DAIRY FARM WIND GENERATOR MODEL

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RESEARCH SUMMARY

Recent studies have revealed the high potential for agriculture applications of wind energy systems in the United States. The dairy farm is one of the enterprises identified as feasible for wind energy application. To make wind energy application in dairy operations economically feasible, the design and selection of dairy farm wind generator systems should meet specific dairy needs.

Forty to 75 percent of the electrical energy consumed in the dairy farm goes into the cooling of milk and heating of water to meet the 3-A milk standards. Wind energy substitution for utility power to meet these energy needs in milk production operations is an efficient application of wind energy. To make wind energy substitution for utility power economically feasible, accurate design of the wind energy system to match the dairy energy demand, and the utilization of energy saving devices to reduce the dairy energy demand are essential.

This report develops a model which determines the minimum milk cooling and water heating energy demands for different lactating dairy herd sizes relative to the parlor size. The model then identifies and selects the least cost wind energy system which meets the dairy milk cooling and water heating energy demand for a wide range of herd sizes, at four levels of energy conservation under various wind regimes.

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TABLE OF CONTENTS

Chapter	Page

LIST OF TABLES

Table		Page

Table		Page

LIST OF FIGURES

Figure		Page

LIST OF SYMBOLS

Symbol	Description
A	area of wind stream intercepted by wind generator
b	parameter of wind speed and median wind speed
CO	installed cost of wind generator excluding land costs
C_p	aerodynamic efficiency of wind generator
D	rotor diameter
E1	net milk cooling and water heating energy demand for energy conservation Level 1
E2	net milk cooling and water heating energy demand for energy conservation Level 2
E3	net milk cooling and water heating energy demand for energy conservation Level 3
E4	net milk cooling and water heating energy demand for energy conservation Level 4
Em	gross milk cooling energy demand
Em_{net}	net milk cooling energy demand
E_s	energy saved by a milk precooler
Ew	gross water heating energy demand
Ew_{net}	net water heating energy demand
K	dimensional constant
n	dairy herd size
P	power in a wind stream
PC	energy cost of wind generated electricity
P_r	rated power of wind generator
$\bar{P}$	average power output of a wind generator
P(v)	wind generator power output at a given wind speed
p(v)	wind speed distribution

Symbol	Description
q	milk flow rate
T	number of hours for one milking operation for a dairy herd
t	wind speed return time
to	minimum wind run duration time
VDC	cumulative wind speed distribution
V	reference wind speed at hub height
V_m	average of rated and cut-in speeds of a wind generator
V_n	median wind speed
V_i	cut-in speed of a wind generator
V_o	cut-out speed of a wind generator
V_r	rated speed of a wind generator
$\overline{V}$	long-term mean wind speed at site
$\overline{V}_{min.downtime}$	average mean wind speed resulting in minimum down of a wind generator of given cut-in and cut-out speeds
W	dairy hot water use
x	parlor factor; this is half maximum number of cows milked together in a herringbone parlor
y	milk production throughput or number of cows milked in one hour
z	average herd milk production
ΔT	drop in milk temperature through a Surge precooler
$\lambda(t)$	hazard function
η_G	gearbox efficiency
η_E	electrical efficiency of generator
ρ	air density

Chapter 1

INTRODUCTION

The diminishing and restricted supply of fossil fuels, coupled with general worldwide inflation, have led to persistently escalating energy costs. Hickok (1975) postulates the probability of the retirement of all fossil burning systems by the year 2020. To evade an imminent energy crisis and preserve the legacy of this civilization for future generations, dependable, replenishable, pollution free, non-fossil fuels are now being explored, developed and exploited.

1.1 Small Wind Energy Conversion Systems

Wind power, and especially power from Small Wind Energy Conversion Systems (SWECS), are not new as an alternative energy source. SWECS had been successfully used in Europe for centuries, and even in the United States, they served as a recognized source of power in the nineteenth and early twentieth centuries. In the early 1940's, the technical feasibility of large wind generators was successfully demonstrated (Putnam, 1948). But despite the prediction by those on the Smith-Putnam project, that "at some future time homes may be illuminated and factories may be powered by this new (wind generator) means," wind generators suffered a great setback from economic factors in the mid-twentieth century.

In the last decade the urgent need for alternative energy sources has spurred scientists and engineers to improvements in the knowledge and art of wind power utilization techniques. Substantial improvements in wind generator design, supported by better performance reported during tests, have cleared doubts that a measurable portion of the total energy needs of the nation can be filled by wind energy. With the increasing fossil fuel costs, wind energy systems now have a better economic future.

1.2 Dairy Farm Wind Generator (DFWG) Model

Although wind is free, the equipment to harness it is very expensive. Therefore, to make wind energy substitution an economic reality requires:

1. The close matching of wind generator capacity to the energy demand of the application.
2. The careful selection and design of generator parameters and the adoption of management procedures that result in minimum energy demand dairy systems.
3. The design, manufacture and selection of wind generator systems for particular applications.

These criteria have not been followed in the past with the result that wind energy systems have been excessively expensive.

The primary objective of this study is to develop a model that selects the most economic wind generator system to substitute utility power for the milk cooling and water heating energy requirements in a dairy farm application, given the lactating herd size and the long-term mean wind speed at hub height for the location. To achieve this, it was necessary to develop functions which predict the milk cooling and water heating energy demands, and those functions which predict from the wind generator parameters, the least energy cost wind system. A secondary objective is to determine the effect of energy conservation devices on the DFWG system. Conservation devices considered are the use of a tube cooler to precool the milk and the use of the ice builder compressor condenser to heat sanitation water.

1.3 Background and Problem

Dairy farm operation requires a substantial and relatively constant level of energy. About 542 Kwh (1,849,304 BTU's) per cow-year are used in dairy operations (Frank, 1975). Depending on geographical location, herd size and the degree of mechanization, 45-75 percent of this energy is used to cool milk and heat sanitation water as required by the 3-A milk standards. There is a tendency towards larger and more automated dairy farms because of increasing labor costs. The result is a greater dependence of dairy operations on electrical energy, which presently is based on diminishing and expensive fossil fuels.

The dairy farmer is interested in inexpensive alternative energy sources to maintain production and remain in business. Wind is a proven and acceptable non-fossil energy source that can substitute for utility power in dairy farm operations. Current application of SWECS to dairy farm operations is limited by the following problems:

1. The lack of proper methods to determine energy demand of various dairy farm operations for different herd sizes and geographical locations.
2. The absence of information on the functional and economic characteristics of DFWG systems suitable for various herd sizes, management configurations and wind regimes.
3. Lack of feedback to SWECS manufacturers on the system configurations required to meet specific needs of DFWG systems.

The present study provides answers to these problems. The answers will enhance the interest of dairy farmers in energy conservation and in the use of wind energy systems; they will also provide a basis for the extension agricultural engineer and dairyman to respond intelligently and convincingly to the question of dairy farmers on the selection and use of wind energy generators in dairy farm operations. Finally, the answers will be a guide to manufacturers in the design and fabrication of wind generators to meet the specific need of wind energy substitution for milk cooling and water heating in dairy farms.

1.4 Procedure

The procedure adopted in this study consists of five major steps:

1. Determine the average annual milk cooling and water heating energy demand for a given herd size for different possible parlor sizes, and select the parlor size resulting in the least energy demand.
2. Determine the average annual power output of each of a set of preselected discrete sizes of wind generators and select those whose outputs are most closely matched to the known dairy energy demand.
3. Compute the energy cost of each of the wind generator systems that match the energy demand.
4. Select the system resulting in least cost wind energy for a given herd size and wind regime.
5. Repeat steps 1 through 4 for each of four levels of energy conservation of interest, for each herd size and wind regime.

The four levels of energy conservation for the dairy milking operation covered in the study are:

Level 1. Full energy conservation measures: a tube milk precooler and condenser water heater are used.

Level 2. Incomplete energy conservation measures: tube milk precooler in use, but no condenser water heating.

Level 3. Incomplete energy conservation measures: no tube precooler but water heating condenser is used.

Level 4. No energy conservation measures: no tube precooler or condenser water heating is used.

The dairy farm energy demand for each of these levels of energy conservation is determined. The least cost wind system which meets the energy demand is computed. By comparing the least cost wind systems which meet the energy demand of a herd size at each level of energy conservation, the effect of the conservation devices on the dairy farm wind generator system is evaluated.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Since the middle ages, man has realized the enormous potential of wind as an energy source. Originally he harnessed it to drive boats across the oceans. Windmills and watermills are also known to have had a historical place as power plants for grinding corn and pumping water. With the large scale re-organization and energy demands of the industrialized world, the low density and velocity of the wind became handicaps which stood in the way of its use as an economical prime mover (Putnam, 1948). Yet Golding (1956) quotes A. Parker as estimating the annual energy available in the winds over the earth's surface at 13 trillion kilowatt-hours.

At the end of the first world war, the Central Wind Power Institute of Moscow was established to supply power to a large number of widely scattered agricultural communities in Russia. Golding (1956) reports that by 1954, 29,500 wind power plants with an aggregate capacity of 167,000 horsepower were operating in Russia. Recent detailed Wind Mission Analysis Studies (McGowan and Sarkisian, 1978) have pointed out the high potential of residential and agricultural applications for wind energy systems in the United States. The indication is therefore that the possibilities exist for a wide variety of applications for wind energy.

2.2 Wind Energy Applications to Dairy Farm Operations

Buzenberg (1979) analyzed the wind energy potential applications for over 2.8 million commercial and non-commercial farms in 50 states. Among the enterprises he found to be economically viable if low wind system costs and a high alternative energy costs ($0.08 per Kwh) are assumed, are the dairy applications in the states of New York and Wisconsin. However, since the hypothetical systems modeled by Buzenberg lacked storage of the wind generated electricity and included no energy saving components, his results should only be regarded as a rough conservative estimate and guide. Buzenberg did not develop definite relationships between wind generator systems and dairy herd sizes; however, his wind generator cost functions appear compatible with the cost goals of the Department of Energy SWECS program.

Gunkel et al. (1979) have successfully designed and tested a wind powered water heater for dairy application. The energy conversion unit power absorption is matched to wind turbine output at any wind speed. The resulting efficiency of the conversion of the wind mechanical energy to thermal energy is nearly 100 percent. The isolated direct use of wind energy for heating in a resistance or friction system, however, may lack the practical economy necessary to justify the use of wind energy systems. Dairy farms require heat for sanitation water heating and cooling to chill milk. Such a combination provides a very efficient application for wind powered heat pumps. The use of wind energy by means of a heat pump to cool milk and heat water can leverage the useful energy of a wind generator by more than fivefold. For example, a heat pump with a coefficient of performance of 2.1 would convert 1 Kwh of wind generated electricity to 2.1 Kwh of cooling on the cold side and 3.1 Kwh of heating on the hot side simultaneously. Gunkel et al. did not relate the wind system to herd size and did not show that their system is economically viable.

Curtis et al. (1979) demonstrated that it is possible to use wind energy in a system which results in substantial savings in milk cooling and water heating energy costs of a fairy farm. Such a system is efficient and conserves energy. Curtis et al. did not determine quantitatively the effect of conservation measures with different herd sizes and did not match herd sizes to least cost wind systems.

2.3 Energy Conservation in Milking Operations

Peterson (1978), reporting the tests on three New York state dairy farms, indicates that the introduction of heat exchangers in dairy refrigeration systems can reduce water heating costs considerably. The results confirm the proposal by Evans (1977) "that booster coolers, instant coolers, energy converters, and water heating condensing units all improve the energy efficiency ratio (EER) and contribute greater profits to the dairyman." EER is the measure of the system output compared to the energy input. A simulation model developed by Timmons et al. (1977) checked the effect of milk precoolers on the total energy savings, and showed that a water-cooled condenser used in preheating water results in significant energy savings. In none of these studies was there an effort to determine the extent of energy savings over a wide range of herd sizes, or to determine the effects on a wind energy substitution system. They do, however, confirm the need and usefulness of precoolers and water heating condensers for energy conservation in dairy farm operations.

2.4 Milk Cooling and Water Heating Energy Demand

The amount of energy expended in cooling milk in a dairy farm can be estimated with reasonable accuracy given the average milk production and herd size. Until recently no data or method was available for estimating the hot water use of a herd size within acceptable accuracy. Wiersma and Armstrong (1979) attribute this to the fact that previously with cheap energy, accurate design of dairy energy systems was not particularly important. In dairy farms hot water is required at 45°C for udder washing and at 75°C or more for sanitation. Wiersma and Armstrong measured hot water use (adjusted to 75°C hot water requirements), for a wide range of dairy herd sizes and geographical locations, for herringbone parlors and side opening parlors with and without prep stalls. The work by Wiersma and Armstrong now makes it possible to determine water heating energy use in these parlors. Their work also showed that the hot water use in herringbone parlors is the most economical, and that hot water use per cow decreases with increasing herd size.

2.5 Milking Parlors

Various comparative studies have been carried out by extension dairymen on different milking parlor types. Bickert and Armstrong (1976, 1976, 1977) developed annual milking costs per cow for polygon, herringbone, side-opening and rotary milking parlors. The results show a decreasing milking cost with increasing herd size and larger palor size, for each parlor type. In addition the herringbone parlor has the minimum costs for each herd size for each comparative parlor size.

Herringbone parlors thus appear to be the most economical parlor in milking costs and energy use.

2.6 Wind Generator Parameters and Power Output

The power output of a wind generator is the convolution of the generator power output as a function of wind speed and the frequency distribution of the wind speed (Cliff, 1977). Therefore, an accurate estimation of the power output of a wind generator requires a knowledge of the wind generator function and the wind speed distribution at the point of interest. Many statistical distributions have been successfully fitted to historic wind data; Cliff (1977) recommends the use of the Rayleigh distribution because it requires only a single, easily available parameter--the mean wind speed at the site. The generator function depends on the generator parameters--cut-in, rated and cut-out speeds--which vary from one wind generator to another and from manufacturer to manufacturer. Coty and Vaughn (1977) indicate that the cut-in speed can be determined by the wind power required to turn the wind generator at its synchronous rotational speed and provide for power train losses. Buzenberg (1979) fixed this speed at that speed which produces 10 percent of the rated power, that is 46 percent of the rated speed. Cliff (1977) developed a function for determining the cut-out speed in a given wind regime if the cut-in speed is known, that results in minimum downtime.

Studies by Coty (1976) and Buzenberg (1979) also show that wind generator costs are very sensitive to wind generator parameters. There has not been any specific guide to wind generator manufacturers on the parameters that could produce a required annual power output to meet specific needs in a dairy application at minimum costs.

2.7 Conclusion

All these studies indicate that the potential exists for wind energy application in dairy farm operations and that such an application could be more economical if energy conservation devices are incorporated in the system. They also indicate that by a careful selection of wind generator parameters, a minimum energy cost wind generator which matches the energy needs of a particular herd size in a given wind regime could be produced.

This report will determine the milk cooling and water heating energy demands for a wide range of lactating herd sizes, select an appropriate least energy cost dairy wind generator for each size for various wind regimes, and also determine the effects of energy conservation devices on such wind generator systems.

Chapter 3

DAIRY FARM WIND GENERATOR MODEL

The main objective of this dairy farm wind generator model is to determine the net milk cooling and water heating energy demand of any given dairy herd size and to select the least energy cost wind generator that matches the demand in a known wind regime. Dairy herd sizes from 50 to 500 lactating cows at increments of 50 and wind regimes from 4 to 10 meters per second are examined in this study. Various herringbone parlor sizes are considered for each herd size. The parlor size resulting in minimum energy demand, while permitting two milkings per day, is recommended for each herd size. Four configurations of energy conservation hardware have been considered.

3.1 Description of the Dairy Wind Generator System Components

A schematic description of the dairy farm wind generator system components is given in Figure 1. The essential components are:

a. The utility grid: provides a backup in lull wind periods and an extra storage for excess wind generated electricity produced in zero demand periods.

b. The wind generator: generates synchronous electricity to drive the heat pump to produce ice for milk cooling and heat for sanitation water heating (could be a horizontal or vertical axis wind generator).

c. The tube precooler: precools the milk. (A single standard Surge tube cooler model 80463 is specified because it is the only heat exchanger for which information was available for this study. Tap water is used in the tube for milk precooling. The warm water resulting from the precooling of the milk may be stored and used for udder washing and drinking in winter, or passed on for further heating to sanitation temperature requirements and stored.)

d. Motor compressor (heat pump): an electrically powered compressor which drives a refrigeration system. (The cold side--evaporator--will provide chilling for an ice builder that supplies chilled water for use in the plate collers. The hot side--condenser--provides heat for heating precooler-warmed-water to a hot temperature.)

e. Plate cooler: a heat exchanger that cools the milk to storage temperature instantaneously.

f. Ice builder: makes ice for chilling the water. (It also acts an an energy storage device and should have sufficient capacity to meet two days milk cooling demand. It should be properly insulated.)

g. Hot water storage tank: an insulated tank with sufficient capacity to meet two days hot water requirements. (It is also an energy storage device in the system.)

h. Control system: starts up the wind generator when sufficient winds are available and switches to the utility power in lull periods.

3.2 <u>Description of the Model</u>

The DFWG model has been incorporated into a computer program prepared in a manner to select the least energy cost wind generator for a given lactating herd size and wind regime. The computer program listing is provided in Appendix A, and the flow chart in Figure 2. The program uses five subroutines.

1. Routine DENERGY computes herringbone parlor sizes which permit two milkings per day for a given herd size and the milk cooling, water heating and total milking energy demand for the herd size, given the level of energy conservation.

2. Routine GENDATA computes all the possible practical wind generator parameters for a given mean wind speed at hub height.

3. Routine WINSPRD computes the Rayleigh wind speed distribution given the mean wind speed at hub height.

4. Routine WINDPWR computes the average annual power output of the wind generator given the wind generator parameters and the wind speed distribution.

5. Routine ECON computes the installed cost of the wind generator (land excluded) and the energy cost of the generated power.

One methodology for the selection of an optimal wind system is described by Bae and Devine (1977). They utilized piecewise linear approximations of the nonlinear wind energy system functions and separable programming techniques to generate optimal solutions to their test models. The simplicity of the present study and the fact that solutions are considered only at specific points, does not call for such rigorous and expensive analysis. This computer program alternatively selects a least energy cost wind system that meets the load demand within an upper power output bound of 150 percent of the load demand.

Chapter 4

GOVERNING EQUATIONS AND PARAMETERS

The dairy farm wind generator model uses the following input data:

a. Wind speed frequency distribution.

b. Discrete wind turbine generator functions and parameters.

c. Dairy farm energy use data.

d. Heat exchanger functions.

e. Wind generator cost functions.

f. An economic analysis model.

Each of these inputs is used to derive a subroutine for the computer program which constitutes the main tool of the model. The main equations and parameters developed for each of these input data are described below.

4.1 Wind Speed Frequency Distribution

The energy content of the wind is proportional to the density of the air and the cube of the wind speed, and is generally given by:

$$P = \frac{1}{2} \rho \; A \; V^3 \qquad 4.1$$

where P = energy in the wind, dimensionally consistent

ρ = air density

A = area of wind

V = wind speed

The portion of the wind energy which is usable from a wind generator is determined by the aerodynamic efficiency of the rotor blades, the electrical efficiency of the generators and the mechanical efficiency of the bearings. The overall efficiency of the wind generator varies with the wind velocity and the machine. Ugo and Vaughn (1977) summarized the output of a wind generator in the equation:

$$P = C_p \cdot \eta_G \cdot \eta_E \cdot \frac{P}{2} \cdot \frac{\pi}{4} \cdot D^2 \cdot V^3 \cdot K \qquad 4.2$$

where C_p is the power coefficient of the rotor and reflects its aerodynamic efficiency. Other symbols are defined as follows:

η_G = efficiency of the gearbox

η_E = electrical efficiency of the generator

D = rotor diameter

V = wind speed at hub height

K = dimensional constant

It is thus obvious that the forcing function which drives the wind generator is the wind, and the amount of power produced is a function of the machine characteristics and the wind speed at a particular instance (Cliff, 1977). The wind speed distribution is required to estimate the annual power output of a wind generator.

Many wind power climatologists have fitted different analytic statistical distributions to observed wind data. Based on the analysis of long-term records at several sites it has been shown that the Weibull distributions provide an accurate description of the observed wind speed distributions. Cliff (1977) recommends the use of the Rayleigh distribution which is a special case of the Weibull distribution, that requires only a single parameter, the annual mean wind speed. This is available from climatological records near most sites. For an annual mean wind speed of 4.0 meters per second or more, the wind speed distribution is closely approximated by this Rayleigh distribution which may be written as:

$$p(v) = \frac{V\pi}{2\overline{V}^2} \exp - (V^2\pi/4\overline{V}^2) \qquad 4.3$$

where p(v) = frequency distribution of wind speed

$\overline{V}$ = long-term mean wind speed

The velocity duration curve (VDC), which yields the number of hours that the wind speed is greater than V, is given by:

$$VDC = 8760 \exp - (V^2\pi/4\overline{V}^2) \qquad 4.4$$

Sites with annual mean wind speeds of 4.0 meters per second or more are viable wind energy sites. The frequency distribution, velocity distribution and the most frequency wind speeds as functions of mean annual wind speed are given in Figures 3 through 5.

4.2 Wind Turbine Generator Functions and Parameters

In Equation 4.2, C_p, η_G, and η_E reflect the overall efficiency of a wind generator. If the wind generator function and parameters are known, the energy output can be determined at any given hub height wind speed. Using the annual wind speed distribution, the average annual power output of the machine can be estimated.

Generator functions: Justus (1976) used a Weibull distribution to characterize the wind speed distribution and developed the function

$$\overline{P} = \int_0^\infty P(v)\ p(v)\ dv \qquad 4.5$$

for the average power output from a wind powered generator, where P(v) is the power output of the generator as a function of wind speed, sometimes called the generator response function. A simple idealized response function suggested by Buzenberg (1979) which utilizes the cubic relationship of wind speed and power output has been modified and used in this study. It is given by:

$$P(v) = \begin{cases} O & ; V_o < V \leq V_i \\ P_r(V/V_r)^3 & ; V_i < V < V_r \\ P_r & ; V_r \leq V < V_o \end{cases} \qquad 4.6$$

where V_i, V_r, and V_o are all defined at rotor hub height and

V_i = cut-in speed

V_r = rated speed

P_r = rated power

V_o = cut-out speed

Other response functions established and used by wind power scientists are generally more tedious but do not seem to yield significantly different results. For example, Justus (1976) described the response function $P(v)$ analytically by:

$$P(v) = \begin{cases} O & ; V \leq V_i \\ P_r(A + BV + CV^2) & ; V_i < V \leq V_r \\ P_r & ; V_r < V \leq V_o \\ O & ; V_o < V \end{cases} \qquad 4.7$$

A, B and C are coefficients determined by the conditions:

$$\begin{aligned} P(V_i) &= A + BV_i + CV_i^2 = 0 \\ P(V_r)/P_r &= A + BV_r + CV_r^2 = 1 \\ P(V_m)/P_r &= A + BV_m + CV_m^2 = (V_m/V_r)^3 \end{aligned} \qquad 4.8$$

In Equation 4.8 V_m is defined by $V_m = (V_i + V_r)/2$.

Generator Parameters. Certain basic parameters affect the power output of a wind generator and consequently the cost of the energy produced from the wind. They are the rated power, the mean wind speed at the site, the cut-in, rated and the cut-out speeds of the wind generator. Buzenberg (1979) states that the rated power and the rated speed are the most important parameters. Gunkel et al. (1979) in a sensitivity analysis confirmed this, but also include the cut-out speed as an important parameter. Both authors agree that the cut-in speed has little effect on the overall most economical size of a wind generator for a given site.

In this study the mean wind speed at hub height for the site is assumed. According to Reed (1974) most farms and areas for safe human habitation lie within mean annual wind speeds from 4.0 m/s through 10.0 m/s; consequently, this study is limited to that range. For the rated power, discrete wind generator sizes from 5 Kw to 50 Kw are selected at 5 Kw increments for the study. Experience has shown that for the range of herd sizes covered in this study, a least cost wind generator system can be selected from these discrete wind generator sizes that economically meets the energy requirements for milk cooling and water heating in a particular dairy application.

The cut-in speed is the minimum speed at which the wind turbine can generate usable electricity. It is determined by the power required to turn the wind turbine at its synchronous rotational speed and to provide for generator, gearbox and aerodynamic losses (Coty and Vaughn, 1977). Since generator characteristics show a power output of zero for input of 5 percent or less of rated power, and gearbox efficiency is estimated at 95 percent, Buzenberg (1979) set

$$P(V_i) = 0.1P_r \tag{4.9}$$

Thus

$$V_i = (0.1)^{1/3}\ V_r \tag{4.10}$$

or

$$V_i = 0.4642V_r \tag{4.10a}$$

The rated speed is the wind speed at which the wind generator attains its rated power. No studies appear to have been completed to determine the optimum rated power for wind generators in a given mean wind speed situation. However, the median wind speed is always lower than the mean wind speed. Assuming Rayleigh distribution, it may be defined from Equation 4.4 by:

$$V_n = 2\overline{V}\ \sqrt{(-\ln\ 0.5)/\pi} \tag{4.11}$$

where V_n is the median wind speed. To capture the maximum amount of energy from a given wind generator, the rated speed should be above the median wind speed. Generally wind generators of lower rated speeds will be more efficient than those of a higher rated speed for equivalent rated power. Justus (1976) confirms this in his study in which he found that the capacity factor of a wind generator decreases with the rated speed, and for a given mean wind speed is higher for a low rated speed than for a higher rated speed. Lower rated speeds also imply larger turbine diameters and therefore higher capital costs (see Figure 6). In this study, the rated speed is selected by optimizing the system with rated speed varying between the mean speed and twice the mean speed.

The cut-out speed defines the maximum wind speed at which the wind turbine will produce usable power without damage to the wind system. A high cut-out speed allows the exploitation of wind energy over a wider spread of the wind distribution spectrum. A high cut-out speed also implies a higher rigidity for the system. Gunkel et al. (1979) have shown that the unit energy cost of a wind generator is very sensitive to the cut-out speed. The higher capital costs of high cut-out speed wind generators is not adequately compensated for in power outputs from the less frequent higher speed winds.

Cliff (1977) defines the percentage downtime as the percentage of the time the wind speed is below the wind generator cut-in speed plus the percentage of the time the wind speed is above the cut-out speed. The percentage downtime is dependent on the ratio of cut-out speed to the annual mean speed for values of the ratio equal to or less than 5. To minimize downtime for a given mean wind speed situation (Cliff, 1977) specifies:

$$\overline{V}_{min.downtime} = \frac{\pi \, (V_o^2 - V_i^2)}{4(\ln V_o^2 - \ln V_i^2)} \qquad 4.12$$

For a given mean wind speed, and with a predetermined cut-in speed, the cut-out speed is determined from Equation 4.12 by trial and error.

4.3 Milk Production Energy Use Functions

General

Historically most forms of dairy farm fuels and energy sources have been relatively inexpensive. The substitution of electrical power for human power in dairy farms was dependent on the capital position of the dairyman and his ability to acquire production increasing machinery and equipment (Frank, 1975). As the number of dairy farms is decreasing and the average herd size is increasing, the energy cost for producing milk has increased. Increased mechanization and higher sanitary standards required by law have all added to the increased energy use in dairy operations. The dairy industry is energy intensive and electrical energy dependent. To design a proper energy conservation system, or to develop alternative energy technology for an economic dairy farm management, a methodology for determining the energy used directly in milk production is required.

Generally it is estimated that water heating accounts for 30 percent or more of the electrical energy consumed on the dairy farm while 25-45 percent is required for milk cooling (Frank, 1975). The electrical energy consumed is a function of the system, the herd size, average production level of the herd, and management. Improving on the system by introducing conservation gadgets and adequate insulation of storage sinks, coupled with good management will lead to increased energy cost savings.

