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AN INTERACTIVE COMPUTER SIMULATION OF DAIRY FARM SYSTEMS
AS A METHOD FOR MAKING ENERGY MANAGEMENT DECISIONS

presented by

Ernest James Hewett III

has been accepted towards fulfillment
of the requirements for

DOCTOR OF PHILOSOPHY degree in Agricultural Engineering Technology

[signature]
Major professor

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AN INTERACTIVE COMPUTER SIMULATION OF DAIRY FARM SYSTEMS AS A METHOD FOR MAKING ENERGY MANAGEMENT DECISIONS

BY

Ernest James Hewett III

A DISSERTATION

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ABSTRACT

AN INTERACTIVE COMPUTER SIMULATION OF DAIRY FARM SYSTEMS AS A METHOD FOR MAKING ENERGY MANAGEMENT DECISIONS

BY

Ernest James Hewett III

High energy costs prompted the energy intensive dairy industry to determine alternative methods to reduce fossil fuel consumption. To facilitate management decisions an analytical model was developed which predicted energy and labor requirements and costs for milking and feed handling systems. The Dairy Farm Simulation Model was based on detailed time and motion studies, and energy audits of 21 dairy farms in Michigan. Printed output includes labor hours and energy consumption per month for each operation required for milking and feed handling. The printout also includes a list of energy charges based on Detroit Edison electrical rate schedules. The milking system simulator modeled a low-line milking system with a single milk receiving jar. The feeding system simulator modeled stationary and mobile feed handling options and allowed the user to select three feed types which could be delivered by electrically and/or diesel powered equipment. Results include a table of average yearly energy consumption for Michigan dairy farm operations on a per cow basis. The result of optimizing the electrical rate charges for simulated milking systems is indicated by the Time-of-Day Rate Schedule which provides the lowest cost to farm operators willing to adjust milking times. Simulation of

mobile and stationary feeding systems for six herd sizes includes calculations of capital investment and operating costs in addition to labor and energy costs. The results further indicate that mobile systems required a lower investment cost while stationary systems realize lower energy costs. Labor requirements per cow decreased as herd size increased for mobile systems, but remained the same for stationary systems regardless of herd size. The energy required to operate each system, based on the number of oil barrel equivalents, indicates the stationary system required less energy for herd sizes up to and including 150 cows, while mobile systems indicate a lower energy requirement for herd sizes greater than 150 cows. In general, no single system emerged as the best, rather it depended on the operator's personal preference. However, it is reasonable to conclude that a national energy policy designed to lessen dependence on imported oil would most likely favor electrically powered systems.

Approved ______________________
Major Professor

Approved ______________________
Major Professor

Approved ______________________
Department Chairman

Dedicated with love to
Ernest James Hewett Esquire,
Linda Gail Hewett and Carol Ann Martin.

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The author wishes to express his gratitude to Drs. Thomas H. Burkhardt and Truman C. Surbrook for their guidance, encouragement, and assistance over the past years, and for serving as major professors.

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Ernest James Hewett III
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LIST OF ABBREVIATIONS

Abbreviation	Description
A	Area
AMB	Ambient air temperature
a.m., A.M.	After midnight and before noon
A.S.A.E.	American Society of Agricultural Engineers
avg., Av	Average
bbl.	Barrel(s)
BTU, Btu	British Thermal Unit(s)
bu	Bushel(s)
C	Celsius, Centigrade (metric temperature)
cal	Small calorie
C_x	Coefficient of heat transfer
cd	Candela (metric light intensity)
cfm	Cubic feet per minute
cu.	Cubic
cwt.	Hundredweight, 100 pounds
D	Diameter
DC	Distric of Columbia
DM	Dry matter
Dr.	Doctor
E	Electric motor efficiency

ABBREVIATIONS (continued). . . . .

Abbreviation	Description
et al.	And others
etc.	And so forth
EXP	Exponential
F	Fahrenheit
F.C.	Fixed Cost(s)
FL	Florida
ft	Foot or feet
ft^2	Square feet
ft^3	Cubic feet
GA	Georgia
gal.	Gallon(s)
gm	Gram (metric mass)
GW	Gigawatts (electrical power)
hp, Hp	Horsepower
hpD	Horsepower (advertized diesel tractor)
hpX	Horsepower (percent load)
hr	Hour
I	Amperage (electrical current)
IA	Iowa
i.e.	That is
IL	Illinois
IN	Indiana

ABBREVIATIONS (continued). . . . .

Abbreviation	Description
J	Joule (metric energy)
k	Thermal conductivity
kJ	Kilojoule (metric energy)
kg	Kilogram (metric mass)
kW	Kilowatt (electrical power)
kWh	Kilowatt•hour (electrical energy)
L, l	Liter
lm	Lumens (lighting)
L.P.	Linear programing
LPG	Liquified petroleum gas
lb.	Pound(s)
lb_m	Pound(s) mass
m	Meter (metric)
m^2	Square meter (metric)
m^3	Cubic meter (metric)
m.	Month
Mcal	Thousand small calories
Mfr.	Manufacture, -r
MI	Michigan
min.	Minute(s)
MN	Minnesota

ABBREVIATIONS (continued). . . . .

Abbreviation	Description
MO	Missouri
NA	Not available
NE	Nebraska
NY	New York
OH	Ohio
p	Page
PA	Pennsylvania
Pa	Pascals (metric pressure)
p.m., P.M.	Afternoon
pp	Pages
psi	Pounds per square inch
PTO	Power take-off
Quad	Quadrillion British Thermal Units
R	Resistance (electricity)
sr	Steradian (lighted surface area)
Std. Dev.	Standard Deviation
t	Ton (metric)
tn	United States short ton
T, t.	Temperature or time
TN	Tennessee
Univ.	University

ABBREVIATIONS (continued). . . . .

Abbreviation	Description
U.S.	United States
V	Volume
v., V	Volt (electricity)
w	With
w., W.	Watt (electrical power)
WI	Wisconsin
w/o	Without
wt.	Weight
yr., y.	Year(s)

LIST OF SYMBOLS

Symbol	Description
&	and
*	asteric, multiply by
@	at
{ }	braces
[ ]	brackets
✓	check
°	degree
→	direction of flow
÷	divided by
$	dollar(s)
=	equal to
>	greater than
<	less than
-	minus
x	multiply by
•	multiply by
#	number
( )	parentheses
/	per

SYMBOLS (continued). . . . .

Symbol	Description
+	plus
±	plus or minus
ϕ	power phase (electricity)
$\sqrt{}$	square root

INTRODUCTION

The relationship between agricultural production and energy consumption has received much attention in recent years. In a time of rising world population, serious inflation and dwindling nonrenewable energy resources, the agricultural industry is facing an uncertain future. At the present time, the total food system uses about 16.5 percent of the nation's energy (A.S.A.E., 1982), while on-farm energy use comprises only 3.2 percent of all energy used in the United States. This is an extremely critical percentage as it constitutes 93 percent petroleum (C.A.S.T., 1977). Since the 1973 oil embargo, fossil fuels have risen in cost 400 percent, Figure I.1 (C.S.W.C., 1979), and have become a less dependable source of energy.

In the next five years, there will continue to be a heavy reliance on a declining number of oil suppliers, who in 1979, provided half of the world's energy. A continued dependence on politically unstable imported crude oil will ultimately have an adverse effect on the agricultural industry worldwide (Stobaugh, 1980).

The United States' dependence on foreign oil grew dramatically from 1960 to 1979. Imports rose from 19 percent of the market to 47 percent. By 1990 demand for foreign oil may exceed supplies. Despite intense exploration and the advent of newly developed synthetic fuels, fuel needs by the end of the current decade may not be adequately met (S.E.A.C., 1981). Energy conservation will be the most readily available and economic "source" of additional energy during the first half of the 1980's.

The dairy industry, an energy intensive industry, relies heavily on electricity and fossil fuels. Although feed costs represent the largest part of a dairy producer's budget (accounting for about 40 percent of the total annual outlay), the energy requirement and cost for dairy animals is higher per animal than for any other livestock production system.

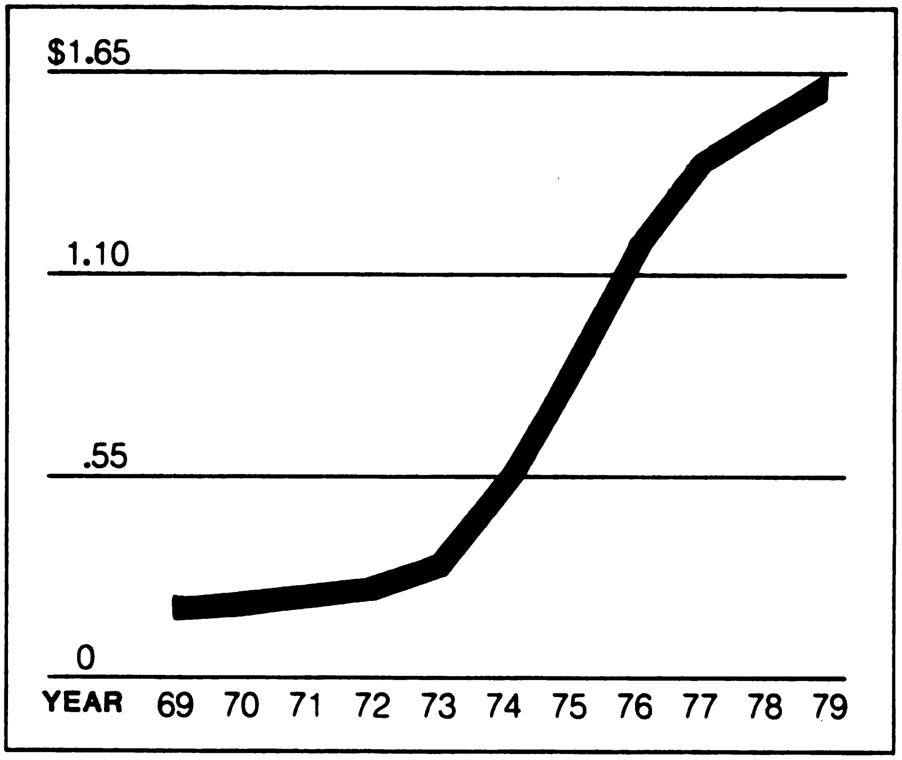
During the past decade milk production per farm worker increased dramatically (N.M.P.F., 1980). This increase was accomplished by a corresponding increase in energy consumption per worker. Nationally, the dairy industry consumed 32×10^9 kWh, 3.6×10^9 gallons of gasoline, 2.6×10^9 gallons of diesel fuel, and 3.04×10^8 gallons of fuel oil annually (Pimentel, 1975). In comparison, Michigan utilized 8.3×10^7 kWh, 7.8×10^6 gallons of gasoline, 5.1×10^6 gallons of diesel fuel, and 5.5×10^5 gallons of fuel oil (U.S. Census, 1977).

It is possible that feed cost may remain fairly steady, however, production costs, which increased more than 13 percent in 1980 (U.S.D.A., 1980), were forecast to rise dramatically. These costs are fueled by rapidly rising energy prices, interest rates, and direct costs (other than feed) which include transportation, fuel and electricity, hired labor, and interest on operating capital. Fuel prices form a major portion of these direct cost increases and future increases in the prices paid for energy will push this expense even higher. As a result of cost increases, dairymen are now forced to look for alternate methods of reducing their fossil fuel consumption.

To survive, the farm operator will be faced with a need to reorganize or restructure and modernize operations. The extent of reorganization and/or modernization may range from replacement of outdated equipment to construction of completely new facilities. Expansion or construction of a totally new facility will allow for incorporation of many desired features since all options will be available and the only restrictions will be those which are self-imposed. It is important that farm operators consider the impact on labor use, investment cost and returns, and the amount and type of energy used if and when they modernize component parts of their operation. This project was initiated to consider these factors.

FIGURE I.1

Fuel Costs
(per million BTU)



1. RESEARCH OBJECTIVES

Although energy conservation is of utmost concern, increased emphasis should and must be placed on energy management, a concept which encompasses conservation. Dairymen must make several management decisions when considering a particular dairy system. The selection of the type of enterprise technology and size combinations to use can be difficult, particularly when there are ecological, sociological, energy conservation, and cost benefit concerns. The best method of appraising a system is to locate a functioning unit of a similar type and observe it during operation. Time restrictions and limited system availability often make this impossible.

The primary objective of this research was the development of a model which gives dairymen flexibility in designing dairy systems and the ability to analyze affects of a system's milking capacity and production technology on energy consumption. Specific objectives were:

1. To identify components and determine farmstead task options within each particular phase of milking and feed handling of a dairy system.

2. Develop a computer model to simulate, on a minute by minute basis, labor and energy use of a dairy feeding and milking system and tabulate the results on a monthly basis.

3. Validate the model by comparing and adjusting the model's simulated energy use to within ± ten percent of the actual energy use observed on three representative dairy farms in Michigan.

4. Determine the average yearly energy consumption, on a per cow basis, for milking and feed handling systems. Data collected from the Michigan Energy Audit and simulated by the dairy system model for dairy farms in Michigan will be used.

5. Compare energy use, labor, capital investment, and operating cost for two alternative feeding system. Milking herd sizes ranging from 100 to 300 head will be used to determine which is most energy efficient at the least total cost.

6. Evaluate and compare electrical energy cost for different rate schedules and determine strategies for selecting the most appropriate rate schedule for a dairy system.

2. REVIEW OF LITERATURE

This review of literature presents a glimpse of the national energy outlook, as well as the United States' role in world food production. Also presented is a summary of energy audits conducted attempting to quantify various amounts of energy consumed by U.S. Agriculture. In addition, these audits show the historically increasing reliance of U.S. Agriculture on energy. Management trends for dairy farms and previously published optimization studies are examined. Finally, future trends for Michigan dairy farms as a function of technology, herd size, milk production, and energy consumption are presented.

Literature reviewed dates from 1956. Reports were published prior to 1956, however, most of the documented research relevant to this project occurred within the last twenty-five years. Consequently only this material was reviewed. A somewhat surprising and significant finding in the literature of this period was that not much changed in twenty-five years relevant to enterprise options on the dairy farm. (Many authors in the literature review cited references dating as far back as 1942). The literature revealed there had been an increase in herd size, milk production, and energy consumption but required tasks to be performed remained the same.

2.1 Energy

An insight into changes that occurred in energy production in general, and electricity in particular is essential in order to understand the nature and scope of the agricultural energy management problem. Energy use in this country grew from 34 Quads in 1950 to 71 Quads (quadrillion Btu's) in 1975. Total energy figures for 1978 from the United States Bureau of Mines indicated usage at 78 Quads which was higher than the record 74.6 Quads in 1973. The Institute for Energy Analysis gave two estimates for the year 2000: 101 Quads in the "low case" and 126 Quads in the "high case," as opposed to 187 Quads for a continuation of the historical rate of growth.

The total food system used about 16.5 percent of the nation's energy (A.S.A.E.,1982), while on-farm energy use comprised only 3.2 percent of all energy use in the United States. Approximately 45 percent of the total on-farm agricultural energy use was in production processes such as power for machinery and equipment, irrigating, heating livestock facilities, and drying grain. The remaining 55 percent was used in the production of fertilizers, pesticides, herbicides, and fungicide (McKinsey, 1975).

In the mid-1970's, gasoline was the major energy source for agricultural production, accounting for approximately 44 percent of all energy expenditures. Only 22.4 percent of the energy dollar was spent on diesel fuel, 19.6 percent on electricity, and 10.6 percent on propane gas. Gasoline, diesel fuel, electricity, and propane gas combined accounted for 96.7 percent of all energy dollars spent on raw energy sources utilized in agricultural production in the United States (Rogers, 1977).

2.1.1 Electricity Demand

During the 1970's electricity production continued to place a burden on U.S. oil supplies. As evidence, over nine percent of the total U.S. oil usage during this time was for electricity production. This constituted 636 million barrels or the equivalent of over one-fifth of U.S. oil imports (A.R.C., 1979). The primary energy sources used for electricity generation by the utility industry in 1972 and 1978 respectively are shown in Table 2.1. (Electricity generation is expressed in units of gigawatt-years, where one GW-year is the amount of electricity produced by a 1000-megawatt plant operating uninterruptedly for 1 year).

Electricity, which is a secondary energy source of great importance to U.S. agriculture, comprised 22 percent of the total primary energy consumed on farms as secondary energy sources (Torgersen, 1980). This is compared with 29 percent of the total primary energy converted to electricity for the entire economy (Gyflopous, 1980). The future growth rate of electrical production and the means by which that growth is achieved will be determining factors in successfully decreasing U.S. demand for oil and thus restraining higher energy costs.

At this point it is necessary to consider conservation. The success of conservation can best be expressed in terms of the reduction in number of barrels of oil consumed rather than in terms of the total Quads of energy consumed. Thus, successful conservation policies must emphasize a decrease in the use of oil, through substitution of electricity for oil. The choices society will make will depend upon economic factors, the importance placed on the reduction in the use of oil, and the perception of the environmental hazards of nuclear power and coal.

TABLE 2.1 SOURCES OF U.S. ELECTRICITY GENERATION IN 1972 AND 1978 (A.R.C.,1978).

PRIMARY SOURSE	PRODUCTION (GW YEAR)		FRACTION (%)	
	1972	1978	1972	1978
Coal	88.0	111.0	44.0	44.0
Petroleum	31.0	42.0	16.0	17.0
Gas	43.0	35.0	21.0	14.0
Hydroelectric	31.0	32.0	16.0	13.0
Nuclear	6.0	32.0	3.0	12.0
Other	0.2	0.4	0.1	0.2
TOTAL	**199.2**	**252.4**	**100.1**	**100.2**

2.2 Agricultural Energy Consumption

Nearly a decade has passed since the oil crisis of 1973-74 which signaled a new era in United States and world history. The effort to develop a satisfactory policy response to what was once characterized as the "moral equivalent of war" has stretched out so long that weariness, rather than vigor, characterizes the national debate. One reason is the lack of accurate predictions. Each interest group has its own energy use data and projections, which usually reflects favorably upon the claims and concerns of that group.

In 1973, the year of the OPEC oil embargo, an article by David Pimentel appeared in Science magazine accusing American agriculture of energy inefficiency and waste (Pinentel, 1973). A small furor arose resulting in a controversial topic. A new discipline, energy accounting, was initiated.

One of the first major attempts to quantify energy consumption in the U.S. food chain was done by Eric Hirst in 1973 (Hirst, 1973). The study claimed that the U.S. food system consumes about 12 percent of the total U.S. energy consumption. These figures were derived by converting readily available economic data into energy terms using national statistics. Robert Herendeen of the Oak Ridge National Laboratory produced a series of tables of energy coefficients to be used with the Department of Commerce's economic input/output tables of the U.S. economy to determine energy costs of goods and services (Herendeen, 1973). Hirst used these tables to look at the aggregate energy use in the U.S. food system. Energy analysis, using an economic to energy conversion, has its critics (Southwell, 1977), as it should. It contains many inherent assumptions and approximations, however, it seemed to open the door to further work and provide some basic guidelines in an area where there were few statistics to work with.

In 1974, the year after Hirst's study was released, two reports were published which were similar in nature. The reports looked at agricultural energy use in California (Cervinka, 1974) and New York (Gunkel, 1976 & 1974) respectively. Data in both reports were derived using three basic methodologies: engineering analysis, questionnaires or surveys, and the conversion of enterprise cost budgets to energy terms. The New York study, (done at Cornell), only looked at the energy required for production agriculture while the California study considered the food system in its entirety.

In 1977, Southwell and Rothwell, of the University of Guelph, released a massive study of energy use for agricultural production in Ontario, Canada. This study looked at the energy required for nonenergy inputs as well as the energy cost of energy supply using a process analysis of industries as opposed to economic data.

Most energy consumption studies released were primarily "paper" studies which used economic data, engineering analysis, questionnaires, and statistics to compute energy requirements. However, researchers involved with projects in Kansas-Nebraska (Kramer, 1978) and Michigan (Myers, 1980) worked directly with farmers and measured actual on-farm energy use. These projects were the first comprehensive efforts to measure energy use on commercial farms and record its use by enterprises, operation, depth of tillage, etc.

The Kansas-Nebraska program selected 100 farms with the assistance of County Extension Agents from both states. A staff engineer from the respective state university visited each farmer to explain the project, and what would be expected of them as a cooperating farmer. Energy use handbooks for all vehicles and power units, and supply tank fuel meters were distributed to those who agreed to cooperate. The data collected was summarized using a computer and was compiled per operation and per enterprise.

An attempt to compare data presented in any of the previously discussed studies was difficult. There were few accepted standards for terminology, processes, and units, making it difficult to compare numbers. To achieve any consistancy in terminology and units, some manipulation of the data was required. This evidence shows that a major problem existed with energy accounting. In addition, there had been a lack of detailed explanations in many reports as to how figures were derived. It is hoped, the Michigan Energy Audit Project (discussed in Section 3 and a major part of this research) will advance the field of energy accounting and help resolve many of these problems.

2.3 Management Trends for Dairy Farms

Management input on any size dairy farm, usually comes from the owner and the owner's immediate family. Management of a dairy farm involves making decisions related to all phases of the operation consistent with resources available and operator objectives (Nott, 1981). Management can be divided into various subsets, i.e. crop management, herd management, machinery management, labor management, business management, and energy management. This section will deal with several of these subsets.

A study of national trends from 1956 through 1980, revealed a considerable degree of diversity with respect to management schemes. Just as every region had its own land variation, resources, and climate, dairy farmers in those regions had their own management styles. For example, dairy cows were housed in a variety of barn types ranging from outdoor corrals to free stall barns to traditional or stanchion barns. The stanchion barn was most prevalent. In 1974 over half the new barns built in New York, Pennsylvania, and Wisconsin were stanchion barns (Hoglund, 1974).

2.3.1 Labor

Labor was usually the second largest expense on dairy farms if all unpaid labor was charged against the business at its opportunity cost (Kearl, 1968). Data showed that dairy farmers improved their labor efficiency over the last 25 years. A cost accounting project involving a small sample of New York dairy farmers indicated that milk produced per hour of labor increased more than 2.5 times during this period of time. This occurred because milk production per cow rose and because labor hours per cow declined. Although this data came from an unpublished cost accounting of New York dairy farms (Snyder, 1978) it was expected the results would be reproduceable anywhere in the United States.

2.3.2 Feeding Systems

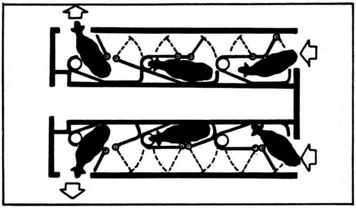
Feeding strategy received considerable attention, since feed is the single largest cost item on a dairy farm. Dairy farm managers fed cows with systems ranging from a rusty coffee can to a push button silo unloader to a microcomputer controlled manager that recognizes an individual cow and apportions an allotted amount.

In the decade after 1956, there was a continuation of earlier trends to move away from dry hay towards the more easily mechanized and nutritious hay crop silage and corn silage. Tower silos with mechanical unloaders enable silage to be moved into mechanical feed bunks. Trench and bunker silos were used, especially on larger herds in open housing. Feed often moved from the bunker silo in an unloader wagon to a fence line feed bunk. A dichotomy in feeding systems emerged between stationary (tower silo and mechanical feed bunk) and mobile (bunker silo, mobile unloading boxes, open feed bunks) feeding systems. This dichotomy created a major investment decision for expanding farms (Mix, 1978).

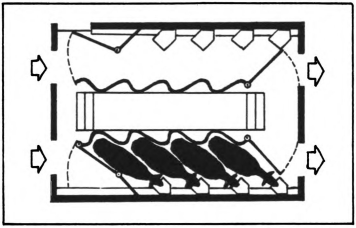
2.3.3 Milking Systems

Dairy herd managers, like managers in all facets of American agriculture began to substitute machinery for labor wherever possible. The first Herringbone milking parlor in the United States was installed in 1957 (Lindsey, 1960). Since 1971, other parlor designs were put to use (see Figure 2.1). These included the Diagonal, the Sawtooth

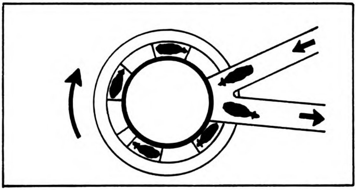
FIGURE 2.1 MILKING PARLOR SYSTEMS ADAPTABLE TO EXTENDED AUTOMATION.



DOUBLE-3 DIAGONAL STALL MILKING PARLOR



DOUBLE-4 SAWTOOTH HERRINGBONE MILKING PARLOR



8-STALL ROTARY MILKING PARLOR

Herringbone, and the Rotary. Advances were also made in specialized accompanying equipment for milking parlors which made it possible to automate many parts of the milking chore routine. This specialized equipment included entry and exit (crowd) gates capable of nearly automatic operation, devices (prep-stalls) which used water sprays to clean and prepare cows for milking, and equipment that sensed the end of milk flow and then removed (detaches) the milker from the cow. The dairy herd manager was faced with making the decisions as to the cost-benefit of these substitutions.

The conversion from cans to bulk tanks occurred within the last twenty-five years. Although herd managers readily accepted bulk tanks, many felt they were forced into acceptance by decision makers off the farm. On large farms, one could find milk cooled in the line as it moved from the milking machine directly into a parked tank truck. Since 1976, herd managers started installing heat exchangers to help meet rising energy prices. There were two types, one used the heat from the bulk tank compressor to heat water; the second used well water to reduce milk temperature as it flowed from the parlor to the bulk tank. Widespread adoption of these heat exchangers was expected in the future (Nott, 1981).

2.3.4 Management Optimization

During the 1950's, linear programming (L.P.) replaced budgeting as the preferred way to determine optimum resource allocations. An agriculturally-oriented book (Heady, 1958) was one of the earliest comprehensive texts on L.P. It was suggested that whole-farm planning could be done by L.P. Farm managers can obtain this type of help in several states through regionally accessible interactive computer systems created by extension service workers. These systems include: CMN at Virginia, started in 1969; TELPLAN at Michigan State, started in 1969; and AGNET at Nebraska, started in 1975 (Nott, 1981). Among their software libraries are dairy farm planning packages, accounting systems, and ration formulations. Ration balancing is the most heavily used program.

Current computer aided research included Michigan State University's 1975 dairy farm model which studied the cost of milk production in terms of energy consumption (Misener, 1975). Misener's macro model of the entire milk production system evaluated the trade-off in the mass-energy and monetary cost associated with various production systems necessary for the production of milk as a function of technology and capacity. The farmstead subsystem model included housing, milking parlor, feed storage, and other components concerned with confining, milking, and caring for the milking herd. In general, the study found there were economies of size in all variables of production with the exception of fossil fuel. Analysis of the effect of free stall barn type, waste storage type, and forage type indicated that average costs were lowest, in terms of the economic and energy variables, with an open lot and solid waste system, and highest with the warm-enclosed free stall barn and liquid waste system. The analysis was only valid for the processes and costs in the analysis. The resources considered were land, labor, electricity, fossil energy, capital, and the dollar, all of which have changed since 1974.

Linear programming research in the Department of Agricultural Economics at Virginia Polytechnic Institute and State University, in 1976, was directed at how a profit-oriented dairy farmer could adjust his farm business to a domestic energy gap. The energy gap was the result of either an increase in the price of energy-related inputs in relation to prices for farm products and prices of other inputs, or due to a decrease in the availability of energy-related inputs. The research concluded that Grade A dairy farms using no-till corn (grain and silage) production will have more profitable operations, but use more energy per acre of land and per dollar of return than farms using conventional corn tillage. Farms using liquid manure systems for handling manure will have higher net returns than farms using solid manure systems. Reductions in the supply of fossil energy inputs would reduce farm income much more than a similar percentage increase in the price of fossil energy inputs. For example, a 40 percent reduction in energy supply would reduce returns much more than a 50 percent increase in input prices (Burton, 1977).

A 1978 study by Fred Sistler, Assistant Professor of the Agricultural Engineering Department at Louisiana State University used a computer model to simulate milking chores for dairy barns with pipeline or bucket and transfer stations (Sistler, 1978). The study included a detailed time and motion evaluation of milking and feeding chores conducted in 34 confinement-stall barns in Wisconsin. The computer model developed predicted the duration of various milking procedures events using two, three, and four milking units per operator for the milking operation. The simulated results indicated an operator could never use more than three units unless he had assistance in prepping the cows. In addition, he must limit his machine stripping time to a few seconds to perform all of the milking chores in a timely manner.

A computer model which would predict forage feeding time based upon cart travel speeds and unloading rates was not developed, as the authors questioned the usefulness of such a model based only upon theoretical information. The authors concluded that, "the most important advantage of a mechanized milking or feeding system was not the time savings, but rather the effort it saved the operator."

2.4 Michigan Dairy Industry

Although Michigan, ranked first in the nation in the production of several fruits and vegetables, its dairy industry remained the state's largest agricultural enterprise in 1979. Dairy farming dominates Michigan's agriculture with cash receipts from marketing totalling more than 570 million dollars. This return normally represents about 25 percent of the state's total cash farm receipts. Nationally, Michigan ranked 9th in milk production per cow with 12,166 pounds per cow and was 6th in both milk cow numbers with 397,000 cows and total milk production of 4.83×10^9 pounds (M.A.R.S., 1980).

In 1980, the net cost of producing 100 pounds was forecasted at $11.33, up eight percent from 1979, the average milk price per hundred weight (cwt) received by farmers in 1980 was projected to be $13.22 per cwt, a 10 percent jump. Thus, the average net return to milk producers in 1980 was projected at $1.89 per cwt, up from $1.49 in 1979 and $1.18 in 1978 (U.S.D.A., 1980). Encouraging as these figures were, increasing production cost accompanied by lagging demand and price supports ($11.22 per cwt in 1979 and $12.07 per cwt in 1980), resulted in a continued need to stress the importance of efficient and economical use of farm resources.

The Michigan State University Agricultural Experiment Station and the Cooperative Extension Service published a report in 1972 entitled "The Michigan Dairy Industry of 1985" (Boyd, 1972). The intent of the study was to project the status of the Michigan dairy industry in 1985. Some of the following predictions were made by authors contributing to the report:

1. The number of active dairymen in Michigan has been declining for the past 20 years, and it is expected that by 1985 only 3,500 - 4,500 Grade A dairymen will be selling milk.

2. The number of milk cows in 1985 will be in the range of 320,000 to 400,000.

3. Herd sizes will dramatically increase. More than 25 percent of all dairies will have greater than 100 cows and 50 percent of the milk cows or more will be located on dairies with greater than 100 cows.

4. Man equivalents per farm will decrease to 2.5 by 1985, while milk output per man will increase dramatically.

5. Feed sources will consist of increased amounts of corn silage and grain mixes and less hay.

6. A great increase will occur in total confinement housing systems. It is estimated that by 1985, 35 percent of all herds and 55 percent of all cows will be in covered facilities.

In general, the report indicated that Michigan dairymen would be milking greater numbers of cows per farm, the per-farm labor needs would increase and energy consumption per worker would correspondingly increase. This projection further indicated the need for dairymen to adopt different production methods in order to conserve labor and energy.

2.5 Summary

From the review of the literature, it was evident that the impact of the energy crisis was going to be an unknown. In the past, energy was plentiful and inexpensive. Now it was becoming scarce, and increasingly expensive. According to Burton (1977), doubling energy prices would result in a 13 percent increase in farm commodity prices. An energy shortage of five percent in each region of the country would result in a 26 percent increase in farm commodity prices.

In the new discipline of energy accounting, several attempts were made to quantify agriculture's energy consumption. Since few accepted standards for terminology, processes, and units existed, the comparison of the energy reports was difficult. Future energy auditors were advised to concentrate on a limited number of farms in order to accurately measure and report input to output per enterprise operation. To accomplish this the audits would require highly knowledgeable people capable of understanding the complexity of the facilities surveyed.

In the area of dairy farm management, several authors attempted to define one "best" system for a dairy enterprise (Misener, 1975) (Burton, 1977), (Sistler, 1978). Their analysis techniques used simulation or linear programing and, in some cases, the two were used in combination. In such situations, "best" was generally reserved for that system which either minimized cost or labor, or allowed maximization of farm profit. Safley (1975), in his analysis of animal waste handling systems, concluded that there was no one "best" system for all dairy farms, rather the decision regarding system choice depends on a combination of factors tempered by personal preferences of individual dairymen. Dairy farmers usually select a system based upon the following factors: a) total initial cost; b) daily labor requirements; c) peak labor demands, and when they occur; d) maintenance needs; and e) energy demands of the system, and when they occur.

It appears, the main problem confronting dairymen is lack of an organized method of incorporating selected evaluation criteria so comparison of several complete units can be made despite little or no previous knowledge of actual systems. The following research attempts to provide concise answers to principal questions of general concern regarding selection of milking and feeding systems, their energy consumption, and cost.

3. MICHIGAN FARM ENERGY AUDIT

The Michigan Farm Energy Audit and Education Program was a three year study conducted at Michigan State University, by the Department of Agricultural Engineering, to develop a data base on energy consumption of production agriculture in Michigan. A grant from the Energy Administration of the Michigan Department of Commerce through the U.S. Department of Energy provided $154,000 to implement and conduct the first two years of the study. An additional $85,000 was provided for the third year to develop conservation measures (Stout, 1980). The specific objectives of the project were: 1) to determine the use of specific types of energy by farm size and type, enterprise, and operation; and 2) to use this data base as a needed input in evaluating energy conservation measures on individual farms (Myers, 1980).

The project was conducted in three specific phases. Phase I was conducted over a 14 1/2 month period from February 15, 1978 to April 30, 1979. This phase was a pilot study to develop reporting forms, procedures, computer programs, and acquire the necessary expertise to undertake an audit of a larger number of farms during the second year. The energy types considered were gasoline, diesel fuel, propane, natural gas, electricity, and the invested energy in fertilizers and chemicals. The second phase began in April of 1979 and continued through April, 1980. By expanding the study to 100 or more farms, a detailed data base on energy use on Michigan farms would be obtained. The third and final phase of the project involved the analysis of the data collected and the development of conservation measures on individual farms.

3.1 Phase I

Phase I, began in February, 1978, with data collection starting in May, 1978 and continuing through April, 1979. This phase involved final design of the project, preparation of the necessary forms, selecting and training cooperative farmers, development of computer programs for procurring the data, and evaluating the feasibility of the data collection procedure. Data was collected from twelve farms in southern lower Michigan. Included were: four cash grain farms, two dairy farms, two cattle feeding enterprises, two swine operations, one potato farm, and one fruit farm.

3.1.1 Phase I Procedure

Cooperative Extension Service staff selected cooperators who were interested in the energy audit project and were also enrolled in TELFARM, a farm accounting program operated by the Agricultural Economics Department at Michigan State University. The utilization of this source proved beneficial in three respects. First, farmers participating in TELFARM had experience in keeping records and sending in data regularly. Second, most of these individuals had participated in University research studies in the past. And third, TELFARM maintained information on farm size and production which proved useful in analyzing recorded data. One possible disadvantage, however, was that the selected group of farms may not have been typical in their ability to make efficient use of energy.

The methodology for determining energy requirements for production agriculture was relatively uncomplicated. During the last two weeks of April, 1978, members of the on-campus study team visited each farm to explain the project in detail. Team members made a quick sketch of the farmstead, labeled all electrical, liquid petroleum, and natural gas meters, and delivered the first set of record books. A separate book was provided for each power unit and vehicle used on the farm each month. Fuel meters were supplied to farms which did not already have meters. Additional electrical meters were installed, where possible, to record electrical use for specific operations. Cooperators were asked to indicate the fill-ups and provide a description of what was done between fill-ups. Electricity, natural gas, and propane meters were read once a month by the cooperators. They were also asked to fill out a form indicating fertilizer and chemical use for each crop. As compensation for their work, each cooperator's TELFARM fees for the year (approximately $200 per farm) were paid.

Data forms were received from cooperators every two months. The information was then coded, keypunched, and fed into a computer program. Problems such as illegible handwriting or unintelligible entries frequently arose during the coding process. In each case the cooperator was personally contacted to clarify any misunderstanding or problem. The computer print-outs produced by the program indicated energy consumption by month, energy type versus enterprise, operation, and specific vehicles, and power units.

3.1.2 Phase I Results

A key factor for the success of Phase I of the Michigan Farm Energy Audit and Education Program was the selection of cooperating farmers who were also enrolled in TELFARM. However, the sample of twelve farms, ranging in size from 300 acres to 1700 acres, was too small to adequately represent the state. The participating farms did offer some interesting insights into energy use patterns. For example, during the first year of the energy audit, over 475,000 gallons of gasoline equivalents were recorded. Approximately 55 percent of this amount was in the form of direct energy inputs while indirect energy inputs associated with fertilizers and chemicals accounted for the remaining 45 percent.

An important aspect of the energy accounting project was its ability to reveal the quantity of energy used by various equipment and processes. A case in point is the forced ventilation of a dairy barn. In Figure 3.1, the pie chart shows the percentage breakdown of electrical energy used on a dairy farm over the course of the first year. In Figure 3.2, where the dwelling load was removed from the farm represented in Figure 3.1, about 26 percent of the total farm electrical energy was used for ventilation. An alternate design, natural ventilation, could have achieved adequate ventilation, thus eliminating the need for fans. This may not always be possible, but it is a factor which should be considered when investigating methods to reduce farm electrical energy costs.

