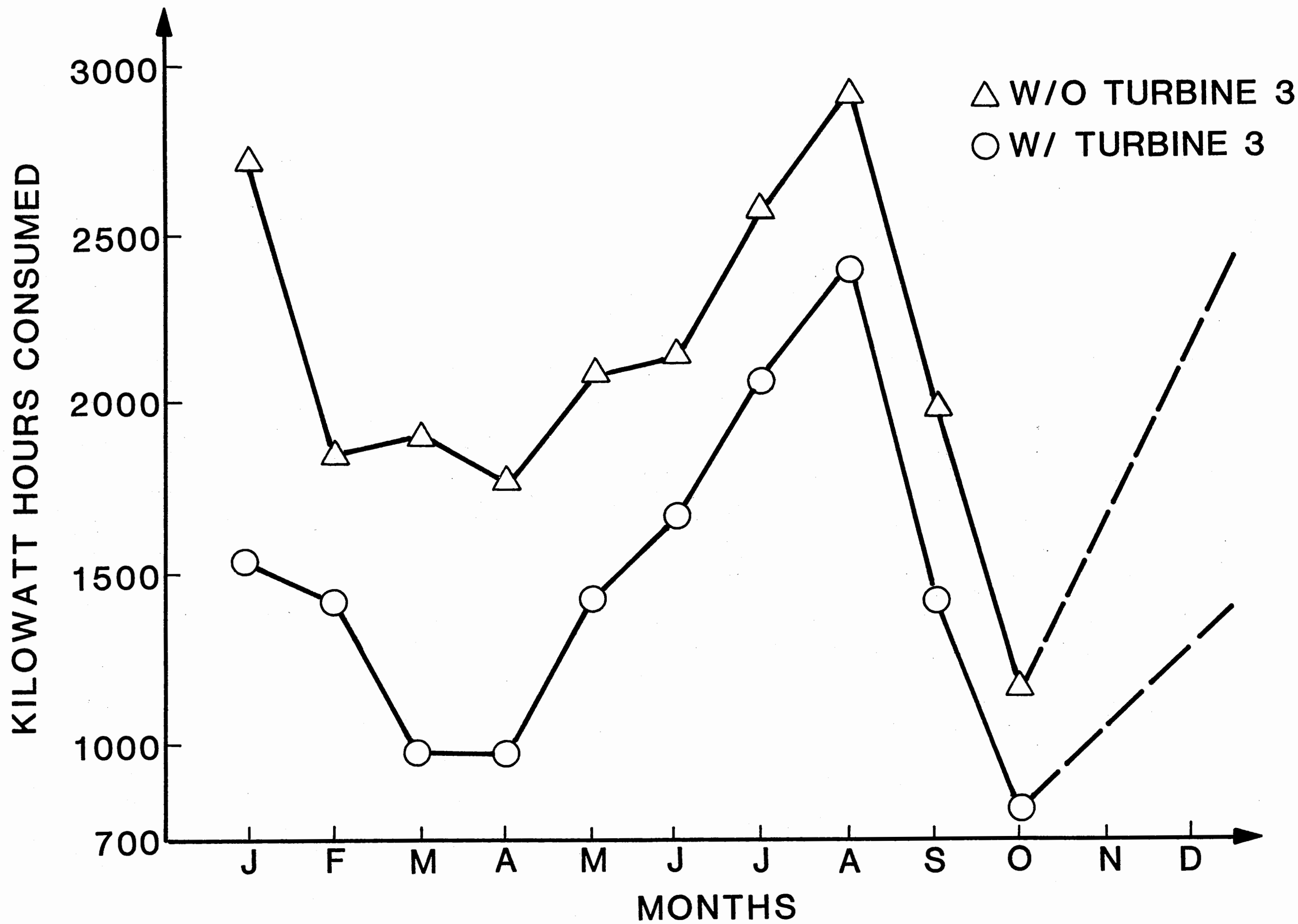

Figure 5. East House Monthly Consumption Levels

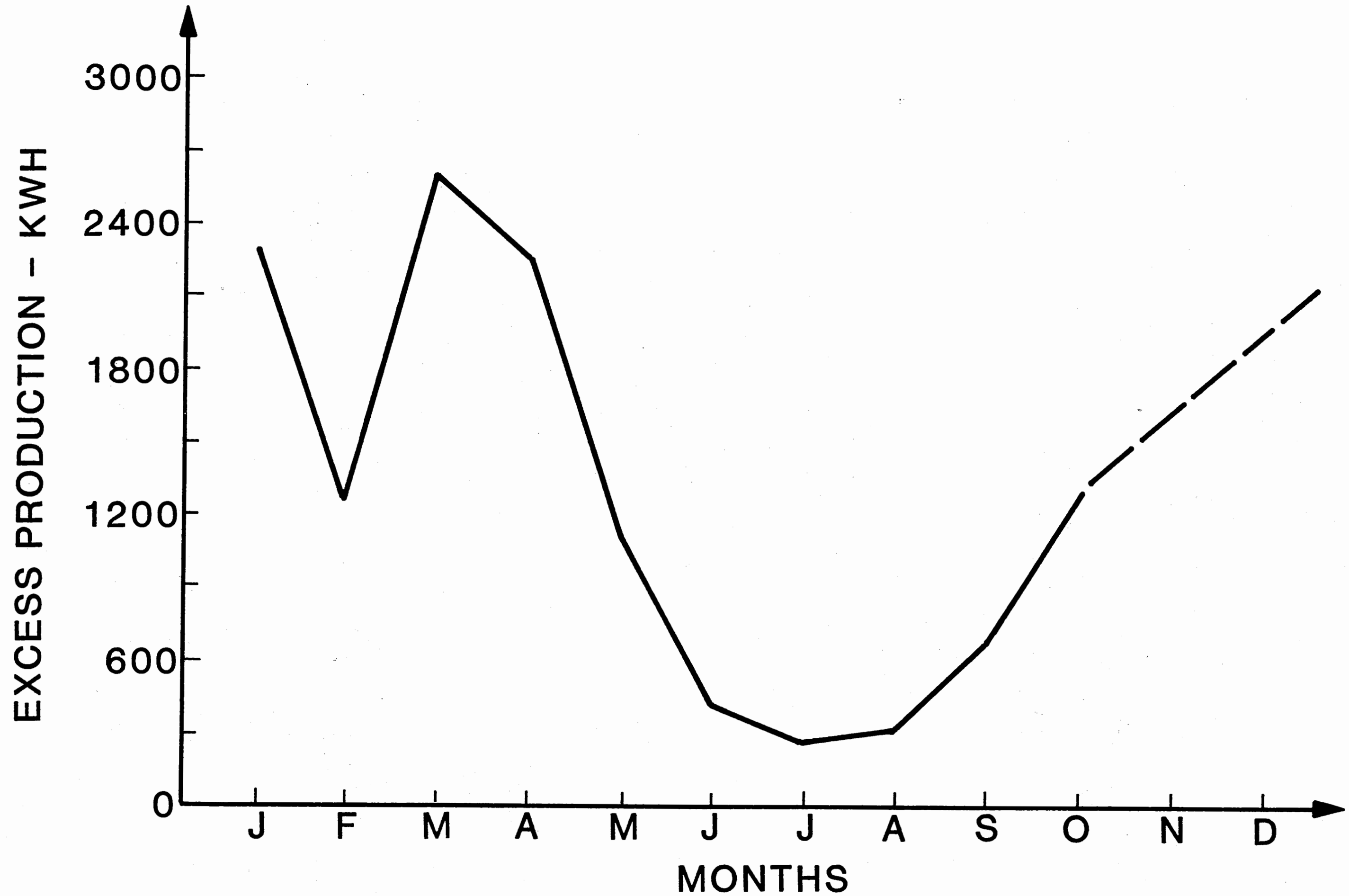

Figure 6. Excess Energy Production (Turbine 3)

turbine. Figure 5 shows that most of the power generated by the turbine occurred in the first five months of the year. Figure 6 on page 34 shows the monthly excess energy generated by turbine #3 and indicates that most of the excess energy was also produced in the first five months of the year.

The dashed lines in Figures 5 and 6 show the lines through the approximation points for the various kilowatt-hour levels that were generated by Equations (4-4) and (4-5). The total yearly consumption levels of the East house both without and with turbines one through three are shown below in Table VI. The final column of Table VI shows the percent of the house load met by each turbine system for the year 1982.

TABLE VI

APPROXIMATED YEARLY CONSUMPTION LEVELS

System Description	Kilowatt-Hours Consumed	% of House Load Met
East House	25,000	100%
East House with Turbine #1	22,600	9.6%
East House with Turbine #2	23,430	6.3%
East House with Turbine #3	17,000	32.0%

The annual house consumption, wind turbine production, and excess energy produced by the wind turbines are used in Equations (4-2) and (4-3) to yield the system economics and performance measures. The net present value and annual equivalent cost for each system, along with its measure of performance based on a ten-year system life, are presented in Table VII below. The values in Table VII are based on state and federal first year residential energy tax credits of 20% and 40% which apply to the first $10,000 of the investment.

TABLE VII

INITIAL CASE SUMMARY ECONOMICS AND PERFORMANCE MEASURES

Turbine System Rating	Net Present Value ($)	Annual Equivalent Cost ($/YR)	Turbine Production (KWH/YR)	M.O.P. ($/KWH)
System #1 (2.5 KW)	(9,015.00)	(1,467.00)	2,643	(0.555)
System #2 (1.5 KW)	(5,903.00)	(960.00)	1,625	(0.591)
System #3 (20 KW)	(21,124.00)	(3,437.00)	24,200	(0.142)

The M.O.P. figures of Table VII show that the turbine systems produced power at a more expensive rate ($/KWH) than most utilities produce power. Turbine system three produced the most inexpensive power of the three systems. Based on these initial case values consumer investment is not recommended since electricity can be bought at a cheaper rate ($/KWH) than the turbine can produce it.

Although traditional engineering economics rejects negative net present values (NPV), the three systems were not rejected on that basis. The proper decision criteria for each turbine system is the M.O.P. value. This performance measure divides the system annual cost by the total energy produced by the turbine resulting in a unit cost for power. When this cost reaches the marginal cost the consumer pays for purchased power, the turbine becomes cost effective, even though the measure remains negative. The NPV, AEC, and MOP values of Table VII are dependent on interest rates, inflation rates, turbine system life, and the utility rate structure. These inputs were varied in order to perform sensitivity analysis on the three residential turbine systems.

Sensitivity Analysis

The economic analysis of the previous section evaluated the initial case. This case was based on a life of ten years, an investor's MARR of 10%, a general economy inflation rate of 8%, an electric energy price inflation rate of

8%, a simple rate structure with a purchase rate of \$0.05/KWH and a utility buy back rate of \$0.025/KWH, and state and federal energy tax credits totaling 60%. The inflation rates used in the analysis gave an equivalent single inflation rate (k') equal to zero. This is a conservative figure since the current general economy inflation rate is approximately 8%, and the electric energy price inflation rate for eight large United States cities for the period from May 1981 to May 1982 reached an average of 13.75% [27].