Little documentation is available of the quantitative energy use by components or various operations on dairy farms. Frank (1975), however, has developed one relation for the electrical energy and gasoline used per year in small dairy herds which is given by:

$$\text{Kilowatt hours} = 13{,}620 + 265.65(n) + (0.1z(n)) \qquad 4.13$$

$$\text{Gallons of gasoline} = 600 + 8.4(n) \qquad 4.14$$

where n = herd size; $75 \leq n \leq 125$

z = average herd milk production in pounds

assuming only electrical water heater system is used. Where L.P. gas or propane is used for water heating the functions become:

$$\text{Kilowatt hours} = 3{,}180 + 192(n) + (0.01z(n)) \qquad 4.15$$

$$\text{Gallons of propane} = 610 + 4.33(n) \qquad 4.16$$

$$\text{Gallons of gasoline} = 60 + 8.4(n) \qquad 4.17$$

Unfortunately Frank's functions assume no energy conservation devices such as precoolers, cover only a small range of herd sizes and did not develop the energy use directly related to milk production.

An energy use function has been developed in this study for a wide range of herd sizes covering milk production energy use but applicable only to the herringbone parlor.

Milk Cooling Energy Use

The USDA (1978) official records give the figures for U.S. total dairy as 2,476,947 lactating cows with an average production of 14,631 pounds of milk per cow per year in 31,783 herds. At two milkings per day this is 20.04 pounds of milk per cow per milking. Herd sizes varied from 38 in Alaska to 500 in New Mexico.

The development of direct milk production energy functions requires the determination of average milking time, the milk rate of flow in the system and its relation to the milking parlor size. Milking time (that is the time the milking machine is on the cow), and the actual production at each milking per cow was measured for 1,794 cows in 14 milking episodes at the Colorado State University dairy farm. The average milk production was 20.45 pounds per milking, average milk flow rate was 1.4715 litres (0.3887 gallons) per minute per cow (see Table 1).

Milk leaves the cow's body at 33 to 37°C (92 to 98°F), and is stored in the bulk tank at 1 to 3°C (34 to 38°F). Assuming average temperatures of 35°C (96°F) and 2°C (36°F) for the initial and storage temperatures of milk respectively, the gross energy required to cool milk per lactating cow per year using USDA average production is given by:

$$Em = 239.2760 \text{ Kwh/cow-year} \qquad 4.18$$

where Em = milk cooling energy demand without a precooler

a. <u>Energy Conservation Using Surge[1] Hi-Volume Precooler</u>

The extent of precooling is a function of the bulk flow rate of milk through the precooler assuming a selected constant water flow rate, or

$$\Delta T = f(q), \text{ where } q = \text{milk flow rate}$$

and

$$q = f(2x), \text{ where } x = \text{parlor factor} = \frac{1}{2} \text{ number}$$

of cows milked in a herringbone parlor. For a given herringbone milking parlor, q is maximum for full utilization of parlor and is therefore a function of parlor size.

Bickert and Armstrong (1976) determined the relation between parlor size and throughput (see Table 2) for herringbone type parlors. For an average level of mechanization comprising self-detaching milking units and crowd gate, and one milking operator, the following relation between throughput and parlor size was developed:

$$y = -16.0836 + 44.4882 \ln x \qquad 4.19$$

where y = throughput or cows milked per hour

An appropriate parlor size for a given herd size is selected based on throughput (allowing two milkings per day) with the constraint that,

$$K = n/y \leq 6.0 \qquad 4.20$$

where K = hours per milking

[1]A Surge Hi-Volume precooler is specified because it is the only one for which data was available at the time of this study.

Thus the milk flow rate is defined by

$$q = 2.9530\ x \text{ litres per minute} \qquad 4.21$$

or

$$q = 0.7774\ x \text{ gallons per minute} \qquad 4.21a$$

The manufacturer's specifications of expected temperature drop for the precooler at different rates of milk flow were examined (see Figure 7). Assuming an annual mean water temperature of 10°C (50°F), the expected milk temperature drop for different flow rates was obtained (Tables 3 and 4). The following functions were developed:

$$\Delta T = 19.6222 q_1^{-0.4033} \qquad 4.22$$

or

$$\Delta T = 11.4708 q^{-0.4033} \qquad 4.22a$$

where ΔT = milk temperature drop through the precooler, °C

q = milk flow rate, litres per minute

q_1 = milk flow rate, gallons per minute

The energy saved by the precooler E_s is then calculated and related to parlor size by substituting q from Equation 4.21

$$E_s = 155.9104 x^{-0.4033} \text{ Kwh/cow-year} \qquad 4.23$$

b. Net Milk Cooling Energy Demand

Combining Equations 4.18 and 4.23, the net energy demand for milk cooling Em_{net} is given by:

$$Em_{net} = 239.2760 - 155.9104 x^{-0.4033} \text{ Kwh/cow-year} \qquad 4.24$$

Hence for a given herd size, the energy demand for milk cooling incorporating a precooler is given by:

$$Em_{net} = n(239.276 - 155.9104x^{-0.4033}) \text{ Kwh/year} \qquad 4.24a$$

where Em_{net} = milk cooling energy demand using a precooler

Energy Used for Water Heating

The total hot water use in a herringbone parlor is given in Figure 8 after Wiersma and Armstrong (1979), all water is converted to 75°C hot water. The hot water use is related to herd size by the power function,

$$W = 43.6295n^{-0.4148} \text{ litres per cow-day} \qquad 4.25$$

or

$$W = 15923n^{-0.4148} \text{ litres per cow-year} \qquad 4.25a$$

where W = dairy hot water use

The gross energy required for water heating was derived and is given by:

$$Ew = 1{,}211.6278n^{-0.4148} \text{ Kwh/cow-year} \qquad 4.26$$

where Ew = gross water heating demand

The energy exchange in the Surge precooler is almost 100 percent efficient. If all the hot water is derived from the preheated water, then,

$$Ew_{net} = 1{,}211.6278n^{-0.4148} - 155.9104x^{-0.4033} \qquad 4.27$$

and for a given herd size, the annual hot water energy demand becomes

$$Ew_{net} = 1{,}211.6278n^{0.5852} - 155.9104nx^{-0.4033} \qquad 4.27a$$

where Ew_{net} = net water heating energy demand, Kwh/year

Net Water Heating and Milk Cooling Energy Demands for Various Levels of Energy Conservation

As discussed in Section 1.4 of Chapter 1, four levels of energy conservation have been considered in this study. Net energy demand will vary with the level of conservation.

If the milk cooling system uses an ice builder with condensing units, then for each pound of water frozen, 144 BTU's are recovered. In addition heat is rejected by the condensing units. The heat removed from the water and that rejected by the condenser can be recovered in the form of usable hot water by using desuperheaters and water heating condensing units. The temperature of the heated water depends upon the systems condensing temperature (Evans, 1977), and that of the refrigerant. Condensing units capable of recovering 100 percent of the total rejected heat can be obtained by careful sizing of the compressor and selection of an appropriate refrigerant. Kaman Sciences Corporation (1976) showed that by using freon R-22 as a refrigerant and a suitably sized compressor, the heat rejected by the compressor and that removed from the smilk, is sufficient to meet the water heating energy demand. For Level 1 of energy conservation, therefore, the net energy demand for water heating and milk cooling will be equivalent to the milk cooling energy demand.

$$E1 = Em_{net} = n(239.276 - 155.9104x^{-0.4033}) \text{ Kwh/year} \quad 4.28$$

where E1 = dairy energy demand for Level 1 energy conservation measures, Kwh/year

For Level 2 of energy conservation, no condenser is used to heat the water. The energy demand is thus the sum of Equations 4.24 and 4.27 and

$$E2 = n(1{,}211.6278n^{-0.4148} - 311.8208x^{-0.4033} + 239.276) \qquad 4.29$$

where E2 = dairy energy demand for Level 2 energy conservation measures, Kwh/year

At Level 3 of energy conservation, no precooler is used but the hot water demand is met by proper sizing of the compressor. Thus energy demand is equivalent to the gross milk cooling energy demand and,

$$E3 = 239.276n \text{ Kwh/year} \qquad 4.30$$

For Level 4 of energy conservation, no conservation measures are applied. From Equations 4.18 and 4.26,

$$E4 = 239.276n + 1{,}211.6278n^{0.5852} \text{ Kwh/year} \qquad 4.31$$

where E3 and E4 are the dairy energy demands for Levels 3 and 4 of energy conservation, for a given herd size, Kwh/year.

4.4 Energy Storage

Provision of energy storage in a wind generator system is essential for the following reasons:

1. To increase the stability and dependability of the system.
2. To reduce energy waste and increase the economic viability of the system.

Energy that will be stored are of two types:

1. Energy produced during periods of zero demand.
2. Energy produced above the energy use levels.

Some of the conventional energy storage systems for wind generators are flywheels, electric storage batteries, pumped air storage, hydrogen storage, pumped water storage, hot water or hot air storage (Park and Schwind, 1978). For a dairy wind generator system, energy storage will be in the form of ice bank and hot water storage.

Coty (1976) estimates the output conversion efficiency of storage systems from 71.4 percent for battery storage to 31.4 percent for hydrogen storage. With an input efficiency of about 43 percent (overall wind system efficiency), a high output efficiency is desirable for wind energy storage systems. Hot water and ice are the forms in which energy would be used in a dairy farm for sanitation and milk cooling, and so achieve near 100 percent output conversion efficiency if adequate insulation is provided.

Accurate sizing of wind energy storage systems requires a knowledge of the "return time" of the cut-in speed. Return time is the length of time it takes for the wind speed to return to a given value once it has fallen below (or above) that value (Coty, 1976).

Recent studies carried out by Corotis (1977), Corotis et al. (1978) and Edwards (1978), show that the probability that the wind speed will remain above (or below) a given threshold level for time, t, for $100 \leq t \leq 10^6$ seconds, is well described by a simple power law in t. This implies that the conditional probability that the wind will fall below (or rise above) a given speed, given that it has already remained below (or above) that speed for time interval, t is:

$$\lambda(t) = (b-1)/t \qquad 4.32$$

where $b-1$ = slowly varying function of v/v_n

v_n = median wind speed

or $$\lambda(t) = f(t)/F(t) \text{ (hazard function)} \qquad 4.33$$

and $$f(t) = (t/t_o)^{-b}(b-1)/t_o \qquad 4.34$$

= probability density function

where t_o = minimum run duration generally taken as 0.5 hours

b = independent parameter (must be greater than unity for convergence) and is estimated by:

$$(b-1)^{-1} = E[\ln t] - \ln t_o \qquad 4.35$$

in which E[ln t] is the average of the logarithms of the observed runs.

$$F(t) = P(>t) \quad \text{(cumulative distribution function)} \qquad 4.36$$

$$= (t/t_o)^{1-b} \qquad 4.37$$

It is thus possible to determine the return time for winds at the cut-in speed for a given location. Provision of storage capacity sufficient to deliver power for the longest probable lulls is not only very expensive and uneconomical but also unnecessary with a utility grid tie-in wind system. Putnam (1948) showed that in the most productive season the daily average power output was 138 percent of the mean expected output over a 5-year period. Hourly changes varied from 118 percent to 78 percent. Coty (1976) investigated 10-years historic wind data from various regions of the United States, and related the return time to probability of occurrence based on the rated speed. He found that for 95 percent probability of occurrence the return interval exceeded two days only in one case. This result is very conservative since in practice the cut-in speed ought to be used. A return time of two days is recommended by this report and the storage systems should be calculated on two-days energy requirements at two milkings per day.

4.5 Wind Generator Cost Function

"Modern wind generator systems have not been produced in significant quantities, hence the determination of accurate system costs is difficult" (Buzenberg, 1979). Buzenberg (1979) developed a set of functions to estimate wind generator costs. The lower bound values, while optimistic, are good long-term expected cost for wind systems. The function is given by:

$$\ln(\$/kw) = 7.7391 - 0.46578 \ln(P_r) + 0.02573 \ln(P_r)^2 \qquad 4.38$$

where $P_r \geq 1kw$ for wind generators rated at 11.18 m/s (25 mph). The total capital cost for the installed wind generator is determined by multiplying $/kw obtained from Equation 4.38 by the rated power and Buzenberg's correction factor $(v_{ref}/v_r)^2$, where $v_{ref} = 11.18$ m/s. This lower bound appears compatible with projected cost goals of the Department of Energy SWECS program.

4.6 Economic Analysis

The selection of the optimal DFWG system assumes a complete utilization of all wind energy produced by the system. This assumption appears rational since milk cooling and water heating account for 40-75 percent of the electric energy use on the farm. Moreover, the present energy situation has created prospects for the purchase of surplus wind energy by public utility companies.

The wind system which results in a minimum energy cost, while meeting a given dairy energy demand, is selected as the optimal solution. The following parameters are used in the economic analysis:

a. Estimated installed cost: is determined by Equation 4.38 and corrected for rated power and rated speed. It excludes the cost of land.

b. Annual wind generator cost: is computed assuming a 20-years life, straight line depreciation, income and property taxes of 2 percent, insurance, and operation and maintenance costs of 0.5 percent and 2 percent of capital costs respectively. An interest rate on capital of 15 percent is also assumed.

c. The average annual energy yield: is computed from Equation 4.5

Thus,

$$\text{Energy cost} = \frac{\text{Annualized Wind Generator Cost}}{\text{Average annual energy yield}} \qquad 4.39$$

or

$$PC = 18.04282\ CO/\overline{P} \qquad 4.40$$

where PC = energy cost, ¢/Kwh

CO = installed cost of wind generator, $

and $\overline{P}$ = average annual energy output of the wind generator, Kwh

Energy cost as computed in Equation 4.40 is based on the average power output of the wind generator and not on the milk production energy use. The matching of generator output to milk production energy demand is not exact. Consequently surplus energy is generated in all cases. Where this surplus energy cannot be utilied or sold, Equation 4.40 should be modified to reflect energy utilized in milk production and not the average annual energy output of the generator.

Chapter 5

RESULTS AND DISCUSSIONS

The primary result of this study is a dairy farm wind generator model and the development of this model into a FORTRAN computer program. The program can be easily modified and adjusted to yield either new solutions as improved data become available, or to yield more exact solutions at specific points of interest. The flow chart of the program is given in Figure 2 and the program listings in Appendix A.

5.1 Optimal Generator Selection

The optimal wind generators developed by the model for the four levels of energy conservation are given in Tables 5a through 8g. For full energy conservation it was found that no feasible generator could match energy demand for a herd size of 50 within the specified constraints. A separate run for this herd size using lower rated powers was made and the results are shown in Table 5h.

5.2 Energy Conservation

A secondary result of this study is the determination of the effect of the four levels of energy conservation on dairy wind generator systems. Figure 9 gives the relation between dairy energy demand and herd size for each level of energy conservation. The results indicate that using both a precooler and condenser water heating cuts energy demand by more than 50 percent. Between a herd size of 50 and 100, condenser water heating provides higher energy savings than the precooler, but above herd size of 100, the precooler is a more effective energy saver. This trend is also shown by the installed cost of the optimal wind generators. Figures 10a through 10g display the installed costs, and Figures 11a through 11g show the energy costs of optimal wind generators for each level of energy conservation and different wind regimes. Installed costs for full energy conservation wind systems are 25 to 50 percent of the system costs for cases of no conservation and are always lower than the cases of incomplete conservation. Data curves for dairy farm wind generators in cases of full energy conservation are given in Figures 12 through 14.

5.3 Energy Costs

A final result from this study is the establishment of a relation between energy cost and wind generator power output, and installed wind generator cost and generator power output given in Figures 15 and 16. These figures show that for any given wind regime the installed cost of dairy farm wind generators increases with annual generator output while energy cost decreases with increasing output.

Numerical procedure for selection of dairy farm wind generator is given in Appendix B.

5.4 Problems Encountered, Program Decisions and Model Validation

One of the initial problems in the development of the model was the determination of energy use in dairy milk production. Dairy farm energy use studies appear to be few. Energy use functions were established in this study for herringbone parlors. Credibility of these functions was measured by comparing milk cooling energy use in a system incorporating a precooler at Colorado State University dairy farm with model prediction of Equation 4.28. About 120 to 150 cows are milked daily at the Colorado State University dairy farm. For an average of 135 cows milked daily, the results (Table 9) indicate an agreement within 3 percent between model predictions and recorded data based on a half-year period of observations.

Another important problem in the development of the model was the establishment of suitable cost functions that yield acceptable installed costs of wind generators. The practice of estimating wind generator costs on unit rated power seems inaccurate. Cost per unit rated power is not constant, but varies with rated power and rated speed (Figure 6). Given the overall wind generator efficiency, the rated speed can be related to the rotor diameter. The function used in the study gives the wind generator capital costs as a function of the rated power and rated speed and is based on 1979 dollars. The costs obtained from the results were compared with current costs (supplied by Briggs, 1980 at Rockwell International) of preliminary cost projections for 1,000 units per year production volumes of several SWECS under development. The results (Figure 10) indicate very reasonable agreement between Rockwell projections and the model in the rotor diameters. Very reasonable agreements also exist in the costs except that high cut-out speeds of the Rockwell prototypes imply high rigidity and this is reflected in the higher costs of some models.

Another problem encountered in this study was the determination of overall wind system efficiency at rated speed. Overall efficiency is directly related to the aerodynamic efficiency of the rotor which varies with the tip speed ratio. Aerodynamic efficiency attains a maximum value before the rated speed is reached and declines thereafter in constant rpm machines. Maximum overall efficiencies of 0.35 to 0.43 are attained by many machines. By inspecting a series of wind generator characteristics, an overall efficiency of 0.25 at the rated speed was selected for the computation of rotor diameter. An air density of 1.015 Kg per meter cubed was used in the calculations.

A decision on the limits of the generator output capacity that meets energy demand, while avoiding undue oversizing and yet provide a reasonable safety against lull periods, was an important decision. A safety factor of 100 percent while reducing energy costs considerably, led to oversizing and much higher capital costs. A safety factor of 50 percent was finally chosen herein, and the subsequent results appear reasonable.

With these basic assumptions, this study has shown that least energy cost dairy farm wind generators can be designed and manufactured to meet specific dairy farm energy needs. Design and manufacture of wind generators for each single case may not be a reality. However, the results may provide a useful guide to wind generator manufacturers at this early stage of the industry. The results indicate that energy costs are more competitive for large herd sizes and at high mean annual wind speeds. Finally, the results show that the tube precooler and condenser water heater are high energy savers in dairy milk production and are worthwhile in a dairy farm wind generator system.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the results of this study the following conclusions can be made:

Dairy wind generators of competitive energy costs are feasible if they are designed to meet the energy demands of known herd sizes in specific wind speed regimes. The optimal dairy wind generators developed from this study are a good basis for such design.

Dairy wind energy costs in wind regimes of 5.0 m/s or below are very high. For herd sizes of 150 cows or less the wind energy costs are excessively high and uneconomic for average mean wind speeds of 4.0 or 5.0 m/s.

Dairy wind energy costs decrease and become competitive with conventional energy costs as herd size increases in every wind regime.

A precooler and condenser water heater are effective energy savers in dairy milk production operations. When used together, they cut energy demands of milk production by about 50 percent.

6.2 Recommendations

Dairy farmers interested in the use of wind energy should use a precooler and condenser water heating as energy conservation devices. This will greatly reduce the investment costs of the wind generator system.

Wind generator manufacturers interested in developing a market in the dairy farm industry should design and manufacture wind generators for specific herd sizes and wind regime situation.

In the course of this study, it has been found that further work is necessary to define wind generator cost and its relation to other wind generator parameters. It is also necessary to determine the best rated speed of a wind generator in a given wind regime.

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TABLES

Table 1. Measured milk production data.

No. of Operations	No. of Cows Milked No.	Total Milk Production lbs	Total Milking Time min.	Average Milk Production Per Cow Per Milking lbs	Average Milking Time Per Cow min.	Milk Flow Rate lbs/min.
1	143	2,867.60	883.00	20.0531	6.1743	3.2476
2	126	3,066.0	887.70	24.3333	7.0456	3.4539
3	128	2,320.00	674.80	18.1313	5.2719	3.4392
4	137	2,930.70	819.80	21.3920	5.9839	3.5749
5	122	2,317.00	643.50	18.9918	5.2746	3.6006
6	138	2,941.60	844.10	21.3159	6.1167	3.4849
7	134	2,283.30	676.80	17.0396	5.0507	3.3737
8	136	2,766.00	1,008.50	20.3382	7.4154	2.7427
9	137	2,985.20	833.90	21.7898	6.0869	3.5798
10	101	2,137.20	714.60	21.1604	7.0752	2.9908
11	121	2,647.00	709.40	21.8760	5.8628	3.7313
12	136	2,975.70	848.70	21.8801	6.2404	3.5062
13	122	2,406.50	685.10	19.7254	5.6156	3.5126
14	113	2,058.00	760.90	18.2124	6.7336	2.7047
Total	1,794	36,701.80	10,990.80	286.2393	85.9472	--
Average	--	--	--	20.4457	6.1391	3.3393

Table 2. Throughput for various herringbone parlor sizes (after Bickert and Armstrong)

Parlor Size	Double-4	Double-6	Double-8	Double-10
Throughput	45	64	78	85

Table 3. Drop in milk temperature through single Surge precooler.[1]

Milk Flow Rate gal/min.	Milk Outlet Temperature °C	Drop in Milk Temperature °C
0	--	--
1	16.67	18.89
2	20.00	15.56
4	24.44	11.11
6	25.56	10.00
8	27.22	8.33
10	28.28	7.50
12	28.33	7.22

[1]Water inlet temperature assumed to be 10°C average.

Table 4. Drop in milk temperature through the precooler for different parlor sizes.

Parlor Size	Double-4	Double-6	Double-8	Double-10
Maximum milk flow rate, gal/min.	3.1096	4.6644	6.2191	7.7740
Minimum drop in milk temperature, °C	12.4175	10.5443	9.3892	8.5811

Table 5a. Optimal wind generators for Level 1 energy conservation at 4.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 4.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
NO FEASIBLE WIND GENERATOR FOR HERD SIZE= 50											
100	DOUBLE- 4	15013.77	5.00	2.32	7.00	5.00	20.04	19232.14	29468.96	27.65	4218.37
150	DOUBLE- 4	22520.66	10.00	2.79	7.00	6.00	21.56	28261.61	30712.10	19.61	5740.95
200	DOUBLE- 4	30027.54	15.00	2.79	7.00	6.00	26.41	42392.41	38944.19	16.58	12364.87
250	DOUBLE- 4	37534.43	15.00	2.79	7.00	6.00	26.41	42392.41	38944.19	16.58	4857.98
300	DOUBLE- 6	49075.37	25.00	2.79	7.00	6.00	34.09	70654.02	52526.09	13.41	21578.65
350	DOUBLE- 6	57254.60	30.00	2.79	7.00	6.00	37.34	84784.83	58445.34	12.44	27530.22
400	DOUBLE- 8	68750.46	35.00	2.79	7.00	6.00	40.34	98915.63	63967.49	11.67	30165.17
450	DOUBLE- 8	77344.27	40.00	2.79	7.00	6.00	43.12	113046.43	69171.00	11.04	35702.16
500	DOUBLE-10	88838.40	45.00	2.79	7.00	6.00	45.74	127177.24	74111.06	10.51	38338.84

Table 5b. Optimal wind generators for Level 1 energy conservation at 5.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 5.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
NO FEASIBLE WIND GENERATOR FOR HERD SIZE= 50											
100	DOUBLE- 4	15013.77	5.00	2.79	9.00	6.00	15.25	20735.17	20464.55	17.81	5721.40
150	DOUBLE- 4	22520.66	10.00	3.25	8.00	7.00	17.11	27930.36	22563.99	14.58	5409.70
200	DOUBLE- 4	30027.54	15.00	3.25	8.00	7.00	20.96	41895.54	28612.06	12.32	11868.00
250	DOUBLE- 4	37534.43	20.00	3.25	8.00	7.00	24.20	55860.72	33862.83	10.94	18326.29
300	DOUBLE- 6	49075.37	25.00	3.25	8.00	7.00	27.05	69825.90	38590.59	9.97	20750.53
350	DOUBLE- 6	57254.60	30.00	3.25	8.00	7.00	29.64	83791.08	42939.44	9.25	26536.48
400	DOUBLE- 8	68750.46	35.00	3.25	8.00	7.00	32.01	97756.26	46996.52	8.57	29005.80
450	DOUBLE- 8	77344.27	40.00	3.25	8.00	7.00	34.22	111721.44	50819.51	8.21	34377.17
500	DOUBLE-10	88838.40	45.00	3.25	8.00	7.00	36.30	125686.62	54448.94	7.82	36848.22

Table 5c. Optimal wind generators for Level 1 energy conservation at 6.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 6.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
NO FEASIBLE WIND GENERATOR FOR HERD SIZE= 50											
100	DOUBLE- 4	15013.77	5.00	3.25	11.00	7.00	12.10	21289.90	15035.18	12.74	6276.13
150	DOUBLE- 4	22520.66	10.00	3.71	10.00	8.00	14.00	32376.45	17275.56	9.63	9855.79
200	DOUBLE- 4	30027.54	15.00	4.18	10.00	9.00	14.37	37238.19	17308.53	8.39	7210.64
250	DOUBLE- 4	37534.43	20.00	4.18	10.00	9.00	16.60	49650.91	20484.92	7.44	12116.49
300	DOUBLE- 6	49075.37	25.00	4.18	10.00	9.00	18.56	62063.64	23344.93	6.79	12988.27
350	DOUBLE- 6	57254.60	30.00	4.18	10.00	9.00	20.33	74476.37	25975.71	6.29	17221.77
400	DOUBLE- 8	68750.46	40.00	4.18	10.00	9.00	23.47	99301.83	30742.66	5.59	30551.37
450	DOUBLE- 8	77344.27	45.00	4.18	10.00	9.00	24.90	111714.56	32938.25	5.32	34370.29
500	DOUBLE-10	88838.40	50.00	4.18	10.00	9.00	26.24	124127.29	35034.81	5.09	35288.89

Table 5d. Optimal wind generators for Level 1 energy conservation at 7.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 7.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
NO FEASIBLE WIND GENERATOR FOR HERD SIZE= 50											
100	DOUBLE- 4	15013.77	5.00	3.71	13.00	8.00	9.90	22105.13	11511.31	9.40	7091.36
150	DOUBLE- 4	22520.66	10.00	4.64	12.00	10.00	10.02	28893.22	11056.36	6.90	6372.56
200	DOUBLE- 4	30027.54	15.00	4.64	12.00	10.00	12.27	43339.83	14019.91	5.84	13312.29
250	DOUBLE- 4	37534.43	15.00	4.64	12.00	10.00	12.27	43339.83	14019.91	5.84	5805.40
300	DOUBLE- 6	49075.37	25.00	4.64	12.00	10.00	15.84	72233.05	18909.39	4.72	23157.68
350	DOUBLE- 6	57254.60	25.00	4.64	12.00	10.00	15.84	72233.05	18909.39	4.72	14978.45
400	DOUBLE- 8	68750.46	35.00	4.64	12.00	10.00	18.75	101126.27	23028.30	4.11	32375.81
450	DOUBLE- 8	77344.27	40.00	4.64	12.00	10.00	20.04	115572.88	24901.56	3.89	38228.61
500	DOUBLE-10	88838.40	45.00	4.64	12.00	10.00	21.26	130019.49	26679.98	3.70	41181.09

Table 5e. Optimal wind generators for Level 1 energy conservation at 8.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 8.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
NO FEASIBLE WIND GENERATOR FOR HERD SIZE= 50											
100	DOUBLE- 4	15013.77	5.00	5.11	14.00	11.00	6.14	15569.69	6088.63	7.06	555.92
150	DOUBLE- 4	22520.66	10.00	5.11	14.00	11.00	8.69	31139.39	9137.48	5.29	8618.73
200	DOUBLE- 4	30027.54	15.00	5.57	13.00	12.00	9.34	35569.04	9736.05	4.94	5541.50
250	DOUBLE- 4	37534.43	20.00	5.57	13.00	12.00	10.78	47425.38	11522.77	4.38	9890.96
300	DOUBLE- 6	49075.37	30.00	5.57	13.00	12.00	13.20	71138.07	14611.34	3.71	22062.70
350	DOUBLE- 6	57254.60	35.00	5.57	13.00	12.00	14.26	82994.42	15991.87	3.48	25739.82
400	DOUBLE- 8	68750.46	40.00	5.57	13.00	12.00	15.25	94850.77	17292.75	3.29	26100.30
450	DOUBLE- 8	77344.27	45.00	5.57	13.00	12.00	16.17	106707.11	18527.77	3.13	29362.84
500	DOUBLE-10	88838.40	40.00	5.11	14.00	11.00	17.37	124557.56	20579.80	2.98	35719.16

Table 5f. Optimal wind generators for Level 1 energy conservation at 9.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 9.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
NO FEASIBLE WIND GENERATOR FOR HERD SIZE= 50											
100	DOUBLE- 4	15013.77	5.00	5.57	16.00	12.00	5.39	16845.42	5116.14	5.48	1831.65
150	DOUBLE- 4	22520.66	10.00	5.57	16.00	12.00	7.62	33690.84	7678.03	4.11	11170.18
200	DOUBLE- 4	30027.54	15.00	6.03	15.00	13.00	8.28	39441.40	8295.80	3.79	9413.86
250	DOUBLE- 4	37534.43	20.00	6.03	15.00	13.00	9.56	52588.53	9818.22	3.37	15054.10
300	DOUBLE- 6	49075.37	25.00	6.03	15.00	13.00	10.69	65735.67	11188.99	3.07	16660.29
350	DOUBLE- 6	57254.60	25.00	5.57	16.00	12.00	12.05	84227.10	13131.52	2.81	26972.50
400	DOUBLE- 8	68750.46	30.00	5.57	16.00	12.00	13.20	101072.52	14611.34	2.61	32322.06
450	DOUBLE- 8	77344.27	40.00	6.03	15.00	13.00	13.52	105177.06	14734.65	2.53	27832.79
500	DOUBLE-10	88838.40	50.00	6.03	15.00	13.00	15.12	131471.33	16791.83	2.30	42632.93

Table 5g. Optimal wind generators for Level 1 energy conservation at 10.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 10.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
NO FEASIBLE WIND GENERATOR FOR HERD SIZE= 50											
100	DOUBLE- 4	15013.77	5.00	6.03	18.00	13.00	4.78	17526.95	4359.31	4.49	2513.18
150	DOUBLE- 4	22520.66	10.00	6.50	17.00	14.00	6.05	29105.61	5641.00	3.50	6584.95
200	DOUBLE- 4	30027.54	15.00	6.50	17.00	14.00	7.41	43658.41	7153.01	2.96	13630.87
250	DOUBLE- 4	37534.43	15.00	6.03	18.00	13.00	8.28	52580.86	8295.80	2.85	15046.43
300	DOUBLE- 6	49075.37	25.00	6.50	17.00	14.00	9.56	72764.01	9647.65	2.39	23688.64
350	DOUBLE- 6	57254.60	35.00	6.96	16.00	15.00	10.20	80181.65	10234.80	2.30	22927.05
400	DOUBLE- 8	68750.46	45.00	6.96	16.00	15.00	11.57	103090.70	11857.77	2.08	34340.24
450	DOUBLE- 8	77344.27	50.00	6.96	16.00	15.00	12.20	114545.22	12612.53	1.99	37200.95
500	DOUBLE-10	88838.40	45.00	6.50	17.00	14.00	12.83	130975.23	13612.24	1.88	42136.83

Table 5h. Optimal wind generators for herd size = 50 and full energy conservation.

