INVESTIGATION AND SIMULATION OF HOT WATER USE AND PRODUCTION IN FARM DAIRIES

by

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ABSTRACT

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The dairy farming sector of European Agriculture is currently under considerable economic pressure so the aim of each farmer should be to produce saleable milk, at the lowest cost. One important area of concern is the expenditure on hot water for hygiene, as to be acceptable to the buyer the milk must have a low level of contaminants. Clean milk is produced from clean, healthy udders by means of equipment which is adequately and appropriately cleaned. To facilitate this hygienic milk production most dairies are equipped with heaters to provide water at 40°C (for cleaning udders) and 80 - 100°C (for plant cleaning). The practice of udder washing is a subjective process as it depends on the operator's judgement of a 'clean' udder and his view of necessity. In England and Wales there are two only accepted methods of plant cleaning, circulation cleaning and Acidified Boiling Water (A.B.W.). Prior to the audit described it was expected that water and electricity consumption for plant cleaning would be predictable.

To date there has been little information on the volume and temperature of water used on commercial dairy farms and the electricity consumed to produce this hot water. It is therefore difficult for farmers to make informed judgement on methods of reducing their electricity costs.

Thirteen farms in South Devon have been monitored, to establish current practice: farmers were questioned about their water use; electricity and water consumption were metered for two years; and cleaning practices were observed. This survey has revealed that many non-standard cleaning methods are used on dairy farms, making the prediction of water and electricity consumption difficult. The management of equipment has been revealed as the most important aspect in determining the energy used.

A computer model has been produced to simulate water heating in the farm dairy, which can be used to advise farmers as to the energy cost of their cleaning practices. This model has been successfully used on several of the farms surveyed, on one farm its use resulted in energy savings in excess of 400 kWh per month.

CONTENTS

LEGEND

Abbreviations used in the text;

A.B.W.	Acidified Boiling Water.
A.D.A.S.	Agricultural Development and Advisory Service.
E.E.C.	European Economic Council.
H.R.U.	Heat Recovery Unit.
M.A.F.F.	Ministry of Agriculture, Fisheries and Food.
S.W.E.B.	South Western Electricity Board.

1.0 INTRODUCTION

Dairy farmers in England and Wales are currently subject to considerable economic constraints, with their incomes reducing in real terms. During the decade 1970-79, United Kingdom milk producers experienced the second most severe squeeze between input and output prices in the E.E.C. and in 1980 the relative profitability of producing a kilogram of milk in the United Kingdom was the lowest in the Community (Milk Marketing Board, 1980). Dairy farmers are therefore concerned to reduce their costs as far as possible. Energy consumption in the farm dairy is a particular focus of attention, due to increasing energy prices and increasing consumption caused by the trend towards larger herds. On a national basis, the cost of electricity consumed in the farm dairy is £50 000 000 (at a cost of 4.9p / kWh). Although the savings possible on each individual farm may be modest, when repeated over the 43 thousand dairy farms in England and Wales there is potential for considerable saving to national energy use.

Most farm dairies in England use electricity as the sole source of energy, although oil firing is used for heating water on a few farms. The major uses of energy are water heating, milk cooling and provision of vacuum for the withdrawal of milk from the cows. The only published British work which quantifies these energy uses was carried out at the Shropshire Farm Institute (1967), which indicates that water heating was the largest single use at 57% of total dairy consumption.

1.1 Hygiene Requirements of Milk Production

Milk producers contract to supply pure, clean, unadulterated milk fit for human consumption. To be accepted as such by the buyer (the Milk Marketing Board) the milk must pass certain tests which indicate the level of contaminatants in the milk. These are primarily of two types; sediment, which comes mainly from dirty udders; and bacteria, from diseased udders or contaminated milking plant. To facilitate hygienic milk production most dairies are equipped with water heaters to provide water at two temperature levels, 40°C and 80 - 100°C. The warm water is used principally for washing the cows' udders before milking and is generally supplied by a specialised heater through a hose spray. Alternatively this water may be obtained from the main water heater and used from a bucket. After milking the plant is disinfected using hot water and chemicals. There are two methods of cleaning currently practised in England - 'circulation cleaning' and 'Acidified Boiling Water' (A.B.W.) cleaning. Circulation cleaning generally involves an initial rinse of the milking plant with cold or tepid water, followed by circulation, under vacuum, of a hot solution of detergent and disinfectant and a final cold rinse. A.B.W. is a once-through process using almost boiling water (98°C) and either nitric or sulphamic acid, which is drawn through the plant under vacuum. Until recently general recommendations have been that hot cleaning should take place after every milking. However a number of dairy farmers, seeking to reduce their energy costs, have successfully replaced the evening hot wash by a cold wash containing sodium hypochlorite as the disinfectant.

While it is imperative for farmers to produce milk which consistently passes the hygiene tests imposed by the buyer it is in their own interests to do so as cheaply as possible. Due to the cost of energy most farmers wish to reduce their water heating bills. This may be done by replacing electricity with cheaper forms of energy, by reducing the energy used for heating water through decreasing the volume, temperature or frequency of hot water used for plant cleaning and udder washing. The effects on the quality of milk of changing hot water use are uncertain; there is a wide range in the recommendations published as to the volume, temperature and frequency of hot water required for adequate hygiene. These recommendations are, in the main, based on experimental work, they are not necessarily a reflection of common practice on dairy farms.

Although many recommendations have been made to farmers, no reliable information is available as to the volume, temperature and timing of hot water actually used and the reasons for its use, on commercial dairy farms. The aims of the present work are to monitor thirteen farms in South Devon to establish current practice concerning hot water use and the energy used for its production. The farms were selected from a list provided by the Agricultural Development and Advisory Service (A.D.A.S.) of farmers willing to participate in investigational work. The farms were selected to give a range of herd size, location, milking equipment and management practice. On each farm meters were installed to monitor electricity and water use for plant cleaning and udder washing over a period of two years.

2.0 PUBLISHED WORK REGARDING HOT WATER USE IN FARM DAIRIES

The aim of each dairy farmer is to produce saleable milk; each producer contracts to supply pure, clean, unadulterated milk fit for human consumption. Clean milk is produced from healthy udders, which are themselves clean, and withdrawn hygenically by means of equipment which is properly cleaned (Palmer 1975). Cleaning is of particular importance in the food industry because the material handled is an excellent substrate for microbial growth (Galeshoot 1966), dairy hygiene is designed to control the multiplication of spoilage bacteria (Currier 1977). Cleaning aims for the complete removal of all extraneous matter, particularly organic which forms a substrate for bacterial growth (Davis 1965), and reduction of microbial organisms to a level where they do not affect the milk.

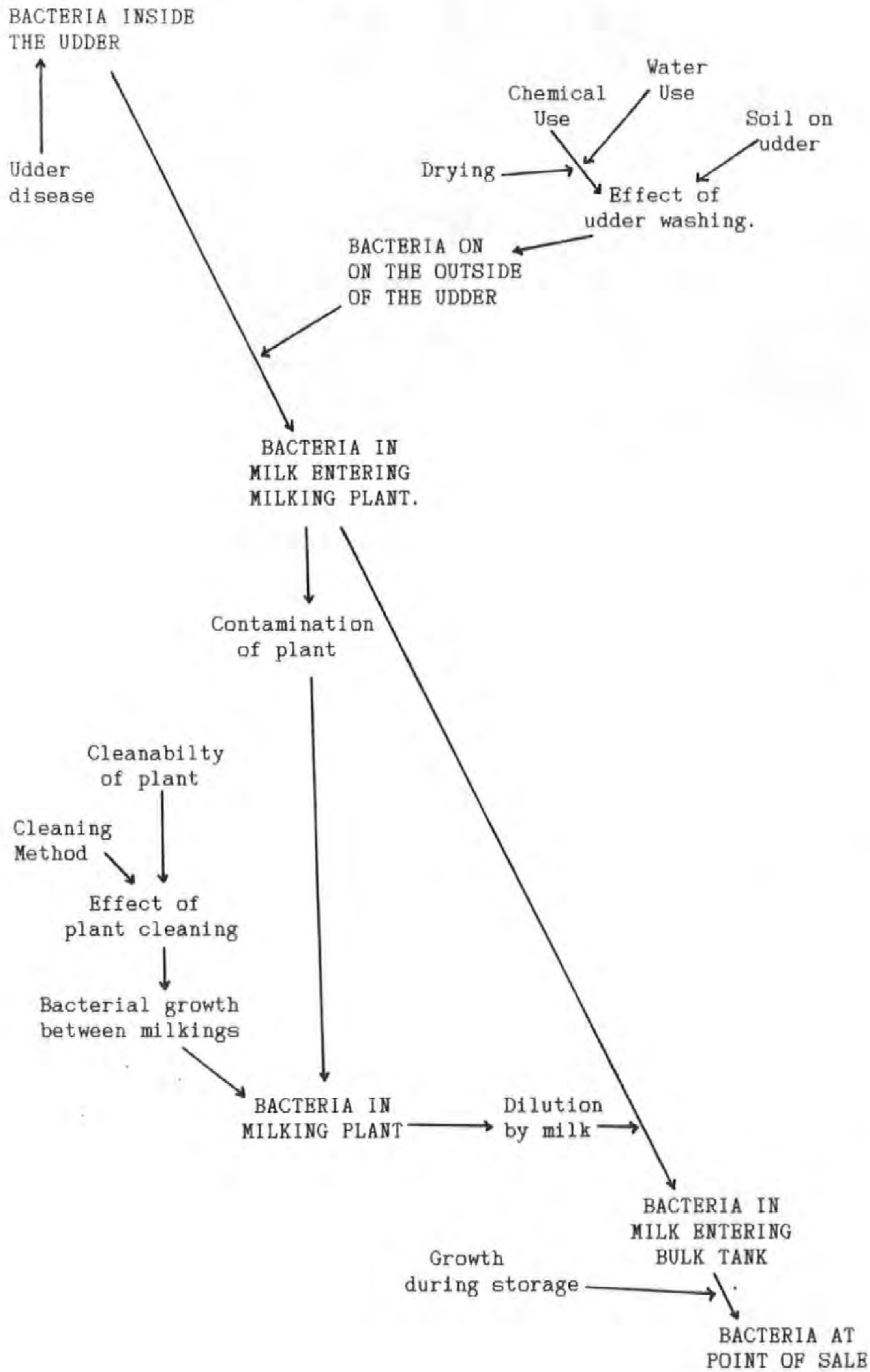
2.1 Sources of Contamination of Milk

Milk is subject to contamination from many sources, as outlined in Figure 2.1.1. Bacteria in milk may originate from the inside of the udder, where the presence of bacteria is caused by disease. As the milk is extracted it may also be contaminated by bacteria in the teat canal. The first major source of bacteria in the the milk is from the outside of the udder. The level of contamination will depend firstly on the soil on the udder and then the effect of udder washing. The effectiveness of udder washing is influenced by the volume of water used, any chemical additives and whether the udder is dried. These two sources, the interior and exterior of the udder, result in bacteria in the milk as it enters the milking plant.

The milking plant is contaminated by some of the bacteria in this milk. The bacteria in the plant will be reduced by plant cleaning, the effectiveness of which will depend on the cleanability of the plant, and the plant cleaning technique. The bacteria which are not removed by cleaning will multiply during the period between milkings and will then re-contaminate the milk. The level of the contamination will depend on the number of bacteria present and the volume of milk in which the bacteria are diluted.

Figure 2.1.1

Factors Affecting the Bacterial Contamination of Milk



The milk then enters the bulk milk vat, where multiplication of the bacteria will depend on the storage conditions within the vat. Bacteria in the milk at the point of sale therefore has three major sources; the interior of the udder, the exterior of the udder, and the milking plant. The final level of contamination also depends on the growth during storage. Each of these factors are now examined.

2.1.1 Contamination from Within the Udder

If milk is removed from the udder by surgical techniques sterile samples can be obtained (Tolle 1980). However milk withdrawn via the teat is contaminated by bacteria from the teat canal. Levels of contamination of milk withdrawn via the teat canal as found by Tole (1980) are shown in Table 2.1.1.1.

Table 2.1.1.1.
Levels of Contamination of Milk

Bacterial Count colony formimg units	Percentage of samples
$<10^2$	41
$10^2 - 10^3$	35
$10^3 - 10^4$	23
$10^4<$	1

A number of authors have provided further evidence of variable, but significant contamination. For example the range of bacterial counts of milk from individual cows on the same farm was found to be up to one hundredfold by Morse et al (1968). Cousins (1978) found a range of $<10^2$ to $>10^5$ bacteria per millilitre for individual cows milk. Milk for animals in the first and second lactations show significantly lower counts than that of older cows (Bacic, Jackson and Clegg 1968). The fore milk contains a much greater number of bacteria, however the small volume of this milk results in little increase in the total bacterial count.

A major cause of raised bacterial count in milk immediately after withdrawal from the udder is bovine mastitis, a multifunctional disease for which 80 species have been indentified as casual agents (Philpot 1979). Most mastitis infections are caused by coccus bacteria, particularly staphylococci and streptococci species. Coliform bacteria cause a relatively low proportion of infection, approximately ten percent of all clinical cases, but can be a major cause (up to 50%) in certain herds (Bramley 1978). Infection caused by coccus bacteria are generally limited in effect to the udder, but coliform infection often produces widespread disease and only 20% of infected cows recover completely (Bramley 1978).

Coliform bacteria are widely distributed in the environment and are generally transmitted, between milkings, by contact with bedding and other materials which are contaminated by faeces. Cocci generally inhabit diseased udders and are transmitted during milking by clusters, hands and udder cloths.

Mastitis is caused by interplay between mechanical forces exerted by the milking machine and bacterial infection. The machine acts as a vector in disease transmission, it causes trauma and actively injects bacteria into the udder (Boyer 1979). Wilson and Richards (1980) examined 27 526 cows in 501 herds and found major udder pathogens in 99.8% of herds, 32% of cows and 14.1% of quarters.

Infection of the udder by mastitic organisms results in greatly increased bacterial counts and changes in the microfloral composition of milk. Mastitis infections are generally grouped into two types: subclinical mastitis where the milk is not visibly altered and clinical mastitis where clots may be seen in the milk. Olsen (1962) suggests that 25% of mastitis infections result in milk which is grossly abnormal and Cousins (1967) reports that 50% of cows may have a mastitic infection, 2 - 3% of cows having clinical mastitis. Subclinical mastitis results in bacterial counts of 10^4 - 10^5 organisms per millilitre of milk, a clinically infected cow can excrete up to 10^8 organisms / ml of milk (Dodd and Neave 1970). The fluctuations in the number of organisms are considerable.

In general the contribution of bacteria from the interior of the udder is low (Bacic, Jackson and Clegg, 1968). However a clinically infected quarter, with clots in the milk, may increase the bacterial count in the milk by up to 10^5 bacteria/ml (Cousins 1972). In those farm bulk milk supplies which have bacterial counts over 10^4/ml udder pathogens may comprise 90% of microflora (Cousins 1972). The incidence of mastitis pathogens can obscure assessment of the contribution from other sources of contamination of bulk milk (Cousins 1978).

2.1.2. Contamination from the Exterior of the Udder

The exterior of the cow is an abundant reservoir of micro-organisms, particularly the surface of the teats, udder and flanks. These microorganisms are of enteric, soil and water origin. Dirty teats are a major source of sediment in the milk. In addition to sediment the bacteria associated with soil are also washed into the milk, as at every pulsation cycle the tip of the teat is washed with milk (Tolle 1975). The contribution of bacteria from the outside of the udder to the milk has been reported as 10^3 - 10^4 bacteria/ml (Joergensen 1980), 10^4 - 10^5 bacteria/ml (Cousins 1972) and 10^4 - 10^5 bacteria/ml (Johns 1962). The environment of the cow affects the level of soil on the udder, the udder being generally drier and cleaner during the grazing period compared with the period during which the cows are housed (Joergensen 1980). The clean teats of cows on grass may contribute less than 10^2 bacteria per millilitre of milk, while teats of cows kept on contaminated bedding can contribute up to 10^4 bacteria/ml of milk (Cousins 1977).

2.1.3. Contamination from the Milking Plant

In practice the milking plant contributes more to the total bacterial count of the milk than any other factor (Cousins 1972, Thomas and Thomas 1977 and Marshall 1980). Unsatisfactory bacterial counts in milk were wholly or partly attributed to inadequately cleaned milking plant on 65% of farms studied by Thom (1962). The contribution of bacteria from the milking machine has been estimated at 67% (Fascar and Pandi 1980) and 75% (Marshall 1980) of the total bacterial count in milk. When farm milk is heavily contaminated the prime source of contamination is usually poorly cleansed equipment. If an effective cleaning and sterilising routine is used on the milking equipment it will contribute less than 10^3 bacteria per millilitre of milk (Palmer

1980). Chatelin and Richard (1978) reported an increase of 4 x 10^5 bacteria/ml milk caused by a badly cleaned plant.

Within the milking plant the rubber parts are the major source of contamination (Druce and Thomas 1972) as micro-organisms can grow in crevices in the rubber and in the layers of fat on the rubber surfaces. Deposits removed from liners have been found to have a rich microflora (Berridge 1951). Major (1962) reported that milking equipment rubberware added 10 - 117 times the number of bacteria contributed by the metal parts on farms where the milk was bacteriologically unsatisfactory. Chemical sterilisation is less effective on rubber than on metal, as the irregular surface of rubber allows the formation of deposits. Bacteria within these deposits are not affected by chemicals (Clegg 1956), and the residues provide a source of nutrients for microbial growth (Olsen 1962).

2.1.4. The Effect of Storage Conditions

After the milk has been removed from the cow it has to be stored until its collection for subsequent processing. The Milk and Dairies (General) Regulations (1959) require that milk should be cooled rapidly after production and stored at a low temperature until collection. All farm dairies in England and Wales now store milk in a bulk milk vat which is usually refrigerated, alternatively the milk is pre-cooled and stored in an insulated vat. These vats must comply with the requirements of the United Kingdom Federation of Milk Marketing Boards Specification BC56, which requires that the refrigeration unit be capable of cooling the tank's nominal capacity of milk from 35°C to 4.4°C in an ambient temperature regime of 32.2°C, cooling to be complete within half an hour of the end of milking. Cooling of milk to low temperatures immediately after milking is the only acceptable means of controlling growth of the micro-organisms (Olsen 1962). If cooling is delayed for two to three hours there will be a significant increase in bacterial counts, whereas if the milk is cooled immediately to 4°C there will be little growth for 72 hours (Stadhouders 1968).

2.1.5 Summary

In summary bacteria in the milk at the point of sale have three major sources; the interior of the udder, the exterior of the udder and the milking plant. The final level of contamination also depends on the growth during storage. Of these factors it has been seen that the interior of the udder contributes few bacteria, in the absence of mastitis. In addition the growth during storage is minimal if the bulk milk vat is functioning correctly. The major sources of contamination are, firstly, the milking plant, and secondly, the exterior of the udder.

Reduction of contamination of milk by bacteria and extraneous matter requires many, linked, activities. Some of these activities are long-term and their effect is long acting; for example the treatment of cows with intramammary antibiotic infusion at the end of a lactation to reduce the level of sub-clinical mastitis and therefore reduce the bacteria excreted in the next lactation. Other activities are short term, for example washing of udders prior to milking to reduce the sediment, and associated bacteria, on the udder, which would otherwise be washed into the milk. The interactions of these processes are complex. For example; alteration in the cows' environment will affect the requirement for udder washing, the frequency of renewal of rubber parts in the milking plant will influence the rigour of plant cleaning techniques required to maintain plant hygiene at a satisfactory level. In general a low level of bacterial contamination from one source will mitigate a high level from a second source so minimising the risk of a high overall level of contamination.

In order to reduce the contamination of milk two activities requiring hot water are carried out by dairy farmers. The first is to wash the udders prior to milking with lukewarm water, the second to wash the plant after milking with hot water to clean it.

2.2 Udder Washing

The aim of udder washing is firstly to remove dirt and associated bacteria and thus reduce the contamination of the milk. There is a requirement, imposed on farmers by the Milk and Dairies (General) Regulations (1959), that visible dirt is removed from cows' flanks udders and tails. Secondly udder washing aims to destroy mastitis organisms to reduce cross infection of cows. Finally it stimulates oxytocin production allowing let-down of milk.

Udder washing is usually carried out using warm water (35 - 40°C) although cold water may be used, particularly in summer. Originally the warm water was carried in a bucket and the udders were washed using a single cloth. Spray washing was introduced after 1965, which allows clean water to be used for each cow, the udders being dried with disposable paper towels. This method reduces cross contamination.

The volume of water required for udder washing is very variable, it depends initially on the cleanliness of the cows' udders and then on the personal judgement of the herdsman. In practice the frequency of udder washing varies considerably; some herdsmen wash all the udders at every milking, others wash only the dirty udders, some have different regimes in summer and winter, and some herdsmen do not wash any udders. After washing some herdsmen dry the udders with disposable paper towels, some use the same cloth for all the cows and others leave the udders wet.

The effectiveness of udder washing in reducing the sedimental and bacterial contamination of milk is variable. "Good" udder washing technique was found to reduce sediment and bacteria in milk by Panes Parry and Leech (1979). The effect of different udder washing techniques on bacterial contamination of milk has been investigated by Cousins (1978), the results of this survey are shown as Table 2.2.1.

Table 2.2.1

Contamination of Milk with Bacteria from Surfaces of Cows' Teats After Different Hose Washing Treatments

Treatment	Level of contamination	
	Geometric mean	Range
Unwashed	7.5	0.5 - 75.6
Washed and left wet	7.9	0.6 - 111.0
Washed and dried	4.2	0.1 - 54.0
Washed with NaOCl* and left wet	4.1	0.4 - 64.0
Washed with NaOCl* and dried	1.5	0.1 - 22.0

*NaOCl contains 600 ppm Cl

These results show that udder washing without subsequent drying does not reduce bacterial contamination of milk, but washing followed by drying is effective. McKinnon et al (1971) found that the bacterial count of individual cow's milk often exceeded 10^4 / ml if the udders were not washed or if they were washed with dirty water and not dried. If udder washing is not carried out carefully it was found by Richard (1978) to be less effective than not washing when the udders appeared clean. This effect was attributed to incompete washing loosening the soil and allowing its subsequent removal into the milk. Hoare and Roberts (1972) found a significantly higher incidence of mastitis in herds where washing of udders was unsatisfactory.

There is agreement between authors that careful udder washing is effective in reducing contamination of milk by bacteria and sediment from the outside of the udder. However the volume of water recommended to carry out the process varies widely, as shown in Table 2.2.2

Table 2.2.2

Volume of Water Recommended for Udder Washing

Author	Date	Recommendation litres per cow
Ministry of Agriculture	1970	1 - 1.5
Fellows	1975	0.5 (summer)
		1.0 (winter)
Prosser	1979	1.0

According to M.A.F.F. (1970), the temperature of udder washing water should be 40°C. This temperature aids sediment removal and is comfortable for both herdsman and cow.

2.3 Plant Cleaning

2.3.1 Principles of Plant Cleaning

The milking plant is the most prolific source of bacterial contamination of milk (Cousins 1972). The contamination is a result of the numbers of bacteria in the plant, their growth rate, and their degree of attachment to the plant. The numbers of bacteria in the plant will be highest after soiling and lowest after a full cleaning routine. The numbers of bacteria may increase between the cleaning routine and the next milking, if conditions are favourable to bacterial multiplication.

The contamination of the plant starts with the deposition of soil and bacteria, major sources being milk, cleaning solutions, animals and personnel. The relative importance of these sources depends on the number and type of organisms involved. Both milk and cleaning solutions will carry bacteria from outside sources into the plant and from one part of the plant to another (Dunsmore at al 1981). The bacteria then undergo attachment, either directly to the plant itself or to soil which is attached to the plant. Bacterial cells attach by means of extracellular polysaccharides which require, in general, six to twelve hours to form (Zobbel 1943), although some species can attach immediately (Dunsmore and Bates 1980). The number of bacteria which become attached to the plant depends on the number of attachment sites, these increase with soil deposition and corrosion of the plant. Soil on the plant can be classified into two groups; "thin film" where the organisms are exposed and "harbourage" where soil accumulates in cracks and joints and the organisms are embedded in a nutritive base where they are protected (Dunsmore et al 1981). The attachment of micro-organinsms reduces their removal by cleaning solutions.

The purpose of plant cleaning is to deplete the numbers of micro-organisms. This is achieved by physical removal or by killing or by inactivation through stasis or injury. Complete sterilization of the milking plant, that is the destruction or removal of all forms of life, is not possible in practice (Sykes 1960). Plant cleaning therefore aims for removal of all extraneous matter, particularly organic matter, and reduction of bacterial numbers to an acceptable level. Efficient cleaning will remove approximately 99% of bacteria by mechanical means (Davis 1965). Bacteria will also be killed by chemical agents in the cleaning solution or by the temperature of the solution, a process known as disinfection (Sykes 1960). The ability of cleaning agents to remove bacteria is affected by many factors, including the nature of the plant substrate; the type, turbulence and temperature of the cleaning solution; the duration of cleaning; and the constituents and level of soil present. After cleaning the remaining bacteria will grow, if conditions are favourable. The degree of bacterial growth will depend on selection pressures such as temperature, nutrient and water availability, pH and the nature of the surface. During milking some of these remaining organisms will contaminate the milk (Dunsmore at al 1981). The level of contamination is difficult to predict, Twomey and Crawley (1969) found a tenfold day to day variation in contamination of milk by thermoduric bacteria, the only source of which is the milking plant.

The principles of plant cleaning are as follows;

1) Removal of food residue that can serve as a nutrient source for bacteria.
2) Destruction of any bacteria not killed or removed from the surfaces with the food residues.
3) Storage of equipment under conditions which discourage or prevent growth of surviving organisms in the period between milkings. (Swartling 1959)
4) Removal of cleaning solution that may contaminate the milk. (Dunsmore et al 1981)

Soiling is a spontaneous process and results in a decrease in the free energy of the system. Therefore to remove the soil, energy must be supplied, which in general is mechanical, detergents are used to reduce the work requirement. In the detergent free system the lowest energy state of the soil is that of the attached particle, its removal requires overcoming the energy barrier. When the particle has been removed detergents react with the suspended particle to reduce its energy level and to enlarge the energy barrier that must be overcome before redepostion can occur (Galeshoot 1966). The soil removal mechanisms are as follows;

1) Intimate contact of detergent with soil, this employs wetting and penetrating properties.

2) Displacement of soil by melting fat, by wetting and peptizing protein and by dissolving minerals.

3) Dispersal of soil by deflocculation and emulsification.

4) Preventing redeposition of soil by providing good dispersing, emulsifying and rinsing properties.

(Dunsmore et al 1981)

2.3.2. Agents of Plant Cleaning

The agents of soil removal are kinetic energy (turbulence), thermal energy and chemical energy. Difficiency in one of these agents can be compensated for by an increase in one or both of the others. The factors affecting the efficiency of these agents have been the subject of many studies, notably those of Dunsmore et al (1981), Galeshoot (1966), Hankinson et al (1965) and McCulloch (1965).