3.2 Phase II

The second phase of the Michigan Farm Energy Audit Study was basically an expansion in the number of participating farms. The purpose of expansion was to broaden sample size and the subsequent data base from which energy conservation TELPLAN programs were developed in the third year.

Eight of the original twelve farms from Phase I continued participation in Phase II, with a total of 63 farms enrolled in the project as of May, 1979. These included 33 dairy farms, 17 cash crop farms, seven beef cattle operations, and six farms emphasizing swine production.

3.2.1 Phase II Procedures

All farms in Phase II participated on a voluntary basis with no financial remuneration provided. The energy data collected during this phase was quite similar in type and detail to Phase I. The cost of detailed sub-metering of electrical use was judged to be excessive, and so electrical use was monitored only with meters presently on the farm site.

3.2.2 Phase II Results

One of the goals of the second phase of the study was to expand the initial pilot study to 100 - 200 farms of selected sizes and types. Unfortunately, the final number of cooperators completing Phase II was only 48. This included eight of the original twelve farms. Thus, the sample was still too small, however, it did represent the state more accurately than Phase I.

The energy accounting project in Phase II revealed some interesting information concerning the quantity of energy used by various pieces of equipment and processes. The ventilation fans, for example, again represented a major portion of the electrical energy load. Also, the residence (with the exception of livestock operations with mechanical feeding) consumed a major portion of the electrical energy used on a farm. In Figure 3.4, the dwelling load has been removed from the farm represented in Figure 3.3. A comparison of the electrical energy use in 1979-80 (Figure 3.4) with the 1978-79 data (Figure 3.2) revealed two significant conclusions. First, the electrical energy used by the milking parlor vacuum pump was reduced 20 percent through better management. Second, the addition of a heat exchanger, which used the heat from the bulk tank cooling compressor to heat water, reduced the amount of energy required to heat the water by 27 percent.

3.3 Phase III

The last phase of the three year research project involved the development of conservation programs based on the data collected in Phases I and II. The thrust of this phase was twofold: 1) the development of an energy workbook for interested farmers for recording energy usage for comparison to standards or norms established during the first two years of data collection; and 2) the development of TELPLAN and hand calculator programs to assist farmers with analysis of specific energy management concerns. The TELPLAN programs were a continuation of Michigan State University's automated computerized programs which were currently available for least cost feed rations, machinery replacement, and farm organization.

3.3.1 Phase III Procedures

The third phase of the project involved analysis and interpretation of data collected during the previous two years. In order to accomplish the following seven goals (Haueter, 1980) each on-campus study team was assigned an area of expertise.

1. Compile, summarize, and determine averages for energy consumption data for field operations in terms of gallons per acre and fuel used per hour.

2. Develop one workbook, for each enterprise studied, for use by the general agricultural public to compare their energy usage with the data collected in the first two years of the energy audit study.

3. Develop extension bulletins to assist farmers to determine what management or environment factors might be responsible for above average fuel consumption.

4. Develop management guidelines for farm operators to evaluate alternative equipment (primarily electrical versus gas or diesel powered) in terms of capital expenditure, operating cost and fuel cost.

5. Develop an extension bulletin as well as a TELPLAN or programmable calculator program for economic and energy efficient use of fertilizers and pesticides.

6. Develop extension leaflets and accompanying programmable calculator programs for electric motor selection, irrigation scheduling, optimizing irrigation pumping plant size, and performance of grain drying bin fans.

7. Develop a linear program for cash-grain operations which realistically describes conservation and profitability trade-offs within a management framework.

3.3.2 Phase III Results

The primary result of the three year research project was a notebook entitled "Farm Energy Use: Standards, Worksheets, Conservation" (M.S.U., 1981). The notebook is comprised of four sections: field operation standards, crop energy budgets, livestock energy budgets, and conservation programs. Provided in the first three sections of the notebook are worksheets designed to help farmers conduct an energy audit of their own farms and compare their energy consumption with standard values obtained during Phases I and II. Table 3.1 is an example of the energy budget standards compiled for dairy farms in Michigan. The table shows the average energy usage for dairy farm operations on a per milking cow basis. Due to the small sample size, the data in many of the energy budget standards may not always represent typical energy use.

The final section of the notebook contains a series of management tools specifically designed for problem area analysis and the promotion of efficient energy use through conservation measures. This section is divided into the following subject areas: Drying, Field Operations, Livestock, and Tractors. Included are several extension bulletins and programmable calculator programs on specific topics relative to each subject area.

In addition to the notebook and other extension bulletins, two linear programming models were developed as a result of Phase III of the Michigan Farm Energy Audit Study and Education Program. The first linear program developed, was a realistic model of a cash grain operation's energy conservation, and profitability trade-offs within management frameworks. The second linear program simulates a dairy farm's energy use as a function of management and alternative equipment options. The development of the second linear program, "A Dairy Farm Simulation Model," is the subject of the following sections.

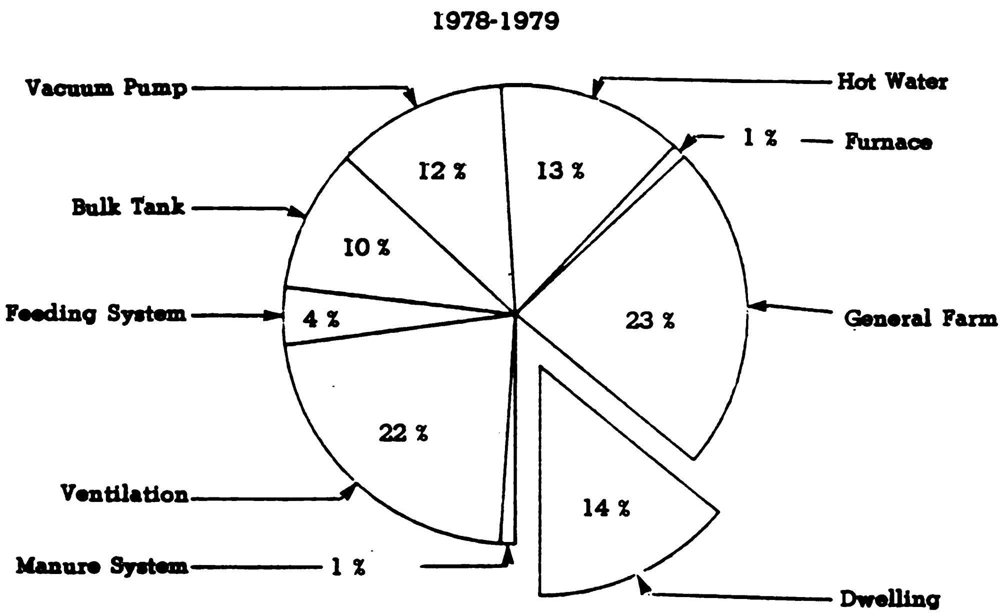


FIGURE 3.1 BREAKDOWN OF DAIRY FARM ELECTRICAL USAGE FROM MAY 1978 TO APRIL 1979, INCLUDING THE HOME.

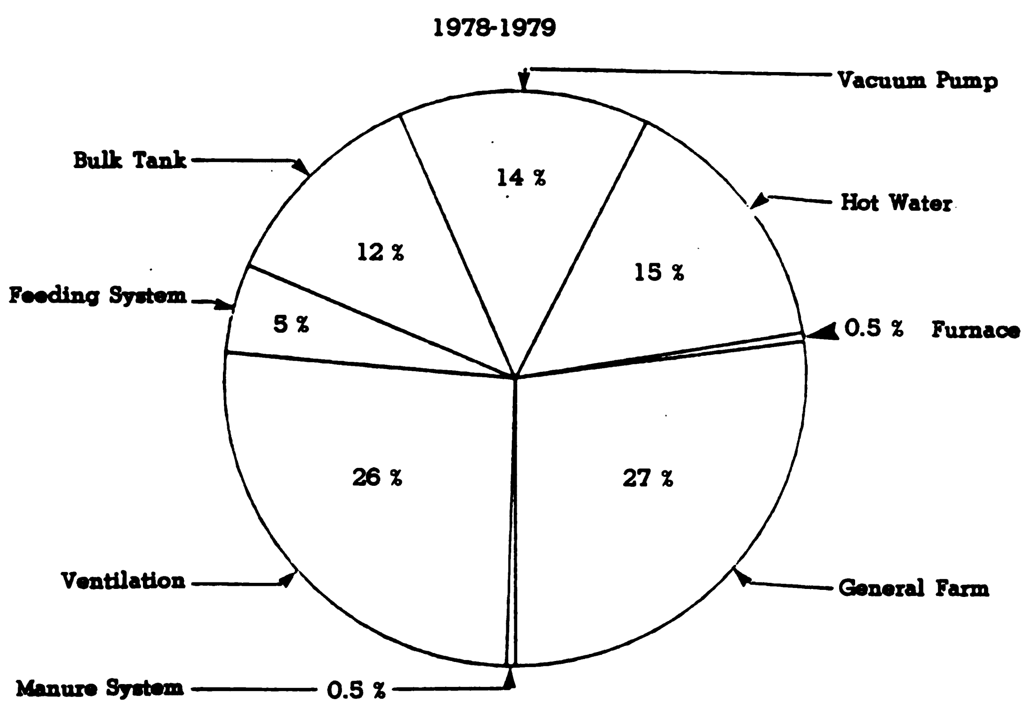


FIGURE 3.2 BREAKDOWN OF DAIRY FARM ELECTRICAL USAGE FROM MAY 1978 TO APRIL 1979, WITHOUT THE HOME.

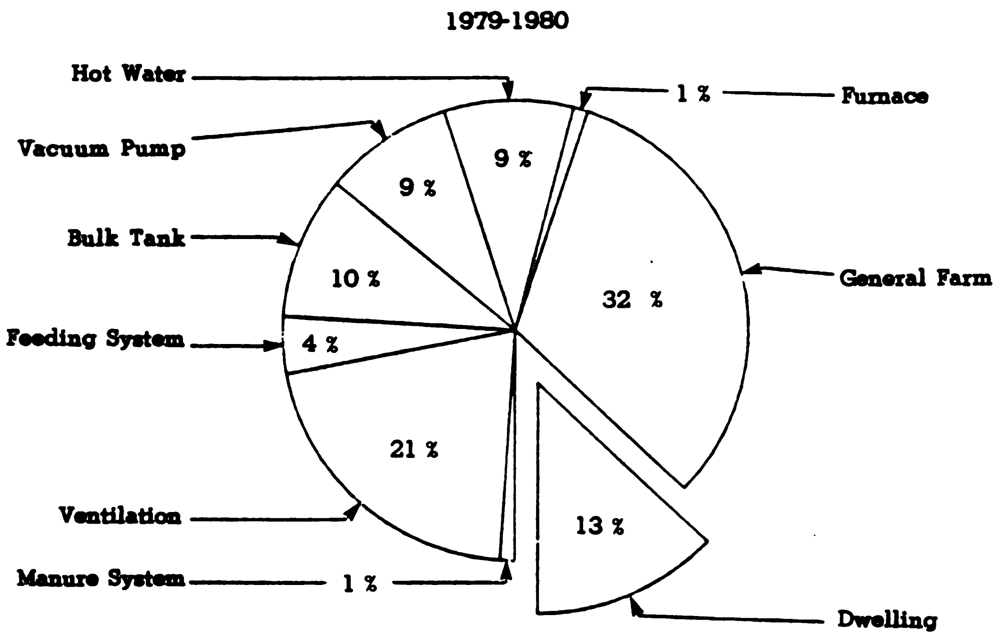


FIGURE 3.3 BREAKDOWN OF DAIRY FARM ELECTRICAL USAGE FROM MAY 1979 TO APRIL 1980, INCLUDING THE HOME.

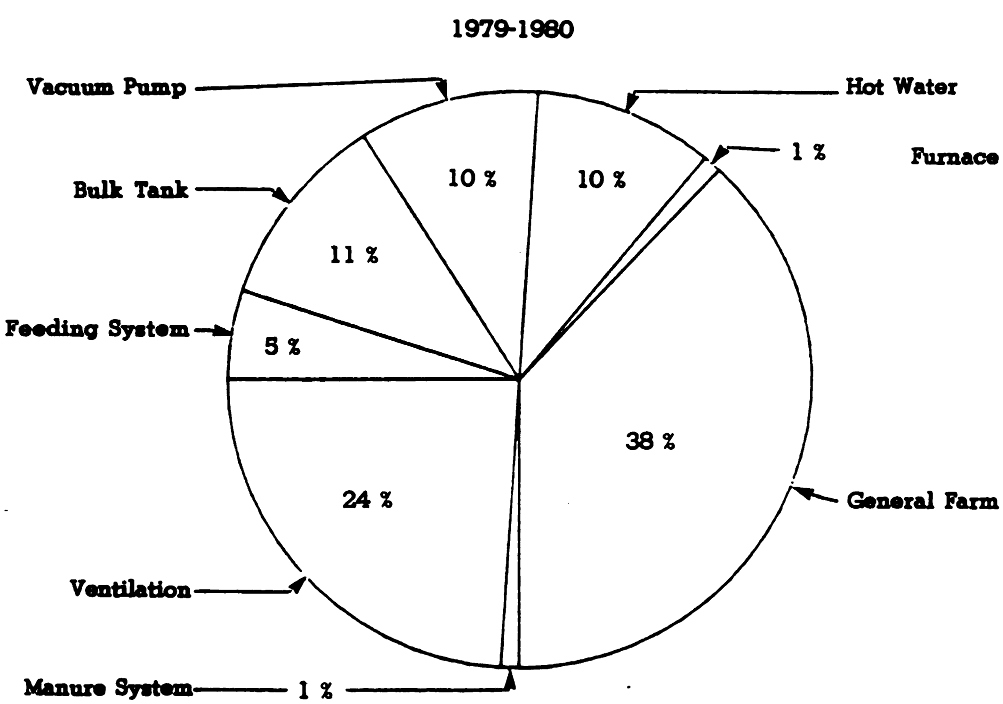


FIGURE 3.4 BREAKDOWN OF DAIRY FARM ELECTRICAL USAGE FROM MAY 1979 TO APRIL 1980, WITHOUT THE HOME.

TABLE 3.1 ANNUAL DAIRY FARM ENERGY USE PER MILK COW PER OPERATION[1].

OPERATION	Electric Only [2]	Liquid Fuel [3]	Electric and Liquid Fuel[4]
Feed Handling	62.6 kWh	4.2 gal.[5]	35.1 kWh + 5.2 gal.[5]
Lighting	48.5 kWh	*	* *
Milk Cooling w/o pre-cooler	143.0 kWh	*	* *
Milk Cooling w/ pre-cooler	94.7 kWh	*	* *
Milking System	124.0 kWh	*	* *
Milk Handling	252.3 kWh	*	* *
Space Heating	9.8 kWh	9.3 gal.[6]	11.7 kWh + 1.0 gal.[6]
Ventilation	224.7 kWh	*	* *
Waste Disposal	*	12.6 gal.[7]	5.6 kWh + 4.9 gal.[7]
Water Heating w/o heat recovery	175.9 kWh	12.6 gal.[6]	* *
Water Heating w/ heat recovery	151.1 kWh	*	* *
Water Supply	17.6 kWh	*	* *

[1] A total of 1,588 milk cows on 21 farms were used in the study. The rolling herd average was 15,100 pounds of milk per cow.
[2] Based on those farms utilizing only electricity for that operation.
[3] Based on those farms utilizing only liquid fuel for that operation.
[4] Based on those farms utilizing a combination of electricity and liquid fuel for that operation.
[5] Based on those farms utilizing only gasoline for that operation.
[6] Based on those farms utilizing only propane for that operation.
[7] Based on those farms utilizing only diesel for that operation.

4. DESCRIPTION OF DAIRY FARM SIMULATION MODEL

A major emphasis of this research was to develop an analytical method for evaluating daytime use of various dairy farm operations. The Dairy Farm Simulation model examined two major energy-using farm operations, milking and feed handling. The ability to choose two energy alternatives (diesel fuel and electricity) for performing the same task within an operation was incorporated into the interactively run computer model. The model also addressed questions regarding resource allocation among alternative operations of the dairy farm systems, showed how changing management strategies influenced the level of profitability, and showed how different energy price scenarios influenced optimal resource allocation.

Examination of actual monthly and yearly energy required to operate various pieces of equipment on Michigan Energy Audit dairy farms, from 1978 to 1980, indicated that monthly, as well as yearly energy use was fairly constant. This consistency lead to the contention that if two days could be modeled successfully, an adequate representation of the average monthly and yearly energy use could be determined from the two-day period. The two-day simulation period was chosen for computing purposes to account for the two-day milk storage used on most dairy farms in Michigan.

4.1 Model Development and Operating Parameters

The Dairy Farm Simulation Model was written in Fortran and was compatible with the CDC 6500 computer available at M.S.U. Each factor used to describe some aspect of a particular option was assigned a variable name which in most cases was mnemonic. Variable names were limited to seven digits, and if they referred to an integer number they commenced with the letters, I, J, K, L, M, or N as is the rule for standard Fortran language. The overall flow of information within the computer model is illustrated in Figure 4.1.

The model was divided into three major operational areas and nine support routines. The three major operational areas included the model's operating parameters, the Milking System Simulator, and the Feeding System Simulator. Both simulators were systematic models within themselves which could be used independently of each other or together. Section 5 describes in detail the development and the operation of the Milking System Simulator and its three support routines, CLEAN, COOL MILK, and WATER. Section 6 describes in detail the development and the operation of the Feeding System Simulator and its one support routine, SILO. The following sections discuss in detail the operating parameters of the Dairy Farm Simulation Model, along with its five support routines, three of which were associated with both system simulators.

4.1.1 Model Implementation

The simulation process for the dairy farm model, shown in Figure 4.1, required approximately two minutes of computer time to simulate each minute of operation of each system for two days. The program began the simulation process by dimensioning all inputs and outputs at the beginning of the program. At this point, the user of the program was asked a series of questions. Figure 4.1 is an example of the interaction that occurs between user and computer during the operation of the program. Additional questions were asked upon selection of a particular system simulator.

It can be seen in Figures 4.1, 5.2, and 6.1 how a decision at each phase forces the program to advance to the subsequent section and present compatible options. Option selection was made by typing in the appropriate YES or NO response to each option choice. Following this step the computer would ask the user if the option selected was correct. If the reply was affirmative, it proceeded to the next selection. If a negative response or an incorrect response was given, all options for that section were repeated.

Following the last decision, the users input was completed and the simulation model would check all system simulator equations for indication of equipment operation during the previous time interval. When all systems had been checked, the model calculated energy consumption which occurred during the previous time interval and then advanced the simulated time interval one minute. The procedure was then repeated 2,880 times to represent the total number of minutes required for two days of simulated system operation. When the simulation of energy consumption was completed, the model tabulated and printed the energy consumption for each system by operation, and calculated the cost of the energy consumed. When the print-out was completed, the user was asked if another system was to be analyzed. An

FIGURE 4.1 OPERATIONAL FLOW CHART FOR DAIRY FARM SIMULATION MODEL.

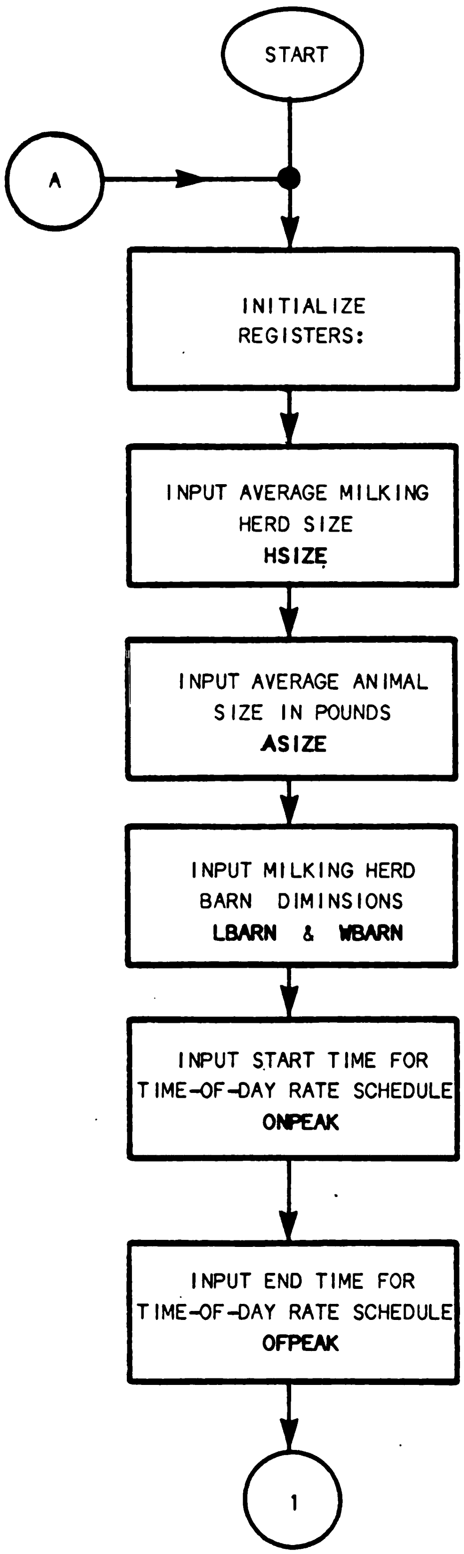


FIGURE 4.1 CONTINUED

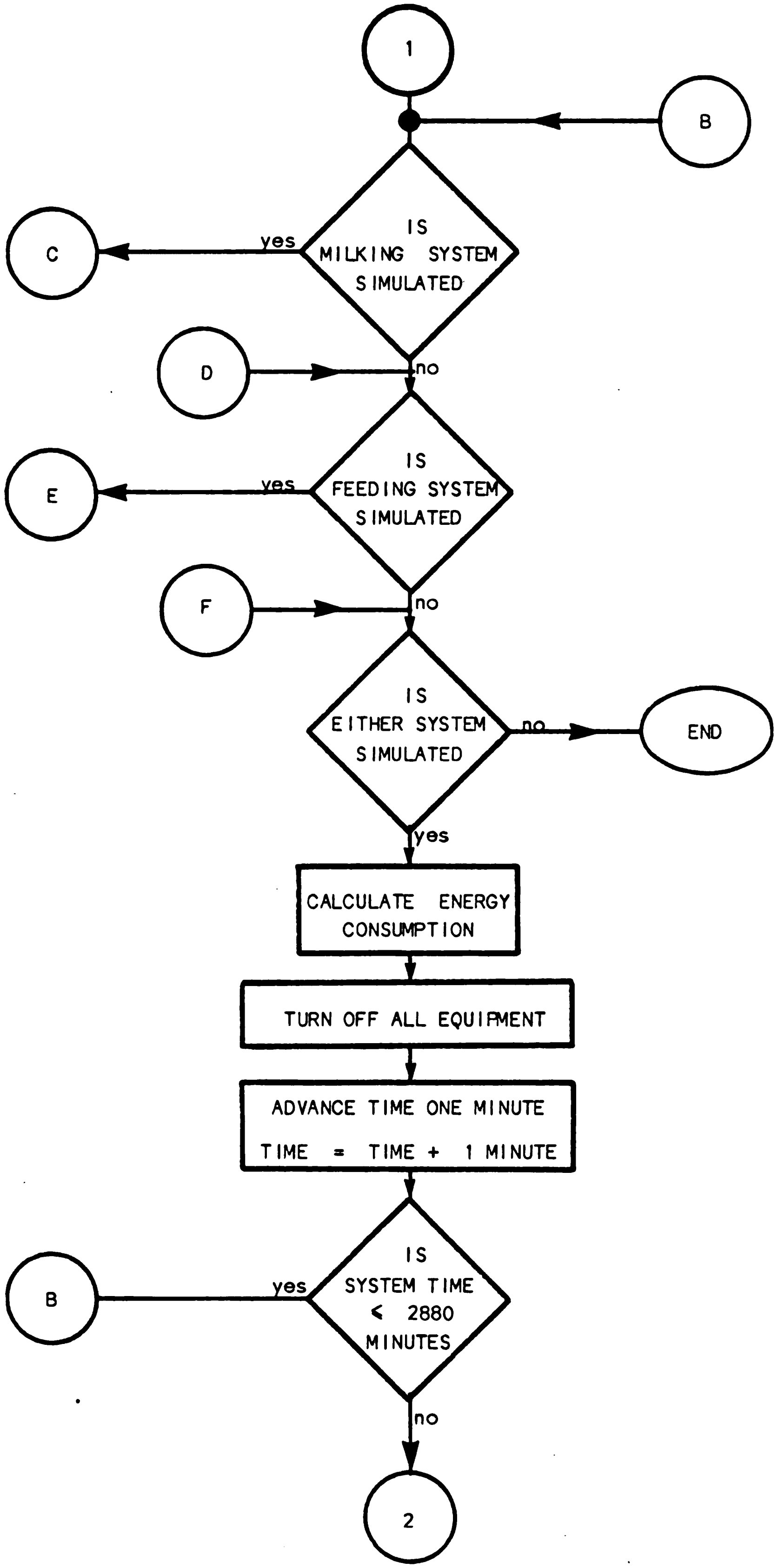
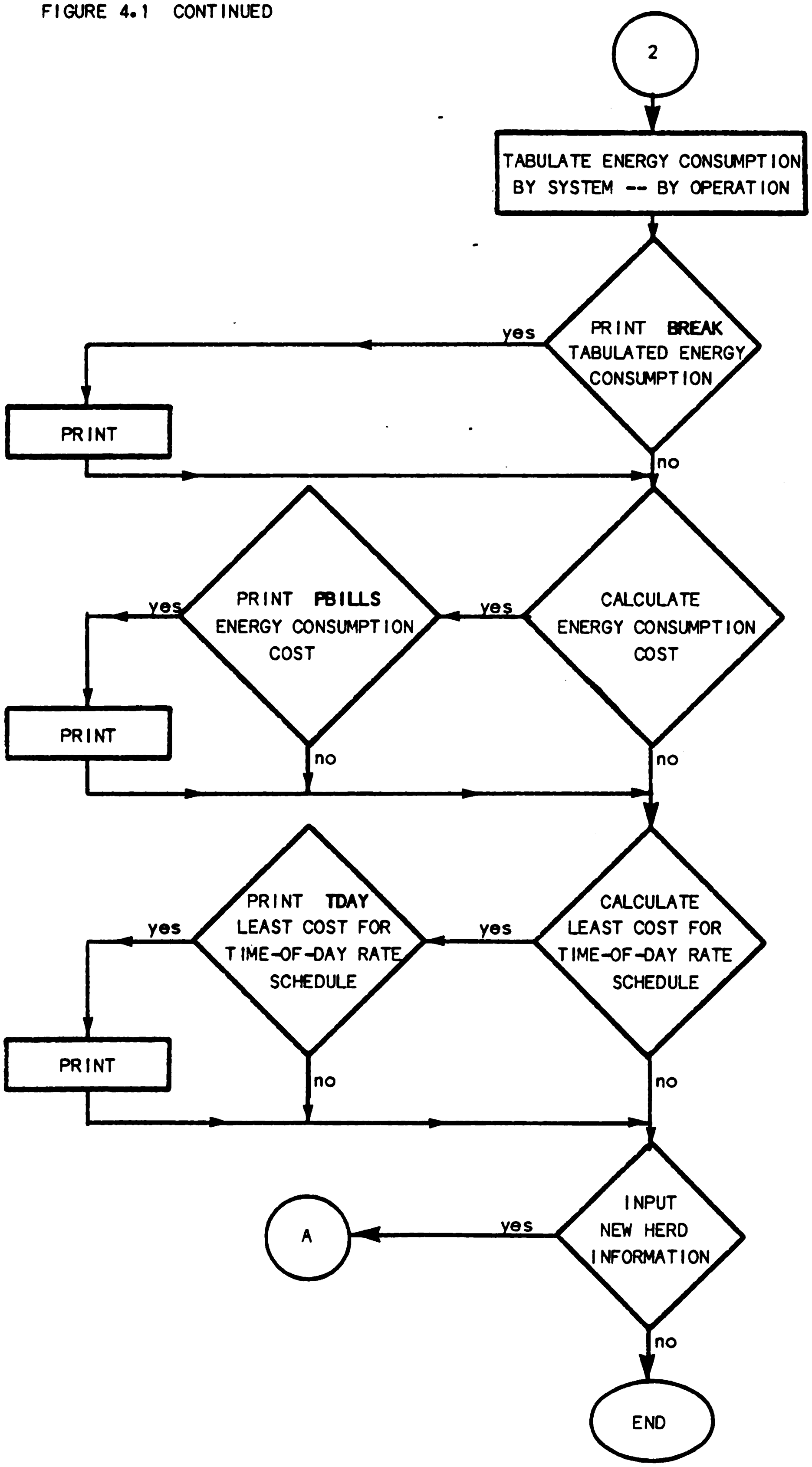


FIGURE 4.1 CONTINUED



affirmative response would return the program to the beginning. A negative response would terminate the program and allow the user to logout.

4.1.2 Herd and Housing Information

The first six operational steps of the dairy farm simulation model, shown in Figure 4.1, require the input of basic information needed to study a particular farm. Each input was used by the model to determine the amount of energy required per cow and the time when the energy was demanded. The inputs include the average milking herd size, average animal size, barn dimensions, and the on-peak electrical period used by power suppliers for their Time-of-Day Rate Schedule. The Time-of-Day Rate Schedule consisted of a two step rate for determining the energy charge. Energy consumption is first recoded using two meters which can determine the time of day electrical energy is consumed. The time of day when each meter records energy consumption is determined by the power companies' Time-of-Day Rate Schedule.

4.1.3 Time Inputs

Two support routines, UNCLOCK and CLOCK, were developed to simplify inputs to the model's operation parameters by noncomputer specialists. The support routine, UNCLOCK (Figure 4.2), allows all times entered for the start of a specific operation to be in clock form, i.e., 6:45 a.m., 5:30 p.m. While this form cannot be used directly by the program, it is used by the support routine, which converts the clock form to 24 hour clock form, i.e. 0645, 1730, for use in all time inputs to the three major operational areas of the model.

The support routine designated CLOCK (Figure 4.3), returns the 24 hour clock form to clock form for use with the print controls described in the next section.

4.1.4 Print Controls

The print controls associated with the models operating parameters, allow the selection of three levels of output. The selection of any output level, shown in Figure 4.1, will initiate the appropriate support routine. The first output level initiates the support routine BREAK which provides a complete summary of the energy consumption by system and operation. The next output level uses the support routine PBILLS to calculate energy costs for electricity and diesel fuel used during an operation. The final output which can be selected required the support routine TDAY to optimize the Time-of-Day electrical energy costs based on the power supplier's Time-of-Day Rate Schedule. A further explanation of the routines BREAK and PBILLS is given in Sections 4.3 and 4.4 respectively.

4.2 Calculation of Energy Consumption

Energy consumption simulated by equations contained in the dairy farm model assumed equipment, which operated for any fraction of a minute time interval, was operated for the entire minute. The particular time a piece of equipment's energy consumption was calculated, was dependent on an operator's input to each of the system's simulators. These inputs included the time when milking began and the time feeding started. Other inputs required to sequence equipment operations are detailed in Sections 5 and 6. After the appropriate calculations for energy consumption were made, a running

FIGURE 4.2 FLOW CHART OF THE SUBROUTINE UNCLOCK.

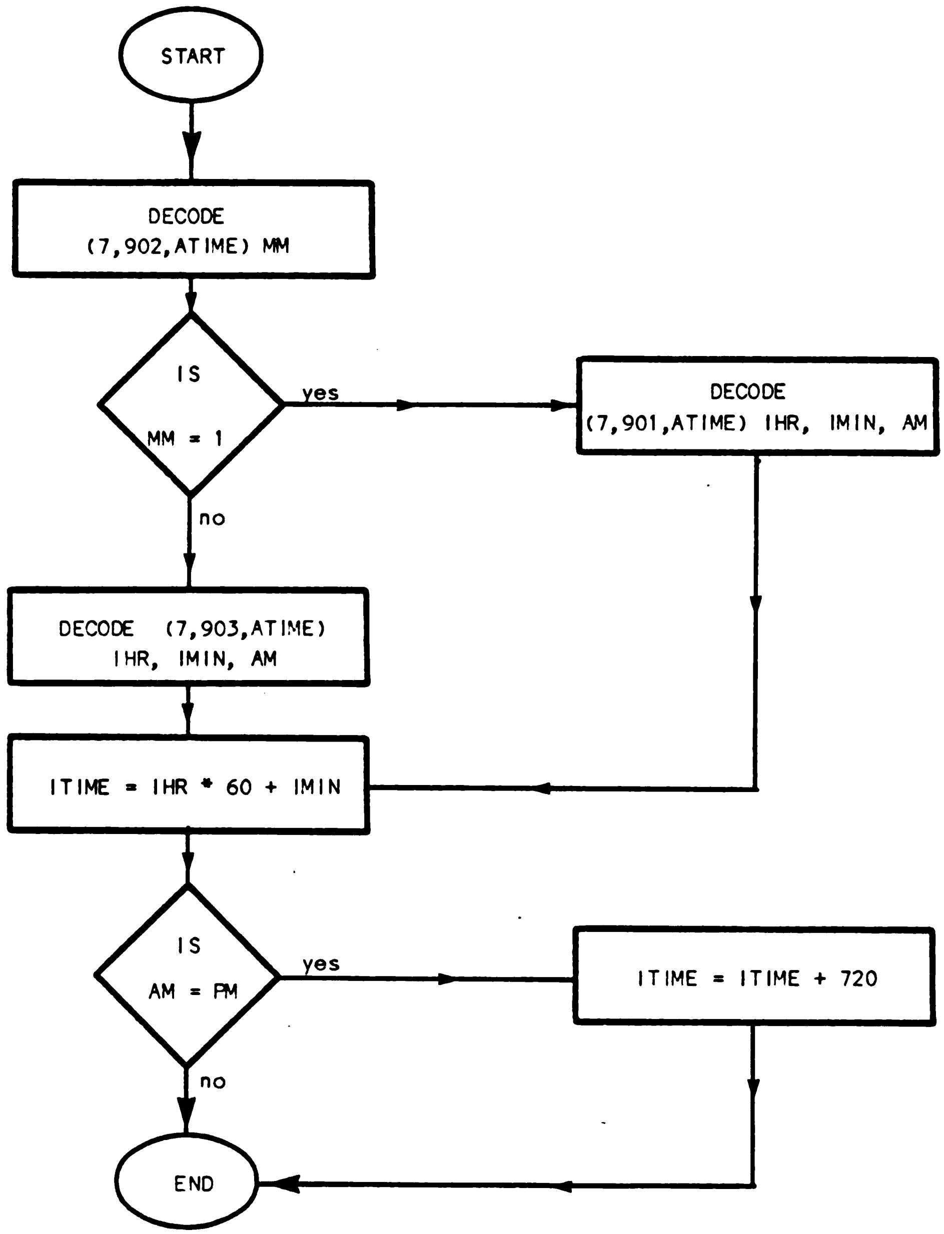
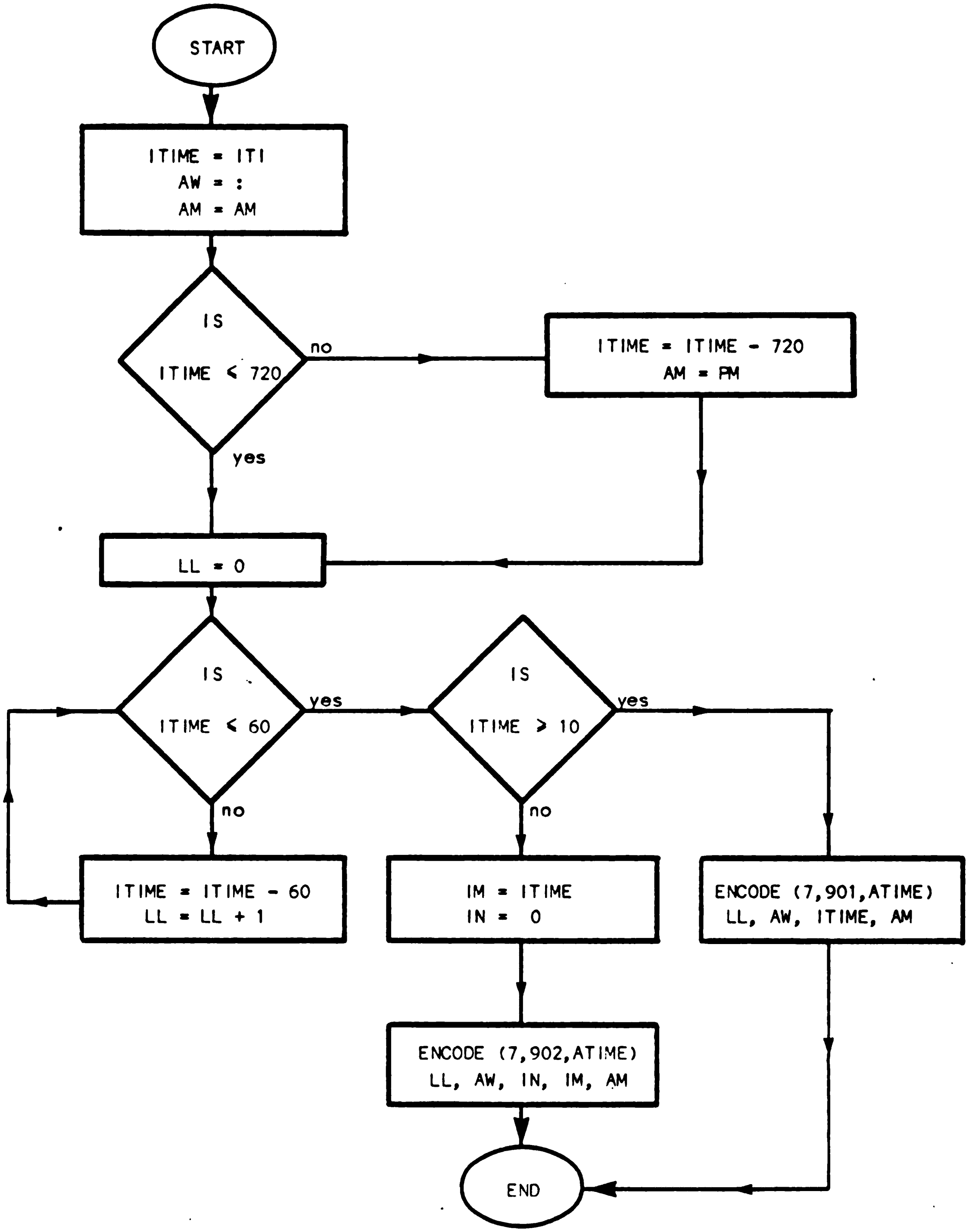


FIGURE 4.3 FLOW CHART OF THE SUBROUTINE CLOCK.



total of the energy use was stored in an appropriate energy use array. Two separate arrays were used for equipment operated by electricity. One array was a peak storage location for operations during a power company's on-peak time and the other for off-peak operation times. When all systems had been checked and energy use determined and stored in the appropriate array, each piece of equipment was "turned off." The term "turned off" refers to the model's method of resetting the energy consumption equations to zero. At this point the simulation model advanced the simulated time one minute. The procedure was then repeated 2,880 times, representing the number of minutes required to simulate two days.