Mean Speed m/s	Parlor Size	Milk Cooling Energy Demand KWHS	Rated Power KWS	Cut-in Speed m/s	Cut-out Speed m/s	Rated Speed m/s	Rotor Diameter m	Energy Output KWHS	Installed Cost $	Energy Cost ¢/KWH	Surplus Energy KWHS
4	Double-4	7506.89	3.00	2.79	7.00	6.00	11.81	8478.48	15172.95	32.29	971.60
5	Double-4	7506.89	4.00	3.25	8.00	7.00	10.82	11172.14	13193.21	21.31	3665.26
6	Double-4	7506.89	4.00	4.18	10.00	9.00	7.42	9930.18	7981.08	14.50	2423.30
7	Double-4	7506.89	3.00	4.64	12.00	10.00	5.49	8667.97	5462.26	11.37	1161.08
8	Double-4	7506.89	4.00	5.57	13.00	12.00	4.82	9485.08	4489.36	8.54	1978.19
9	Double-4	7506.89	4.00	6.03	15.00	13.00	4.28	10517.71	3825.25	6.56	3010.82
10	Double-4	7506.89	3.00	6.03	18.00	13.00	3.70	10516.17	3232.11	5.55	3009.29

Table 6a. Optimal wind generators for Level 2 energy conservation at 4.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 4.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	15006.54	5.00	2.32	7.00	5.00	20.04	19232.14	29468.96	27.65	4225.61
100	DOUBLE- 4	24037.74	10.00	2.79	7.00	6.00	21.56	28261.61	30712.10	19.61	4223.86
150	DOUBLE- 4	31891.35	15.00	2.79	7.00	6.00	26.41	42392.41	38944.19	16.58	10501.07
200	DOUBLE- 4	39111.02	20.00	2.79	7.00	6.00	30.49	56523.22	46091.07	14.71	17412.20
250	DOUBLE- 4	45914.91	20.00	2.79	7.00	6.00	30.49	56523.22	46091.07	14.71	10608.31
300	DOUBLE- 6	60485.71	30.00	2.79	7.00	6.00	37.34	84784.83	58445.34	12.44	24299.11
350	DOUBLE- 6	68101.19	35.00	2.79	7.00	6.00	40.34	98915.63	63967.49	11.67	30814.44
400	DOUBLE- 8	82163.87	40.00	2.79	7.00	6.00	43.12	113046.43	69171.00	11.04	30882.56
450	DOUBLE- 8	90268.63	45.00	2.79	7.00	6.00	45.74	127177.24	74111.06	10.51	36908.61
500	DOUBLE-10	104043.95	50.00	2.79	7.00	6.00	48.21	141308.04	78828.32	10.07	37264.09

Table 6b. Optimal wind generators for Level 2 energy conservation at 5.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 5.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	15006.54	5.00	2.79	9.00	6.00	15.25	20735.17	20464.55	17.81	5728.64
100	DOUBLE- 4	24037.74	10.00	3.25	8.00	7.00	17.11	27930.36	22563.99	14.58	3892.61
150	DOUBLE- 4	31891.35	15.00	3.25	8.00	7.00	20.96	41895.54	28612.06	12.32	10004.19
200	DOUBLE- 4	39111.02	20.00	3.25	8.00	7.00	24.20	55860.72	33862.83	10.94	16749.70
250	DOUBLE- 4	45914.91	20.00	3.25	8.00	7.00	24.20	55860.72	33862.83	10.94	9945.81
300	DOUBLE- 6	60485.71	30.00	3.25	8.00	7.00	29.64	83791.08	42939.44	9.25	23305.37
350	DOUBLE- 6	68101.19	35.00	3.25	8.00	7.00	32.01	97756.26	46996.52	8.67	29655.07
400	DOUBLE- 8	82163.87	40.00	3.25	8.00	7.00	34.22	111721.44	50819.51	8.21	29557.57
450	DOUBLE- 8	90268.63	45.00	3.25	8.00	7.00	36.30	125686.62	54448.94	7.82	35417.99
500	DOUBLE-10	104043.95	50.00	3.25	8.00	7.00	38.26	139651.80	57914.69	7.48	35607.85

Table 6c. Optimal wind generators for Level 2 energy conservation at 6.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 6.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	15006.54	5.00	3.25	11.00	7.00	12.10	21289.90	15035.18	12.74	6283.36
100	DOUBLE- 4	24037.74	10.00	3.71	10.00	8.00	14.00	32376.45	17275.56	9.63	8338.70
150	DOUBLE- 4	31891.35	15.00	4.18	10.00	9.00	14.37	37238.19	17308.53	8.39	5346.84
200	DOUBLE- 4	39111.02	20.00	4.18	10.00	9.00	16.60	49650.91	20484.92	7.44	10539.90
250	DOUBLE- 4	45914.91	25.00	4.18	10.00	9.00	18.56	62063.64	23344.93	6.79	16148.73
300	DOUBLE- 6	60485.71	35.00	4.18	10.00	9.00	21.96	86889.10	28430.00	5.92	26403.39
350	DOUBLE- 6	68101.19	40.00	4.18	10.00	9.00	23.47	99301.83	30742.66	5.59	31200.64
400	DOUBLE- 8	82163.87	45.00	4.18	10.00	9.00	24.90	111714.56	32938.25	5.32	29550.69
450	DOUBLE- 8	90268.63	50.00	4.18	10.00	9.00	26.24	124127.29	35034.81	5.09	33858.66
500	DOUBLE-10	104043.95	50.00	4.18	10.00	9.00	26.24	124127.29	35034.81	5.09	20083.34

Table 6d. Optimal wind generators for Level 2 energy conservation at 7.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 7.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	15006.54	5.00	3.71	13.00	8.00	9.90	22105.13	11511.31	9.40	7098.59
100	DOUBLE- 4	24037.74	10.00	4.64	12.00	10.00	10.02	28893.22	11056.36	6.90	4855.48
150	DOUBLE- 4	31891.35	15.00	4.64	12.00	10.00	12.27	43339.83	14019.91	5.84	11448.48
200	DOUBLE- 4	39111.02	20.00	4.64	12.00	10.00	14.17	57786.44	16592.78	5.18	18675.42
250	DOUBLE- 4	45914.91	20.00	4.64	12.00	10.00	14.17	57786.44	16592.78	5.18	11871.53
300	DOUBLE- 6	60485.71	30.00	4.64	12.00	10.00	17.36	86679.66	21040.32	4.38	26193.95
350	DOUBLE- 6	68101.19	35.00	4.64	12.00	10.00	18.75	101126.27	23028.30	4.11	33025.08
400	DOUBLE- 8	82163.87	40.00	4.64	12.00	10.00	20.04	115572.88	24901.56	3.89	33409.01
450	DOUBLE- 8	90268.63	45.00	4.64	12.00	10.00	21.26	130019.49	26679.98	3.70	39750.86
500	DOUBLE-10	104043.95	50.00	4.64	12.00	10.00	22.41	144466.10	28378.20	3.54	40422.15

Table 6e. Optimal wind generators for Level 2 energy conservation at 8.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 8.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	15006.54	5.00	5.11	14.00	11.00	6.14	15569.69	6088.63	7.06	563.16
100	DOUBLE- 4	24037.74	15.00	5.57	13.00	12.00	9.34	35569.04	9736.05	4.94	11531.29
150	DOUBLE- 4	31891.35	20.00	5.57	13.00	12.00	10.78	47425.38	11522.77	4.38	15534.04
200	DOUBLE- 4	39111.02	20.00	5.57	13.00	12.00	10.78	47425.38	11522.77	4.38	8314.37
250	DOUBLE- 4	45914.91	20.00	5.11	14.00	11.00	12.28	62278.78	13713.05	3.97	16363.87
300	DOUBLE- 6	60485.71	35.00	5.57	13.00	12.00	14.26	82994.42	15991.87	3.48	22508.71
350	DOUBLE- 6	68101.19	40.00	5.57	13.00	12.00	15.25	94850.77	17292.75	3.29	26749.58
400	DOUBLE- 8	82163.87	50.00	5.57	13.00	12.00	17.05	118563.46	19707.08	3.00	36399.59
450	DOUBLE- 8	90268.63	40.00	5.11	14.00	11.00	17.37	124557.56	20579.80	2.98	34288.92
500	DOUBLE-10	104043.95	50.00	5.11	14.00	11.00	19.42	155696.94	23453.05	2.72	51652.99

Table 6f. Optimal wind generators for Level 2 energy conservation at 9.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 9.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	15006.54	5.00	5.57	16.00	12.00	5.39	16845.42	5116.14	5.48	1838.88
100	DOUBLE- 4	24037.74	10.00	5.57	16.00	12.00	7.62	33690.84	7678.03	4.11	9653.10
150	DOUBLE- 4	31891.35	15.00	6.03	15.00	13.00	8.28	39441.40	8295.80	3.79	7550.05
200	DOUBLE- 4	39111.02	20.00	6.03	15.00	13.00	9.56	52588.53	9818.22	3.37	13477.51
250	DOUBLE- 4	45914.91	25.00	6.03	15.00	13.00	10.69	65735.67	11188.99	3.07	19820.76
300	DOUBLE- 6	60485.71	25.00	5.57	16.00	12.00	12.05	84227.10	13131.52	2.81	23741.39
350	DOUBLE- 6	68101.19	30.00	5.57	16.00	12.00	13.20	101072.52	14611.34	2.61	32971.33
400	DOUBLE- 8	82163.87	45.00	6.03	15.00	13.00	14.34	118324.20	15786.97	2.41	36160.33
450	DOUBLE- 8	90268.63	50.00	6.03	15.00	13.00	15.12	131471.33	16791.83	2.30	41202.70
500	DOUBLE-10	104043.95	45.00	5.57	16.00	12.00	16.17	151608.78	18527.77	2.20	47564.83

Table 6g. Optimal wind generators for Level 2 energy conservation at 10.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 10.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	15006.54	5.00	6.03	18.00	13.00	4.78	17526.95	4359.31	4.49	2520.42
100	DOUBLE- 4	24037.74	15.00	6.96	16.00	15.00	6.68	34363.57	6231.07	3.27	10325.82
150	DOUBLE- 4	31891.35	20.00	6.96	16.00	15.00	7.71	45818.09	7374.57	2.90	13926.74
200	DOUBLE- 4	39111.02	20.00	6.50	17.00	14.00	8.55	58211.21	8465.71	2.62	19100.19
250	DOUBLE- 4	45914.91	30.00	6.96	16.00	15.00	9.45	68727.13	9351.25	2.45	22812.22
300	DOUBLE- 6	60485.71	30.00	6.50	17.00	14.00	10.48	87316.82	10734.86	2.22	26831.11
350	DOUBLE- 6	68101.19	35.00	6.50	17.00	14.00	11.32	101869.62	11749.13	2.08	33768.43
400	DOUBLE- 8	82163.87	40.00	6.50	17.00	14.00	12.10	116422.42	12704.88	1.97	34258.55
450	DOUBLE- 8	90268.63	45.00	6.50	17.00	14.00	12.83	130975.23	13612.24	1.88	40706.59
500	DOUBLE-10	104043.95	50.00	6.50	17.00	14.00	13.53	145528.03	14478.67	1.80	41484.08

Table 7a. Optimal wind generators for Level 3 energy conservation at 4.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 4.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	11963.80	5.00	2.79	7.00	6.00	15.25	14130.80	20464.55	26.13	2167.00
100	DOUBLE- 4	23927.60	10.00	2.79	7.00	6.00	21.56	28261.61	30712.10	19.61	4334.01
150	DOUBLE- 4	35891.40	15.00	2.79	7.00	6.00	26.41	42392.41	38944.19	16.58	6501.01
200	DOUBLE- 4	47855.20	25.00	2.79	7.00	6.00	34.09	70654.02	52526.09	13.41	22798.82
250	DOUBLE- 4	59819.00	30.00	2.79	7.00	6.00	37.34	84784.83	58445.34	12.44	24965.83
300	DOUBLE- 6	71782.80	35.00	2.79	7.00	6.00	40.34	98915.63	63967.49	11.67	27132.83
350	DOUBLE- 6	83746.60	40.00	2.79	7.00	6.00	43.12	113046.43	69171.00	11.04	29299.83
400	DOUBLE- 8	95710.40	50.00	2.79	7.00	6.00	48.21	141308.04	78828.32	10.07	45597.64
450	DOUBLE- 8	107674.20	50.00	2.79	7.00	6.00	48.21	141308.04	78828.32	10.07	33633.84
500	DOUBLE-10	119638.00	50.00	2.79	7.00	6.00	48.21	141308.04	78828.32	10.07	21670.04

Table 7b. Optimal wind generators for Level 3 energy conservation at 5.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 5.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	11963.80	5.00	3.25	8.00	7.00	12.10	13965.18	15035.18	19.43	2001.38
100	DOUBLE- 4	23927.60	10.00	3.25	8.00	7.00	17.11	27930.36	22563.99	14.58	4002.76
150	DOUBLE- 4	35891.40	15.00	3.25	8.00	7.00	20.96	41895.54	28612.06	12.32	6004.14
200	DOUBLE- 4	47855.20	25.00	3.25	8.00	7.00	27.05	69825.90	38590.59	9.97	21970.70
250	DOUBLE- 4	59819.00	30.00	3.25	8.00	7.00	29.64	83791.08	42939.44	9.25	23972.08
300	DOUBLE- 6	71782.80	35.00	3.25	8.00	7.00	32.01	97756.26	46996.52	8.67	25973.46
350	DOUBLE- 6	83746.60	40.00	3.25	8.00	7.00	34.22	111721.44	50819.51	8.21	27974.84
400	DOUBLE- 8	95710.40	50.00	3.25	8.00	7.00	38.26	139651.80	57914.69	7.48	43941.40
450	DOUBLE- 8	107674.20	50.00	3.25	8.00	7.00	38.26	139651.80	57914.69	7.48	31977.60
500	DOUBLE-10	119638.00	50.00	3.25	8.00	7.00	38.26	139651.80	57914.69	7.48	20013.80

Table 7c. Optimal wind generators for Level 3 energy conservation at 6.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 6.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	11963.80	5.00	3.71	10.00	8.00	9.90	16188.22	11511.31	12.83	4224.42
100	DOUBLE- 4	23927.60	10.00	3.71	10.00	8.00	14.00	32376.45	17275.56	9.63	8448.85
150	DOUBLE- 4	35891.40	20.00	4.18	10.00	9.00	16.60	49650.91	20484.92	7.44	13759.51
200	DOUBLE- 4	47855.20	25.00	4.18	10.00	9.00	18.56	62063.64	23344.93	6.79	14208.44
250	DOUBLE- 4	59819.00	35.00	4.18	10.00	9.00	21.96	86889.10	28430.00	5.90	27070.10
300	DOUBLE- 6	71782.80	40.00	4.18	10.00	9.00	23.47	99301.83	30742.66	5.59	27519.03
350	DOUBLE- 6	83746.60	50.00	4.18	10.00	9.00	26.24	124127.29	35034.81	5.09	40380.69
400	DOUBLE- 8	95710.40	50.00	4.18	10.00	9.00	26.24	124127.29	35034.81	5.09	28416.89
450	DOUBLE- 8	107674.20	50.00	4.18	10.00	9.00	26.24	124127.29	35034.81	5.09	16453.09
500	DOUBLE-10	119638.00	50.00	3.71	10.00	8.00	31.31	161882.25	44340.93	4.94	42244.25

Table 7d. Optimal wind generators for Level 3 energy conservation at 7.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 7.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	11963.80	5.00	4.64	12.00	10.00	7.09	14446.61	7367.24	9.20	2482.81
100	DOUBLE- 4	23927.60	10.00	4.64	12.00	10.00	10.02	28893.22	11056.36	6.90	4965.62
150	DOUBLE- 4	35891.40	15.00	4.64	12.00	10.00	12.27	43339.83	14019.91	5.84	7448.43
200	DOUBLE- 4	47855.20	20.00	4.64	12.00	10.00	14.17	57786.44	16592.78	5.18	9931.24
250	DOUBLE- 4	59819.00	30.00	4.64	12.00	10.00	17.36	86679.66	21040.32	4.38	26860.66
300	DOUBLE- 6	71782.80	35.00	4.64	12.00	10.00	18.75	101126.27	23028.30	4.11	29343.47
350	DOUBLE- 6	83746.60	40.00	4.64	12.00	10.00	20.04	115572.88	24901.56	3.89	31826.28
400	DOUBLE- 8	95710.40	45.00	4.64	12.00	10.00	21.26	130019.49	26679.98	3.70	34309.09
450	DOUBLE- 8	107674.20	50.00	4.64	12.00	10.00	22.41	144466.10	28378.20	3.54	36791.90
500	DOUBLE-10	119638.00	50.00	4.64	12.00	10.00	22.41	144466.10	28378.20	3.54	24828.10

Table 7e. Optimal wind generators for Level 3 energy conservation at 8.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 8.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	11963.80	5.00	5.11	14.00	11.00	6.14	15569.69	6088.63	7.06	3605.89
100	DOUBLE- 4	23927.60	15.00	5.57	13.00	12.00	9.34	35569.04	9736.05	4.94	11641.44
150	DOUBLE- 4	35891.40	20.00	5.57	13.00	12.00	10.78	47425.38	11522.77	4.38	11533.98
200	DOUBLE- 4	47855.20	30.00	5.57	13.00	12.00	13.20	71138.07	14611.34	3.71	23282.87
250	DOUBLE- 4	59819.00	35.00	5.57	13.00	12.00	14.26	82994.42	15991.87	3.48	23175.42
300	DOUBLE- 6	71782.80	45.00	5.57	13.00	12.00	16.17	106707.11	18527.77	3.13	34924.31
350	DOUBLE- 6	83746.60	40.00	5.11	14.00	11.00	17.37	124557.56	20579.80	2.98	40810.96
400	DOUBLE- 8	95710.40	45.00	5.11	14.00	11.00	18.43	140127.25	22049.57	2.84	44416.85
450	DOUBLE- 8	107674.20	50.00	5.11	14.00	11.00	19.42	155696.94	23453.05	2.72	48022.74
500	DOUBLE-10	119638.00	50.00	5.11	14.00	11.00	19.42	155696.94	23453.05	2.72	36058.94

Table 7f. Optimal wind generators for Level 3 energy conservation at 9.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 9.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	11963.80	5.00	5.57	16.00	12.00	5.39	16845.42	5116.14	5.48	4881.62
100	DOUBLE- 4	23927.60	10.00	5.57	16.00	12.00	7.62	33690.84	7678.03	4.11	9763.24
150	DOUBLE- 4	35891.40	20.00	6.03	15.00	13.00	9.56	52588.53	9818.22	3.37	16697.13
200	DOUBLE- 4	47855.20	25.00	6.03	15.00	13.00	10.69	65735.67	11188.99	3.07	17880.47
250	DOUBLE- 4	59819.00	25.00	5.57	16.00	12.00	12.05	84227.10	13131.52	2.81	24408.10
300	DOUBLE- 6	71782.80	40.00	6.03	15.00	13.00	13.52	105177.06	14734.65	2.53	33394.26
350	DOUBLE- 6	83746.60	45.00	6.03	15.00	13.00	14.34	118324.20	15786.97	2.41	34577.60
400	DOUBLE- 8	95710.40	50.00	6.03	15.00	13.00	15.12	131471.33	16791.83	2.30	35760.93
450	DOUBLE- 8	107674.20	45.00	5.57	16.00	12.00	16.17	151608.78	18527.77	2.20	43934.58
500	DOUBLE-10	119638.00	50.00	5.57	16.00	12.00	17.05	168454.20	19707.08	2.11	48816.20

Table 7g. Optimal wind generators for Level 3 energy conservation at 10.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 10.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	MILK COOLING ENERGY DEMAND KWHS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	11963.80	5.00	6.03	18.00	13.00	4.78	17526.95	4359.31	4.49	5563.15
100	DOUBLE- 4	23927.60	15.00	6.96	16.00	15.00	6.68	34363.57	6231.07	3.27	10435.97
150	DOUBLE- 4	35891.40	15.00	6.03	18.00	13.00	8.28	52580.86	8295.80	2.85	16689.46
200	DOUBLE- 4	47855.20	30.00	6.96	16.00	15.00	9.45	68727.13	9351.25	2.45	20871.93
250	DOUBLE- 4	59819.00	30.00	6.50	17.00	14.00	10.48	87316.82	10734.86	2.22	27497.82
300	DOUBLE- 6	71782.80	45.00	6.96	16.00	15.00	11.57	103090.70	11857.77	2.08	31307.90
350	DOUBLE- 6	83746.60	40.00	6.50	17.00	14.00	12.10	116422.42	12704.88	1.97	32675.82
400	DOUBLE- 8	95710.40	45.00	6.50	17.00	14.00	12.83	130975.23	13612.24	1.88	35264.83
450	DOUBLE- 8	107674.20	50.00	6.50	17.00	14.00	13.53	145528.03	14478.67	1.80	37853.83
500	DOUBLE-10	119638.00	50.00	6.03	18.00	13.00	15.12	175269.53	16791.83	1.73	55631.53

Table 8a. Optimal wind generators for Level 4 energy conservation at 4.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 4.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	23920.37	10.00	2.79	7.00	6.00	21.56	28261.61	30712.10	19.61	4341.24
100	DOUBLE- 4	41865.40	20.00	2.79	7.00	6.00	30.49	56523.22	46091.07	14.71	14657.81
150	DOUBLE- 4	58632.83	30.00	2.79	7.00	6.00	37.34	84784.83	58445.34	12.44	26151.99
200	DOUBLE- 4	74766.33	35.00	2.79	7.00	6.00	40.34	98915.63	63967.49	11.67	24149.30
250	DOUBLE- 4	90484.05	45.00	2.79	7.00	6.00	45.74	127177.24	74111.06	10.51	36693.19
300	DOUBLE- 6	105900.57	50.00	2.79	7.00	6.00	48.21	141308.04	78828.32	10.07	35407.48
350	DOUBLE- 6	121085.18	50.00	2.79	7.00	6.00	48.21	141308.04	78828.32	10.07	20222.86
400	DOUBLE- 8	136083.75	50.00	2.79	7.00	6.00	48.21	141308.04	78828.32	10.07	5224.30
450	DOUBLE- 8	150928.49	50.00	2.32	7.00	5.00	63.38	192321.45	113512.78	10.65	41392.96
500	DOUBLE-10	165643.15	50.00	2.32	7.00	5.00	63.38	192321.45	113512.78	10.65	26678.29

Table 8b. Optimal wind generators for Level 4 energy conservation at 5.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 5.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	23920.37	10.00	3.25	8.00	7.00	17.11	27930.36	22563.99	14.58	4009.99
100	DOUBLE- 4	41865.40	20.00	3.25	8.00	7.00	24.20	55860.72	33862.83	10.94	13995.32
150	DOUBLE- 4	58632.83	30.00	3.25	8.00	7.00	29.64	83791.08	42939.44	9.25	25158.24
200	DOUBLE- 4	74766.33	40.00	3.25	8.00	7.00	34.22	111721.44	50819.51	8.21	36955.10
250	DOUBLE- 4	90484.05	45.00	3.25	8.00	7.00	36.30	125686.62	54448.94	7.82	35202.56
300	DOUBLE- 6	105900.57	50.00	3.25	8.00	7.00	38.26	139651.80	57914.69	7.48	33751.23
350	DOUBLE- 6	121085.18	50.00	3.25	8.00	7.00	38.26	139651.80	57914.69	7.48	18566.61
400	DOUBLE- 8	136083.75	45.00	2.79	9.00	6.00	45.74	186616.56	74111.06	7.17	50532.81
450	DOUBLE- 8	150928.49	50.00	2.79	9.00	6.00	48.21	207351.73	78828.32	6.86	56423.24
500	DOUBLE-10	165643.15	50.00	2.79	9.00	6.00	48.21	207351.73	78828.32	6.86	41708.58