2.3.2.1. Kinetic Energy

Kinetic energy was originally supplied to cleaning routines by means of a bristle brush (Jennings 1961). Jennings at al (1957) investigated the role of turbulence in cleaning. This study used the Reynolds number to relate fluid flow to cleaning effectiveness, using P^{32} labelled milk to indicate residue levels. A sharp break in the data was found at Re 25 000 below which there was little cleaning action.

2.3.2.2 Thermal Energy

The effect of increasing temperature on the efficiency of plant cleaning is complex. This is due to the the complex nature of the soil, which is changed by heat. Protein and fat, two major constituents of milk, are both altered by heat, forming substances which are more difficult to remove (Palmer 1980). However, increasing temperature accelerates chemical reaction rates, rate of penetration of soil and alters solution turbulence. In general the rate of soil removal increases by a factor of 1.6 for every 10°C rise (Jennings 1959). Hankinson and Carver (1968) found that peak soil removal occured at 55°C. At lower temperatures more soil was removed with increasing temperatures, above 55°C soil removal decreased with increasing temperature. This was attributed to denaturation of protein resulting in a tenacious soil. A higher optimum cleaning solution temperature of 65°C was given by Dunsmore et al (1981) and Calbert (1963) found satisfactory cleaning at final solution temperatures of 32°C.

2.3.2.3 Chemical Energy

Two types of chemicals are used in milking plants; detergents to remove soil and sanitiser to kill any residual bacteria. The chemicals may be applied separately, as is general practice in North America, or together, as is general in Britain. Separate application has the advantage that the sanitizer works on a clean surface and may be used at lower concentrations. Chemical sanitizers are very sensitive to organic matter, particularly protein; the reaction products of hypochlorite and protein still have some bactericidal properties, those of iodine and protein do not. The combined detergent-sterilizer system allows a shorter cleaning process and also prevents the build up of bacteria in the detergent solution (McCulloch 1965). In England and Wales any sterilant or combined detergent-sterilizer used for cleaning milking plants must be approved by the Ministry of Agriculture, Fisheries and Food. There is no control over the use of detergents as their use has never been obligatory.

The most commonly used sterilants are hypochlorite and quarternary ammonium compounds. Hypochlorites of sodium or calcium have many advantages, being cheap, convenient to use with a wide bactericidal action, so they are most commonly used. Hypochlorites are however corrosive and have a strong odour so they are unpleasant to use. Quarternary ammonium compounds are non-corrosive, without appreciable odour and are convenient to use. Although they are very effective against Gram-positive bacteria they are less effective against Gram-negative bacteria and this is their greatest disadvantage (Davis

1965). Other sterilants available are alkalis such as sodium hydroxide, iodophors and chloro-compounds.

Detergents used are of three main classes; heavy duty alkaline, general purpose and acidic. The class of detergent defines its general characteristics, but differences in formulation also influence cleaning performance (Dunsmore et al 1981). Acidic detergents are the most effective at removing mineral salts, but alkaline detergents remove protein soil most effectively. Surface active agents are required for the removal of fat.

2.3.2.4. Length of Cleaning Time

Hankinson and Carver (1981) examined the rate of soil removal and found that 70% of the soil was removed in the first five minutes of recirculation and that there was little further soil removal after 20 minutes. At the start of cleaning increasing contact time between detergent and soil increases cleaning performance. However an equilibrium will be established between the soil being removed from the plant into the cleaning solution and the soil being redeposited from the solution back onto the plant.

2.3.2.5. Milking Plant Substrate

The physical and chemical nature of the surface will effect the efficiency of cleaning. Glass and stainless steel have excellent cleanability, however stainless steel is subject to corrosion. Rubber initially has a smooth surface but is mechanically and chemically abraded in use. Soil accumulates in cracks providing harbourage for bacteria (Dunsmore et al 1981). The design of the milking plant may adversely affect its cleanabillty, for example poor fitting of milk and vacuum lines, the present of dead ends and large numbers of joints can provide harbourage for bacteria. The design of the milking plant may also not allow for sufficient turbulence in cleaning solutions (McCulloch 1965).

2.3.2.6 Use of Periodic Cleaning Routines

Periodic cleaning routines are required as no detergent is totally effective, allowing a resistant soil to develop which is only controlled by periodic treatments. Periodic cleaning may involve complementary chemicals, for example a six day alkali - one day acid system, the alkaline detergent allows a mineral soil to develop which is removed by the acid. Alternatively the periodic treatment may be more energetic, using a higher detergent concentration, higher temperature or higher kinetic energy (Dunsmore et al 1981).

2.2.2.7. Staff

Many farm dairy staff are untrained and may therefore not operate the cleaning routine correctly (Dunsmore et al 1981). Evans-Scott (1978) found considerable difference in swab counts of milking plants on different farms, although there was no significant difference between cleaning methods on the farms. It was concluded that most of the variation in plant hygiene was due to the difference in the care of application of cleaning methods. The effect of staff on plant cleanliness has also been reported by McCulloch (1963) and Orr and Baines (1976).

2.3.3. Methods of Plant Cleaning

In England and Wales almost all milking plants are cleaned using either circulation cleaning or the Acidified Boiling Water (A.B.W.) method. In Ireland cold circulation cleaning is also used (Palmer 1977). Outside the British Isles separate cleaning and sanitising processes are used, the sanitiser wash being delayed until the start of the following milking. In New Zealand and Australia the triple cleaning system (Heyes et al 1980) and reverse flow cleaning (Dickens 1980) are most often used.

2.3.3.1 Circulation Cleaning

The earliest pipeline milking machines were cleaned by flushing, daily steaming and complete dismantling once a week for hand brushing. Early attempts at circulation cleaning involved flooding the complete system with detergent-disinfectant solution which, because of the volume involved, was used cold. This system was laborious and ineffective, so the recording jars were removed for general milking to reduce the volume of water required for cleaning. Hot cleaning solutions could then be used, allowing for more effective cleaning. However the absence of recording jars caused problems during milking, principally the inability to reject abnormal milk and loss of steady milking vacuum (Theil 1964). Changes in parlour design, notably the introduction of jetters to allow in place cleaning of clusters and spreaders inside recording jars which distribute the cleaning solutions over the internal surfaces of the jar, now allow pipeline milking plants to be satisfactorily cleaned using relatively small volumes of hot water.

The generally accepted method for circulation cleaning is as follows;

1) Pre-rinse using warm or cold water, discharged to waste, to remove milk residues. This stage may be omitted (B.S. 5226:1978).
2) Hot wash using detergent-sterilant, circulated for 5-20 minutes.
3) Cold rinse, using 45 litres of water, either discharged to waste or recirculated. A sterilant may be added to this rinse, particularly if the bacteriological status of the water is poor.

The temperature required for the hot cleaning solution to provide good plant hygiene with circulation cleaning has been the subject of a considerable volume of work. Most current recommendations to farmers suggest that initial water temperatures of 82-85°C are required (Electricity Council 1978, B.S. 5226:1978, Castle and Watkins 1979, Ministry of Agriculture, Fisheries and Food 1981). The Electricity Council (1978) and the British Standard (1978) also state that water should be discharged from the plant, until the temperature of the water returning from the plant reaches 65-70°C, before circulation commences. These recommendations are based on findings that circulation cleaning temperatures below 80°C result in high bacterial contamination of the milking plant, as assessed by rinses. Swift, Alexander and Scarlet (1962) examined plant cleaning techniques on twelve farms using circulation cleaning that had a high standard of plant cleaning as normal practice. The results of plant rinses, shown as Table 2.3.3.1.1., indicate that the higher wash temperature of 82°C results in a significant improvement in plant hygiene.

Table 2.3.3.1.1.

The Effect of Cleaning Solution Temperature on Bacterial Contamination of Milking Plants

Level of contamination bacteria per ft^2	Initial wash temperature 60°C	82°C
	number of plants	
up to $5x10^3$	23	18
$5x10^3$ - $5x10^4$	14	8
over $5x10^4$	11	6

Clough et al (1965) report that rinse counts of a milking plant at the National Institute for Research in Dairying regularly exceeded 5×10^3 bacteria/ft^2 when the wash temperature was below 71°C.

However if milk quality is used as the criterion to judge plant cleaning techniques, lower temperatures are satisfactory. Swift, Alexander and Scarlett found that wash temperatures of 60°C or 82°C produced milk of similar bacterial quality. Bigalke (1978) examined initial wash temperatures of 71°C, 66°C, 60°C, 54°C and 44°C and reported no difference in the microbial status of the milk or milking plant at the 95% confidence level. Theil (1962) reported that it was common practice on farms for the initial water temperature for circulation cleaning to be 62°C. Kruger et al (1962) tested a circulation temperature of 59°C and reported satisfactory results.

The volume of hot water recommended for circulation cleaning varies widely, as is summarised in Table 2.3.3.1.2.

Table 2.3.3.1.2

Recommended Volumes of Hot Water for Circulation Cleaning

Author	Date	Recommended volume (litres per milking unit)
Clough and Theil	1961	4.5
Electricity Council	1978	6 - 9
Gascoigne Ltd		5 - 6
Fulwood Ltd	reported in	5 - 7
Alfa-Laval Ltd	Theil (1964)	7 - 11
Simplex Ltd		11 - 14
Cousins	1979	10 - 14
M.A.F.F.	1981	15

The frequency of hot washes required is stated by most authors to be after every milking (Ministry of Agriculture, Fisheries and Food 1981; B.S. 5226:1978; Electricity Council, 1978). However there is no published work which indicates that two hot washes per day are more effective than one, if measured by visual assessment of the plant or bacteriological quality of the milk (Cousins 1977). Some plant cleaning chemical manufacturers now recommend once daily hot cleaning (Lisboa 1976) and this policy is followed on many farms (Cousins 1977).

2.3.3.2 The Acidified Boiling Water (A.B.W.) Method

The A.B.W. method was developed at the National Institute for Research in Dairying by Clough et al (1965). This is a one stage cleaning process using 14-18 litres of boiling water for each milking unit. Nitric or sulphamic acid is used in conjunction with boiling water to prevent deposition of calcium salts (Clough et al 1965). The boiling water is drawn through the milking plant at such a rate that the total volume is discharged within 5 to 6 minutes. During the first 2 to 3 minutes of flow one litre of dilute acid is introduced to the water, the concentration of which depends on the number of units. During this first period the plant is heated to a minimum of 76°C and maintained at this temperature until the end of cleaning (B.S. 5226:1978).

Periodic cleaning to remove any film which develops on the internal surface of glass vessels is also recommended (B.S. 5226:1978). This entails replacing the acid by sodium hypochlorite for one cleaning treatment, at intervals greater than one month.

The A.B.W. system was developed specifically for in-place cleaning of milking machines, by a single group of workers, unlike circulation cleaning which evolved from earlier techniques. In consequence almost all authors follow the recommendations of Clough et al (1965) (B.S. 5226:1978, Cousins 1967, Sinclair 1978). There is however, dispute as to the frequency of hot washes required. The British Standard (1978) states that a hot wash must be used after every milking but other authors suggest a single hot wash each day is sufficient (Clough 1976, Cousins 1977, Sinclair 1978). Where only one hot wash is carried out each day it usually occurs in the morning and in the evening a cold once-through rinse with hypochlorite is substituted.

The A.B.W. method was developed to minimize the time spent cleaning the parlour while maintaining standards at reasonable cost (Parry and Egdell 1968). It is often considered to give beter results than circulation cleaning (Clough 1976, Cousins 1977) but requires more water at a higher temperature to do so. The cost of chemicals is lower for A.B.W. cleaning than for circulation cleaning however, so the relative costs of the two systems depend on the relative costs of detergent-disinfectant chemicals and energy for water heating.

2.3.3.3 Cold Cleaning

Both circulation cleaning and A.B.W. cleaning require large volumes of hot water. Heating this water is energy expensive, and although the cost is a small part of total production costs it is of concern to dairy farmers. Cold in-place cleaning therefore seems attractive (Cousins 1977). However, although cold cleaning once each day is in use on farms, as an alternative to either A.B.W. or circulation cleaning, complete replacement of hot washes with cold methods has yet to find favour in England.

Work on cold cleaning techniques has been carried out in Ireland (Palmer and O'Shea 1973, Palmer 1977 and Murray et al 1979). The technique developed is as follows:

After milking:

1) Cold pre-rinse with 13.5 litres / unit

2) Wash plant using 9 litres of water per unit, with 0.23 kg caustic detergent per 45 litres of water. Run the first 4.5 litres to waste and circulate remainder for 10 minutes. Retain the solution for the second daily wash.

Before milking

3) Rinse the plant with 13.5 litres cold water per unit.

A periodic hot (85°C) wash using hypochlorite and caustic detergent is advised whenever deposits are apparent, or at least once per month.

This system was tested against A.B.W. cleaning once or twice per day, on 24 farms for nine months, by Murray et al (1979). Each parlour was cleaned using each system for three months. It was found that all three systems gave better plant hygiene in the period January to April, and in all periods once daily A.B.W. cleaning gave inferior results to either twice daily A.B.W. or cold circulation, which gave similar results (Murray et al 1979). This system is also cheaper at 13.4p / day than either hot circulation cleaning (22.4p / day) or A.B.W. used twice per day (Palmer and O'Shea 1973). The authors did not examine once daily hot circulation cleaning which would be more competitive with cold cleaning.

In contrast to this Cousins (1977) states that it has yet to be shown that twice daily cold cleaning is capable of keeping milking machines visibly clean for more than a few days, except by using chemicals costing as much as the energy necessary to heat water for conventional methods.

2.3.3.4 The Triple system

The triple system is recommended by the Ministry of Agriculture and Food in New Zealand, for use after every milking (Heyes et al 1980). This system uses a pre-rinse, hot wash, post-rinse method similar to circulation cleaning. The major difference is the post-rinse, which in the triple system uses water at 85°C. Alkali detergent is used for six days, with acid detergent on the seventh (Dunsmore et al 1980)

2.3.3.5 Reverse Flow Cleaning

Reverse flow cleaning differs from all other methods in that the cleaning fluids are pumped in the opposite direction to the milk flow and discharged to waste through the teat cups. The complete wash cycle takes only five minutes so that labour costs are low (Dickins 1980). However the large volume of water required to allow sufficient contact time for the cleaning solutions results in high fuel costs (Evans-Scott 1978). The cleaning routine is as follows

1) Cold rinse - 15 litres / milking unit plus 35 litres
2) Hot wash - 9 litres / milking unit at 70 - 80°C
3) Hot rinse - 5 litres / milking unit at 70 - 80°C

(Dickins 1980)

This system was developed in New Zealand for cleaning milking plants of 17 or more units

2.4 Tests of Milk and Plant Hygiene

The major contaminants of milk are sediment and bacteria, the major source of sediment being the outside of the udder and of bacteria, the milking plant. There are three methods of control and assessment of these contaminants; The Milk and Dairies (General) Regulations (1959); tests imposed by the buyer, the Milk Marketing Board; and recommendations from the British Standards Institute.

2.4.1. Tests of Sedimental Contamination

To reduce the sediment in milk the Milk and Dairies (General) Regulations (1959) require that the visible dirt is removed from cows' udders, flanks and tails before milking. This requirement is usually interpreted to mean that dirty udders should be washed (Cousins 1972). The Milk Marketing Board routinely tests all milk and rejects that which contains more than 3 mg sediment per litre. Following a failure the milk is retested ten days later and if it fails this, or any routine test within 6 months, the supply is placed on "special delivery". This special delivery is subject to a financial penalty and the milk is tested daily. The special delivery system is stopped when the milk has passed the sediment test on two consecutive days.

2.4.2 Tests of Bacterial Contamination

The control of bacterial contamination is more difficult as the factors causing the contamination are complex. Bacterial contamination can be assessed by direct testing of the milk or by testing of the milking plant, as the plant contributes more to the total bacterial contamination of milk than any other factor (Cousins 1972). The following four methods are used for assessment of bacterial contamination.

1) Assessment of bacterial activity in milk.
2) Enumeration of bacteria in milk.
3) Visual assessment of plant hygiene.
4) Assessment of plant hygiene by enumeration of bacteria recovered by rinses.

2.4.2.1. Dye Reduction Tests

Dye reduction tests provide a measure of bacterial action and therefore provide an indirect measure of numbers of bacteria. These tests are easy to administer to a large number of samples and require only a short incubation period of two to three hours. For these reasons the Resazurin Dye Reduction Test has been used for many years by the Milk Marketing Board as the criterion for rejecting milk of poor bacterial quality. However the dye reduction test was developed for testing milk collected in churns which was subjected to poor cooling and subsequent storage under ambient conditions, which allows considerable bacterial growth. The bacterial count of churn milk is therefore affected by the time of delivery to the factory (Jones-Evans 1948), the temperature of the water used for cooling and the ambient temperature. When milk is stored in refrigerated bulk milk vats there is virtually no growth for 24 hours (Cousins 1972) so the Resazurin test is not an appropriate test of bacterial contamination of bulk milk samples (Thomas 1974). Jackson (1982) reported that only 0.26% of milk samples failed the two hour Resazurin test, although 2.9% of these samples had bacterial counts in excess of 5×10^5 organisms per millilitre of milk. Cousins (1972) considers that properly refrigerated milk does not fail the two hour Resazurin test.

2.4.2.2. Bacterial Counts of Milk

The assessment of bacterial contamination of milk by colony count techniques provides a better indication of the hygienic quality of low count milk than dye reduction tests (Thomas and Thomas 1975 and Scroggins and Marshall 1976). However the technique is complex, difficult to standardise and requires highly skilled workers (Thomas and Thomas 1975) so has been difficult to administer on a large scale. Recent developments in automatic testing equipment have allowed the introduction of the Total Bacterial Count for routine testing of milk supplies.

A total bacterial count of less than 5×10^4 organisms per millilitre of milk is frequently quoted as indicative of good production conditions (Thomas 1974, Mabbit 1980, Orr 1964 and Davis 1965). Lower bacterial counts of $<5 \times 10^3$ and $<1 \times 10^3$ (Cousins 1972) have also been suggested as attainable with good production conditions. Jones et al (1971) examined 94 farms, testing the milk supply of each farm twice, in winter and in summer. In general the total count was higher in summer than winter, with 10% of summer milk exceeding 5×10^5 organisms per millilitre, but only 1% in winter. Seventy percent of all samples contained less than 5×10^4 bacteria per millilitre. A pilot survey by the Milk Marketing Board prior to the introduction of the Total Bacteria Count suggested that, while only 1% of supplies failed the two hour Resazurin test, 8% were expected to fail the Total Bacteria Count (Fuller 1981).

Plant hygiene can be assessed by the contamination of milk by thermoduric bacteria, as the only source of these bacteria in milk is the milking plant. The presence of thermoduric bacteria in milk is indicative of poorly cleansed equipment (Thomas et al, 1966). Cuthbert (1955) suggests that thermoduric counts of 10^3/ml milk or less indicate good hygiene and 10^5/ml milk indicates poor plant hygiene.

2.4.2.3. Tests of the Milking Plant

The Milk and Dairies (General) Regulations (1959) require that all milking equipment is "in a state of thorough cleanliness" immediately prior to milking, so that the contribution to bacterial contamination from the equipment is minimised. The criterion to be used for assessing cleanliness is not defined, but is frequently taken to be visual assessment. Clough (1976) states that it is unlikely that a milk test failure (i.e. Resazurin test failure) will be associated with a plant that is visually clean.

The bacterial contamination of the milking plant should not exceed 5×10^4 bacteria / ft^2 (5.4×10^5 / m^2) (code of practice referred to in B.S. 5226: 1976). This based on experimental findings that if the milking utensils increase the bacterial contamination of the milk by no more than one organism per millilitre the keeping quality of the milk is not affected (Clegg and Cousins 1969). The number of bacteria removed from the plant by rinses indicates the general level of contamination, however the rinse counts vary greatly with the method of rinsing used (Cousins 1963). The recovery of bacteria by a single rinse ranges from 10% to 33% of the total present (Cousins 1972). Subsequent rinses will remove more bacteria, with maximum release after three or four rinses (Bacic and Clegg 1967). As with rinsing solutions the milk will not remove all the bacteria present in the plant, although milking will remove up to five times the bacteria removed by plant rinses (Cousins 1972). The contamination of the milk by bacteria from the milking plant will be low, due to dilution by the large volume of milk involved. For instance a surface of 4.5 m^2 with a contamination of 10^8 bacteria / m^2 would only increase the bacteria count of 450 litres of milk by 10^3 / ml (Palmer 1980). In addition it cannot be argued that contaminated vessels will inevitably result in milk spoilage, but cleaning methods consistently producing rinse counts less than $5.4 \times 10^5/m^2$ will give little trouble (Cuthbert 1961). Recommended standards for bacterial counts of milking machines vary widely; Cousins (1967) states that while 5.4×10^4 bacteria per square metre is the aim for plant cleaning techniques, contamination of 5.4×10^5 will result in few milk hygiene problems. Thomas and Thomas (1977) state that 10^4 / m^2 is attainable and satisfactory, counts of up to 2.7×10^6 / m^2 should be regarded as fair, over this figure plant hygiene should be regarded as poor. In contrast to this Clegg and Cousins (1969) report that satisfactory milk can be produced from plants with a bacterial count of $1.1 \times 10^8/m^2$.

2.5 The Energy Requirement for Hot Water

2.5.1. Published Data on Heat Loads in Farm Dairies

The only published British work which quantifies electricity consumption in farm dairies was carried out at the Shropshire Farm Institute (1967). In this work seven "consumers" of elecricity were monitored for 28 weeks, from October 7th. 1966 to April 21st. 1967, the results are shown in Table 2.5.1.1.

Table 2.5.1.1.
Electricity Consumption at Shropshire Farm Institute

Application	Electricity consumption for 28 weeks (%)	Percentage of Total consumption
Plant Cleaning		759938.2
Milk Cooling		384619.2
Udder Washing		394019.3
Vacuum Pump 2473		12.4
Lighting 1772		8.9
Frost Protection		326 1.6
Milk Pump 32		0.2

The volume of water used for plant cleaning and udder washing was not measured. The authors state that for ABW cleaning "approximately the same quantity of water (70 gallons) is used each day". This is equivalent to 20 litres per milking unit per wash. To quantify the water use for udder washing the authors assume a temperature rise of 60°F (33°C) and calculate that the average daily consumption of 0.18 kWh/cow means that "about one gallon of warm water is used per cow per day for udder washing". From these calculations it seems that between 1.14 and 3.03 litres per cow per milking are used for udder washing, with a mean of 2.27 litres.

Electricity consumption for water heating "does seem rather high" (Shropshire Farm Institute, 1967), but is justified in view of the high bacterial quality of the milk produced.

2.5.2. Reduction of Energy Costs

As outlined previously, there is considerable dispute as to the temperature, volume and frequency of hot washes required to maintain the milking plant in an hygienic condition. It seems reasonable, therefore, that farmers may manipulate these factors in order to reduce energy use. The replacement of one hot wash per day by cold cleaning techniques is becoming accepted (Clough 1976, Cousins 1977, Lisboa 1976), although official bodies still recommend hot cleaning after every milking (B.S. 5226:1975, M.A.F.F. 1981).

There are no published reports of farmers manipulating the volume or temperature of cleaning water for energy savings.

As an alternative to reducing the energy required for heating water farmers may attempt to produce the energy more cheaply. The reduction of energy costs may be brought about by a combination of the following methods:

i. Reducing the cost of conventional fuels.

ii. Using alternative fuels, to replace conventional fuels.

iii. Recovery of waste heat for re-use.

Electricity costs can be reduced by using it at night, under the terms of special tariffs. The South Western Electricity Board offer cheap electricity under the terms of their Farm Day/Night Tariff. Under this system the entire farm supply is charged at a rate of 5.26 p/kWh during the day and 1.82 p/kWh during the "night" period (at 1982 prices). This is a period of 7 hours within the period 23.00 to 08.30 GMT, the timing being determined by the Board. The night rate compares very favourably with the standard charge of 4.9 p/kWh, but the day rate is somewhat more expensive. Therefore adoption of the Farm Day/Night Tariff will depend on how much of the farm's electricity requirement can be consumed at night. Water heating for the milking parlour is well suited to this, especially if once daily hot cleaning is used with the hot wash being carried out in the morning.

2.5.3. Use of Substitute Energy Sources

2.5.3.1. Oil

Economic savings may be made by changing fuel. The use of oil to heat plant cleaning water may save 50% of fuel costs, when compared with standard price electricity (Bromwell 1982).

2.5.3.2. Solar Energy

The regular demand for significant amounts of low grade thermal energy for heating water in the farm dairy makes solar energy an attractive proposition (Thompson 1979). Workers in New Zealand, the U.S.A. and England have studied the use of solar energy in the farm dairy.

In New Zealand there is a stringent legal demand for hot water; by law water use is 14 litres per milking point plus 90 litres for "incidentals" and 50 litres for each bulk tank, at 95 - 98°C (Currier and Westwood 1976). The major source of energy for heating this water is electricity which is sold to the farmer at an "unrealistically low price" (Studman 1979). Two solar water heating systems have been studied, firstly a pumped circulation system (Currier and Westwood 1976) and secondly a "once-through" design (Studman 1979). Currier and Westwood (1976) report that 25% of the energy required for heating water can be provided at a very similar cost to electricity. During the milking season (August to May) the solar water heating system contributed an average of 20.5 kWh / day, worth 70 cents at 3.4 cents per kWh. The installation was estimated to cost $NZ 2,040 which is equivalent to 68 cents per day spread over 10 years with a 300 day milking season. The authors state that these figures show investment is worthwhile although they do not take account of interest charges or opportunity costs. The second of the New Zealand systems, reported by Studman (1979), consists of 13.5 m^2

of solar panels through which the water flows into a storage cylinder. The water flow is adjusted so that the water reaches 95°C under ideal conditions. In this system solar energy provided 25 kWh per day, which represents 28.9% of the energy used for heating water. However the return on the initial investment of $NZ 2000 was only 14% in 1979, even though the price paid for electricity on the University farm is considerably higher than the general farm tarrifs in New Zealand.

In the U.S.A. Thompson, Hayden and Carson (1979) have investigated a full scale solar energy system which provides supplemental heat for water heating and space heating at the Beltsville Agricultural Center. The system was shown to have a net negative present worth.

The Agricultural Development and Advisory Service in England is monitoring one farm in Dorset where solar panels have been fitted to heat dairy and udder washing water (Hirion and Dunn 1980). No results from this work have been published to date.

2.5.3.3 Recovered Heat

In England there is a requirement imposed by the buyer for milk to be cooled to 4.4°C within half an hour of the end of milking and to be maintained at, or close to, this temperature until collection. Milk enters the bulk tank at 35°C, unless it is precooled. The milk therefore represents a large reservoir of low grade heat, equivalent to 125 MJ/m^3. This heat is usually removed by a refrigeration system and voided to the atmosphere. In recent years much interest has been shown in recapturing this heat and re-using it for water heating. To allow this the refrigerant gas passes through a coil of pipe in a water vessel, where heat is removed. The gas then passes to the air cooled condenser, before returning to the evaporator in the usual manner.