4.2.1 Electrical Lighting

Lighting accounts for three to six percent of a typical dairy farm's total electric bill. The lighting system model, contained within the Milking System Simulator, consisted of two fluorescent lights in the milkhouse, a fluorescent light for every two parlor stalls, and a mercury vapor light in the free stall area (Energy Facts: E-1273, 1979).

The fluorescent lights in the milkhouse and parlor were modeled as eight foot fixtures with two tubes. Although the input variables can be changed, fluorescent fixtures were modeled rather than incandescent bulbs because they provide three to four times as much light (lumens) per unit of energy as incandescent bulbs (Energy Facts: E-1288, 1979). The lighting system model assumed the fluorescent lights would be on during milking and calculated the energy use for each minute of operation during this period. The following equation assumed each fixture had a power consumption of 216 watts or an energy use per minute of 3.6 watt• minutes.

WATT (I + 9) = WATT (I + 9) + (LITEMH * 3.6) **(4.1)**

Where

WATT (I + 9) = energy used by the lighting system (watt• min)

LITEMH = total number of fluorescent fixture units (integer)

The mercury vapor lamp located outside the milkhouse in the free stall area was modeled as a fixture with a lighting output of 11,000 lumens. The high intensity discharge lamp was chosen because it was intended for all night lighting of a large outdoor area; it provides more than twice as much light per watt as do standard incandescents; its efficiency is not affected by temperatures below 50°F as are fluorescent lights (Energy Facts: E-1288, 1979). The lighting system model assumed the mercury vapor lamp will be on from 7:00 p.m. in the evening to 7:00 a.m. in the morning and calculated the energy use for each minute of operation during this period. The following equation assumed the fixture had a power consumption of 312 watts or an energy use per minute of 5.2 watt• minutes.

WATT (I + 9) = WATT (I + 9) + 5.2 **(4.2)**

Where

WATT (I + 9) = total energy used by the lighting system (watt)

4.2.2 Electrical Power Units

An electric motor's efficiency rating determines how well it converts electrical energy into mechanical energy. The higher the rating, the more efficiently the motor uses energy. The energy that is not transmitted to the driven equipment is referred to as the motor losses. These losses are equal to the power input minus the power output. Motor losses can be broken down into four categories (Anderson, 1978): 1) I^2R losses result from the energy required to drive the current (I) through the resistance (R) of the conductors; 2) friction and windage losses are due to the energy required to overcome friction in the bearings and resistance that air presents to rotating parts such as cooling fans used to cool the motor; 3) core losses are attributed primarily to energy lost in the process of overcoming hystersis, a magnetic memory acquired in the steel cores of the motor; and 4) stray losses which include several types of losses too difficult to measure and typically vary as the motor load varies. These four categories of losses represent the only energy that is consumed by the motor. The rest of the energy is transmitted to the equipment that is being driven.

A motor rated at 100 percent efficiency uses 746 watt• hours of energy per horsepower (Gould, 1975). Since the efficiency of a motor will vary with its load, assigning an efficiency rating to a motor was rather complicated. The situation required the development of a load profile of electric motors using Michigan Energy Audit data. This consisted of a plot of motor loads versus time, and assigning efficiencies for each operating load. Analysis of the data indicated significant variations in motor loads and efficiencies.

An average efficiency of 74.6 percent was assigned to all electric motors simulated by the Dairy Farm Simulation Model. However, allowances for adjustment were made when the motor's actual load and efficiency were known. Equation 4.3 was developed to predict the energy use of electric motors. The electrical energy consumption is given in watt• minute, where E is the efficiency of the motor expressed as a decimal with a default value of .746.

$$WATTS\ (I) = WATTS\ (I) + hpE\ (746 \div E) \div 60 \qquad (4.3)$$

Where

WATTS (I) = total electrical energy consumption (watt• min)

hpE = advertised power of the electric motor (hp)

E = percent efficiency of the electric motor (decimal)

4.2.3 Diesel Power Units

A.S.A.E. D230.0 Agricultural Machinery Management Data (A.S.A.E., 1981) includes formulae to model fuel use of tractor and combine engines based on type of fuel and percent load. Concern over the accuracy of the predictions was expressed with the fuel use equations, after checking actual fuel use data collected during the Michigan Energy Audit Study (M.S.U., 1981). The main concern was that the model predicted fuel consumption higher than was generally reported. An excerpt of paragraph 3.3 of A.S.A.E. D230.3 shows the typical diesel fuel consumption given in gallons per horsepower• hour.

$$gal/hp \cdot hr = 0.52X + 0.77 - 0.04\sqrt{738X + 173} \qquad (4.4)$$

The equation predicts fuel consumption at full speed control lever setting where X is the ratio of equivalent PTO power required by an operation to the maximum available from the PTO. There is a conversion factor of 0.1970 gal/hp• hr per L/kWh to convert the English units to metric units.

The inverse of the fuel consumption equation from A.S.A.E. D230.3 indicates fuel efficiency in units of fuel economy hp• hr/gal in English units and of kWh/L in metric units. A closer examination of the diesel fuel economy equation of the present A.S.A.E. D230.3 reveals three notable aspects; 1) the full load fuel economy is about 12.18 hp• hr/gal which is below the 14.72 hp• hr/gal that may be considered to be a more typical full load fuel economy figure (Nebraska Tractor Test Laboratory, 1981); 2) the equation does not suitably predict fuel economy at very light loads as evidenced by the fact at zero load the fuel economy, hp• hr/gal, does not equal zero; and 3) a plot of the fuel economy equation versus percent load reveals the curve "hooks down" at high loads indicating that typical fuel economy falls off above an 80 percent load.

In order to further evaluate the present fuel economy model and develop other models with current information, a data base was developed that contained selected information from Nebraska Tractor Test reports. All diesel tractors that were listed in the booklet "Nebraska Tractor Test Data for 1981," were included in the data base (Nebraska Tractor Test Laboratory, 1981). This was representative of new tractors on the market as of January 1, 1981.

The fuel economy data for 206 diesel tractors with PTO were taken from the "Varying Power and Fuel Consumption" section of the Nebraska Tractor Test reports. These tests consist of six load settings equally spaced from zero power to rated power. The data were then used as input data for the Statistical Analysis System (SAS) programs. This versatile set of statistical programs was used to analyze the existing standard and develop and analyze other models.

Statistical analysis with SAS revealed that the present diesel fuel economy model is substantially below the average data. Further research confirmed that the present fuel consumption standard has a 15 percent allowance for fuel consumption of tractors in good condition but not in the new condition of the Nebraska test tractors. What this indicated was that the present diesel fuel economy model values must be multiplied by 1.15 to give typical present Nebraska Tractor Test fuel economy values. In terms of fuel consumption, this indicated that the present diesel fuel consumption model gives values 15 percent above typical present Nebraska Tractor Test fuel consumption. Even when the model was adjusted, it still "hooks down" at high loads and did not accurately handle very low load cases. Development of a new fuel economy model was pursued with the main objective being to develop as simple a model as possible that would accurately predict typical fuel economy for the entire load range.

Several different forms of equations were considered as potential diesel fuel economy models. The final equation considered was a third order polynomial without the zero order term. The omission of the zero order term simplifies the equation by eliminating one coefficient and also forces the curve through the origin to make it more accurate at low loads. The equation $AX + BX^2 + CX^3$ had the lowest error value and fit the average data. This particular equation and its coefficient used for power units in the Dairy Farm Simulation Model is shown at the top of the next page. Typical fuel consumption is given in gallons for each minute of operation, where hpX is the load expressed as a decimal.

$$DF = DF + hpD\left[1.0 \div (41.829\ hpX - 42.692\ hpX^2 + 15.838\ hpX^3)\right] \div 60 \qquad (4.5)$$

Where

DF	= total diesel fuel consumption	(gal)
hpD	= advertised power for tractor and/or loader unit	(hp)
hpX	= percent load on power unit	(decimal)

4.3 Tabulation of Energy Use

The total energy use determined by the model's simulation of two days of feeding and/or milking systems operation was multiplied by 15.208 to represent the total average monthly energy use of the operations. The multiplier was based on 365 days per year divided by 12 months which was then divided by two to represent the two days of each month which were simulated. Figure 4.4 is a reproduction of a table generated by the Dairy Farm Simulation Model. The simulation model produced the table using the support routine BREAK and shows energy consumption for a 150 cow stationary feeding system utilizing a mobile mixer for feed delivery. Included in the table are the power supplier's on-peak times for their Time-of-Day Rate Schedule; the times when the morning and evening feeding processes began; and the total average monthly energy use, by system, operation, and individual equipment.

FIGURE 4.4 A SAMPLE TABLE FROM THE DAIRY FARM SIMULATION MODEL FOR SIMULATED AVERAGE MONTHLY ENERGY CONSUMPTION OF A 150 COW STATIONARY FEEDING SYSTEM UTILIZING A MOBILE MIXER.

Peak Period From 11:00 A.M. to 6:00 P.M.

Morning Feeding Time: 5:00 A.M.

Evening Feeding Time: 4:30 P.M.

Operation	On Peak **kWh**	Off Peak **kWh**	Total **kWh**	Diesel **Gal.**
Feeding System				
Corn Silage	56.97	102.59	159.55	0.00
Haylage	5.43	9.77	15.20	0.00
H. M. Corn	5.43	9.77	15.20	0.00
Feed Mixer	0.00	0.00	0.00	54.96
Conveyors	9.04	16.28	25.33	0.00
Sub Totals	76.87	138.41	215.28	54.96
Farm Totals	**76.87**	**138.41**	**215.28**	**54.96**

4.4 Calculation of Energy Use Charges

Fuel price and different types of electrical energy rate schedules used in the model by the support routine PBILLS are explained in this section. Initially, the price of fuel and the electricity rates were set at current 1981-82 prices. Diesel fuel was $0.264 per liter during this period, which is equivalent to $1.00 per gallon.

The Michigan Public Service Commission governs the electrical rates and rules under which electricity is sold. The price of electricity varies from one power supplier to another. This particular model used current, Winter 1981, Detroit Edison Electric rates for economic comparisons. The amount of electrical energy used by a piece of equipment within a system simulator was calculated in kilowatt• hours(kWh). For example, a 100-watt light bulb burning for 10 hours uses one kWh of energy for each hour of operation.

The electrical energy bills were based upon the number of kilowatt• hours used during an average simulated month. Typically, the electrical energy bill was calculated as the sum of the following:

- Minimum Monthly Service Charge

- Electrical Energy Use Charge (cost per kWh times the number of kWh used)

- Fuel and Purchased Energy Adjustment Charge (varying cost per kWh times the number of kWh used)

- State Sales Tax (electrical energy use charge times 0.04)

4.4.1 Electrical Energy Use Charge

The electrical energy rate schedules, including minimum monthly service charges used by the model, are four typical schedules used by most electrical power suppliers. The rates used were current Detroit Edison charges for the Inverted Rate, the Farm Flat Rate, the Commercial Rate and the Time-of-Day Rate Schedules. The rates were used in the model to compare the cost advantage of various rate schedules. Future cost comparisons will only be accurate when a specific power supplier's electrical energy rate schedule is used for a particular farm.

The Inverted Rate Schedule, developed several years ago by the Michigan Public Service Commission, was directed toward power suppliers with 200,000 or more customers. The so-called "life line rates" were designed to reward conservation by imposing a higher per unit charge on consumers who used large amounts of electricity. The Public Service Commission allowed adjustments in the rates for senior citizens and customers with special needs such as farmers. The following rate was used in the model:

Minimum Monthly Service Charge: $ 2.65

Energy Charge:

First	400	kWh	@	$ 0.0488	per	kWh
Next	400	kWh	@	$ 0.0548	per	kWh
Over	800	kWh	@	$ 0.0618	per	kWh

The Farm Flat Rate Schedule for energy consumption was a special farm rate schedule approved by the Public Service Commission for farm enterprises consuming considerably more than 800 kWh per month, and thus, always paying the maximum rate when using the Inverted Rate

Schedule. The energy charge used in connection with the Farm Flat Rate Schedule was the same rate used for the second step of the Inverted Rate Schedule, $0.0548 per kWh. The minimum monthly service charge remained the same. Generally, it was not advantageous for a farm to be on this special farm rate schedule unless the monthly electrical energy consumption was greater than 1,142 kWh. The requirements for consumption of 1,142 kWh or more was predicated by the lower rate charged by the Inverted Rate Schedule for the first 400 kWh and the higher charge for energy consumption greater than 800 kWh.

The Commercial Rate Schedule applied to commercial, industrial, and farm service customers who required in excess of 50 kW transformer capacity for all uses excluding residential, but including lighting, heating, and power. Commercial Rate Schedules were generally based on a flat rate, while some others were based on a customer's load factor, therefore providing an incentive to control kW demand, and range from one half cent ($0.005) to one cent ($0.01) higher than domestic rates for the same power supplier. The energy charge assumed for the model when using the Commercial Rate Schedule was $0.0590 per kWh. A customer on the Commercial Rate Schedule was also subject to a minimum monthly service charge of $5.55 as well as any fuel and purchased energy adjustment charges.

The Time-of-Day Rate Schedule developed by power suppliers was designed to compensate customers who could voluntarily shift part of their load from the peak demand periods of the day to times when the electrical demand on the generators was lower. The philosophy behind this rate schedule, was to serve the customers' electrical loads with fewer and more efficient generating plants, thus holding down the cost of production.

Time-of-Day Rate Schedules varied from one power supplier to another. Generally, the rate schedule consisted of a two step rate for determining the energy charge (some suppliers had three) with each step based on a specific time period during the day. Energy consumption is first recorded using two meters or a meter with two registers which can determine the time of day the electrical energy is consumed. The time of day when each meter or register records energy consumption is determined by the power companies' Time-of-Day Rate Schedule. The program simulated Detroit Edison's Time-of-Day Rate Schedule with the first period, the on-peak period, extending from 11:00 a.m. to 6:00 p.m.; with the second period, the off-peak period, extending from 6:00 p.m. to 11:00 a.m. The rate charged for electrical energy consumed during the on-peak period of the day was usually higher than the rate charged for the off-peak period. The difference in cost was usually large enough to offer an incentive for the farm customer to operate much of the farm's electrical equipment during the off-peak period. The electrical energy use charges were calculated as follows:

Minimum Monthly Service Charge: $ 4.00

Energy Charge:

On-Peak	kWh	@	$ 0.0815	per	kWh
Off-Peak	kWh	@	$ 0.0315	per	kWh

This rate schedule can produce a monetary savings for the farmer who is able to shift much of the electrical energy consumption to the off-peak period. Farmers anticipating a switch to the Time-of-Day Rate Schedule should carefully analyze their electrical use throughout the entire day before switching. Cost savings must be evaluated with respect to any inconvenience resulting from the shift of electrical loads to the off-peak period. The shift to off-peak periods may result in a lower operating efficiency and even reduced productivity or, with an on-peak rate of $0.0815 per kWh, a much higher bill could occur if too much of the electrical energy was used during the on-peak period.

4.4.2 Energy Adjustment Charge

The fuel and purchased energy adjustment charge was applied to all rate schedules to make adjustments for the often fluctuating cost of fuel used to generate electricity. This production cost adjustment provision was generally different from one month to another, and in some cases this charge became a credit. In accordance with this provision the model added a fuel and purchased energy adjustment rate of $0.0038 per kWh consumed to the monthly bill.

4.4.3 State Sales Tax

A state sales tax exemption was available to farmers on the portion of their electrical energy bill for farm buildings utilized for direct production of a farm product. To be eligible for a sales tax exemption the farm operator had to complete a sales tax exemption form and file it with the utility company. The State Government decided on the amount of electrical energy used in the farm residence. The balance of the electrical energy used in farm buildings could then be exempt from sales tax charges. The model assumed no sales tax exemption and calculated a four percent sales tax on the energy charge portion of the bill. The assumption was due to the inconsistancy within the state's application of policy and the inconsistancy of application within other states.

5. MILKING SYSTEM SIMULATOR

Economic factors and a natural desire to lessen dairy labor loads has motivated dairymen to direct more attention to milking parlor automation. The milking process consists of up to 70 percent of total time spent in the milking parlor on an annual basis (Babson, 1976). Actual time spent in the milking parlor involves: assembling and sanitizing equipment, moving cows, washing and stimulating cows, milking, and cleaning.

Three basic types of milking parlor systems adapt well to extended automation (Babson, 1976): the Diagonal side-opening stall, the Sawtooth Herringbone, and the Rotary milking parlor (see Figure 2.1). Two other types, flat milking barns and conventional stanchion barns, have a limited capability for automation. Table 5.1 is a summary of the different milking systems and milking units recorded by the Michigan Energy Audit Survey (Appendix A). The Sawtooth Herringbone design, using a single milk receiving jar and low-mounted milk lines, was the most common milking parlor reported. The low-mounted milk lines allow milk to flow downward from the milking unit to the low-mounted lines thus reducing turbulence and obstruction to milking vacuum. While several farmers reported using weigh-jars incorporated into their low line systems, the performance of the system was not altered if the weigh-jars were installed so the milk entry equalled or was lower than the lowest point of the connecting milk hose. The low-line milking system shown in Figure 5.1 was representative of most of the systems surveyed, regardless of parlor type or herd size.

5.1 Simulator Development

The dairy farm milking system simulator was designed to simulate the low-line milking system in Figure 5.1 based on the results of the Michigan Energy Audit Survey. Many components make up the low-line milking system and they all must be compatible to provide the necessary cow milking capacity. Any reference to commercial products or trade names in this section does not imply discrimination or endorsement by the author. The Dairy Housing and Equipment Handbook (Midwest Plan Service, 1978) was used as a guide in the development of the simulation model, while the equipment performance data for various milking system combinations were furnished by Bow•Matic, 1979 and Surge, 1979 dairy equipment companies. All the information was adjusted to be in agreement with real situations as described and recorded by dairy farmers participating in the Michigan Energy Audit.

5.1.1 Milking Time

Performance of the simulated milking system was based on the capacity of the system measured in cows per minute. To calculate milking system performance, the model required the first five user inputs shown in Figure 5.2 and a previous input, the number of cows milked. The input parameters shown in Figure 5.2 include the beginning times for morning and evening milkings, the average yearly milk yield per cow, the estimated milking time per cow, and the number of milking units. The first calculation performed using these inputs, determines the variable EMILK which was the time when milking ends.

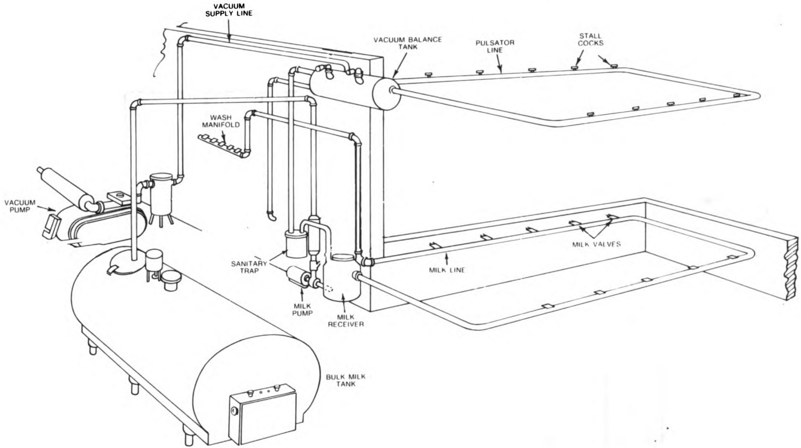


FIGURE 5.1 TYPICAL DOUBLE SLOPE LOW-LINE MILKING SYSTEM WITH A SINGLE MILK RECEIVING JAR.

FIGURE 5.2 OPERATIONAL FLOW CHART FOR MILKING SYSTEM SIMULATOR.

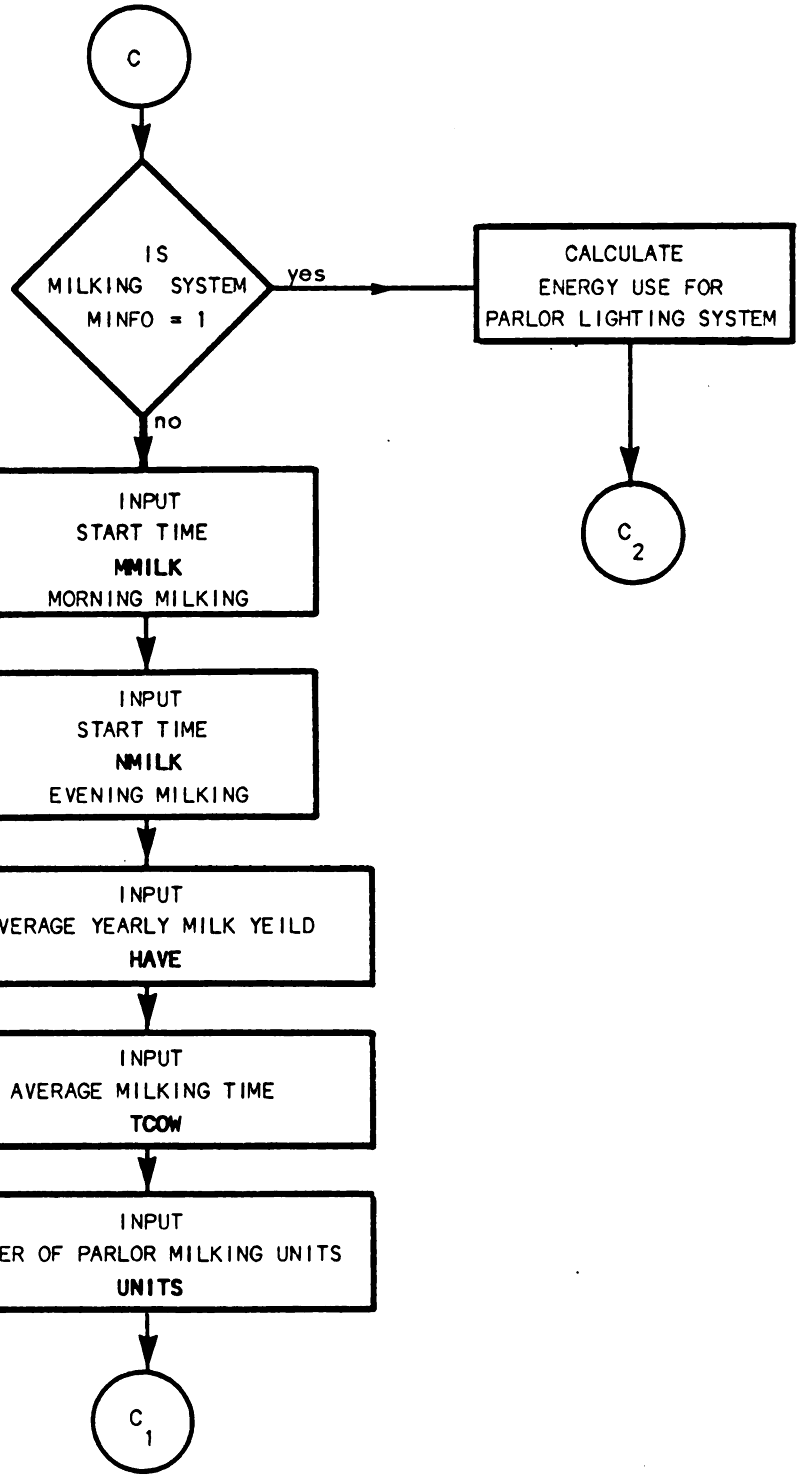


FIGURE 5.2 CONTINUED

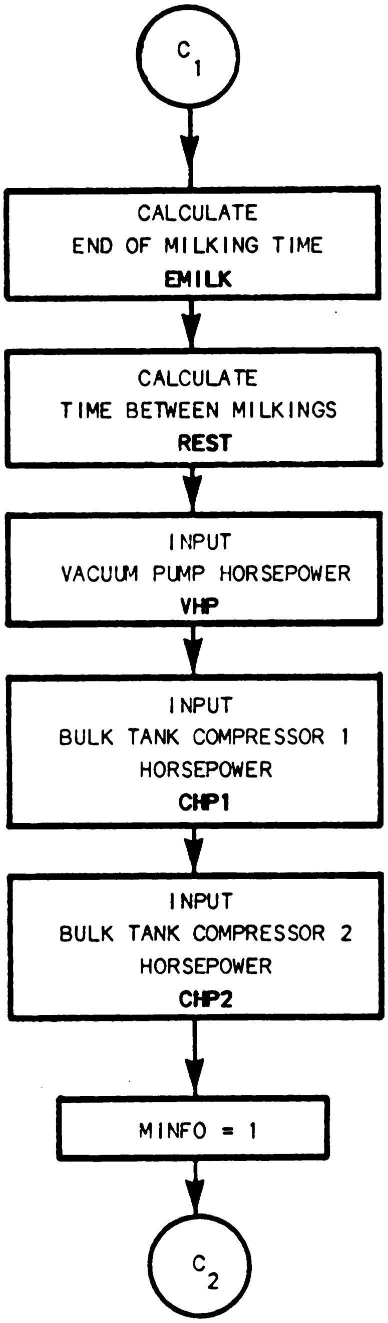
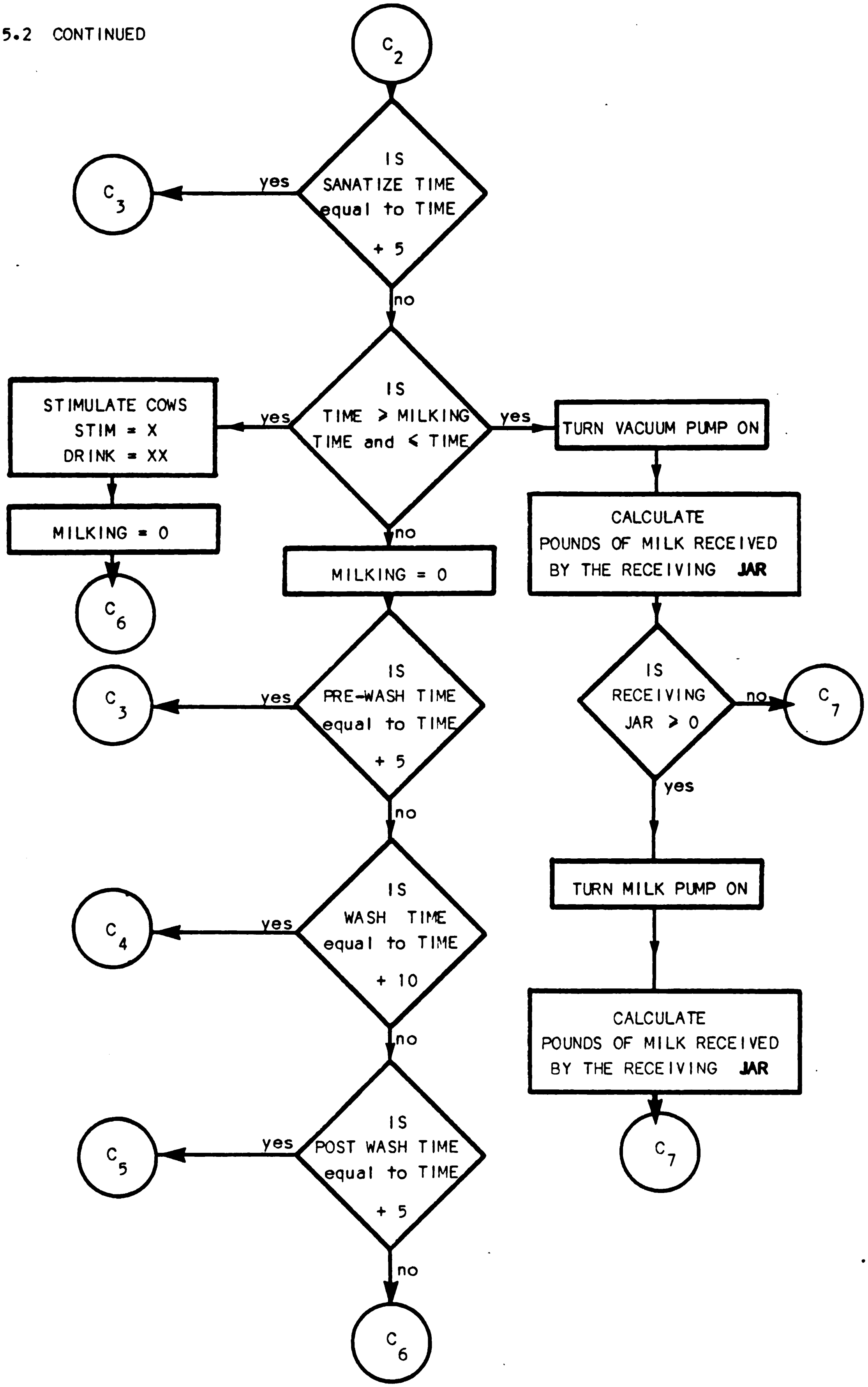


FIGURE 5.2 CONTINUED



$$EMILK = [(HSIZE * TCOW) \div UNITS] + SMILK \quad (5.1)$$

Where:

EMILK = end of milking (minutes after midnight)

HSIZE = number of cows milked (integer)

TCOW = estimated milking time per cow (minutes)

UNITS = number of milking units (integer)

SMILK = beginning time for milking (minutes after midnight)

The second calculation determined the variable REST which was the time between milkings. The combination of the two variables, EMILK and REST, determined the times when all parlor operations occurred.

$$REST = NMILK - MMILK \quad (5.2)$$

Where:

REST = time between milkings (minutes)

NMILK = evening milking time (minutes after midnight)

MMILK = morning milking time (minutes after midnight)

5.1.2 Milking Units

The number of cows a system can milk in a given period of time (Table 5.2) was directly related to the fifth user input, the number of milking units. The milking units themselves did not require a direct energy input to function, however, the number of units operated determined the vacuum requirement of the system. The essential components of the milking units were the teat cup assembly, air and milk hoses, and the claw.

The addition of automatic milking machine detaching units are intended to be a step-saving routine to protect the cow from injurious milking and permit the operator to be more efficient. Automatic detaching units do not necessarily improve labor efficiency simply because they save time required for the operator to remove the milking

TABLE 5.1 MILKING PARLOR DESIGNS USED BY MICHIGAN DAIRY FARMERS PARTICIPATING IN MICHIGAN ENERGY AUDIT.

Stanchion Barn[1]		**Sawtooth Herringbone Parlor**[2]	
Milking Units	Observations	Milking Units	Observations
3	1	3	1
4	2	4	3
		6	1
		8	5
		12	3
		16	1

[1] Around-the-barn pipeline.
[2] Low-line, with and without weigh jars.

TABLE 5.2 MILKING CAPACITY FOR MILKING FACILITIES WITH VARIOUS AMOUNTS OF AUTOMATION.[1]

Milking Facility Types[4]								
	Stanchion (3–6)							
	Diagonal (3–12)							
	Rotary (3–16)							
		Herringbone (4–24)						
Number of Milking Units:	**3**	**4**	**6**	**8**	**12**	**16**	**20**	**24**
Type of Mechanization								
None[3]	28	34	49	37	60	75[2]	86[2]	115[2]
Crowd Gates		36	51	42	65[2]	81[2]	94[2]	126[2]
Crowd Gates & Prep-Stalls	31	40	55	44	68[2]	70	97[2]	132[2]
Detacher Units		44	54	41	59	72	78	97[2]
Detacher Units & Crowd Gates				45	64	78	85	106
Detacher Units, Crowd Gates, and Prep-Stalls		48	58	47	67	82	89	111

[1] Derived from Babson Brothers Dairy Research Publication, 1976.
[2] Denotes the number of operators milking.
[3] A facility with base equipment including pipeline milking system.
[4] Steady-state throughputs, parlor set-up and clean up not included.

machine. The actual removal process represents only a small portion of the time that an operator spends with each cow. With the addition of automatic detachers, the amount of vacuum required per milking unit increases and thus the amount of energy required for the milking operation increases. Users of the program wishing to simulate automatic detaching units need only adjust the "milking time per cow" input and the horsepower requirement of the vacuum system.

5.1.3 Vacuum System

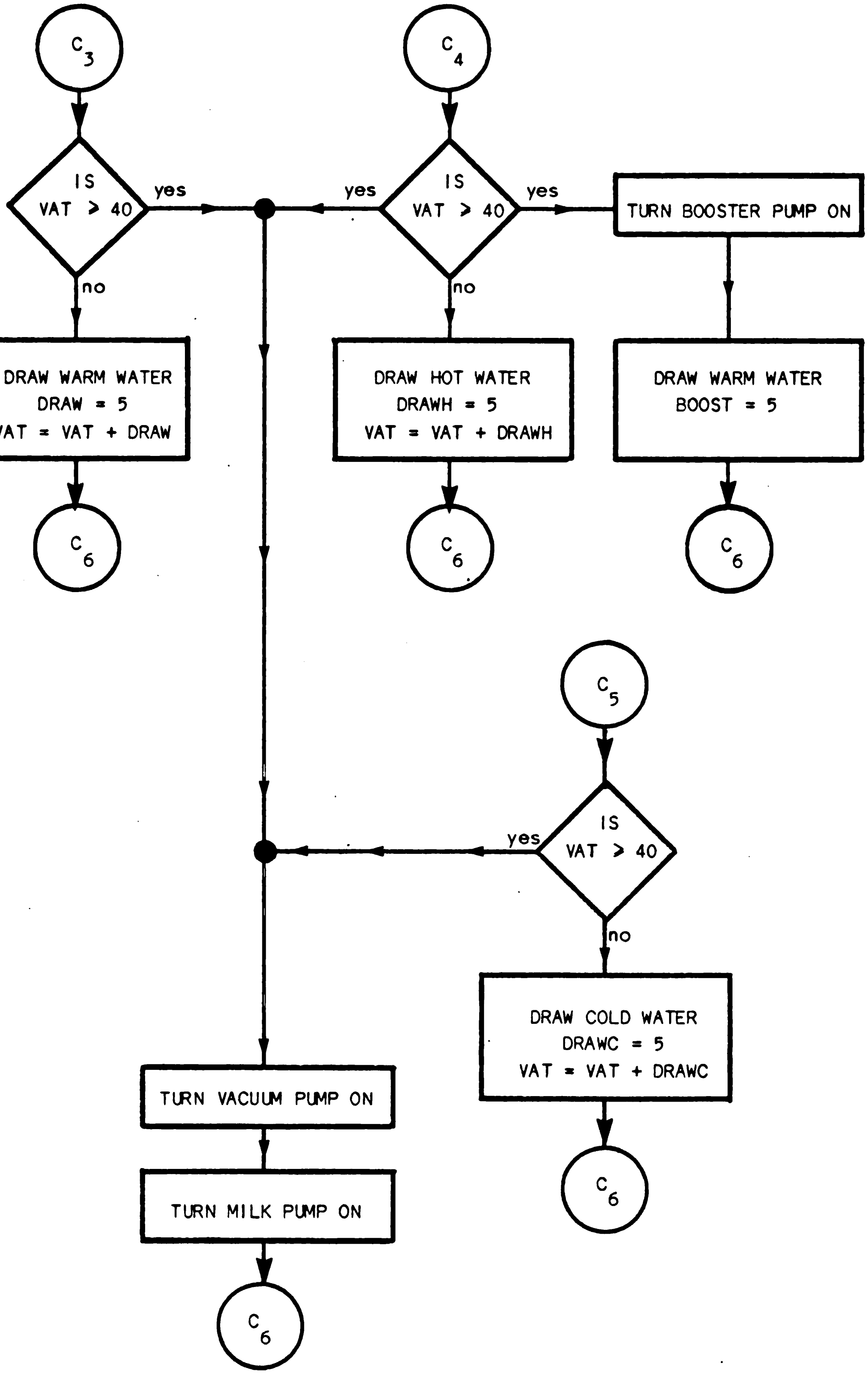
Two methods are used to rate the air flow of a vacuum pump. The New Zealand method measures air volume at half the vacuum the American Standard (15.0 inches of mercury) method does, so equivalent New Zealand cfm (cubic feet per minute) capacities are double the American Standard cfm capacities at equal vacuums. The required air flow capacity of a vacuum pump is based on the size and design of the system. The milking system model allowed for variations in system design by permitting the vacuum pump(s) horsepower to be a user input. The horsepower requirement for a vacuum pump can best be determined by obtaining the machine manufacturer's specifications.