Table 8c. Optimal wind generators for Level 4 energy conservation at 6.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 6.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	23920.37	10.00	3.71	10.00	8.00	14.00	32376.45	17275.56	9.63	8456.08
100	DOUBLE- 4	41865.40	25.00	4.18	10.00	9.00	18.56	62063.64	23344.93	6.79	20198.24
150	DOUBLE- 4	58632.83	35.00	4.18	10.00	9.00	21.96	86889.10	28430.00	5.90	28256.27
200	DOUBLE- 4	74766.33	45.00	4.18	10.00	9.00	24.90	111714.56	32938.25	5.32	36948.23
250	DOUBLE- 4	90484.05	50.00	4.18	10.00	9.00	26.24	124127.29	35034.81	5.09	33643.23
300	DOUBLE- 6	105900.57	50.00	4.18	10.00	9.00	26.24	124127.29	35034.81	5.09	18226.72
350	DOUBLE- 6	121085.18	50.00	3.71	10.00	8.00	31.31	161882.25	44340.93	4.94	40797.06
400	DOUBLE- 8	136083.75	50.00	3.71	10.00	8.00	31.31	161882.25	44340.93	4.94	25798.50
450	DOUBLE- 8	150928.49	50.00	3.25	11.00	7.00	38.26	212898.98	57914.69	4.91	61970.49
500	DOUBLE-10	165643.15	50.00	3.25	11.00	7.00	38.26	212898.98	57914.69	4.91	47255.83

Table 8d. Optimal wind generators for Level 4 energy conservation at 7.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 7.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	23920.37	10.00	4.64	12.00	10.00	10.02	28893.22	11056.36	6.90	4972.85
100	DOUBLE- 4	41865.40	20.00	4.64	12.00	10.00	14.17	57786.44	16592.78	5.18	15921.04
150	DOUBLE- 4	58632.83	30.00	4.64	12.00	10.00	17.36	86679.66	21040.32	4.38	28046.83
200	DOUBLE- 4	74766.33	35.00	4.64	12.00	10.00	18.75	101126.27	23028.30	4.11	26359.94
250	DOUBLE- 4	90484.05	45.00	4.64	12.00	10.00	21.26	130019.49	26679.98	3.70	39535.44
300	DOUBLE- 6	105900.57	50.00	4.64	12.00	10.00	22.41	144466.10	28378.20	3.54	38565.53
350	DOUBLE- 6	121085.18	50.00	4.64	12.00	10.00	22.41	144466.10	28378.20	3.54	23380.91
400	DOUBLE- 8	136083.75	50.00	4.64	12.00	10.00	22.41	144466.10	28378.20	3.54	8382.35
450	DOUBLE- 8	150928.49	50.00	3.71	13.00	8.00	31.31	221051.29	44340.93	3.62	70122.80
500	DOUBLE-10	165643.15	50.00	3.71	13.00	8.00	31.31	221051.29	44340.93	3.62	55408.14

Table 8e. Optimal wind generators for Level 4 energy conservation at 8.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 8.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	23920.37	15.00	5.57	13.00	12.00	9.34	35569.04	9736.05	4.94	11648.67
100	DOUBLE- 4	41865.40	20.00	5.11	14.00	11.00	12.28	62278.78	13713.05	3.97	20413.38
150	DOUBLE- 4	58632.83	35.00	5.57	13.00	12.00	14.26	82994.42	15991.87	3.48	24361.59
200	DOUBLE- 4	74766.33	45.00	5.57	13.00	12.00	16.17	106707.11	18527.77	3.13	31940.78
250	DOUBLE- 4	90484.05	40.00	5.11	14.00	11.00	17.37	124557.56	20579.80	2.98	34073.50
300	DOUBLE- 6	105900.57	50.00	5.11	14.00	11.00	19.42	155696.94	23453.05	2.72	49796.38
350	DOUBLE- 6	121085.18	50.00	5.11	14.00	11.00	19.42	155696.94	23453.05	2.72	34611.76
400	DOUBLE- 8	136083.75	50.00	5.11	14.00	11.00	19.42	155696.94	23453.05	2.72	19613.20
450	DOUBLE- 8	150928.49	50.00	5.11	14.00	11.00	19.42	155696.94	23453.05	2.72	4768.45
500	DOUBLE-10	165643.15	50.00	4.64	14.00	10.00	22.41	185706.37	28378.20	2.76	20063.22

Table 8f. Optimal wind generators for Level 4 energy conservation at 9.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 9.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	23920.37	10.00	5.57	16.00	12.00	7.62	33690.84	7678.03	4.11	9770.47
100	DOUBLE- 4	41865.40	20.00	6.03	15.00	13.00	9.56	52588.53	9818.22	3.37	10723.13
150	DOUBLE- 4	58632.83	25.00	5.57	16.00	12.00	12.05	84227.10	13131.52	2.81	25594.27
200	DOUBLE- 4	74766.33	40.00	6.03	15.00	13.00	13.52	105177.06	14734.65	2.53	30410.73
250	DOUBLE- 4	90484.05	50.00	6.03	15.00	13.00	15.12	131471.33	16791.83	2.30	40987.28
300	DOUBLE- 6	105900.57	45.00	5.57	16.00	12.00	16.17	151608.78	18527.77	2.20	45708.21
350	DOUBLE- 6	121085.18	50.00	5.57	16.00	12.00	17.05	168454.20	19707.08	2.11	47369.01
400	DOUBLE- 8	136083.75	50.00	5.57	16.00	12.00	17.05	168454.20	19707.08	2.11	32370.45
450	DOUBLE- 8	150928.49	50.00	5.57	16.00	12.00	17.05	168454.20	19707.08	2.11	17525.71
500	DOUBLE-10	165643.15	50.00	5.57	16.00	12.00	17.05	168454.20	19707.08	2.11	2811.05

Table 8g. Optimal wind generators for Level 4 energy conservation at 10.0 m/s wind regime.

OPTIMAL DAIRY WIND GENERATORS FOR 10.00 M/S WIND REGIME

HERD SIZE NO.	PARLOR SIZE	TOTAL MILKING ENERGY DEMAND KHRS	RATED POWER KWS	CUTIN SPEED M/S	CUTOUT SPEED M/S	RATED SPEED M/S	ROTOR DIAMETER M	ENERGY OUTPUT KWHS	INSTALLED COST $	ENERGY COST C/KWH	SURPLUS ENERGY KWHS
50	DOUBLE- 4	23920.37	15.00	6.96	16.00	15.00	6.68	34363.57	6231.07	3.27	10443.20
100	DOUBLE- 4	41865.40	20.00	6.50	17.00	14.00	8.55	58211.21	8465.71	2.62	16345.81
150	DOUBLE- 4	58632.83	30.00	6.50	17.00	14.00	10.48	87316.82	10734.86	2.22	28683.98
200	DOUBLE- 4	74766.33	45.00	6.96	16.00	15.00	11.57	103090.70	11857.77	2.08	28324.36
250	DOUBLE- 4	90484.05	45.00	6.50	17.00	14.00	12.83	130975.23	13612.24	1.88	40491.17
300	DOUBLE- 6	105950.57	50.00	6.50	17.00	14.00	13.53	145528.03	14478.67	1.80	39627.46
350	DOUBLE- 6	121085.18	50.00	6.03	18.00	13.00	15.12	175269.53	16791.83	1.73	54184.35
400	DOUBLE- 8	136083.75	50.00	6.03	18.00	13.00	15.12	175269.53	16791.83	1.73	39185.79
450	DOUBLE- 8	150928.49	50.00	6.03	18.00	13.00	15.12	175269.53	16791.83	1.73	24341.04
500	DOUBLE-10	165643.15	50.00	6.03	18.00	13.00	15.12	175269.53	16791.83	1.73	9626.38

Table 9. Comparison of milking cooling energy use using a precooler at CSU dairy farm with model prediction.

Date	Power Meter Reading Kwh	Period Covered Years	Average Herd Size	Energy Use Kwh
07:11:79	44236	--	--	--
01:11:80	54654	½	135	10418
Probable energy use for one calendar year			135	20836
Energy use as predicted by model - eqn 4.28 - for one year			135	20268.6

Table 10. Comparison of actual SWECS prototype data for 1,000 units per year production (after W. Briggs, 1980) with model predictions.

Manufacturer	Rated Power Kw	Rated Speed m/s	Cut-in speed, m/s		Cut-out speed,m/s		Installed cost,$*		Rotor diameter,m	
			Prototype	Model	Prototype	Model	Prototype	Model	Prototype	Model
Northwind	2	8.94	4.02	4.15	26.85	7.21 -- 17.83	7787	5385	5.0	5.3
Enertech	2	8.94	3.58	4.15	25.04	7.21 -- 17.83	7905	5385	5.0	5.3
Windworks	8	8.94	3.13	4.15	20.12	7.21 -- 17.83	17879	12128	10.06	10.6
UTRC	8	8.94	3.35	4.15	22.35	7.21 -- 17.83	18894	12128	9.45	10.6
Grumman	8	8.94	3.58	4.15	15.65	7.21 -- 17.83	18937	12128	10.13	10.6
Kaman	40	8.94	4.47	4.15	26.82	7.21 -- 17.83	31243	31129	19.51	23.7

*1979 dollars, assuming inflation rate of 12 percent per annum.

FIGURES

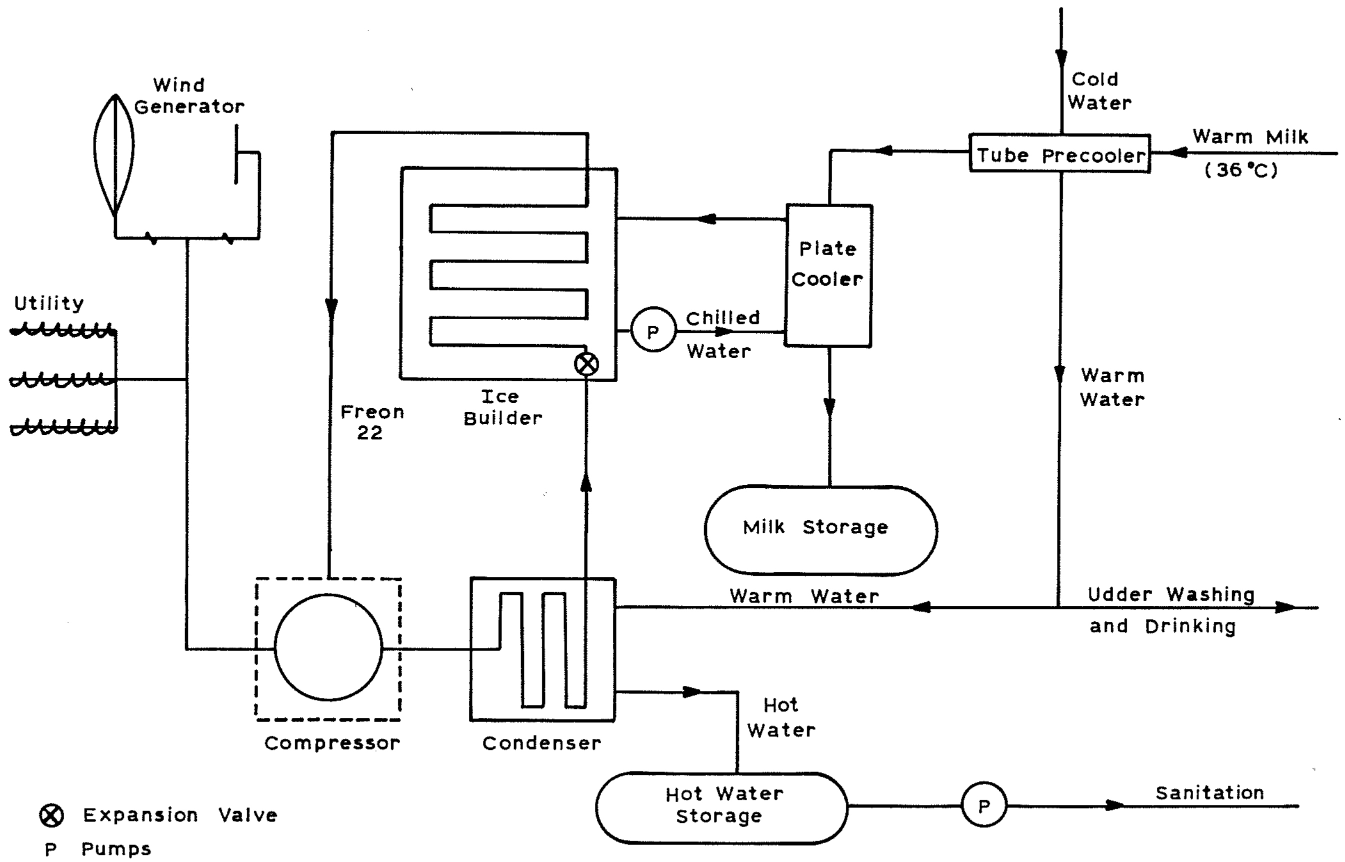

Figure 1. Schematic drawing of dairy wind generator components.

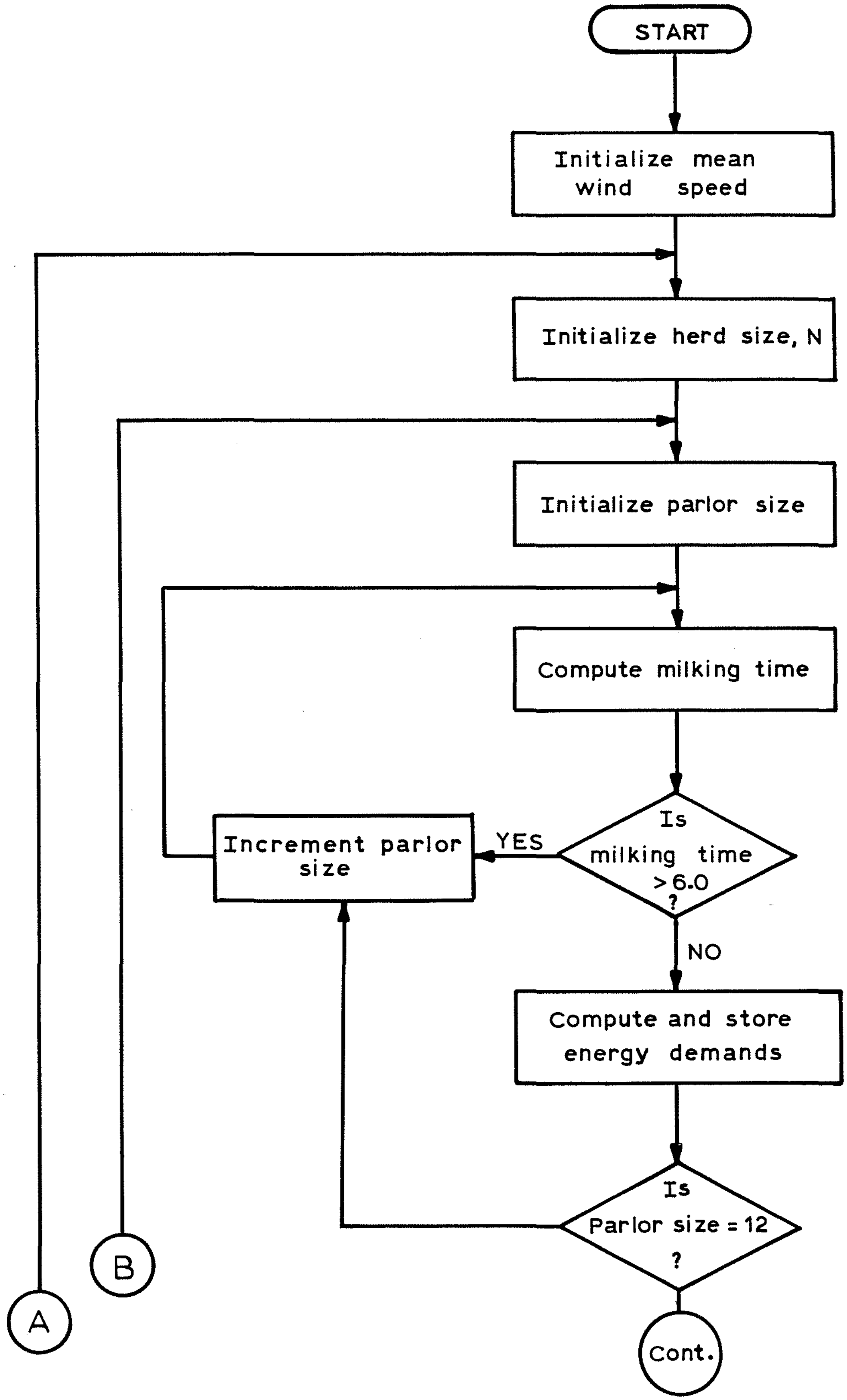

Figure 2. Flow chart diagram of dairy wind generator model.

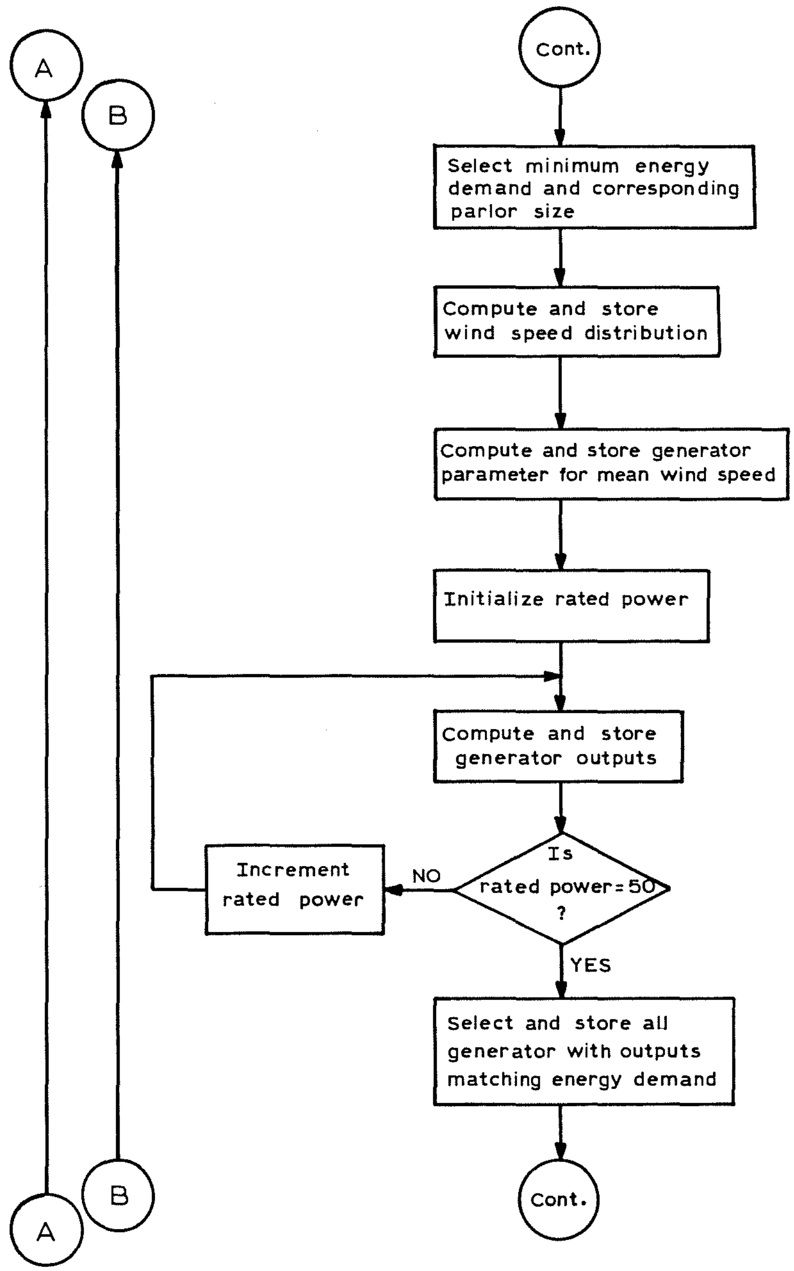

Figure 2. (continued)

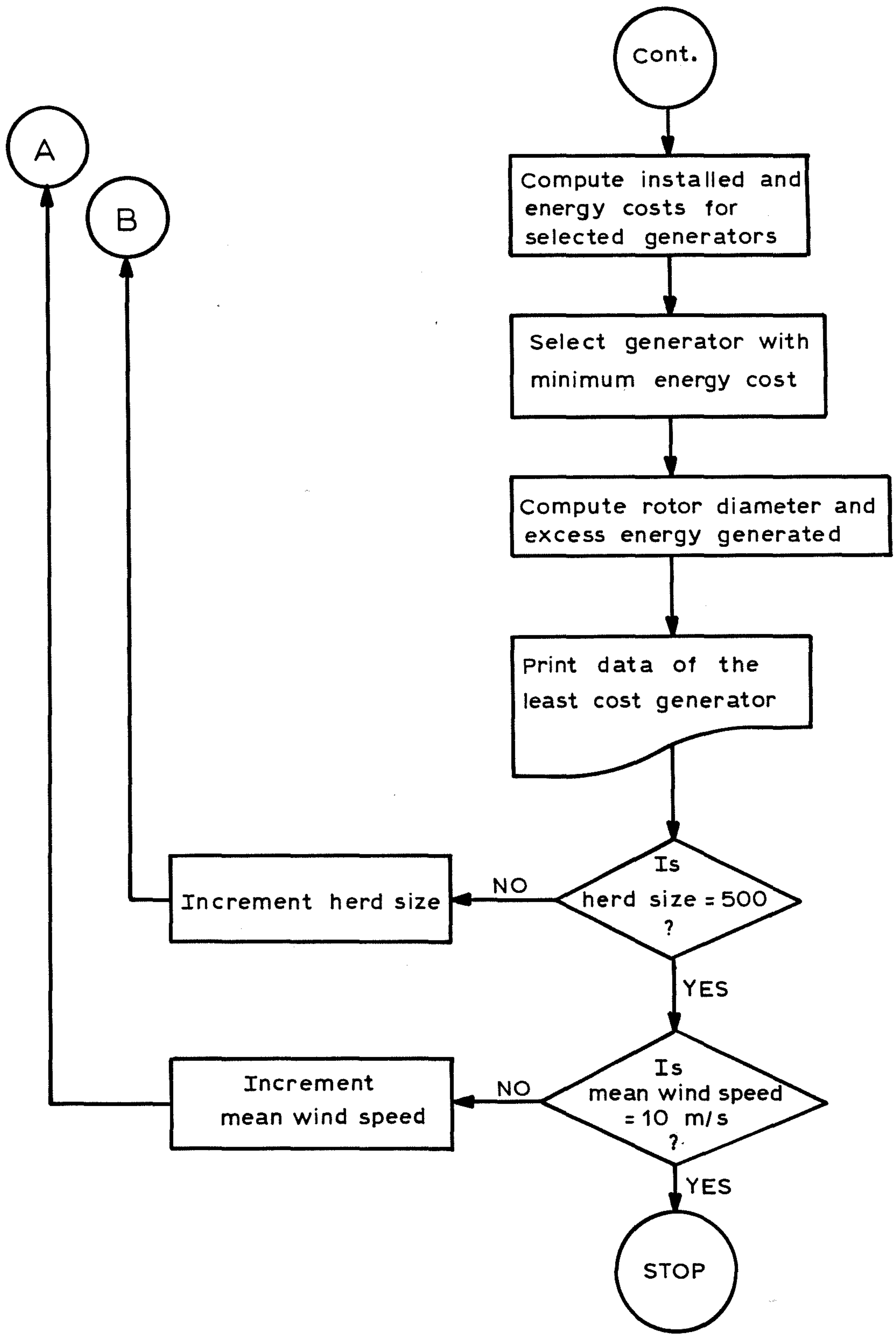

Figure 2. (continued)

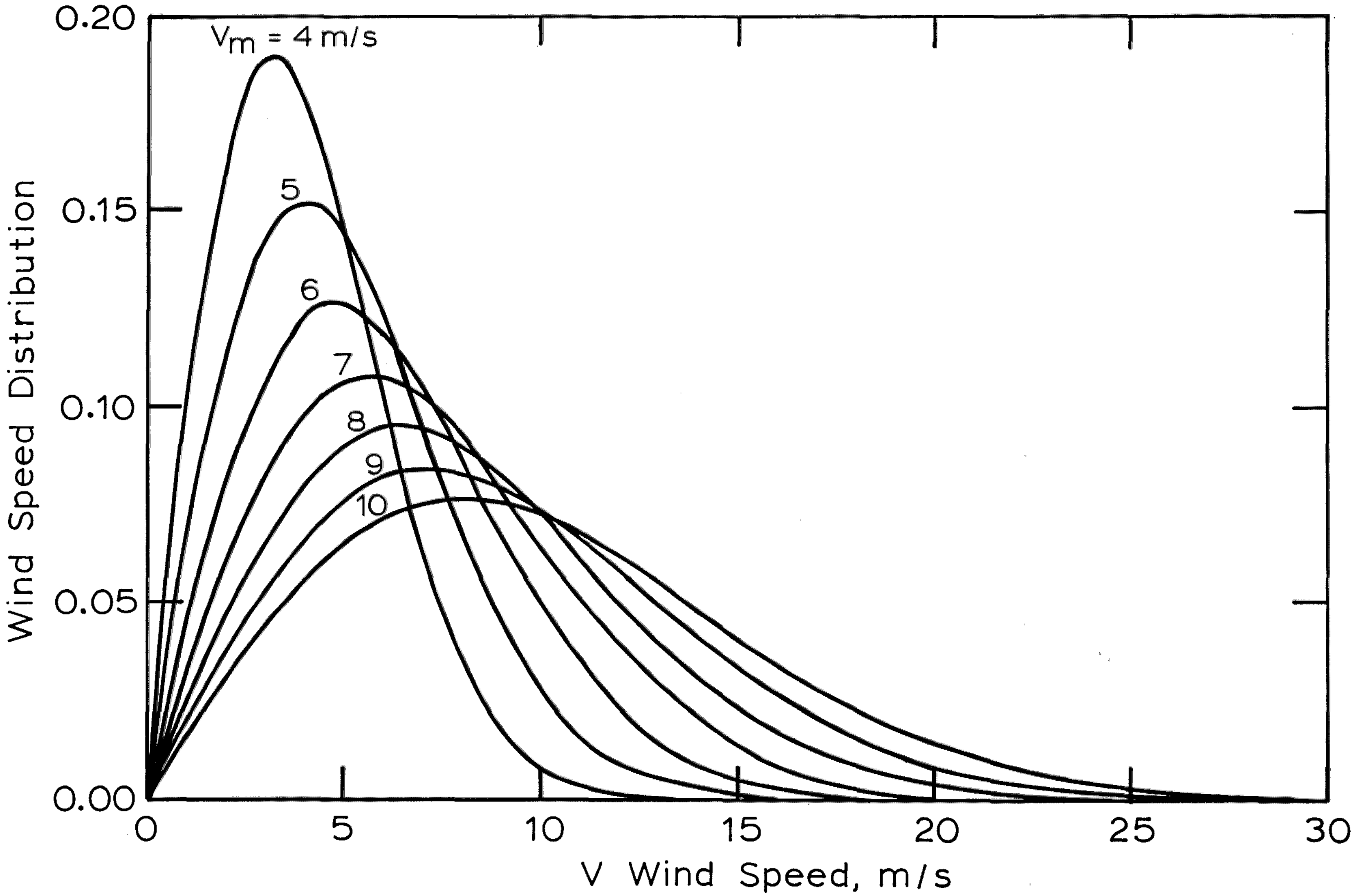

Figure 3. Wind speed distribution based on Rayleigh distribution.