This section addresses the investigation of the sensitivity of the results of Table VII. Various components of the initial case were altered to determine if any significant changes occur in the initial case conclusions. The first component which was varied, while holding the other initial case components constant, was the price the consumer paid for electricity, or simply the utility rate. The utility is assumed to buy back excess energy at one-half the purchase rate. The electric energy price graph for system #3 (Figure 7) on page 39 shows the effect of increasing the electricity price from 5¢ to 10¢ on the system's performance measure. The X-axis shows the increase in the utility rate (\$/KWH) and the Y-axis shows the change in the turbine system's performance measure (\$/KWH). The dashed line shows the break-even threshold where the utility rate equals the system performance measure. The electric energy price graphs for residential systems one and two are

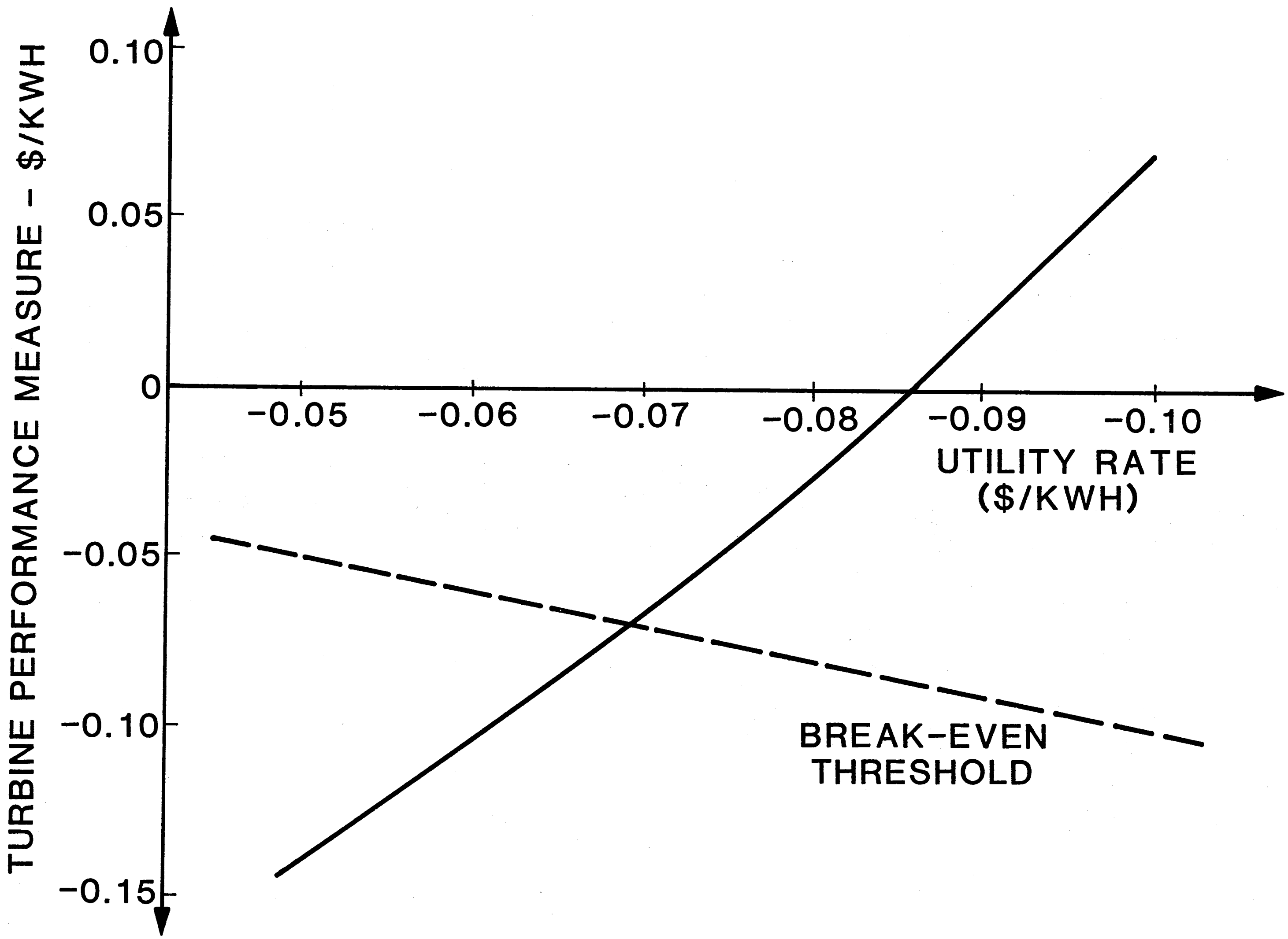

Figure 7. Electric Energy Price Sensitivity (Turbine 3)

in the Appendix on pages 67 and 68. System #3 was the only residential turbine system that crossed the break-even threshold. Figure 7 and the two graphs in the Appendix show that each system becomes more economical as the utility rate increases. If the initial case conditions were held constant for residential turbine system #3, it would cross the break-even threshold at $0.069/KWH and would begin to actually return a profit as the utility rate increased past $0.07/KWH. Any point falling below the break-even threshold is considered a bad investment and any point falling above the break-even threshold is considered a good investment.

The first sensitivity case study dealt with a single variable analysis on the initial case. The second sensitivity case study was a multi-variable analysis. The three initial case components that were varied were the equivalent single inflation rate (k'), the system life and the residential energy tax credits. The general economy inflation rate (j) was held constant and the utility rate structure was initialized as in the first case ($0.05/KWH - consumer purchase rate, and $0.025/KWH - utility buy back rate). However, these values will change with k'. The k' value of Equation (4-1) was increased by increasing the energy price inflation rate (k). Figure 8, the equivalent single inflation rate/system life graph for turbine system three on page 41 shows the effect of varying the equivalent single inflation rate and the system life, while holding residential energy tax credits constant at 60%. The X-axis represents

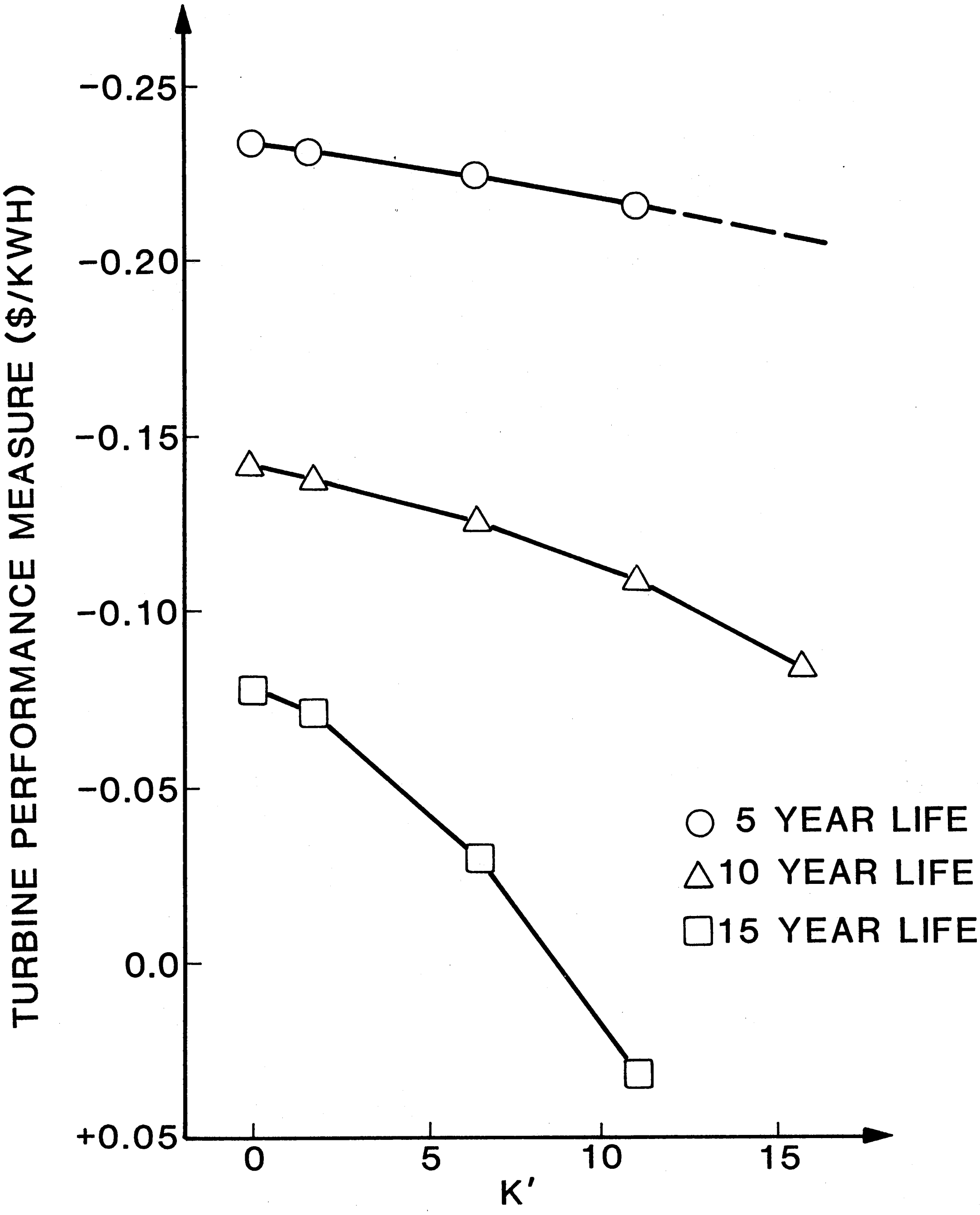

Figure 8. k'/System Life Sensitivity Graph (Turbine 3)

the k' values and the Y-axis represents the turbine system's performance measure. The energy price inflation rate (k) was changed to generate four new performance measures from the initial case conditions at a system life of 10 years. Then, the system life was changed to 5 and 15 years. Holding the life constant at 5 and 15 years, the energy price inflation rate (k) was changed to generate a total of eight more performance measures. Notice from Figure 8 that as the system life and the equivalent single inflation rate increase, it becomes more economical to produce power with turbine #3.

The final sensitivity case dealt with the state and federal energy tax credit values. The procedure to generate Figure 8 was followed with one exception to generate Figure 9 on page 43. The exception was to set the energy tax credit values to zero before changing the energy price inflation rate. Therefore, Figure 9 shows the equivalent single inflation rate/system life for turbine system #3 without the benefit of the energy tax credits. The performance measures for a given system life yield higher negative values without the energy tax credits than the performance measures with the energy tax credits. The results of Figures 8 and 9 are shown on the cumulative energy inflation/system life graph for turbine #3 (Figure 10) on page 44. Similar cumulative graphs for turbine systems one and two are in the Appendix on pages 69 and 70.