Many claims in the popular press suggesting payback times in the region of 2 to 2½ years, are made for Heat Recovery Units on installation costs of £1000 - £1200. These calculations generally assume that the water is heated to 60°C (Fellows 1975), however work by Prosser (1979) indicates that during many months of the year 60°C was not obtainable, the maximum temperature being 45°C for these months. The National Institute for Research in Dairying (Belcher 1978) reports that "water at an average temperature ranging from 45°C to 60°C" was obtained from laboratory assesment of an HRU, giving a saving of £70 - £100/year in 1978, thus giving a simple payback time of 10 to 17 years.

A Heat Recovery Unit has been installed at the North of Scotland College of Agriculture and is used to provide warm water to both plant cleaning and udder washing heaters. Comparison of theoretical electricity requirements and electricity used by these heaters when the HRU was installed indicates a saving of 5840 kWh, worth £234 at current prices of 4p per kWh (Shepherd 1981). Installation costs, at September 1981, were reported to be £750 giving a simple payback time of 3.2 years.

2.6 Conclusions

The requirement for hot water in the farm dairy is due to hygiene requirements; as stated earlier cleaning is of particular importance in the food industry because the material handled is an excellent substrate for microbial growth (Galeshoot 1966). All dairy hygiene is designed to control the multiplication of spoilage bacteria (Currier 1977), the major sources of which are the udder and the milking equipment.

Success in cleaning routines can be measured in three ways;

i) Buyer's tests of bacterial contamination of the milk.

ii) Visual inspection of the plant.

iii) Measurement of bacterial contamination of the milking plant.

To date most recommendations on cleaning routines given to farmers are based on assessment of cleaning routines in experimental or research farm conditions and the method of assessment is generally bacterial contamination of the plant as measured by rinses. Farmers are, however, more concerned that their milk is acceptable to the buyer - who assesses contamination in the milk not the plant. The relationship between contamination of the plant and subsequent contamination of the milk is complex and is affected by factors outside the cleaning system. For example, efficient cooling of milk can restrict the growth of micro-organisms sufficiently to compensate for high bacterial contamination caused by inadequate cleaning. It should be remembered that the performance of a cleaning system needs to be related to its function, which is to maintain equipment in such a state that it does not impair the quality of the product (Dunsmore et al, 1981). A minimum efficiency level of cleaning can be defined as the level of cleaning which can be relied on to produce milk of sufficient quality to always meet quality criteria by a safe margin. The minimum effficiency level of cleaning is affected by the initial quality of the milk and also by its treatment after passing through the plant. The best cleaning system meets product quality criteria at least cost: the bacterial standard of milk is the most sensitive measure of product quality (Dunsmore et al, 1981). It is therefore considered, within this work that, if the milk produced meets the buyer's requirements of bacterial quality the cleaning routine used is adequate, within the system used on the particular farm. Plant rinses will not be used as a criterion for quality; firstly it is the contamination of the milk which is of primary importance, and secondly the link between plant contamination and milk contamination is not direct. Indeed Clegg and Cousins (1969) state that "At present we demand excessively high standards of cleanliness for equipment and then proceed to allow standards for raw milk which can only be produced on dirty equipment!".

3.0. INTRODUCTION TO THE CURRENT WORK

3.1. Aims of the Work

Little work is reported in the literature on the cleaning routines practised on commercial dairy farms. The volume and temperature of water used for udder washing and plant cleaning has not been reported. It is therefore difficult to advise farmers on the energy requirement for providing hot water and on how to reduce their costs.

In the final analysis each farmer will choose or develop a system which meets his own requirements. In addition to bacteriological standards the farmer must consider the cost, convenience and simplicity of each cleaning system. Some producers may seem to disregard all recommendations and yet maintain their equipment in a satisfactorily hygienic condition. But "such producers should not be advised to 'improve their ways' because they may know more than their advisors" (Clegg and Cousins, 1969).

The aim of the current work is therefore to monitor commercial dairy farms to ascertain the energy requirement for producing hot water. The volume of water used for udder washing and plant cleaning will be established by metering the volume of water used from the water heaters. The energy consumed to heat the water will established by metering electricity and oil consumption. The meters will be read weekly; this frequency being considered the best compromise between accurate recording and effective use of time.

The use of hot water for udder washing and plant cleaning would be most effectively monitored by continuous automatic monitoring on all farms. However the equipment would be very expensive to install, and the time required for data analysis would be excessive. Water use is therefore monitored by portable chart recorders, which are moved from farm to farm and by visits to farms during milking and cleaning, when very frequent recording will be possible. This observations will be used in conjunction with interviews to establish what cleaning is carried out, and why. Any deviations from recommended practise will be recorded and their effect on milk quality noted. The use of energy saving devices, where all ready fitted will be examined.

3.2. The Survey Farms

3.2.1. Selection of the Farms

Thirteen farms in South Devon, including the Seale-Hayne College farm, have been monitored. A list of farmers willing to participate in investigational work was supplied by the Agricultural Development and Advisory Service. Each of these farmers were approached and surveyed as to their milking equipment and management practices, the replies being recorded, as shown in Table 3.2.1.1. From these farms twelve were selected which fulfilled the following criteria;

1) The milking plant was installed within the previous five years, and is of the 'herringbone' type. (Thus showing the farmer's commitment to new parlour technology.)

2) The farmer was known to A.D.A.S. as potentially co-operative

3) The farm should be within reasonable travelling distance of Seale-Hayne College.

4) When taken as a group the farms should show a range of equipment, (including energy-saving equipment), herd sizes, and cleaning techniques.

Table 3.2.1.1.

Prospective Farms for Seale Hayne College Audit

GENERAL DESCRIPTION		
Name		
Address		
Herd size		
Calving pattern	Annual milk sales	litres
Housing	Electricity a) supply	
Water supply	b) stand by	
PARLOUR		
Make		
Type	Size	
PLANT CLEANING		
Cleaning	Temperature	
Volume of water	Frequency (hot wash)	
Waste water disposal		
HEATER Make	Capacity	
Control	Thermostat	
UDDER WASHING		
Heater type		
Size	Temperature	
MISCELLANEOUS WATER USE		
Handwashing	hot / cold	
Calf feeding	hot / cold	
Hosing down	hot / cold	
BULK TANK		
a) Make	Size	
Cooling system	Type	
b) Make	Size	
Cooling system	Type	
Cleaning system		
Compressor type	Make	siting
Precooling system		
VACUUM PUMP Make	Rating	
Vacuum ancillaries		
MILK PUMP Make	Rating	
ENERGY SAVING DEVICES		
MISCELLANEOUS ELECTRICAL USAGE		
Parlour heating		
LABOUR IN DAIRY		
COMMENTS		

3.2.2. Equipment on the Survey Farms

After selection the farms were coded A to H, G to M and X, following the nominal herd size and divided into three groups: The small farms (A-D) have herds of 55-70 cows, the group of medium farms (E-H and X) have herds of 90-120 cows and the group of large farms (J-M) have herds of 120-210 cows. The equipment on the thirteen farms is summarised in Table 3.2.2.1. From this table it can be seen that there is a wide volume range in water heaters used for plant cleaning which is not solely due to differences in plant size; the volume of hot water available varies from 15 to 27 litres per milking unit. The temperature of water also varies, thermostat settings are from 70°C to 104°C. Initially the plant cleaning water heaters on eight farms were fitted with time switches, most other heaters being left on at all times, controlled only by thermostat. At Farm A time control is exerted manually as the heater is switched on at the start of morning milking and off immediately prior to plant cleaning. Circulation cleaning is the more popular cleaning method; only three farms used A.B.W. cleaning. Half the farmers used one hot wash per day, as opposed to the recommended two hot washes.

Table 3.2.2.1.

Plant Cleaning Water Heating Equipment on Survey Farms

Farm	Parlour size	Clean method	Freqncy wash/day	Capacity litres	Rating kW	Thermo °C	Heater control
A	5/10	C.C.	1	90	3	88	Manual
B	5/10	C.C.	1	135	3	70	Manual
C	5/10	A.B.W.	2	120	3	95	T.S.
D	5/10	C.C.	2	135	3	85	Manual
E	5/10	C.C.	1	115	3	82	Manual
X	6/12	C.C.	2	135	4	80	T.S.
F	12/12	C.C.	1	135	3	82	T.S.
G	10/10	A.B.W.	2	135	oil	100	T.S./man
H	8/16	C.C.	2	135	3	93	T.S.
J	8/16	C.C.	1	135	6	82	Manual
K	10/10	A.B.W.	1	160	5	95	T.S.
L	12/12	A.B.W.	2	180	3	95	T.S.
M	10/20	C.C.	1	160	6	104	T.S.

Four of the farms have energy saving equipment installed, as detailed in Table 3.2.2.2.

Table 3.2.2.2.

Energy Saving Equipment Installed on Survey Farms

Farm	Equipment	Siting	Use of recovered heat
E	H.R.U.	milk tank	plant cleaning
	H.R.U.	vacuum pump	udder washing
	Plate Cooler	milk line	
F	H.R.U.	milk tank	plant cleaning
H	Plate Cooler	milk line	
M	H.R.U.	milk tank	plant cleaning and udder washing

For udder washing water most farms are equipped with a small volume heater (9-14 litres) that has a large power rating as shown in Table 3.2.2.3. The water is heated quickly for each batch of cows. The exceptions to this are Farms J and M which have domestic-type water heaters that heat sufficient water for the whole herd. None of the udder washing water heaters have timeswitches and most are left switched on.

Table 3.2.2.3.

Udder Washing Water Heating Equipment on Survey Farms

Farm	Capacity litres	Rating kW	Thermostat °C	Status between milkings
A	10	3	40	off
B	10	3	40	off
C	10	3	40	on
D	9	3	32	on
E	10	3	40	on
X	10	3	40	on
F	14	4	43	on
G	uses plant cleaning water heater			
H	11	2.5	40	off
J	65	3	43	on
K	14	4	40	on
L	14	4	40	on
M	180	6	32	on

Prior to the start of the survey all farmers selected were asked whether they had any plans to change their parlour equipment or management practices. All stated they had no plans for major changes within a period of five years, and only Farmer C had plans for equipment changes; he was considering installation of a plate cooler for pre-cooling his milk. It can be seen from Table 3.2.2.4. that major changes have occured at several farms, most notably Farm L which ceased milk production. Farms E and K increased parlour size, Farms E,H and K changed some equipment and Farms C and K altered their cleaning routines.

Table 3.2.2.4.

Changes on Survey Farms

C	Change of cleaning routine to once daily A.B.W. during August 1981
E	Parlour changed to 12/12 during September 1980 Plant cleaning water heater changed, 30.12.81, similar type and capacity, timeswitch control.
H	Plant cleaning water heater replaced 18.4.82, indentical model.
K	Plant cleaning - A.B.W. once per day; until 27.3.80 twice per day; 27.3.80 to 3.2.81 circulation cleaning twice per day; 3.2.81 to 29.6.81 once per day; 14.8.81 onwards. Parlour changed to 16/16 during July 1981
L	Ceased milk production, 5.6.81

3.3. Monitoring Equipment

3.3.1. Water Consumption

Water was metered using Kent digital volume meters. These were calibrated against mass of water before installation and the calibration checked against the manufacturer's specification. All the meters were found to be well with in the stated range, the best meter being correct, the worst having an error of +2.25% and most falling within the range -1% to +1%. The meters were installed following the manufacturers recommendations, in particular they were sited within straight pipe runs at a distance of 30 times the meter diameter from any bend or junction. The size of meter was choosen to ensure that the flow rate of water was within the calibration of the meter. The meters were re-calibrated in situ, and most meters were found to be within -2% to +2%.

On all farms the volume of hot water used from the udder washing and plant cleaning water heaters and the total volume of water entering the dairy is monitored. At Seale-Hayne the water used for rinsing the milking plant, for rinsing the two bulk tanks and for the power hose is also monitored.

3.3.2. Electricity consumption

Electricity meter installation was carried out by the South Western Electricity Board using refurbished meters which were calibrated to +1% / -2% of reading. On all farms five major electricity uses were monitored, these being; bulk milk tank, water heater for plant cleaning, water heater for udder washing, vacuum pump and lighting. An overall meter was also installed to monitor further minor uses and to provide a check of the other meters. At Seale-Hayne there were additional meters on the milk pump, two bulk milk tank compressors, two milk agitators, two tank rinsers, the pulsator and the power hose pump.

3.3.3. Oil Consumption

The single Kent volume meter needed for oil, at Farm G, was calibrated against mass of oil. It was found to have an error of -1.05%

3.3.4. Ambient Temperature Measurememt

Ambient temperature in each dairy is recorded using Casella bimetalic strip thermographs. The average temperature for the period of each thermograph chart record was found using a planimeter to measure the area under the time/temperature graph.

3.3.5. Water Temperature Measurement

The temperature of water from the water heaters and energy saving devices, that are used for cleaning, and from the cold supply at each farm was measured. It was not possible to monitor each farm continuously so portable Rustrak chart recorders, measuring by thermocouples, were left for week long periods on each farm in turn. Immersion probes were used for measurement of cleaning water temperatures and for the internal temperatures of water heaters, where possible. The temperature of water in pipes was measured using thermocouples with low thermal inertia, strapped to the external surface of the pipe and insulated from ambient temperature effects. Both types of probe were calibrated in situ and were found to read 1°C - 3°C lower than the true situation. The Rustraks are used in conjunction with on-site measurement, as detailed later, during which the readings were checked.

A hand held Comark digital thermometer is used to make detailed recordings of temperatures, for example of plant cleaning water. This instrument was calibrated over the required range against a mercury in glass thermometer. The range of errors were found to be linear from -1.5°C at 0°C to -0.75°C at 90°C, so a correction factor could be applied. All reported temperatures are corrected.

3.4. Laboratory Equipment

Model validation experiments were carried out in the laboratory using a dairy water heater of the Loheat BWAC type. Electricity and water consumption were monitored using South Western Electricity Board meters and Kent water meters. Temperatures were recorded with Ni-Cr/Ni-Al thermocouples linked to a Foster Cambridge six channel pen recorder using a Zeref Fristor cold junction. The recorder was calibrated with the thermocouple wire which was used for experimentation. The following temperatures were recorded; ambient, cold water inlet to the heater and lower and upper hot water temperatures.

3.5. Data Collection From Farms

3.5.1. Meter Readings

For the first full year of the audit, data were collected from each farm every week. All electricity and water meters were read, the week's consumption calculated and compared to the previous week's consumption before leaving the farm. This was done so that any inconsistent reading could be investigated immediately. The thermograph chart was also changed. All farmers were asked to record any unusual occurences, such as accidents, infrequent routines or changes in routine that could affect electricity or water consumption. These records were then discussed at the next meter reading session.

After twelve months it was decided that the frequency of recording should be changed to monthly. For the second year of the audit the meters were read on the last day of each calendar month, to coincide with milk records.

3.5.2. Data From Farm Records

Data concerning milk production, cows milked and cows in herd were collected from farms at intervals. The degree of detail in these records varied, some farms have weekly records, others only monthly. The farmers were also questioned about recent milk quality reports to ascertain whether any hygiene problems had been revealed by the buyer. On two farms (F & J) water is used from the plant cleaning water heater for preparation of calf milk, each calf requiring 4.5 litres per day. On these farms numbers of calves born were recorded so that this hot water could be allowed for.

3.5.3 On Farm Observations

Farmers were questioned as to their use of hot water for plant cleaning and udder washing. The form used for collection of this information is shown as Table 3.5.3.1

During the second year of the audit detailed observations of cleaning technique were carried out. The information recorded for circulation cleaning is shown as Table 3.5.3.2 and for A.B.W. cleaning as Table 3.5.3.3. All temperatures were recorded at 30 second intervals. During these visits each farmer was questioned about his routine, any deviation from recommended practice was queried and the reason, if any, was noted. These statements were compared with observed practice and also with statements made before the start of the investigation.

Finally the equipment was checked; timeswitch and thermostat settings were noted and compared against actual time or temperature of operation. Insulation levels of heaters and water pipes were observed. The milking plant was examined visually for cleanliness, especially rubberware and blind ends. Table 3.5.3.4 shows the form used during visual examination (after A.D.A.S., 1967).

The Rustrak recorders were used during these visits and then left for approximately one week. The record from the observed cleaning routines are then compared to the other routines in the week for any differences.

Table 3.5.3.1

Use of Hot Water on Audit Farms

Farm________ Date__________________

Cleaning Method____________________________________

Frequency____

Pre-Rinse

Volume used______________litres_

Temperature hot / warm / cold

Discharge to floor / circulate (specify time)

Hot wash

Volume used______________litres

Temperature initial______°C
circulation______°C

Discharge to floor prior to circulation yes / no
If yes; criterion for start of circulation____________________

Length of time of circulation__________minutes

Final rinse

Volume used______________litres

Temperature hot / warm / cold

Discharge to floor / circulate (specify time)

For once-a-day hot wash: describe alternate method.

Recommendations on which method based: ADAS /manufacturer /other (specify)

Other uses of hot water

Notes

Table 3.5.3.2
Observations of Circulation Cleaning

i) Pre-rinse
- Volume and temperature of water used.
- Return temperarure of water.

ii) Hot Wash
- Temperature of water in heater.
- Temperature of water at tap.
- Volume of water used.
- Temperature of water in trough and returning from plant.
- Volume of water used to warm the plant, i.e. discharged to waste.
- Criterion for end of discharge; volume, temperature or time.
- Length of circulation time.
- Chemical use; type and timing.

iii) Post-rinse
- Volume and temperature of water used.
- Return temperature of water.
- Chemical use.

Table 3.5.3.3
Observations on Acidified Boiling Water Cleaning

- Temperature of water in heater (where possible).
- Volume of water used.
- Temperature of discharge water (where possible).
- Length of cleaning period.

Table 3.5.3.4

Features recorded when making a visual assessment of milking conditions

Farm________ Date__________

Aspect examined	Distinguishing criteria examined
Teat washing	none washed / some washed / all washed
Standard of teat washing	poor / fair / good
Teat drying practised	yes / no
Teat disinfection practiced	all cows every milking / no
System of cleaning plant	hand / circulation / ABW / other (specify)
Frequency of hot wash	twice per day /once per day /other (specify)
Alternative cleaning system	specify
Sterilising agent employed	specity
Cleanliness and condition:-	
of liners	poor / fair / good
of glass surfaces	poor / fair / good
of outside of clusters	poor / fair / good
of jetters (if fitted)	poor / fair / good
Resazurin test failures	yes / no (if yes, specify)
Has inclusion in survey influenced farm conditions	yes / no

4.0 SAMPLE RESULTS FOR A SINGLE FARM - H

A full set of results are shown here for a single farm, H. This farm was choosen to illustrate the data collection as it had no changes in equipment, cleaning method or personnel for the duration of the survey.

4.1. Initial Information Collected

Table 4.1.1. shows the information which was collected from each of the farms that were on the original list provided by A.D.A.S. of farmers willing to participate in experimental work. The information was collected by questioning the farmer and direct observation.

Table 4.1.1.

Prospective Farms for Seale Hayne College Audit

GENERAL DESCRIPTION

Herd size: *105*
Calving pattern: *Winter* — Annual milk sales *700 000* litres
Housing: *Cubicles* — Electricity a)supply: *Two phase 480V*
Water supply: *Private well* — b)stand by: *generator*

PARLOUR
Make: *Alfa-Laval*
Type: *eye-level* — Size: *8/16*

PLANT CLEANING
Cleaning: *circulation* — Temperature: *80°C*
Volume of water: *120 litres* — Frequency (hot wash): *twice per day*
Waste water disposal: *Under tank to drain*

HEATER
Make: *Loheat BWAC 35* — Type: *immersion*
Rating: *3kW* — Capacity: *120 litres*
Control: *timeswitch* — Thermostat: *80°C*

UDDER WASHING
Heater type: *immersion*
Rating: *3 kW* — Temperature: *26°C*

MISCELLANEOUS WATER USE

Handwashing	<u>hot</u> / cold
Calf feeding	hot /<u>cold</u>
Hosing down	hot /<u>cold</u>

BULK TANK
a) Make: *Desco* — Size: *2450 litres*
Cooling system: *sump & spray* — Type: *Jacketed*
Cleaning system: *automatic*

Compressor
Make: *Prescold* — siting: *North wall*
Precooling system: *none*

VACUUM PUMP
Make: *Alfa-Laval* — Rating: *3 hp*
Vacuum ancillaries: *Automatic cluster removal*

MILK PUMP
Make: *Alfa-Laval* — Rating: *0.5 hp*

ENERGY SAVING DEVICES
none

MISCELLANEOUS ELECTRICAL USAGE
Parlour heating: *none*

LABOUR IN DAIRY
Herdsman and relief

COMMENTS

4.2 Metering of Farm H

After selection of the farm for inclusion in the survey electricity and water meters were installed, as detailed previously. A schematic diagram of water meter positions is shown as Figure 4.2.1. Electricity meters were installed by S.W.E.B., who had to split the supply to the bulk tank, vacuum pump and overall consumption for metering purposes. These supplies therefore have two meters each which are referred to, for convenience only, as overall "top" and "bottom", bulk tank "top" and "bottom" and vacuum pump "left" and "right", each pair must be added for the consumption. The meters installed are shown in Table 4.2.2. The outbuildings supply is included in the overall meter reading, but is not part of the survey, so this consumption must be subtracted from the overall meter reading to obtain the 'total dairy and parlour' consumption. The generator supply is not included within the overall meter reading, so that, if the generator is used, the reading on this meter needs to be added to the overall value.

Each week every meter was read, and the difference from the previous reading calculated to give the weekly consumption. The current week's consumption was then compared to the previous week's in order to reveal any changes in the level of consumption. If the consumption was outside the range which was normally found then the farmer would be questioned immediately. Finally the current week's figures were copied onto a new sheet for the next week's readings. A sample weekly meter readings sheet is shown as Table 4.2.3. Before leaving the farm the log of events, which every farmer was asked to keep, was inspected. This log is shown as Table 4.2.4

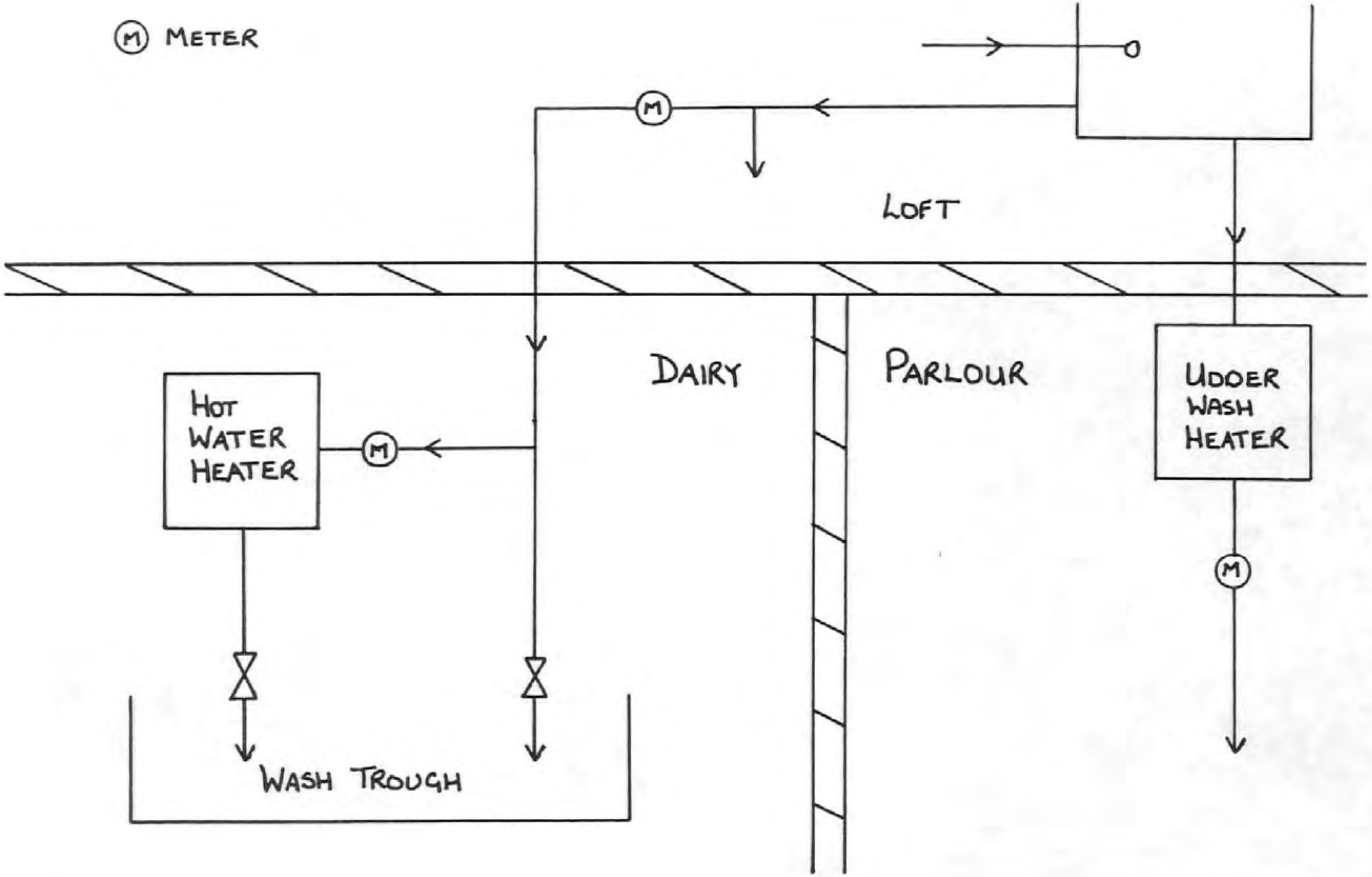


Figure 4.2.1.
Siting of Water Meters, Farm H.