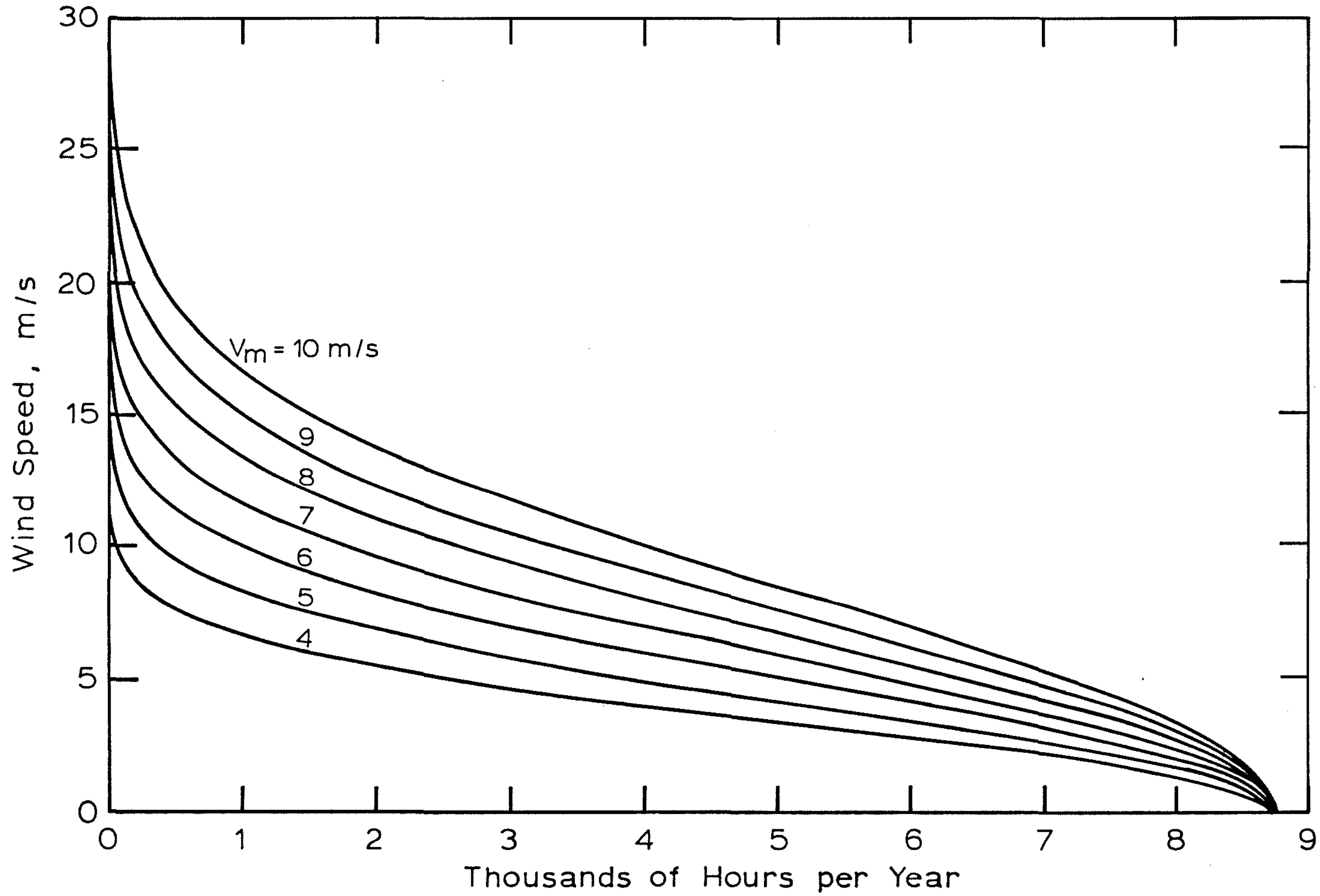

Figure 4. Velocity duration curve based on Rayleigh distribution.

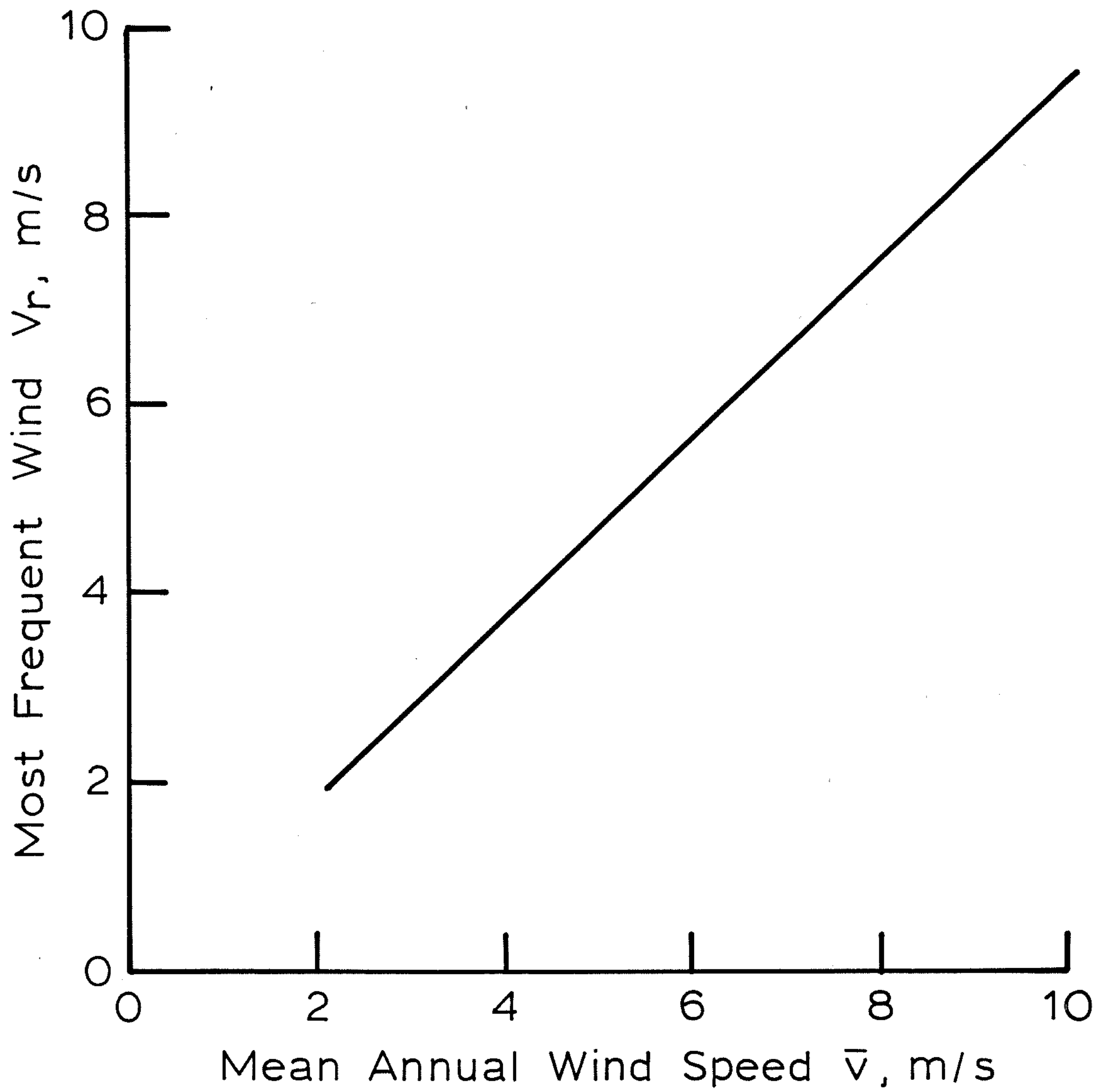

Figure 5. Relation of most frequent wind and mean wind speed.

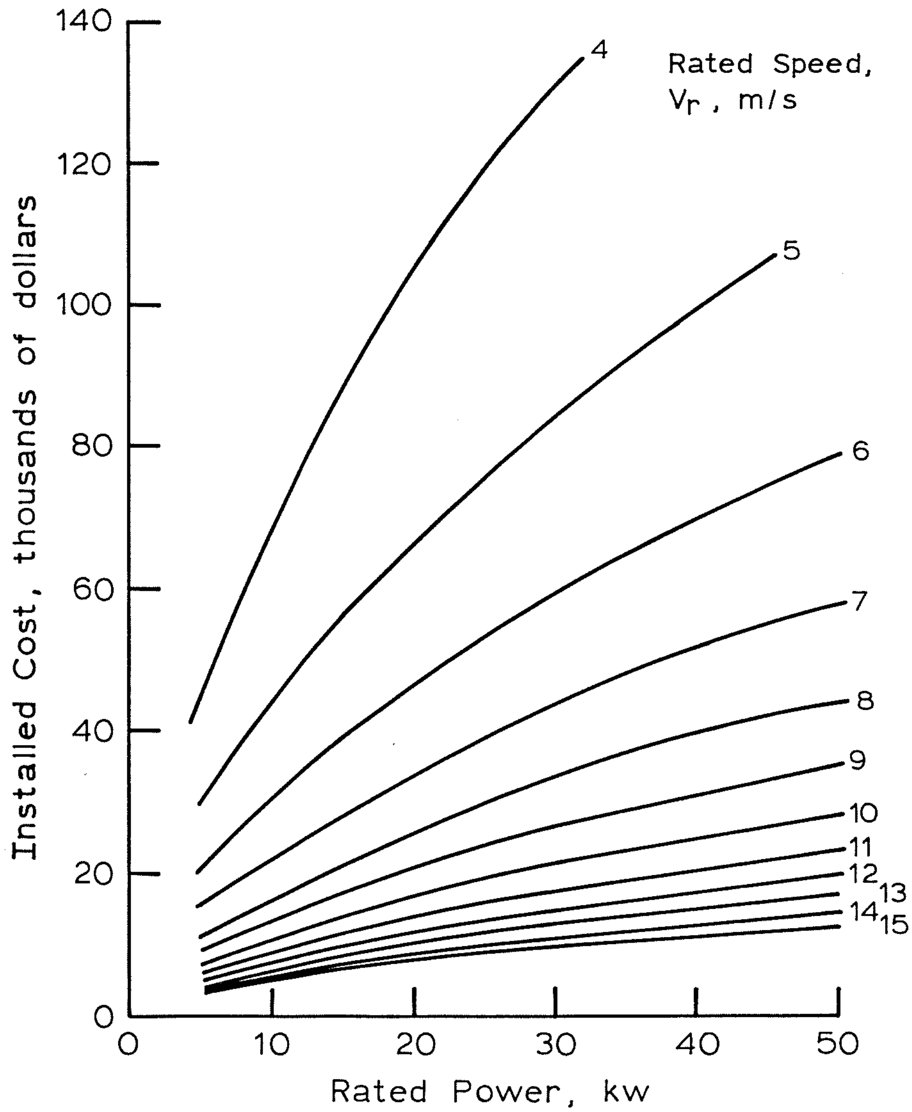

Figure 6. Installed cost as a function of rated power and rated speed.

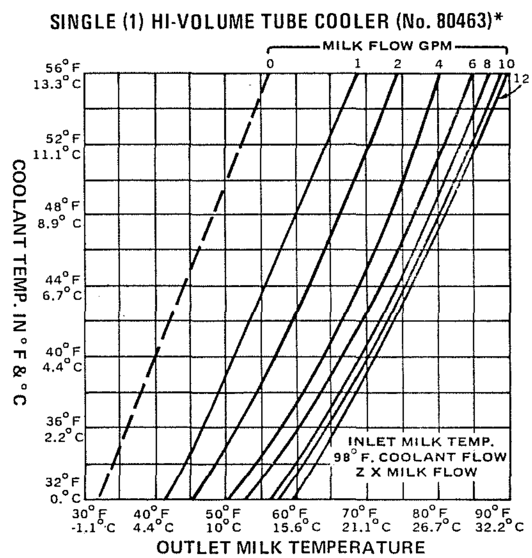

Figure 7. Relation between milk flow rates and outlet milk temperature for Surge precooler.

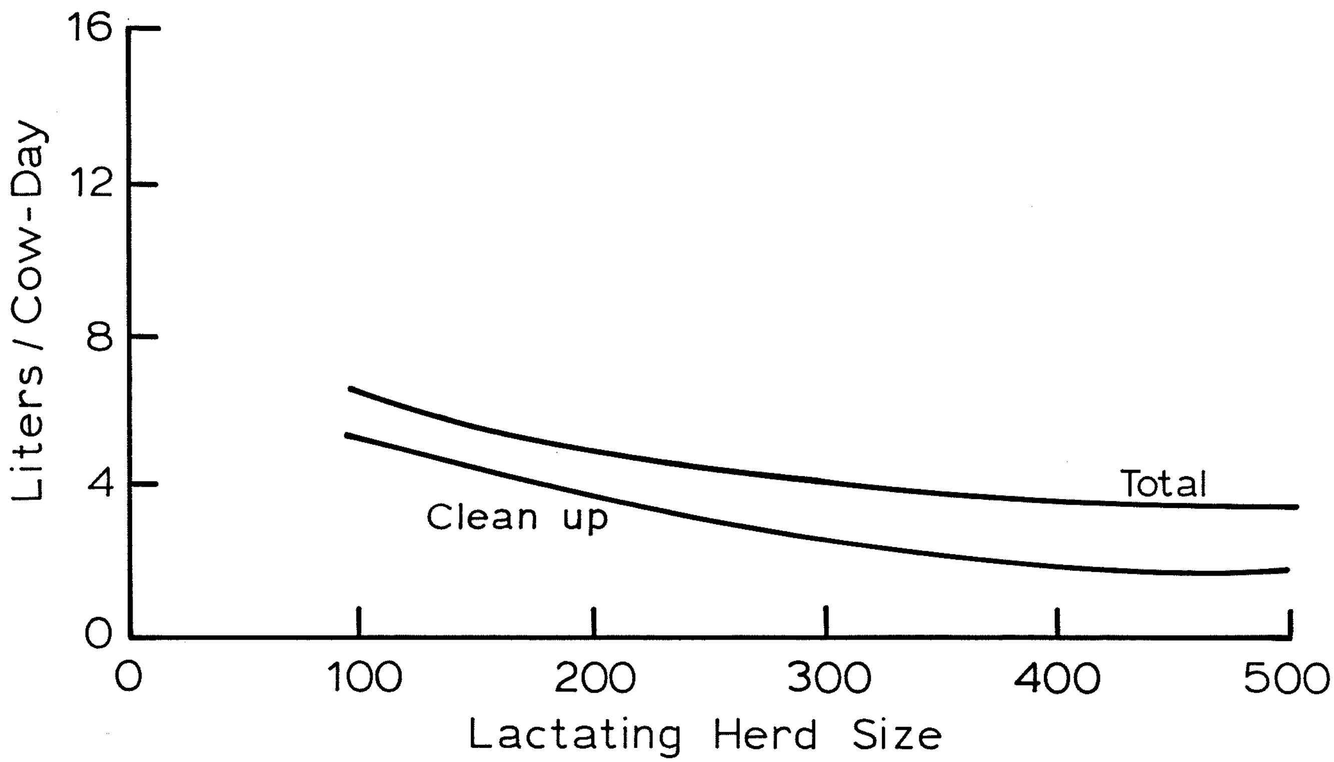

Figure 8. Total hot water use and use for equipment cleanup vs. lactating herd size in herringbone parlors (after Wiersma and Armstrong, 1979).

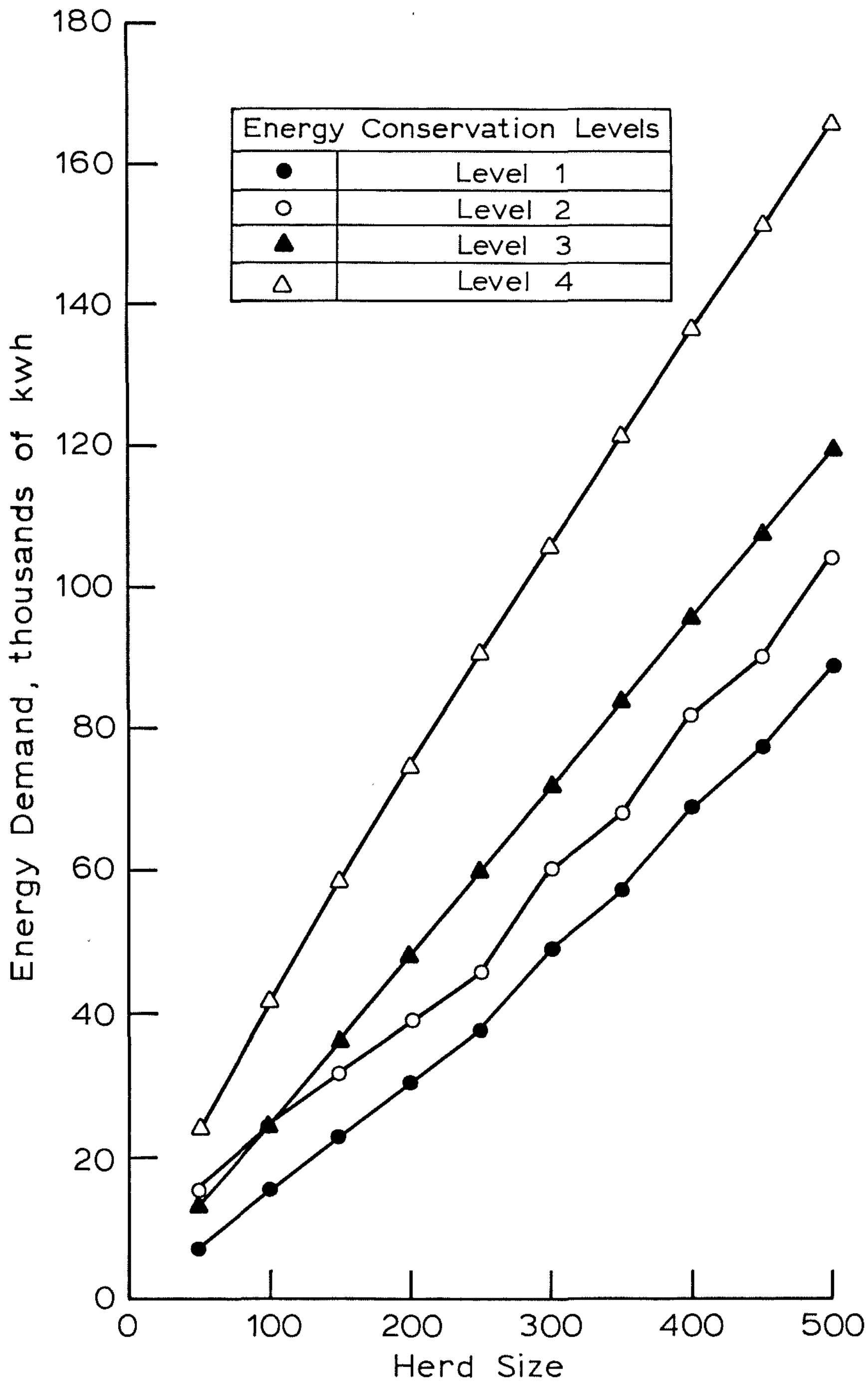

Figure 9. Milk cooling and water heating energy demand vs. lactating herd size for different energy conservation levels.

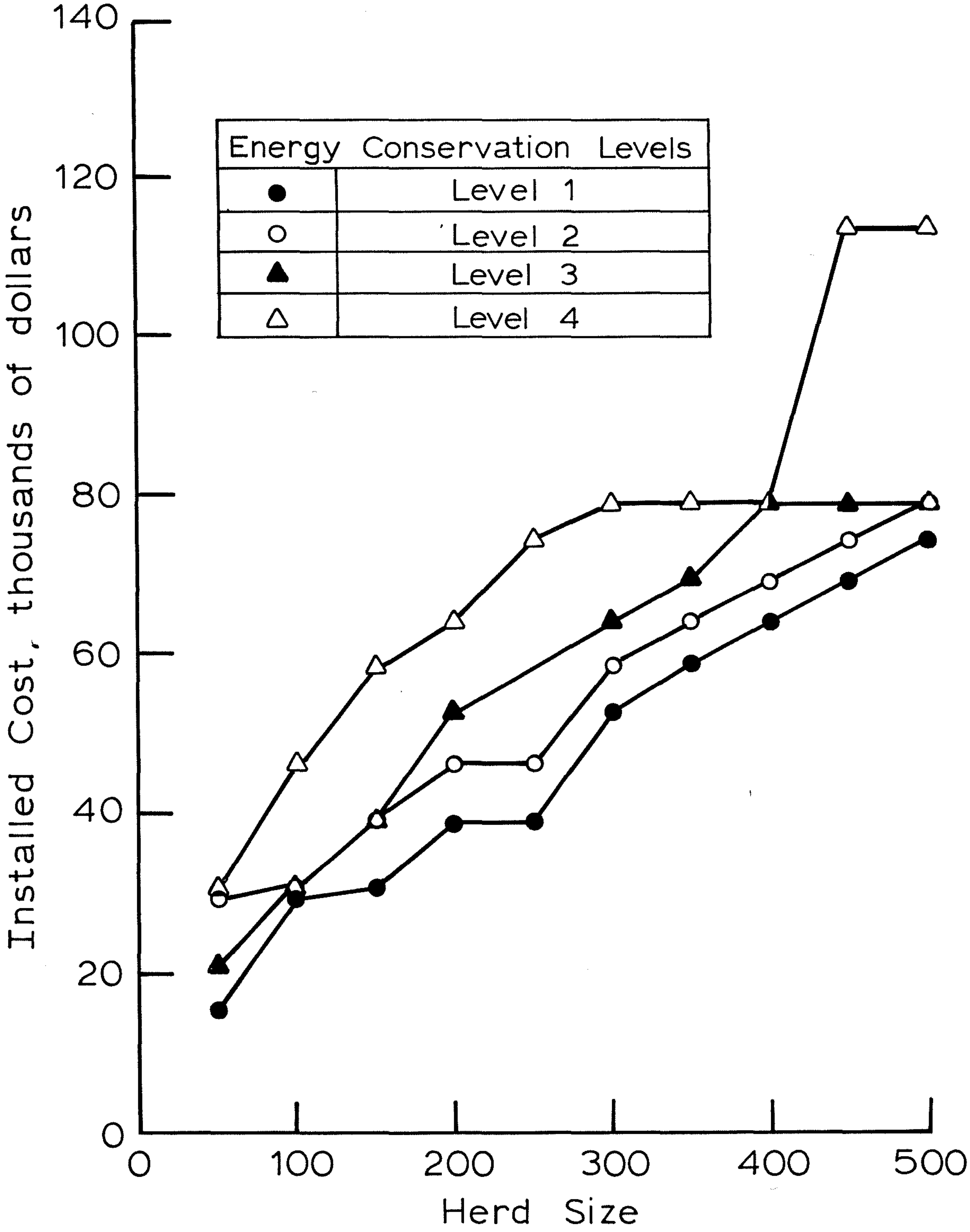

Figure 10a. Installed cost of optimal wind generators vs. lactating herd size at 4.0 m/s mean wind speed.

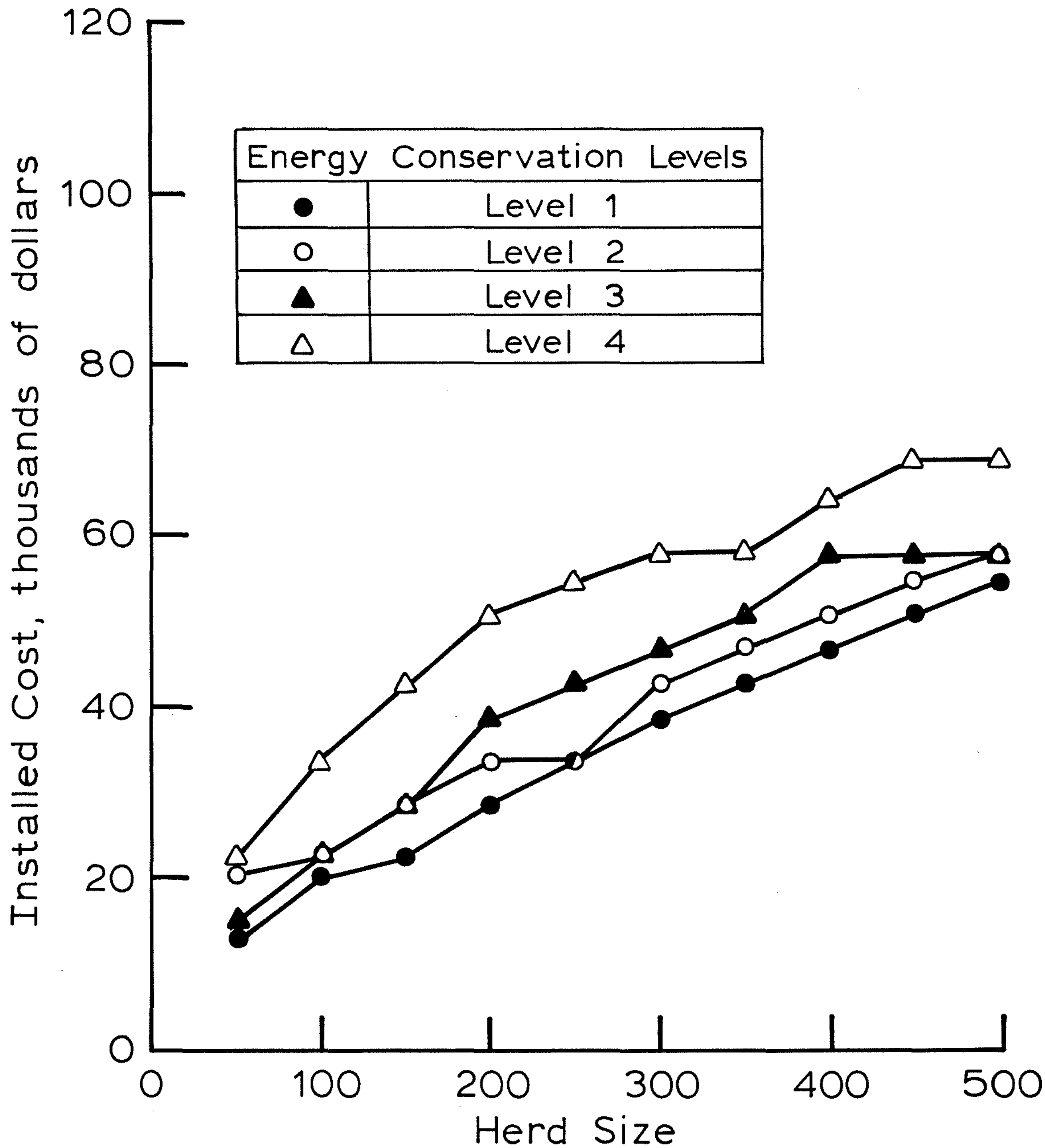

Figure 10b. Installed cost of optimal wind generators vs. lactating herd size at 5.0 m/s mean wind speed.