Figure 10 shows that the best economic situation for

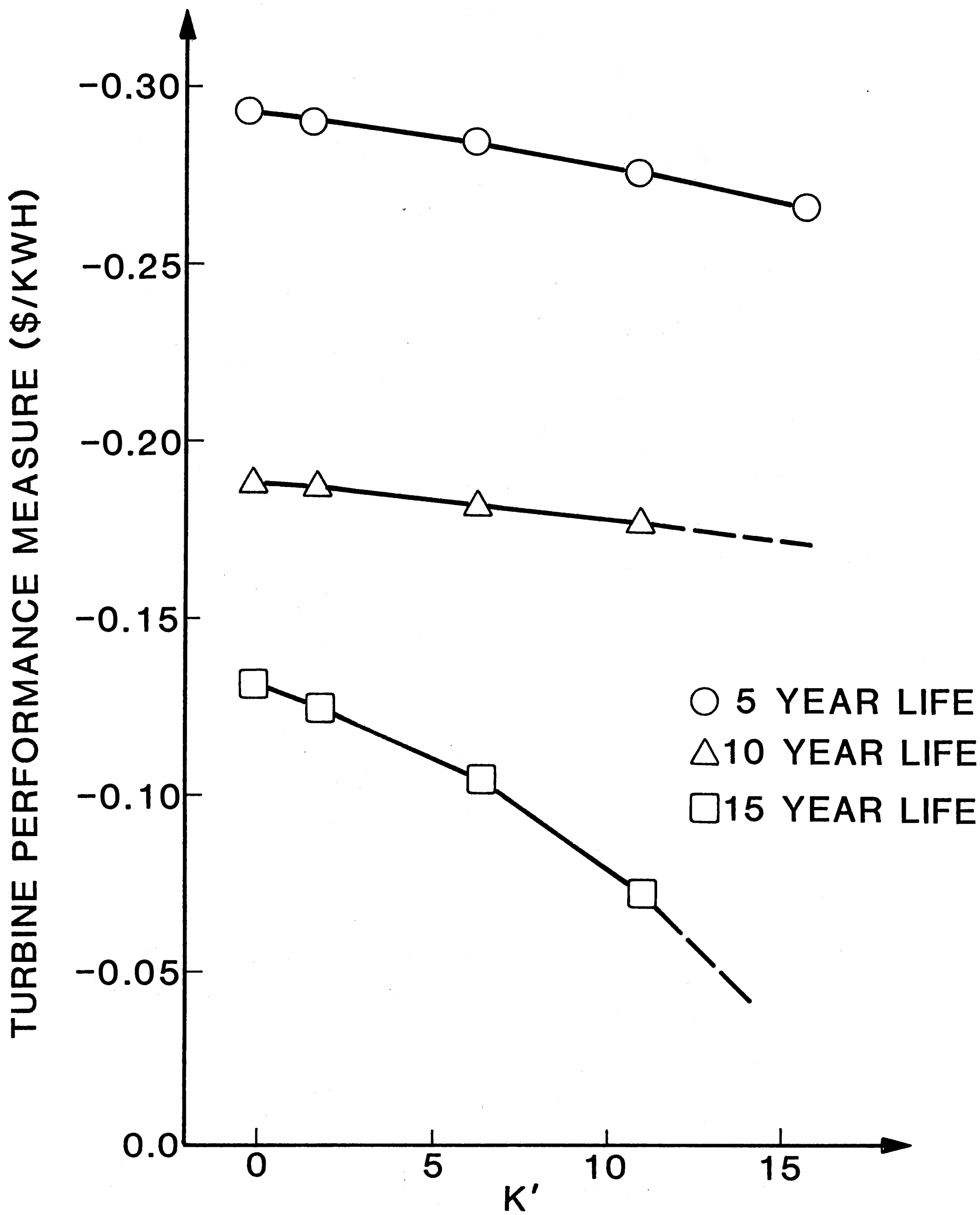

Figure 9. k'/System Life/Tax Credit Sensitivity Graph (Turbine 3)

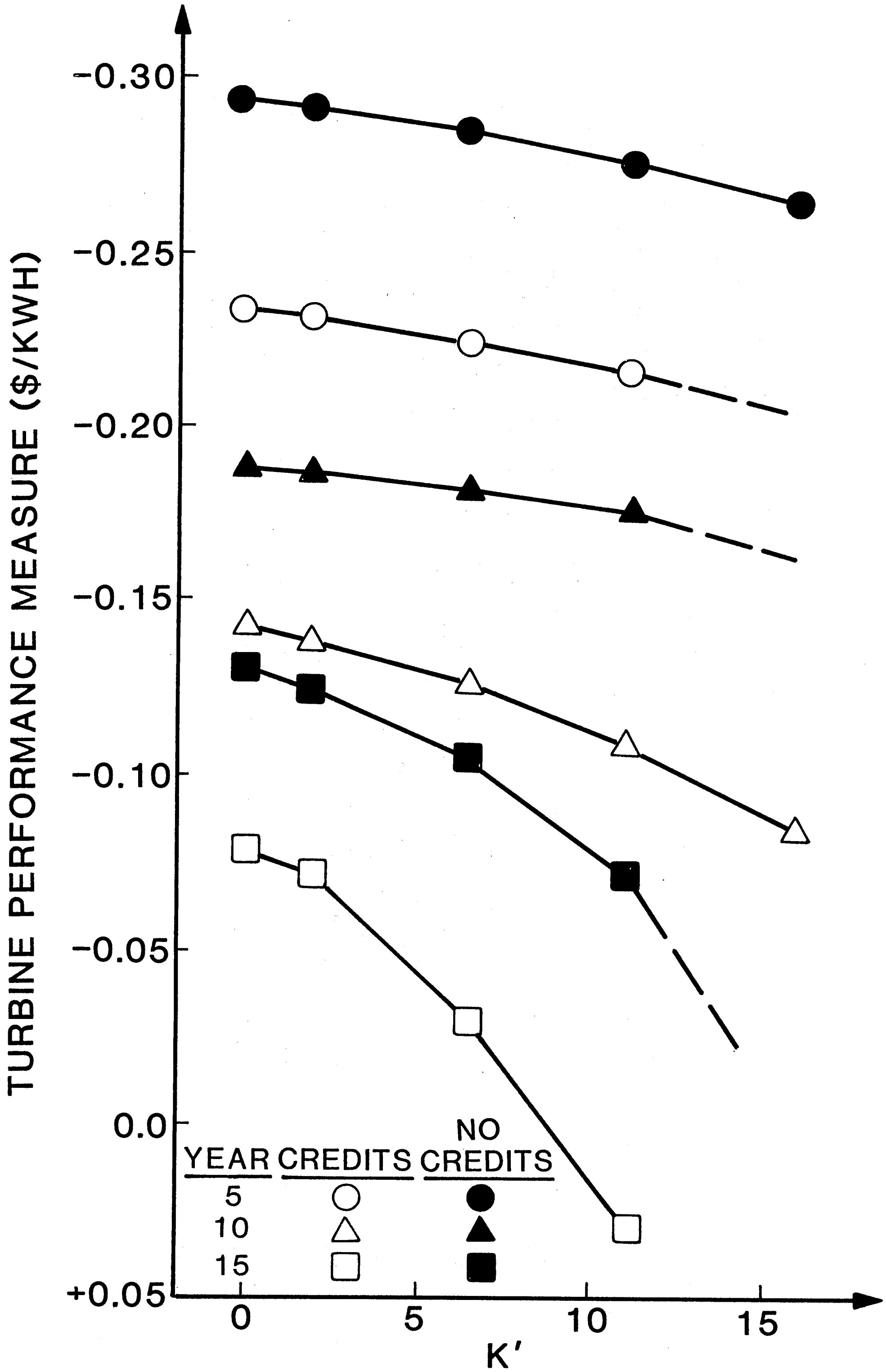

Figure 10. Cumulative k'/System Life/Tax Credit Sensitivity Graph (Turbine 3)

turbine system #3 would be a scenario with a long system life utilizing energy tax credits during a period of energy price inflation. Conversely, the worst scenario for turbine system #3 would have a short system life during a period of negligible energy price inflation after the time the energy tax credits have expired.

CHAPTER V

CONCLUSIONS

A study was made on both the technical and economic feasibility of three residential wind turbine systems utilizing an empirical data base. A computer model was used to determine the gross and net house consumption levels for a residence, both with and without three different residential wind turbine systems. Further computer calculations yielded a performance measure ($/KWH) for each turbine system. Economic sensitivity analyses were performed by a second computer program in order to graphically portray the dependence of the turbine systems' performance measures upon system life, inflation, and residential energy tax credits. In summary, this thesis presented two computer programs used to quantitatively analyze the technical feasibility and economics of a residential wind turbine system in a given wind speed profile.

General conclusions drawn from this research effort are:

1) The wind speed and house consumption levels show little evidence of correlation.
2) Although minute by minute data is preferred for both house consumption levels and wind speed measurements, the 15 minute interval data closely

approximates the true environment and does not bias the economic outcomes.

3) The 20 KW wind turbine (#3) produced the most power and had the best performance measures of the turbine systems tested.

4) Under the first sensitivity case, turbine system #3 becomes economically feasible when the residential utility rate is at $0.07/KWH.

5) In general, the most favorable economic conditions for residential wind turbine systems occur in a scenario with long system life, under present residential energy tax credits, during periods of high energy price inflation.

Two areas are recommended for further research so that more rigorous conclusions can be made on the evaluation of residential wind turbine systems. First, more research on the life of various residential wind turbines is needed to solidify conclusions based on sensitivity to turbine system life. Secondly, acquisition of a 15 minute data base covering a period of at least two years would greatly enhance the reliability of the performance measure calculations for the wind turbines.

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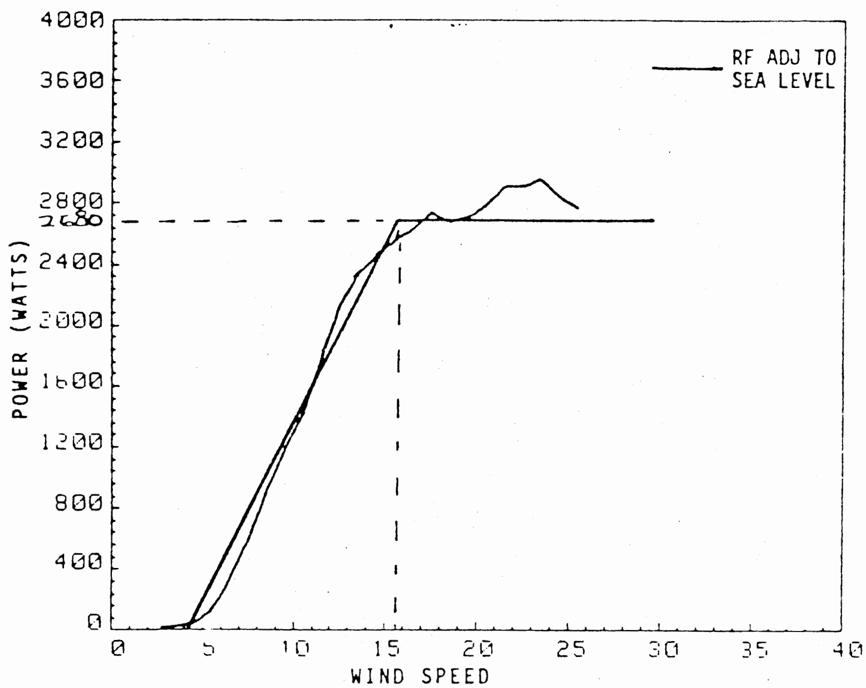
APPENDIX

ROCKY FLATS PERFORMANCE DATA

TURBINE ONE

MEASURED CHARACTERISTICS
(ADJUSTED TO SEA LEVEL)

CUT-IN WIND SPEED .... 4 m/s (9 mph)
CUT-OUT WIND SPEED .... NONE
SURVIVED WIND SPEED .... 36 m/s (80 mph)
OUTPUT @ 9 m/s (20 mph) .... 1.1 kW
OUTPUT @ 11 m/s (22 mph) .... 1.9 kW
NOISE @ RATED OUTPUT (at base of tower) .... 55 dBA



(1 m/s = 2.24 mph)

P_r = 2.68 kw
V_i = 9.4 MPH
V_R = 35 MPH

ESTIMATED ANNUAL ENERGY PRODUCTION
(USING A RAYLEIGH WIND DISTRIBUTION)

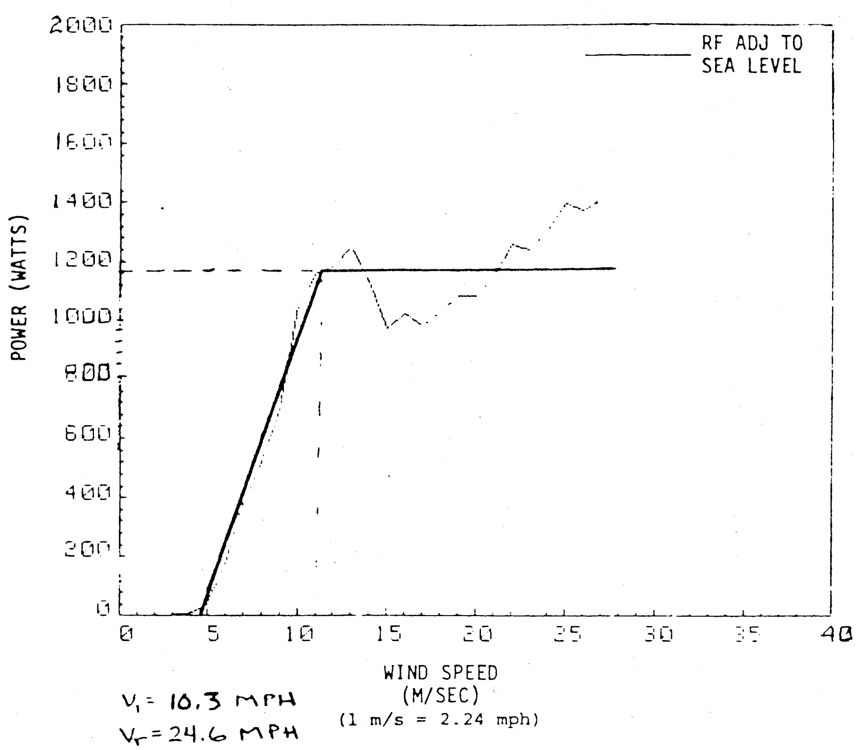
AVERAGE WIND VELOCITY (m/s)	(mph)	ANNUAL ENERGY OUTPUT (kWh)
3.58	8	720
4.47	10	1680
5.36	12	3000
6.26	14	4540
7.15	16	6200