5.1.4 Sanitation Equipment

The method used to clean any type of equipment depends on the nature of the material that needs to be removed. Circulation cleaning, used exclusively on large dairy farms, will adequately clean cold milk soil from milk handling equipment. The cleaning process is affected by time, temperature, turbulence, detergent concentration and composition, and water composition (U. of F., 1978). A standard procedure for circulation cleaning consists of a rinse, wash, acid rinse, and sanitize schedule.

The simulated cleaning cycle, CLEAN, shown in Figure 5.3 was designed for washing a pipeline system and bulk tank. Each cycle consisted of filling a wash vat with 40 gallons of water and then operating the vacuum and milk pumps to circulate the water through the system. The prewash rinse cycle consisted of circulating 105-110°F water for five minutes. The rinse cycle, immediately following the milking process, was designed to remove 95 percent or more of the soil load from the equipment and reduced the amount of detergent required during washing. The wash cycle used water at 170°F along with an alkaline, nonfoaming detergent. This cycle began after the prewash rinse and lasted ten minutes. Residual detergent and soil that was loosened during washing was removed during the five minute postrinse. The post-wash rinse used cold water and acid to clean the equipment and control the development of milkstone. Sanitation of the equipment with a chlorine sanitizer was delayed until just prior to the next milking so that any bacterial contamination of the equipment that might have occurred between the washing time and the next use would be destroyed. Operation of the sanitation cycle was identical to the prewash rinse except for the chlorine sanitizer added to the 105-110°F water. The simulated cleaning of the the milk handling equipment also included a parlor wash-down using a booster pump and water at 105-110°F. The parlor washing began five minutes after the end of milking and continued for ten minutes. The simulated booster pump was a one horsepower surge water gun with a water delivery rate of two gallons per minute.

FIGURE 5.3 FLOW CHART OF THE SUBROUTINE CLEAN



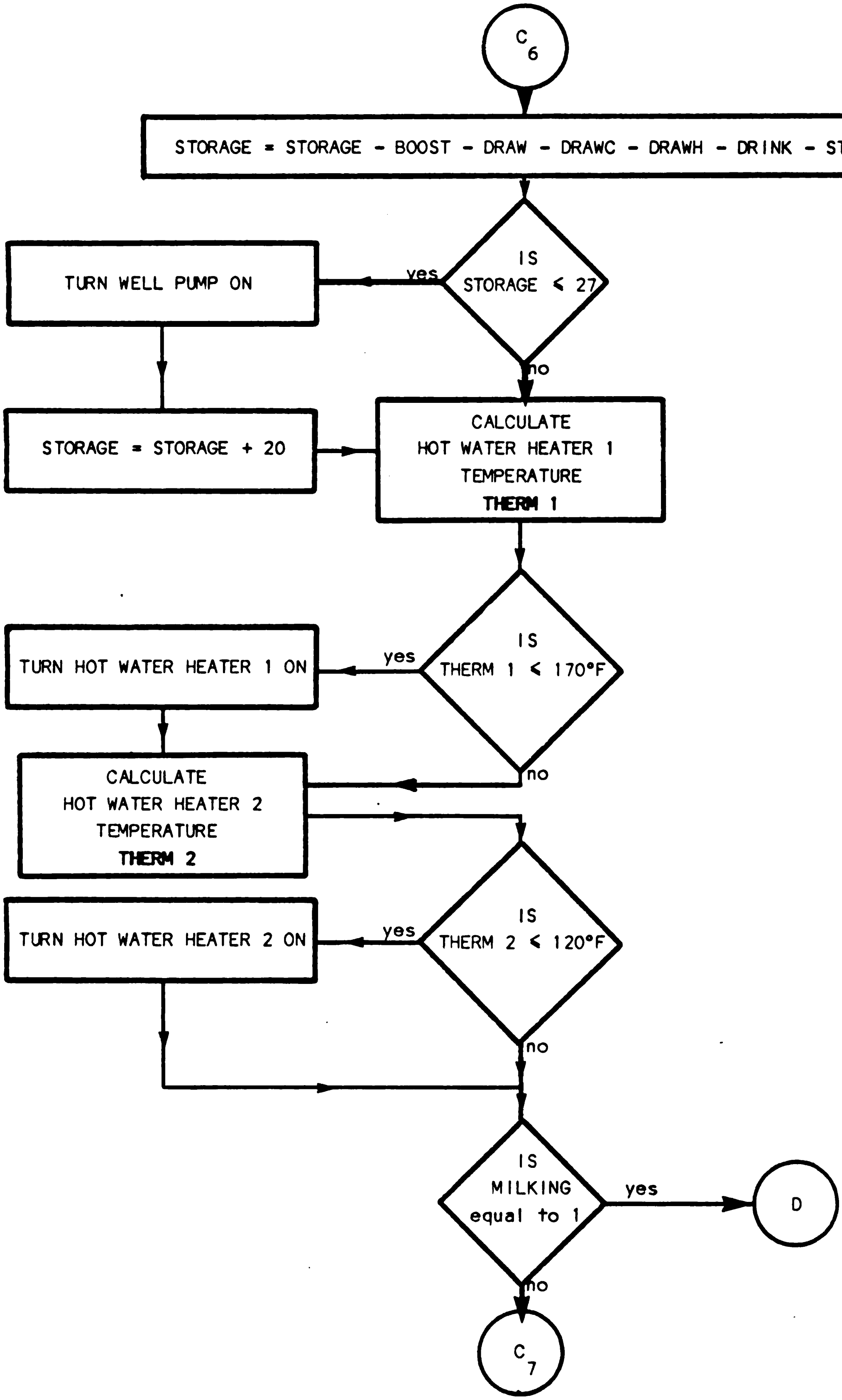
5.1.5 Water Heating and Supply System

Many of the operations within the milking system required an adequate water supply. The subroutine WATER, shown in Figure 5.4 simulated water use on an as-needed basis for the milking center and daily drinking water. The system modeled a two-inch deep well with a one horsepower submersible pump. The well supplied water to a 42 gallon pressure tank at a rate of 20 gallons per minute. The pressure tank supplied water to the hot water heaters, cold water for the parlor washing and daily drinking water. The water supplied for drinking begins immediately after each cow is milked and was calculated at a rate of 30 gallons per day per cow.

The two electric hot water heaters simulated in Figure 5.4 were for use in the milking parlor. Hot water heater one (HWAT 1) was modeled as a large hot water heater used by the major water heating loads required for washing the milking system and cleaning the parlor. Hot water heater two (HWAT 2) was modeled as a smaller hot water heater set at a lower temperature for prepping cows. The size and element wattage of the hot water heaters can be inputs to the program. In case of default the values assumed are 120 gallons and 6000-watts for HWAT 1 and 80 gallons and 4000-watts for HWAT 2.

Water drawn from either hot water heater was replaced by 50°F water from the water supply system. The temperature of the water mixture in the hot water tank was then recalculated. Equation 5.3 determined the temperature of the water mixture in the tank by assuming perfect mixing.

FIGURE 5.4 FLOW CHART OF THE SUBROUTINE WATER



$$HWAT_T = \{[(HWAT_C - HWAT_D) * HWAT_t] + (HWAT_D * 50)\} \div HWAT_C \quad (5.3)$$

Where:

$HWAT_T$ = new temperature of the hot water heater (°F)

$HWAT_C$ = capacity of the hot water heater (gal)

$HWAT_D$ = amount of water drawn from the water heater (gal)

$HWAT_t$ = previous temperature of the hot water heater (°F)

The result of Equation 5.4, THERM, was to turn on or off the heating elements of the hot water heaters. The thermostat for HWAT 1 was set to turn the element on at 170°F and off at 180°F. The thermostat for HWAT 2 was set to turn the element on at 120°F and off at 130°F. The equation also included a heat transfer coefficient of .004 Btu/ft^2•°F to determine loss or gain of heat to the environment.

$$THERM = [(HWAT_T - AMB) * EXP(-0.0167 * C_x)] + AMB \quad (5.4)$$

Where:

THERM = temperature of the water at the thermostat (°F)

$HWAT_T$ = new temperature of the hot water heater (°F)

AMB = ambient air temperature hot water heater room (°F)

EXP = preceding term is in exponential form

C_x = hot water heater heat transfer coefficient (Btu/ft^2• °F)

The hot water heater temperature was then recalculated using a specific heat coefficient of 0.0068 gal• °F/W• min. The equation assumed 100 percent heat transfer for one minute of heating. The new calculated temperature from Equation 5.5 was stored for use in the next minute of system operation. If no heating was required during the previous minute of system operation, $HWAT_t$ was equated to THERM.

$$HWAT_t = THERM + \left[ELWAT * (0.0068 \div HWAT_C)\right] \quad (5.5)$$

Where:

$HWAT_t$ = temperature of the hot water heater after heating (°F)

THERM = temperature of the water at the thermostat (°F)

ELWAT = element wattage of the hot water heater (watt)

$HWAT_C$ = capacity of the hot water heater (gal)

5.1.6 Washing and Stimulation

Proper premilking stimulation was the first and most important step in the milking operation. Thorough washing with warm water, massaging of the udder, drying, and stripping out foremilk was the most successful method of udder stimulation. Research indicated that udder stimulation done automatically using a prep-stall required a 45 second spray of 120°F water at a minimum pressure of 50 pounds per square inch (Babson, 1976). An alternate method to automated prep-stalls was a vigorous manual washing and massaging of the udder for 15 to 30 seconds.

The milking capacity of a system with no mechanization and one using prep-stalls is shown in Table 5.2. A conservative estimate of the time saved per cow milking using prep-stalls was 30 seconds. The amount of water required for automated prep-stalls, however, was four times greater than manual requirements. Equation 5.6 of the milking system simulator assumed manual prepping with a water requirement of 0.25 gallons per cow milking. Parlors using automated prep-stalls can be simulated by increasing the variable PGAL to one gallon per cow milking and making appropriate adjustments in the estimated milking time per cow.

$$PREP = (HSIZE * PGAL) \div (EMILK - SMILK) \qquad (5.6)$$

Where:

PREP	= water required for prepping	(gal/min)
PGAL	= water required for prepping	(gal/cow-milking)
EMILK	= end of milking	(minutes after midnight)
SMILK	= beginning time for milking	(minutes after midnight)

5.1.7 Milk Handling Equipment

In the low-mounted milk line system, milk flows downward from the milking unit and into the low-mounted lines which slope to the milkroom. Once in the milkroom, the milk is collected in a glass receiver jar. When the milk level in the receiver jar reaches an established point a magnetic float switch starts the milk pump. The milk is pumped from the receiver jar to the milk tank for cooling. When the milk level in the receiver jar drops the milk pump stops. A time-lag control allows the milk pump to operate long enough to remove the remaining milk in the glass receiver at the end of milking.

The milk handling section of the model assumed a 24 gallon receiving jar and a 0.5 horsepower milk pump with a capacity of 22 gallons per minute. The pounds of milk received by the receiving jar per minute was determined by Equation 5.7 while Equation 5.8 determined the total amount of milk contained in the receiving jar after each minute of pump operation.

JAR = (HSIZE * HAVG) ÷ (DMILK * 2) (EMILK - SMILK) (5.7)

Where:

JAR = amount of milk in the receiving jar (lbs/min)

HSIZE = number of cows milked (integer)

HAVG = average annual cow milk production (lbs/cow)

DMILK = average days in milk (integer, default = 305)

EMILK = end of milking (minutes after midnight)

SMILK = beginning time for milking (minutes after midnight)

JART = JART + JAR - DUMP (5.8)

Where:

JART = total pounds of milk in the receiving jar (lbs)

JAR = amount of milk in the receiving jar (lbs/min)

DUMP = JART, unless JART > 60 then DUMP = 60 (lbs/min)

5.1.8 Milk Cooling Systems

The most important single factor in maintaining milk quality is fast, proper cooling and holding of milk. The milk cooling system subroutine modeled a bulk tank designed for every other day pickup with two refrigeration compressors. Cooling requirements for milk in a farm bulk milk tank designed for every other day pickup were formulated using A.S.A.E. Standards developed by the International Association of Milk, Food and Environmental Sanitarians, the United States Public Health Service, and the Dairy Industry Committee (A.S.A.E., 1980). According to the requirements, a tank designed for every other day pickup shall cool 25 percent of the rated volume of the tank, containing raw milk, from 90°F to 50°F within one hour after the tank has been filled to 25 percent of its rated capacity, with the cooling system in operation during the filling period. For subsequent milkings the cooling capacity of the tanks must be capable of preventing the blend temperature of the milk from rising above 50°F at any time.

The size of the bulk tank and the horsepower of each compressor were designated as user inputs as shown in Figure 5.2. This allowed examination of a wide range of herd sizes without extensive changes to the program. In the case of parlors with a single cooling compressor, the horsepower input for the second compressor could be set to zero. A flow chart of the subroutine COOL MILK, shows the operation of the simulated milk cooling system (see Figure 5.5). The total amount of milk in the bulk tank each minute was determined by Equation 5.9.

$$TANK = TANK^1 + DUMP \qquad (5.9)$$

Where:

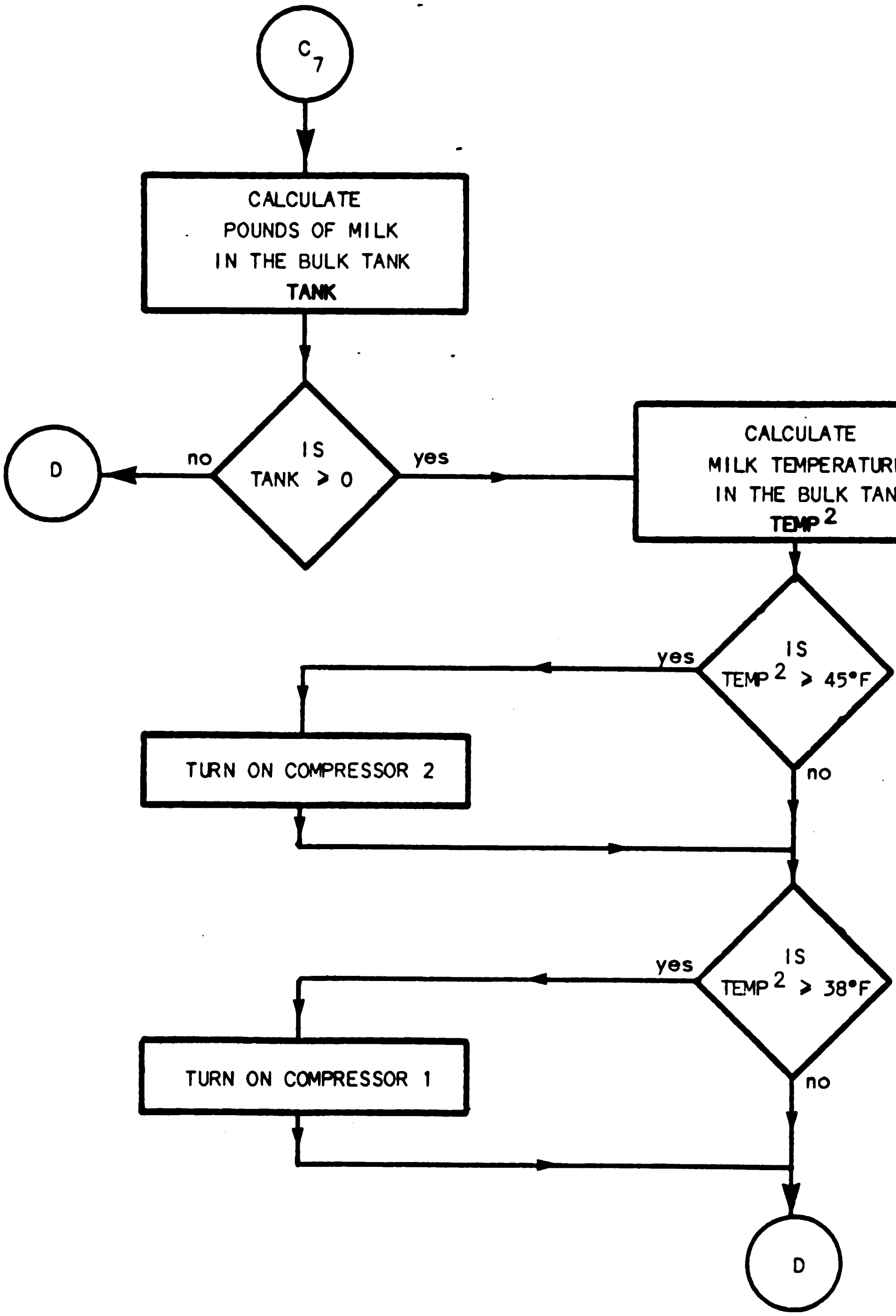
TANK = total amount of milk in the bulk tank (lbs)

$TANK^1$ = amount of milk previusly in the bulk tank (lbs)

DUMP = amount of milk pumped into the bulk tank (lbs)

Once the milk began to enter the bulk tank the temperature of the milk was checked continuously to determine when the compressor(s) would operate. The temperature of the milk in the bulk tank including any new milk pumped into the tank at 90°F was determined by Equation 5.10. The equation assumed a specific heat value of 1.0 Btu/lb•°F for milk (Bou•Matic, 1979).

FIGURE 5.5 FLOW CHART OF THE SUBROUTINE COOL MILK



$$TEMP^1 = [(TANK^1 * TEMP^3) + DUMP * 90] \div (TANK^1 + DUMP) \quad (5.10)$$

Where:

$TEMP^1$ = milk temperature in the bulk tank before cooling (°F)

$TANK^1$ = amount of milk previusly in the bulk tank (lbs)

$TEMP^3$ = milk temperature in the bulk tank after a heat gain or loss due to the environment (°F)

DUMP = amount of milk pumped into the bulk tank (lbs)

If the temperature of the milk in the bulk tank was greater than 45°F both refrigeration compressors were designed to operate. Once below 45°F the first compressor was designed to cool the milk down to 36-38°F. The amount of heat removed per minute from the milk was determined by the number of compressors operating, compressor horsepower, and design of the cooling system. A direct expansion cooling system, with the condensing unit as an integral part of the tank, has a cooling capacity of approximately 8000 Btu/hp• hr. The change in milk temperature using this type of system was modeled by Equation 5.11.

$$TEMP^2 = \left[TANK * TEMP^1) - (BTU\ 1 + BTU\ 2)\right] \div TANK \quad (5.11)$$

Where:

$TEMP^2$ = milk temperature in the bulk tank after cooling (°F)

TANK = total amount of milk in the bulk tank (lbs)

$TEMP^1$ = milk temperature in the bulk tank before cooling (°F)

BTU 1 = heat removed by compressor 1 (Btu)

BTU 2 = heat removed by compressor 2 (Btu)

Calculation of the milk temperature in both cases assumed perfect mixing of the milk. This was accomplished by allowing the agitator to operate whenever the refrigeration compressors were operating. The final calculation used a heat transfer coefficient of 0.004 Btu/ft^2•°F to determine heat gain or loss to the bulk milk tank because of the environment. The result of Equation 5.12 usually increased the needed cooling capacity five percent.

$$TEMP^3 = \left[(TEMP^2 - AMB) * EXP(-0.0167 * C_x)\right] + AMB \qquad (5.12)$$

Where:

$TEMP^3$ = milk temperature in the bulk tank after a heat gain or loss due to the environment (°F)

$TEMP^2$ = milk temperature in the bulk tank after cooling (°F)

AMB = ambient temperature in the milk room (°F)

EXP = preceding term is in exponential form

C_x = bulk tank heat transfer coefficient ($Btu/ft^2 \cdot °F$)

Energy saving devices, such as heat exchangers, especially plate or tube coolers, and heat recovery units for space heating or water heating, were not modeled. Validation of energy savings was not possible because an insufficient number of Michigan Energy Audit farms used such devices. Farms which reported the use of the heat recovery devices showed energy savings ranging from nine percent to thirty-five percent when compared to similar farms without the devices. Observations, although limited, correlated with performance values reported by eighteen New York farms (Koelsch, 1979).

5.2 Validation of Milking System Simulator

The milking system model was validated by simulating an actual milking system and comparing results obtained to actual requirements. A dairy farm, representative of the 21 dairy farms participating in the Michigan Energy Audit, provided the actual system and requirements needed for validation.

The farm used for validation was located in Caseville, Michigan. The farm milked 100 cows with a herd average of 15,914 pounds per cow. The milking system used was a basic Double-4 Sawtooth Herringbone parlor with eight milking units. The average milking time per cow, including manual washing and stimulation by one operator, was six minutes. The vacuum unit needed for this system required a ten horsepower pump to maintain sufficient vacuum pressure. The milk was pumped to a 2,000 gallon bulk milk tank designed for every other day pick-up with milk cooling accomplished by two five horsepower refrigeration compressors.

Water heating from 1978 to 1979 was done by two conventional electric hot water heaters with specifications similar to those described in Section 5.1.5. From 1979 to 1980 the main water heating load was assisted by the addition of a heat recovery unit. The unit, a Surge ARC condensing unit, utilized a special water cooled heat exchanger to condense the refrigerant from the milk tank, and at the same time heat water. The resulting hot water was transferred to a special tank for later use with the main hot water heater. If the water in this special tank reached 140°F, a valve closed and the refrigeration system was switched over to an air-cooled system.

5.2.1 Milking Parlor Validation

The values represented by the bar graph in Figure 5.6 indicate the total electrical energy consumption by the milking parlor each month from 1978 to 1980. The solid line drawn horizontally across the graph shows the total electrical energy consumed per month as predicted by the computer simulation. The line represents 3,653.7 kWh. The values which should be noted are the mean kWh and the standard deviations

FIGURE 5.6 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY MILKING PARLOR (Farm Number 32-0088).

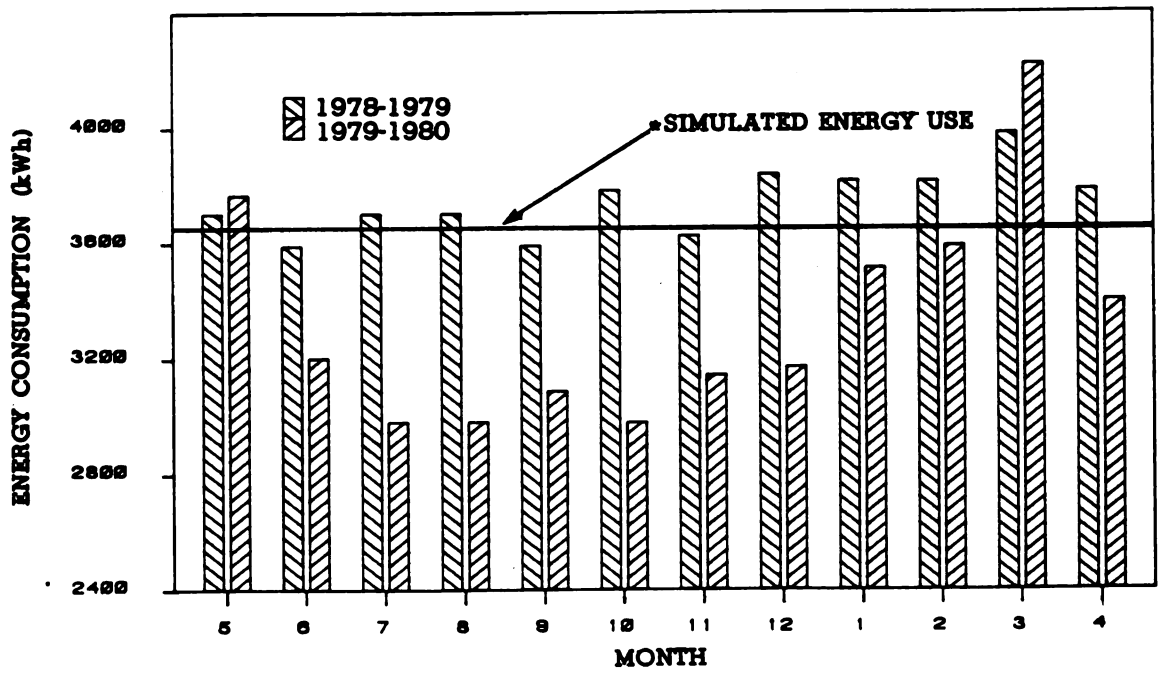


TABLE 5.3 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY MILKING PARLOR (Farm Number 32-0088).

MONTH	COMPUTER SIMULATION MEAN MONTH kWh	1978 to 1979 Total kWh	1978 to 1979 Simulation Difference %	1979 to 1980 Total kWh	1979 to 1980 Simulation Difference %
5	3,653.7	3,703	-1.33	3,768	-3.03
6	3,653.7	3,590	1.77	3,203	14.07
7	3,653.7	3,703	-1.33	2,982	22.53
8	3,653.7	3,703	-1.33	2,982	22.53
9	3,653.7	3,590	1.77	3,088	18.32
10	3,653.7	3,782	-3.39	2,980	22.61
11	3,653.7	3,625	0.79	3,143	16.25
12	3,653.7	3,838	-4.80	3,171	15.22
1	3,653.7	3,816	-4.25	3,513	4.01
2	3,653.7	3,814	-4.20	3,589	1.80
3	3,653.7	3,980	-8.20	4,219	-13.40
4	3,653.7	3,782	-3.39	3,401	7.43
TOTALS	43,844.4	44,926.0	*	40,039.0	*
MEAN	3,653.7	3,743.8	-2.41	3,336.6	9.50
Std. Dev.	*	114.7	*	379.8	*

calculated for each of the two years. The values for simulated and actual data are within one standard deviation both years despite the addition of the heat recovery unit. The other values given in the table indicate the percent difference between the simulated and actual results. The monthly values for the first year range from -8.20 percent to 1.77 percent with an average monthly difference of only -2.4 percent. The addition of the unmodeled heat recovery unit caused monthly values to range from -13.40 percent to 22.61 percent during the second year. The average monthly difference between the simulated and actual results was 9.50 percent.

5.2.2 Milking System Validation

The milking system consists of the milking units, vacuum pump and milk pump. Submetering of the electricity consumed per month by the vacuum pump and milk pump enabled validation of this system. Figure 5.7 provides a bar graph of the electricity consumed by the system from 1978 to 1980. The predicted electrical energy consumption was 1,067.4 kWh. The horizontal line across the bar graph represents the simulated energy consumed. It is evident that a major difference exists between the real and simulated systems for the first year of data. The values for 1978-79 differed an average of 15.47 percent. A major contributor to the difference between the simulated and the actual electricity consumed was the length of time the vacuum pump was allowed to operate. As a result of careful management of the system during the second year, the difference was decreased to less than one standard deviation. The monthly difference between the simulated and the actual electricity consumed for 1979-80 ranged from -24.72 percent

FIGURE 5.7 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY MILKING SYSTEM (Farm Number 32-0088).

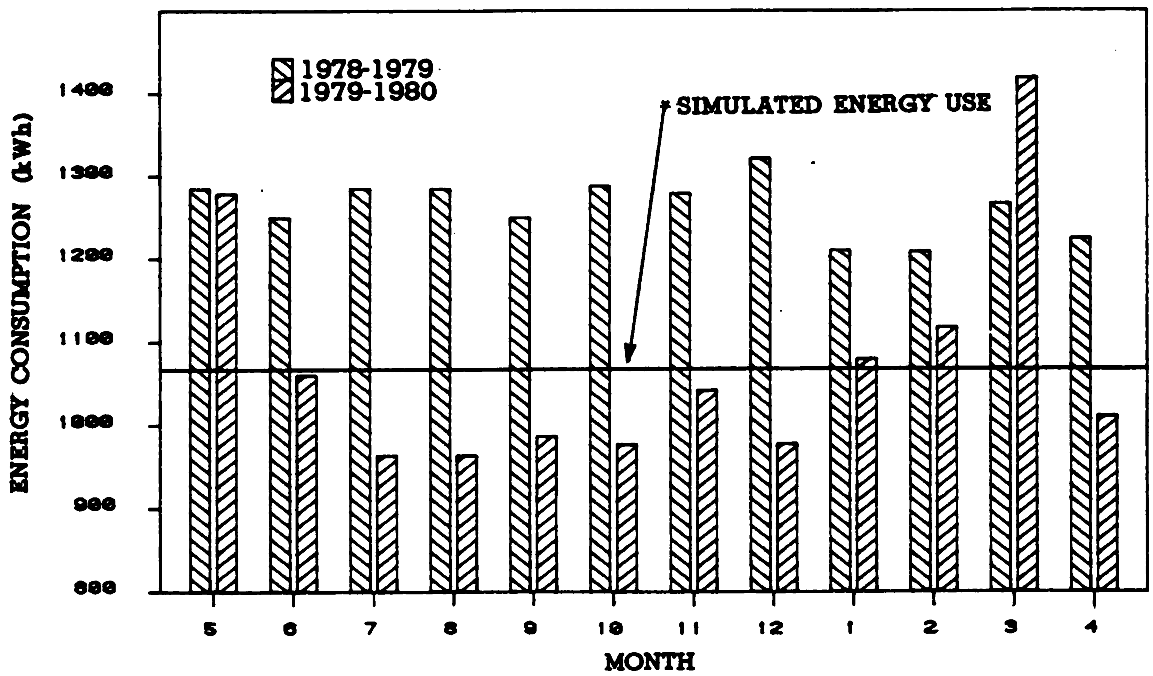


TABLE 5.4 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY MILKING SYSTEM (Farm Number 32-0088).

MONTH	COMPUTER SIMULATION MEAN MONTH kWh	1978 to 1979 Total kWh	1978 to 1979 Simulation Difference %	1979 to 1980 Total kWh	1979 to 1980 Simulation Difference %
5	1067.4	1,285	-16.93	1,279	-16.54
6	1067.4	1,250	-14.61	1,060	0.70
7	1067.4	1,285	-16.93	964	10.73
8	1067.4	1,285	-16.93	964	10.73
9	1067.4	1,250	-14.61	987	8.15
10	1067.4	1,288	-17.13	977	9.25
11	1067.4	1,279	-16.54	1,042	2.44
12	1067.4	1,321	-19.20	978	9.14
1	1067.4	1,210	-11.79	1,080	-1.17
2	1067.4	1,209	-11.71	1,118	-4.53
3	1067.4	1,267	-15.75	1,418	-24.72
4	1067.4	1,225	-12.87	1,011	5.58
TOTALS	12,808.8	15,154.0	*	12,878.0	*
MEAN	1,067.4	1,262.8	-15.47	1,073.2	-0.54
Std. Dev.	*	34.7	*	140.7	*

to 10.73 percent with an average of one half of one percent while still milking the same number of cows with approximately the same milk production.

5.2.3 Water Heating System Validation

This system was validated by comparing the simulated data to actual data obtained from submetering the two hot water heaters used in the parlor. The actual data obtained per month from 1978 to 1980 are shown by the bar graph in Figure 5.8. The water heating system was simulated using the appropriate input data for the real system during 1978-79. For the 1979-80 year, the input data were left unchanged even though a heat recovery unit was added to assist the main hot water heater.

The horizontal line across the bar graph represents the simulated energy consumed by hot water electrically heated for this farm. The simulated value of 1,521.4 kWh did not compare closely to the real values. Water heating for the real system during 1978-79 was lower than that predicted by over three standard deviations or 10.81 percent. A probable cause for this difference is less hot water was used for cleaning the system than was predicted.

The major difference between the real and simulated data for the second year was explained by the addition of the Surge ARC heat recovery unit. The Surge unit was a heat exchanger installed in the discharge line of the refrigeration compressor. Concentric tubes carry water and refrigerant gas in counter-current fashion. Equipped with a pump to circulate water through the heat exchanger, the Surge unit stored the water in a separate tank for future use by the main hot water heater. It should be noted that the 40.18 percent difference between the real and simulated energy use was greater than was expected

FIGURE 5.8 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY HOT WATER SYSTEM (Farm Number 32-0088).

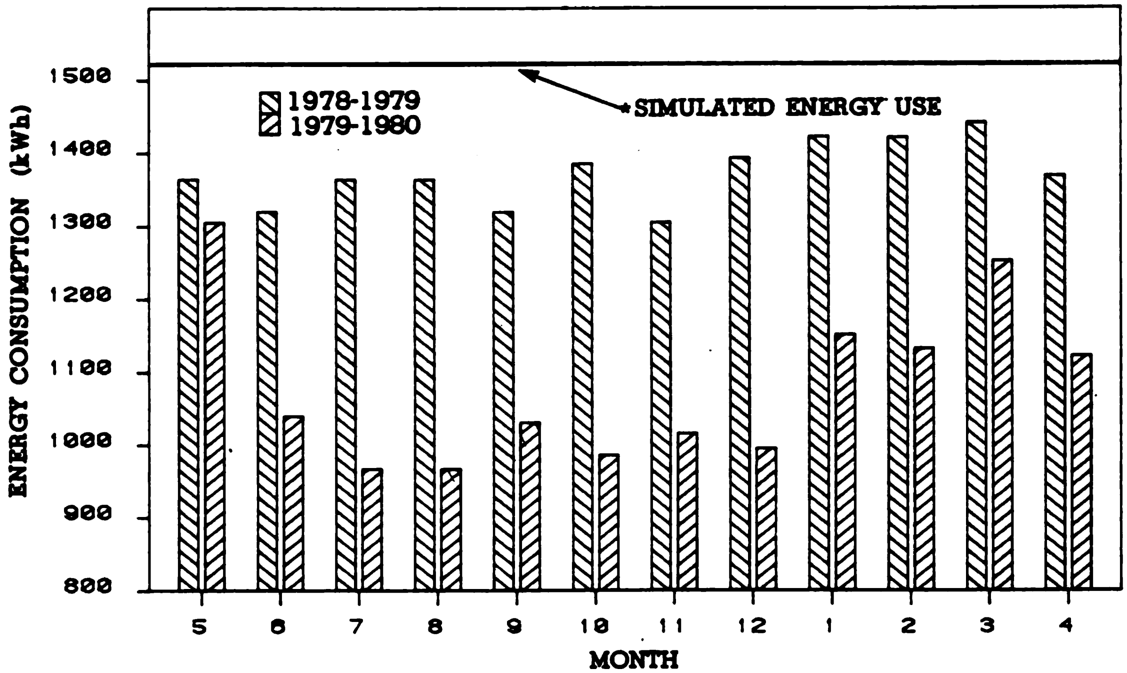


TABLE 5.5 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY HOT WATER SYSTEM (Farm Number 32-0088).

MONTH	COMPUTER SIMULATION MEAN MONTH kWh	1978 to 1979 Total kWh	1978 to 1979 Simulation Difference %	1979 to 1980 Total kWh	1979 to 1980 Simulation Difference %
5	1,514.4	1,364	11.03	1,305	16.05
6	1,514.4	1,320	14.73	1,040	45.62
7	1,514.4	1,364	11.03	967	56.61
8	1,514.4	1,364	11.03	967	56.61
9	1,514.4	1,320	14.73	1,031	46.89
10	1,514.4	1,386	9.26	986	53.59
11	1,514.4	1,305	16.05	1,016	49.06
12	1,514.4	1,393	8.72	995	52.20
1	1,514.4	1,423	6.42	1,151	31.57
2	1,514.4	1,422	6.50	1,132	33.78
3	1,514.4	1,444	4.88	1,252	20.96
4	1,514.4	1,369	10.62	1,122	34.97
TOTALS	18,172.8	16,474.0	*	12,964.0	*
MEAN	1,514.4	1,372.8	10.31	1,080.3	40.18
Std. Dev.	*	43.4	*	112.6	*

by the addition of such a unit. The 29.87 percent difference between the two years of real data was the approximate energy savings expected when adding this type of heat recovery (Koelsch, 1979).

5.2.4 Milk Cooling System Validation

The validity of the milk cooling system was checked by comparing the simulated energy consumed with the actual requirement of two refrigeration compressors. The actual energy requirements for the two compressors were obtained from a single submeter of the two units. The results of the 1978 to 1980 audits are shown by the bar graph in Figure 5.9.

The energy consumed by the milk cooling system is usually very consistent except during the spring months of February, March, and April, when milk production increases due to calving. The line drawn horizontally across the bar graph represents the simulated energy consumption for cooling the average monthly milk production. The computed value obtained for milk cooling was 1,064.9 kWh.

The simulated value compared closely with the average monthly energy consumed. During the first year the difference was 3.92 percent while the difference rose to just under 10.0 percent the second year. Variations from month-to-month ranged from -16.22 percent to 4.40 percent for 1978-79, and -31.25 to 4.71 percent from 1979-80. The monthly variations between actual and simulated energy consumption were expected because of fluctuations in herd milk production, especially during the spring. The larger variation which occurred during the second year may be attributed not only to milk production rates, which increased slightly the second year, but also to the addition of the Surge heat exchanger. The heat exchanger which uses water to assist

FIGURE 5.9 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY MILK COOLING SYSTEM (Farm Number 32-0088).