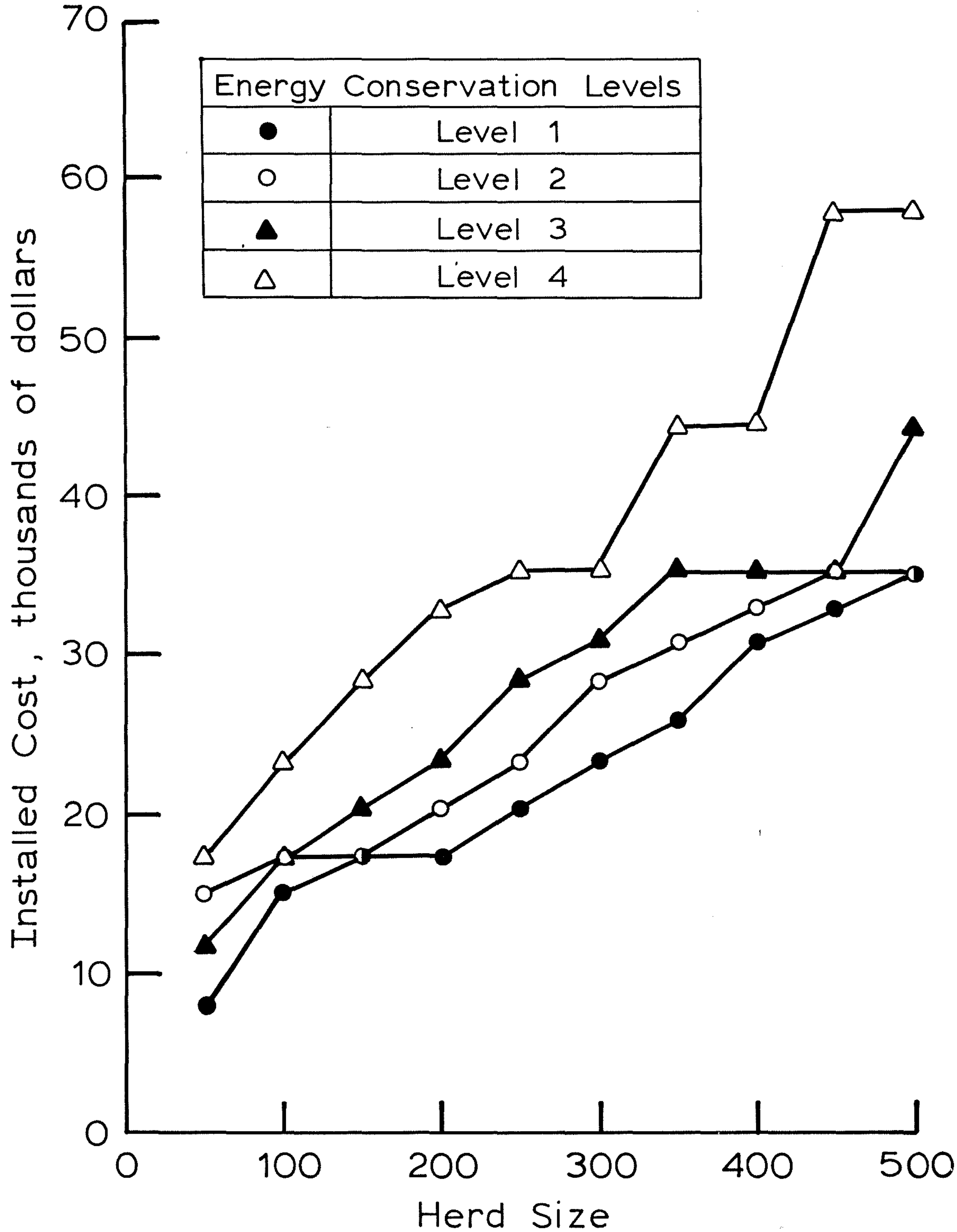

Figure 10c. Installed cost of optimal wind generators vs. lactating herd size at 6.0 m/s mean wind speed.

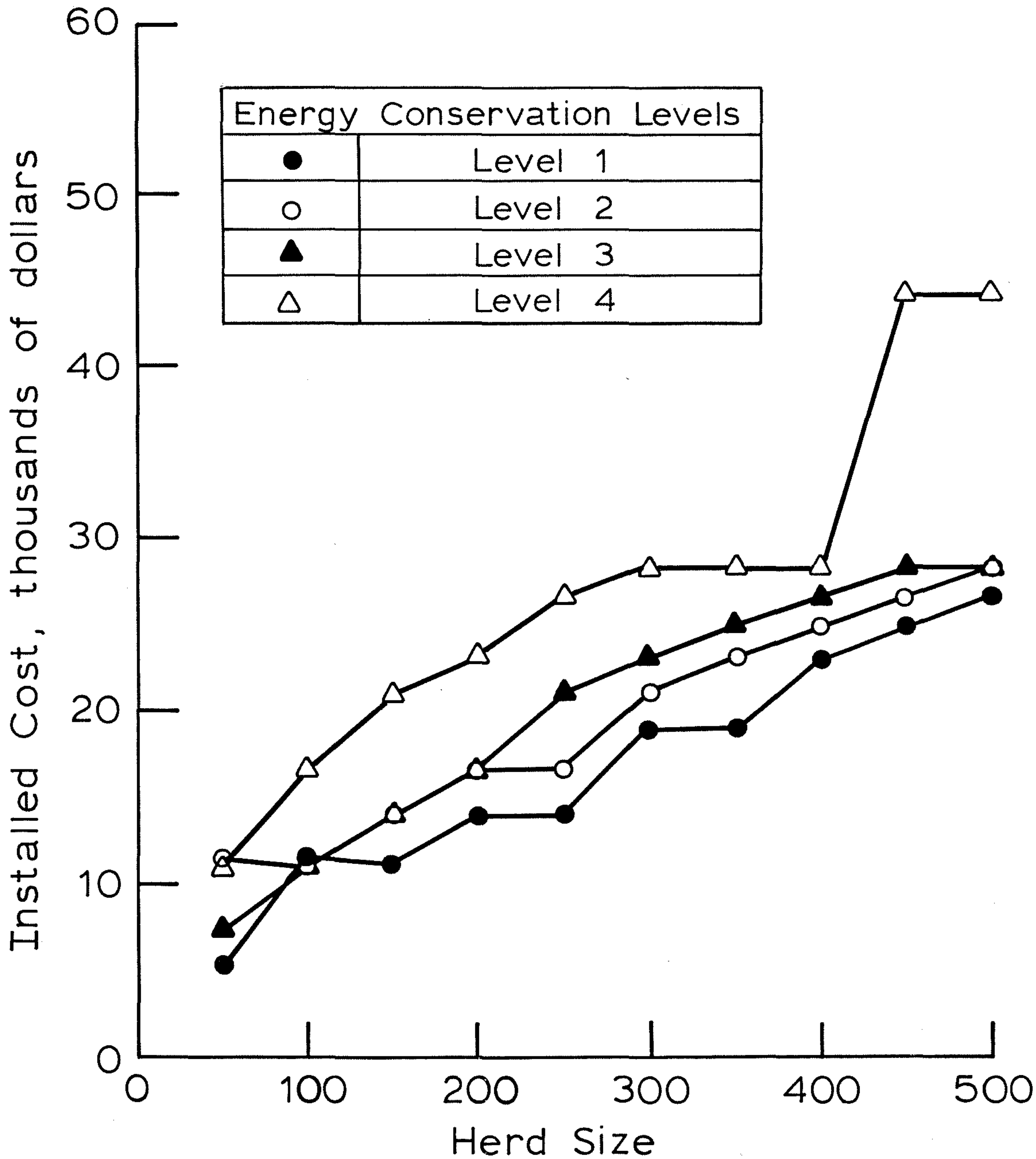

Figure 10d. Installed cost of optimal wind generators vs. lactating herd size at 7.0 m/s mean wind speed.

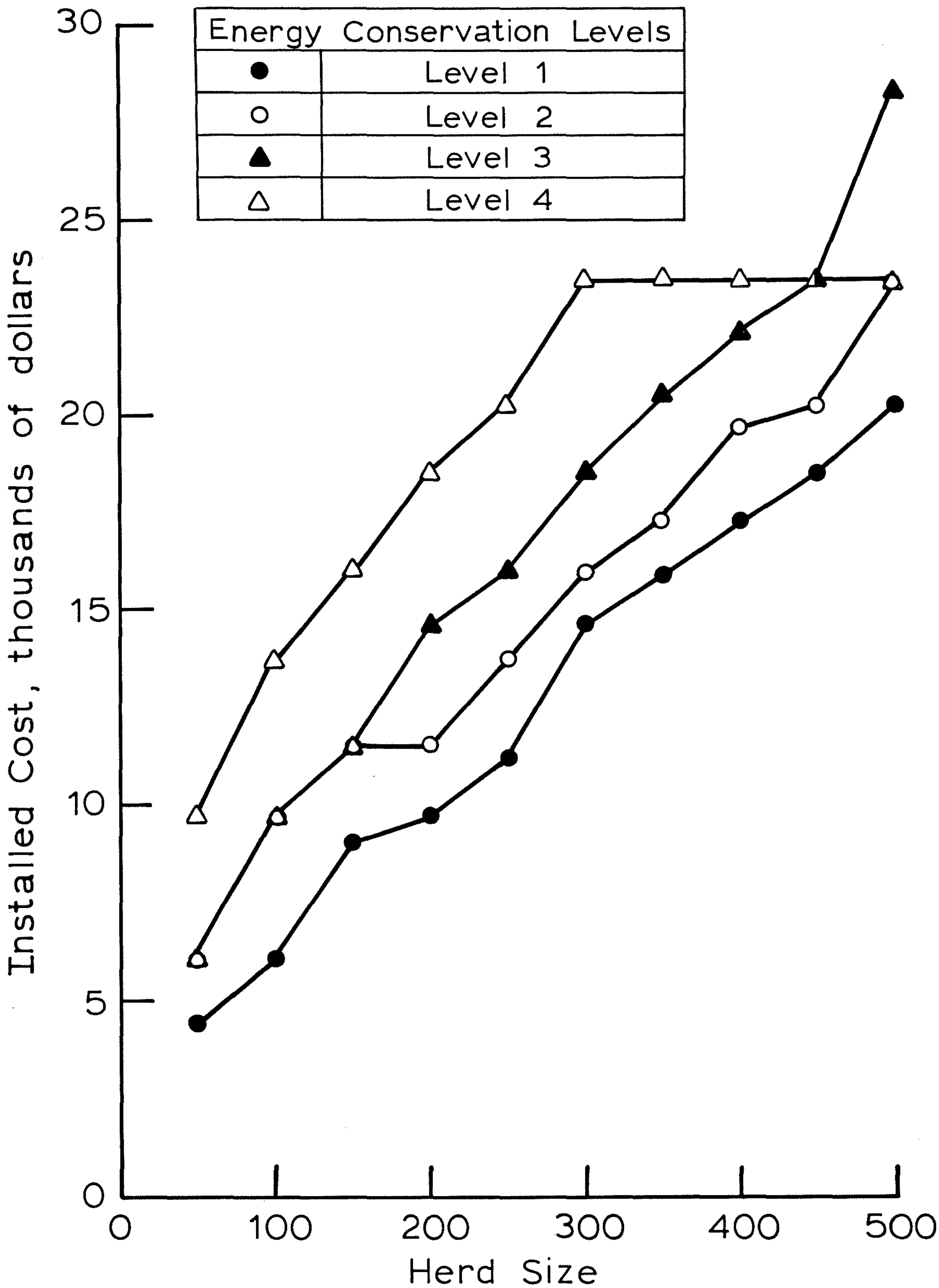

Figure 10e. Installed cost of optimal wind generators vs. lactating herd size at 8.0 m/s mean wind speed.

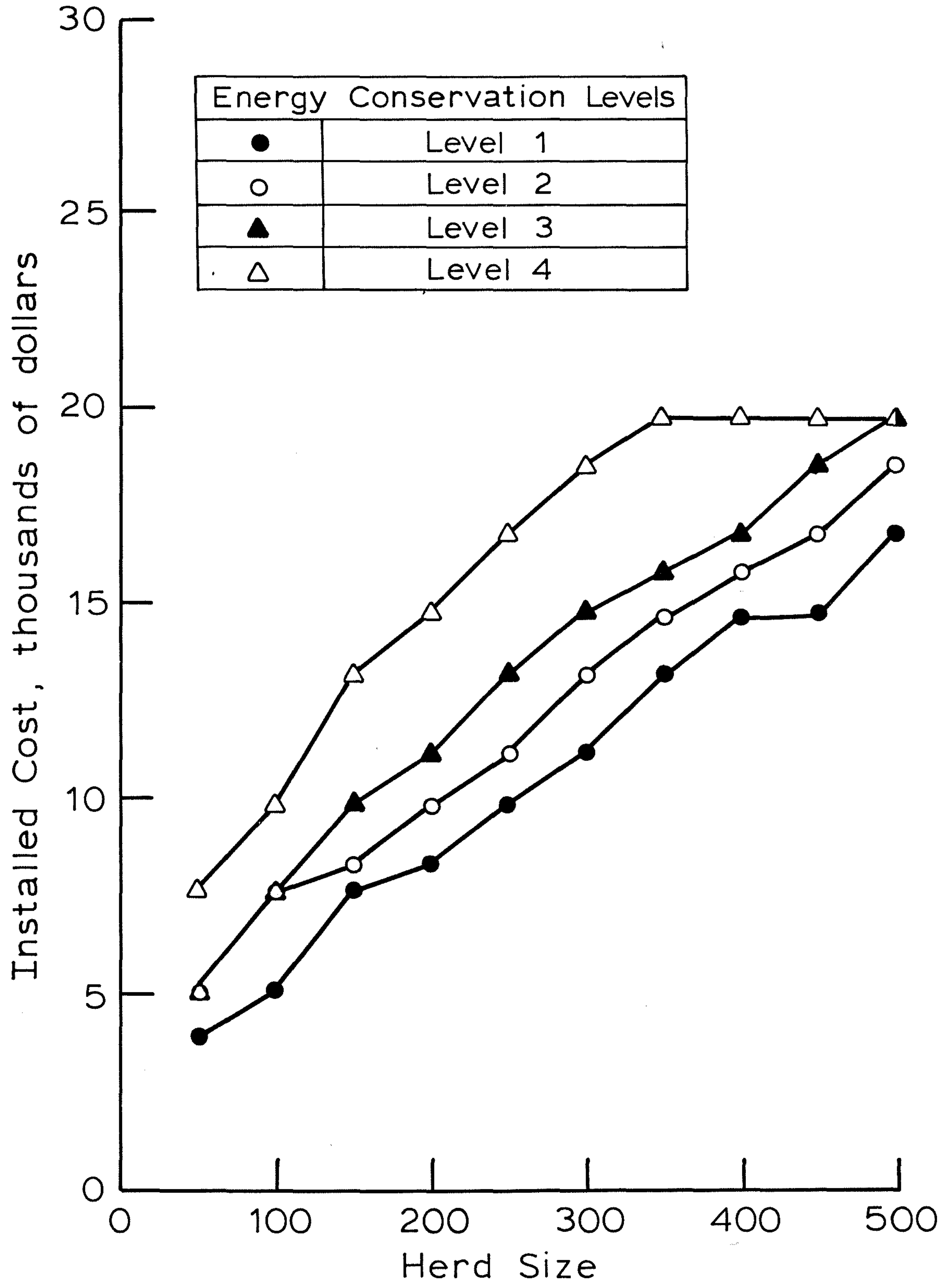

Figure 10f. Installed cost of optimal wind generators vs. lactating herd size at 9.0 m/s mean wind speed.

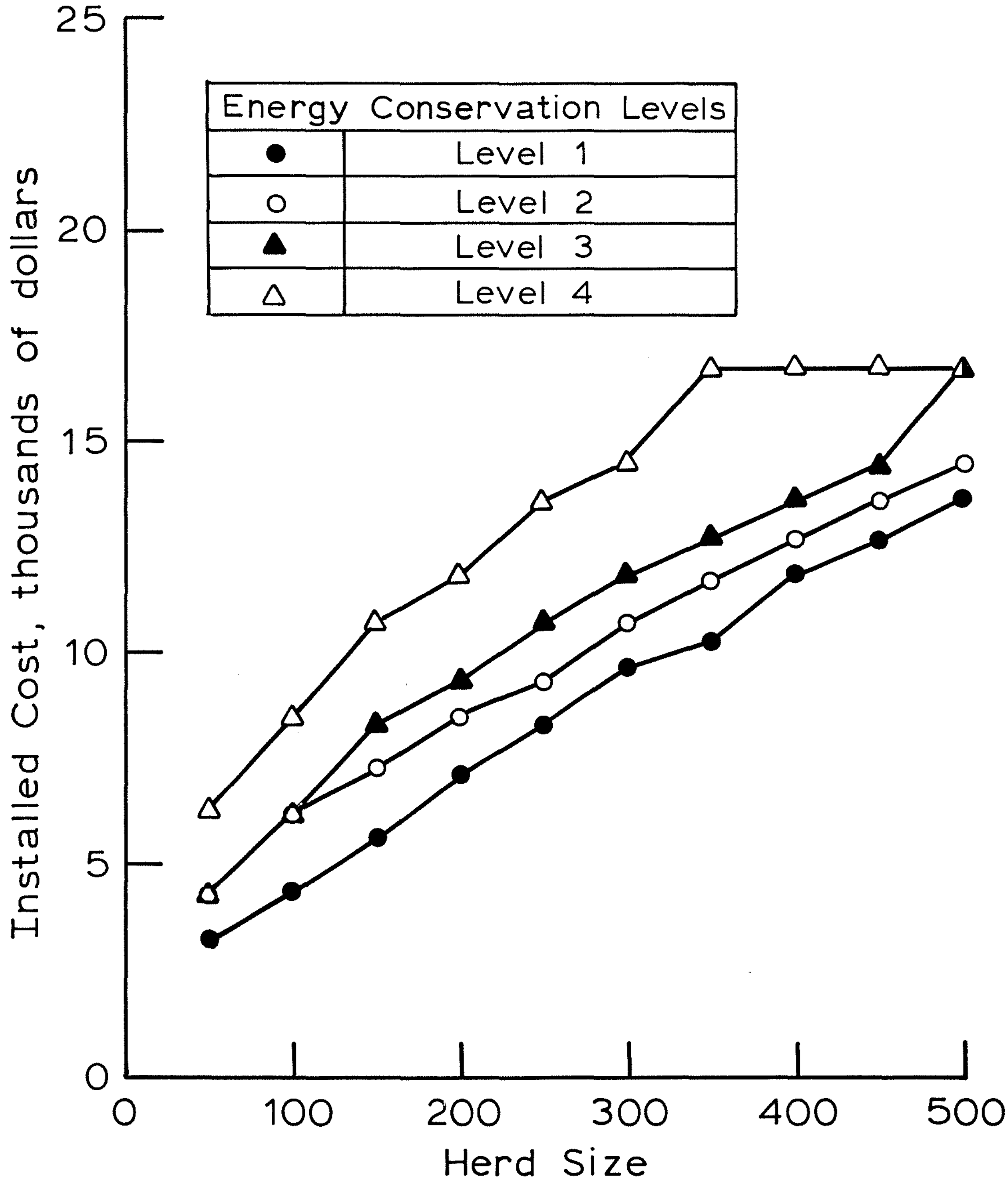

Figure 10g. Installed cost of optimal wind generators vs. lactating herd size at 10.0 m/s mean wind speed.

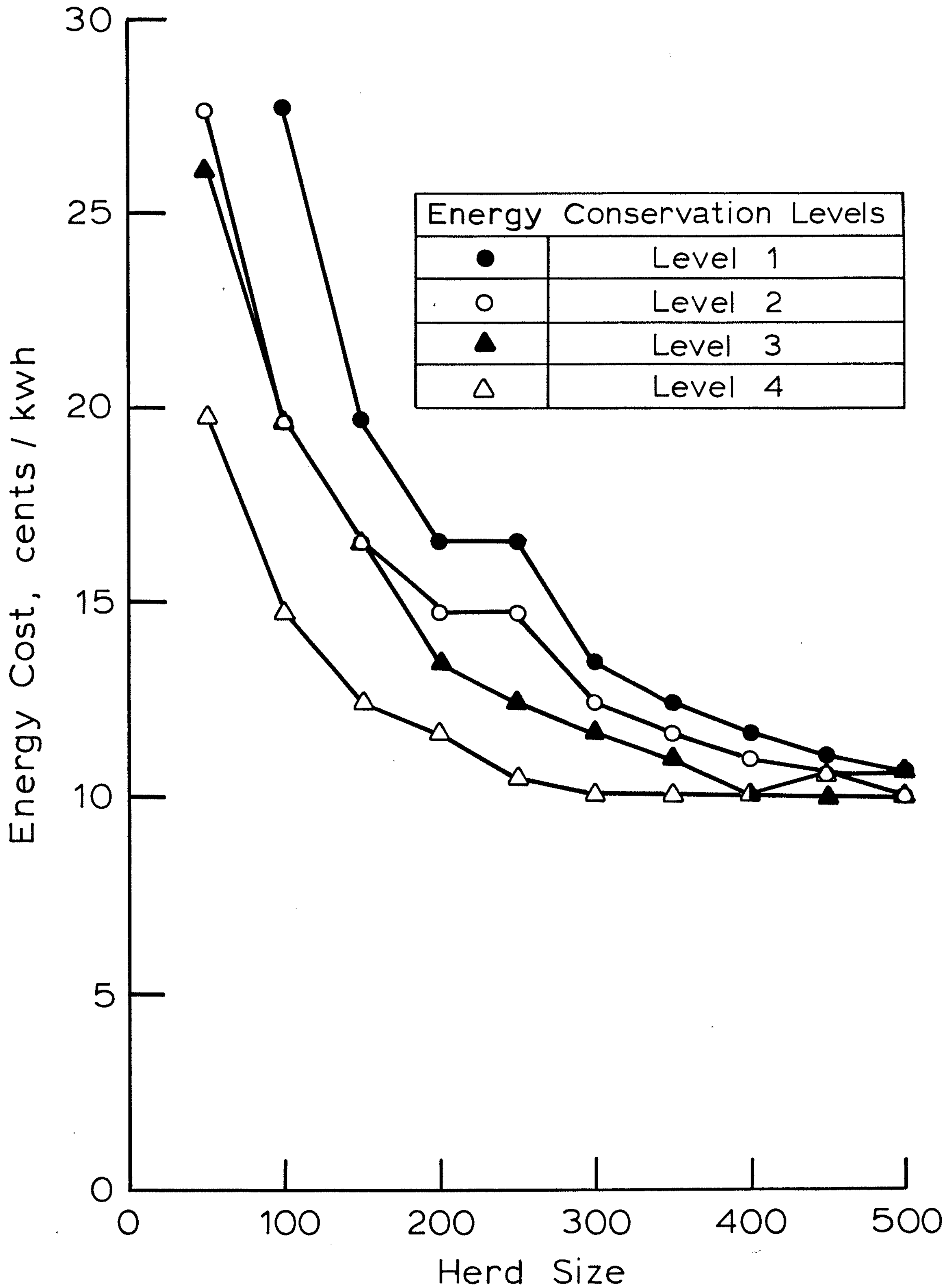

Figure 11a. Wind energy costs vs. lactating herd size for different energy conservation levels at 4.0 m/s mean wind regime.

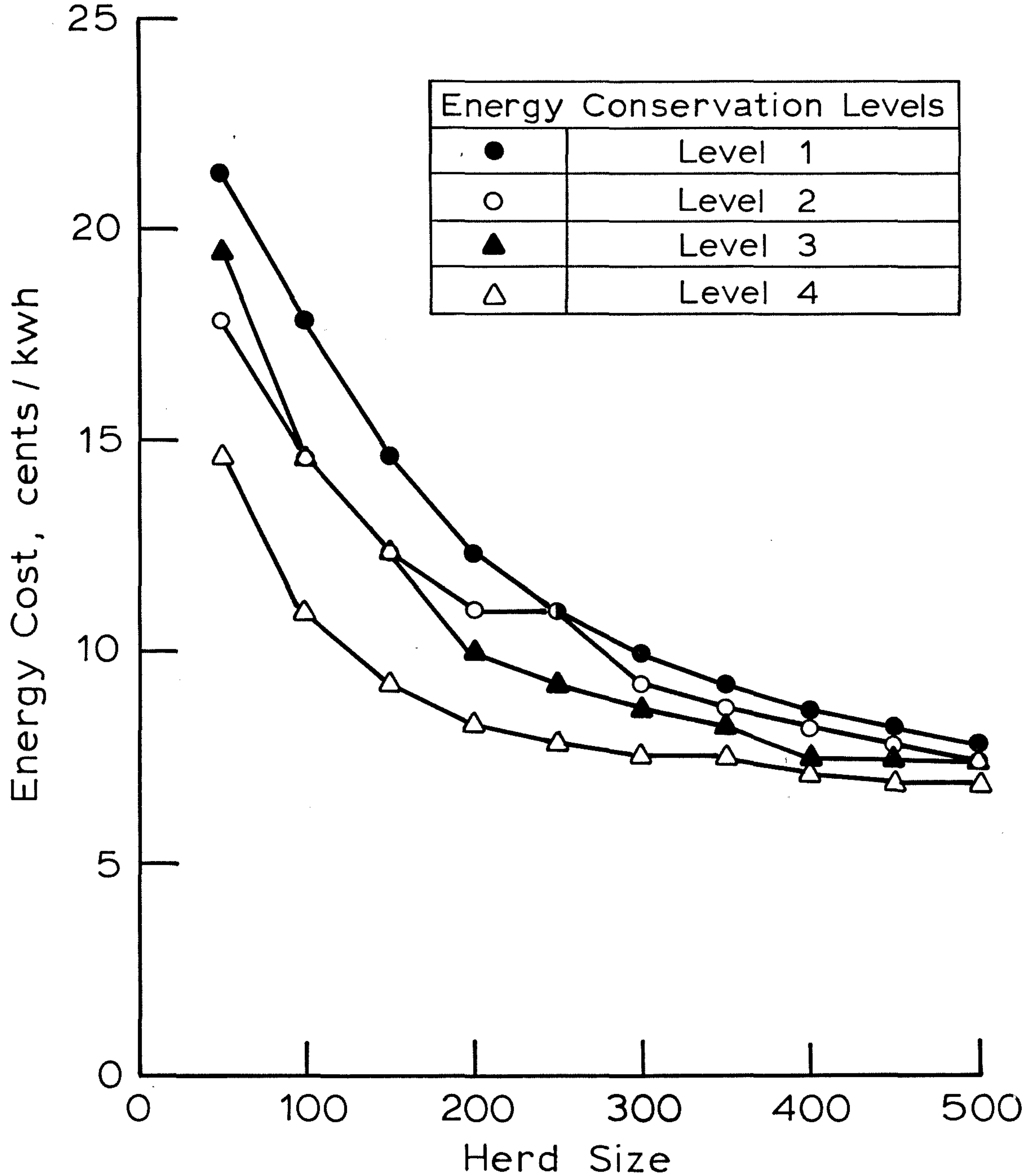

Figure 11b. Wind energy costs vs. lactating herd size for different energy conservation levels at 5.0 m/s mean wind regime.