ROCKY FLATS PERFORMANCE DATA

TURBINE TWO

MEASURED CHARACTERISTICS
(ADJUSTED TO SEA LEVEL)

CUT-IN WIND SPEED......................4.2 m/s (9.5 mph)
SHUT DOWN SPEED....30-second average of 26.8 m/s (60 mph)
SURVIVED WIND SPEED....................44.7 m/s (100 mph)
OUTPUT @ 9 m/s (20 mph)........................695 Watts
OUTPUT @ 9.8 m/s (22 mph).....................1095 Watts
NOISE @ RATED OUTPUT......................Not Available



V_1 = 10.3 MPH
V_r = 24.6 MPH
P_r = 1.160 KW

ESTIMATED ANNUAL ENERGY PRODUCTION
(USING A RAYLEIGH WIND DISTRIBUTION)

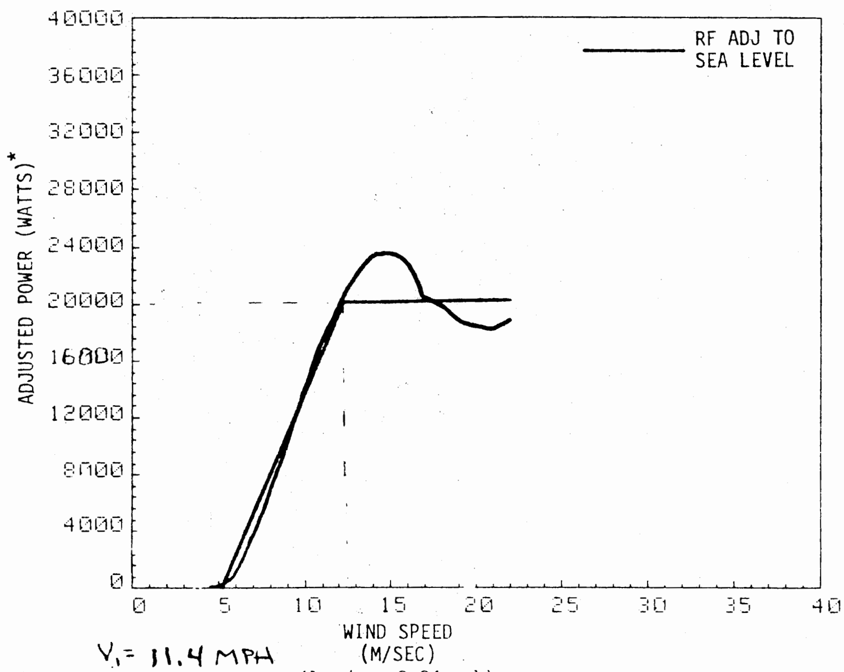
AVERAGE WIND VELOCITY (m/s)	(mph)	ANNUAL ENERGY OUTPUT (kWh)
3.58	8	528
4.47	10	1225
5.36	12	2115
6.26	14	3048
7.15	16	3920

ROCKY FLATS PERFORMANCE DATA

TURBINE THREE

MEASURED CHARACTERISTICS*
(ADJUSTED TO SEA LEVEL)

CUT-IN WIND SPEED........................4 m/s (9 mph)
CUT-OUT WIND SPEED..................................NONE
SURVIVED WIND SPEED....................40.2 m/s (90 mph)
OUTPUT @ 9 m/s (20 mph)..........................10.3 kW
OUTPUT @ 11.6 m/s (26 mph)........................19 kW
NOISE @ RATED OUTPUT.......................NOT AVAILABLE



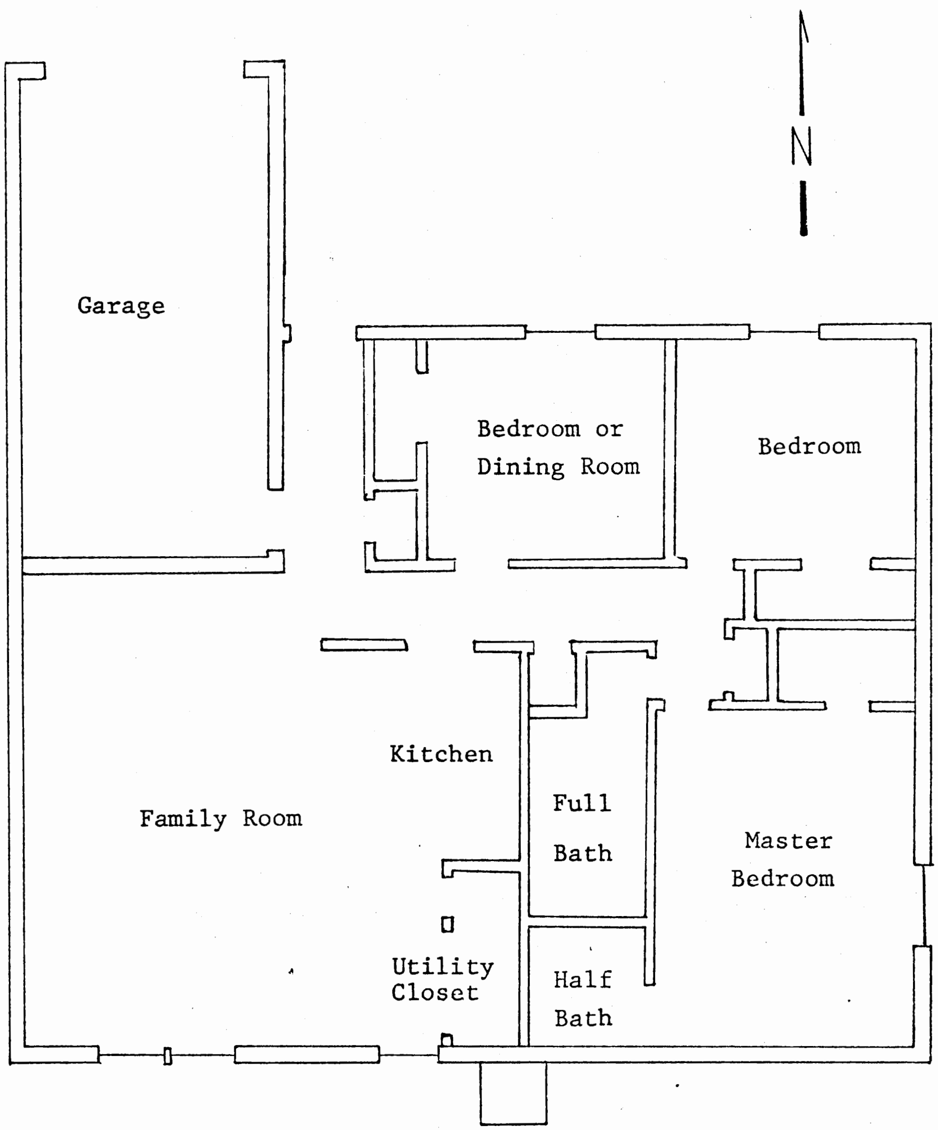
V_i = 11.4 MPH
V_r = 28.0 MPH
P_r = 20.0 kW

ESTIMATED ANNUAL ENERGY PRODUCTION
(USING A RAYLEIGH WIND DISTRIBUTION)

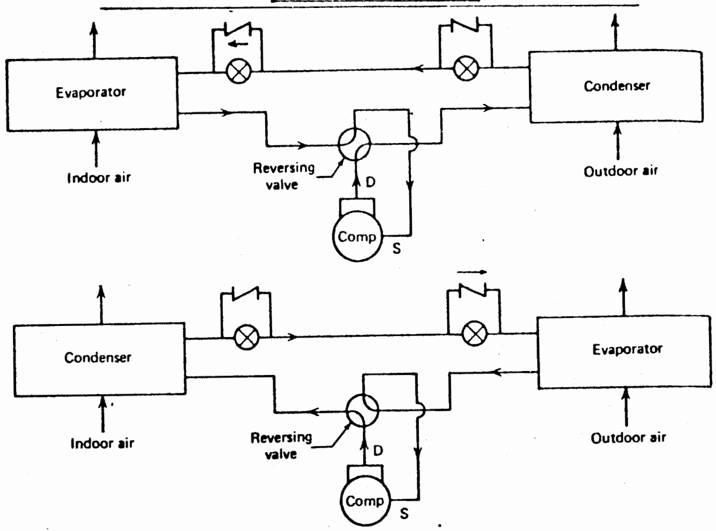
AVERAGE WIND VELOCITY (m/s)	(mph)	ANNUAL ENERGY OUTPUT* (kWh)
3.58	8	4840
4.47	10	13,870
5.36	12	27,130
6.26	14	42,640
7.15	16	58,430

NOTE: *The annual energy output is based on the measured Rocky Flats power curve for this machine. The power curve is superimposed on a Rayleigh velocity duration curve which is then integrated over time to obtain energy. Energy output will vary at specific sites due to variations in wind characteristics and other factors.*

Basic Floor Plan of All Three Houses

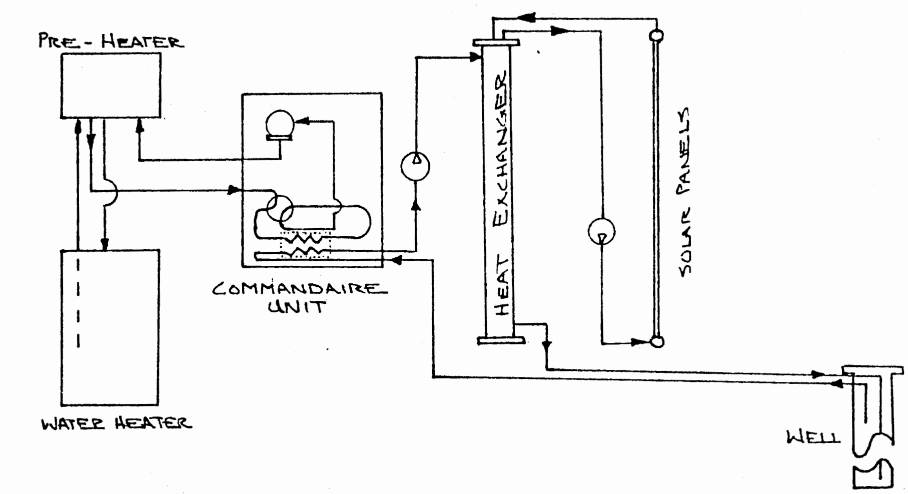


EAST HOUSE

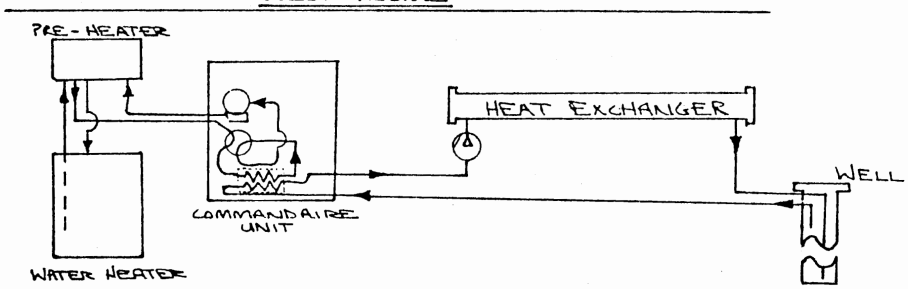


Schematics of a simple heat pump in cooling and heating modes.