Table 4.2.2

Notes on Metering of Water and Electricity Supplies

Farm H

1) Electricity Meters

Comments:	
a) Overall "top"	add for overall use (a + b)
b) Overall "bottom"	
c) Bulk Tank "top"	add for bulk tank (c + d)
d) Bulk Tank "bottom"	
e) Plant Cleaning Water Heater	
f) Lights	
g) Udder Washing Water Heater	
h) Outbuildings	subtract from overall
i) Generator	add to overall, if used
j) Vacuum Pump "left"	add for vacuum pump (j + h)
h) Vacuum Pump "right"	located in pump room

Calculations: "Total Dairy & Parlour" use = (a + b + i) - h
unmetered uses = (a + b) - (c + d + e + f + g + h + j + k)

Water Meters

x) Hot water	Inlet to hot water tank
y) Udder washing water	Adjacent to heater in parlour
z) Overall	Inlet to storage tank in loft

Calculations: "Total Dairy and Parlour" use = z + y
Cold water use = z - x

Table 4.2.3

Weekly Meter Readings - Farm H

Previous date *24.4.80* Current date *1.5.80* time *11:35*

Meter	Previous Difference	Previous Reading	Current Reading	Current Difference
Electricity (kilowatt-hours)				
a) OA top	159.4	14658.9	14806.8	147.9
b) OA bottom	525.8	29623.7	30127.7	504.0
c) BT top	161.3	14658.3	14807.9	149.6
d) BT bottom	148.0	2948.4	3085.8	137.4
e) Water heater	179.6	88401.9	88577.0	175.1
f) Lights	11.7	98239.7	98249.7	10.0
g) Udder washer	33.7	31555.9	31594.6	38.7
h) Outbuildings	18.4	4331.2	4345.8	14.6
i) Generator	0.0	532.6	532.6	0.0
j) VP left	46.0	1661.2	1705.8	44.6
k) VP right	71.2	2797.3	2863.1	65.8
Water (cubic metres)				
x) Hot water	2.0055	33.2514	34.7865	1.5351
y) UW water	1.2901	24.8145	25.8961	1.0816
z) Overall	10.0341	201.7120	212.3664	10.6544

Notes

Table 4.2.4

Log of Events, Farm H

Date	Event
March 1980	Electricity meters installed.
6 March 1980	Monitoring started, electricty only.
12 March 1980	Water meters installed.
20 March 1980	Monitoring of water meters started.
10 April 1982	Heater failed, no hot water for plant cleaning
13 April 1982	New heater fitted, adjusted for 80 litres, no timeswitch.
17 April 1982	Heater volume adjusted to 135 litres.

4.3 Data from Farm H

The weekly meter readings were then transcribed into the form shown as Table 4.3.1. The ambient temperature data shown on this table was obtained from the thermograph charts, by calculating the area under the graph. Data on milk volume and numbers of cows in milk wereobtained, periodically, from the farmer's records.

Monthly data from Farm H are shown in Appendix 1.

Table 4.3.1

Electricity and Water Use - Weekly Data

	Electricity - kWh			Water - litres		Ambient	Milk	Cows in
Date	Total	Plant	U.V.	Plant	U.V.	Temp°C	litres	milk
1980								
20.3	615.7	182.5	47.7				15296	118
27.3	637.6	182.5	59.1	1385.7	1157.3	7	15296	117
3.4	641.8	174.8	45.8	1522.7	1241.6	10	15559	117
10.4	630.6	175.7	48.2	1868.4	1311.6	11	15909	117
17.4	657.1	170.0	42.2	1345.7	918.7	13	15909	117
24.4	649.7	172.8	49.7	1192.2	958.7	13	15909	117
1.5	666.8	179.6	33.7	1468.2	1345.9	12	15826	116
8.5	637.3	175.1	38.6	2006.6	1290.1	11	15331	115
15.5	669.6	171.7	45.4	1535.1	1081.6	15	15331	113
22.5	657.6	164.3	27.4	1381.0	676.4	17	15331	112
29.5	657.8	168.9	33.1	1288.0	802.4	15	15331	111
5.6	646.3	167.5	33.2	2202.1	932.2	15	13348	107
12.6	616.8	165.5	33.7	1296.3	825.8	16	12554	103
19.6	582.6	170.2	27.6	1323.1	837.6	16	12554	98
26.6	551.8	172.0	26.1	1357.4	626.2	14	12554	94
3.7	533.8	163.7	26.7	1232.3	816.2	15	10786	87
10.7	519.4	170.8	25.6	1426.0	675.5	16	8435	80
17.7	475.5	163.0	25.8	1133.5	770.0	15	8435	73
24.7	464.6	157.3	23.7	1102.8	620.2	16	8435	66
31.7	462.2	161.4	23.7	1231.4	672.6	19	8435	59
7.8	454.8	159.5	17.2	1229.3	507.9	17	5447	58
14.8	441.2	161.4	19.4	1165.0	504.5	18	5447	56
21.8	413.7	157.1	19.5	1197.5	505.5	18	5447	55
28.8	381.9	161.5	21.8	1175.1	497.4	16	5447	53
4.9	436.1	161.2	24.0	1301.5	648.6	17	7556	59
11.9	473.3	165.5	21.9	1202.1	508.0	16	9138	66
18.9	525.1	158.4	26.4	1205.0	699.5	15	9138	72
25.9	572.7	161.4	32.3	1116.0	999.3	15	9138	78
2.10	589.1	162.8	35.8	1414.1	1010.4	15	10134	80
9.10	569.6	169.4	33.0	1410.1	1172.1	12	12624	81
16.10	578.0	169.8	32.2	1589.2	856.7	10	12624	83
23.10	570.0	168.3	43.5	1290.9	1169.0	10	12624	85
30.10	592.8	171.4	34.9	1312.9	1101.3	12	12624	87

Table 4.3.1. continued

Date	Electricity - kWh Total	Plant	U.W.	Water - litres Plant	U.W.	Ambient Temp°C	Milk litres	Cows in milk
6.11	575.5	174.5	43.0	1369.7	1278.9	8	15059	89
13.11	595.5	184.5	48.3	1315.2	1026.5	5	15465	92
20.11	617.5	164.4	39.0	1309.1	1112.6	10	15465	94
27.11	659.9	172.5	42.5	1405.9	1030.7	10	15465	97
4.12	598.9	177.8	44.1	1436.9	1044.8	5	16728	99
11.12	673.6	173.8	51.5	1466.0	1169.0	6	17675	103
18.12	687.3	174.8	44.1	1326.1	1327.1	9	17675	107
23.12	714.3	173.2	41.0	1326.6	925.1	8	17675	111
30.12	693.1	173.6	41.8	1274.3	893.1	8	17675	115
1981								
6.1	696.2	176.9	47.9	1335.7	1075.6	8	18064	114
13.1	632.7	182.2	48.9	1481.3	995.8	6	18128	114
20.1	694.2	178.8	48.0	1387.0	1268.7	7	18128	113
27.1	701.5	173.5	46.6	1345.7	1035.4	9	18128	112
3.2	662.8	177.4	45.4	1355.0	969.5	6	17729	112
10.2	667.3	178.1	46.8	1364.9	1029.3	7	17196	113
17.2	612.1	170.6	49.5	1216.4	1023.2	4	17196	114
24.2	630.7	179.0	54.1	1340.7	1137.7	4	17196	114
3.3	634.5	172.0	46.8	1235.0	1069.2	5	17021	114
10.3	656.8	170.0	45.9	1374.0	1005.6	8	16811	115
17.3	645.4	171.8	41.5	1340.0	856.0	8	16811	116
24.3	653.7	172.3	49.9	1352.6	1362.6	7	16811	116
31.3	649.0	174.0	47.0	1421.0	1233.0	8	16811	116
7.4	628.4	171.9	48.2	1361.1	1236.7	7	15757	116
14.4	628.7	172.9	44.6	981.2	1274.9	8	15757	116
21.4	617.8	171.7	39.6	1473.1	1042.0	8	15757	115
28.4	611.1	173.3	37.9	1252.9	831.7	9	15757	113
5.5	636.3	176.3	49.0	1279.5	1699.1	10	14418	111
12.5	630.7	172.0	40.5	1458.1	1202.4	10	13882	109
19.5	619.4	177.3	43.7	1772.1	1437.9	12	13882	106
26.5	579.2	168.8	37.0	1389.4	1215.8	11	13882	103
2.6	611.3	172.7	42.1	1444.1	1159.8	11	13119	100
9.6	585.8	168.4	36.8	1276.1	1151.5	12	11210	97
16.6	626.5	166.3	48.6	1294.2	1620.3	13	11210	95
23.6	686.6	170.1	33.5	1320.0	1242.1	16	11210	89
30.6	677.6	163.9	29.6	1278.2	1043.6	14	11210	83

4.4 Data Analysis

Weekly and monthly meter readings were analysed using the statistical package 'Minitab', full output from this analysis is shown in Appendix 1. Table 4.4.1 gives average values for Farm H data.

Table 4.4.1

Averages of Monthly Data   Farm H

	Mean	Standard Deviation	Sum
Plant cleaning water volume (litres)	5721.6	733.0	137317.
Plant cleaning water electricity (kWh)	732.92	30.5	17590.
Udder washing water (litres)	4234.5	811.0	101628.
Udder washing electricty (kWh)	161.13	36.1	3867.1
Total electricity (kWh)	2630.3	291.0	63127.
Cows in milk	101.35	24.4	
Ambient temperature (°C)	10.342	4.22	
Milk volume (m^3)	60.839	19.4	1460.1
Days in month	30.417		
Calculated Values			
Plant electricity as % of total	28.151	2.92	
Udder washing elec as % of total	6.0724	0.944	
Water heating elec as % of total	34.223	2.66	
Plant cleaning water heater litres/kWh	7.7943	0.830	
Udder washing water heater litres/kWh	27.009	6.11	
Plant water litres/unit/wash	11.755	1.43	
Plant electricity kWh/unit/wash	1.5063	0.0544	
Udder washing water litres/cow/milking	0.71078	0.153	
Udder washing elec. kWh/cow/milking	0.026572	0.00437	

4.5 Observations of Plant Cleaning

Prior to observation of cleaning routines the farmer was questioned about hot and warm water use, responses are shown as Table 4.5.1. Plant cleaning routines were then observed on eight occasions, the results from the first observation are shown as Tables 4.5.2, other observations are shown in Appendix 2. Results from a visual assessment of milking plant conditions are shown as Table 4.5.3

Table 4.5.1
Use of Hot Water on Audit Farms

Farm *H* Date *19.5.1981*

Cleaning Method; *Circulation cleaning*
Frequency; *twice per day*

Pre-Rinse
Volume used *50 - 70 litres*
Temperature hot / warm / cold
Discharge to floor / circulate (specify time)

Hot wash
Volume used *90 - 100 litres*
Temperature initial *82 °C*
circulation *60 °C*
Discharge to floor prior to circulation yes / no
If yes; criterion for start of circulation *"Hot to touch"*
Length of time of circulation *6 minutes*

Final rinse
Volume used *sufficient to cool plant*
Temperature hot / warm / cold
Discharge to floor / circulate (specify time)

For once-a-day hot wash: describe alternate method.
not applicable

Recommendations on which method based: ADAS / manufacturer /other
specify *Alfa-Laval*

Other uses of hot water
External surfaces of jars, clusters etc, hand cleaned daily using hot water. Approximately 10 litres per milking.

Notes

Table 4.5.2

Cleaning Observation Results

Farm; H   Date; 23.9.81 a.m.

Meter Readings

	Initial	Final	Difference
Electricity	17543.5	17553.3	9.8
Water	105423.6	105511.5	87.9

Temperature Recordings

Time	Water Temperatures °C Tap	Trough Hot	Trough Cold	Return	Comments
9:18	89	79	14		
	89	80	14	14	Cold rinse, discharge to waste
19	89	82	14		
	89	82		16	Hot wash starts, discharge to waste
20	88	83			
	88	83		32	
21	88	83		41	
	88	83			
22	88	84		48	Chemicals added
	88	85		52	
23	88	76			Circulation starts
	88	66		59	Hot tap off
24		64		62	
		63		62	
25		63		62	
		62		60	
26		60		59	
		59		57	
27		57		56	
		56		55	End of circulation, discharge to waste
28			14	52	Cold rinse, discharge to waste
			14	52	
29			14	51	
			14	45	
30			14	39	
				31	
31				28	
				21	
32				22	
				21	
33				19	

Table 4.5.3

Features recorded when making a visual assessment of milking conditions

Farm *H* Date *14.10.82*

Aspect examined	Distinguishing criteria examined
teat washing	none washed / *summer* some washed / *winter* all washed
standard of teat washing	poor / fair / good
Teat drying practised	yes / no *in winter only*
teat disinfection practiced	all cows every milking / no
system of cleaning plant	hand / circulation / ABW / other (specify)
frequency of hot wash	twice per day /once per day /other (specify)
alternative cleaning system	specify *none*
sterilising agent employed	specity *combined detergent/sterilizer*
cleanliness and condition:- of liners	poor / fair / good
of glass surfaces	poor / fair / good
of outside of clusters	poor / fair / good
of jetters (if fitted)	poor / fair / good
Resazurin test failures	yes / no (if yes, specify)
has inclusion in survey influenced farm conditions	yes / no

5.0 INDIVIDUAL FARM DISCUSSIONS

5.1 Farm A

Plant Cleaning Routine	Circulation cleaning, mornings only
Udder Washing Routine	All udders washed

Table 5.1.1

Summary of Water and Electricity Use

Water Use		
Plant cleaning water	1646.4	litres / month
	10.8	litres / unit / wash
Udder washing water	5076.1	litres / month
	1.5	litres / cow / milking
Electricity Use		
Total dairy and parlour use	1131.8	kWh / month
Plant cleaning water heater	171.6	kWh / month
	1.1	kWh / unit / wash
as percentage of total	15.6	%
Udder washing water heater	111.1	kWh / month
	0.033	kWh / cow / milking
as percentage of total	10.1	%

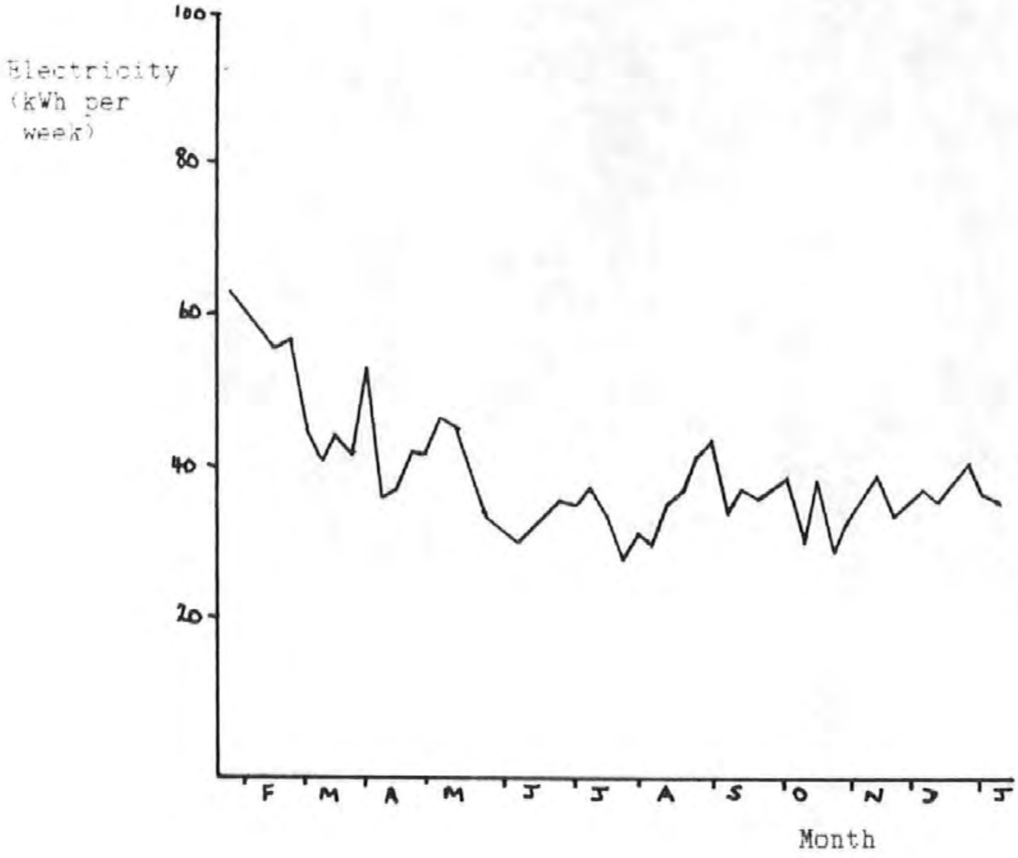
The plant cleaning water heater at Farm A is a "domestic" type, in which hot water is removed from the top of the heater by cold water entering at the base. Due to low water pressure cold water only enters the heater very slowly so that only 40 - 45 litres of hot water, of the 90 litres capacity, can be taken from the heater at once. This is therefore the volume of water used for plant cleaning, equivalent to eight litres per milking unit. Mean monthly water use from the heater indicates a daily water use of 54 litres, the difference of 10 - 15 litres being used for washing the clusters, hand washing and veterinary purposes. There is no timeswitch on the water heater, heating time control being exerted manually. The heater is switched on at the start of morning milking and off immediately prior to plant cleaning, a period of approximately 1.5 hours.

Weekly electricity and water consumption from the plant cleaning water heater, for 52 weeks, are shown as Figure 5.1.2. Water use shows a drop from a mean of 64.5 litres in the first 20 weeks of monitoring to a mean of 45.6 litres in the second twenty weeks. This drop in water use is considered to be a response to monitoring, which has made the farmer more aware of water use for purposes other than plant cleaning, particularly as even the lower figure represents more hot water than will be used for plant cleaning.

Observation of cleaning routines has been carried out on four occasions, three mornings and one evening routine. The temperature of cleaning water during one of the morning observations is shown as Figure 5.1.3. Circulation cleaning is preceeded by a once through rinse using 45 litres of cold water. The temperature of the hot water in the trough prior to use is satisfactory, at 75 - 80°C, however it falls rapidly at the start of circulation to 55 - 45°C. This is due to no water being discharged to waste prior to circulation of the cleaning solution, so that the residue of the cold rinse is added to the hot solution. No water is discharged because of the low initial volume of hot water that can be removed from the heater. Circulation cleaning is not timed, it continues while the walls and floor of the parlour are hosed down, circulation periods of 12, 10 and 7 minutes have been recorded. After circulation the plant is rinsed with 45 litres of cold water, discharged to the floor. In the evening the plant is rinsed with 90 litres of cold water. The water is sucked through the clusters to the milk line, rather than passing from the wash trough via the cleaning line to the clusters to return through the milk line.

A report on water heating and use was sent to Farm A, which stated that the temperature of circulation cleaning water was low and recommended that this could be improved by using a greater volume of hot water and discharging 10 - 20 litres of hot water to waste before circulation starts. The report also discussed the excessive capacity of the water heater, 90 litres, when only 40 litres are used for plant cleaning. Model simulation of the water heater suggests that 3.6 kWh are required for heating 40 litres of water, from an inlet temperature of 10°C, to 85°C, the temperature at which the water is withdrawn from the heater. However an average of 5.7 kWh/day are used, the excess of 750 kWh p.a. represents 5% of the total

Figure 5.1.2.
Weekly Electricity and Water Use for Plant Cleaning, Farm A



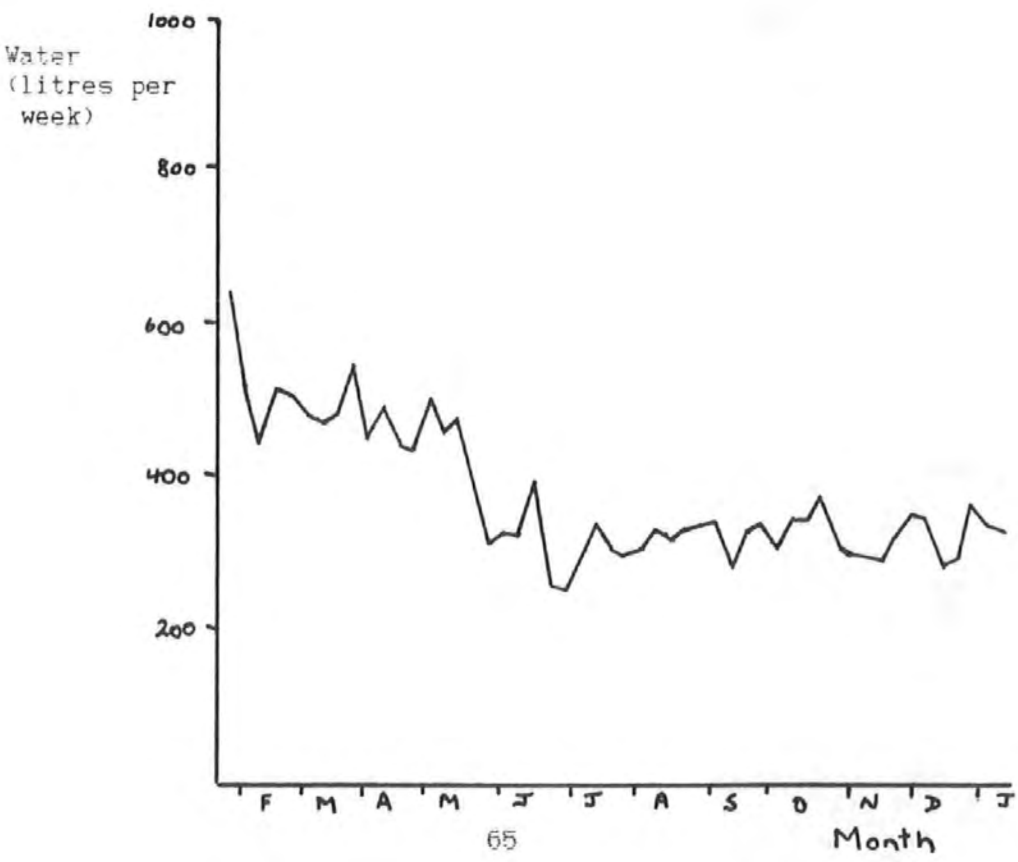
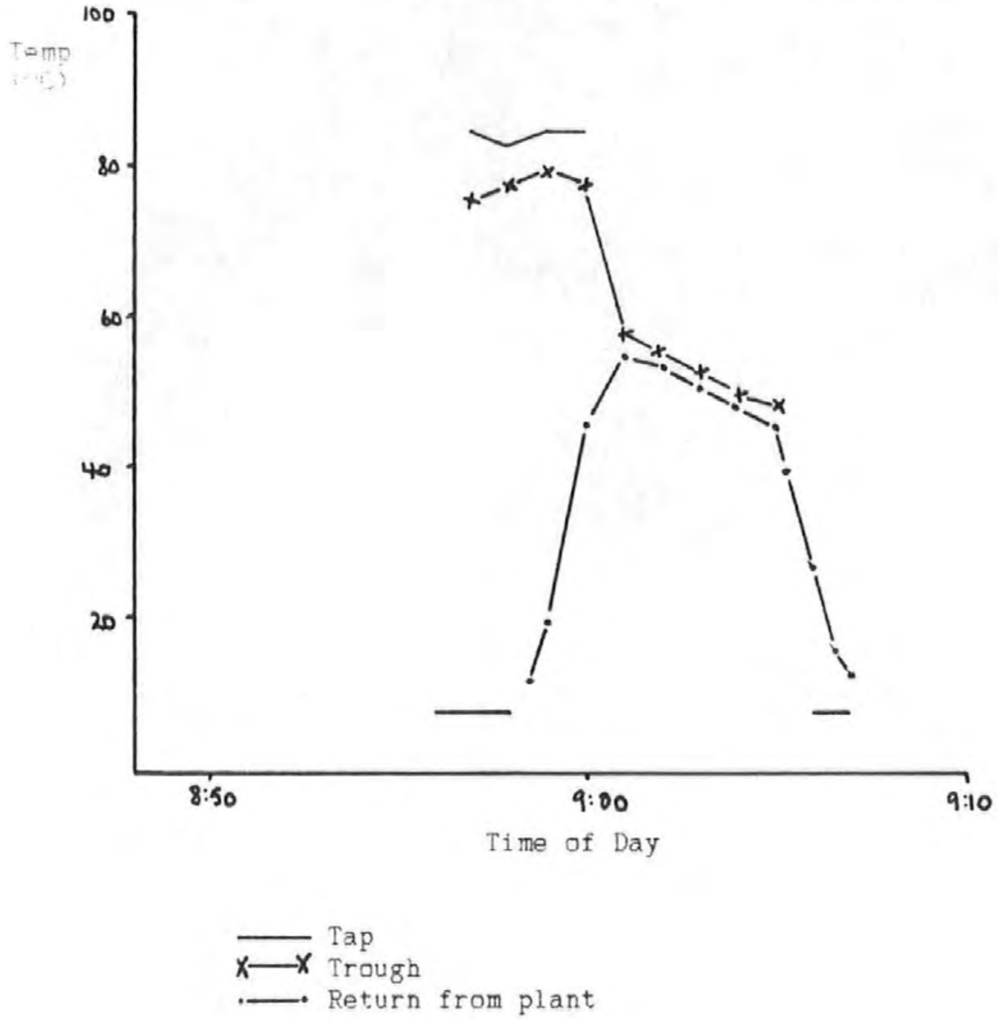


Figure 5.1.3.
Plant Cleaning Water Temperatures, Farm A



electricity used in the dairy and parlour. It was recommended that when the plant cleaning water heater was replaced an open-top model is fitted, this would allow all the heated water to be removed and thus a greater volume of water may be used for plant cleaning. In addition only the volume of water required for plant cleaning need be heated.

An observation of plant cleaning routine was carried out following the report, which showed that hot water was now discharged to waste before circulation commenced. The drop in temperature of the water in the trough was less than previously, however the circulation temperature was no higher than on previous occasions as the initial water temperature was 5°C lower than earlier.

Visual assessment of the plant indicates that the cleanliness of the internal glass surfaces is good. No deposits could be seen on any internal surface but the liners felt greasy. The external surfaces were generally fair, although the outside of the jars and clusters had some brown deposits. During the period of investigation the Resazurin milk hygiene test was passed consistently. The Total Bacterial Count was always within Band A, with a rise in November 1982, which was attributed to dirty udders caused by kale feeding.

5.2 Farm B

Plant Cleaning Routine	Circulation cleaning, on alternate days
Udder Washing Routine	Udders washed when dirty

Table 5.2.1

Summary of Water and Electricity Use

Water Use		
Plant cleaning water	1593.0	litres / month
	21.9*	litres / unit / wash
Udder washing water	2969.0	litres / month
	1.1	litres / cow / milking
Electricity Use		
Total dairy and parlour use	953.3	kWh / month
Plant cleaning water heater	205.8	kWh / month
	2.7*	kWh / unit / wash
as percentage of total	21.4	%
Udder washing water heater	86.2	kWh / month
	0.031	kWh / cow / milking
as percentage of total	8.9	%

* Assuming circulation cleaning on alternate days. see text.

Farm B is equipped with a large (135 litre) plant cleaning water heater which provides the equivalent of 27 litres of water per milking unit, well in excess of recommended volumes (10-15 litres) of hot water for circulation cleaning. Prior to the start of the investigation it was stated by the farmer that circulation cleaning was carried out on a once daily basis. However observation of plant cleaning routines showed that 90 litres were used for each hot wash, which did not correlate with mean weekly plant cleaning water use of 260 litres. When hot washing frequency was queried the farmer stated that hot washing was not carried out every day, its frequency depended on other farm work. Mean hot water use over two years was 1600 litres per month, suggesting that, if 90 litres are used for each wash, 17 washes are carried out over 30 days, i.e. hot plant cleaning is carried out on alternate days. This was later confirmed by the farmer. Despite this infrequent use of hot water the heater remains switched on at all times, under the control of a thermostat.