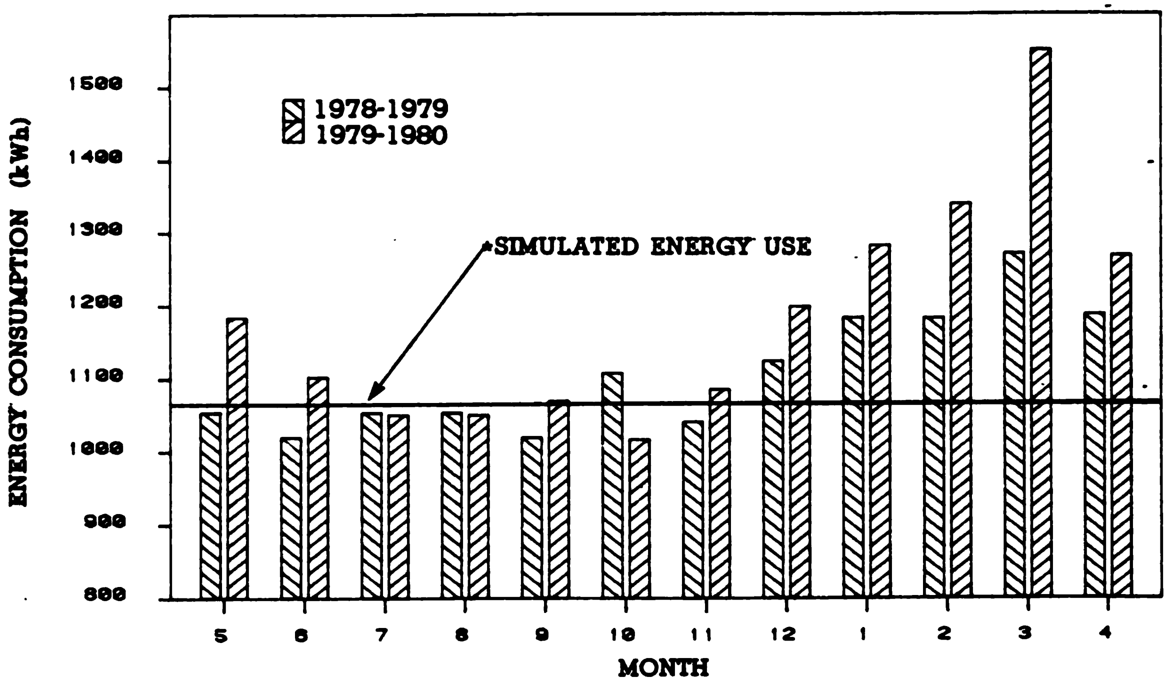


TABLE 5.6 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY MILK COOLING SYSTEM (Farm Number 32-0088).

MONTH	COMPUTER SIMULATION MEAN MONTH kWh	1978 to 1979 Total kWh	1978 to 1979 Simulation Difference %	1979 to 1980 Total kWh	1979 to 1980 Simulation Difference %
5	1,064.9	1,054	1.03	1,184	-10.06
6	1,064.9	1,020	4.40	1,103	-3.45
7	1,064.9	1,054	1.03	1,051	1.32
8	1,064.9	1,054	1.03	1,051	1.32
9	1,064.9	1,020	4.40	1,070	-0.48
10	1,064.9	1,108	-3.89	1,017	4.71
11	1,064.9	1,041	2.30	1,085	-1.85
12	1,064.9	1,124	-5.26	1,198	-11.11
1	1,064.9	1,183	-9.98	1,282	-16.93
2	1,064.9	1,183	-9.98	1,339	-20.47
3	1,064.9	1,271	-16.22	1,549	-31.25
4	1,064.9	1,188	-10.36	1,268	-16.02
TOTALS	12,778.8	13,300.0	*	14,197.0	*
MEAN	1,064.9	1,108.3	-3.92	1,183.1	-9.99
Std. Dev.	*	81.6	*	155.0	*

condensor cooling, can through mismanagement cause the condensing temperature to rise above 110°F. An increase in condensing temperatures results in an increase in discharge pressure which in turn decreases compressor efficiency.

5.3 Energy Requirements for Simulated Milking Systems

Many alternative systems or techniques are available to reduce labor and energy requirements for milking a dairy herd. The validated Milking System Simulator was used to predict energy requirements for milking six different herd sizes. The major emphasis was placed on scheduling milking times to take advantage of the Time-of-Day Rate Schedule, although both energy use and its costs were examined. The selected systems were designed to meet Bow•Matic high capacity milking parlor specifications. Assumptions used in the analysis of this work are described in the following sections.

5.3.1 Milking Time

The major assumption which affected all other milking parlor specifications was milking capacity. The milking capacity of the simulated farms was based on the average milking time of those farms surveyed. The total milking time for those farms was approximately two hours regardless of herd size. The average milking time per cow was six minutes with a range of five to ten minutes per cow.

Most farms began their milking operations at 5:15 a.m. and 4:45 p.m. Some farms began as early as 5:00 a.m. and 4:30 p.m. or as late as 7:00 a.m. and 6:30 p.m. The simulated systems were designed to begin milking at 5:00 a.m. and 4:30 p.m. The optimizing routine, TDAY, was then used to minimize electrical energy charges using the Time-of-Day Rate Schedule.

5.3.2 Milking Equipment

The milking equipment used to meet Bow•Matic specifications based on herd size are shown in Table 5.7. The number of milking units was determined by using an average milking time of six minutes per cow while maintaining the total milking time between 1.5 and two hours. The recommended horsepower for the vacuum pump was based on requirements for Bow•Matic rotary vacuum pumps assuming a New Zealand airflow rate of 20 cfm per milking unit.

The requirements for the bulk tank and refrigeration units were dictated by standard available sizes. The bulk tank sizes were calculated for a maximum of five milkings plus a ten percent reserve. The assumed milk production was 55 pounds per day per cow. The refrigeration compressors designed for direct expansion cooling and every-other-day pickup met A.S.A.E. Standards described in 5.1.8. The horsepower required to operate the compressors met Bow•Matic specifications.

TABLE 5.7 MILKING PARLOR EQUIPMENT INPUTS ASSUMED FOR SIMULATED MILKING PARLORS.

MILKING PARLOR EQUIPMENT		REQUIRED EQUIPMENT BY HERD SIZE				
		100	**150**	**200**	**250**	**300**
Number of Milking Units	(#)	8	10	12	14	16
Bulk Tank Size	(gal)	2000	2500	3000	4000	5000
Bulk Tank Compressor 1	(hp)	5	5	8	10	10
Bulk Tank Compressor 2	(hp)	5	5	8	10	10
Vacuum Pump	(hp)	10	10	12.5	15	17.5

5.3.3 Energy Requirements for Simulated Milking Parlors

The energy requirements for the simulated milking parlors are listed in Table 5.8. The table expresses the electrical energy use for each parlor system in kWh by herd size. As expected, the results show the total average energy requirements increasing from 3,089.99 kWh to 7,945.13 kWh as herd size increased. The electrical energy requirement on a per cow basis indicated "economy's of size." The small herd required 61.8 kWh per cow. While the simulated large herd needed only 26.5 kWh per cow. The difference in energy requirements per cow is explained by examination of the simulated energy requirements by milking parlor system.

The energy used by the milking and milk cooling systems, hot water for cow preparation, and the water supply system, will not explain the difference in simulated energy per cow. Each of these systems performed as expected. The simulated energy requirements for each system increase with herd size while maintaining approximately the same energy requirement per cow for each operation. The remaining two systems, the main hot water heater and the booster pump, are therefore responsible for the difference between the expected total energy consumption use and that shown in Table 5.8. The simulation results show little or no difference in the amount of energy consumed by these systems regardless of herd size.

The two systems used the main hot water heater and the booster pump for cleaning and washing the parlor and its milking equipment. The modeling method used for both systems assumes the same amount of water, detergent, and equipment operating hours used for these parlor operations, independent of herd or parlor size. In reality this may or

TABLE 5.8 SIMULATED MONTHLY ELECTRICAL ENERGY REQUIREMENTS IN KILOWATT•HOURS FOR MILKING PARLOR SYSTEMS BY HERD SIZE.

MILKING PARLOR SYSTEMS	MONTHLY ELECTRICAL ENERGY USE BY HERD SIZE				
	100	150	200	250	300
Milking System:					
Vacuum Pump	1,053.60	1,205.57	1,633.63	2,066.76	2,499.89
Milk Pump	13.76	19.75	25.61	29.30	30.57
Sub-Total (kWh)	1,067.36	1,225.32	1,659.24	2,096.06	2,530.46
Milk Cooling:					
Compressor 1	697.80	1,046.15	1,388.07	1,605.88	1,679.35
Compressor 2	273.55	495.22	496.48	448.38	471.19
Agitator	93.51	140.18	116.25	107.25	112.52
Sub-Total (kWh)	1,064.86	1,681.55	2,000.80	2,161.85	2,263.06
Water Heating:					
Water Heater - Main	1,521.39	1,521.42	1,521.42	1,521.42	1,521.42
Water Heater - Prep	312.02	435.65	549.14	649.46	737.62
Sub-Total (kWh)	1,833.41	1,957.07	2,070.56	2,170.88	2,259.04
Parlor Clean-up:	11.14	11.15	11.15	11.15	11.15
Water Pump - Well:	129.29	188.08	231.76	263.67	264.81
Lighting:	312.16	391.22	468.10	543.24	616.62
Total (kWh)	**4,418.89**	**5,454.39**	**6,441.61**	**7,246.85**	**7,945.13**

may not be true as it is highly dependent on operator preference, temperature, hardness of water, and the amount and type of detergent used in the cleaning operation. While the model assumed a standard operating procedure for an average milking parlor, as recommended by dairy equipment manufacturers, adjustments in the model can be made for individual farms.

The simulated energy requirements shown in Table 5.8 are not intended to be the actual energy requirements for the simulated herd sizes in all situations. Many factors affect the standard values presented. These standard values can be used as management tools to analyze specific operations and promote efficient energy use through conservation. For example, dairy operations using less energy than these standard values could be considered energy efficient while operations using more energy suggest a need for improvement in energy management.

5.3.4 Energy Cost

The various electrical energy rates charged by power suppliers provided another area for analysis through the use of the computer model. The monthly energy charges by herd size and electrical rate schedule are summarized in Table 5.9.

As expected, a savings resulted with the Farm Flat Rate as compared to the Inverted Rate. The savings realized was approximately 9.3 percent of the Inverted Rate for each herd size. In comparison to the Commercial Rate, a similar savings of 7.8 percent was realized.

The energy charges listed in Table 5.10 were calculated by the subroutine TDAY. The optimizing routine is capable of shifting the starting time for morning and evening milkings in order to minimize time-of-day electrical rate charges. The program maintained the 11 1/2 hour interval between morning and evening milkings while shifting the starting times at 15 minute intervals. The milking parlors on Time-of-Day metering with a milking time of 5:15 a.m. and 4:45 p.m. realized a 27 percent reduction in their energy charges over the Farm Flat Rate, and 34 percent over the Inverted Rate. Parlors which gained the maximum benefit from time-of-day metering had to change their starting time for milking. By delaying the start of milking by 1.5 hours, a savings of 24 percent was obtained. In comparison to the Farm Flat and Inverted Rates the savings amounted to 45 percent or more.

Generally, dairy operations switching to time-of-day metering will reduce their electrical energy operating costs. The shift to off-peak periods may result in lower operating efficiency and reduced productivity. Unless an appropriate milking time is selected and other electrical loads are controlled, the operating cost of a dairy operation could increase. Finally, time-of-day metering will not directly reduce the amount of energy consumed. Indirectly the amount of energy consumed may be reduced by virtue of the awareness created while controlling the electrical loads.

TABLE 5.9 MONTHLY ELECTRIC ENERGY CHARGES IN DOLLARS FOR SIMULATED MILKING PARLORS UTILIZING VARIOUS RATE SCHEDULES.

ELECTRICAL RATE SCHEDULE	ENERGY CHARGE IN DOLLARS BY HERD SIZE				
	100	150	200	250	300
COMMERCIAL RATE	277.68	341.45	402.25	451.84	494.84
INVERTED RATE	279.35	346.14	409.83	461.77	506.81
FARM FLAT RATE	255.41	314.64	371.11	417.17	457.11
TIME OF DAY RATE[1]	191.60	227.24	269.48	301.81	328.88
TIME OF DAY RATE[2]	144.10	173.29	207.03	232.62	255.17

[1] ON PEAK 11:00 a.m. to 6:00 p.m., 5:15 a.m. MILKING - 4:45 p.m. MILKING
[2] ON PEAK 11:00 a.m. to 6:00 p.m., 6:45 a.m. MILKING - 6:15 p.m. MILKING

TABLE 5.10 MONTHLY ELECTRIC ENERGY CHARGES IN DOLLARS FOR SIMULATED MILKING PARLORS UTILIZING TIME-OF-DAY RATE[1] SCHEDULES.

MILKING START TIME		ENERGY CHARGE IN DOLLARS BY HERD SIZE		
AM	**PM**	**100**	**200**	**300**
5:00	4:30	197.63	277.71	339.82
5:15	4:45	191.60	269.48	328.88
5:45	5:15	178.97	252.63	310.17
6:00	5:30	174.79	247.31	302.82
6:15	5:45	160.93	231.92	285.52
6:30	6:00	153.04	223.10	266.34
6:45	6:15	144.10	**207.03**	**255.17**
7:00	6:30	**137.56**	207.67	256.82
7:15	6:45	139.43	209.42	258.52
7:30	7:00	141.29	211.27	260.16

[1] ON PEAK 11:00 a.m. to 6:00 p.m.

6. FEEDING SYSTEM SIMULATOR

Dairy farmers had primarily two feeding system options. They could feed their herds with either a stationary (tower silo and mechanical feed bunk) or a mobile (bunker silo, mobile unloading boxes, and open feed bunks) feeding system. The choice of system depended on farmstead layout, barn layout, herd size, feed storage, feed type, investment cost, labor required, and operator preference. There was a third feeding system option, manual feeding, however, it was used only when the situation warranted and only if labor requirements could be satisfied.

6.1 Simulator Development

The Feeding System Simulator, like the Milking System Simulator, was an interactive model run as one of two options to the Dairy Farm Simulation Model. The development of the feeding system segment of the model required acquisition of data on which equipment and labor requirements for feeding the milking herd could be based. Data in the literature pertaining to these requirements were insufficiently documented or detailed to be of use to this part of the model. A study which reported data with sufficient detailed discussion of system design and collection method was the Cooperative Regional Project NC-119 (Speicher, 1979).

The NC-119 project, conducted in 1979 by Michigan State University and University of Minnesota personnel, determined labor inputs for stationary and mobile feeding systems on dairy farms. The project was a time and motion study of twenty Michigan dairy farms. The farms surveyed had many similarities with farms participating in the Michigan Energy Audit Study. Ten of the farms had stationary systems which were made up of upright silos, a series of flight conveyors, a stationary mixer and a mechanical feeder. The other ten farms had a mobile system consisting of a tractor drawn mixer wagon and a combination of upright and bunker silos. Data recorded on each farm included time required for: a) set up; b) setting the mixer load scale; c) loading various feeds; d) batch mixing; e) mixer wagon travel; and f) batch unloading. The results of the time and motion study, and information collected through the Michigan Energy Audit were utilized in developing the Feeding System Simulator shown in Figure 6.1. Any reference to commercial products or trade names in this section does not imply discrimination or endorsement by the author.

6.1.1 User Inputs

Performance of the simulated feeding system was dependent on over fifteen user inputs. The first two inputs, morning and evening feeding times, sequence all of the feeding events shown in Figure 6.1. The three questions which follow pertained to the forage, grain, and supplements fed on a dairy farm. While there were several feed types and storage units on the market, the feed types and storage units simulated were based on current practices as determined by the Michigan Energy Audit Survey (Appendix A). Feed types selected included corn silage, haylage, and high moisture corn. A user can select one or all three of the feed types and an appropriate silo type. The subroutine SILO, (Figure 6.2), allowed for a choice of either a bunker silo or an upright silo for each feed type along with the necessary support equipment.

The quantity of feed apportioned to each cow daily was also a user input to the subroutine SILO. The input was used in Equation 6.1 and Equation 6.2 to calculate total amount of feed apportioned per feeding and the amount of feed to be unloaded from each silo.

$$TFED = (FED^1 + FED^2 + FED^3)(HSIZE) \div 2 \qquad (6.1)$$

Where:

TFED	= total pounds of feed fed per feeding	(lbs)
FED^1	= pounds of corn fed per cow per day	(lbs)
FED^2	= pounds of haylage fed per cow per day	(lbs)
FED^3	= pounds of high moisture corn fed per cow per day	(lbs)
HSIZE	= number of cows milked	(integer)

$$FEDU = FEDU^1 - (100 \div UNR) \qquad (6.2)$$

Where:

FEDU	= pounds of feed remaining to be unloaded	(lbs)
$FEDU^1$	= pounds of feed to be unloaded	(lbs)
UNR	= silo unloading rate	(cwt/min)

The next input allowed users a choice with respect to mixing the feed ration prior to its delivery to the herd. If a mixer was chosen, the desired mixer type, with or without a weigh scale and the horsepower required to operate the unit, was selected.

FIGURE 6.1 OPERATIONAL FLOW CHART FOR FEEDING SYSTEM SIMULATOR.

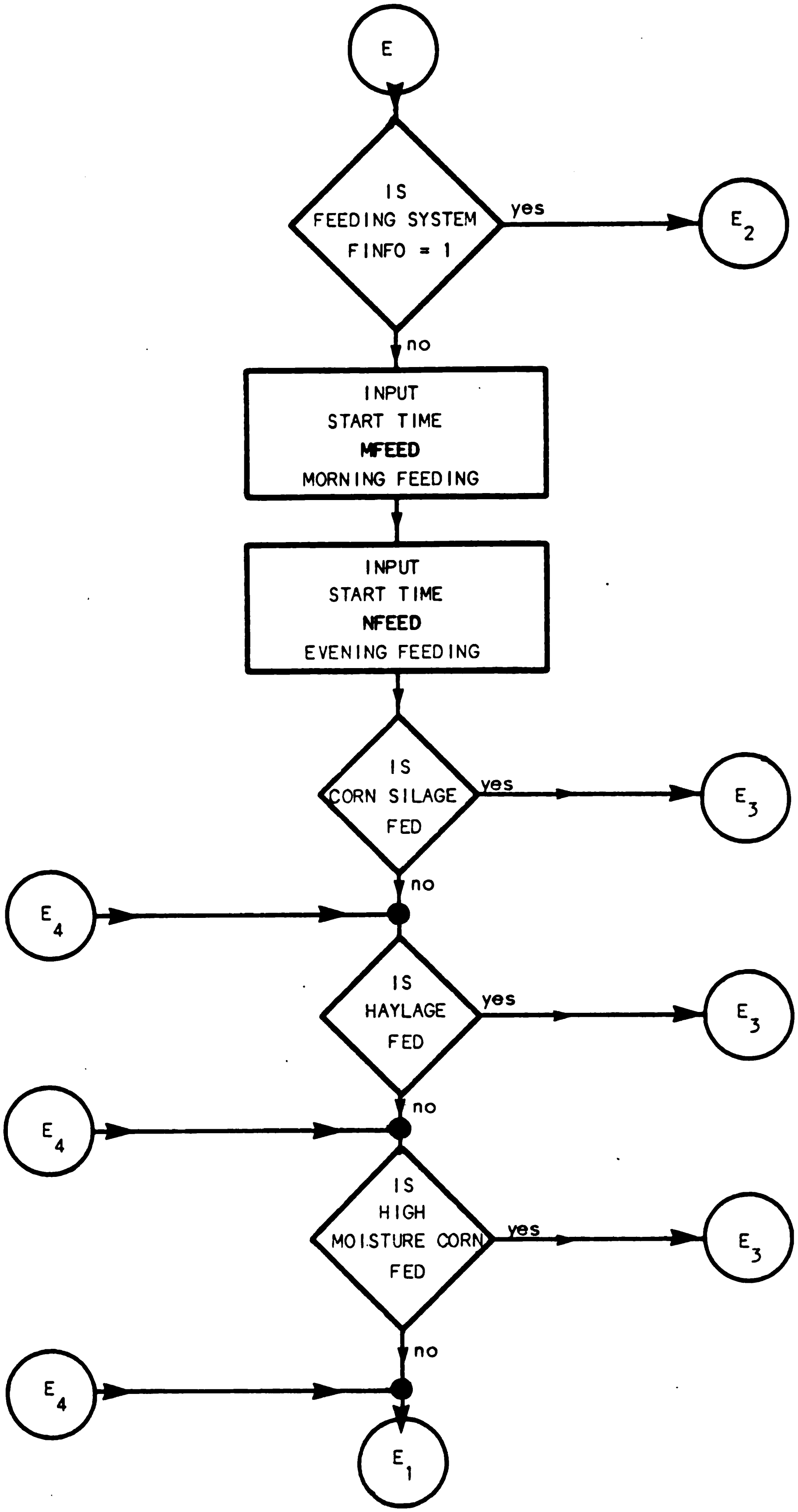


FIGURE 6.1 CONTINUED

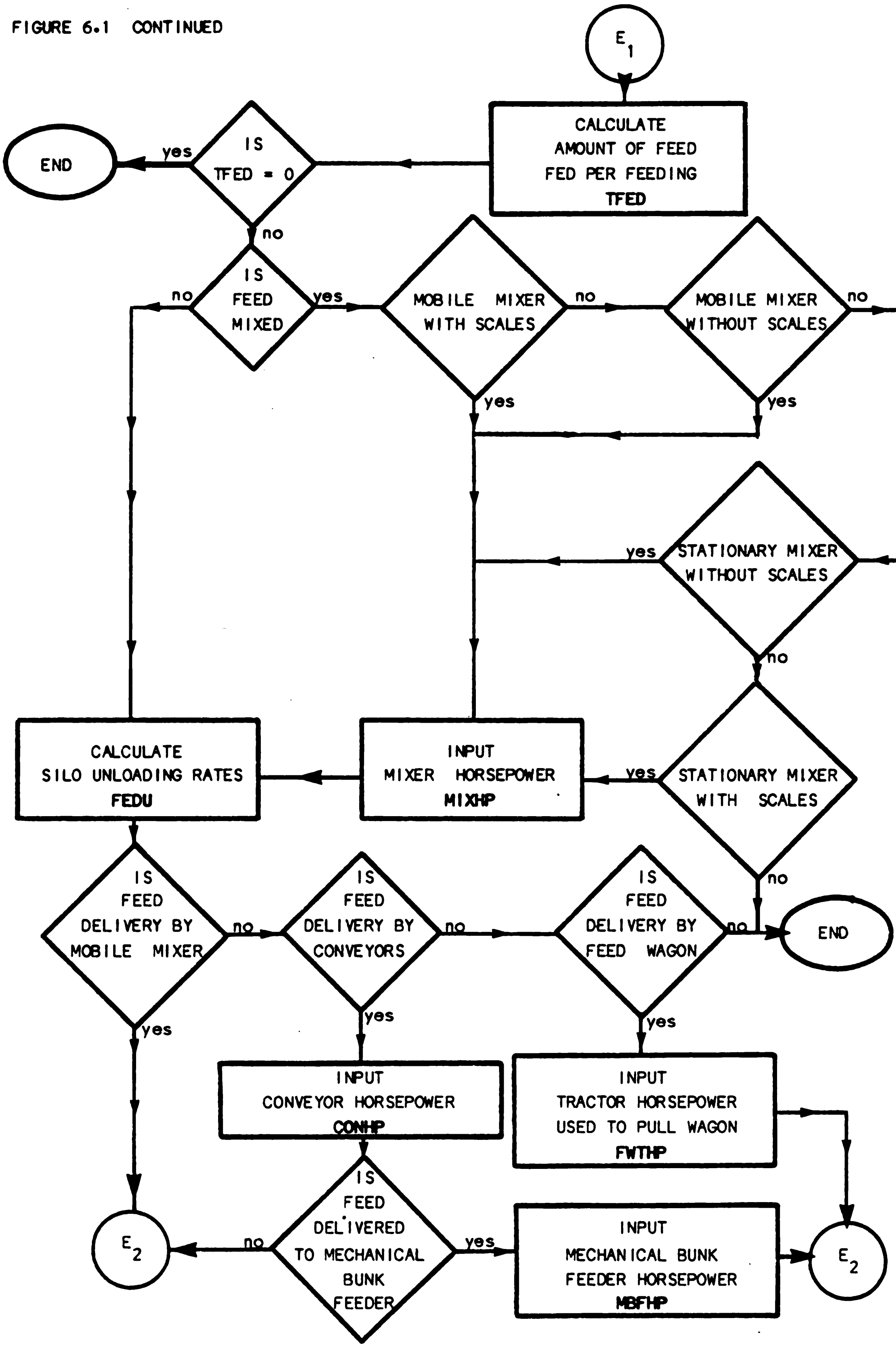


FIGURE 6.1 CONTINUED

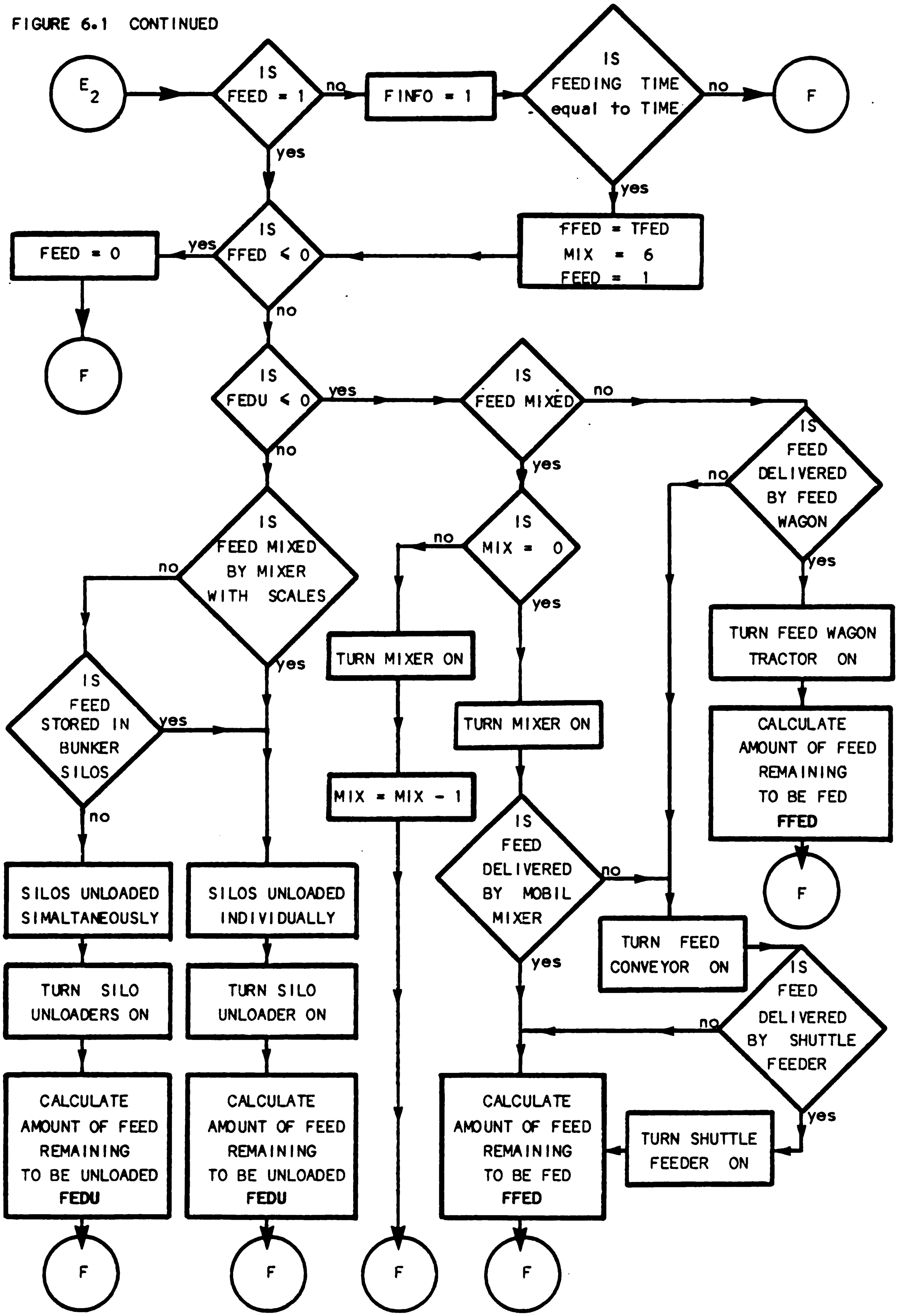
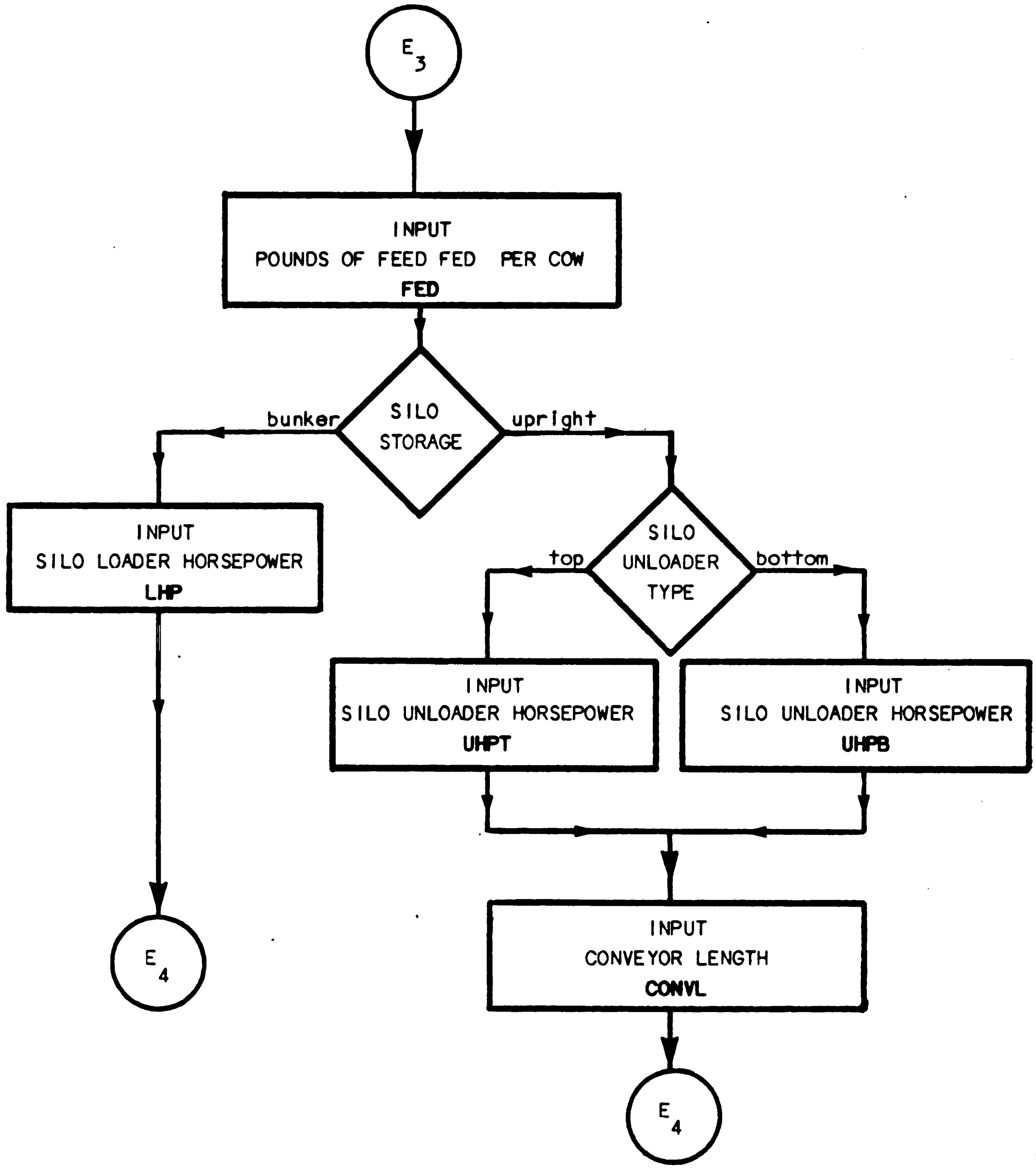


FIGURE 6.2 FLOW CHART OF THE SUBROUTINE SILO



The final set of user inputs related to the feed delivery method. A user analyzing a mobile feeding system could choose to deliver the feed by feed wagon or, a mobile mixer. A stationary feeding system allowed feed delivery by conveyor and/or mechanical bunk feeder or in rare cases, a mobile feed wagon. The time required to deliver the feed was based on the delivery method. Equation 6.3 assumed a feed mixer was used for feed delivery while, Equation 6.4 assumed a delivery rate adjusted for the system capacity of the delivery method.

$$FFED = FFED^{1} - (100 \div MIXUNR) \qquad (6.3)$$

Where:

FFED	= pounds of feed remaining to be fed	(lbs)
$FFED^{1}$	= pounds of feed to be fed	(lbs)
MIXUNR	= mixer unloading rate	(cwt/min)

$$FFED = FFED^{1} - (100 \div DELUNR) \qquad (6.4)$$

Where:

FFED	= pounds of feed remaining to be fed	(lbs
$FFED^{1}$	= pounds of feed to be fed	(lbs)
DELUNR	= system delivery rate	(cwt/min)

6.1.2 Time Requirements for Feeding Events

The variables used by the model to predict the daily and monthly labor and energy requirements for feed handling included: set up, feed loading, mixing, mixer unloading, travel time, and other miscellaneous chores associated with feed handling.

Time required to set up the feeding system, before feeding could begin ranged from two to seven minutes for farms with mobile feeding systems. Set up for the mobil system included starting two tractors and positioning them at a bunker silo. The set up time for stationary systems required only checking the system controls; a duration of less than one minute.

Time required to set mixer load cell scale ranged from 0.1 to 0.2 minutes in stationary systems and 0.2 to 1.3 minutes with a mobile mixer. Longer times associated with mobile feeding systems were due to the operator having to dismount and remount the loader tractor or skid loader and recalibrate the load cell every time the mixer was moved.

Time required to unload a feed type from a silo was recorded in minutes per hundredweight (min/cwt). Unloading rates for upright silos filled with high moisture corn, corn silage, and haylage are in Table 6.1. The tower silo unloading rates were influenced by the moisture content of ensilage, length of ensilage cut, ensilage compaction, ambient temperature, depth of unloader cut, and position of unloader balance weights.

The time to load bunker ensiled forages and high moisture corn with a tractor mounted loader or skid loader is shown in Table 6.2. Unloading rates for bunker silos included operator transit time from the mixer or feed wagon tractor to the loading device, time to load the desired amount of feed and the time to dump any excess feed. Very little difference existed between tractor mounted loaders, and skid loaders in loading rates on a minutes per hundredweight basis.

Batch mixing time varied greatly between farms and between feeding systems. Generally, feed mixing started when loading of the last feed was completed. The feed was mixed from two to six minutes before unloading started and lasted throughout the unloading process.

TABLE 6.1 UNLOADING RATES FOR UPRIGHT SILOS STORING CORN SILAGE, HAYLAGE, AND GROUND HIGH MOISTURE CORN.

FEED TYPE	SILO DIAMETER	UNLOADER TYPE	RATE	RANGE
	ft		**min/cwt**	**min/cwt**
Corn Silage	20	Top	0.41	0.36 to 0.62
	24	Top	0.47	0.36 to 0.62
	16 to 24	Bottom	0.21	0.19 to 0.24
Haylage	20	Bottom	0.61	0.56 to 0.69
	20 to 24	Top	1.10	0.73 to 1.80
Ground High Moisture Corn	14 to 20	Top	0.61	0.50 to 0.75
	16 to 24	Bottom	0.21	0.19 to 0.24

TABLE 6.2 UNLOADING RATES FOR BUNKER SILOS STORING CORN SILAGE, HAYLAGE, AND GROUND HIGH MOISTURE CORN.

FEED TYPE	UNLOADER TYPE	RATE	RANGE
		min/cwt	**min/cwt**
Corn Silage	Tractor with loader	0.21	0.07 to 0.35
	Skid Loader	0.17	0.06 to 0.23
Haylage	Tractor with loader	0.21	0.07 to 0.35
	Skid Loader	0.17	0.06 to 0.23
Ground High Moisture Corn	Tractor with loader	0.29	0.24 to 0.34
	Skid Loader	0.31	0.24 to 0.38

Batch unloading time was defined as the amount of time required for all feed to be placed into the feed bunk. In the stationary system the unloading time included travel time through a series of flight conveyors and the mechanical feeder. The unloading rate for the mobile mixer included travel time from the last load station to the feed bunk and the time required to return the equipment to the storage area. Table 6.3 is a summary of mixer unloading rates. In general, mobile systems were able to unload a hundredweight of ration in 0.20 minutes per hundredweight faster than stationary systems.

TABLE 6.3 STATIONARY AND MOBILE MIXER UNLOADING RATES (MIN/CWT).

FEEDING SYSTEM	RANGE min/cwt	AVERAGE min/cwt
Stationary[1]	0.14 to 0.46	0.30
Mobile[2]	0.03 to 0.12	0.08
Mobile[3]	0.17 to 0.26	0.20

1. Time for all feed to reach the feed bunk by conveyor.
2. Time to unload mixer with tractor positioned at the bunk.
3. Time to unload mixer starting at last loading position and ending when equipment is parked.