MIDDLE HOUSE



WEST HOUSE



SYSTEM COSTS

Turbine One

Turbine		$ 8,500	
40 Ft. Tower		2,000	
Site		2,500	
Installation		2,000	
			$15,000
Salvage Value	$1,000		
Annual Maintenance	$ 100		
Life (Before Major Failure)	10 years		

Turbine Two

Turbine		$ 5,000	
40 Ft. Tower		2,000	
Site Preparation		2,500	
Installation		2,000	
			$11,500
Salvage Value	$,700		
Annual Maintenance	$ 100		
Life (Before Major Failure)	10 years		

Turbine Three

Turbine		$15,000	
60 Ft. Tower		4,000	
Site Preparation		5,000	
Installation		6,000	
			$30,000
Salvage Value	$2,000		
Annual Maintenance	$ 200		
Life (Before Major Failure)	10 years		

EXAMPLE PROGRAM LISTING - 15 MINUTE DATA BASE

```
//TRYHARD  JOB (XXXXX,451-15-5838),BYRON,TIME=(0,40),CLASS=B
***MESSAGE MOUNT T2997-FP
***ROUTE PRINT LOCAL
// EXEC SAS
//ONE DD DSN=AUG82.TAPE.DATA,UNIT=TAPE,VOL=SER=T2997,LABEL=1,
//    DCB=(LRECL=80,BLKSIZE=6160,RECFM=FB),DISP=SHR
//TWO DD DSN=JUL82.TAPE.DATA,UNIT=TAPE,VOL=SER=T2997,LABEL=3,
//    DCB=(LRECL=80,BLKSIZE=6160,RECFM=FB),DISP=SHR
//THREE DD DSN=JUN82.TAPE.DATA,UNIT=TAPE,VOL=SER=T2997,LABEL=2,
//    DCB=(LRECL=80,BLKSIZE=6160,RECFM=FB),DISP=SHR
//SYSIN DD *
    DATA WONE;
      INFILE ONE;
          INPUT #3 WEST 20-23 MIDDLE 28-31 EAST 36-39 WIND 52-55 #7;
          HEIGHT = 25.0;
          TOWER = 40.0;
          EXP = 0.1429;
      WINDSPD = WIND*((TOWER/HEIGHT)**EXP);
      WKWH = WEST*0.024;
      MKWH = MIDDLE*0.024;
      EKWH = EAST*0.024;
      IF WINDSPD >= 35 THEN POWER = 2.68;
      IF WINDSPD <= 9.4 THEN POWER = 0.0;
      IF WINDSPD > 9.4 AND WINDSPD < 35 THEN
                  POWER = 0.105*(WINDSPD - 9.4);
      DROP WEST MIDDLE EAST WIND HEIGHT TOWER EXP;
      ENERGY = POWER*0.25;
      NETHSLD = EKWH - ENERGY;
      IF NETHSLD >= 0 THEN DO;
          BILLED = NETHSLD;
          BILTOT = BILTOT + BILLED;
          END;
      IF NETHSLD < 0 THEN DO;
          SOLD = ABS(NETHSLD);
          SOLTOT = SOLTOT + SOLD;
          END;
      OLDTOT = OLDTOT + EKWH;
           IF _N_ = 2970 THEN DO;
          PUT 132*'-';
          PUT 132*' ';
          PUT '      THE CONSUMPTION WITHOUT THE TURBINE IS 'OLDTOT 'KWH.';
          PUT 132*' ';
          PUT '      THE NET CONSUMPTION (FROM UTILITY) IS 'BILTOT 'KWH.';
          PUT 132*' ';
          PUT '      THE NET SELL BACK (EXCESS ENERGY) IS 'SOLTOT' KWH.';
          PUT 132*' ';
          PUT 132*'-';
      END;
      RETAIN BILTOT 0 SOLTOT 0 OLDTOT 0;
    PROC CORR;
      VAR WINDSPD;
      WITH WKWH MKWH EKWH;
      TITLE5 HOUSELOAD VS. WIND CORRELATION ANALYSIS;
    PROC CORR;
      VAR ENERGY;
      WITH WKWH MKWH EKWH;
      TITLE5 TURBINE GENERATED POWER VS. HOUSELOAD CORRELATION ANALYSIS;
    //
```

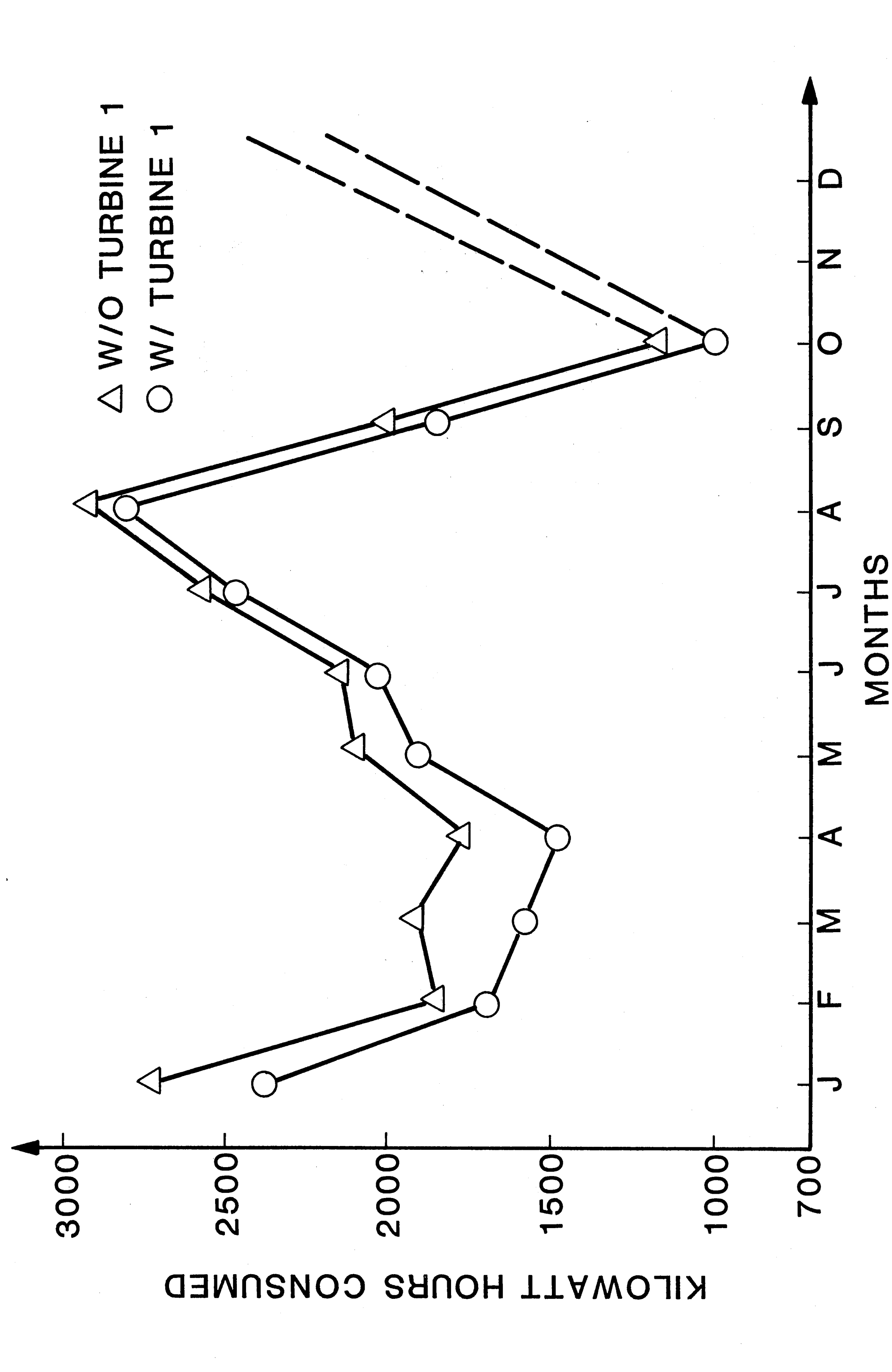
EXAMPLE PROGRAM LISTING – HOURLY DATA BASE

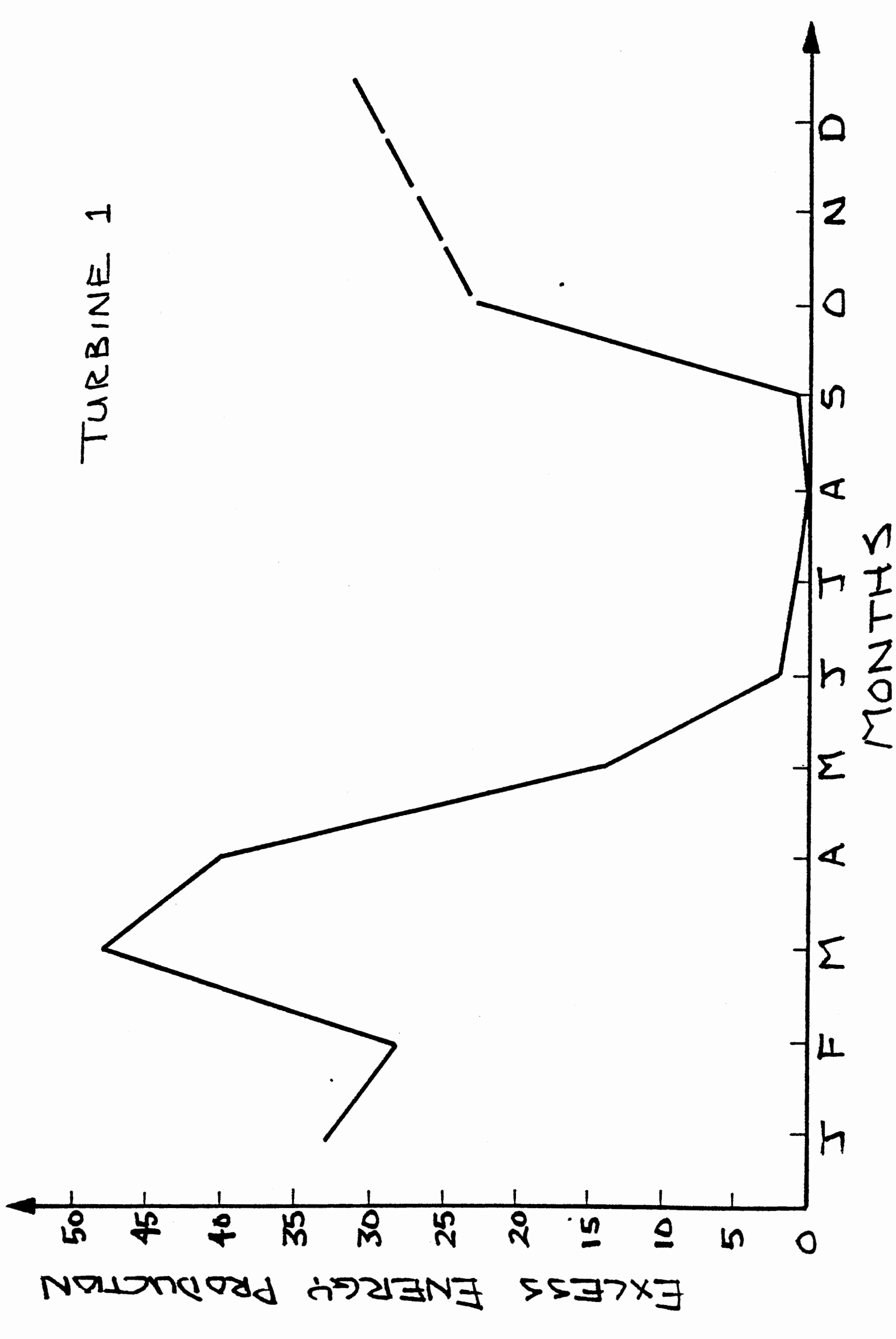
```
//TRYHARD  JOB (XXXXX,451-15-5838),BYRON,TIME=(0,40),CLASS=B
***MESSAGE MOUNT T2997-FP
***ROUTE PRINT LOCAL
// EXEC SAS
//ONE DD DSN=AU82HR.TOTAL.DATA,UNIT=TAPE,VOL=SER=T2997,LABEL=5,
//      DCB=(LRECL=80,BLKSIZE=6160,RECFM=FB),DISP=SHR
//SYSIN DD *
    DATA WONE;
      INFILE ONE;
      INPUT #3 WEST 17-22 MIDDLE 25-30 EAST 33-38 WIND 49-54 #7;
          HEIGHT = 25.0;
          TOWER = 60.0;
          EXP = 0.1429;
      WINDSPD = WIND*((TOWER/HEIGHT)**EXP);
        WKWH = WEST;
        MKWH = MIDDLE;
        EKWH = EAST;
      IF WINDSPD >= 28 THEN POWER = 20;
      IF WINDSPD <= 11.4 THEN POWER = 0;
      IF WINDSPD > 11.4 AND WINDSPD < 28 THEN
                   POWER = 1.2*(WINDSPD - 11.4);
      DROP WEST MIDDLE EAST WIND HEIGHT TOWER EXP;
      ENERGY = POWER;
      NETHSLD = EKWH - ENERGY;
      IF NETHSLD >= 0 THEN DO;
          BILLED = NETHSLD;
          BILTOT = BILTOT + BILLED;
          END;
      IF NETHSLD < 0 THEN DO;
          SOLD = ABS(NETHSLD);
          SOLTOT = SOLTOT + SOLD;
          END;
      OLDTOT = OLDTOT + EKWH;
      IF _N_ = 743 THEN DO;
          PUT 132*'-';
          PUT 132*' ';
          PUT '     THE CONSUMPTION WITHOUT THE TURBINE IS 'OLDTOT 'KWH.';
          PUT 132*' ';
          PUT '     THE NET CONSUMPTION (FROM UTILITY) IS 'BILTOT 'KWH.';
          PUT 132*' ';
          PUT '     THE NET SELL BACK (EXCESS ENERGY) IS 'SOLTOT' KWH.';
          PUT 132*' ';
          PUT 132*'-';
      END;
      RETAIN BILTOT 0 SOLTOT 0 OLDTOT 0;
    PROC CORR;
      VAR WINDSPD;
      WITH WKWH MKWH EKWH;
      TITLE5 HOUSELOAD VS. WIND CORRELATION ANALYSIS;
    PROC CORR;
      VAR ENERGY;
      WITH WKWH MKWH EKWH;
      TITLE5 TURBINE GENERATED POWER VS. HOUSELOAD CORRELATION ANALYSIS;
//
```