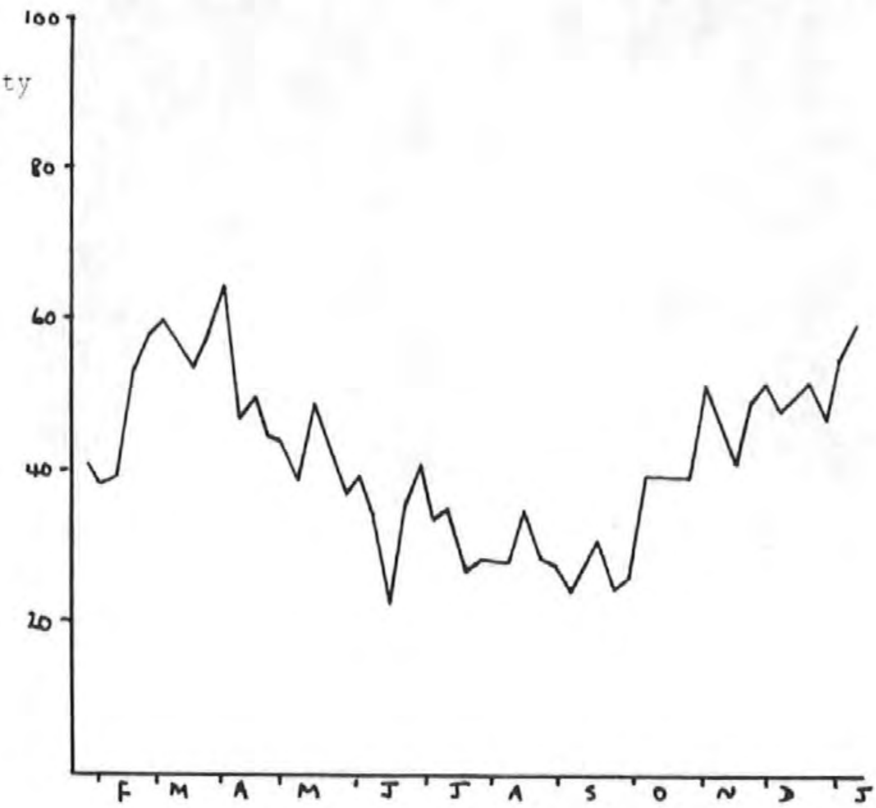
Electricity consumption for heating plant cleaning water at Farm B is high, given the infrequent use of hot water for plant cleaning and its relatively low temperature. The mean monthly electricity use is 206 kWh, which is higher than Farm A where the plant is washed every day.

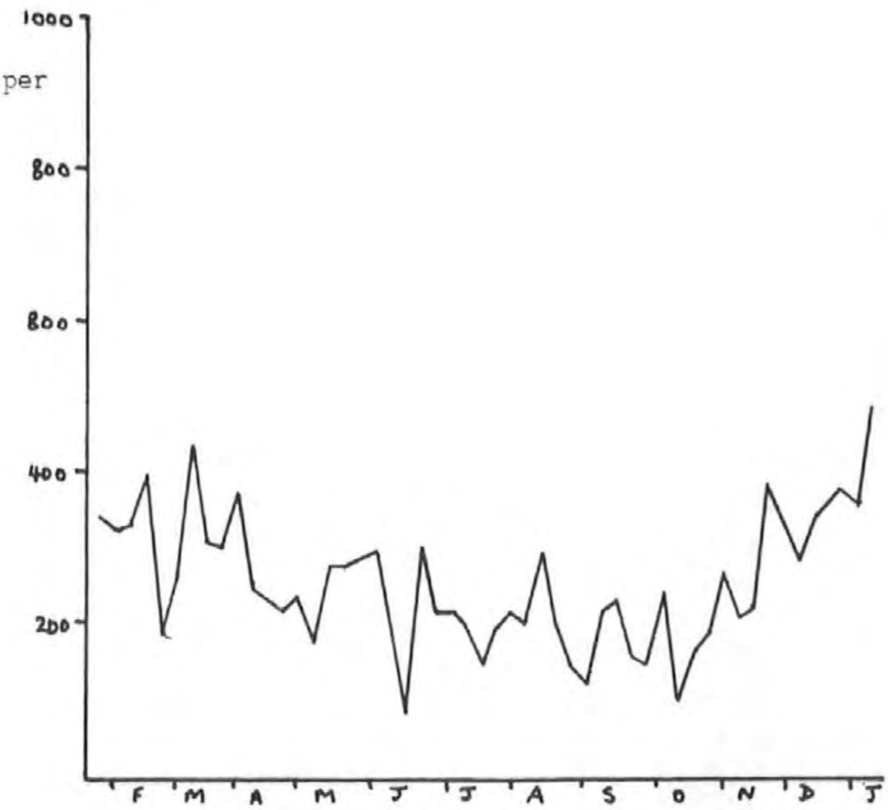
Weekly water and electricity consumption by the plant cleaning water heater for the first year of monitoring is shown as Figure 5.2.2. Plant cleaning water use shows fluctuations from week to week, which are attributed to differences in the number of hot plant cleaning routines carried out. Water use also shows a seasonal variation with less water used in the summer months, when there are other demands on the farmer's time. This is particularly noticable in week 24, when silage was being made and the plant was only hot washed once. Electricity use follows the same trend, the direct relationship between water and electricity use is illustrated by Figure 5.2.3, the correlation coefficient being 0.88.

Observations of plant cleaning technique have been carried out on five occasions, four mornings and one evening. On only one visit was a hot wash carried out. The cold wash routine consists of a single once through rinse with 100 litres of cold water with no added chemicals. When a hot routine is used the cold rinse is followed by a hot circulation clean using 90 litres of hot water with chemicals. The initial temperature of this water is low at 67°C. However water is discharged to waste until the discharged water is hot to the touch, which requires about 30 litres, before circulation commences, so that the water temperature falls by only 5°C at the start of circulation to give a circulation temperature of 55-43°C. Circulation continues until the cleaning water is warm to the touch, i.e. about 15 minutes. Figure 5.2.4 shows the water temperatures during circulation cleaning.

A Rustrak temperature recorder was used to investigate the frequency and temperature of circulation cleaning. Table 5.2.5 shows that hot washing took place on six of the nine days, a higher frequency than expected. The pattern of more frequent washes early in the nine day period suggests that this is due to the presence of a monitoring device, the effect of which was reduced by the end of the period.

Figure 5.2.2.
Weekly Electricity and Water Use for Plant Cleaning, Farm B





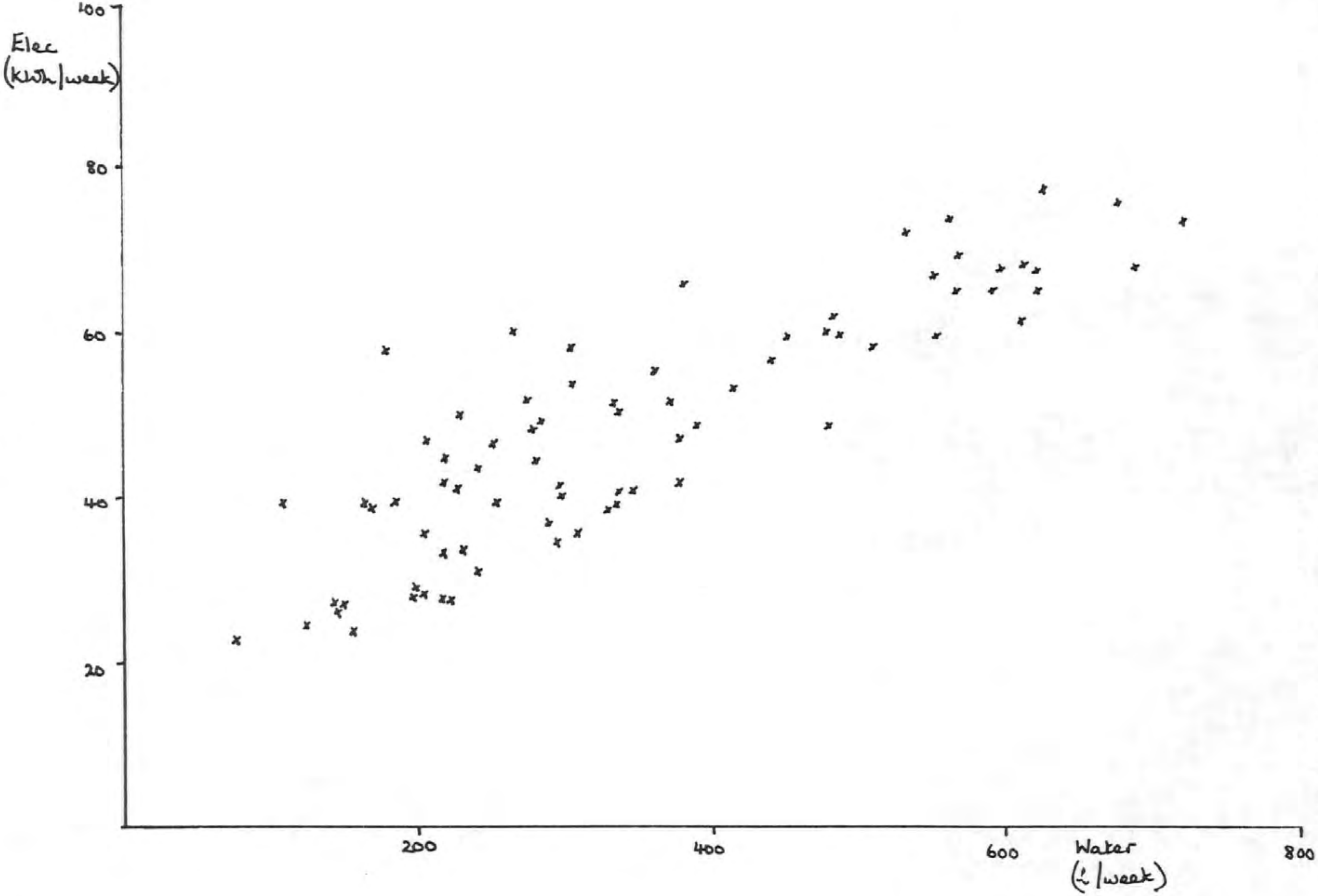


Figure 5.2.3
Relationship between Plant Cleaning Water and Electricity, Farm B

Figure 5.2.4.
Plant Cleaning Water Temperatures, Farm B

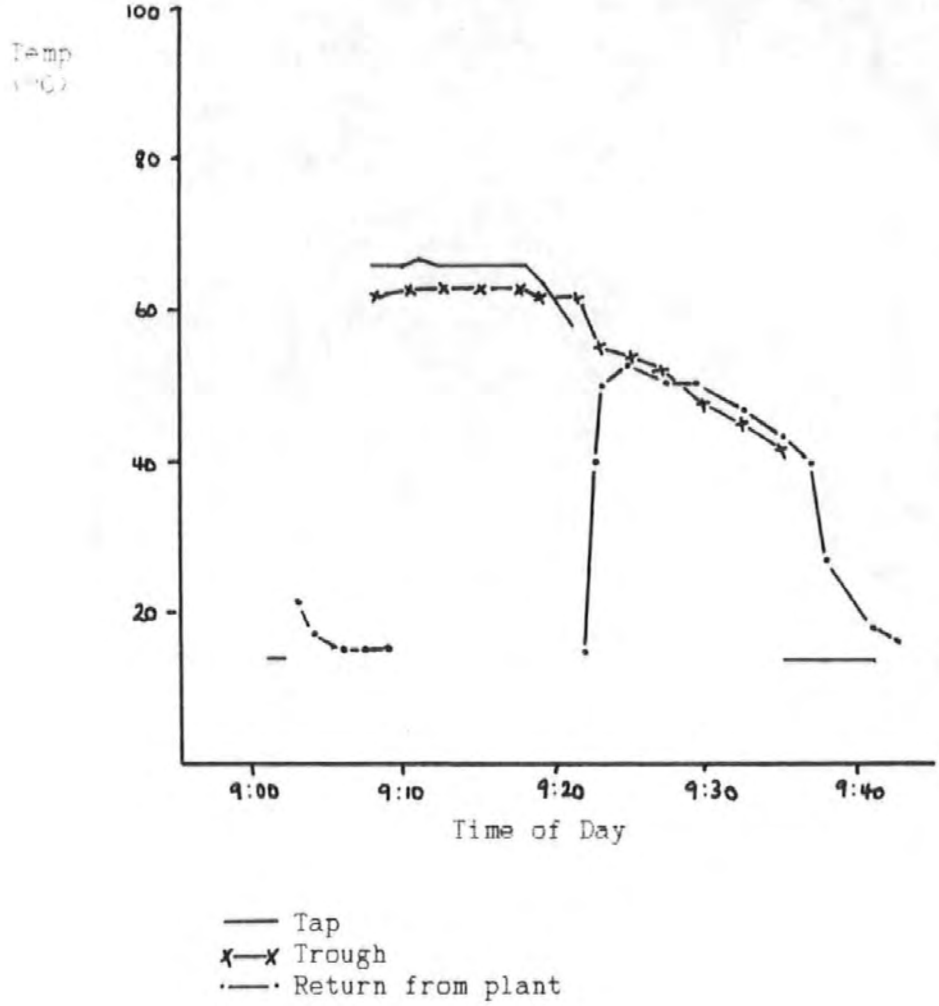


Table 5.2.5

Circulation Cleaning Frequency, Temperature and Duration, Farm B

Day	Temperature (°C)	Time (mins)
1	62	15
2	60	15
3	58	20
4	No hot wash	
5	60	12
6	55	20
7	No hot wash	
8	No hot wash	
9	58	10

Two reports have been produced for Farm B, The first concerned hot water production and use, the second concerned the implementation of the Farm Day/Night Tariff. The first report discussed the temperature and frequency of hot circulation cleaning, stating the A.D.A.S. recommendations of 85°C as the initial temperature for circulation cleaning, once or twice per day. The report also discussed the excess capacity of the heater and the absence of a timeswitch as outlined earlier. The report recommended fitting a timeswitch to heat water only when required, and adjustment of the thermostat to 85°C. Follow up observations revealed that the farmer intended to continue his own routine, as it was his opinion that good milk hygiene reports suggested that his plant cleaning methods, however unorthodox, were satisfactory.

Following an enquiry from the farmer a report was produced to discuss the use of the Farm Day/Night Tariff. Table 5.2.6 shows the results of the model simulation on which the report was based. Following the report it was decided to implement the Farm Day/Night Tariff and a timeswitch was immediately fitted to the plant cleaning water heater. The timeswitch was set to heat sufficient water for plant cleaning every day. This was considered necessary as the decision to hot wash the plant is not generally taken until the end of the morning milking.

Table 5.2.6

Cost of Plant Cleaning Water Heating at Farm B

Water heated Volume litres	Temperature °C	Washes /week	Electricity consumption kWh/annum	Cost / annum Standard Tariff £	Night Tariff £
Present use					
135	65	3-4	2326	122	-
Model simulation					
90	65	7	2692	141	51
90	65	3	1151	60	22
135	65	7	4039	212	77
135	65	3	1725	91	33
135	85	7	5385	283	102
135	85	3	2301	121	44

Visual assessment of the plant reveals that the cleanliness of the internal surfaces is good, but there are deposits on the external surfaces of glass and rubber parts. Milk hygiene quality at Farm B is good; during the period of the investigation the Resazurin test has been passed consistently. Counts of thermoduric bacteria in the milk are low, the highest value recorded being 2 000 bacteria per millilitre. This level is regarded as indicative of good plant hygiene. The Total Bacteria Count is also low, the milk being consistently being within Band A.

5.3 Farm C

Plant Cleaning Routine	A.B.W. twice per day
Udder Washing Routine	Dirty udders washed

Table 5.3.1

Summary of Water and Electricity Use

Water Use		
Plant cleaning water	9299.4*	litres / month
	30.6*	litres / unit / wash
Udder washing water	589.0	litres / month
	0.20	litres / cow / milking
Electricity Use		
Total dairy and parlour use	1720.0	kWh / month
Plant cleaning water heater	893.7*	kWh / month
	2.9*	kWh / unit / wash
as percentage of total	52.0*	%
Udder washing water heater	42.6	kWh / month
	13.1	kWh / cow / milking
as percentage of total	2.6	%

* Data for twelve months only (twice daily hot cleaning)

Farm C used A.B.W. cleaning throughout the period of the survey, initially a hot wash routine was carried out twice each day, but this was later reduced to once per day, on 13.8.81.

Plant cleaning water is heated in an unpressurized dairy water heater which has a capacity of 130 litres. This is equivalent to 26 litres of hot water per milking point, an excessive allowance as the maximum recommended volume is 18 litres per milking point.

During the first six months of the project water use from the heater, as measured by the plant cleaning water meter, averaged 180 litres per hot wash, 50 litres more than the capacity of the water heater. This is due to cold water being allowed to enter the heater and then the milking plant during cleaning. The vacuum valve, which would normally prevent the entry of cold water during cleaning, is disconnected from the vacuum line. Therefore the plant cleaning water use, as measured by the water meter, includes some cold water and so is an over estimate of the hot water used. However the volume of water used for plant cleaning can be accurately estimated from the capacity of the water heater as no hot water is left in the heater after cleaning, and water cannot be extracted from the heater for other purposes as it is plumbed directly into the milking plant. For these reasons the figure of 130 litres of hot water for each hot wash is used in all calculations.

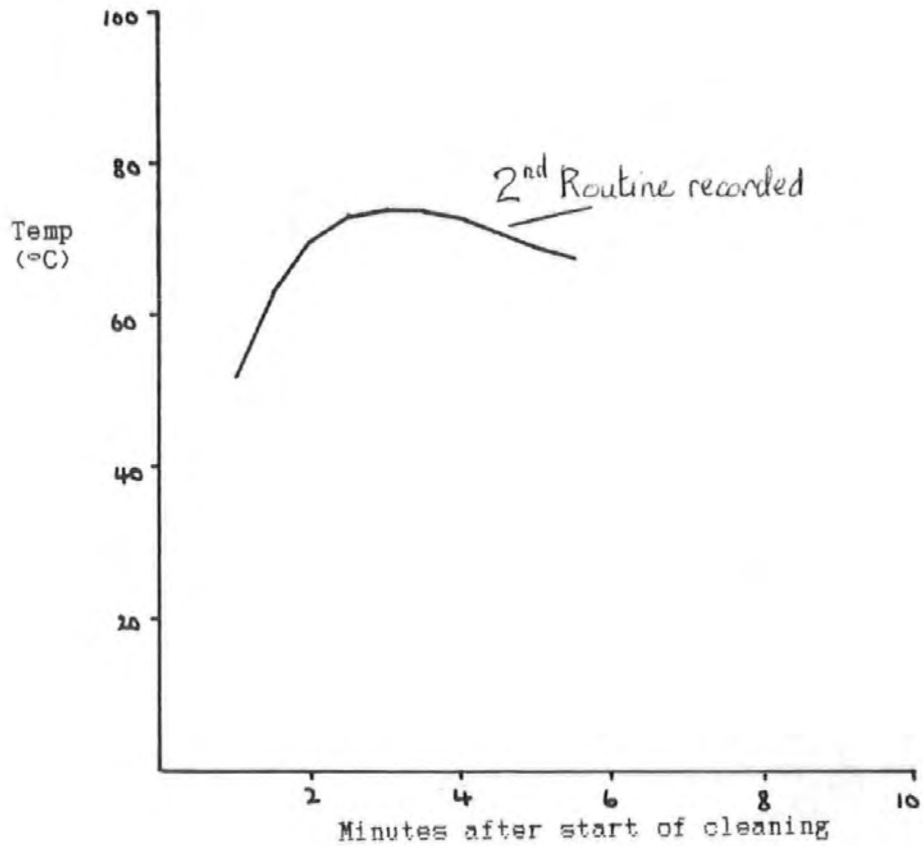
The plant cleaning water heater is controlled by a timeswitch which is generally carefully set, however on 24/12/81 the timeswitch failed, causing increased electricity use. Mean electricity use for the five weeks preceeding this date was 111 kWh per week, during the five weeks that the timeswitch was inoperative this increased to a mean of 263 kWh per week; an increase of 152 kWh per week, which represents 38% of the total average dairy use for farm C.

The use of A.B.W. cleaning twice each day and the large volume of water heated each day leads to high electricity use by the plant cleaning water heater. On Farm C electricity for heating plant cleaning water represents 47% of the total dairy and parlour consumption, a very high proportion when compared with other farms.

Plant cleaning routines have been observed on three occasions, two mornings and one afternoon. On each occasion the temperature of the water in the heater prior to cleaning was 95°C. The temperature of the water returning from the plant during the two morning routines is shown as Figure 5.3.2. During the first of these two routines cold water was entering the heater throughout cleaning, resulting in a low return temperature. After this observation the farmer was advised to make use of the vacuum valve to prevent cold water entering the heater. This advice was acted on and the effect can be seen in the temperature of the cleaning water in the second routine observed. In the second case the cleaning routine was considerably shorter, as less water was used, but high water temperatures (over 70°C) were maintained for longer, 160 seconds as opposed to 55 seconds in the earlier routine. Results from a Rustrak recorder indicate that similar routines are carried out every day.

The high cost of heating the plant cleaning water was a cause of concern to the farmer at Farm C, as electricity for plant cleaning cost £536 at 1981 prices. A report of water heating costs was

Figure 5.3.2.
Temperature of Water after Plant Cleaning, Farm C



produced, using model simulation figures, shown as Table 5.3.3. This report indicated that reducing the volume of water heated from the current volume of 120 litres to the upper recommended volume of 90 litres would reduce electricity consumption by about 30%, while using the lower recommended volume of 70 litres would reduce electricity consumption by over 40%. Reduction of the frequency of hot washing from twice to once per day would halve electricity consumption. Adoption of the Farm Day/Night Tariff would reduce the cost of electricity from 4.9 to 1.82 per kWh. Changing cleaning method from A.B.W. to circulation cleaning was also investigated, using the upper and lower recommended volumes of 75 and 50 litres per wash.

Table 5.3.3

Water Heating Costs for Farm C

Cleaning System	Water Heated (litres)	Electricty used kWh / wash	Cost of heating water (£ p.a.) Normal Tariff 14 washes	7 washes	Farm Day/Night 7 washes
	120	14	495	248	92
A.B.W.	90	10	372	186	69
	70	8	290	145	54
Circulatⁿ cleaning	75	7	264	132	49
	50	5	177	88	33

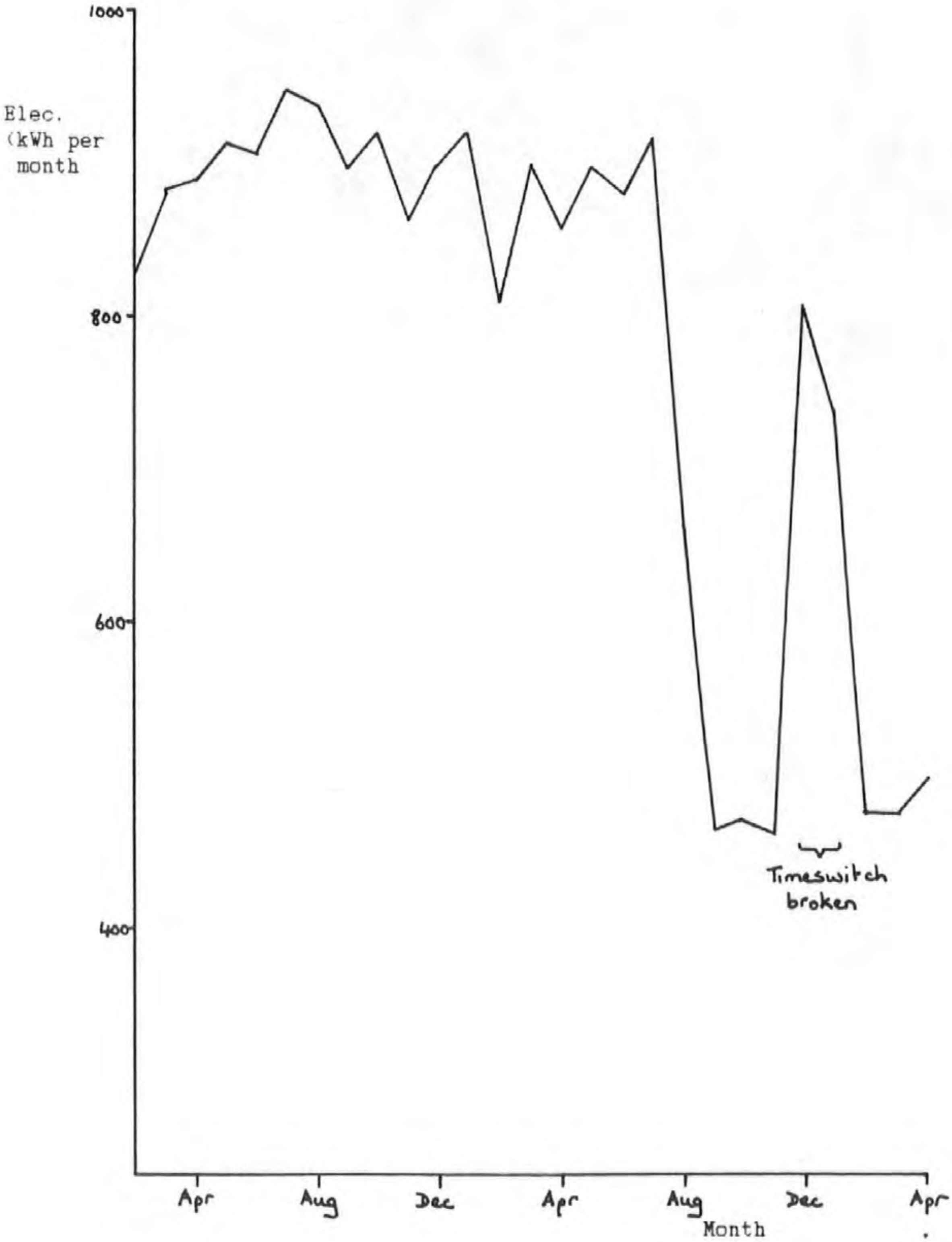
The model analysis indicates that circulation cleaning once per day, with the water heated in the night period of the Farm Day/Night Tariff is the cheapest method of cleaning the parlour. However the effectiveness of cleaning routines must also be considered, as well as economy. Following discussions with the farmer and A.D.A.S once daily A.B.W. cleaning was selected, as being more satisfactory than once daily circulation cleaning. The South Western Electricity Board reported that the Farm Day/Night Tariff was not suitable due to high day time consumption of electricity outside the parlour.

The evening hot wash was immediately changed to a cold hypochlorite rinse. The timeswitch on the plant cleaning water heater was adjusted to prevent heating of the water in the evening and after the morning wash. The timeswitch was set so that the water had reached 100°C at the end of milking. Observation of cleaning routine verified that an acceptable cleaning temperature was reached.

Electricity consumption for heating plant cleaning water is shown as Figure 5.3.4. This illustrates the considerable reduction in electricity consumption which resulted from the change, during month 20, to a once daily hot wash. The effect of the broken timeswitch during months 24 and 25 is also apparent. The average electricity consumption for heating plant cleaning water twice per day was 893.7 kWh per month, which was reduced to 459.0 kWh per month for those months when the plant was hot cleaned once per month and the timeswitch was working correctly.

A visual assessment of the plant showed it to be in good condition, and the milk Total Bacterial Count is consistently within Band A.