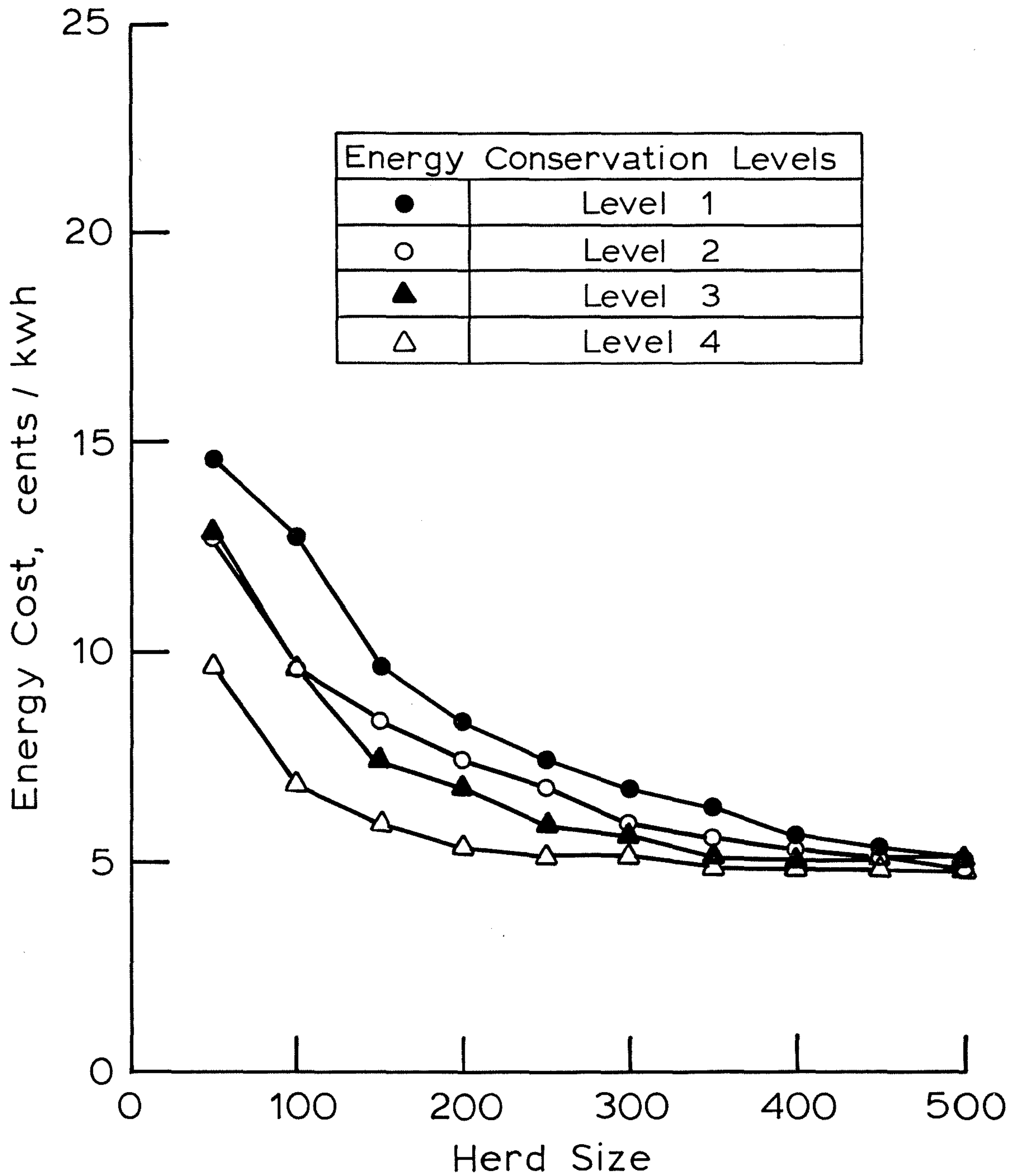

Figure 11c. Wind energy costs vs. lactating herd size for different energy conservation levels at 6.0 m/s mean wind regime.

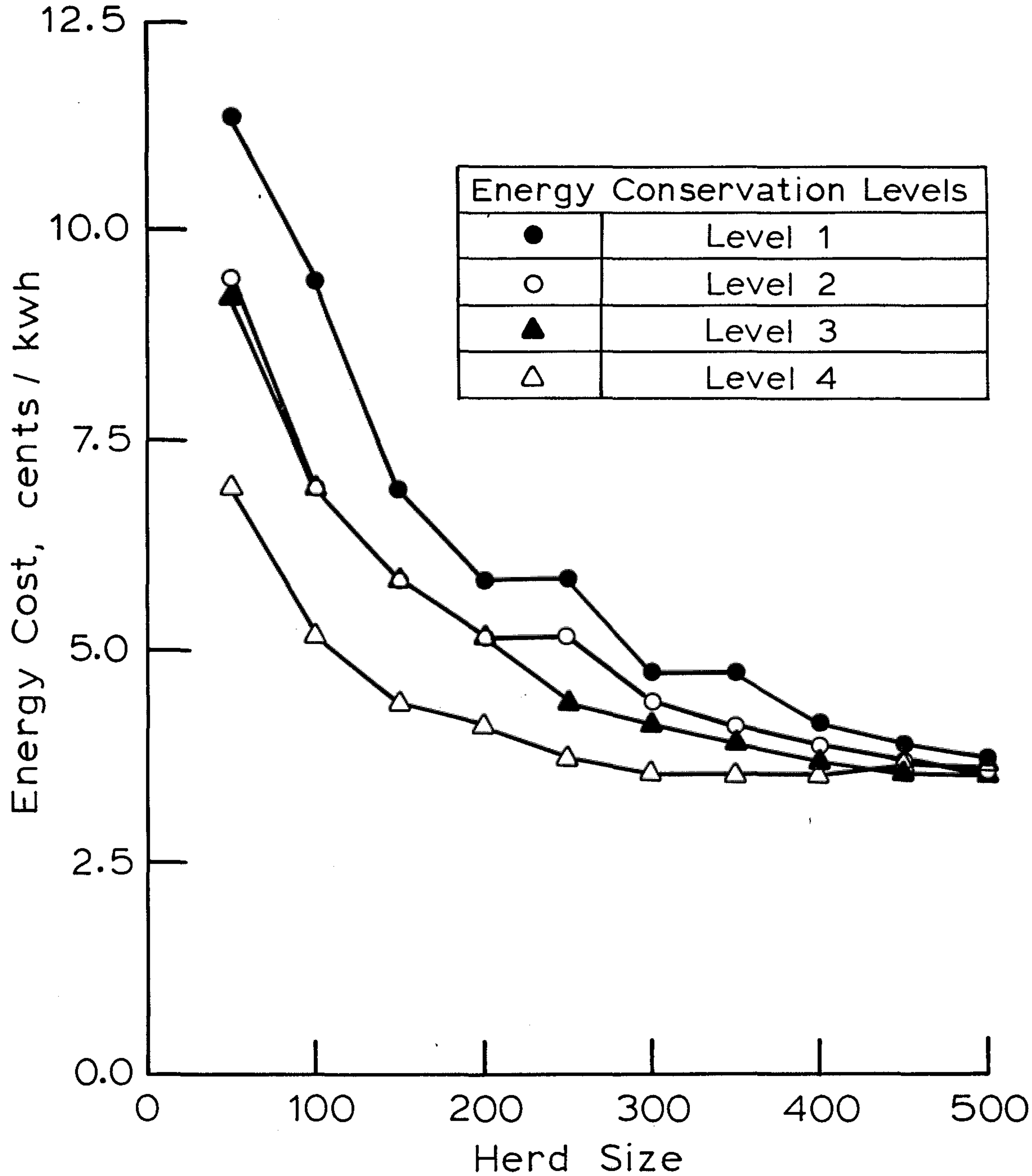

Figure 11d. Wind energy costs vs. lactating herd size for different energy conservation levels at 7.0 m/s mean wind regime.

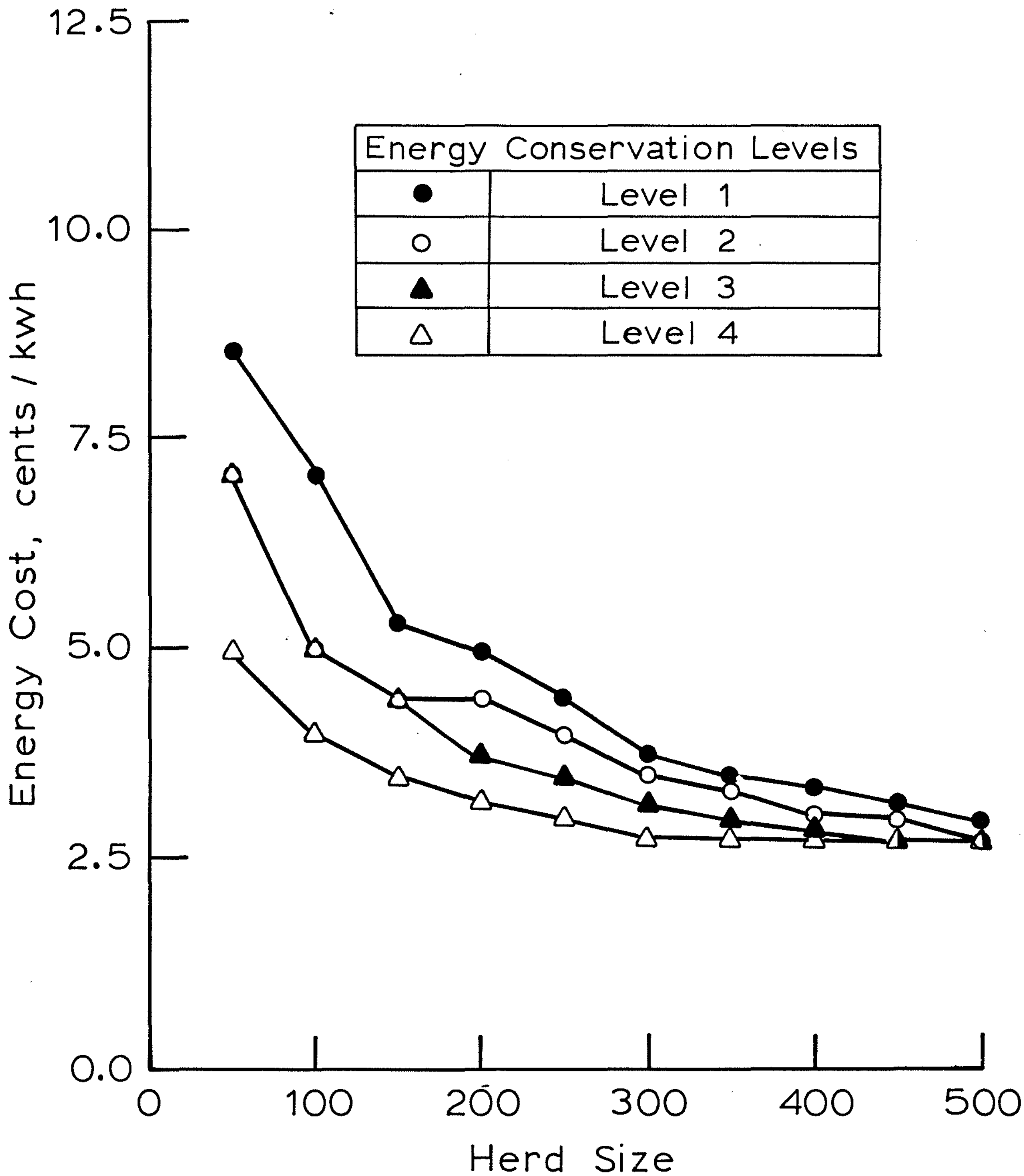

Figure 11e. Wind energy costs vs. lactating herd size for different energy conservation levels at 8.0 m/s mean wind regime.

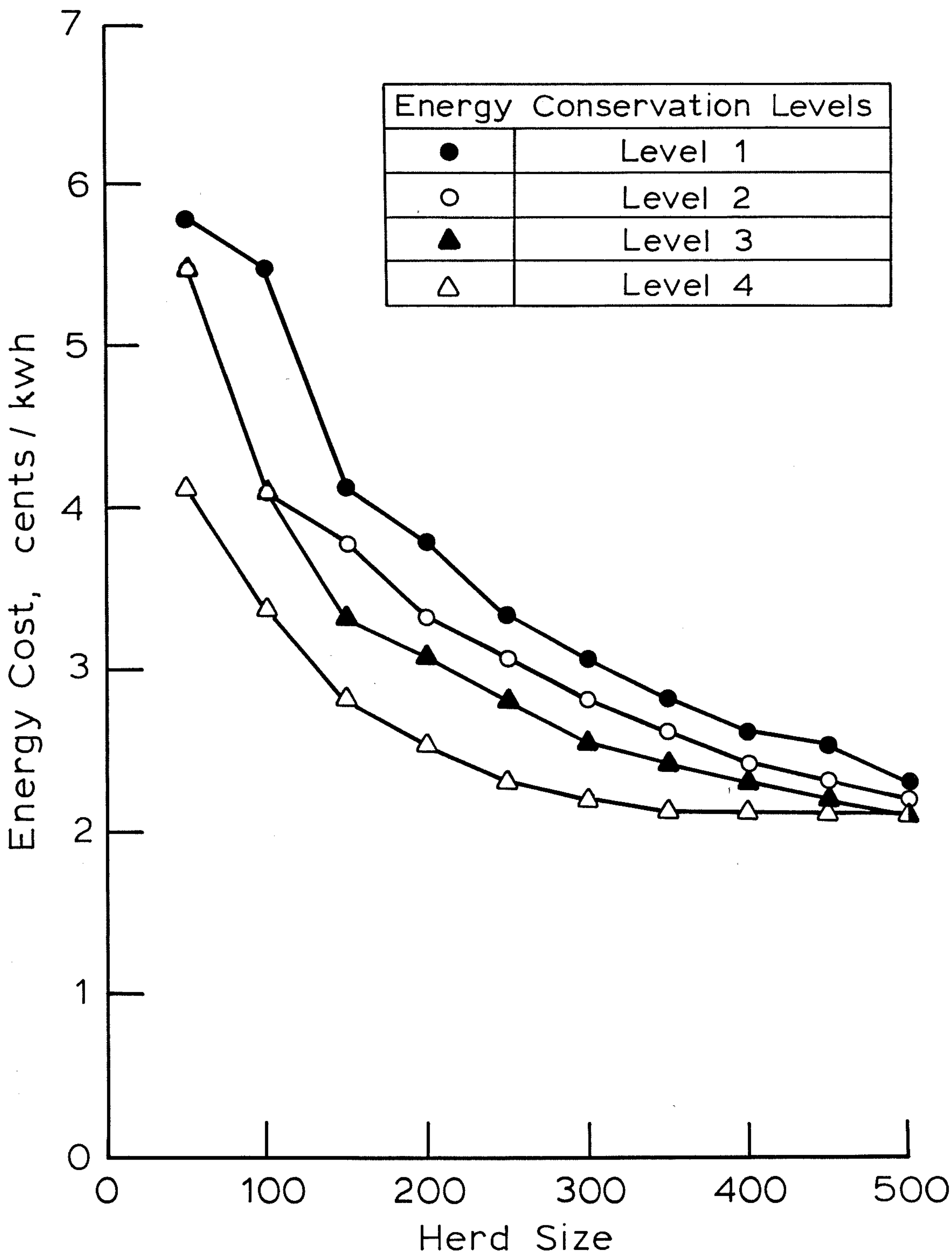

Figure 11f. Wind energy costs vs. lactating herd size for different energy conservation levels at 9.0 m/s mean wind regime.

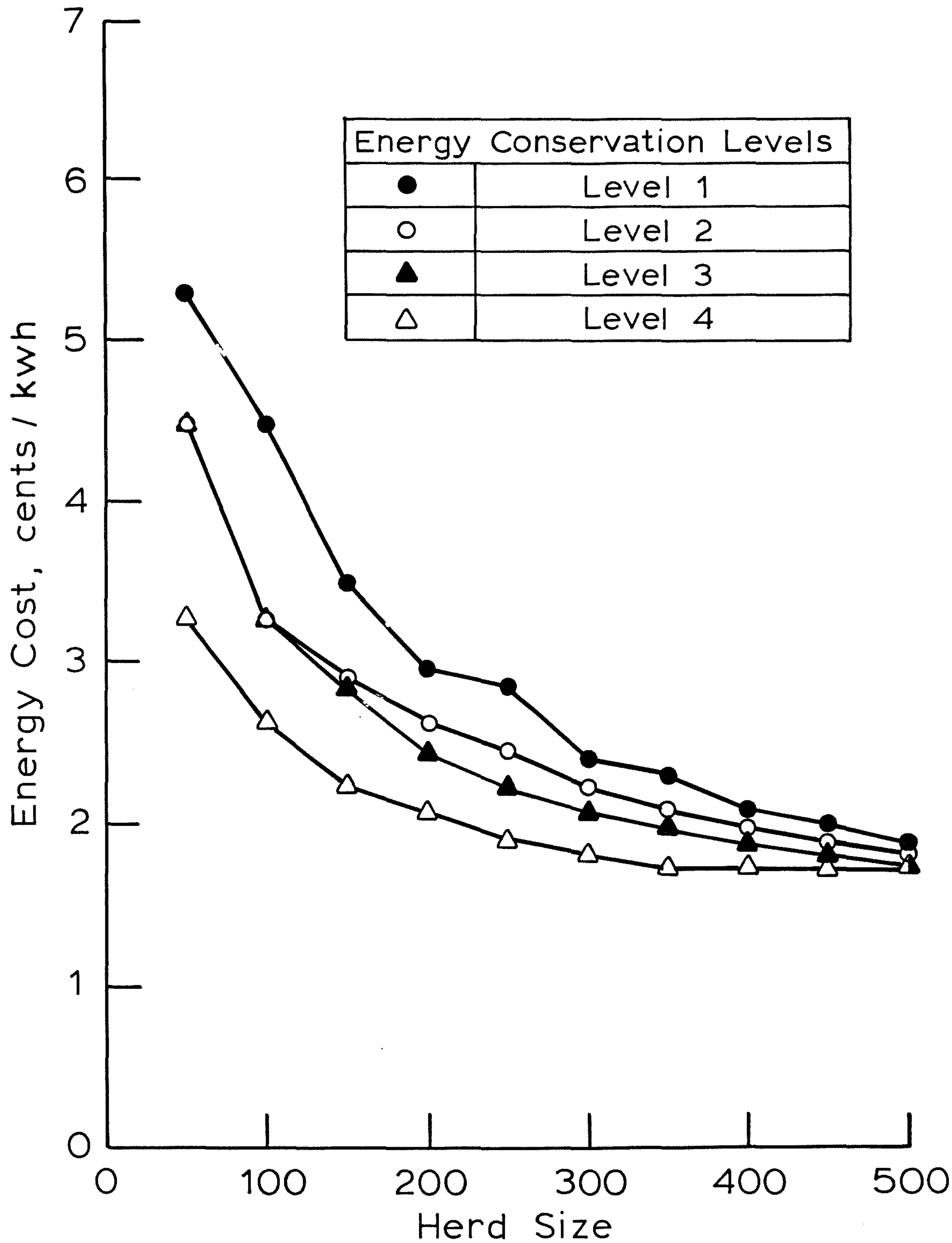

Figure 11g. Wind energy costs vs. lactating herd size for different energy conservation levels at 10.0 m/s mean wind regime.

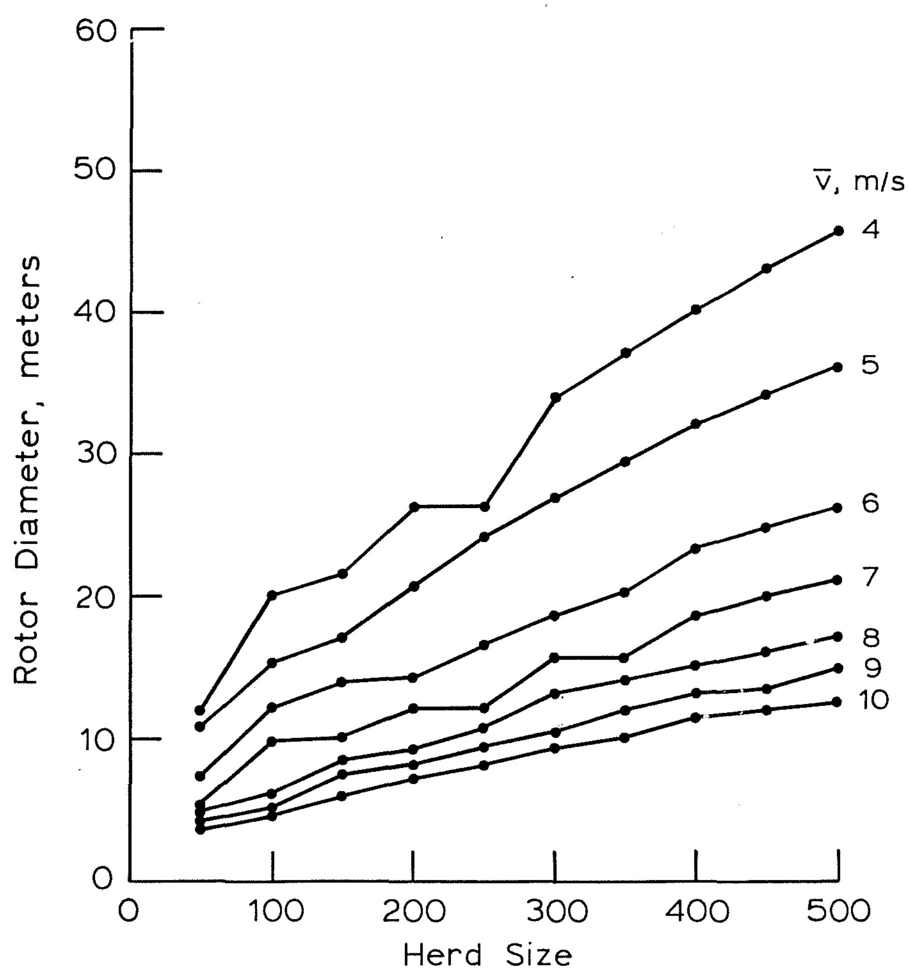

Figure 12. Rotor diameter vs. lactating herd size at different mean wind speeds for Level 1 energy conservation.

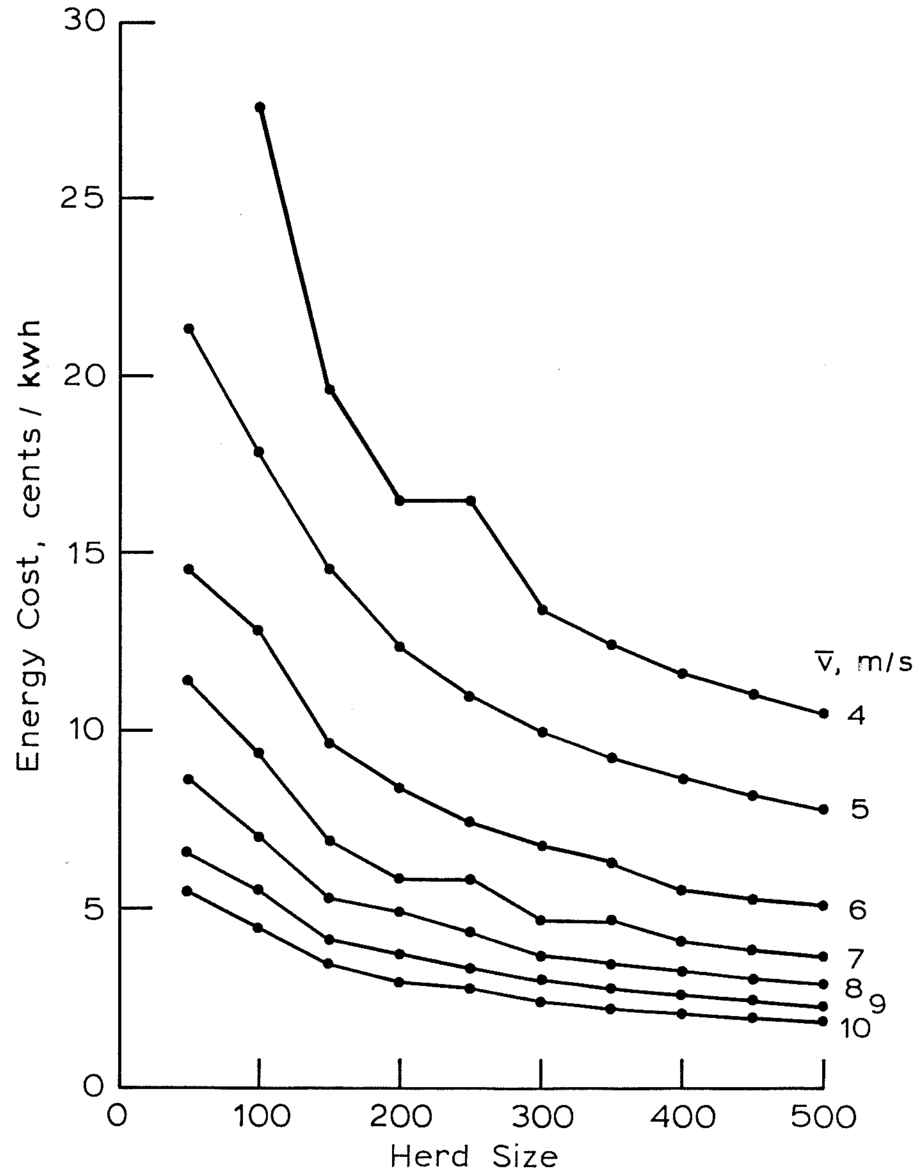

Figure 13. Wind energy costs vs. lactating herd size at different mean wind speeds for Level 1 energy conservation.

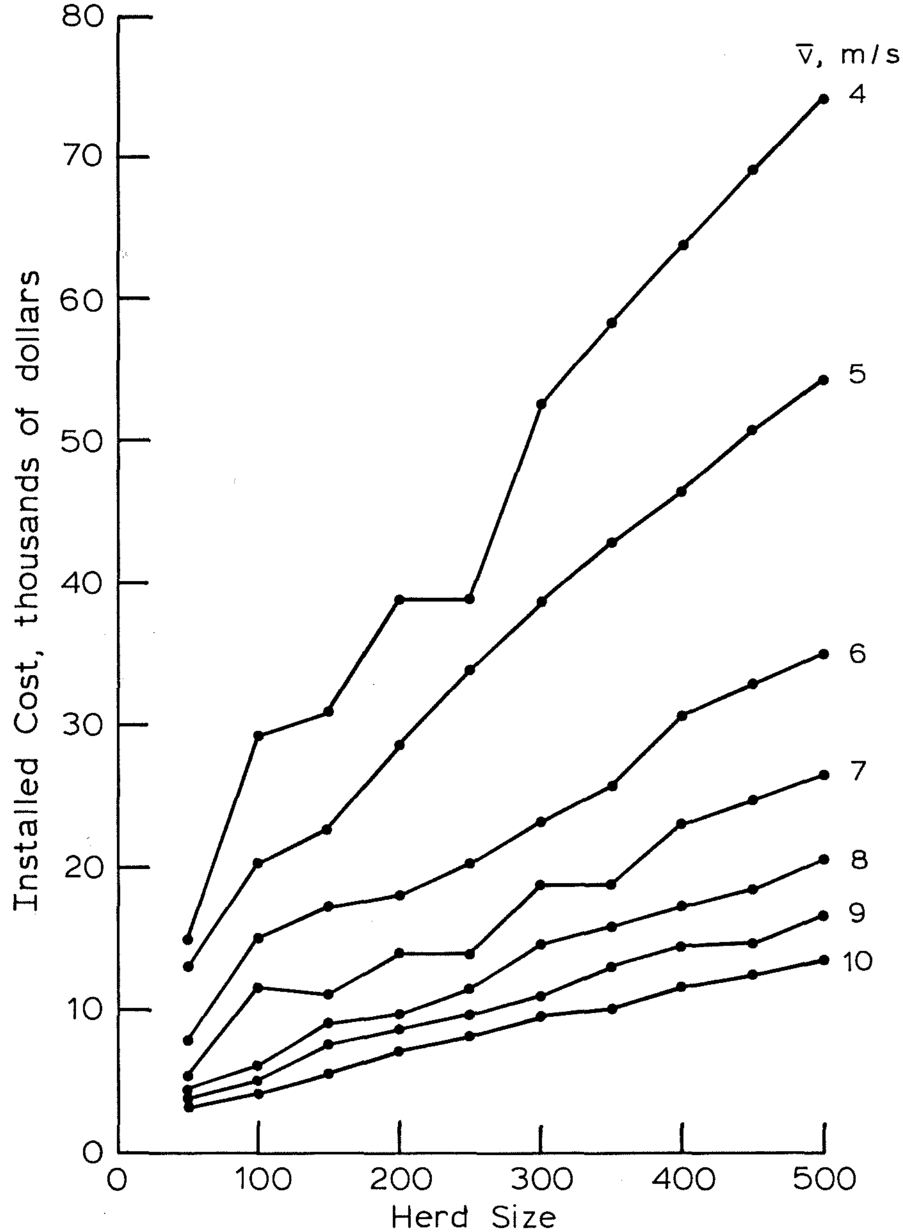

Figure 14. Installed costs vs. lactating herd size at different mean wind speeds for Level 1 energy conservation.