6.2 Validation of Feeding System Simulator

In order to verify the results obtained from the computer modeling procedure, the Feeding System Simulator was validated by simulating actual systems. Two dairy farms participating in the Michigan Energy Audit from 1978 to 1980 provided the actual system requirements. The simulated results were compared to the actual requirements of the real situation to form the validation. Validation of the stationary feeding system is described in Section 6.2.1, and validation of the mobile feeding system is described in Section 6.2.2.

6.2.1 Stationary Feeding System

A dairy farm in Caseville, Michigan, milking 100 cows, was used to validate the stationary feeding system options of the model. Feeding equipment used on the farm included four upright silos, a series of flight conveyors, and a stationary mixer which unloaded into two long flight conveyors connected to a mechanized bunk feeder.

The two silos used for corn silage were 20 by 70 feet conventional top unloading silos with ten horsepower motors. The haylage silo was an 18 by 70 feet sealed concrete silo with a five horsepower bottom unloader. The fourth silo, a steel 18 by 60 feet glass lined silo with a five horsepower bottom unloader was used to store high moisture corn. Silo flight conveyor length was influenced by the location of the upright silos and the stationary mixer located in the feed loading center. The conveyor lengths and the horsepower required for the above silos were: 30 feet and one horsepower for each of the corn silage silos, 30 feet and one horsepower for the haylage silo, and five feet and one horsepower for the silo storing high moisture corn.

The feed was loaded into a Model 1830 Oswalt mixer with scales and operated by a ten horsepower motor. Mixing started after the last feed was loaded and lasted for six minutes. The mixer continued to operate while unloading the feed ration into two 30-foot conveyors operated by one horsepower motors. The feed was conveyed to the feed bunk and distributed by a two horsepower shuttle feeder.

A comparison between the data simulated and actual energy consumed is shown in Figure 6.3. While each piece of equipment was not sub-metered the total energy used each month by the feeding system was recorded. The values on the bar graph represent the total electrical energy used each month for feeding the dairy herd from 1978 to 1980. The solid line drawn horizontally across the graph represents 471 kWh, the total electrical energy consumed per month as predicted by the computer simulation.

Values to note in Table 6.4 are the mean kWh and the standard deviation calculated for each of the two years. The variance between simulated and actual data were within one standard deviation in each case. The other values in the table indicate the percent difference between simulated and actual monthly data. These values ranged from -4.27 percent to 14.32 percent during 1978-79 and -21.50 percent to 14.32 percent during 1979-80. Although a wide variation existed monthly, the mean percent difference for each year was less than four percent.

6.2.2 Mobile Feeding Systems

A dairy farm in Stockbridge, Michigan was used to validate the mobile feeding system options of the model. In 1978 the milking herd included 39 cows, and in 1979 the herd size was increased to 50 cows. The feeding operation on this farm consisted of a wood and concrete bunker silo measuring 12 by 40 by 80 feet, and a 30 horsepower tractor mounted bucket loader. The silo was used to store a combination of corn and alfalfa silage. The silage was removed from the silo by the tractor mounted bucket loader and delivered by the bucket loader to a

FIGURE 6.3 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY STATIONARY FEEDING SYSTEM (Farm Number 32-0088).

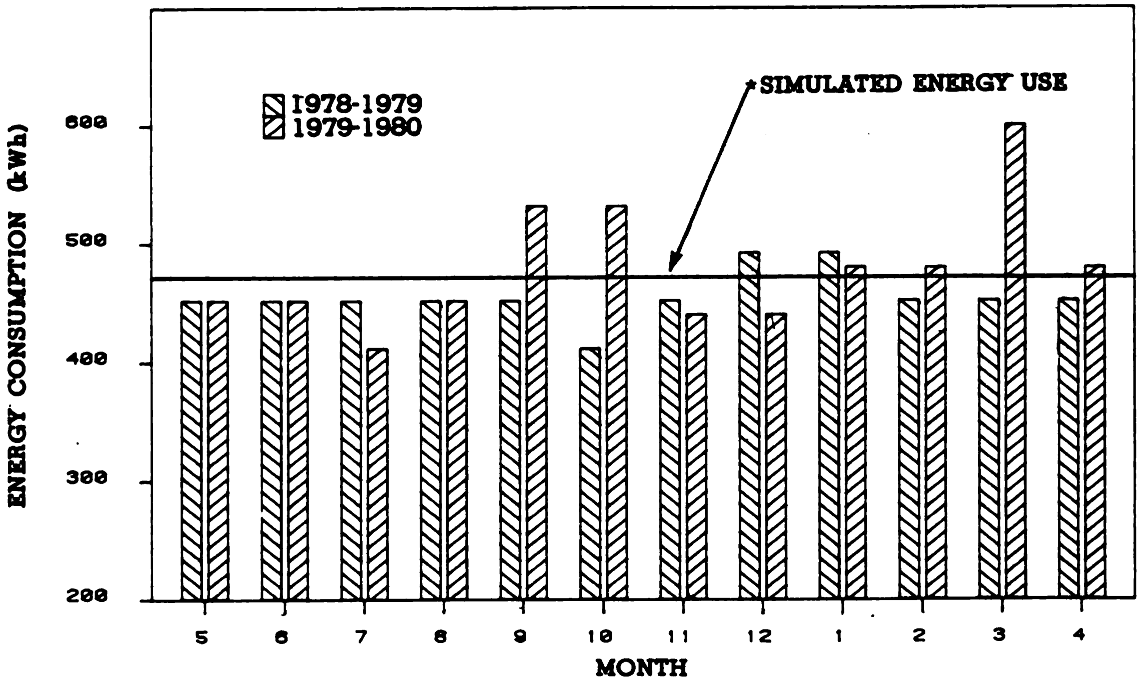


TABLE 6.4 MONTHLY SUMMARY OF SIMULATED AND ACTUAL ELECTRICAL ENERGY USE FOR THE CASEVILLE DAIRY STATIONARY FEEDING SYSTEM (Farm Number 32-0088).

MONTH	COMPUTER SIMULATION MEAN MONTH kWh	1978 to 1979 Total kWh	1978 to 1979 Simulation Difference %	1979 to 1980 Total kWh	1979 to 1980 Simulation Difference %
5	471.0	452	4.20	452	4.20
6	471.0	452	4.20	452	4.20
7	471.0	452	4.20	412	14.32
8	471.0	452	4.20	452	4.20
9	471.0	452	4.20	532	-11.47
10	471.0	412	14.32	532	-11.47
11	471.0	452	4.20	440	7.05
12	471.0	492	-4.27	440	7.05
1	471.0	492	-4.27	480	-1.88
2	471.0	452	4.20	480	-1.88
3	471.0	452	4.20	600	-21.50
4	471.0	452	4.20	480	-1.88
TOTALS	5,652.0	5,464.0	*	5,752.0	*
MEAN	471.0	455.3	3.45	479.3	-1.73
Std. Dev.	*	20.6	*	52.2	*

feed bunk located in the center of the free stall area. Concentrates were fed manually to the herd during the milking operation.

A similar system was simulated with the use of the computer model. Input parameters were used which closely represented the real experimental system. A comparison of the actual and simulated data are shown in Figure 6.4. Values on the bar graph represent the total diesel fuel used each month for feeding the dairy herd in 1978 and 1979. Solid lines drawn horizontally across the graph represent the simulated diesel fuel use per month for each of the two herd sizes for 1978 and 1979.

Values to note in Table 6.5 are the gallons of diesel fuel consumed and the standard deviations calculated for each of the two years and herd sizes. In each case, the difference between the actual and simulated values were within one standard deviation. The monthly percent difference ranged from -18.56 percent to 1.8 during 1978-79 and -25.43 percent to 4.40 percent during 1979-80. Each year the system required more diesel fuel than was predicted by the model. The mean percent difference indicated the model was 8.12 percent low during 1978-79 and 14.14 percent low during 1979-80. A major contributing factor related to this consistently low prediction was farm management. The operator elected to use the tractor mounted bucket loader to deliver each bucket load of feed to the feed bunk. The excess travel time related to this delivery method was not accounted for in the model since this was the exception rather than the rule among feed handling systems. Another factor affecting the low prediction for diesel fuel use was the variation in tractor engine fuel consumption due to environmental temperatures. In Figure 6.4 the increase in fuel

FIGURE 6.4 MONTHLY SUMMARY OF SIMULATED AND ACTUAL DIESEL FUEL USE FOR THE STOCKBRIDGE DAIRY MOBILE FEEDING SYSTEM (Farm Number 32-0270).

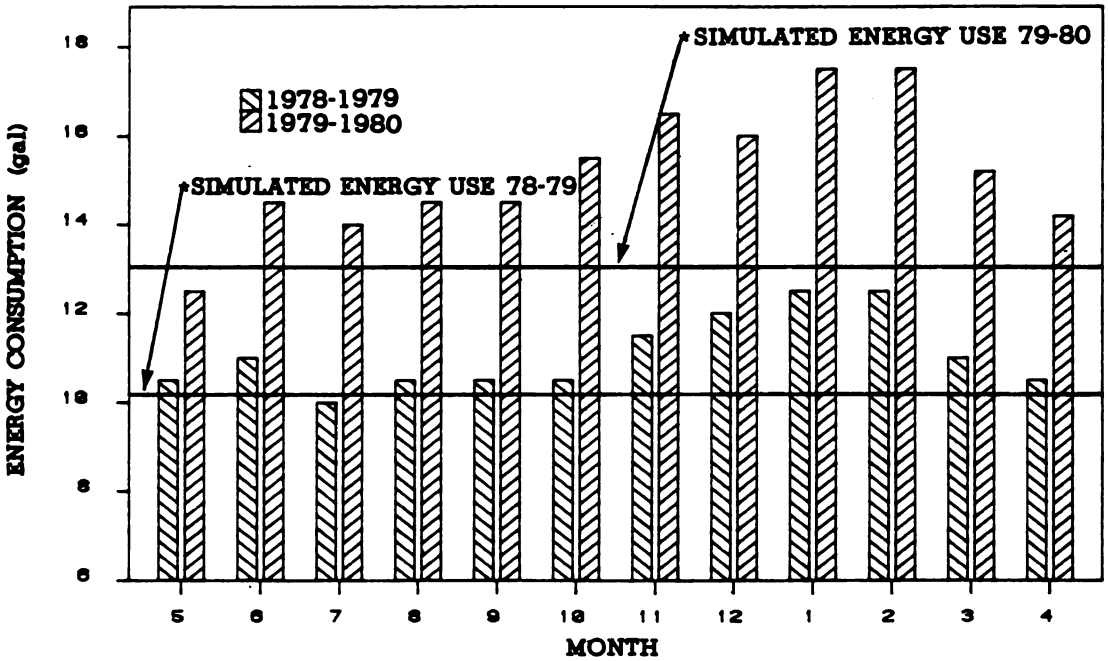


TABLE 6.5 MONTHLY SUMMARY OF SIMULATED AND ACTUAL DIESEL FUEL USE FOR THE STOCKBRIDGE DAIRY MOBILE FEEDING SYSTEM (Farm Number 32-0270).

MONTH	39 COWS COMPUTER SIMULATION MEAN MONTH gal	1978 to 1979 Total gal	Simulation Difference %	50 COWS COMPUTER SIMULATION MEAN MONTH gal	1979 to 1980 Total gal	Simulation Difference %
5	10.18	10.5	-3.05	13.05	12.5	4.40
6	10.18	11.0	-7.45	13.05	14.5	-10.00
7	10.18	10.0	1.80	13.05	14.0	-6.79
8	10.18	10.5	-3.05	13.05	14.5	-10.00
9	10.18	10.5	-3.05	13.05	14.5	-10.00
10	10.18	10.5	-3.05	13.05	15.5	-15.81
11	10.18	11.5	-11.48	13.05	16.5	-20.91
12	10.18	12.0	-15.17	13.05	16.0	-18.44
1	10.18	12.5	-18.56	13.05	17.5	-25.43
2	10.18	12.5	-18.56	13.05	17.5	-25.43
3	10.18	11.0	-7.45	13.05	15.2	-14.14
4	10.18	10.5	-3.05	13.05	14.2	-8.10
TOTALS	122.16	133.0	*	156.60	182.40	*
MEAN	10.18	11.08	-8.12	13.05	15.20	-14.14
Std. Dev.	*	0.85	*	1.47	*	*

consumption during the winter months, November, December, January, and February is graphically shown. Presently, the model does not have the requisite weather simulation package necessary to adjust the fuel consumption equation, for temperatures less than 75°F and a barometric pressure less than 28.60 inches of mercury (Equation 4.5).

6.3 Energy Requirements for Simulated Feeding Systems

There was considerable variation in daily feeding chore time and energy use with respect to feeding systems among the farms surveyed. The daily chore time for mobile systems averaged 0.58 minutes per cow, with a range of 0.20 to 1.80 minutes, and an average of 0.012 gallons of diesel fuel per cow was consumed. The daily chore times for stationary systems averaged 0.70 minutes, with a range of 0.30 to 1.20 minutes per cow, and an average of 0.17 kWh per cow per day was consumed. Variations in chore time and energy consumption were explained by differences in: a) ration components; b) number of cow groupings; c) number of feedings; d) silage unloading rates; e) travel time connected with mobile systems; f) batch unloading rates; and g) farmstead layout. To enable a fair comparison between both feeding systems these factors had to be controlled.

The Feeding System Simulator allowed the user to input many of the variables which control the feed handling system and subsequent variations in daily chore time and energy consumption. The ability of the simulator to analyze feeding systems was demonstrated by the simulation of two feeding system designs, a mobile and a stationary design, with similar feed rations. The basic design of each simulated feed handling system is shown in Figure 6.5 and Figure 6.6.

The analysis of the two systems included a complete capital investment and an operating cost breakdown. The equipment and practices selected for each system were based on comparable systems and equipment described in the Michigan Energy Audit Survey (see Appendix A). Prices for simulated feeding systems were determined from individual component prices. The prices reflected factory prices for new equipment, and varied widely depending on equipment size, options selected, and terms of sale. Prior to making a decision regarding any feeding system, dairymen will want to check with local suppliers.

6.3.1 Herd Size

The simulated farms consisted of five specific herd sizes. The herd sizes selected, 100, 150, 200, 250, and 300 cows, represented the average number of cows milked daily. Sizes were selected from those previously examined by the Michigan Energy Audit Study and represented those most commonly found in Michigan.

6.3.2 Feed Ration

The feeding of dairy cattle for maximum production with a minimum feed cost per hundredweight (cwt) of milk required a balanced mixture of forage and grain (Bath, 1978). Although computer formulated dairy rations based on least cost, milk price, cow maintenance, and levels of milk production and fat content were available, the ration assumed for analysis was based on sample rations fed by Michigan Energy Audit cooperators. The balanced feed ration, shown in Table 6.6 and 6.7, consisted of dry hay, haylage, corn silage, high moisture corn, soybean meal, and minerals.

TABLE 6.6 RATION FORMULATED FOR A 1400 POUND COW PRODUCING 55 POUNDS OF MILK (3.5 PERCENT FAT) DAILY.

FEED TYPE	DRY MATTER BASIS AMOUNT FED lbs	AS FED BASIS AMOUNT FED lbs	AS FED BASIS TOTAL RATION %
ALFALFA HAY (AVERAGE)	2.70	3.00	3.210
ALFALFA SILAGE (EARLY)	4.80	12.00	12.820
CORN SILAGE (AVERAGE)	21.00	60.00	64.100
ROUGHAGE SUBTOTAL	**28.50**	**75.00**	**80.130**
HIGH MOISTURE CORN	10.40	14.00	14.960
SOYBEAN MEAL	3.90	4.40	4.700
DICALCIUM PHOSPHATE	0.19	0.20	0.210
CONCENTRATE SUBTOTAL	**14.49**	**18.60**	**19.870**
RATION TOTAL	**42.99**	**93.60**	**100.000**

TABLE 6.7 NUTRITIONAL CONTENT OF RATION FORMULATED IN TABLE 6.6.

FEED TYPE	NE Mcal	PROTEIN lbs	Ca lb	P lbs	TDN lbs	DM %
	DRY MATTER BASIS					
ALFALFA HAY (AVERAGE)	1.59	0.4644	0.0338	0.006	1.566	90
ALFALFA SILAGE (EARLY)	2.83	0.8592	0.0614	0.011	2.784	40
CORN SILAGE (AVERAGE)	15.14	1.7010	0.0567	0.042	14.700	35
ROUGHAGE SUBTOTAL	**19.56**	**3.0246**	**0.1519**	**0.059**	**19.050**	
HIGH MOISTURE CORN	9.58	1.0400	0.0031	0.032	9.464	74
SOYBEAN MEAL	3.29	2.0202	0.0140	0.029	3.159	89
DICALCIUM PHOSPHATE	0.00	0.0000	0.0450	0.036	0.000	96
CONCENTRATE SUBTOTAL	**12.87**	**3.0602**	**0.0621**	**0.097**	**12.623**	
RATION TOTAL	**32.43**	**6.0848**	**0.2140**	**0.156**	**31.673**	

In order to insure accurate weighing of ingredients and a consistently balanced ration, both systems utilized an Oswalt mixer equipped with a four-point load cell scale. The Oswalt mixer used a three auger design which moved the feed from front-to-back as well as from side-to-side within the mixer. The design enabled the ration to be mixed in four to six minutes (Butler Manufacturing, 1979). An electrically powered mixer was selected for the stationary feed handling system, while a trailer mounted mixer powered by a diesel tractor was chosen for the mobile system.

6.3.3 Feed Storage

There were several storage units on the market for both forage and grain. Using the same type of storage for all feed materials, while simplifying system mechanization, may not be appropriate (or expedient). Significant cost differences exist with respect to structure and unloader type so that a specific choice could ultimately affect the profitability of the investment. The storage units used for analysis were those most commonly utilized. The following assumptions were made concerning each feed material and type of storage used with each feeding system.

Storage volume for each unit was determined by calculating the amount of different feed required to produce a balanced ration, for one year (see Table 6.6). The feed requirement was then multiplied by the number of cows milked plus one half cow for each young animal (Midwest Plan Service, 1978). An allowance was included for spoilage, seepage, and fermentation using the information in Table 6.8 and described in Section 6.3.4.

Alfalfa hay continued to be one of the best sources of both protein and energy for dairy cattle. Research showed that hay (90% DM) was important for stimulating normal muscle tone in the animal's rumen and maintaining normal digestive activity (U. of F., 1978). There was a tendency for farmers mechanizing their feeding systems to cut back on the amount of hay fed. The cut back is represented by the low amount of hay fed in the sample ration. It should be noted, however, that even this small amount would reduce the incidence of ketosis and twisted stomach.

At the present time, the Feeding System Simulator does not calculate energy consumption for feeding systems electing to feed dry hay since a majority of the dairy farmers surveyed hand fed dry hay. An investigation of the types of haymaking equipment and the accompanying storage and handling equipment currently on the market revealed that most of the equipment was compatible with both the mobile and the stationary feeding system. In an effort not to effect the final analysis of the two feed handling systems, similar hay feeding methods were assumed.

Alfalfa haylage is hay harvested and processed in the early bloom stage. Normally, haylage will contain about two percent more protein and a higher energy value than when harvested as field cured hay. Haylage usually contains 40 to 70 percent moisture and will usually retain 70 percent moisture and 30 percent dry matter, without seeping at normal silo pressures. Hay at 50 percent moisture or less before ensiling, is too dry for proper storage. Sufficient moisture is necessary in order to provide a top seal which would prevent air from entering the surface, and to provide the weight required for good packing to prevent heat damage. While good packing procedures will prevent heat damage, providing an air tight container is the best way to prevent additional storage losses (Benson, 1978).

Semisealed silos and bunker silos could be used for haylage storage with proper packing but they are not air tight since they must be opened for feeding and air can penetrate loosely packed forage. The economic comparison of stationary and mobile feeding systems assumed: a sealed upright concrete silo with bottom unloading for the stationary feeding system and a precast concrete bunker silo for the mobile feeding system. The haylage assumed for comparison contains 60 percent moisture which was wet enough to provide adequate compaction in the bunker silo.

Corn silage is made from well-eared corn plants harvested in the hard-dough or dent stage. Ensiled at a moisture level of 60 to 70 percent corn silage has a relatively high ranking energy value. The main disadvantage to corn silage is its low protein level content. Additionally, it is lower than legume forages in most minerals, particularly calcium and manganese (Hillman, 1977).

A conventional semisealed concrete silo or bunker silo could be used for corn silage storage. The wetter material helps to form a top seal preventing air from entering the surface and provides the weight necessary for expressing the entrapped air from the silage stored below it (Maddex, 1977). The economic comparison of feeding systems assumed: a conventional upright concrete silo with top unloading for the stationary feeding system and a precast concrete bunker silo for the mobile feeding system.

High moisture corn is whole shelled corn stored at moisture levels above 20 percent, thereby eliminating the drying energy expense. The corn should be ground so that it packs well. Proper harvest moistures are 25 to 30 percent for high moisture corn. If the corn in the field is dryer than 22 percent, some other type of storage should be used; adding water will not raise the moisture level (Harvestore, 1976).

High moisture corn should be stored in sealed silos. These are generally steel construction, but sealed concrete silos featuring bottom unloading of the grain are as reliable. Conventional silos with a good roof and stave silos with additional reinforcement can be used. Bunker silos are not recommended as higher storage losses are associated with these storage units (Benson, 1978).

The economic comparison assumed identical storage units for both feeding systems. Upright sealed concrete silos featuring bottom unloading were selected for the two systems. The silos were sized to unload three to four inches from the top per day, thus preventing additional spoilage losses.

Concentrates include grains and many by-product feeds, including high protein and mineral supplements. Although mineral supplements do not contain energy or protein, they are included in the concentrate class because of their high density. Concentrate mixtures high in protein and minerals are required when low protein feeds, such as corn silage, are fed to dairy cattle. The minerals most commonly lacking in corn silage dairy rations are calcium, phosphorus, sodium, and chlorine (Bath, 1978).

Storage methods for concentrates included bottom unloading gravity bins and fifty pound sacks. Among the dairy farms surveyed, the most common method of storing and feeding concentrates incorporated a centrally located feed center and bin storage. Concentrates were added to the ration simultaneously with the unloading of an upright silo or directly to a mobile mixer or feed wagon by gravity. Since each of the methods used to add concentrations to the ration did not require an additional energy input to the feed handling system, they were not included as a feeding system simulation option.

Similar methods for feeding concentrate were assumed in an effort to minimize any effect on the economic analysis of the two feed handling systems. The principal high moisture protein supplement in the simulated ration, was soybean meal with a 50 percent protein content (Table 6.6). The minerals, calcium and phosphate, were included in the protein supplement as dicalcium phosphate. Salt, fed free choice, provided the minerals sodium and chlorine.

6.3.4 Storage Losses

A key issue in an economic comparison of upright and bunker silos is the difference in storage losses due to spoilage, seepage, and fermentation (Benson, 1978). The losses vary from silo to silo and from farm to farm, depending upon the type and moisture content of the forage, physical condition of the silo, fineness of the chopped forage, and most importantly the level of management. The storage losses shown in Table 6.8 occurred with similar management practices. The difference in performance which existed between horizontal and upright silos was used in the analysis of the simulated feed handling systems to determine the additional annual operating cost associated with horizontal silos. The additional cost was based on the difference in silo losses shown in Table 6.8 and calculated on the feed prices shown in Table 6.9.

TABLE 6.8 DRY MATTER STORAGE LOSSES[1] IN HAY CROP SILAGE ENSILED AT VARIOUS MOISTURE LEVELS IN DIFFERENT TYPES OF SILOS.[2]

MOISTURE LEVEL	OXYGEN LIMITING	CONVENTIONAL	HORIZONTAL
%	%	%	%
71 +	19.10	21.20	13.40
61 - 70	8.80	10.10	14.00
Under 60	4.40	7.50	16.70

1. Includes losses from spoilage, seepage, and fermentation. Does not include field losses.
2. Source T. H. Patton "Silage and Silos," Pennsylvania State Univ. Special Cicular 223, Extension Service, College of Agriculture.

TABLE 6.9 FEED COST VALUES ASSUMED FOR ECONOMIC ANALYSIS.

FEED TYPE	MOISTURE CONTENT	VALUE PER TON[1]
	%	$
CORN SILAGE	65	$25
HAYLAGE	60	$30
HIGH MOISTURE CORN	26	$94

1. On an as fed basis.

6.3.5 Capital Investment

The economic analysis of the stationary and mobile feeding systems involved determining lifetime investment costs for five herd sizes associated with each simulated feeding system. In order to price complete feed handling systems, individual component prices were necessary. Prices reflected factory prices on new equipment, sized and equipped in a comparable manner to that which was described by dairymen in the farm survey. Equipment sizes selected for the simulated stationary feeding systems and mobile feeding systems are shown in Table 6.11 and Table 6.17, respectively.

In January, of every year, Dairy Herd Management magazine publishes an extensive list of farm equipment manufacturers and dealers according to equipment type. Using this listing, approximately 20 firms which sell feed handling equipment were identified. After the companies were identified, local distributors and dealers were visited in an effort to obtain cost and performance figures for the equipment selected. The information obtained was summarized according to category of use on the basis of cost, and in the case of powered equipment, on the basis of energy consumption.

The total component investment costs for the equipment chosen for the simulated stationary and mobile feeding systems are shown in Tables 6.12 and 6.18. The equipment costs and performance figures were obtained from the following dealers.

Prices for silos and appropriate upright silo unloading equipment were supplied by Butler Manufacturing Company: Jamesway Division, Booms Silo Company, Harvestore Products Incorporated, and Northwest Ohio Silo Company. Bunker silo prices were obtained from A.D.L. Systems Inc.

Feed mixer performance and price data were obtained from Butler Manufacturing Company: Jamesway Division for the Oswalt Ensilmixer. The Ensilmixer Models 1830, 320, 370, 380 were used with both feeding systems.

Feed conveyors, associated with upright silos, and shuttle feeder performance and price data were obtained from Butler Manufacturing Company: Jamesway Division, Harvestore Products Incorporated and Van Dale Corporation.

Design information for concrete bunks with a spacing of 26 to 30 inches per cow were obtained from Midwest Plan Service. Fenceline feed bunks which allow eating from one side only were used with mobile feeding systems, and mechanical bunks allowing cows to eat from both sides were used with stationary feeding systems. Prices for construction were obtained from A.D.L. Systems Inc.

The Official Guide• Tractors and Farm Equipment - 1980, a quarterly issue, produced by the National Farm and Power Equipment Dealer's Association, contains cost figures on new and used equipment as well as fuel consumption and horsepower ratings of both later and earlier model tractors. This source provided the data required to derive a regression equation, relating purchase price to power take-off(PTO) horsepower (Equation 6.5). Bucket loaders for tractors in the 20 to 40 horsepower range added an additional $1,800 to the purchase price.

$$T.C. = \$240.00 * PTO \cdot hp \qquad (6.5)$$

Where:

T.C. = Tractor investment cost or purchase price (dollars)

PTO•hp = Power take-off horsepower (hp)

6.3.6 Cost of Capital

In view of the significant differences in capital requirements for different feeding systems, the capital required became important. If funds were borrowed, the cost was in the form of interest paid. If the money was owned, the cost was intangible, represented by returns foregone by not investing in the most profitable project. The latter cost, referred to as an opportunity cost, was generally higher than the prime interest rate. For economic comparisons the opportunity cost and interest paid were equated. The analysis assumed Production Credit Association's fourth quarter 1980 interest rate of 12.5 percent.

6.3.7 Ownership Cost

The economic evaluation of the feeding systems included calculating the annual cost of owning and operating the various systems. The total monthly ownership costs shown in Tables 6.13 and 6.19 represent the annual costs spread over 12 months. The total monthly costs included the fixed costs (F.C.) of depreciation of the initial investment, interest, insurance, taxes and the operating costs for maintenance, repairs, and energy. Values for these costs, excluding energy, were determined by projecting the present day costs over the life of the equipment.

Several assumptions were made to simplify the analysis. A general inflation rate for future costs was considered to be zero. Inflation rates for energy, diesel fuel, and electricity were considered equal and constant over the simulated time period, and were assumed relative to the general inflation rate. The estimated useful life and the annual percentage rates charged for depreciation, interest, insurance, taxes, maintenance and repairs are shown in Table 6.10. These annual percentage rate figures were used in calculation of ownership and operation costs.

The total monthly fixed cost of ownership was determined by multiplying the purchase price of a system component by the total fixed cost percentage which was then divided by 12 to give the monthly ownership cost. The fixed cost (F.C.) in Equation 6.6 included costs for depreciation, interest, taxes, insurance, and shelter.

$$MFC = (SCC * FC) \div 12 \qquad (6.6)$$

Where:

MFC = monthly fixed cost (dollars)

SCC = intial system component investment cost (dollars)

FC = annual fixed cost (decimal)

Equation 6.7 was used to calculate the operating cost for repairs and maintenance. Repair and maintenance expenditures due to normal wear, part failure or accidents were inevitable. The size of the system as reflected by its investment cost and the amount of use the system received were factors affecting the repair and maintenance costs. The monthly repair and maintenance cost was calculated by multiplying the initial system investment cost by the annual percentage rate for repairs and maintenance then dividing the result by 12 months.

$$MRM = (SCC * RCF) \div 12 \qquad (6.7)$$

Where:

MRM = monthly repair and maintenance cost (dollars)

SCC = initial system component investment cost (dollars)

RCF = annual repair cost factor (decimal)

Monthly operating costs for labor and energy were determined by the Dairy Farm Simulator Model. Energy costs for diesel fuel and electricity were based on operating hours per month times the energy rates described in Section 4. The calculated labor charge was based on the total operating time of the system multiplied by a labor rate of $4.50 per hour.

It should be noted that tractors included in the simulated mobile feeding systems were used in other parts of the dairy operation. This assumption required fixed costs and operating costs for tractors to be based on an hourly rate. These costs were determined by multiplying the tractors investment cost by the appropriate annual fixed cost and operating cost percentages from Table 6.10. The annual costs were divided by an annual hourly life of 1,000 hours per tractor and the result multiplied by the hours of tractor operation per month. The hourly charge did not include diesel fuel use as it was determined separately.

TABLE 6.10 ANNUAL OWNERSHIP COST[1] EXPRESSED AS A PERCENTAGE OF THE PURCHASE PRICE[2].

EQUIPMENT ITEM	LIFE[3]	DEPRECIATION	INTEREST[4]	T.I.S.[5]	TOTAL F.C.[6]	RCF[7]
	YRS.	%	%	%	%	%
CONCRETE SILOS:						
UPRIGHT	15.0	6.60	6.25	1.75	14.60	1.0
HORIZONTAL	15.0	6.60	6.25	1.75	14.60	1.0
SILO UNLOADER	7.5	13.30	6.25	1.25	20.80	5.0
TRACTOR/LOADER	11.0	9.10	6.25	2.25	17.60	9.0
FEED MIXER	10.0	10.00	6.25	1.75	18.00	3.0
CONVEYORS/FEEDERS	10.0	10.00	6.25	1.50	17.75	5.0
FEED BUNKS	15.0	6.65	6.25	1.25	14.15	3.0
FEED ALLEYS	20.0	5.00	6.25	1.25	12.50	1.0

1. Operating cost determined by computer analysis "Dairy Farm Simulation Model"
2. W. Bowers, 1975. Modern Concept of Farm Machinery Management.
3. Tractor/Loader Life assumes 11,000 hours of operation.
4. Interest Rate assumed at 12.5 %.
5. T.I.S. = Taxes, Insurance, and Shelter.
6. F.C. = Fixed Cost Per Year.
7. RCF = Repair and Maintenance Cost Factor.

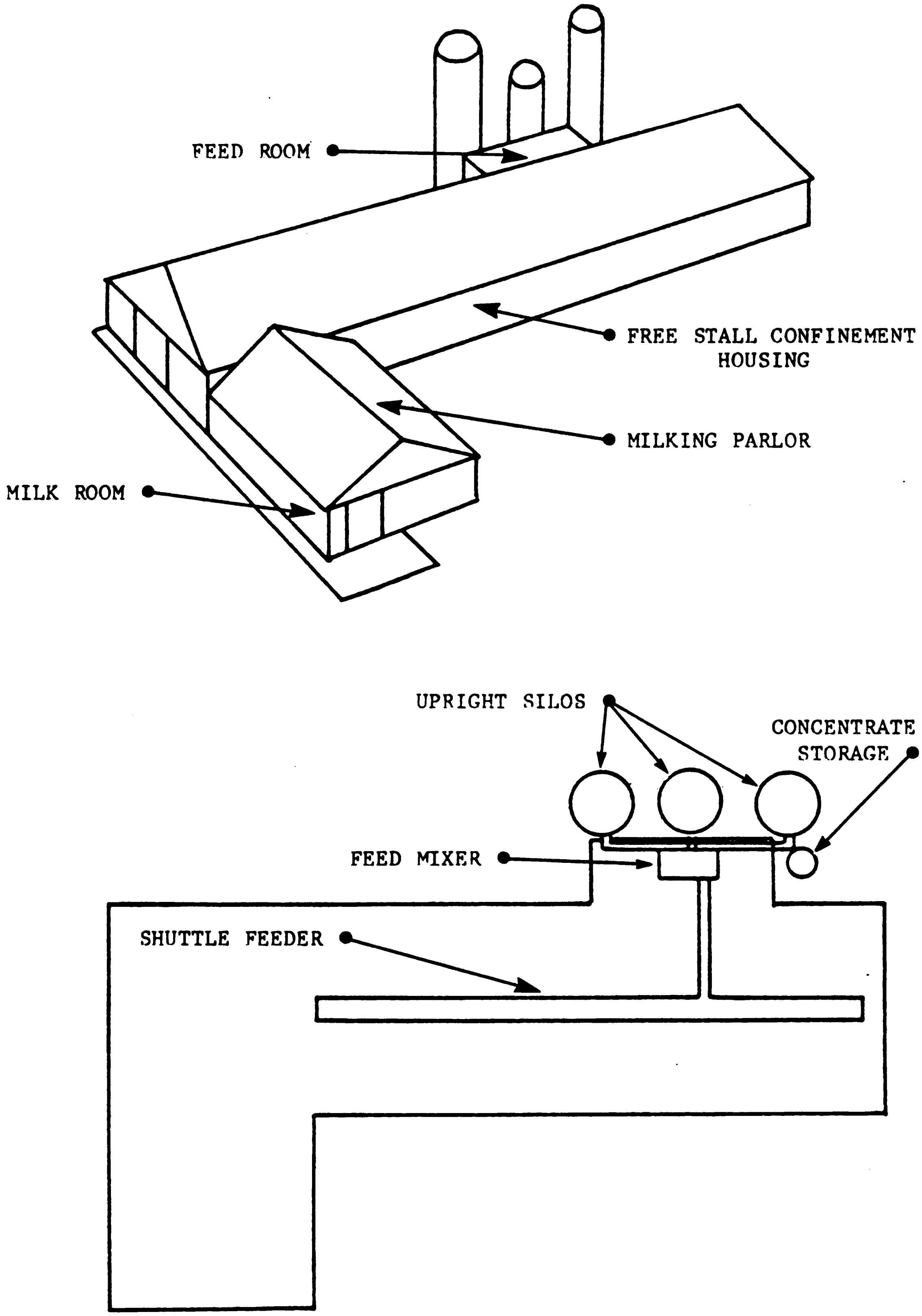


FIGURE 6.5 TYPICAL DESIGN OF A ROOFED FREE STALL SYSTEM UTILIZING UPRIGHT SILOS AND STATIONARY FEED HANDLING EQUIPMENT.

TABLE 6.11 SIMULATED FEEDING EQUIPMENT INPUTS FOR STATIONARY FEEDING SYSTEM.

FEEDING SYSTEM EQUIPMENT	SIZE REQUIREMENTS[1] BY HERD SIZE				
	100	**150**	**200**	**250**	**300**
Feed Storage (tn):					
Corn Silage	1200	1800	2400	3000	3600
Haylage	300	450	600	750	900
High Moisture Corn	300	450	600	750	900
Silo Size (ft):					
Corn Silage	30x70	28x60^{2}	30x70^{2}	28x60^{3}	30x70^{3}
Haylage	18x60	20x70	24x60	28x60	30x60
High Moisture Corn	18x60	20x70	24x60	28x60	30x60
Silo Unloader Size (hp):					
Corn Silage	10	7.5^{2}	10^{2}	10^{3}	10^{3}
Haylage	5	7.5	7.5	10	20
High Moisture Corn	5	7.5	7.5	10	20
Conveyor-Mixer Length (ft):					
Corn Silage	30	17^{2}	20^{2}	15^{3}	20^{3}
Haylage	30	30	30	35	45
High Moisture Corn	5	5	5	5	5
Feed Mixer (hp):					
Oswalt Mixer w/scale	7.5	30	30	35	40
Feed Delivery (hp):					
Feed Bunk Conveyor	2	2	2	2	2
Shuttle Feeder	2	3	3	3	4

1. Subscript indicates number of units required.

TABLE 6.12 SIMULATED INVESTMENT COST FOR STATIONARY FEEDING SYSTEM.