Figure 5.3.4.
Monthly Electricity Use for Plant Cleaning, Farm C



5.4 Farm D

Plant Cleaning Routine	Circulation cleaning, twice per day
Udder Washing Routine	All washed

Table 5.4.1

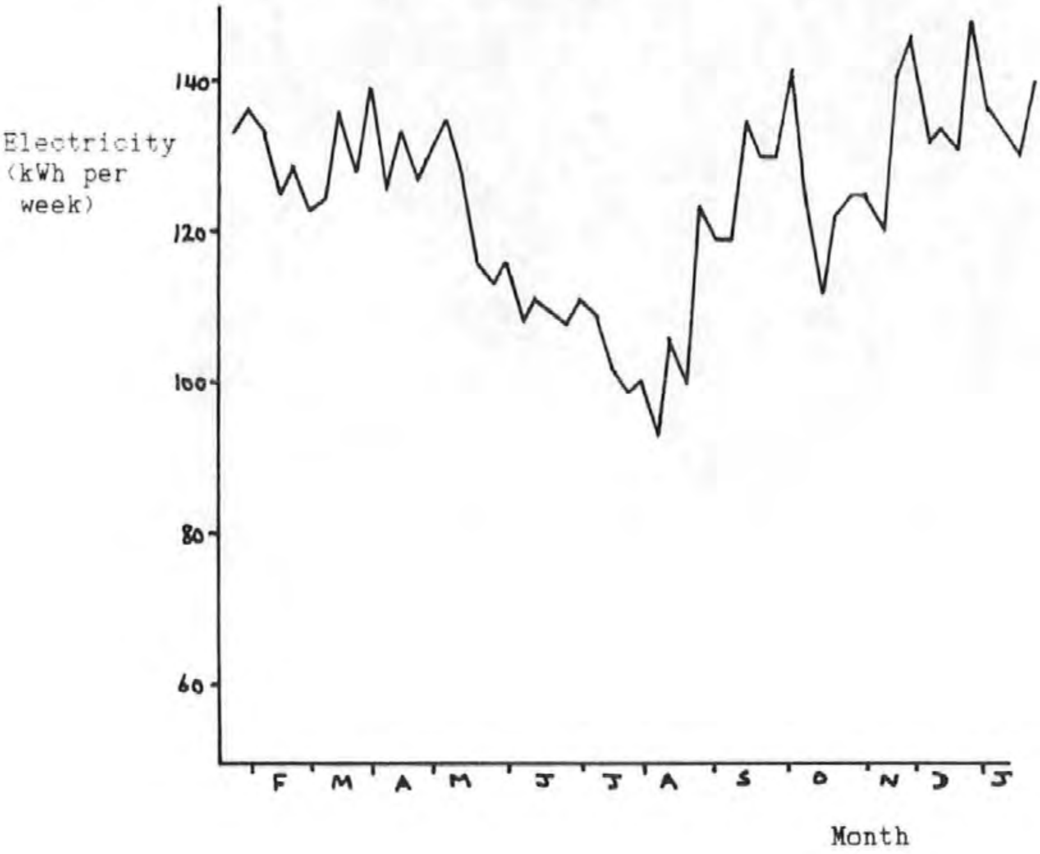
Summary of Water and Electricity Use

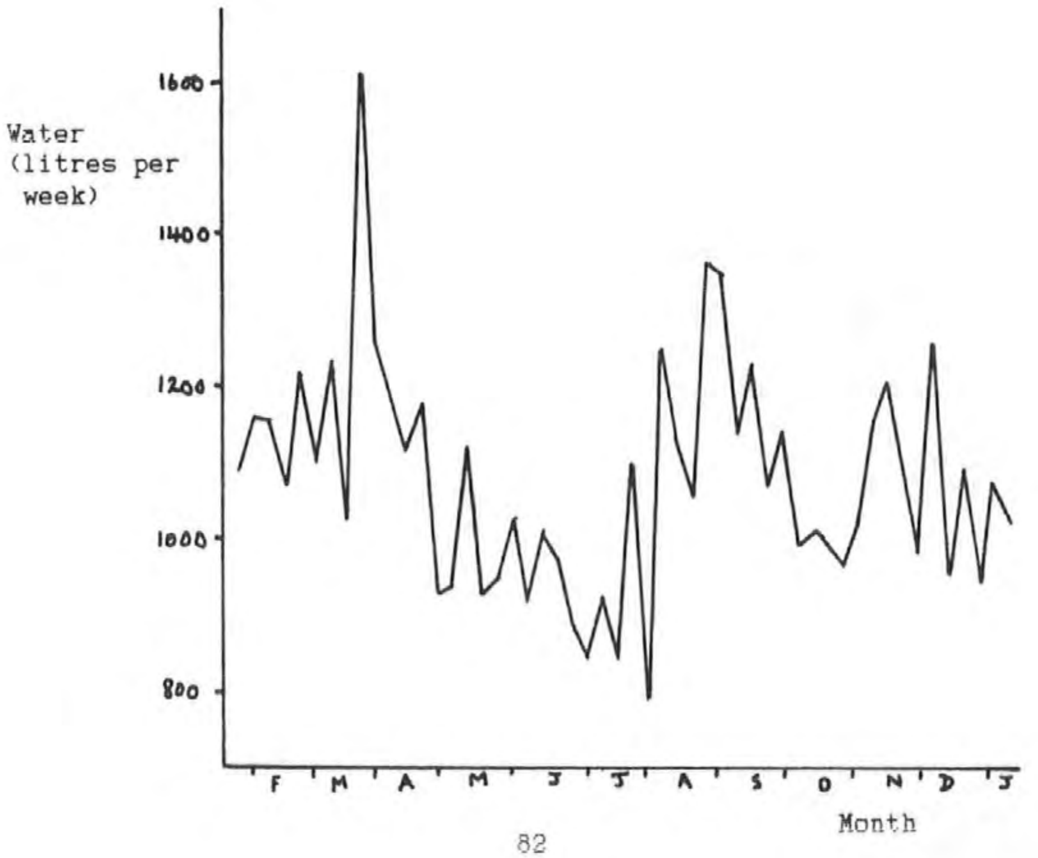
Water Use		
Plant cleaning water	4465.0	litres / month
	14.7	litres / unit / wash
Udder washing water	2303.4	litres / month
	0.6	litres / cow / milking
Electricity Use		
Total dairy and parlour use	1551.1	kWh / month
Plant cleaning water heater	540.8	kWh / month
	1.8	kWh / unit / wash
as percentage of total	34.9	%
Udder washing water heater	85.3	kWh / month
	0.023	kWh / cow / milking
as percentage of total	5.4	%

Farm D is unusual in that the herd is comprised of Jersey cows, whereas all the other survey farms have Freisian cows. The plant cleaning water heater is a domestic type, which is larger than required at 135 litres, which provides 27 litres of hot water per milking point. There is no timeswitch on the water heater, which is left switched on at all times. The parlour is not equipped with jetters, so the units are fitted to a manifold in the wash trough for circulation cleaning.

Circulation cleaning is carried out, using hot water, twice each day in general. However the herdsman is not paid after 17:30, so if there is insufficient time for a full circulation cleaning routine in the evening a single cold rinse is carried out. Figure 5.4.2 shows weekly electricity and water use for the plant cleaning water heater. Water use shows no overall trend but wide weekly fluctuations, due to the washing policy. Electricity use shows a distinct trough in the summer months, due to higher ambient and inlet water temperatures.

Figure 5.4.2.
Weekly Electricity and Water Use for Plant Cleaning, Farm D





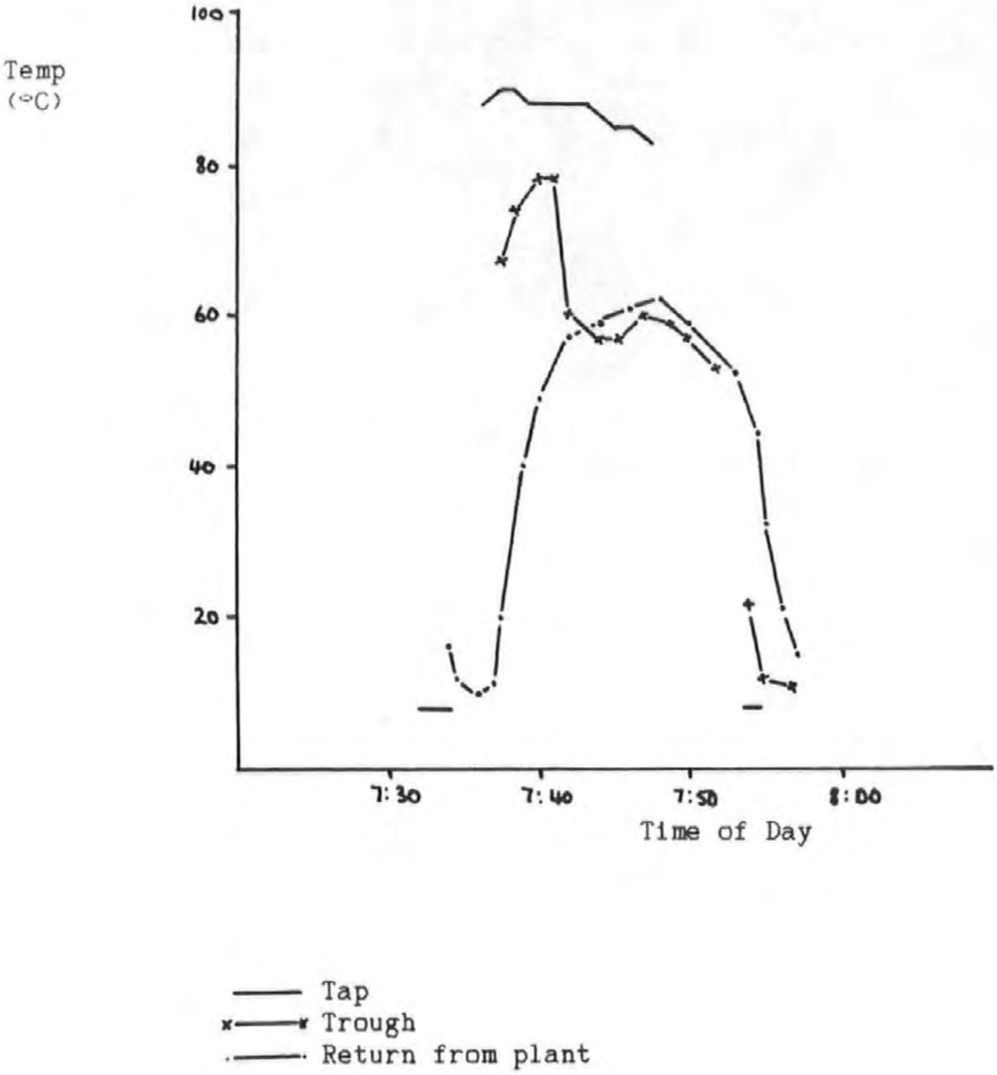
Electricity consumption for heating plant cleaning water is high, at 541 kWh per month. This is due mainly to the use of hot water twice per day, but also due to the lack of a timeswitch. Model simulation indicates that 460 kWh/month is required for heating the volume of water used, 4465 litres, whereas 541 kWh are used. The excess of approximately 80 kWh/month, caused by lack of a timeswitch, costs £50 per annum at 1982 prices. Reduction of the frequency of hot washes to once per day would reduce electricity consumption to 250 kWh/month, provided that a timeswitch was fitted. This represents a reduction of 18.8% in the total electricity use in the dairy and parlour.

Cleaning routines have been observed on six occasions, three mornings and three evenings. A full circulation cleaning routine was carried out on all visits. Cleaning was started on five occasions by a warm pre-rinse, at 25 - 35°C, but on the first visit the pre-rinse was cold (8°C). In all cases the pre-rinse was discharged to waste. Hot water temperatures at the tap were high, at 89 - 95°C, however no hot water is discharged from the plant before circulation starts so maximum circulation temperatures are in the range 54 - 60°C, which is low, considering the high initial temperature of the water. Circulation times were shorter in the evening (mean 7.3 minutes) than in the morning (mean 12.3 minutes). After circulation the plant is rinsed with cold water, discharged to the floor. The water temperatures during a typical routine is shown as Figure 5.4.3.

A report on water heating and cleaning routines was sent to Farm D, which discussed the high electricity use for water heating and suggested the installation of a timeswitch to reduce electricity waste. The drop in temperature of the water at the start of circulation cleaning was described, and discharge of the first 10 to 20 litres of hot water returning from the plant was advised. Two of the six cleaning routines already described were observed after this report was received at Farm D. these observations revealed that neither of the recommendations had been implemented.

Visual assessment of the plant indicated that rubber, glass and metal parts were clean, but that the rubber liners were slightly perished. Milk hygiene reports were not available at this farm.

Figure 5.4.3
Plant Cleaning Water Temperatures, Farm D



5.5 Farm X

Plant Cleaning Routine	Circulation cleaning, twice per day
Udder Washing Routine	Dirty udders washed

Table 5.5.1

Summary of Water and Electricity Use

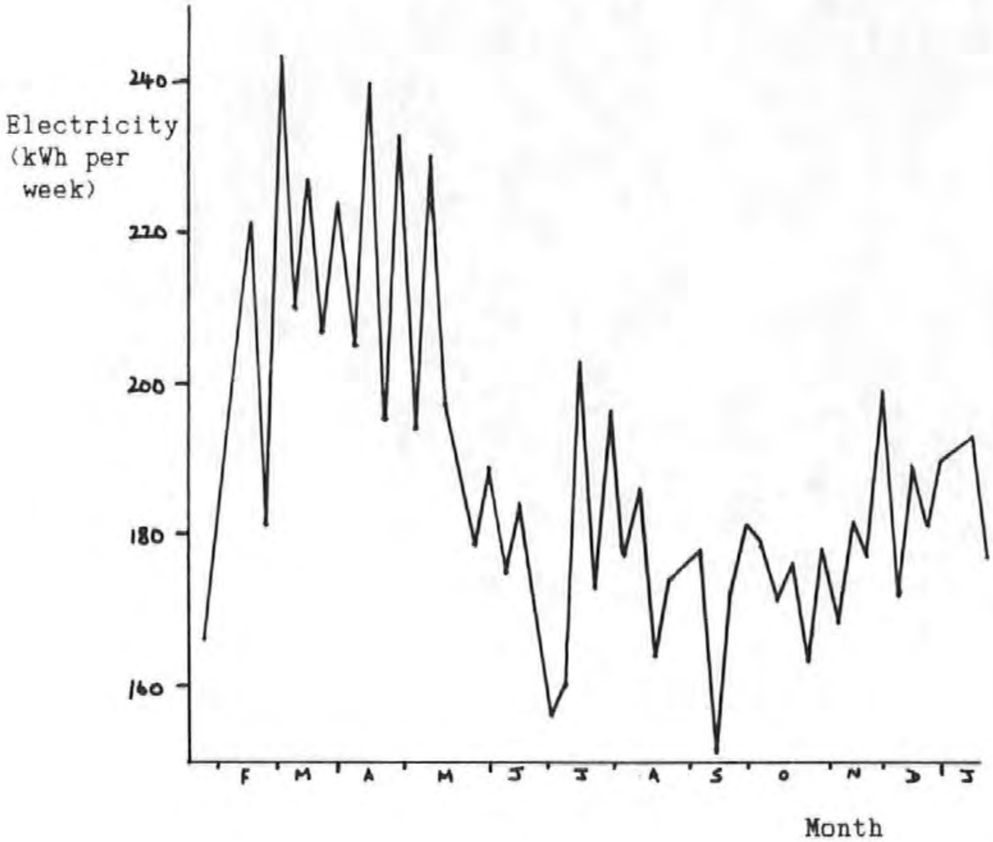
Water Use		
Plant cleaning water	5443.7	litres / month
	14.9	litres / unit / wash
Udder washing water	373.3	litres / month
	0.077	litres / cow / milking
Electricity Use		
Total dairy and parlour use	2196.5	kWh / month
Plant cleaning water heater	702.2	kWh / month
	1.9	kWh / unit / wash
as percentage of total	31.8	%
Udder washing water heater	108.0	kWh / month
	0.025	kWh / cow / milking
as percentage of total	4.9	%

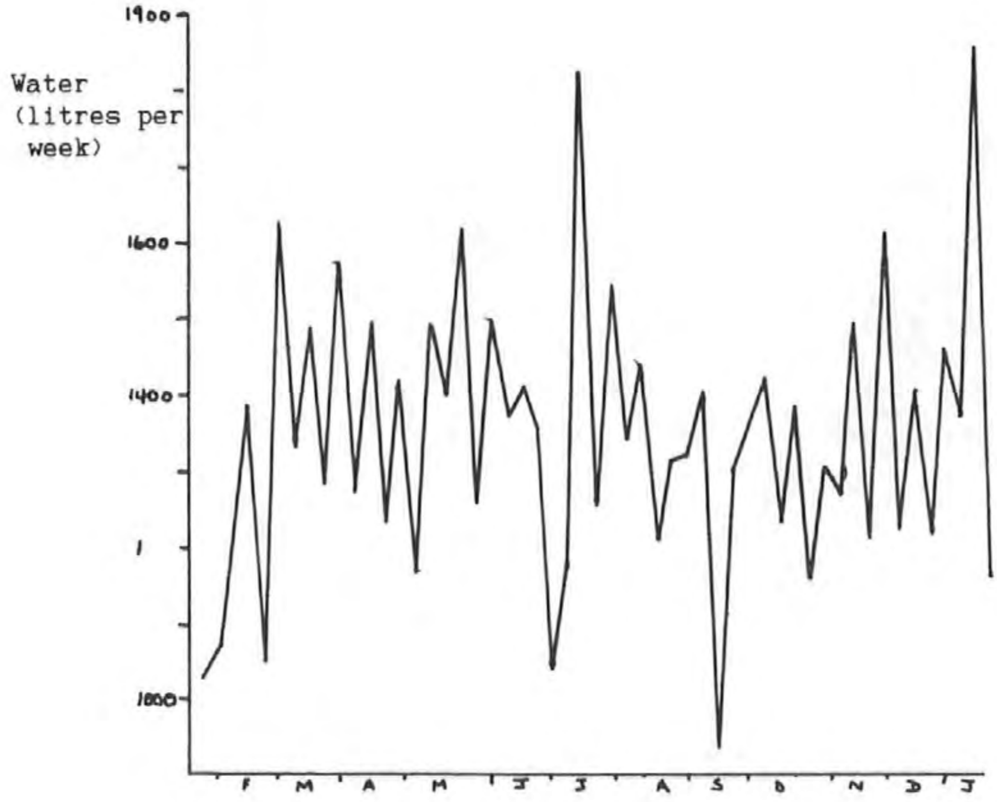
The plant cleaning water heater at Farm X is a "domestic" type, with a capacity of 135 litres and a rating of 4 kW. The dairy unit is staffed by a herdsman and a relief herdsman who carries out the milking on alternate weekends.

Electricity use for heating plant cleaning water is higher than average, at 1.9 kWh/milking unit/hot wash. The higher cost has two contributing factors; a higher than average water use of 16 litres/unit/hot wash and poor timeswitch control. The two herdsmen milk at different times of day so the timeswitch is set to allow for both routines and therefore the water is frequently heated after the hot water has been removed from the heater.

Figure 5.5.2 shows weekly water and electricity use for plant cleaning, and indicates that there are wide weekly fluctuations in water use, with alternate weeks having high and then low consumption. Plant electricity also shows these fluctuations, with an additional trend to lower consumption in the summer weeks. These bi-weekly

Figure 5.5.2.
Weekly Electricity and Water Use for Plant Cleaning, Farm X





fluctuations were analysed as shown in Figure 5.5.3. In the weeks when the relief herdsman carries out 4 of the 14 milkings the mean water consumption is 1253 litres, whereas when the regular herdsman carries out all 14 washes the mean consumption is 1495 litres. Assuming the regular herdsman uses the same volume of water for cleaning on both weeks i.e. 105 litres per wash, then the relief herdsman only uses 45 litres per wash, or less than 50% of normal.

The circulation cleaning routine is poor, resulting in low circulation temperatures. Figure 5.5.4 shows that the temperature of water from the heater is low at 73°C, and the water loses 10°C between tap and trough. This loss is due firstly to residues of cold water in the trough and secondly to the hot water passing over a lead pipe in the trough. Extraction of water from the heater is very slow, taking up to 25 minutes, leading to further heat loss. No pre-rinse is carried out before circulation cleaning, this should have the advantage that the plant is still warm when it is washed, however the length of time between the end of milking and circulation cleaning negates this advantage. When cleaning is carried out very little water is discharged to waste prior to circulation so that the temperature of circulation is very low, at 40 - 25°C.

A report was sent to Farm X detailing the high electricity costs for plant cleaning and the poor circulation technique. The farm manager did not consider that altering the times that the two herdsmen milked was a feasible proposition, so that the timeswitch would not be altered. Figure 5.5.5 shows that the temperature of the circulation cleaning water was improved, mainly by discharging more water to waste prior to circulation. In addition a rubber hose has been added to the hot tap, and the trough is emptied of cold water before the hot water is added.

Visual assessment of the plant indicates that the cleaning of rubber and metal parts is satisfactory, but that the glassware has a slight film. Milk quality is Band A of the Total Bacterial Count classes.

Figure 5.5.3.
Water and Electricity Use by Two Herdsmen, Farm X

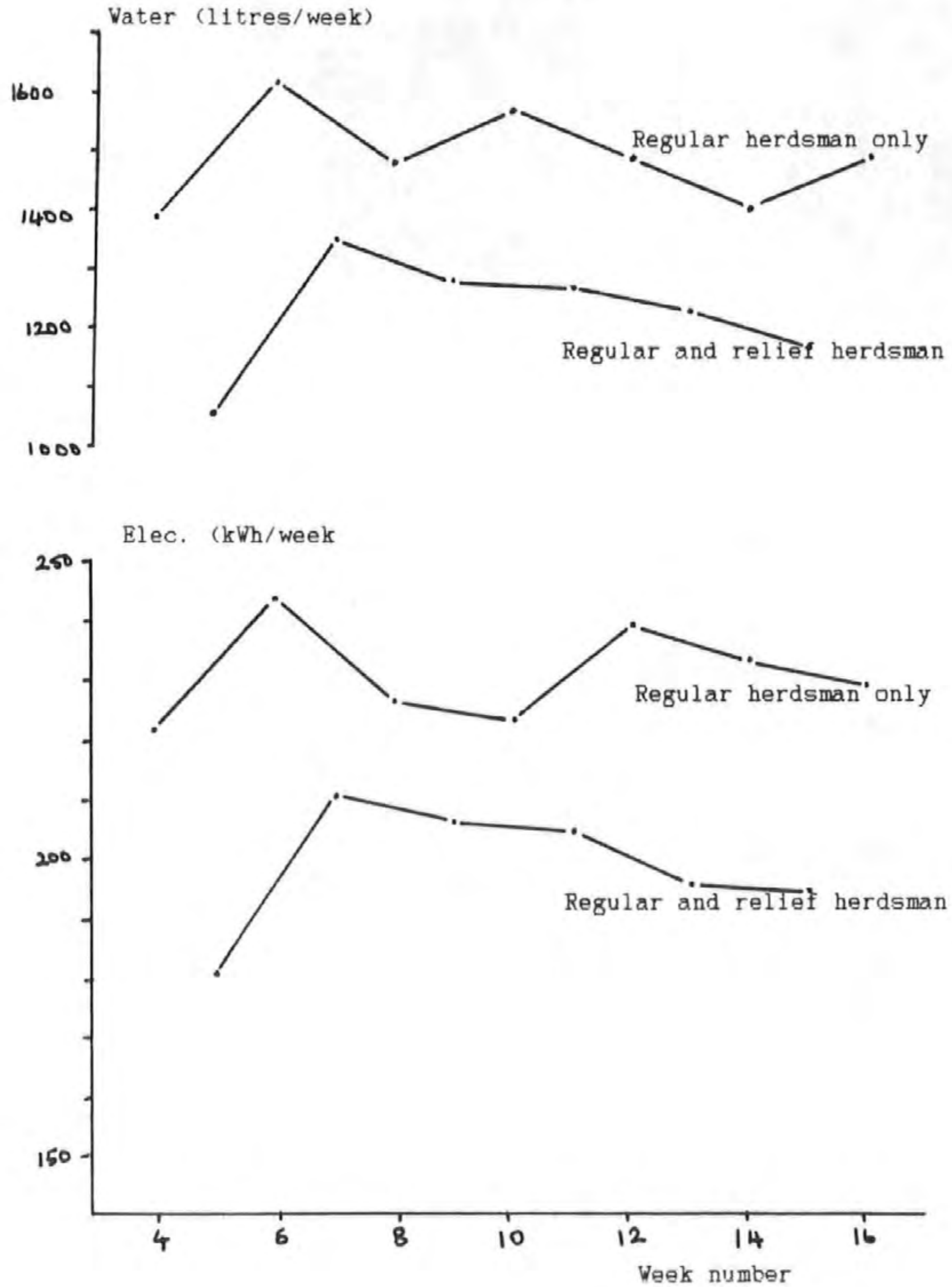


Figure 5.5.4.
Plant Cleaning Water Temperatures, Farm X

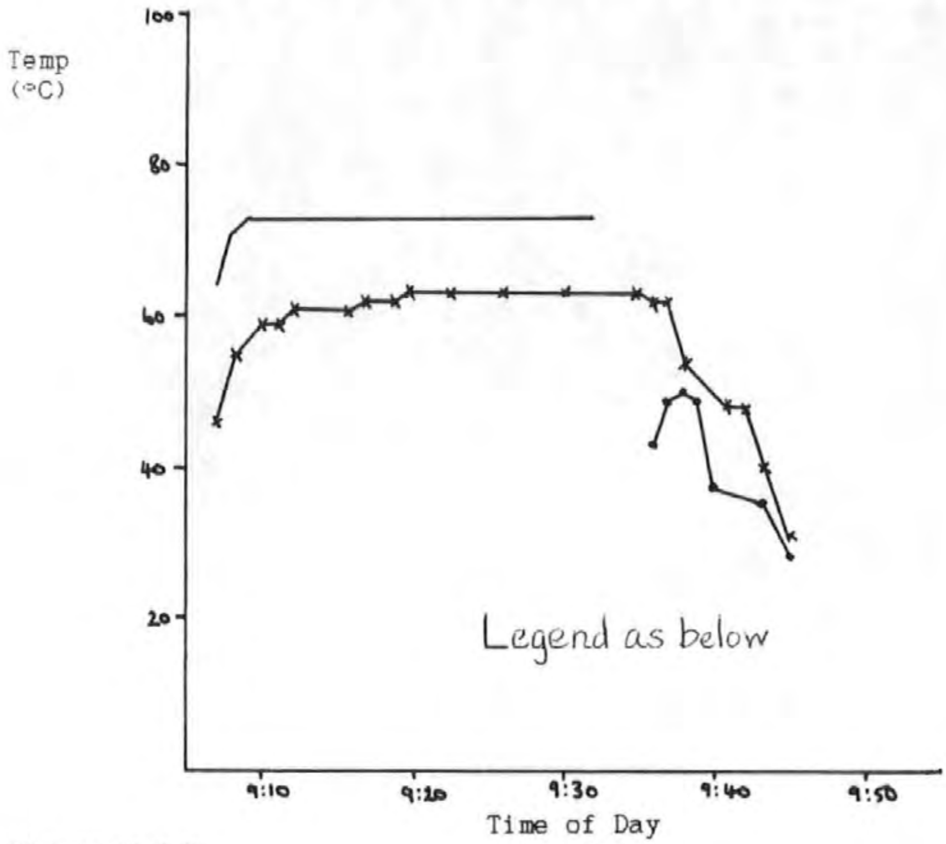
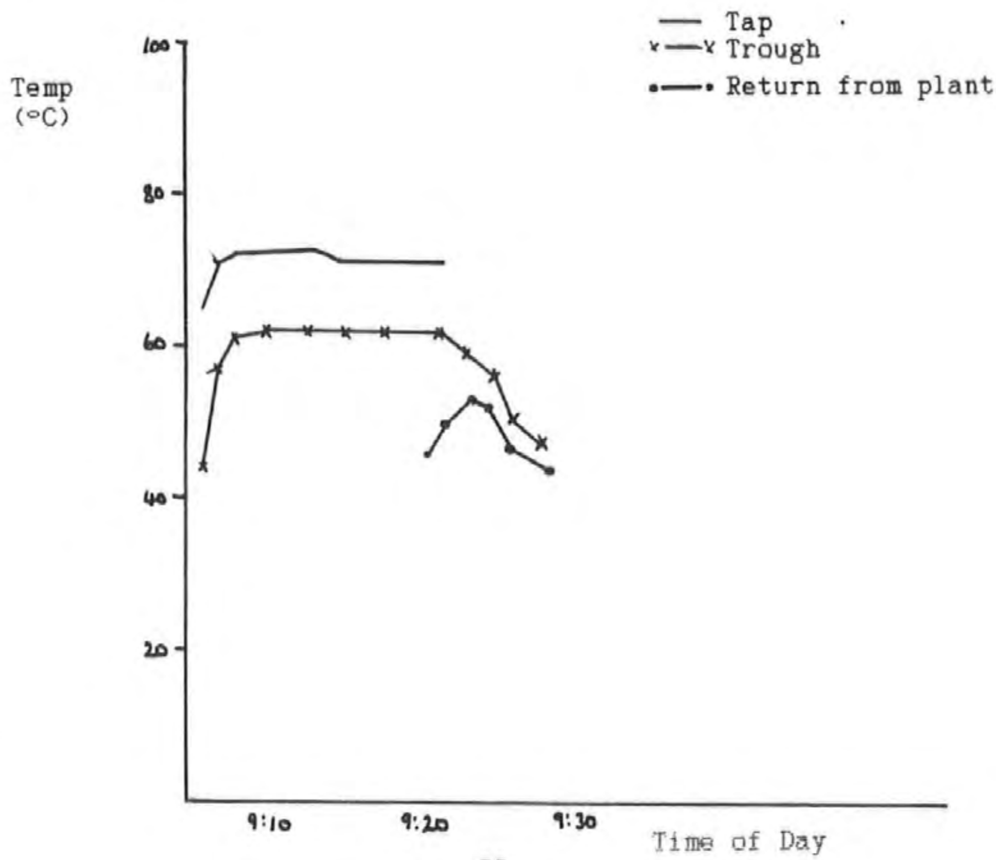


Figure 5.5.5.