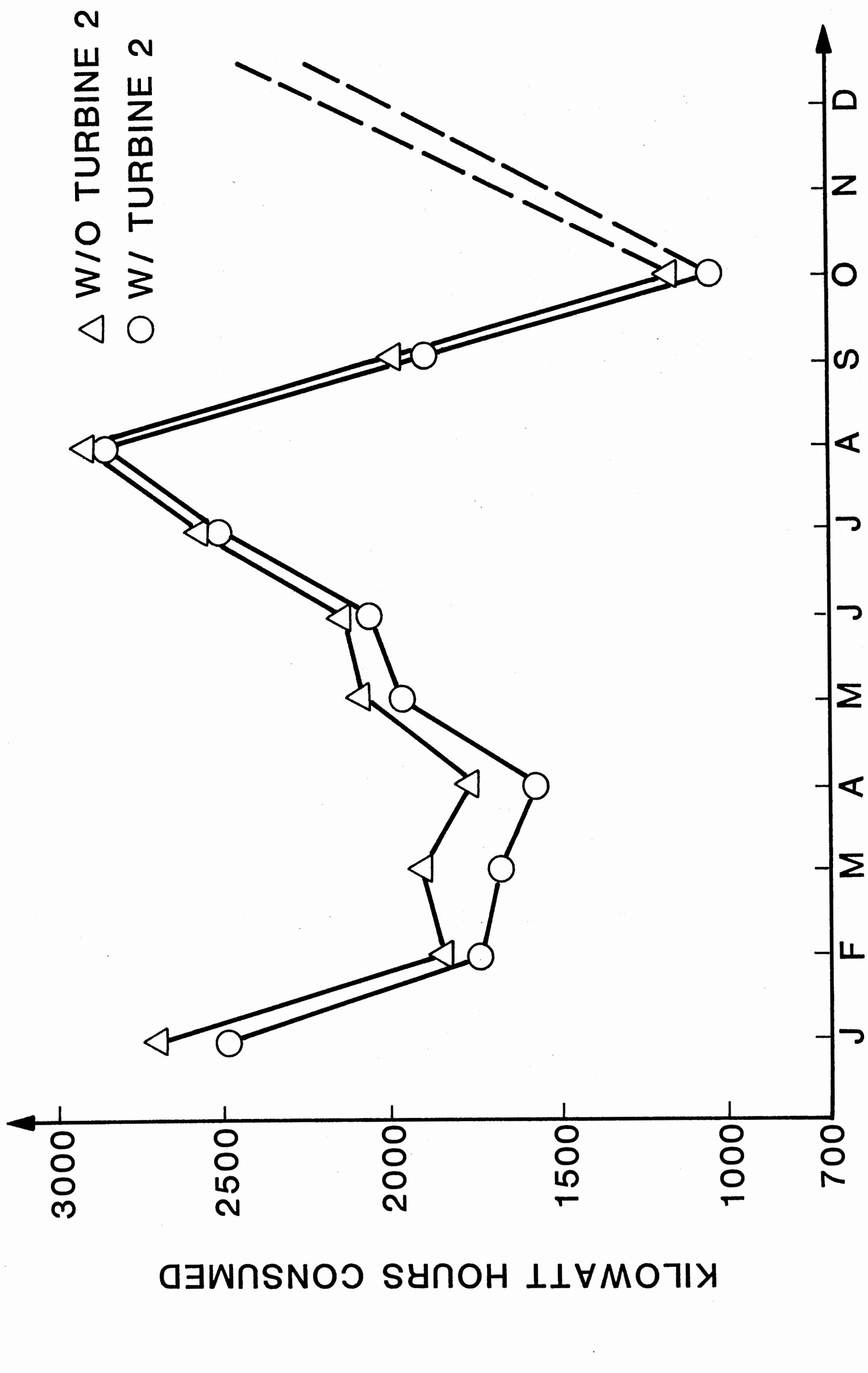
```
C     *************************************************
C     *                                               *
C     *          SENSITIVITY ANALYSIS ON              *
C     *     THE NPW OF THE TURBINE SYSTEM - THESIS    *
C     *                                               *
C     *          VARIABLES:                           *
C     *                                               *
C     *             DELTA IS THE OLD - NEW BILL (KWH) *
C     *                 (BILL W/O TURBINE - BILL WITH )  *
C     *             SELL IS THE CONSUMER SELLBACK (KWH)  *
C     *             RAT1 IS THE PURCHASE RATE ($/KWH)  *
C     *             RAT2 IS THE SELLBACK RATE ($/KWH)  *
C     *             DCR( ) IS THE DECISION CRITERIA   *
C     *             AEC( ) IS THE ANNUAL EQUIVALENCE  *
C     *             NPW( ) IS THE NET PRESENT WORTH   *
C     *             FYC( ) IS THE FIRST YEAR CREDIT   *
C     *             PF IS THE PRESENT WORTH FACTOR    *
C     *             PA IS THE EQUAL SERIES AMOUNT     *
C     *             AP IS THE CAPITAL RECOVERY FACTOR *
C     *             INT( ) IS THE USER MARR           *
C     *             GEN( ) IS THE GENERAL INFLATION RATE  *
C     *             ENG( ) IS THE ENERGY INFLATION RATE   *
C     *             ADJ( ) IS THE EQUIVALENT INCREMENTAL  *
C     *                       INFLATION RATE          *
C     *             LIFE( ) IS THE SYSTEM LIFE        *
C     *             AVOID( ) IS THE AVOIDED COST      *
C     *             SALES( ) IS THE SELLBACK CREDIT   *
C     *             F IS THE SALVAGE VALUE            *
C     *             P IS THE INVESTMENT               *
C     *             AM IS THE ANNUAL MAINTENANCE      *
C     *                                               *
C     *************************************************
C
C
      DIMENSION DCR(50),AEC(50),FYC(50),GEN(50)
      DIMENSION OLD(50),ENG(50),LIFE(50),AVOID(50),SALES(50)
      DIMENSION ADJ(50),STC(50),FDC(50)
      REAL NPW(50),INT(50), NEW(50)
C
C  ****      INTERACTIVE DATA INITIALIZATION
C
        DISPLAY 'ENTER THE NUMBER OF RUNS'
           ACCEPT NNRNS
      DO 5 M=1,NNRNS
      DISPLAY 'ENTER THE OLD AND NEW UTILITY BILLS FOR RUN',M
      ACCEPT OLD(M),NEW(M)
      DISPLAY 'ENTER THE USER INTEREST RATE FOR RUN',M
      ACCEPT INT(M)
      DISPLAY 'ENTER THE GENERAL INFLATION RATE FOR RUN',M
      ACCEPT GEN(M)
      DISPLAY 'ENTER THE ENERGY INFLATION RATE.FOR RUN',M
      ACCEPT ENG(M)
      DISPLAY 'ENTER THE LIFE OF THE SYSTEM FOR RUN',M
      ACCEPT LIFE(M)
      DISPLAY 'ENTER THE STATE AND FEDERAL TAX CREDITS FOR RUN'
     1,M
```