FEEDING SYSTEM EQUIPMENT	INVESTMENT COST IN DOLLARS BY HERD SIZE				
	100	**150**	**200**	**250**	**300**
Corn Silage Silo:					
Conventional Silo	33,000	49,500	66,000	82,500	99,000
Top Unloader[1]	13,325	25,900	26,650	38,840	39,980
Haylage Silo:					
Sealed Type Silo	19,500	29,250	39,000	48,750	58,500
Bottom Unloader[1]	17,700	19,400	20,950	22,465	23,030
High Moisture Corn Silo:					
Sealed Type Silo	19,500	29,250	39,000	48,750	58,500
Bottom Unloader[1]	17,700	19,400	20,950	22,465	23,030
Feed Mixer:					
Oswalt Mixer w/Scale	10,500	16,500	16,500	17,500	20,500
Feed Delivery System:					
Conveyors	4,000	5,500	5,800	8,000	11,500
Shuttle Feeder[2]	3,900	5,850	7,800	9,750	11,700
Feed Bunks[3]:	1,900	2,850	3,800	4,750	5,700
TOTAL ($)	**141,025**	**203,400**	**246,450**	**303,770**	**351,440**

1. Cost represents two silo unloaders since silos were assumed to last 15 years while silo unloaders had a life expectancy of 7.5 years.
2. Cost assumed at $39.50 per cow.
3. Cost assumed at $19.00 per cow - with bunks feeding both sides.

TABLE 6.13 MONTHLY SIMULATED OWNERSHIP COST FOR STATIONARY FEEDING SYSTEM EQUIPMENT.

FEEDING SYSTEM EQUIPMENT	MONTHLY OWNERSHIP COST IN DOLLARS BY HERD SIZE				
	100	150	200	250	300
Corn Silage Silo:					
Conventional Silo	401.50	602.20	803.00	1,003.70	1,204.50
Top Unloader	115.50	224.40	231.00	336.60	346.50
Haylage Silo:					
Sealed Type Silo	237.20	355.90	474.50	593.10	711.70
Bottom Unloader	153.40	168.30	181.50	194.70	199.60
High Moisture Corn Silo:					
Sealed Type Silo	237.20	355.90	474.50	593.10	711.70
Bottom Unloader	153.40	168.30	181.50	194.70	199.60
Feed Mixer:					
Oswalt Mixer w/Scale	157.50	247.50	247.50	262.50	307.50
Feed Delivery System:					
Conveyors	59.20	81.40	85.80	118.30	170.10
Shuttle Feeder	57.70	86.50	115.40	144.20	173.00
Feed Bunks:	22.40	33.60	44.80	56.00	67.30
TOTAL FIXED COST	**1,595.00**	**2,324.00**	**2,839.50**	**3,496.90**	**4,091.50**
Feeding System:					
Repair & Maintenance	230.60	327.30	377.40	434.60	501.30
Labor	164.25	246.60	323.10	395.10	478.80
Electricity[1]	24.30	54.80	70.10	85.10	107.90
TOTAL OPERATING COST	**419.15**	**628.70**	**770.60**	**914.80**	**1,088.00**
TOTAL OWNERSHIP COST	**2,014.15**	**2,952.70**	**3,610.10**	**4,411.70**	**5,179.50**

1. Electricity costs based on the Time-of-Day Rate Schedule, feeding time began at 5:30 a.m. and 5:00 p.m.

6.3.8 Results of Simulated Stationary Feed Handling Systems

The different kinds of feed handling equipment required to simulate stationary feed handling systems for herd sizes of 100, 150, 200, 250, and 300 cows are shown in Table 6.11. The simulated values determined for the stationary feed handling system were for average conditions and should not be considered true for all applications. These values were obtained by considering all previous assumptions and computing the average energy use per month based on a similar farm located in Michigan. The values may vary considerably when viewed with different assumptions.

The investment cost required for each component, for each herd size examined, is shown in Table 6.12. The total investment cost increased as expected with increases in milking cow herd size. The total investment ranged in price from $141,025 for the 100 milking cow herd to $351,440 for the 300 milking cow herd. The more expensive system cost $1,171 per cow, while the less expensive system was $1,410 per cow. The decrease in per cow investment cost which occurred with the increase in herd size was attributed to "economies of size."

Monthly ownership cost for each herd size examined is shown in Table 6.13. The ownership cost was comprised of fixed and operating costs. The ownership cost ranged from $2,014.15 for the 100 milking cow herd to $5,179.50 for the 300 milking cow herd. The ownership cost on a per cow basis, also showed "economies of size." The smallest herd size examined required $20.14 per cow each month, while the 300 milking cow herd required $17.26 per cow each month.

Fixed costs, or cash / noncash costs were borne irregardless of whether the enterprise was currently operative. Fixed cash costs consisted of taxes, insurance, and shelter, while noncash costs included depreciation and interest on the investment. The fixed cost represented 79 percent of the monthly ownership cost and ranged from $15.95 per cow down to $13.64 per cow as herd size increased.

The operating cost was a variable cost incurred when the enterprise was operational. The operating cost included variable costs for repair and maintenance, labor, and energy. Repair and maintenance was based on a percentage of the original investment cost of each component within the system. These costs ranged from $2.31 per cow for the smaller 100 milking cow herd down to $1.67 per cow for the larger 300 milking cow herd.

Labor requirements for stationary feed handling systems were generally high, because the laborer operating the feed handling equipment was assumed to be constantly observing the equipments' operation. The assumption was valid for those systems surveyed, although the larger herd sizes offered the laborer opportunities to perform other tasks during the feeding process. Table 6.14 shows, the simulated monthly labor hours required for each operation within the feeding system by herd size. The labor requirements increased with herd size, but averaged 0.35 minutes per cow per feeding regardless of herd size examined. The labor cost shown in Table 6.13 ranged from $164.24 for the 100 cow herd to $478.80 per month for the 300 cow herd. These costs represented 41 percent of the operating costs.

TABLE 6.14 SIMULATED MONTHLY LABOR USE IN HOURS FOR STATIONARY FEEDING SYSTEM OPERATIONS.

FEEDING SYSTEM OPERATION	MONTHLY LABOR USE BY HERD SIZE				
	100	**150**	**200**	**250**	**300**
SILO UNLOADERS:					
Corn Silage	13.2	21.2	26.4	34.4	43.6
Haylage	3.0	5.0	7.0	9.2	11.2
High Moisture Corn	1.0	2.0	2.0	3.0	4.0
FEED MIXER[1]:	5.0	5.0	5.0	4.0	4.0
FEED CONVEYORS[2]:	*	*	*	*	*
SHUTTLE BUNK FEEDER:	14.3	25.4	31.4	37.2	43.6
TOTAL (hrs)	**36.5**	**58.6**	**71.8**	**87.8**	**106.4**

1. Feed mixer operated while unloading to conveyors and feed bunks, labor was divided proportionately.

2. No labor associate with conveyor operation since operated jointly with other feeding system equipment.

Electricity was the exclusive energy source for the stationary feeding system. Table 6.15 shows the simulated monthly electrical energy use in kilowatt•hours (kWh), by herd size, for each of the stationary feeding system operations. The kilowatt•hours required to operate the 100 cow herd each month was 471 kWh, and increased with corresponding increases in herd size to 2,750.4 kWh per month for the 300 cow herd. The feed mixer, which operated while unloading to the feed conveyor and subsequent shuttle feeder, consumed over 50 percent of the electrical energy required by the stationary feed handling system. The high energy use was due to the feed mixer's unloading capabilities being restricted by the capacity of the feed conveyors and subsequent shuttle feeder. The addition of another feed conveyor and shuttle feeder would allow the feed mixer to unload faster, thus reducing the mixer's energy requirement.

Energy consumption for the simulated stationary feed handling systems shown in Table 6.16 was related to the number of barrels of oil required to produce the needed electricity. The 100 milking cow herd required 0.81 barrels of oil per month to produce the 471 kWh of electrical energy. The number of oil barrel equivalents increased to 4.74 barrels for the 300 milking cow herd. The electrical energy conversion rate was based on the generating efficiency of electrical power suppliers and included transmission losses. The production of 580 kWh of electrical energy required one barrel of oil when an oil fired generating plant using #6 fuel oil at $6.2 * 10^6$ Btu/bbl had an efficiency rating of 32 percent (C.S.W.C., 1979).

Electricity costs based on the Farm Flat Rate Schedule ranged from $24.58 for the 100 milking cow herd to $157.33 for the 300 milking cow herd, with the 200 milking cow herd requiring $83.70 in order to operate. The electricity costs shown in Table 6.13 were based on the Time-of-Day Rate Schedule with feeding times at 5:30 a.m. and 5:00 p.m. The monthly energy cost was only $24.30 to feed the 100 milking cow herd and $107.90 to feed the 300 cow herd. These cost were further reduced to $12.43 and $90.48 when feeding times were changed to 6:45 a.m. and 6:15 p.m. in order to take full advantage of the lower rates available with time-of-day metering.

TABLE 6.15 SIMULATED MONTHLY ELECTRICAL ENERGY USE IN KILOWATT•HOURS FOR STATIONARY FEEDING SYSTEM OPERATIONS.

FEEDING SYSTEM OPERATION	MONTHLY ELECTRICAL ENERGY USE BY HERD SIZE				
	100	**150**	**200**	**250**	**300**
SILO UNLOADERS:					
Corn Silage	151.9	159.6	283.7	354.6	425.5
Haylage	20.3	38.0	53.2	91.2	202.6
High Moisture Corn	5.1	15.2	15.2	30.4	81.0
FEED MIXER[1]:	212.7	759.8	942.1	1,311.9	1,742.5
FEED CONVEYORS[2]:	50.6	68.9	90.1	114.8	140.8
SHUTTLE BUNK FEEDER:	30.4	60.8	79.0	100.3	158.0
TOTAL (kWh)	**471.0**	**1,102.3**	**1,463.3**	**2,003.2**	**2,750.4**

1. Feed mixer operated while unloading to conveyors and feed bunks.
2. Total includes all conveyors operating during the operation of the feeding system.

TABLE 6.16 SIMULATED MONTHLY ENERGY USE IN OIL BARREL EQUIVALENTS FOR STATIONARY FEEDING SYSTEM OPERATIONS.

HERD SIZE	ENERGY USE	OIL BARREL EQUIVALENTS[1] ELECTRIC POWER GENERATION	TOTAL
	kWh	**bbl**	**bbl**
100	471.0	0.81	0.81
150	1,102.3	1.90	1.90
200	1,463.3	2.52	2.52
250	2,003.2	3.45	3.45
300	2,750.4	4.74	4.74

1. Number 6 fuel oil at $6.2 * 10^6$ Btu/bbl = 580 kWh/bbl @ 32 % eff.

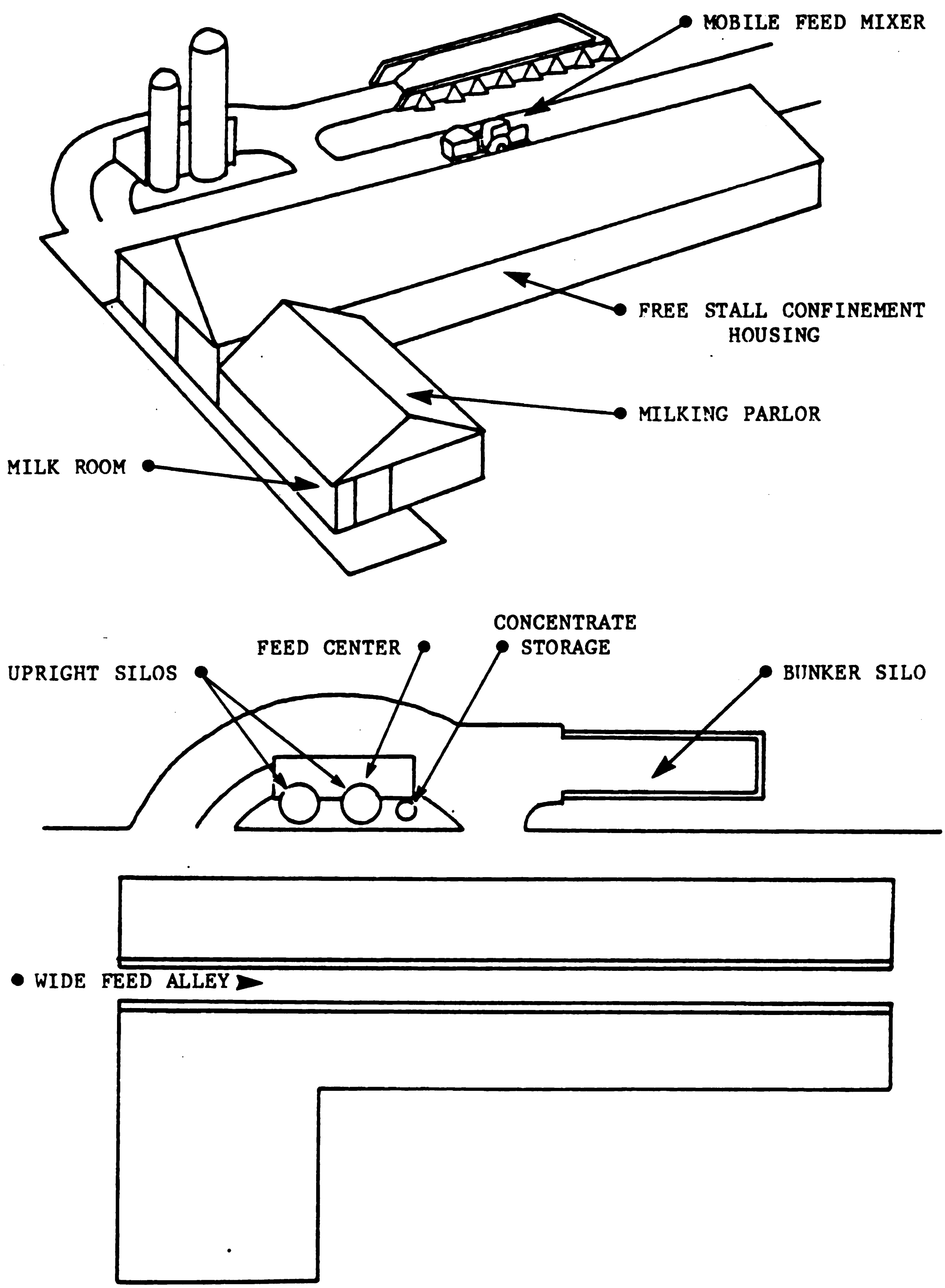


FIGURE 6.6 TYPICAL DESIGN OF A ROOFED FREE STALL SYSTEM UTILIZING UPRIGHT AND BUNKER SILOS AND MOBILE FEED HANDLING EQUIPMENT.

TABLE 6.17 SIMULATED FEEDING EQUIPMENT INPUTS FOR MOBILE FEEDING SYSTEM.

FEEDING SYSTEM EQUIPMENT	SIZE REQUIREMENTS BY HERD SIZE				
	100	**150**	**200**	**250**	**300**
Feed Storage (tn):					
Corn Silage	1200	1800	2400	3000	3600
Haylage	300	450	600	750	900
High Moisture Corn	300	450	600	750	900
Silo Size (ft):					
Corn Silage[1]	50×100	60×120	70×140	80×160	90×170
Haylage[1]	30×40	30×60	40×60	40×80	50×75
High Moisture Corn	18×60	20×70	24×60	28×60	30×60
Silo Unloader Size (hp):					
Corn Silaged[2]	30	30	30	30	30
Haylage[2]	30	30	30	30	30
High Moisture Corn	5	7.5	7.5	10	20
Conveyor-Mixer Length (ft):					
High Moisture Corn	5	5	5	5	5
Mobile Mixer (hp):					
Oswalt mixer w/Scale	60	70	70	90	110
Feed Delivery[3]:	×	×	×	×	×

1. Silo sizes indicate width & length. All bunker silos were 12' high.
2. Bunker silos were unloaded using a tractor mounted bucket loader.
3. Mobile mixer delivered the feed directly to the feed bunk.

TABLE 6.18 SIMULATED INVESTMENT COST FOR MOBILE FEEDING SYSTEM.

FEEDING SYSTEM EQUIPMENT	INVESTMENT COST IN DOLLARS BY HERD SIZE				
	100	**150**	**200**	**250**	**300**
Corn Silage Silo:					
Concrete Bunker Silo	37,080	46,620	56,860	67,810	75,680
Bucket Unloader[1]	x	x	x	x	x
Haylage Silo:					
Concrete Bunker Silo	14,670	20,130	22,440	28,250	29,375
Bucket Unloader[1]	x	x	x	x	x
High Moisture Corn Silo:					
Sealed Type Silo	19,500	29,250	39,000	48,750	58,500
Bottom Unloader[2]	17,700	19,400	20,950	22,465	23,030
Mobile Feed Mixer:					
Oswalt Mixer w/Scale	10,500	16,500	16,500	17,500	20,500
2 Wheel Diesel Tractor[1]	x	x	x	x	x
Feed Bunks[3]:	3,200	4,800	6,400	8,000	9,600
Wider Feeding Alleys[4]:	1,600	2,400	3,200	4,000	4,800
TOTAL ($)	**104,250**	**139,100**	**165,350**	**196,775**	**221,485**

1. No investment cost determined, as equipment was assumed to be used with other farm operations.
2. Cost represents two silo unloaders since silos were assumed to last 15 years while silo unloaders had a life expectancy of 7.5 years.
3. Cost assumed at $32.00 per cow.
4. Cost assumed at $16.00 per cow, with bunks feeding one side only.

TABLE 6.19 MONTHLY SIMULATED OWNERSHIP COST FOR MOBILE FEEDING SYSTEM EQUIPMENT.

FEEDING SYSTEM EQUIPMENT	MONTHLY OWNERSHIP COST IN DOLLARS BY HERD SIZE				
	100	150	200	250	300
Corn Silage Silo:					
Concrete Bunker Silo	451.10	567.20	691.80	825.00	920.80
Bucket Unloader[1]	x	x	x	x	x
Haylage Silo:					
Concrete Bunker Silo	178.50	244.90	273.00	343.70	357.40
Bucket Unloader[1]	x	x	x	x	x
High Moisture Corn Silo:					
Sealed Type Silo	237.20	355.90	474.50	593.10	711.70
Bottom Unloader	153.40	168.30	181.50	194.70	199.60
Mobile Feed Mixer:					
Oswalt Mixer w/Scale	157.50	247.50	247.50	262.50	307.50
Diesel Tractor[1]	x	x	x	x	x
Feed Bunks:	37.80	56.60	75.50	94.40	113.30
Wider Feeding Alleys:	16.70	25.00	33.30	41.70	50.00
TOTAL FIXED COST	**1,232.20**	**1,665.40**	**1,977.10**	**2,355.10**	**2,660.30**
Feeding System:					
Tractor Operating Cost	36.40	49.30	68.90	79.00	104.20
Repair & Maintenance	151.60	201.80	238.00	275.40	317.00
Bunker Silo Spoilage[2]	70.90	106.30	141.80	177.20	212.70
Labor	103.50	139.10	172.80	211.10	249.30
Electricity[3]	.30	.90	.90	1.70	4.20
Diesel Fuel	64.00	84.50	99.50	134.70	179.30
TOTAL OPERATING COST	**426.70**	**581.90**	**721.90**	**879.10**	**1,066.70**
TOTAL OWNERSHIP COST	**1,658.90**	**2,247.30**	**2,699.00**	**3,234.20**	**3,727.00**

1. No fixed ownership cost determined, as equipment was assumed to be used with other farm operations, although an operating cost was calculated.
2. Bunker silo spoilage allowance was calculated for spoilage greater than the spoilage anticipated with a conventional tower silo.
3. Electricity costs were based on the Time-of-Day Rate Schedule, feeding time began at 5:30 a.m. and 5:00 p.m.

6.3.9 Results of Simulated Mobile Feed Handling Systems

The various kinds of feed handling equipment required to simulate mobile feed handling systems for herd sizes of 100, 150, 200, 250, and 300 cows are shown in Table 6.17. The simulated values determined for the mobile feed handling system were for average conditions and should not be considered applicable to all situations. These values were derived by considering all previous assumptions and computing the average energy use per month based on a similar farm located in Michigan. The values may vary considerably when viewed with different assumptions.

The investment cost required for each component for each herd size examined is shown in Table 6.18. The total investment cost increased as expected with increases in milking cow herd size. The total investment ranged in price from $104,250 for the 100 milking cow herd to $221,485 for the 300 milking cow herd. The more expensive system cost $738 per cow, while the lower cost system was $1,042 per cow. The decrease in per cow investment cost which occurred with the increase in herd size was indicative of the benefit of larger mobile feed handling systems.

Monthly ownership cost for each herd size examined is shown in Table 6.19. The ownership cost included fixed and operating costs. The ownership cost ranged from $1,658.90 for the 100 milking cow herd to $3,727.00 for the 300 milking cow herd. The ownership cost on a per cow basis revealed an advantage in utilizing larger herds with mobile feed handling systems. The smallest herd size examined required $16.59 per cow each month, while the 300 milking cow herd required $12.42 per cow each month.

Fixed costs, or cash / noncash costs were borne irregardless of whether the enterprise was currently operative. Fixed cash costs consisted of taxes, insurance and shelter, while noncash costs included depreciation and interest on the investment. The fixed cost represented 73 percent of the monthly ownership cost and ranged from $12.32 per cow down to $8.87 per cow as herd size increased.

The operating cost was a variable cost incurred when the enterprise was operational. The operating cost included variable costs for repair and maintenance, labor, energy, additional silo spoilage related to bunker silos and tractor operating costs. Repair and maintenance was based on a percentage of the original investment cost of each component within the system. These costs ranged from $1.52 per cow for the smaller 100 milking cow herd down to $1.06 per cow for the larger 300 milking cow herd.

Labor requirements shown in Table 6.20 for mobile feed handling systems indicate labor requirements per cow decreased from 0.23 hours down to 0.18 hours per month. The decrease in labor requirements was related to the rate at which a tractor mounted bucket loader could load a mix wagon and the unloading rate of the mobile mixer. The labor costs shown in Table 6.19 ranged from $103.50 for the 100 cow herd to $249.30 per month for the 300 cow herd and represented only 24 percent of the total operating costs.

TABLE 6.20 SIMULATED MONTHLY LABOR USE IN HOURS FOR MOBILE FEEDING SYSTEM OPERATIONS BY HERD SIZE.

FEEDING SYSTEM OPERATION	MONTHLY LABOR USE BY HERD SIZE				
	100	**150**	**200**	**250**	**300**
SET-UP TIME & MISC. CHORES	5.0	7.5	10.0	12.5	15.0
SILO UNLOADERS:					
Corn Silage	6.0	9.2	12.2	15.2	18.2
Haylage	1.0	1.0	2.0	3.0	3.0
High Moisture Corn	1.0	2.0	2.0	3.0	4.0
MOBIL FEED MIXER:	10.0	11.2	12.2	13.2	15.2
FEED CONVEYORS[1]:	*	*	*	*	*
TOTAL (hrs)	**23.0**	**30.9**	**38.4**	**46.9**	**55.4**

1. Labor required for conveyor operation was included in the unloading of the High Moisture Corn silo.

Electricity and diesel fuel provided the energy to operate the mobile feeding system. Table 6.21 shows the simulated monthly electrical energy use in kilowatt•hours (kWh), and the diesel fuel use in gallons (gal) by herd size for each of the mobile feeding system operations. The amount of electricity consumed was relatively insignificant compared to the amount of diesel fuel required to operate the system. The monthly diesel fuel consumption ranged from 64 gallons for the small 100 cow herd to 179.3 gallons for the larger 300 cow herd. The tractor which operated the mobile mixer consumed the greatest amount of diesel fuel.

Energy consumption for the simulated mobile feed handling systems shown in Table 6.22 was related to the number of barrels of oil required to produce the amount of diesel fuel and electricity necessary for operation. The 100 milking cow herd required 1.53 barrels of oil per month to produce the 64 gallons of diesel fuel, and the 6.1 kWh of electrical energy. The number of oil barrel equivalents increased to 4.42 barrels for the 300 milking cow herd. The electrical energy conversion rate was based on the generating efficiency of electrical power suppliers and included transmission losses. The production of 580 kWh of electrical energy required one barrel of oil when an oil fired generating plant using #6 fuel oil at $6.2 * 10^6$ Btu/bbl had an efficiency rating of 32 percent (C.S.W.C., 1979). The diesel fuel refining process required one barrel of crude oil to produce 42.0 gallons of #2 diesel fuel (Exxon Corp., 1980).

The electricity costs and the diesel fuel costs for the mobile feed handling systems are shown in Table 6.19. The combined monthly energy cost to feed the 100 milking cow herd was $64.30 and $183.50 to feed the 300 milking cow herd.

The cost of owning and operating mobile feeding system tractors was listed as a variable cost since tractors were used in other parts of the dairy operation. This cost ranged from $36.40 per month for the 100 cow herd to $104.20 per month for the 300 cow herd.

The variable cost charged for bunker silo spoilage was determined from Table 6.8 which indicates the anticipated silo spoilage losses of various silo types, and Table 6.9 which indicates the as fed cost assumed for each feed type. The spoilage losses shown in Table 6.19 represents the spoilage associated with bunker silos which is greater than the spoilage anticipated with conventional tower silos. These additional spoilage costs ranged from $79.90 for the 100 milking cow herd to $212.70 for the 300 milking cow herd.

TABLE 6.21 SIMULATED MONTHLY ELECTRICAL ENERGY USE IN KILOWATT•HOURS AND DIESEL FUEL USE FOR MOBILE FEEDING SYSTEM OPERATIONS.

FEEDING SYSTEM OPERATION	HERD SIZE 100		150		200		250		300	
	kWh	gal	kWh	gal	kWh	gal	kWh	gal	kWh	gal
SILO UNLOADERS:										
Corn Silage	*	14.4	*	21.6	*	28.7	*	35.9	*	43.1
Haylage	*	2.4	*	2.4	*	4.8	*	7.2	*	7.2
High Moisture Corn	5.1	*	15.2	*	15.2	*	30.1	*	81.0	*
MOBIL FEED MIXER[1]:	*	47.2	*	60.5	*	66.0	*	91.6	*	129.0
FEED CONVEYORS[2]:	1.0	*	2.0	*	2.0	*	3.0	*	4.1	*
TOTAL (kWh)	**6.1**	*	**17.2**	*	**17.2**	*	**33.1**	*	**85.1**	*
TOTAL (gal)	*	**64.0**	*	**84.5**	*	**99.5**	*	**134.7**	*	**179.3**

1. Mobile feed mixer operated after the last feed was loaded and continued throughout the the travel time to the feed bunks.
2. Total includes conveyor used while unloading the High Moisture Corn silo.

TABLE 6.22 SIMULATED MONTHLY ENERGY USE IN OIL BARREL EQUIVALENTS FOR MOBILE FEEDING SYSTEMS.

HERD SIZE	ENERGY USE		OIL BARREL EQUIVALENTS[1] ELECTRIC POWER GENERATION	DIESEL FUEL PRODUCTION	TOTAL
	kWh	gal	bbl	bbl	bbl
100	6.1	64.0	0.01	1.52	1.53
150	17.2	84.5	0.03	2.01	2.04
200	17.2	99.5	0.03	2.37	2.40
250	33.1	134.7	0.06	3.20	3.27
300	85.1	179.3	0.15	4.27	4.42

1. Number 6 fuel oil at 6.2 * 10^6 Btu/bbl = 580 kWh/bbl @ 32 % eff.
Number 2 diesel fuel at 5.88 * 10^6 Btu/bbl = 42.0 gal/bbl.

6.3.10 Comparison of Simulated Stationary and Mobile Feed Handling Systems

Investment cost is likely to be the major criteria when dairymen compare the two feed handling systems. A factor to be considered prior to investing in change, expansion or remodeling of a feed handling system is the profitability of the investment relative to other components of the farm business. For example, many dairymen might pay as much as a 20 percent opportunity cost rather than a 12.5 percent interest charge if they elected not to use the extra investment for more or better cows, more efficient housing or milking systems, or more land.

The investment cost for the simulated mobile feeding systems ranged from 26 to 37 percent lower than a similar simulated stationary feeding system for the herd sizes examined (Figure 6.7). The analysis #1 of the ownership costs for the two feed handling systems (Figure 6.8) revealed the cost advantages for the simulated mobile feeding systems were reduced an average of nine percent for the herd sizes examined, and twelve percent when electricity costs were based on the lowest cost available using the Time-of-Day Rate Schedule, analysis #2, (Figure 6.9). The reduction in cost advantage was explained by further examination of the individual components of the fixed and operating costs which made up the ownership cost.

Fixed costs for the two feed handling systems accounted for slightly less than three percent of the mobile feeding systems' reduction in cost advantage. The reduction was related to differences in life expectancy, taxes, insurance and shelter shown in Table 6.10. These fixed ownership costs, expressed as a percentage of the purchase price, were in themselves an assumption and any attempt to alter the current analysis in an effort to minimize differences was thought to be unwarranted.

Operating costs shown in Figure 6.8 indicated the mobile feeding system tended to be slightly less expensive to operate when compared to stationary feeding systems with herd size greater than 100 milking cows. This tendency was reversed in Figure 6.9, however, when the feeding times were changed in order to take full advantage of the lower rates available with time-of-day metering. The operating costs contributed slightly more than six percent to the mobile feeding systems reduction in cost advantage and approximately nine percent in the latter case. Approximately 1.5 percent of the mobile feeding system's reduction in cost advantage could be related to the cost of energy. This was primarily due to the higher retail cost of diesel fuel compared to current prices for electricity. Two percent of the reduction in cost advantage was attributed to the bunker silo unloading tractors and the tractor used to operate the mixer. The stationary feeding system's counterparts to this equipment are listed as fixed costs in Table 6.13 and become operating costs for the mobile system, (Table 6.19). The change in cost categories was due to the use of the tractors in other parts of the dairy operation. The major reduction in cost advantage was related to the additional spoilage losses associated with bunker silos. The additional operating cost for bunker silos reduced the cost advantage for mobile feeding systems approximately four percent.

<u>Energy consumption</u> and costs were lower for stationary feed handling systems with herd sizes less than or near 150 milking cows. Figure 6.10 indicates that energy costs continued to be lower for herd size of 150 milking cows or more. Based on the Farm Flat Rate, the stationary feeding system saved an average of $25.00 per month. When compared to the Time-of-Day Rate with feeding times beginning at 6:45 a.m. and 6:15 p.m., the stationary feeding system realized an average savings of $63.00 per month for similar mobile feeding systems. The savings equaled a 53 percent reduction in energy costs.

Based on barrels of oil consumed, the stationary feeding system required more energy to feed herd sizes greater than 150 milking cows (Figure 6.11). The seven percent increase in petroleum energy required to feed herd sizes greater than 150 milking cows could be turned around to approximately a 98 percent savings if electricity was produced by nonpetroleum sources.

Electricity produced by coal, nuclear, and hydroelectric power plants requires virtually no petroleum input. Economically, coal and hydro generated electricity compared favorably with oil generated power even when all environmental control costs were included (W.O.C.O.L., 1980). The comparison of petroleum based power plants to nuclear power plants was not as simple, and the answers were dependent upon the assumption used in the analysis. Generally, however, nuclear power was as cheap or cheaper than oil generated power. The alternative for diesel fuel had not proved as promising (Wakefield, 1980).

Labor requirements for systems with "high" capital investments were generally expected to be less labor intensive than "low" capital investment systems. An analysis of dairy feeding systems graphically indicated the opposite to be true (Figure 6.12). The stationary and mobile feeding systems were competitive for herd sizes less than or near 100 milking cows. As herd size increased to over 100 milking cows, the mobile feeding system became more labor efficient. The difference in labor efficiency was related to an assumption made during the analysis of simulated stationary feeding systems. It was assumed the laborer operating the stationary feed handling equipment would oversee the equipment the entire time it operated. The assumption was valid in lieu of the information provided by the Michigan Energy Audit Survey and the NC-119 Regional Project. The larger herd sizes offered the opportunity for the laborer to perform other tasks while the corn silage silo was unloading and while the conveyors were delivering the ration to the herd.

Analysis of the labor requirements for each feeding on a minute per cow basis, revealed that little difference existed within the stationary feed handling system regardless of herd size. The stationary system averaged 0.35 minute per cow per feeding for the herd size examined, while the mobile system decreased labor requirements from 0.23 to 0.18 minute per cow per feeding.

Stationary feeding systems can be made more labor efficient by: a) reducing the number of feeds in the ration; b) properly maintaining and adjusting silo unloaders; c) simultaneously unloading two silos containing the same feed; and d) computer controlled feeding systems.

The effect on labor requirements of simultaneously unloading two silos is shown in Figure 6.7 by line S_1. The reduction in stationary feeding system labor requirements reduced the mobile feeding system's investment cost advantage from the original 34 percent to a final 19 percent on an annual ownership cost basis. The addition of computer controlled feeding to the stationary system would further increase system efficiency and lower the manpower hours to a competitive level with the mobile feeding system for all herd sizes. The additional manpower hours could then be utilized in performance of other farm tasks. Reduction in manpower requirements, would not affect the ownership cost analysis, however, because the savings in operating costs would be made up in fixed investment costs.

FIGURE 6.7 SIMULATED INVESTMENT COST FOR STATIONARY AND MOBILE FEEDING SYSTEMS.

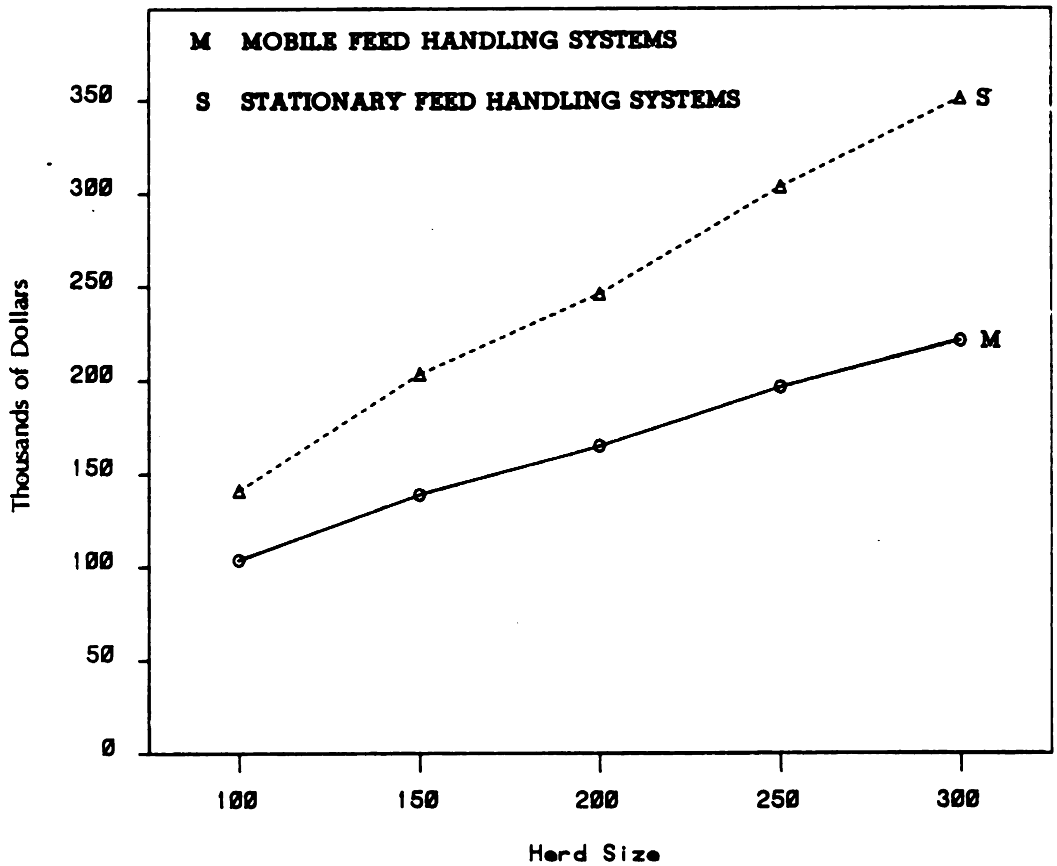


FIGURE 6.8 SIMULATED MONTHLY OWNERSHIP, FIXED, AND OPERATING COSTS FOR STATIONARY AND MOBILE FEEDING SYSTEMS (ANALYSIS 1).