5.6 Farm E

Plant Cleaning Method	Circulation cleaning, morning only
Udder Washing Routine	All udders washed

Table 5.6.1

Summary of Water and Electricity Use

Water Use		
Plant cleaning water	8765.0*	litres / month
	26.7	litres / unit / wash
Udder washing water	7315.1	litres / month
	1.1	litres / cow / milking
Electricity Use		
Total dairy and parlour use	2137.2*	kWh / month
Plant cleaning water heater	480.0*	kWh / month
	1.3	kWh / unit / wash
as percentage of total	22.5	%
Udder washing water heater	197.9	kWh / month
	0.029	kWh / cow / milking
as percentage of total	10.4	%

* Twelve months only (parlour size = 12/12)

Farm E is equipped with three energy saving devices; a plate cooler and two Heat Recovery Units. The plate cooler is used to pre-cool the milk, using water from a private well. The milk is then fully cooled in two bulk vats of 1818 litres and 910 litres capacity. One H.R.U. is fitted to the compressor of the larger bulk tank, which is used at all times, the warmed water is fed into the plant cleaning water heater. The second Heat Recovery Unit is fitted to the vacuum pump exhaust, and feeds water to the udder washing water heater. This heater is wired directly into the main electricity supply and is thus always switched on.

The parlour at Farm E was initially a 5/10 herringbone, which was replaced in September 1980 by a 12/12 herringbone. Plant cleaning water is heated in a 115 litre dairy water heater. Immediately after plant cleaning the water heater is refilled with water from the Heat Recovery Unit. Thirty five litres of the water is from the open header tank of the heater, and so is at ambient temperature. The remainder of the water is directly from the Heat Recovery Unit and is warm. The heater is left switched on at all times under the control of a thermostatic switch. This switch is on "low" between milkings, which sets the thermostat at 60°C. At the start of morning milking the switch is changed to the "high" setting which alters the thermostat to 85°C. The plant cleaning water heater was replaced on 30.12.81, due to a leaking water vessel. The replacement heater was the same type and volume, but was controlled by a timeswitch set to allow heating from 02:00 to 09:00. The warm water from the Heat Recovery Unit is therefore subject to considerable heat loss before it is used; some of the water will remain in the open header tank of the heater, where it will cool to ambient temperature, the remainder of the water will enter the heater, where it will cool until the timeswitch cuts in.

Circulation is carried out with hot water once per day, the circulation solution is stored and used cold at night. Both morning and afternoon cleaning routines start with a cold, once through rinse using 100 litres of cold water. The cleaning solution is then circulated for 15 minutes, hot in the morning and cold in the afternoon. After circulation the plant is rinsed with 100 litres of cold water. Water use from the plant cleaning water heater is high, averaging 135 litres per day up to the end of August 1980 and 320 litres from September 1980, the later representing 27 litres per milking unit per wash. However the maximum capacity of the water heater is 115 litres and plant cleaning observations suggested that 130 litres of water are used from the heater for plant cleaning each day. It appears therefore that a considerable volume of water was being used from the heater for purposes other than plant cleaning, after September 1980.

Cleaning routines have been observed on four occasions, the first two of these took place before the change in parlour size, the third and fourth after the plant cleaning water heater had been replaced. The four observations indicate that little care is taken to follow the same routine each day. On one occasion the pre-rinse was warm (45°C), on all other occasions cold water was used. The different cleaning routines are summarised as Table 5.6.2. From this table it can be seen that the water temperature from the tap is initially high, but this is not maintained, so that the temperature immediately prior to circulation is low at 55-66°C. No water is discharged to waste before circulation commences, which causes a further drop in temperature to result in circulation temperatures of 40-55°C. Circulation times also have a wide range; the length of time that circulation continues depends on the length of time taken to hose down the parlour floor. The volume of hot water used for circulation is generally 100 litres, but was once 148 litres. An additional 15 litres of hot water is used after each milking to clean the external surfaces of the clusters, giving a total of 130 litres of hot water per day for plant cleaning purposes.

Table 5.6.2

Summary of Cleaning Routines

Temperature: (degrees Celcius)				
Initial	90	95	95	76
In trough, before circulation	55	62	62	66
during circulation	41-36	44-38	46-41	55-43
Maximum return temperature	41	43	43	52
Time of circulation (minutes)	10	10	13	23
Volume of hot water (litres)	99	102	148	106

During observations of cleaning routines the temperature of the water from the Heat Recovery Unit was measured. These measurements are shown as Table 5.6.3. These temperatures are lower than could be expected, particularly in the winter months. However the running time of the refrigeration system to which the HRU is fitted is shorter than normal, as the milk stored in the milk vat is pre-cooled by a plate cooler, as described earlier.

Table 5.6.3

Temperature of Water from the Heat Recovery Unit

	Temperature (degrees Centigrade)	
Date	Maximum	Minimum
18/8 /81	41	38
18/12/81	29	28
7/ 1/82	26	21
7/ 8/82	59	30

A report on hot water use at Farm E was produced. This report detailed the temperatures of cleaning water and recommended that the tap should be closed before the water temperature falls below 70°C. In addition 10-20 litres of water should be discharged to waste before circulation commences, to reduce the temperature drop at the start of circulation. The final cleaning observation took place after the report was received at Farm E. During this observation the hot tap was closed before a large drop in water temperature occurred, however the initial water temperature was lower than on previous observations. No water was discharged from the plant prior to circulation. The water temperature was a little higher at the start of circulation, but circulation was over long and the final temperature was as low as on previous occasions.

Visual inspection of the plant indicated that all surfaces are clean. Replacement policy is good, with all milk liners replaced on a six-monthly basis. However during the third cleaning observation clots of milk residue were removed from the plant during the pre-rinse. The Total Bacterial Count of the milk at Farm E is consistently within Band B.

5.7 Farm F

Plant Cleaning Routine	Circulation cleaning, morning only
Udder Washing Routine	All udders washed

Table 5.7.1

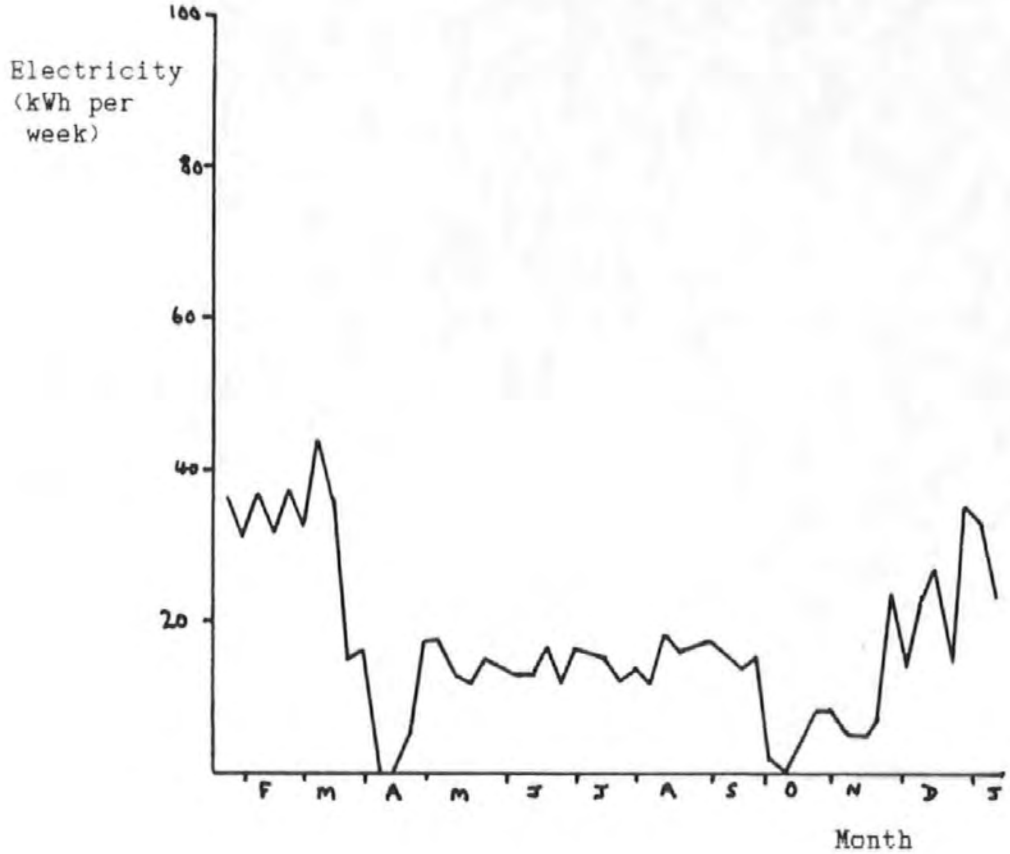
Summary of Water and Electricity Use

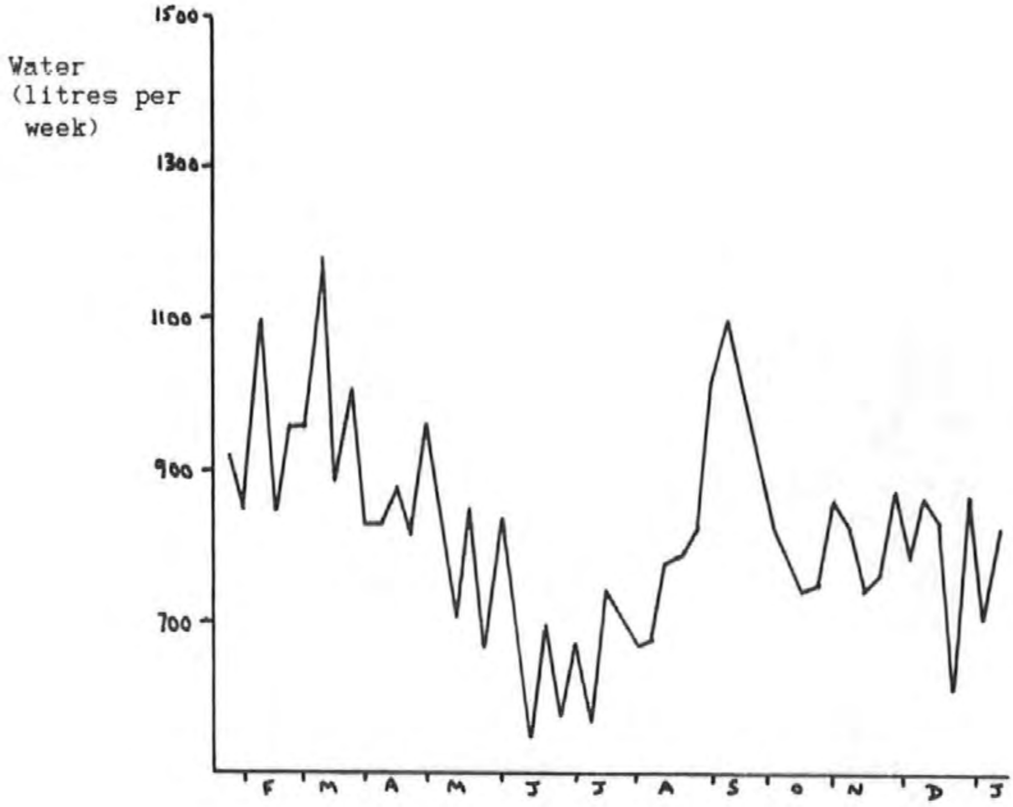
Water Use		
Plant cleaning water	3605.6	litres / month
	9.9	litres / unit / wash
Udder washing water	5266.3	litres / month
	0.9	litres / cow / milking
Electricity Use		
Total dairy and parlour use	1940.8	kWh / month
Plant cleaning water heater	84.3	kWh / month
	0.2	kWh / unit / wash
as percentage of total	4.4	%
Udder washing water heater	248.2	kWh / month
	0.044	kWh / cow / milking
as percentage of total	12.7	%

The plant cleaning water at Farm F is heated in a Heat Recovery Unit which is connected to the refrigeration system of the bulk milk vat. The water is also heated by a 3kW electric element which is controlled by a timeswitch. In addition to plant cleaning use water is taken from the heater for mixing calf feed, in the autumn and early spring. In order to allow calculation of the volume of water used for calf feeds the number of calves being fed was recorded.

Figure 5.7.2 shows weekly use of electricity and water for plant cleaning. There are three phases of electricity use; up to week 14, between weeks 17 and 40 and from week 49 onward. Water use for plant cleaning demonstrates no such pattern, but varies from 1190 litres to 550 litres per week. This indicates that variation in electricity use is not dependant on water use, which is confirmed by the low correlation coefficient, of 0.317, between water use and electricity use for heating that water. Examination of plant cleaning routine

Figure 5.7.2.
Weekly Electricity and Water Use for Plant Cleaning, Farm F





has shown that the use of electricity is governed by the length of time that the heater is switched on. Up to week 14 the timeswitch was set to switch on for three hours per day, during weeks 15 and 16 the timeswitch was switched off and no electricity was used, and from week 18 to 40 the timeswitch was set for 0.75 hours heating per day. From week 42 the timeswitch was inoperative, the wide fluctuations from this date are due to different lengths of heating period under manual control.

The electricity use for heating plant cleaning water at Farm F is extremely low, at 0.23 kWh / unit / wash (average for 9 farms using circulation cleaning = 1.8 kWh / unit / wash). This is the consequence of the short time period during which the electric element is switched on. The effect of this low electricity use on water temperature was investigated by the use of the Rustrak recorder. At the point of use the maximum water temperature was 72°C. This is considerably lower than the Ministry of Agriculture recommendations of 80 - 82°C for plant cleaning water at the point of use.

Following a request from the farmer, calculations using the model were carried out to evaluate the additional cost of heating the water to 82°C. This was calculated to be 6.28 kWh per day, costing £150 p.a.. This additional cost was considered, by the farmer, to be unjustified as milk quality tests are excellent, with the milk consistently meeting the buyer's standards for Band A. In addition the plant was seen to be clean when examined.

The plant cleaning routine was examined on two occasions. The temperature of cleaning water from the first of these is shown as Figure 5.7.3 which illustrates the low temperature of the plant cleaning water. The initial temperature of the water is low, as discussed previously. In addition there is a sharp drop of 30°C, in the water contained in the trough during circulation. This is due to failure to discharge the first returns of circulation water to the waste, this water, at 23°C, is returned straight to the trough, thus lowering the temperature of the water in the trough. There is also a drop of 5°C between the water at the tap and the water in the trough.

A report was sent to the farmer following these observations which recommended the following changes in cleaning routine:

1) Run the cold water from the HRU pipe to waste before filling the trough.
2) Add a hosepipe to the hot tap to reduce heat loss from the water.
3) Discharge the water from the plant until it is hot.

The report was followed by a discussion with the farmer, at which it was decided that the cold pre-rinse would be dispensed with, as the cold water will reduce the temperature of the plant and thus the temperature of the hot wash water. The volume of hot water would be increased to allow some water to be run to waste to warm the plant while maintaining sufficient water for circulation. This additional hot water will rinse the plant. A third observation of the plant cleaning routine was carried out, during which all the above recommendations were carried out. The temperature of the cleaning water is shown as Fig 5.7.4. This indicates that the circulation temperature is higher than previously, at 50 - 42°C. There is however still a drop in temperature between the tap and the trough. The farmer expressed the intention of continuing the new techniques, as they provided a higher circulation temperature, which is desirable, without increasing costs, which is unacceptable.

Figure 5.7.3.
Plant Cleaning Water Temperatures, Farm F

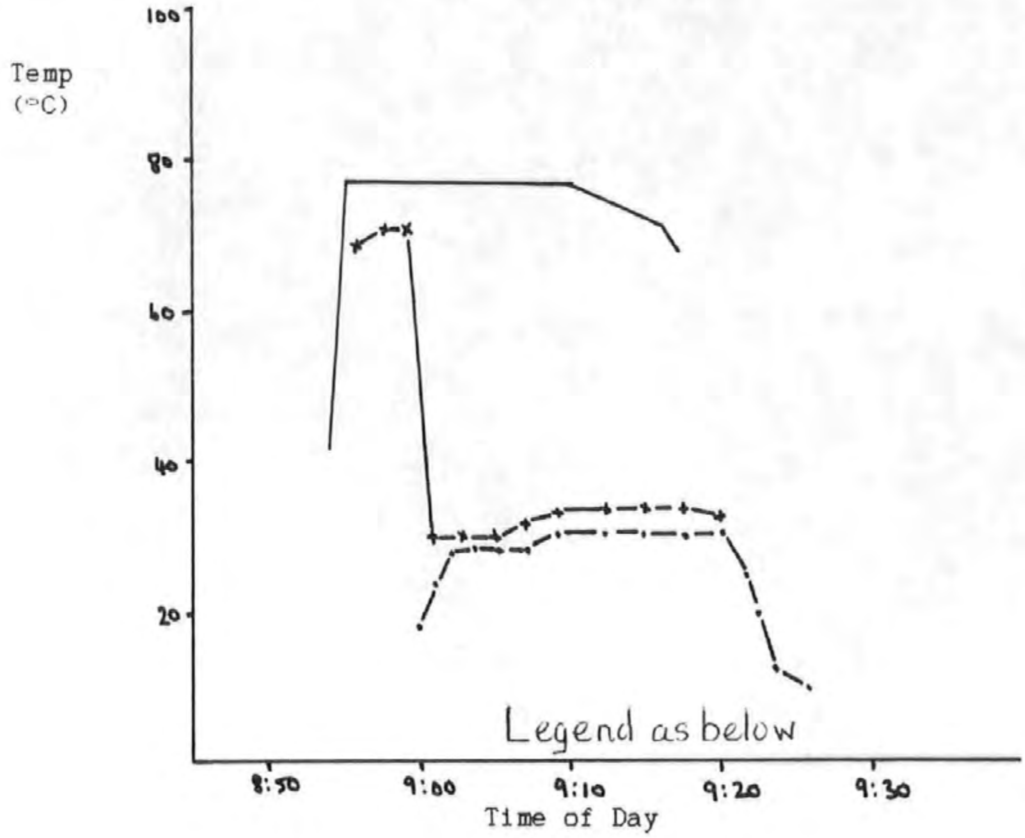
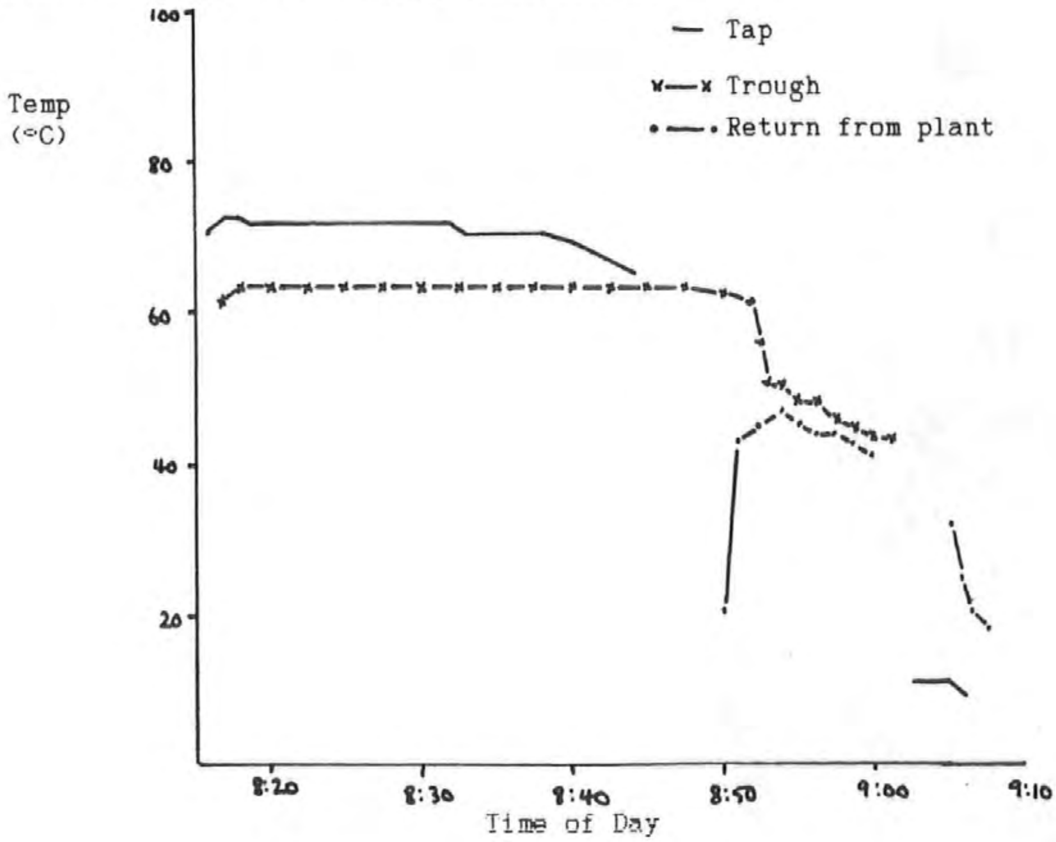


Figure 5.7.4.
Plant Cleaning Water Temperatures, Farm F



5.8 Farm G

Plant Cleaning Routine	A.B.W., twice per day
Udder Washing Routine	Dirty udders washed

At Farm G there is a single oil-fired boiler which is used to heat water for both udder washing and plant cleaning. The heater is controlled by both a timeswitch and manual control; the timeswitch operates first, but the heater does not cut in until the heater is also manually switched on. The water reaches the pre-set udder washing temperature of 42°C within 15 minutes, it is maintained at this temperature throughout milking. At the end of milking the water is heated to boiling point for plant cleaning.

The plant is cleaned using the ABW method with discharge direct into a covered drain. For this reason it was not possible to record final cleaning water temperatures. The temperature of the water in the heater prior to milking was 96°C. Visual examination of the milking plant revealed that the glass components were grimy.

Oil use for water heating was monitored by use of a Kent oil meter. Hot water use was measured by two meters, one on the inflow to the heater and one on the udder washing pipeline. Udder washing water is thus measured directly, plant cleaning water is measured by the difference between the two meters. In order to compare the energy use for hot water at Farm G with the other audited farms the volume of oil was converted to kWh equivalent. The figure thus calculated of 5.9 kWh per milking is considerably higher than the other farms (average for 3 farms using A.B.W. = 1.8 kWh/unit/wash).

Shortly after the water meter was fitted to the udder washing pipeline boiling water was allowed to pass through the meter. This resulted in melting of the plastic components of the meter, and it had to be removed. This failure was repeated with the replacement meter so it was no longer possible to meter udder washing water volume. The meter on the inflow of the heater restricted the filling of the heater to such an extent that the farmer requested that it was moved. Two further sites were tried, without success, and the farmer finally requested that the meter be removed. Finally the oil meter became clogged with dirt and blocked the flow of oil to the heater so that this also had to be removed. For these reasons there is not a full year of recordings from Farm G, it is therefore not included in the analyses.

5.9 Farm H

Plant Cleaning Routine	Circulation cleaning, twice per day
Udder Washing Routine	All washed in winter, some in summer.