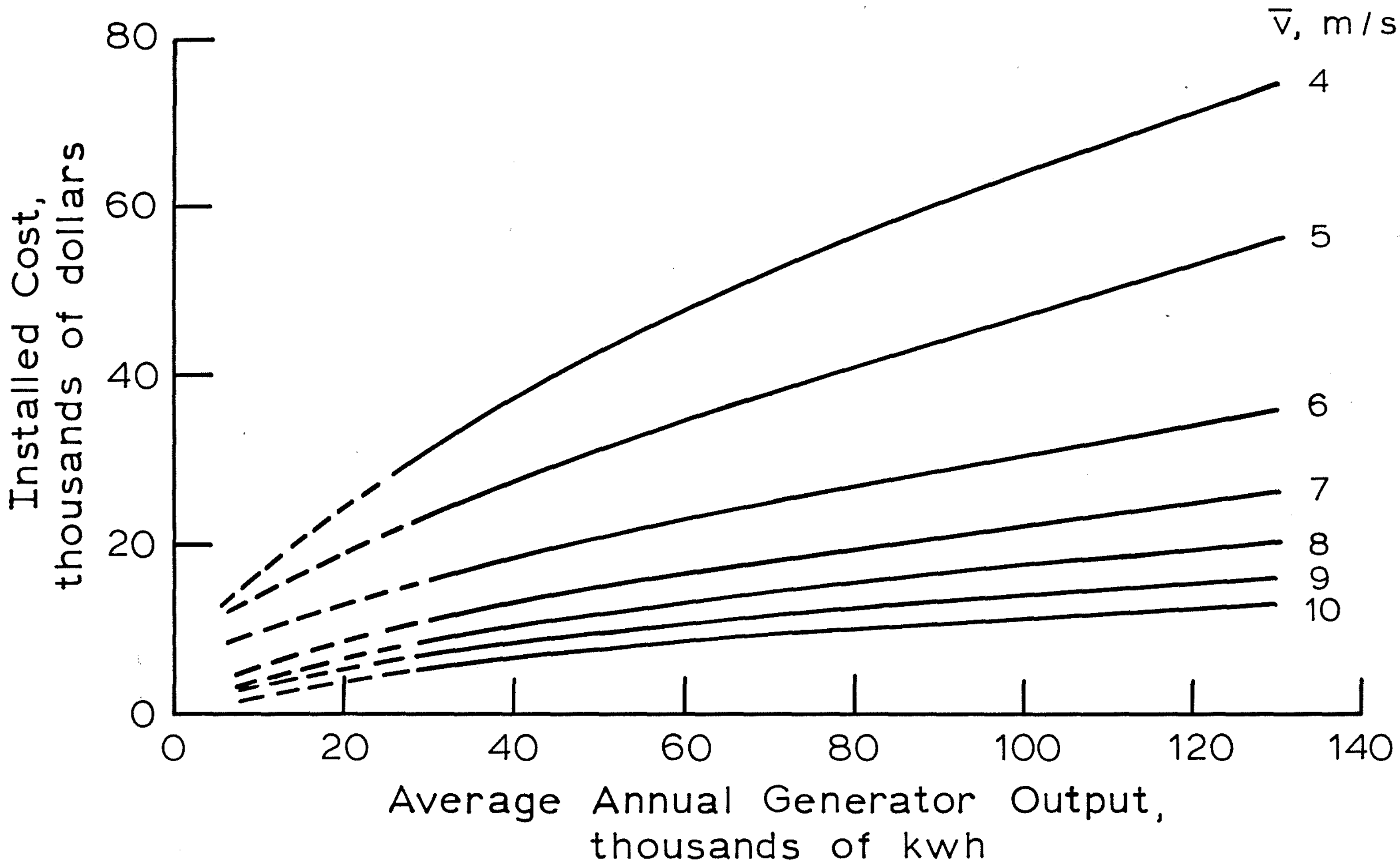

Figure 15. Installed costs vs. generator power output for different mean wind speeds.

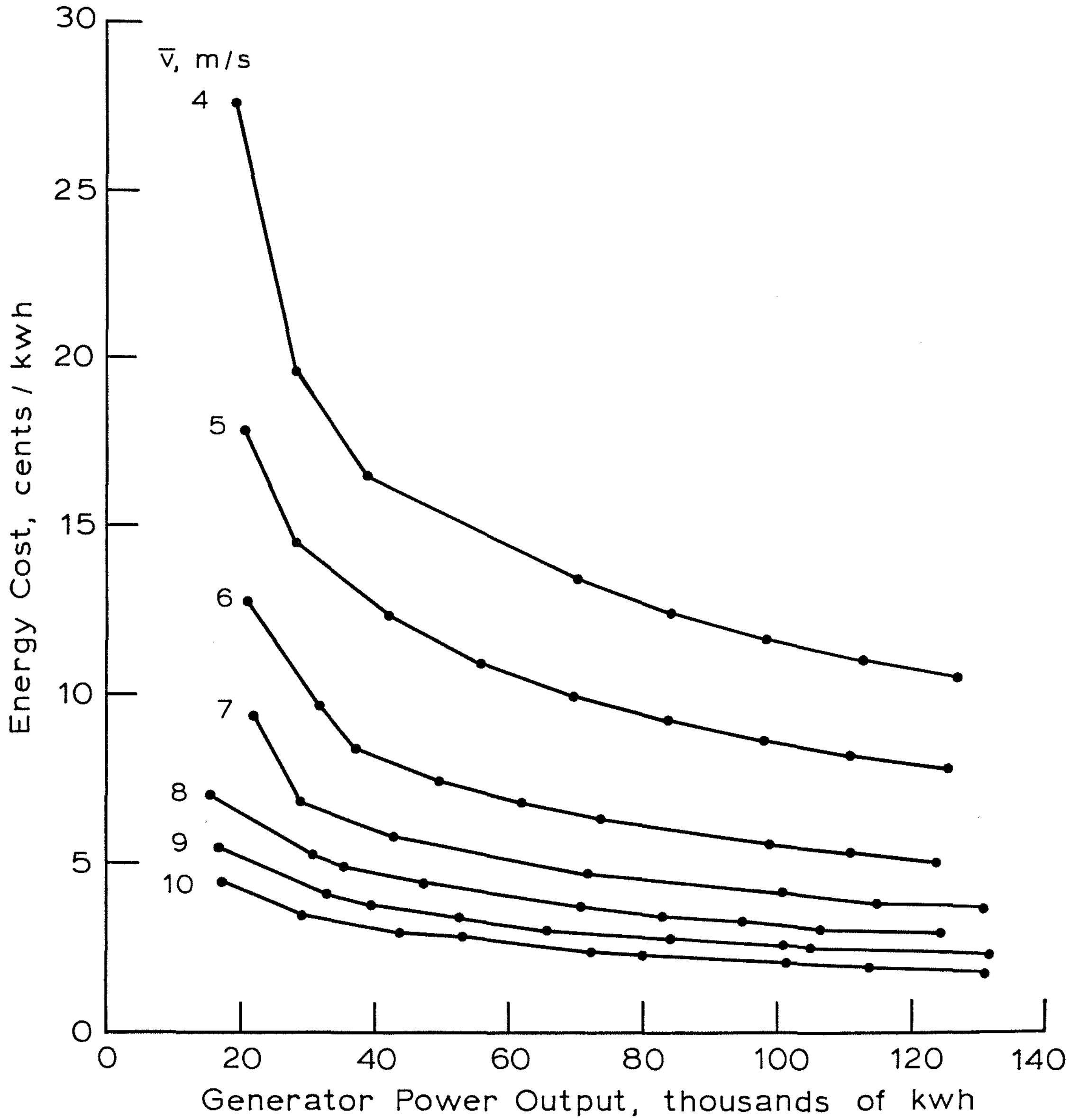

Figure 16. Wind energy costs vs. generator power output for different mean wind speeds.

APPENDIX A

```
      PROGRAM DPOWER
     1(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
C
C     THIS PROGRAM COMPUTES AND SELECTS THE BEST WIND
C     GENERATOR FOR A GIVEN DAIRY HERD SIZE AND WIND
C     SPEED REGIME
C
C     VM=LONG TERM MEAN WIND SPEED AT HUB HEIGHT M/S
C     N =LACTATING DAIRY HERD SIZE
C     EM=MILK COOLING ENERGY DEMAND IN KILOWATT-HOURS/YEAR
C     EW=WATER HEATING ENERGY DEMAND IN KILOWATT-HOURS/YEAR
C     ET=COMBINED MILK COOLING AND WATER HEATING
C       ENERGY DEMAND IN KILOWATT-HOURS/YEAR
C     NX=PARLOR FACTOR
C     BEW=MINIMUM WATER HEATING ENERGY DEMAND IN KILOWATT-HOURS/YEAR
C     BEM=MINIMUM MILK COOLING ENERGY DEMAND IN KILOWATT-HOURS/YEAR
C     BET=MINIMUM COMBINED ENERGY DEMAND IN KILOWATT-HOURS/YEAR
C     NNX=PARLOR FACTOR RESULTING IN MINIMUM ENERGY
C       DEMAND
C     VR=RATED SPEED IN METERS PER SECOND
C     PR=RATED POWER IN KILOWATTS
C     VI=CUTIN SPEED IN METERS PER SECOND
C     VO=CUTOUT SPEED IN METERS PER SECOND
C     GP=ANNUAL POWER OUTPUT OF GENERATOR IN KILOWATT-HOURS
C     CO=INSTALLED COST OF WIND GENERATOR IN DOLLARS
C     PC=POWER COST IN CENTS PER KILOWATT-HOUR
C     BVO=CUTOUT SPEED OF SELECTED WIND GENERATOR IN METERS/SECOND
C     BVI=CUTIN SPEED OF SELECTED WIND GENERATOR IN METERS/SECOND
C     BVR=RATED SPEED OF SELECTED WIND GENERATOR IN METERS/SECOND
C     BGP=POWER OUTPUT OF SELECTED WIND GENERATOR IN KWH/YEAR
C     BPC=ENERGY COST OF SELECTED WIND GENERATOR IN CENTS/KWH
C     BCO=INSTALLED COST OF SELECTED WIND GENERATOR IN 1979 DOLLARS
C     D=WIND GENERATOR ROTOR DIAMETER IN METERS
C     C=COEFFICIENT FOR WIND GENERATOR EFFICIENCY,
C     AIR DENSITY AND DIMENSIONAL CONSTANT
C     AEM=UPPER BOUND FOR  MATCHING WIND
C       GENERATOR OUTPUT IN KILOWATT-HOURS
C     XE=WIND GENERATOR POWER OUTPUT ABOVE LOAD
C      DEMAND IN KILOWATT-HOURS/YEAR
C
      INTEGER                NX(5)
      REAL                   EM(5)        , EW(5)        , ET(5)        ,
     1        PR(100)      , VR(100)      , VI(100)      , VO(100)      ,
     2        GP(100)      , PV(100)      , FPR(50)      , FVR(50)      ,
     3        FVI(50)      , FVO(50)      , FGP(50)      , FCO(50)      ,
     4        FPC(50)
      PI = ATAN(1.0) * 4.0
      C = 0.0001268
C
C     INITIALIZE MEAN WIND SPEED  AND INCREMENT IT
C     IN EACH ROUND
C
      DO 220 KK = 1,7
         VM = 4.0 + (KK - 1.0)
         WRITE (6,230) VM
         WRITE (6,240)
C
C     INITIALIZE HERD SIZE AND INCREMENT IT
C     IN EACH ROUND
C
```

```
         DO 210 M = 1,10
            N = 50 + 50 * (M - 1)
C
C     COMPUTE DAIRY MILK COOLING AND WATER HEATING
C     ENERGY DEMAND FOR ALL POSSIBLE PARLOR SIZES
C
            CALL DENERGY (N,EM,EW,ET,NX)
            BEM = 0.0
            BEW = 0.0
            BET = 0.0
            NNX = 0
            KD = 0
            DO 100 IJ = 1,5
               KD = KD + 1
               IF (EM(IJ).EQ.0.0) GO TO 100
C
C     SELECT THE MINIMUM ENERGY DEMAND
C
               BEM = EM(IJ)
               BEW = EW(IJ)
               BET = ET(IJ)
               NNX = NX(IJ)
               IF (EM(IJ).NE.0.0) GO TO 110
  100       CONTINUE
  110       KN = KD + 1
            DO 130 JJ = KN,5
               IF (EM(JJ).LT.BEM) GO TO 120
               GO TO 130
  120          BEM = EM(JJ)
               BEW = EW(JJ)
               BET = ET(JJ)
               NNX = NX(JJ)
  130       CONTINUE
            AEM = 1.5 * BEM
C
C     COMPUTE THE POWER OUTPUT FOR ALL DISCRETE
C     SIZES OF WIND GENERATORS
C
            CALL WINDPWR (VM,PR,VR,VI,VO,GP,IW)
            J = 0
            DO 160 NN = 1,IW
C
C     SELECT ALL MATCHING WIND GENERATORS
C
               IF (GP(NN).GT.BEM.AND.GP(NN).LE.AEM) GO TO 140
               GO TO 150
  140          J = J + 1
               FPR(J) = PR(NN)
               FVR(J) = VR(NN)
               FVI(J) = VI(NN)
               FVO(J) = VO(NN)
               FGP(J) = GP(NN)
  150          CONTINUE
  160       CONTINUE
            IF (J.EQ.0) GO TO 200
C
C     COMPUTE THE INSTALLED COST AND ENERGY COST
C     FOR THE MATCHING WIND GENERATORS
C
            CALL ECON (FPR,FVR,FGP,J,FCO,FPC)
```

```
C
C     SELECT THE LEAST ENERGY COST WIND GENERATOR
C     THAT MATCHES THE LOAD DEMAND
C
            BPR = FPR(1)
            BPC = FPC(1)
            BVR = FVR(1)
            BVI = FVI(1)
            BVO = FVO(1)
            BGP = FGP(1)
            BCO = FCO(1)
            IF (J.EQ.1) GO TO 190
            DO 180 K = 2,J
               IF (FPC(K).LT.BPC) GO TO 170
               GO TO 180
  170          BPC = FPC(K)
               BPR = FPR(K)
               BVR = FVR(K)
               BVI = FVI(K)
               BGP = FGP(K)
               BCO = FCO(K)
               BVO = FVO(K)
  180       CONTINUE
C
C     COMPUTE THE ROTOR DIAMETER FOR THE SELECTED
C     WIND GENERATOR
C
  190       D = SQRT((4.0 * BPR)/(PI * C * (BVR *  * 3)))
C
C     COMPUTE ENERGY PRODUCED BY WIND GENERATOR
C     ABOVE THE LOAD DEMAND
C
            XE = BGP - BEM
C
C     PRINT THE PARAMETERS FOR SELECTED WIND
C     GENERATOR AND RESULTS FROM THE ECONOMIC ANALYSIS
C
            WRITE (6,250) N,NNX,BEM,BPR,BVI,BVO,BVR,D,BGP,BCO,BPC,XE
            GO TO 210
  200       WRITE (6,260) N
  210    CONTINUE
  220 CONTINUE
      STOP
C
  230    FORMAT (  1H1,5X, 29HOPTIMAL DAIRY WIND GENERATORS,  4H FOR,F6.
    1    2, 16H M/S WIND REGIME)
  240    FORMAT (  1H0,3X,  4HHERD,5X,  6HPARLOR,4X,  5HMILK ,  7HCOOLIN
    1G,    5X,  5HRATED,4X,  5HCUTIN,3X,  6HCUTOUT,3X,  5HRATED,4X,  5HR
    2OTOR,   7X,  6HENERGY,4X,  5HINSTA,  4HLLED,4X,  6HENERGY,4X,  7HS
    3URPLUS,   /4X,  4HSIZE,6X,  4HSIZE,5X, 13HENERGY DEMAND,4X,  5HPOW
    4ER,   4X,  5HSPEED,3X,  5HSPEED,4X,  5HSPEED,3X,  8HDIAMETER,5X,
    5    6HOUTPUT,7X,  4HCOST,7X,  4HCOST,5X,  6HENERGY,/5X,  3HNO.,19X,
    6      4HKWHS,10X,  3HKWS,6X,  3HM/S,5X,  3HM/S,6X,  3HM/S,7X,  1HM,
    7    10X,  4HKWHS,9X,  1H$,9X,  5HC/KWH,5X,  4HKWHS)
  250       FORMAT (  1H0,2X,I4,4X,  7HDOUBLE-,I2,5X,F10.2,4X,F6.2,4X,F5
    1       .2,3X,F6.2,2X,F6.2,4X,F6.2,4X,F10.2,2X,F10.2,4X,F5.2,3X,F10.
    2       2)
  260       FORMAT (  1H0,3X, 26HNO FEASIBLE WIND GENERATOR, 15H FOR HER
    1D SIZE=,      I4)
            END
```

DENERGY 73/73 OPT=1 FTN 4.6+452 80/02/14.

```
      SUBROUTINE DENERGY (N,EM,EW,ET,NX)
C
C     THIS SUBROUTINE COMPUTES THE ENERGY DEMAND FOR
C     MILK COOLING AND WATER HEATING FOR DIFFERENT
C     DAIRY HERD AND PARLOR SIZES IN KILOWATT-
C     HOURS PER YEAR
C
C     N=HERD SIZE OF LACTATING COWS
C     NX=PARLOR FACTOR
C     EM=MILK ENERGY DEMAND=TOTAL ENERGY DEMAND WITH
C      APPROPRIATE CONSERVATION MEASURES IN KILOWATT-HOURS/YEAR
C     EW=WATER HEATING DEMAND IN KILOWATT-HOURS/YEAR
C     ET=SUM OF MILK COOLING AND WATER HEATING
C      ENERGY DEMAND IN KILOWATT-HOURS/YEAR
C
      INTEGER             NX(5)
      REAL                EM(5)       , EW(5)       , ET(5)
      DO 100 J = 1,5
         NX(J) = 4 + 2 * (J - 1)
         X = FLOAT(NX(J))
         EM(J) = 0.0
         EW(J) = 0.0
         ET(J) = 0.0
C
C     SELECT APPROPRIATE PARLOR SIZE
C
         EN = FLOAT(N)
         Y =  - 16.0836 + 44.4882 * ALOG(X)
         Q = EN/Y
         IF (Q.GT.6.0) GO TO 100
C
C     COMPUTE THE MILK COOLING ENERGY DEMAND
C
         EM(J) = EN * (239.276 - 155.9104 * (X *  * ( - 0.4033)))
C
C     COMPUTE THE WATER HEATING ENERGY DEMAND
C
         EW(J) = 1211.6278 * (EN *  * (0.5852)) - (155.9104 * EN * (X *
     1    * ( - 0.4033)))
C
C     COMPUTE THE TOTAL ENERGY DEMAND FOR MILK
C     COOLING AND WATER HEATING
C
         ET(J) = EM(J) + EW(J)
  100 CONTINUE
      RETURN
      END
```

```
 GENDATA     73/73    OPT=1                               FTN 4.6+452         80/02/14.

      SUBROUTINE GENDATA (VM,VR,VI,VO,MG)
C
C     THIS SUBROUTINE COMPUTES THE CUTIN AND CUTOUT
C     SPEEDS FOR A WIND GENERATOR FROM A GIVEN MEAN
C     WIND SPEED FOR MINIMUM DOWNTIME
C
C     VO =CUTOUT SPEED IN METERS/SECOND
C     VI =CUTIN SPEED IN METERS/SECOND
C     VM =LONG TERM MEAN WIND SPEED IN METERS/SECOND
C     VR =RATED WIND SPEED OF THE WIND GENERATOR IN METERS/SECOND
C
      REAL                VO(10)      , VR(10)      , VI(10)
      PI = ATAN(1.0) * 4.0
      AVM = 2.0 * VM
      MG = 0
      DO 120 J = 1,10
C
C     COMPUTE THE RATED SPEED
C
         VR(J) = VM + J - 1
         IF (VR(J).GT.AVM) RETURN
         MG = MG + 1
C
C     COMPUTE THE CUTIN SPEED
C
         VI(J) = 0.4642 * VR(J)
         NV = INT(VM)
         LV = 5 * NV
         XI = VI(J)
C
C     COMPUTE THE CUTOUT SPEED
C
         DO 110 I = NV,100
            XO = I
            EST = SQRT(PI * ((XO *  * 2) - (XI *  * 2))/(4 * ((ALOG(XO *
     1        * 2)) - (ALOG(XI *  * 2)))))
            ER = EST - VM
            IF ((ABS(ER).LE.0.21).AND.(XO.GT.VR(J))) GO TO 100
            GO TO 110
  100       VO(J) = XO
  110    CONTINUE
  120 CONTINUE
      RETURN
      END
```

```
 WINSPRD     73/73    OPT=1                              FTN 4.6+452         80/02/14.

      SUBROUTINE WINSPRD (VM,PV)
C
C     THIS ROUTINE DEVELOPS THE WIND SPEED DISTRIBUTION
C     USING THE RALEIGH DISTRIBUTION, GIVEN THE MEAN
C     LONG TERM AVERAGE WIND SPEED FOR THE LOCATION
C
C     VM =LONG TERM MEAN WIND SPEED FOR THE LOCATION IN METERS/SECOND
C     V  =REFERENCE WIND SPEED IN METERS PER SECOND
C     PV =FREQUENCY DISTRIBUTION OF A GIVEN WIND SPEED
C     VDC=VELOCITY DISTRIBUTION IN HOURS FOR WIND SPEED V
C
      REAL                  PV(100)      , VDC(100)
      PI = ATAN(1.0) * 4.0
      V = 0.0
      DO 100 I = 1,100
         V = V + 1.0
C
C     COMPUTE THE WIND SPEED FREQUENCY DISTRIBUTION
C
         PV(I) = ((V * PI)/(2 * (VM *  * 2))) * EXP( - ((V *  * 2) * PI)
     1   /(4 * (VM *  * 2)))
C
C     COMPUTE THE CUMULATIVE DISTRIBUTION CURVE
C
         VDC(I) = 8760 * EXP( - ((V *  * 2) * PI)/(4 * (VM *  * 2)))
         IF (PV(I).LT.0.001) RETURN
  100 CONTINUE
      RETURN
      END
```

```
 WINDPWR    73/73   OPT=1                          FTN 4.6+452        80/02/14.

      SUBROUTINE WINDPWR (VM,PR,VR,VI,VO,GP,J)
C
C     THIS SUBROUTINE COMPUTES THE AVERAGE ANNUAL
C     POWER OUTPUT FOR GIVEN DISCRETE SIZES OF WIND
C     GENERATORS FROM THE LONG TERM MEAN WIND SPEED
C     USING RALEIGH DISTRIBUTION
C
C     PR =RATED POWER OF WIND GENERATOR IN KILOWATTS
C     VM= LONG TERM MEAN WIND SPEED AT THE HUB HEIGHT, METERS/SECOND
C     VR =RATED SPEED OF WIND GENERATOR IN METERS/SECOND
C     VI =CUTIN SPEED OF WIND GENERATOR IN METERS/SECOND
C     VO =CUTOUT SPEED OF WIND GENERATOR IN METERS/SECOND
C     PV =FREQUENCY DISTRIBUTION OF WIND SPEED USING
C       RALEIGH DISTRIBUTION
C     GP =AVERAGE ANNUAL POWER OUTPUT OF WIND GENERATOR
C       IN KILOWATT-HOURS
C     PT=WIND GENERATOR POWER OUTPUT IN KILOWATTS
C
      REAL                  PV(100)      , VR(100)      , VI(100)      ,
     1        VO(100)     , GP(100)      , PR(100)      , AVR(10)      ,
     2        AVI(10)     , AVO(10)      , APR(10)
      J = 0
      DO 130 I = 1,10
         E = FLOAT(I)
         APR(I) = 5.0  + 5.0  * (E  - 1.0)
C
C     COMPUTE ALL POSSIBLE WIND GENERATOR PARAMETERS
C
         CALL GENDATA (VM,AVR,AVI,AVO,MG)
C
C     COMPUTE WIND SPEED FREQUENCY DISTRIBUTION
C
         CALL WINSPRD (VM,PV)
         DO 120 IM = 1,MG
            J = J + 1
            PR(J) = APR(I)
            VR(J) = AVR(IM)
            VI(J) = AVI(IM)
            VO(J) = AVO(IM)
C
C     COMPUTE AVERAGE HOURLY POWER OUTPUT OF WIND
C     GENERATOR
C
            PT = 0.0
            DO 100 N = 1,100
               IF (PV(N).EQ.0.00) GO TO 110
               V = FLOAT(N)
               IF (V.GT.VO(J)) GO TO 110
               PWR = PR(J) * ((V/VR(J)) *  * 3)
               IF ((V.LT.VI(J)).OR.(V.GT.VO(J))) PWR = 0.0
               IF ((V.GE.VR(J)).AND.(V.LE.VO(J))) PWR = PR(J)
               AP = PWR * PV(N)
               PT = PT + AP
  100       CONTINUE
C
C     COMPUTE AVERAGE ANNUAL WIND GENERATOR
C     POWER OUTPUT
C
  110       GP(J) = 8760.0 * PT
  120    CONTINUE
  130 CONTINUE
      RETURN
      END
```

```
 ECON       73/73   OPT=1                          FTN 4.6+452       80/02/14.

      SUBROUTINE ECON (FPR,FVR,FGP,J,FCO,FPC)
C
C     THIS SUBROUTINE COMPUTES THE INSTALLED COST
C     AND ENERGY COST OF WIND GENERATOR SYSTEMS
C     BASED ON 1979 DOLLARS
C
C     FPR=RATED POWER OF WIND GENERATOR IN KILOWATTS
C     FVR=RATED SPEED OF WIND GENERATOR IN METERS/SECOND
C
C     FGP=AVERAGE ANNUAL POWER OUTPUT OF WIND GENERATOR
C     IN KILOWATT-HOURS
C     FCO=INSTALLED COST OF WIND GENERATOR IN 1979 DOLLARS
C     FPC=ENERGY COST IN CENTS/KILOWATT-HOUR
C
      REAL                FVR(50)      , FCO(50)      , FPC(50)      ,
     1        FGP(50)      , FPR(50)
      DO 100 I = 1,J
C
C     COMPUTE THE INSTALLED COST OF THE WIND
C     GENERATOR
C
         FCO(I) = ((11.18/FVR(I)) *  * 2) * (EXP((7.7391 - 0.46578 * (AL
     1   OG(FPR(I))) + 0.02573 * (ALOG((FPR(I)) *  * 2))))) * FPR(I)
C
C     COMPUTE THE ENERGY COST
C
         FPC(I) = (18.04282 * FCO(I))/FGP(I)
  100 CONTINUE
      RETURN
      END
```

APPENDIX B

Numerical Procedure for Selection of a Dairy Farm Wind Generator

Given:

(1) Lactating dairy herd size = 200 cows

(2) Mean annual wind speed at hub height = 6.0 m/s (13.4 mph)

(3) National average milk production per cow holds

A. Selection of a dairy farm wind generator for a system incorporating a tube milk precooler and a water heating condensing unit (Level 1 energy conservation system).

a. Solution using tables:

For 6.0 m/s, Level 1 energy conservation, Table 5c is applicable. For a herd size of 200 cows enter at row No. 4.

Results:

Recommended parlor size - herringbone double-4

Annual energy demand - 30027.54 Kwh

Recommended wind generator parameters:

Rated power - 15 Kw

Cut-in speed - 4.18 m/s

Cut-out speed - 10.00 m/s

Rated speed - 9.00 m/s

Rotor diameter - 14.37 m

Energy output - 37238.19 Kwh/yr

Installed cost - $17,308.53 (1979 dollars)

Energy cost - 8.39 ¢/Kwh

Surplus energy - 7210.64 Kwh/yr

b. Solution using graphs:

Using Figure 9, energy demand = 30,030 Kwh/yr

From Figure 12, rotor diameter = 14.4 m

From Figure 13, energy cost = 8.4 ¢/Kwh

From Figure 14, installed cost = $17,400.00

B. Selection of a dairy farm wind generator for incomplete energy conservation systems

For Level 2 energy conservation, Tables 6a through 6g are appropriate and for the numerical example Table 6c is applicable. Similarly, for Levels 3 and 4 energy conservation, Tables 7c and 8c will be applicable.