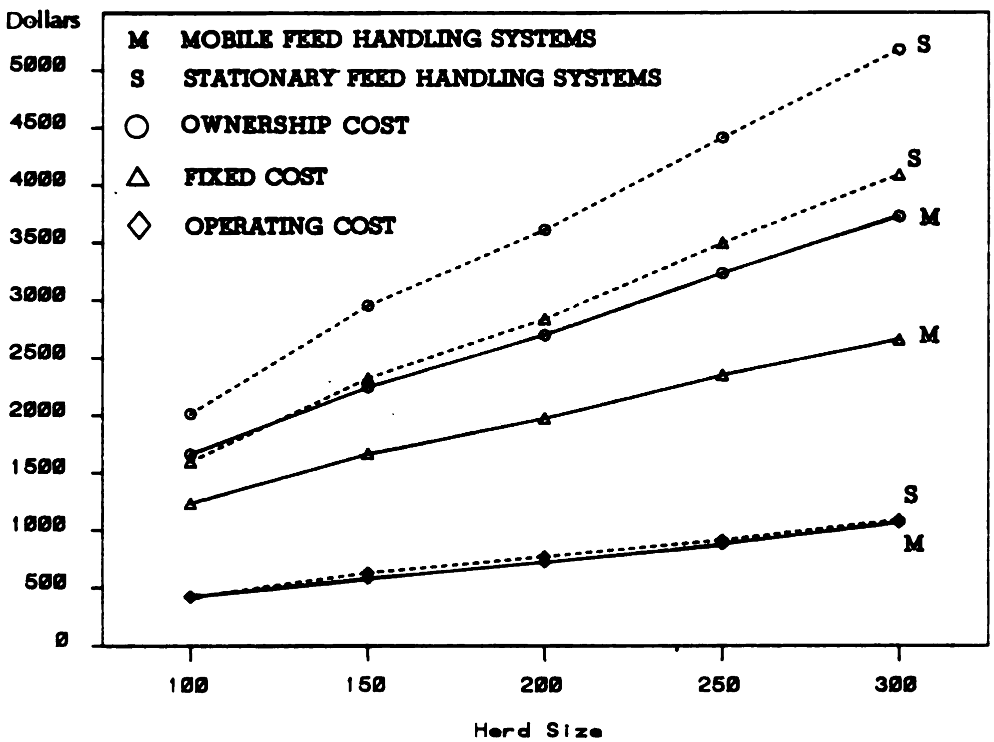


FIGURE 6.9 SIMULATED MONTHLY OWNERSHIP, FIXED, AND OPERATING COSTS FOR STATIONARY AND MOBILE FEEDING SYSTEMS (ANALYSIS 2).

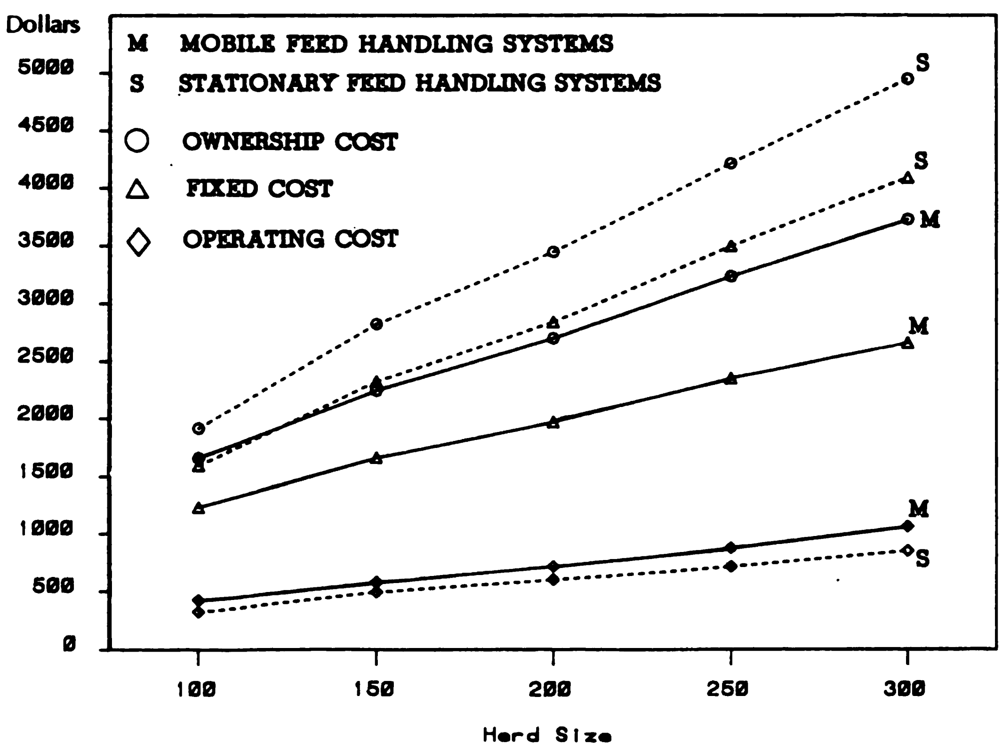


FIGURE 6.10 SIMULATED MONTHLY ENERGY COSTS FOR STATIONARY AND MOBILE FEEDING SYSTEMS.

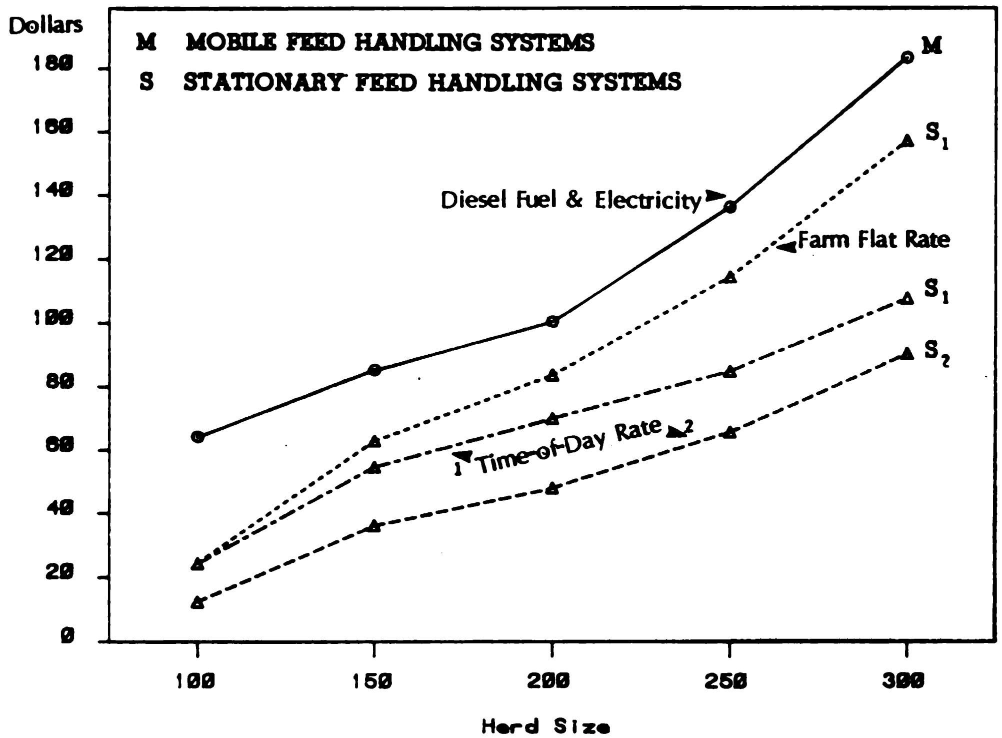


FIGURE 6.11 SIMULATED MONTHLY ENERGY USE IN OIL BARREL EQUIVALENTS FOR STATIONARY AND MOBILE FEEDING SYSTEMS.

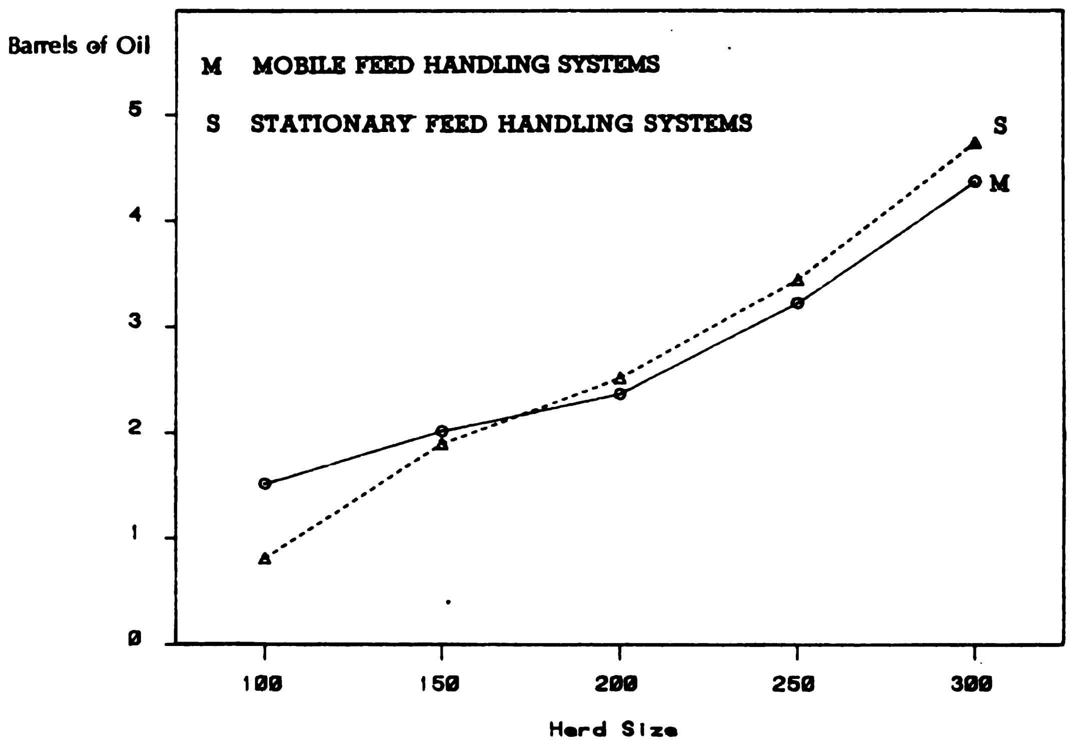
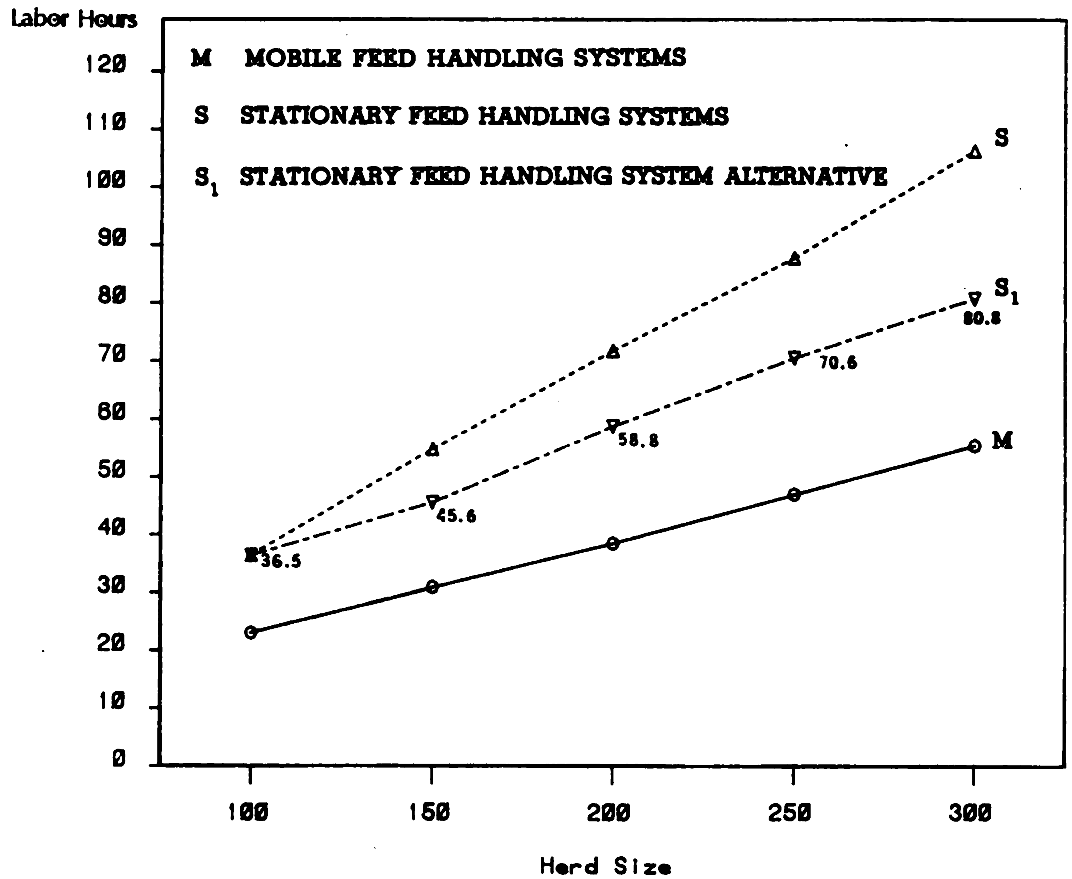


FIGURE 6.12 SIMULATED MONTHLY LABOR REQUIREMENTS FOR STATIONARY AND MOBILE FEEDING SYSTEMS.



7. SUMMARY AND CONCLUSIONS

The agricultural industry has had to make adaptations as a result of rising energy costs. Dairy farming, because of a relatively high energy requirement, is especially susceptible to rising energy costs and energy availability. Dairymen who judge success as a difference between the costs of inputs and the selling price of a product are only capable of viewing energy in terms of an input cost. A national energy policy designed to enforce conservation of energy would be beneficial, however, there is a reluctance among dairy farmers to change from traditional methods to new energy efficient methods due to the financial risks involved.

This research project was designed to assist dairymen, in analyzing the influence of production technology and milking capacity on energy consumption in order that management decisions could be made regarding conservation. The research objectives were: 1) to determine farmstead task options within each particular phase of milking and feed handling on a dairy facility; and 2) to develop an interactive computer model capable of simulating labor and energy use based on those options available within the milking and feed handling operations.

The components and options available within the milking and feed handling operations of a dairy facility have been identified. Approximately 1,000 individual systems can be assembled with the options presently available. The options identified were from the twenty-one dairy facilities surveyed, however, there are many other options. The surveyed facilities are representative of 60 to 70 percent of the dairy facilities in Michigan.

A simulation-computer model, capable of interacting with an operator via telephone lines, was developed. The Dairy Farm Simulation Model, a mathematical model of the milking and feed handling operations of a dairy facility, can predict average monthly labor and energy use requirements for 60 to 70 percent of the dairy facilities in Michigan with an accuracy of ±10 percent, depending on the accuracy of the facility information provided. The simulation model can pinpoint where higher energy costs and shortages will be most severe, where more readily available forms of energy can be substituted, where economies can be made, and what adjustments can be made to increasing prices and decreasing supplies of energy. It is possible to make changes in the current options, to add new options, or to change many of the assumptions used in the calculation of energy consumption and cost without revamping the entire simulation model. This can be useful in the future as prices, equipment, and energy requirements change.

The labor and energy data used in the simulation model were obtained from two additional research projects. Labor information for the feed handling simulation was provided by a cooperative regional project between Michigan State University and the University of Minnesota (Speicher, 1979). Energy consumption data, for both the milking and feed handling simulation of a dairy facility, were obtained from the Michigan Farm Energy Audit project which was conducted by the Agricultural Engineering Department at Michigan State University, and is described in Section 3.

Table 3.1 is an example of an energy budget compiled for Michigan dairy farms. The table shows the predicted average yearly energy consumption for dairy farm operations on a per cow basis. Energy use in Table 3.1 was based on data collected through the Michigan Energy Audit Study, and in some cases simulated by the Dairy Farm Simulation Model. Due to the small sample size, the data may not always be representative of typical energy use. Additional labor and energy use information was obtained from 18 of 21 surveys distributed to dairy facilities participating in the Michigan Farm Energy Audit Study (Appendix A).

Based on the specific assumptions described earlier, the following conclusions were drawn:

1. The result of modeling average yearly milk production and milk cow numbers indicated the model's accuracy for determining monthly electrical energy use varied from 99.5 percent to 68.7 percent for the Milking System Simulator when compared to actual energy consumption data. The difference between the actual energy consumed each year and the energy consumption predicted by the simulation model varied from -2.41 percent to 9.50 percent for all parlor operations and from -15.47 percent to 10.31 percent for individual systems. A higher percent difference of 40.18 percent was encountered for the hot water system for the second year when a heat recovery unit not modeled was installed on the farm used for model validation.

2. The result of modeling average yearly milk cow numbers indicated the model's accuracy for determining monthly electrical energy use varied from 98.2 percent to 74.5 percent for the Feed System Simulator when compared to actual energy consumption data. The difference between the actual energy consumed each year and the energy consumption predicted by the simulation model varied from -1.73 percent to 3.45 percent for the stationary feed handling system and from -14.14 percent to -8.12 percent for the mobile feed handling system.

3. Energy requirements and costs were predicted with the Dairy Farm Simulation Model for two alternative feed handling systems and were consistent with trends reported by Michigan Energy Audit dairy farmers. Herd sizes included 100, 150, 200, 250, and 300 cows. The following conclusions are based on the number of barrels of oil needed to produce the energy required.

    a. The electrically operated stationary feed handling system required the least amount of energy to operate up to and including a herd size of 150 cows.

    b. The mobile feed handling system, using only bunker silos and based on energy consumption, was preferred for herd sizes greater than 150 cows, as it used six to eight percent less energy than the stationary feed handling system.

c. The energy cost to operate the two alternative feed handling systems was lower for the stationary feed handling system regardless of herd size. This advantage was dependent on the electrical rate schedule used for comparison. Based on the Farm Flat Rate, the stationary feeding system saved an average of $25.00 per month. Compared to the Time-of-Day Rate when feeding times were 6:45 a.m. and 6:15 p.m., the stationary feeding system realized an average savings of $65.00 per month for similar mobile feeding systems. The savings equaled a 53 percent reduction in energy costs.

4. The labor requirement predicted by the model for the two alternative feed handling systems was based on the total operating time of the equipment. Assuming the operator was present during all operations, including the time required to unload an upright silo, the stationary feed handling systems were competitive for herd sizes less than or near 100 milking cows. The stationary system averaged 0.35 minutes per cow per feeding regardless of herd size, while the mobile feed handling system became more labor efficient as herd size increased over 100 milking cows. The mobile system decreased labor requirements from 0.23 minutes per cow per feeding for the 100 milking cow herd to 0.18 minutes per cow per feeding for the 300 cow herd.

5. The total cost analysis of owning and operating the two alternative feed handling systems was based on the model's predicted performance of the two systems. However, where economics is involved, answers change when prices change.

   a. The system which required the lowest monetary investment and incurred the lowest total ownership cost was the mobile feed handling system. The investment cost advantage with a herd size of 300 cows was 37 percent but diminished to 26 percent when the herd size was reduced to 100 cows. The ownership cost advantage with a herd size of 300 cows was 28 percent but diminished to 25 percent when the herd size was reduced to 100 cows.

   b. The predicted operating cost of each system varied only slightly. The savings in energy cost of the stationary feed handling system was usually offset by the increase in the labor cost, except when the lowest Time-of-Day Rate(2) available was utilized.

6. The results of simulating a milk handling system for herd sizes of 100, 150, 200, 250 and 300 cows, using the four electrical rate schedules included within the simulation model, indicated that the Time-of-Day Rate Schedule provided an operator with the lowest operating cost. In comparison to the Farm Flat and Inverted Rate Schedules, a savings of 45 percent or more would be realized by dairy farmers willing to alter their milking schedule to gain the maximum benefit from time-of-day metering.

It was concluded that no one system, milking or feed handling, was better than another. The "best" system remained the one designed to meet the needs of the operator by incorporating personal preferences and limitations into the system.

A national energy policy designed to lessen dependence on imported oil will likely identify conservation efforts which turn a greater factor of energy needs to three domestic sources - coal, renewable sources, and nuclear power. These options will provide energy economy as a whole, a somewhat different balance among resources, and an increase in the generation of electricity and systems which use electrical power. Thus, dairymen and electrical power suppliers alike will find that this simulation model has the potential of becoming a powerful tool in providing assistance in the design and management of energy efficient dairy facilities. Further work is required, however, before the model can be applied to the actual design or redesign of a particular dairy facility in Michigan. This model points directly to areas where additional research would be beneficial.

8. SUGGESTIONS FOR FUTURE RESEARCH

The Dairy Farm Simulation Model predicts average energy and labor requirements for various management options essential to future energy management decisions on dairy farms. Assumptions made while developing the model placed restrictions on its range of applicability. In addition, knowledge of the complex management scenarios and interactions which occur between dairy farm systems and equipment within each system was rudimentary at best. As new information relative to energy rates and energy or labor use becomes available, improvements to the Dairy Farm Simulation Model will be possible.

Research needs of the Dairy Farm Simulation Model outside of mathematic or computer programming techniques fall into four areas: 1) improvement of milking and feeding system equipment; 2) model expansion; 3) relaxation of restrictions on the models; and 4) application of the model. Table 8.1 lists future topics for research in decreasing order of importance and shows the areas which each topic would fall.

First, and of utmost importance, is research leading to better prediction of energy use on dairy farms. At the present time there is a need for more accurate energy reporting and measuring of energy input to output per unit operation. Research efforts in the past have failed to provide an accurate measurement of energy input to work output per unit operation on which generally acceptable equations can be

TABLE 8.1 RECOMMENDED FUTURE RESEARCH TOPICS FOR DAIRY FARM ENERGY MANAGEMENT.

TOPIC	PRIORITY	AREA
Energy Accounting	1	IMPROVEMENT
Energy Savings Devices	2	EXPANSION & IMPROVEMENT
Waste Handling System	3	EXPANSION
Cow-Calf Housing System	4	EXPANSION
Parameter Studies	5	APPLICATION
Model Validation	6	APPLICATION
Input Parameters	7	RESTRICTION
Field Application	8	RESTRICTED & APPLICATION
Optimization of Energy Management	9	APPLICATION
Economic Considerations	10	EXPANSION & IMPROVEMENT

developed, i.e. rate and time of energy use by equipment within each operation. New energy saving equipment and management options will necessitate new energy accounting and reporting research. Research which will result in improvements for the model will need to provide more detailed information than that previously conducted. The desired results can best be obtained through expert analysis of a limited number of dairy farms. The energy analysis should provide: 1) a straightforward tabulation of energy use by equipment and operation, including operating times, energy units and prices paid per energy unit; 2) a comparison of the energy use per analog of farm activity, i.e. BTU per cow or BTU per pound of milk; 3) a survey to gain general information and information relative to the facility's management schemes; 4) a feasibility study of alternative energy conserving approaches adaptable to the operation of the facility surveyed; and

5) a mass and energy balance comparing actual inputs to theoretical requirements. An energy analysis conducted using these procedures will permit a more thorough and useful energy accounting.

Several energy saving devices are presently available for installation in milking parlors. Incorporating these options into the model is the second most important research area. Many investigations have already been conducted on this topic. The bulk of the research has not been concerned with recording actual energy use on production dairy farms, however, the addition of these devices to the model will allow users of the program to compare the energy saving potential of each option with the entire dairy operation.

Expansion of the dairy model to include manure handling is the third research area listed in Table 8.1. This is listed third in order because the information is already available for development. Waste disposal is presently the third highest energy consuming dairy operation, accounting for 4.9 to 12.6 gallons of diesel fuel and 5.6 kWh of electricity per cow, (Table 3.1). Simulation of the manure handling system would greatly extend the energy management capacity of the model.

The fourth item, cow-calf housing, rates a relatively high research priority because it is one of the four major dairy operations, and on some dairy farms uses as much energy as the milking and cooling systems combined. Unfortunately, an accurate modeling of cow-calf housing will require extensive reworking of the model. Theoretically, to add housing to the model means support routines simulating weather, heating, cooling, and ventilation will also be required. The incorporation of these support routines into the simulation model will necessitate a more sophisticated, and thus, costly model.

Several types of parameter studies could be conducted on the dairy system model. Such studies could reveal important information on the character of the model and the significance of errors in the input data. A large number of parameters are involved, therefore, careful planning and sound experimental design should be exercised to minimize expense. The relative importance of several parameters was shown earlier. Additional information would result from more formal parameter studies. The knowledge gained from each parameter study should justify the cost increases.

Arguments to place a higher priority than sixth are easily made for continued validation of the model. Nevertheless, the result of such research is merely a more precise definition of the limits of the model. The simulation of additional farms with the existing model is less important than adding and validating the waste handling and housing models.

Seventh in order of priority is the relaxation of restrictions on input parameters since many of the inputs to the existing systems were severely restricted. This was due to the large number of possible management schemes and the complex sequencing which would have resulted without these restrictions. Further research and programming techniques may provide an easing of these previously imposed restrictions.

The eighth research priority is an alteration of the program for field use in workshops with farm operators or by the TELPLAN (MSU) and AGNET (NU) computer networks. In the model's present form, extensive reworking would be necessary to adapt it for field.use. The model does require periodic maintenance to keep the energy charges current with increasing energy cost. Presentation of the model in the field is needed if it is to benefit dairy farm operators. Its usefulness will be severely limited without the needed research to add the other model options and further validate the model's results.

Optimization is assigned a relatively low priority. Although an optimization study is possible with the existent model, better results would be obtained if the above projects were completed first. In the model's present form, unconstrained optimization for minimum energy use would result in dairy operations which are not compatible. Penalties or restrictions associated with certain system combinations would need to be added before an optimum dairy operation or management strategy could be realized.

Finally, additional work may be useful in developing an economic model for use in conjunction with the Dairy Farm Simulation Model. An economic model which utilizes different methods of calculating equipment cost would help in determining the final amount of energy saved. If the available energy supply is limited, equipment cost may have a limited impact on the decision. The current hand-method of calculating equipment costs is slow but exact, as it allows the operator to adjust equipment cost for regional differences and personal preference.

The ten topics listed in Table 8.1 are the "ten most wanted" research considerations for future development and application of the dairy system model. Several of these research topics will require considerable time and research effort. The knowledge gained, however, will have application far beyond improvement of the Dairy Farm Simulation Model.

APPENDICES

APPENDIX A

APPENDIX A

MICHIGAN ENERGY AUDIT SURVEY

Agricultural Engineering Department
East Lansing, Michigan

April 28, 1980

Dear Cooperator:

We would again like to thank you for your cooperation in this project. As indicated earlier, April 30, 1980 will conclude Phase II of the Energy Audit project. While data will no longer be collected during Phase III of the project, we are requesting your help in completing the enclosed survey.

The information you provide will allow us to quickly analyze the data previously collected and will help develop conservation programs that will benefit you. Energy conservation is probably not one of your most popular conversation topics, but if it can be translated into quick paybacks and significant cost reductions, I'm sure you will be willing to listen.

Many dairy farmers are faced with decisions to reorganize and modernize their operation in order to survive. The major problem encountered in making these decisions is receiving specific cost and data information before it becomes obsolete due to fast changing economic conditions. In an attempt to keep our information current with your operation, the survey may ask some questions which may have been asked earlier. We realize some of the information we are requesting may be difficult to obtain without wasting some of your valuable time. If the information is not readily available, simply indicate with the letters N.A. and proceed to the next question.

Please be assured that the information you provide will, as in the past, be held in strict confidence. If you have any questions or comments, please do not hesitate to contact us.

Respectfully,

Ernest James Hewett III

Ernest James Hewett III
On Campus Study Team

EJH/slc
Enclosures

MICHIGAN ENERGY AUDIT SURVEY (continued). . . .

ENERGY AUDIT SURVEY
DAIRY

FARM NAME____________________ ____________________TELFARM NUMBER

DIRECTIONS

1. Please read the survey carefully before completing.

2. The survey is divided into three major operations found on the dairy farm; Housing, Milking and Feed Handling. A variety of possible combinations are listed within each operation.

3. Complete the information, as accurately as possible, for only those items which you presently use within each operation. If the information is unknown, unavailable or too difficult to obtain place the letters N.A. in the space provided and continue.

4. Please feel free to make additional comments on the survey when explanation is necessary.

I. GENERAL INFORMATION

A.

1. Herd Size:

   a. Milking Herd (#)________

   b. Dry Cows (#)________

   c. Young Stock (#)________

2. Labor:

   a. Employees (#)________

   b. Hourly Wage ($)________

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

3. Power Company:

a. Name ____________________

b. Rate Group ____________________

4. Outdoor Lighting:

a. Outdoor Light (#) ________

b. Type(s) ____________ ____________

c. Wattage(s) ________ ________

II. HOUSING

A. MILKING HERD

1. Design Type:

a.	Free Stall	(✓) _____	Stanchion	(✓) _____
b.	Warm	(✓) _____	Cold	(✓) _____
c.	Enclosed	(✓) _____	Covered	(✓) _____

2. Building Size:

a. Length (ft) ____________________

b. Width (ft) ____________________

c. Stalls (✓) _____ (#) ________

3. Construction Material:

a.	Floor	____________	Slotted?	(✓) _____
b.	Walls	____________	Insulation?	(✓) _____
c.	Roof	____________	Insulation?	(✓) _____
d.	Alleys	____________	Scrapers?	(✓) _____

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

4. Lighting:

a. Type(s) ________ ________ ________

b. Light(s) (#) ________ ________ ________

b. Wattage(s) ________ ________ ________

5. Watering Systems:

a. Type ________________________________

b. Mfr. ________________________________

c. Heated (✓) ________(#)________

6. Ventilation:

a. Fan (#) ________

b. Motor Size(s) (Hp)________ ________ ________

________ ________ ________

7. Heating System:

a. Type of Heat ______________

b. Units (#) ______________

c. Output (Btu) ______________

d. Temp. Setting (°F) ______________

B. Young Stock

1. Type:

a. Free Stall(s) (✓) _____ (#) ________

b. Calf Hutches (✓) _____ (#) ________

c. Individual Pens (✓) _____ (#) ________

d. Other ____________________________

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

2. Construction Material:

   a. Floor ______________________

   b. Walls __________ Insulation? (√) ____

   c. Roof __________ Insulation? (√) ____

4. Lighting:

   a. Type(s) ______ ______ ______

   b. Light(s) (#) ______ ______ ______

   b. Wattage(s) ______ ______ ______

5. Watering Systems:

   a. Type ______________________

   b. Mfr. ______________________

   c. Heated (√) ______(#)______

6. Ventilation:

   a. Fan (#) ______

   b. Motor Size(s) (Hp) ______ ______ ______

   ______ ______ ______

7. Heating System:

   a. Type of Heat __________

   b. Units (#) __________

   c. Output (Btu) __________

   d. Temp. Setting (°F) __________

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

III. MILKING

A. GENERAL INFORMATION

1. Milking Schedule:

   a. Milking(s) (#/Day) ________

   b. Milking Times A.M. ________ P.M.________ Other_________

2. Milk Production:

   a. Herd Average (lbs/cow)__________________

   b. Bulk Milk Pick-up (days)__________________

3. Labor Requirements:

		minutes	person(s)	
a.	Set up	________	________	per milking
b.	Collecting Cows	________	________	per milking
c.	Milking	________	________	per milking
d.	Clean-up, Misc.	________	________	per milking

B. MILKHOUSE

1. Hot Water Heater:

   a. Type(s) __________________ __________________

   b. Capacity (gal) __________ __________

   c. Temp. Setting (°F) __________ __________

2. Water Pump:

   a. Type __________________

   b. Capacity (gal/hr) __________

   c. Horsepower __________

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

C. MILKING SYSTEM

1. System Design:

a. Diagonal (✓) _____ Sawtooth Herringbone (✓) _____

Polygon (✓) _____ Tie-Stall Pipeline (✓) _____

Rotary (✓) _____ Other ____________________

b. Crowd Gates (✓) ______

c. Auto-Parlor Gates (✓) ______

d. Auto-Feed Bowls (✓) ______

e. Auto-Detachers (✓) ______ Mfr.________________

f. Auto-Pipeline Wash (✓) ______ Mfr.________________

2. System Operation:

a. Milking Units (#) ______ Mfr.________________

b. Booster Wash Pump (Hp) ______ Mfr.________________

c. Booster Wash Heater (Btu)______ Mfr.________________

IV. FEEDING SYSTEM

A. GENERAL INFORMATION

1. Feeding Schedule:

a. Feedings (#/Day) _________

b. Feeding Times A.M.________ P.M.________ Other________

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

2. Labor Requirements:

a. Set up ________ minutes ________ person(s) per feeding

b. Load Mixer or Feed Wagon ________ minutes ________ person(s) per feeding

c. Feed Mixing ________ minutes ________ person(s) per feeding

d. Unloading Feed ________ minutes ________ person(s) per feeding

d. Clean-up, Misc. ________ minutes ________ person(s) per feeding

3. Feed Ration:

a. High Moisture Corn Grain ________ % moisture ________ lbs/cow/feeding

b. ________ Grain ________ % moisture ________ lbs/cow/feeding

c. ________ Silage ________ % moisture ________ lbs/cow/feeding

d. ________ Haylage ________ % moisture ________ lbs/cow/feeding

e. ________ * Dry Hay ________ % moisture ________ lbs/cow/feeding

f. ________ Supplement ________ % moisture ________ lbs/cow/feeding

g. ________ ____ ________ % moisture ________ lbs/cow/feeding

*Indicate delivery method for dry hay ________

____

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

B. FEED STORAGE (if additional space is needed use back of page)

1. Upright Silos:

		1	2	3
a. Feed Type		______	______	______
b. Silo Size	(ft)	___x___	___x___	___x___
c. Unloader Type		______	______	______
d. Unloader	(Hp)	______	______	______
e. Unloader	(V/ϕ)	______	______	______
f. Conveyor Length	(ft)	______	______	______
g. Conveyor Motor	(Hp)	______	______	______
h. Silo Mfr.		______	______	______
i. Silo Construction		______	______	______

2. Bunker Silos:

		1	2	3
a. Feed Type		______	______	______
b. Silo Size	(ft)	___x___	___x___	___x___
c. Unloader Type		______	______	______
d. Unloader Mfr.		______	______	______
e. Unloader	(Hp)	______	______	______
f. Silo Mfr.		______	______	______
g. Silo Construction		______	______	______

3. Dry Bins (i.e. hoppers):

		1	2	3
a. Feed Type		______	______	______
b. Bin Capacity	(lbs)	______	______	______
c. Unloader Type		______	______	______
d. Unloader	(Hp)	______	______	______
e. Bin Mfr.		______	______	______

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

C. DELIVERY METHOD TO STORAGE

1. Silo Blower:

a. Tractor Mounted (√) ______ Electric Blower (√) ______

b. Capacity ______________ Required Horsepower ______

c. Mfr. ______________________________________

2. Bunker Silo Loader:

a. Tractor Mounted (√) ______ Skid Loader (√) ______

b. Bucket Capacity (ft^3) ______________________

c. Mfr. ________________ Horsepower ____________

D. FEED MIXING

1. Mixer Type:

a. Stationary (√) _____ Mobil (√) _____ None (√) _____

b. Weigh Scale (√) _____

c. Capacity (lbs) _____ Mfr. ______________________

2. Mixer Power Unit:

a. Tractor (√) _____ Electric Motor (√) _____

b. Horsepower ________ Mfr. ______________________

E. DELIVERY METHOD FROM STORAGE

1. System Design:

a. Fence Line Bunk(√)____One side (√)___Both Sides(√)_____

b. Stanchion Barn (√)____Automated(√)___ Manual (√)_____

c. Parlor Feeding (√) ___Automated(√)___ Manual (√)_____

MICHIGAN ENERGY AUDIT SURVEY (continued). . .

2. System Operation:

a. Conveyor Delivery (√)______ % Herd Fed ______

Total Length (ft)______ Horsepower ______

b. Shuttle Feeder (√)______ % Herd Fed ______

Total Length (ft)______ Horsepower ______

Shuttle Capacity (lbs)______ Mfr. ______

c. Drawn Feed Wagon (√)______ % Herd Fed ______

Wagon Capacity (lbs)______ Horsepower ______

d. Tractor Mounted Loader(√)______ % Herd Fed ______

Bucket Capacity (ft^3)______ Horsepower ______

e. Skid-Steer Loader (√)______ % Herd Fed ______

Bucket Capacity (ft^3)______ Horsepower ______

f. Other (please Specify) __________________

____

APPENDIX B

APPENDIX B

UNIT CONVERSIONS

Description	Units	Equivalent	
Area	ft^2	0.092	m^2
Crude Oil	bbl	42.0	gal.
Cooling Capacity	Btu/hp• hr	1.414	kJ/kW• hr
Corn Silage (35% DM)	tn	50.0	ft^3
		14.15	m^3
Flow	cfm	1.699	m^3/min
Haylage (40% DM)	tn	50.0	ft^3
Heat Energy	Btu	1.055	kJ
Heat Transfer Coef.	Btu/hr• ft^2• °F	5.678	W/m^2• °C
High Moisture Corn	tn	54.0	ft^3
		15.28	m^3
	bu.	67.6	lb
		30.6	kg_f
Length	ft	0.305	m
Light	lm	1.0	cd/sr
Mass	lb_m	0.454	kg
Milk	gal.	8.5	lb_m
Power	hp	0.746	kW
Pressure	psi	6.895	kPa

UNIT CONVERSIONS (continued). . . . .

Description	Units	Equivalent	
Specific Heat Coef.	gal•°F/W•min	0.014	l•°C/W• min
	Btu/lb•°F	4.187	kJ/kg•°C
Temperature	°F	[(°F-32)/1.8]	°C
Volume	ft^3	0.283	m^3
	gal.	3.79	l
Weight	tn	2000.0	lb
		0.907	t
		907.2	kg_f
	lb	0.454	kg_f

APPENDIX C

APPENDIX C

ENERGY EQUIVALENTS

Description	Units	Equivalent
Crude Oil	bbl.	6.50×10^{6} Btu
Diesel Fuel	bbl.	5.88×10^{6} Btu
	gal.	1.40×10^{5} Btu
Electricity	bbl.	5.80×10^{2} kWh*
	kWh	3.413×10^{4} Btu
Fuel Oil #6 *	bbl.	6.20×10^{6} Btu
	gal.	1.47×10^{5} Btu
Gasoline	bbl.	5.21×10^{6} Btu
	gal.	1.24×10^{5} Btu
LPG	bbl	3.85×10^{6} Btu
	gal.	9.16×10^{4} Btu
Quad	Btu	1.00×10^{24} Btu

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