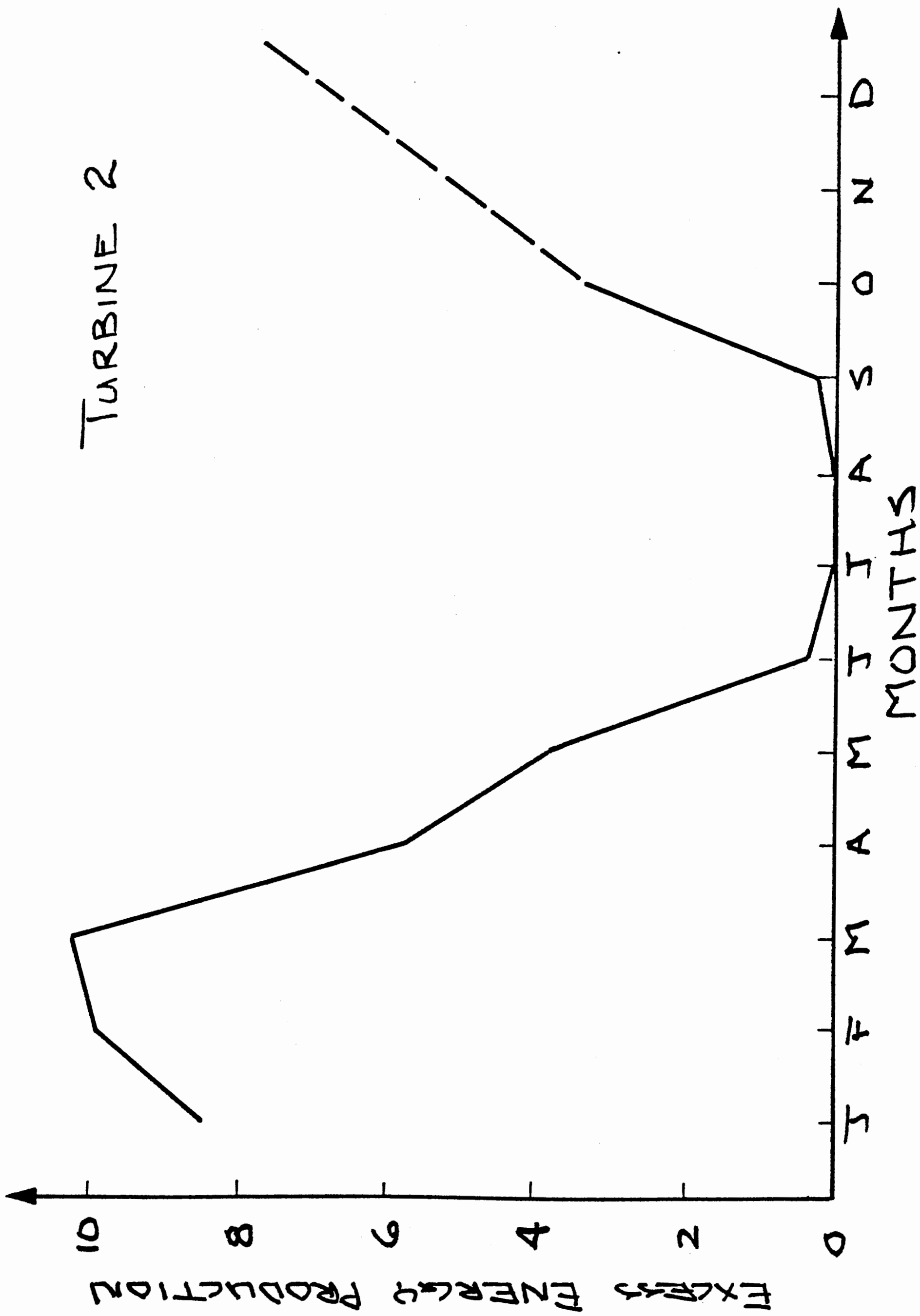
```
      ACCEPT STC(M),FDC(M)
    5 CONTINUE
      DISPLAY 'ENTER THE INVESTMENT'
      ACCEPT P
      DISPLAY 'ENTER THE SALVAGE VALUE'
      ACCEPT F
      DISPLAY 'ENTER THE ANNUAL MAINTENANCE'
      ACCEPT AM
      DISPLAY 'ENTER THE EXCESS ENERGY'
      ACCEPT SELL
      DISPLAY 'ENTER THE UTILITY RATES: PURCHASE AND BUYBACK'
      ACCEPT RAT1,RAT2
      DO 100 N=1,NNRNS
C
C  ****     CALCULATE THE CHANGE IN THE UTILITY BILL, INCREMENTAL
C  ****     INFLATION RATE, THE DISCOUNTING FACTORS, AND THE
C  ****     FIRST YEAR CREDIT.   ( ASSUMES INVESTMENT ) $ 10000 )
C
      DELTA = OLD(N) - NEW(N)
      ADJ(N) = ((1+ENG(N))/(1+GEN(N)))-1
      PF = (1/((1+INT(N))**LIFE(N)))
      PA = (((1+INT(N))**LIFE(N) - 1)/((INT(N))*(1+INT(N))**
     1LIFE(N))).
      FYC(N)= (10000.)*(STC(N) + FDC(N))*(1/(1+INT(N)))
        AP = 1/ PA
C
C  ****     CALCULATE THE AVOIDED COST
C
C  ****     THE ANNUAL AVOIDED COST IS INFLATED BY ADJ(N)
C  ****     AND THEN IT'S PRESENT WORTH IS CALCULATED.
C
      DO 10 L=1,LIFE(N),1
      SUBAV=(DELTA*(RAT1))*(((1+ADJ(N))**L)*(1/((1+INT(N))**
     1L)))
      AVOID(N) = AVOID(N) + SUBAV
   10 CONTINUE
C
C  ****     CALCULATE THE SELLBACK CREDIT
C
C  ****     THE ANNUAL CREDIT IS INFLATED BY ADJ(N) AND
C  ****     THEN IT'S PRESENT WORTH IS CALLCULATED.
C
      DO 15 K=1,LIFE(N),1
      SUBSA=(SELL*(RAT2))*(((1+ADJ(N))**L)*(1/((1+INT(N))**
     1L)))
      SALES(N) = SALES(N) + SUBSA
   15 CONTINUE
C
C  ****     CALCULATE THE ANNUAL EQUIVALENCE      ****
C
C  ****     CALCULATE THE NET PRESENT WORTH FIRST      ****
C
      NPW(N) = (-P) + (F)*(PF) + (FYC(N)) - AM*(PA) + AVOID(N)
     1 + SALES(N)
      AEC(N) = (NPW(N))*(AP)
      DCR(N) = (AEC(N))/(DELTA + SELL)
  100 CONTINUE
```

```
C
C  ****     OUTPUT FORMATS
C
       DO 2000 J=1,NNRNS
      WRITE(7,1000)
1000  FORMAT('1',28X,'*********************')
      WRITE(7,1001)
1001  FORMAT('+',50X,'WIND TURBINE ECONOMIC ANALYSIS')
      WRITE(7,1002)
1002  FORMAT('+',80X, ' ********************')
      WRITE(7,1003)P,LIFE(J),INT(J),RAT1,RAT2
1003  FORMAT('0',//,15X,'THE INSTALLED PRICE IS = $',F9.2
     1,10X,'THE SYSTEM LIFE IS  ',I2,' YEARS',10X,'THE INTEREST RATE IS
     1 ',F6.4,/,20X,'THE RESIDENTIAL CONSUMPTION RATE IS $',F5.3,'/KWH'
     1,10X,'THE UTILITY BUY-BACK RATE IS $',F5.3,'/KWH')
      WRITE(7,1005)
1005  FORMAT('0',//,20X,'$$$$$$$$$$ INFLATION RATES $$$$$$$$$$',//)
      WRITE(7,1006)GEN(J),ENG(J),ADJ(J)
1006  FORMAT('+',30X,'GENERAL RATE  = ',F6.4,//,
     131X,'ENERGY RATE = ',F6.4,//,31X,'INCREMENTAL RATE = ',F6.4)
      WRITE(7,1007)
1007  FORMAT('0',//,20X,'$$$$$$$$$$ COST ANALYSIS $$$$$$$$$$')
      WRITE(7,1008)NPW(J),AEC(J),DCR(J)
1008  FORMAT('0',30X,'THE NET PRESENT WORTH IS $',F20.10,
     1//,31X,'THE ANNUAL EQUIVALENT COST IS  $',F20.10,
     2///,31X,'THE DECISION CRITERIA IS $',F15.10,' / KWH')
2000  CONTINUE
      STOP
      END
```

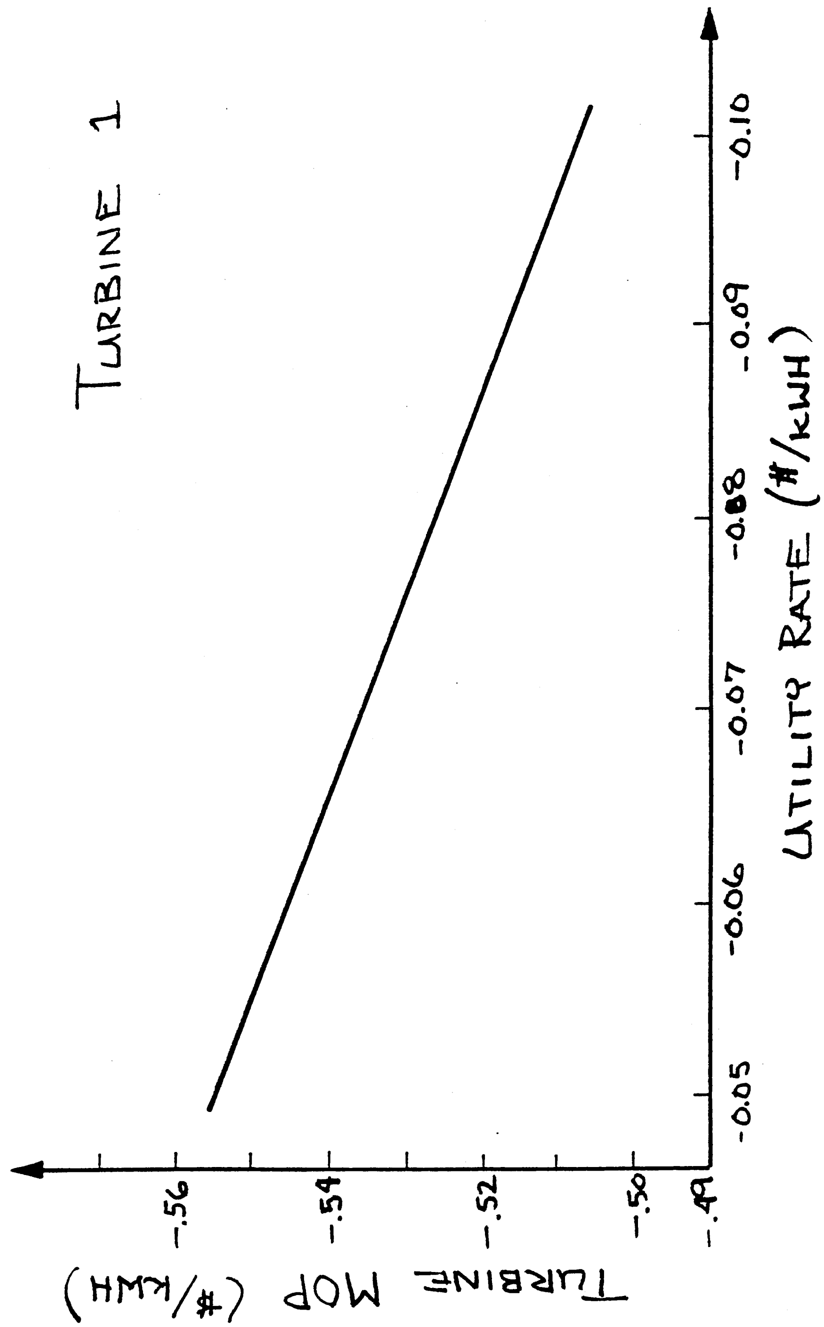

△ W/O TURBINE 1
○ W/ TURBINE 1
KILOWATT HOURS CONSUMED
3000
2500
2000
1500
1000
700
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS

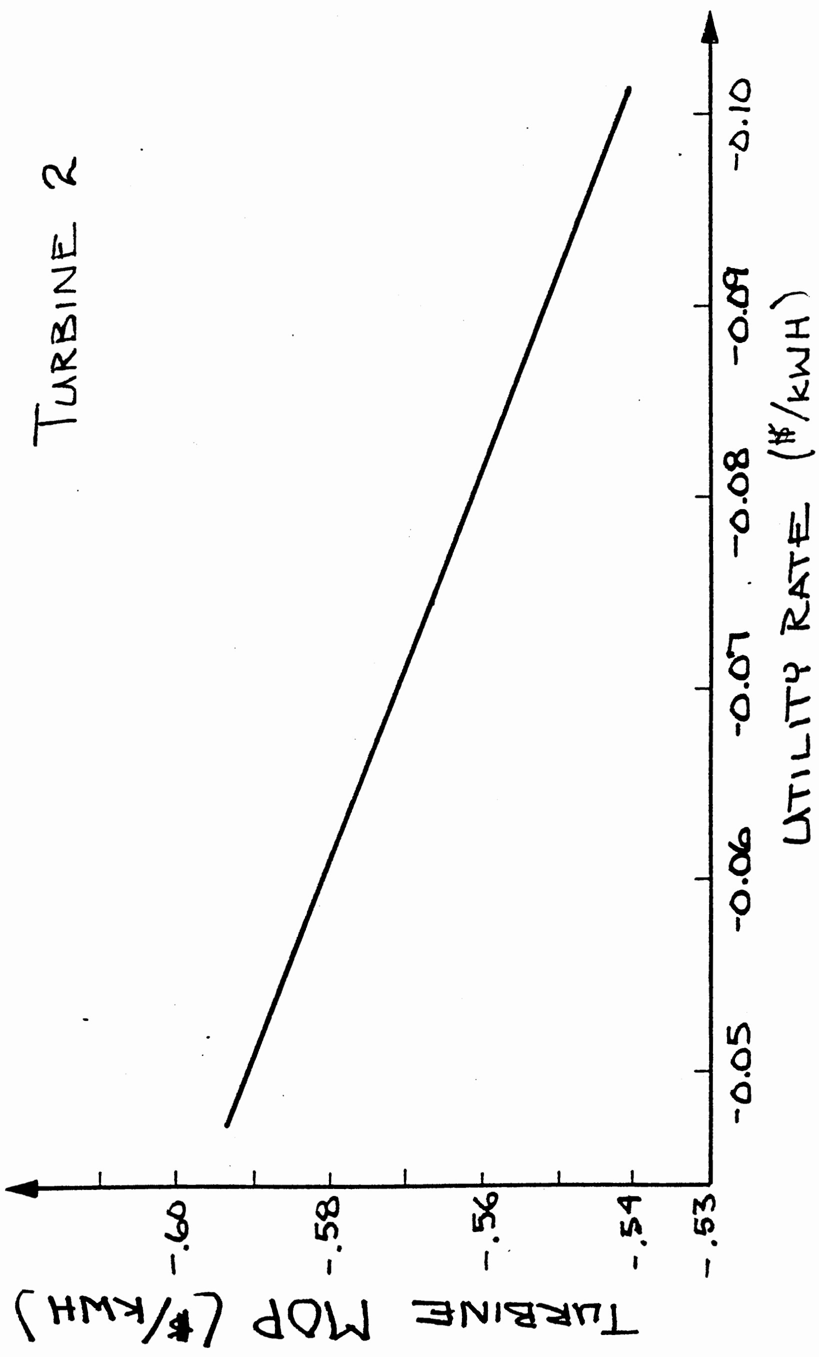

TURBINE 1
EXCESS ENERGY PRODUCTION
0
5
10
15
20
25
30
35
40
45
50
MONTHS
J
F
M
A
M
J
J
A
S
O
N
D

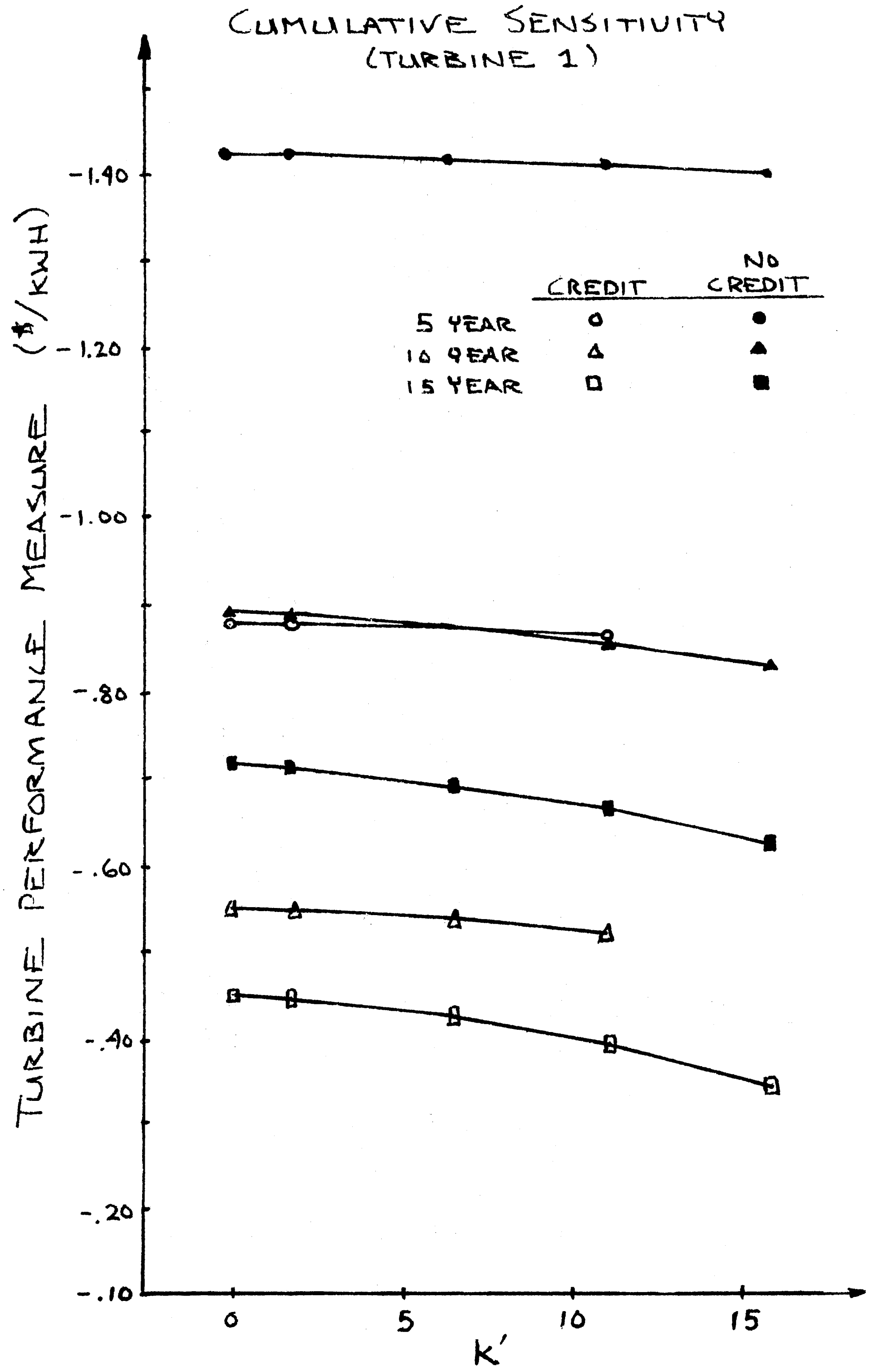

△ W/O TURBINE 2
○ W/ TURBINE 2
KILOWATT HOURS CONSUMED
3000
2500
2000
1500
1000
700
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS



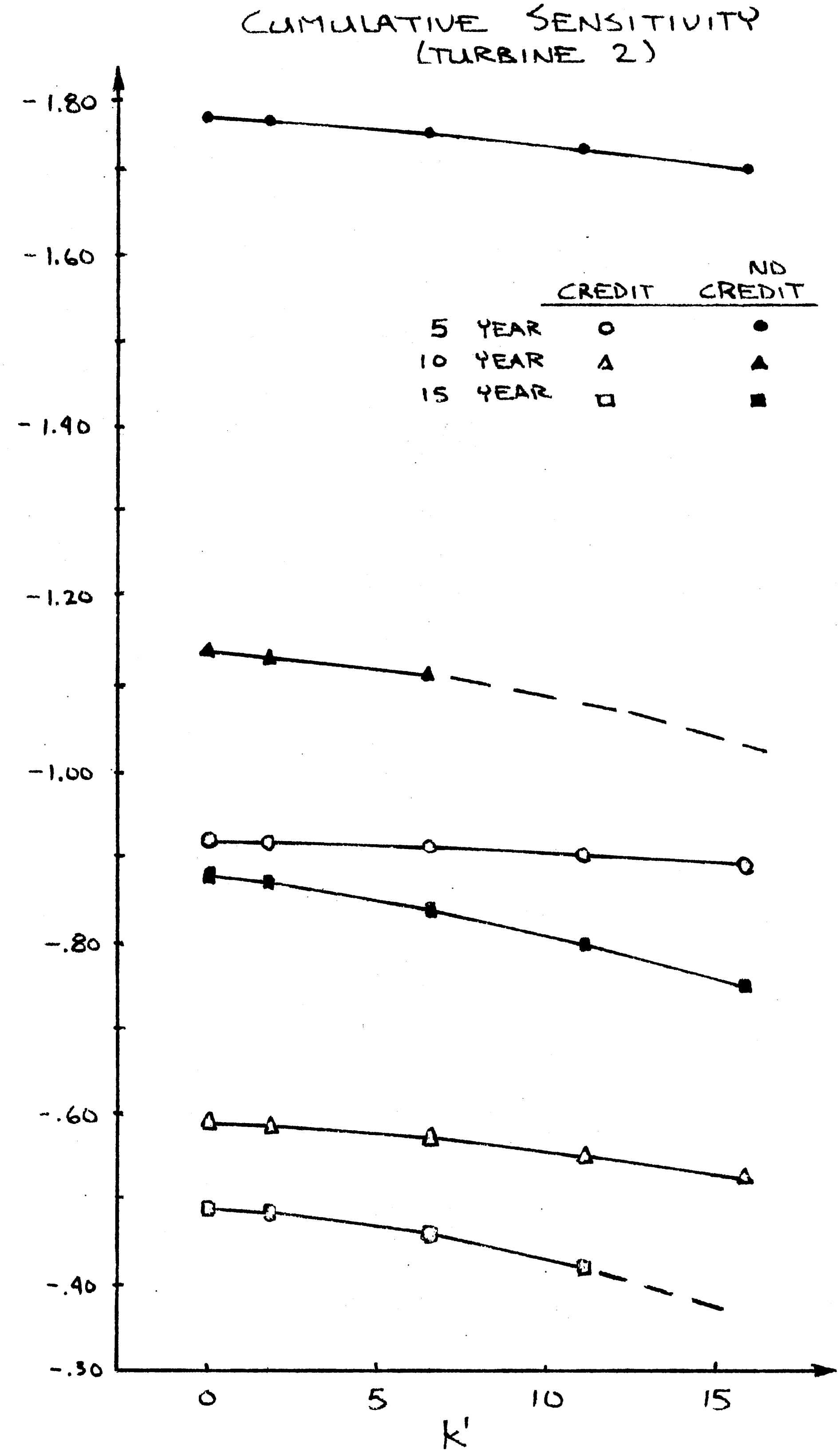
TURBINE 2
EXCESS ENERGY PRODUCTION
0
2
4
6
8
10
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS


TURBINE 1
-0.05
-0.06
-0.07
-0.08
-0.09
-0.10
UTILITY RATE (#/KWH)
-.49
-.50
-.52
-.54
-.56
TURBINE MOP (#/KWH)


TURBINE 2
-0.05
-0.06
-0.07
-0.08
-0.09
-0.10
UTILITY RATE
-.60
-.58
-.56
-.54
-.53
TURBINE MOP



CUMULATIVE SENSITIVITY
(TURBINE 1)
TURBINE PERFORMANCE MEASURE ($/KWH)
-1.40
-1.20
-1.00
-.80
-.60
-.40
-.20
-.10
CREDIT
NO CREDIT
5 YEAR
10 YEAR
15 YEAR
0
5
10
15
K′


CUMULATIVE SENSITIVITY
(TURBINE 2)
-1.80
-1.60
-1.40
-1.20
-1.00
-.80
-.60
-.40
-.30
CREDIT
NO CREDIT
5 YEAR
10 YEAR
15 YEAR
0
5
10
15
k'

VITA

Byron Alexander Black

Candidate for the Degree of

Master of Science

Thesis: AN ECONOMIC EVALUATION OF RESIDENTIAL WIND TURBINE SYSTEMS

Major Field: Industrial Engineering and Management

Biographical:

Personal Data: Born in Tulsa, Oklahoma on July 7, 1957; the son of Mr. and Mrs. A. W. Black.

Education: Graduated from Lloyd V. Berkner High School, Richardson, Texas, in May, 1975; received Bachelor of Science in Industrial Engineering degree from Oklahoma State University in 1980; completed requirements for the Master of Science in Industrial Engineering at Oklahoma State University in December, 1982.

Professional Experience: Graduate Research Assistant, School of Industrial Engineering and Management, The Energy Analysis and Diagnostic Center Program, Oklahoma State University, 1980-1982.