Table 5.9.1

Summary of Water and Electricity Use

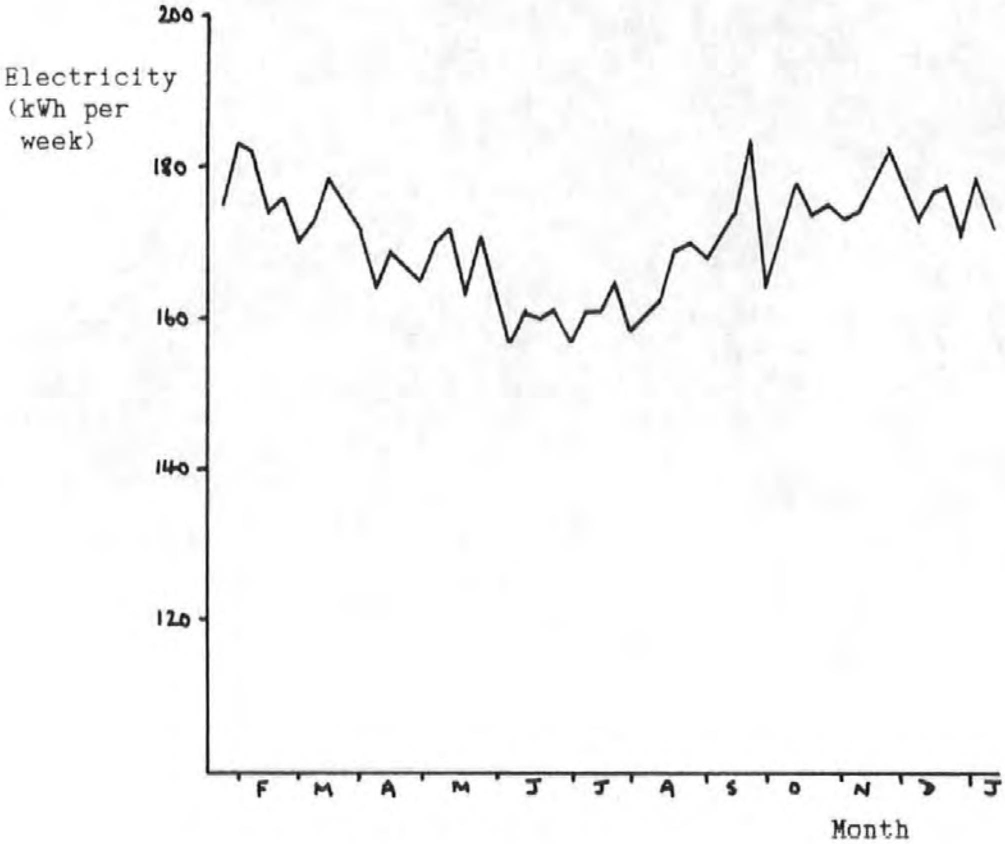
Water Use		
Plant cleaning water	5721.6	litres / month
	11.8	litres / unit / wash
Udder washing water	4234.5	litres / month
	0.7	litres / cow / milking
Electricity Use		
Total dairy and parlour use	2630.3	kWh / month
Plant cleaning water heater	732.9	kWh / month
	1.5	kWh / unit / wash
as percentage of total	28.1	%
Udder washing water heater	161.1	kWh / month
	0.027	kWh / cow / milking
as percentage of total	6.1	%

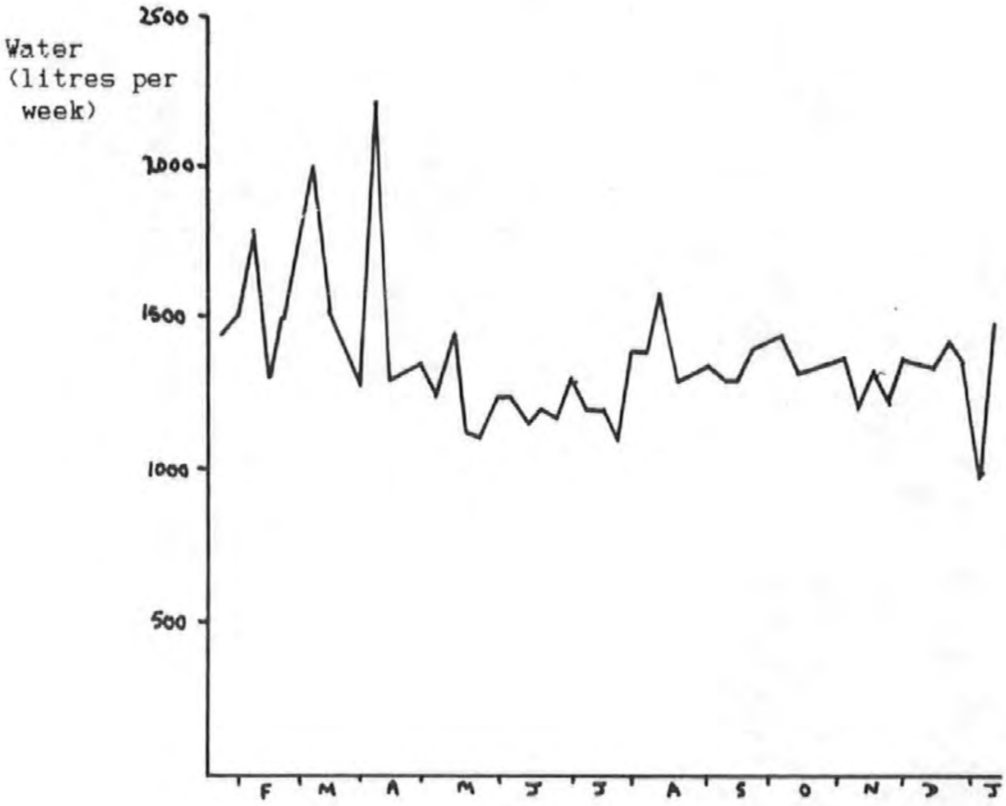
Plant cleaning water is heated in a 135 litre dairy water heater, which is controlled by a timeswitch. The cold fill to the heater is controlled by a stop tap, which is closed while the hot water is removed from the heater and opened only to refill the heater after cleaning. This ensures that the water used for plant cleaning is not cooled by cold inlet water

Electricity costs for plant cleaning are higher than average at Farm H, at 733 kWh per month (mean for 8 farms using circulation cleaning = 490 kWh per month). The higher cost is due to the practice of washing the plant with hot water twice a day, as the electricity use per unit per hot wash is lower than average at 1.5 kWh (mean=1.8 kWh for 9 farms using circulation cleaning). Electricity and water use for plant cleaning are shown as Figure 5.9.2. Electricity use shows a seasonal variation, with a peak in the winter months, however water

Figure 5.9.2

Weekly Electricity and Water Use for Plant Cleaning, Farm H





use shows no such variation, indicating that the increased electricity use is caused by lower inlet and ambient temperatures.

Plant cleaning routine has been observed on five occasions, which reveal a good cleaning routine that is carefully and consistently carried out. The temperature of cleaning water during one observed routine is shown as Fig 5.9.3, all other routines followed this pattern very closely. The relative consistency of cleaning water temperatures, when compared with other farms, is shown in Table 5.9.4, which uses data from cleaning observations and data from Rustrak records. The initial temperature is governed by the thermostat of the plant cleaning water heater as the timeswitch period is sufficiently long for the water to always reach the thermostat temperature. The hot water is initially discharged to waste until the water returning from the plant is judged by the herdswoman to be "very hot" to the hand. This method results in consistently good circulation temperatures. Circulation of the hot water continues while other elements of the dairy routine are carried out, which take from five to ten minutes to complete.

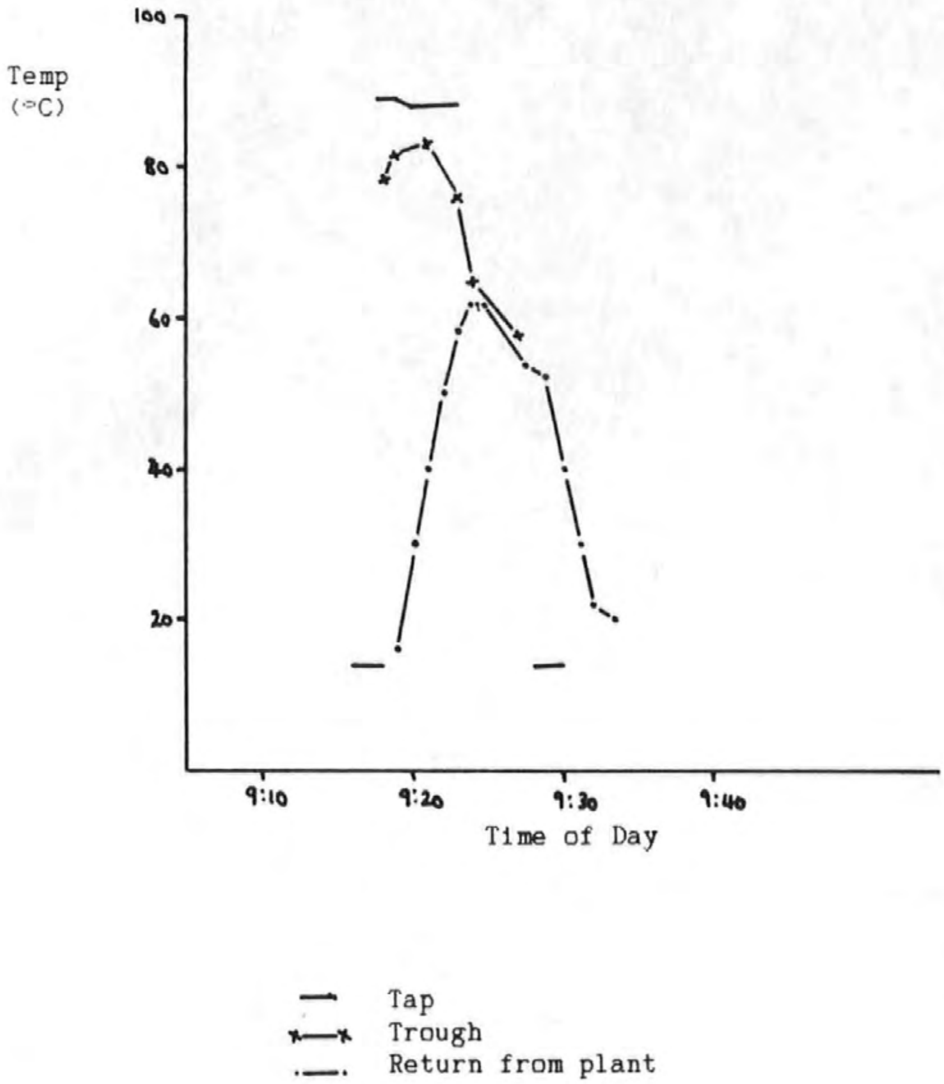
Table 5.9.4

Temperatures of Cleaning Routines

	Temperatures °C			
		Circulation		Circulation
Time of day	Hot tap	Start	Finish	Time (mins)
afternoon	84	60	45	7.5
morning	84	60	50	5.0
afternoon	84	60	30	5.0
morning	78	60	50	7.5
afternoon	87	64	46	10.0
morning	84	40	30	7.5
afternoon	88	62	49	5.0
morning	85	59	48	7.5
*afternoon	92	62	51	6.0
*morning	85	60	49	7.0

* Observed routines

Figure 5.9.3.
Plant Cleaning Water Temperatures, Farm H



The volume of water used for plant cleaning is not as consistent as the temperature of the water. This is because volume is not measured, instead the tap is left running while other tasks in the parlour are carried out. The volume used on the eight observed occasions was 87.9, 90.6, 96.0, 100.7, 126.6, 117.9, 82.3 and 77.4 litres (mean = 97.4 litres). Water is also taken from the plant cleaning water heater for washing of external surfaces of the milking plant. This requires 10 litres of hot water at each milking.

Visual assessment of the milking plant indicates that all surfaces are in good condition, and there are no deposits. The rubber parts are renewed on a regular basis. Milk hygiene reports are also good, with the milk consistently meeting Band A criteria.

A report was sent to the farmer which stated that plant cleaning routine was good, but that costs were higher than on other audited farms. In discussion following this report the farmer expressed satisfaction with his system, he was prepared to pay the higher cost to ensure good hygiene standards.

5.10 Farm J

Plant Cleaning Routine — Circulation cleaning, once per day

Udder Washing Routine — All udders washed

Table 5.10.1

Summary of Water and Electricity Use

Water Use		
Plant cleaning water	9164.3	litres / month
	37.6	litres / unit / wash
Udder washing water	2489.7	litres / month
	0.4	litres / cow / milking
Electricity Use		
Total dairy and parlour use	2422.6	kWh / month
Plant cleaning water heater	764.9	kWh / month
	3.4	kWh / unit / wash
as percentage of total	32.1	%
Udder washing water heater	167.6	kWh / month
	0.028	kWh / cow / milking
as percentage of total	7.0	%

The plant cleaning water heater at Farm J is a "domestic" type with a capacity of 135 litres and a rating of 6kW. The heater has no timeswitch and is left switched on.

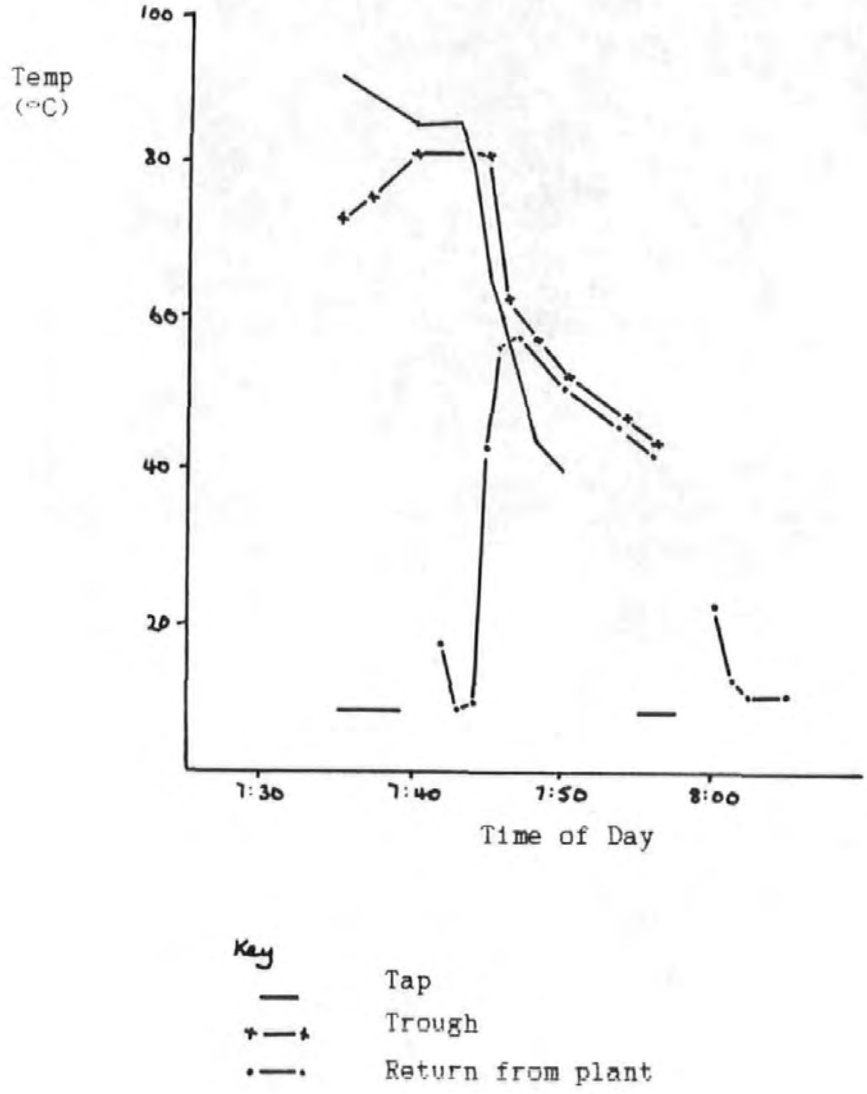
Electricity consumption for heating the plant cleaning water is very high; at 765 kWh/month, which represents 32% of total electricity use in the dairy and parlour. This is due to two factors, firstly the absence of a timeswitch on the heater, and secondly the very high hot water consumption. Hot water use from the heater is equivalent to 38 litres per milking unit per wash, which is much higher than the maximum recommended volume (15 litres). However cleaning routine observations indicate that of the daily hot water consumption of 300 litres only 120 - 150 litres (mean 135 litres) of hot water is used for each plant cleaning routine, so that an average of 165 litres of hot water are used each day for purposes other than plant cleaning. This water is used for hand washing and in a nearby workshop. Results from a Rustrak recorder indicate that hot water is taken from the heater for purposes other than plant cleaning from nine to fifteen times each day.

Circulation cleaning routines have been observed on five occasions, a time-temperature graph of a representative routine is shown as Figure 5.10.2. This shows that the initial temperature of water from the tap is high, at 92 - 87°C, but this drops suddenly after 8 minutes to 65°C and is as low as 40°C when the tap is turned off after 15 minutes. Little water is discharged to waste as the herdsman is of the opinion that it is important to keep a large reservoir of water in the trough during circulation. Circulation starts when the water returning from the plant is "hot" to the hand, about 45°C. These two factors; the low final temperature of water from the tap and low volume of water discharged, lead to a circulation temperature of 55 - 40°C, which is low considering the high initial temperature of the water from the tap. The length of time circulation continues is very variable, from 5 to 20 minutes, and depends on the herdsman's other chores. The volume of water used is relatively high, at 17 litres per milking unit.

A report on water heating and plant cleaning was sent to Farm J. This firstly discussed the high water heating costs, which are attributed to the very high volume of water used and the lack of a timeswitch on the heater. It was suggested that less hot water was used for cleaning, with the hot tap being turned off before the temperature drops, i.e. after about 5 - 8 minutes. The cost of providing water for hand washing was outlined. Discussions with the farm manager revealed that the practice of using hot water from the plant cleaning water heater would not be changed as this is considered to be the cheapest method of providing the water required outside the parlour. This water is required throughout the day so a timeswitch would not be fitted to the heater. The cleaning routine observed after the report had been sent to the farm showed that the hot tap was turned off when the temperature was over 70°C. The length of time that water was taken from the heater, and the volume used, was not reduced. The additional hot water was available as the herdsman prevented the use of water from the heater for other purposes before he had taken the water he required for plant cleaning.

Visual assessment of the plant indicates that the cleanliness of all internal surfaces is good, there is a policy of annual renewal of liners. Milk quality was within Band A of the Total Bacterial Count test.

Figure 5.10.2.
Plant Cleaning Water Temperatures, Farm J



5.11 Farm K

Plant Cleaning Routine A.B.W., twice daily

Udder Washing Routine Udders washed if dirty

Table 5.11

Summary of Water and Electricity Use

Water Use		
Plant cleaning water	7149.4*	litres / month
	11.7*	litres / unit / wash
Udder washing water	8383.9	litres / month
	1.0	litres / cow / milking
Electricity Use		
Total dairy and parlour use	3251.7	kWh / month
Plant cleaning water heater	432.3*	kWh / month
	0.7*	kWh / unit / wash
as percentage of total	13.3	%
Udder washing water heater	56.4	kWh / month
	0.0071	kWh / cow / milking
as percentage of total	2.1	%

*Data for 10 months (A.B.W. cleaning twice per day)

Many changes in plant cleaning routine have occured at Farm K during the period of the audit. For the first two weeks A.B.W. cleaning was carried out once per day, with cold circulation cleaning in the evening, this was then changed to A.B.W. twice each day. During month 14 the cleaning method was changed to hot circulation cleaning twice per day because attacks of mastitis throughout the herd were thought to be due to faulty cleaning of the automatic cluster removal (A.C.R.) mechanisms. The change in cleaning method improved the functioning of the A.C.R. mechanisms and a brown film which had been present on glassware was removed. During August 1981 the parlour was altered from 10/10 to 16/16 and the frequency of cleaning was reduced from twice to once per day.

The plant cleaning water is heated in an unpressurised dairy water heater of 160 litres capacity, after the parlour was extended a second, similar, heater of 115 litres was added. The water is pre-heated in a Heat Recovery Unit, and is transferred to the water heaters, through motorised valves which are controlled by timeswitch, immediately before the water is heated.

Due to the changes in cleaning routine water and electricity use for plant cleaning needs to be considered for three separate periods, as shown in Table 5.11.2

Table 5.11.2

Changes in Cleaning Routine

Parlour size	10/10	10/10	16/16
Cleaning method	ABW	Circulation cleaning	
Cleaning frequency	once	twice	once
Electricity			
Mean per month	432.3	706.1	625.7
Mean per unit per wash	1.4	1.2	1.3
Water			
Mean per month	7149.4	8979.4	
Mean per unit per wash	23.5	14.8	

There are no meter readings for hot water use in the final period as the meter fitted was considered by the farmer to cause problems with the filling of the heater, and he required that the meter be removed. However the herdsman always used all the water from the heaters for cleaning, by leaving the hot tap on until the water stopped flowing. Thus the volume of water used for cleaning can be found by calculating the volume of water which can be extracted from the heaters. This is a total of 228 litres from both heaters, equivalent to 14.26 litres for each unit.

Electricity readings from Farm K illustrate the higher energy cost of A.B.W. cleaning, as opposed to circulation cleaning, with A.B.W. cleaning requiring 1.42 kWh, and circulation cleaning 1.16 kWh per unit per wash.

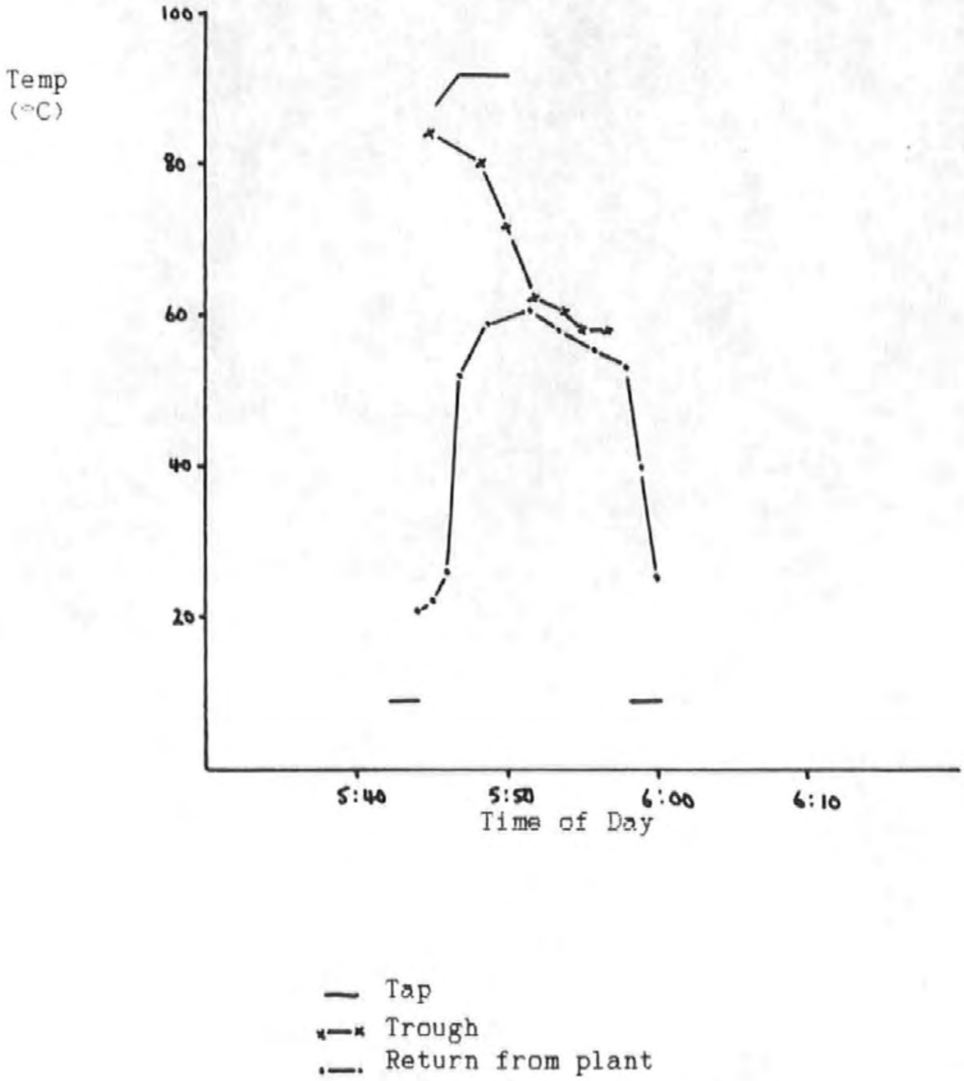
The electricity consumption for heating plant cleaning water for once daily circulation cleaning is low, at 1.16 kWh/unit/wash which compares favourably with the average of 1.8 kWh/unit/wash for the nine survey farms which use circulation cleaning. The low cost is attributed to good management of the Heat Recovery Units installed.

A.B.W. cleaning routines were adequate, with the initial water temperature at 95°C and water being discharged over 5 minutes. It was not possible to measure discharge temperature as the water is discharged directly into a covered drain.

An example of circulation cleaning temperatures is shown as Figure 5.11.3. The plant is first rinsed with 65 litres of warm water which is run to waste. The hot water is discharged to waste until it is "very hot" to touch, when circulation commences. Figure 5.11.3 shows that the cleaning solution temperatures are good, with circulation temperature over 55°C for 10 minutes and the temperature of water returning from the plant at 71 to 58°C.

A report was sent to Farm K, which reported that the cleaning routine was very good, with water temperatures meeting A.D.A.S. recommended standards. Visual assessment of the plant showed that all parts were in very good condition. Total Bacterial Count test results were within Band A.

Figure 5.11.3.
Plant Cleaning Water Temperatures, Farm K



5.12 Farm L

Plant Cleaning Routine	A.B.W. cleaning, twice daily
Udder Washing Routine	All udders washed

Table 5.12.1

Summary of Water and Electricity Use

Water Use		
Plant cleaning water	10656.1*	litres / month
	29.2*	litres / unit / wash
Udder washing water	1043.3*	litres / month
	0.1*	litres / cow / milking
Electricity Use		
Total dairy and parlour use	3416.7*	kWh / month
Plant cleaning water heater	1364.7*	kWh / month
	3.7*	kWh / unit / wash
as percentage of total	40.0*	%
Udder washing water heater	159.4*	kWh / month
	0.021*	kWh / cow / milking
as percentage of total	4.6*	%

* Data for 12 months (ceased trading at the end of May 1981.)

The water for plant cleaning is heated in an unpressurised dairy water heater, of 180 litres capacity and 6 kW rating, for A.B.W. cleaning twice per day. The cleaning routine followed is as recommended, with the water, at 95°C, being withdrawn from the heater into the pipeline and discharged directly into a covered drain. For this reason it is not possible to obtain discharge water temperatures. A vacuum operated valve prevents entry of cold water until the vacuum pump is switched off at the end of cleaning. No water can be removed from the heater for purposes other than plant cleaning.

The heater is controlled by a timeswitch which is set to heat the water for 3.5 hours prior to morning milking and 4.5 hours prior to evening milking. Electicity consumption for plant cleaning is high, at 3.7 kWh/unit/wash, due to the use of A.B.W. cleaning twice per day. Visual inspection of the plant indicates that all surfaces are cleaned satisfactorily. The Resazurin test was passed consistently, milk production ceased before routine Total Bacterial Count testing was started.

5.13 Farm M

Plant Cleaning Routine	Circulation cleaning, once per day
Udder Washing Routine	Dirty udders washed

Table 5.13.1

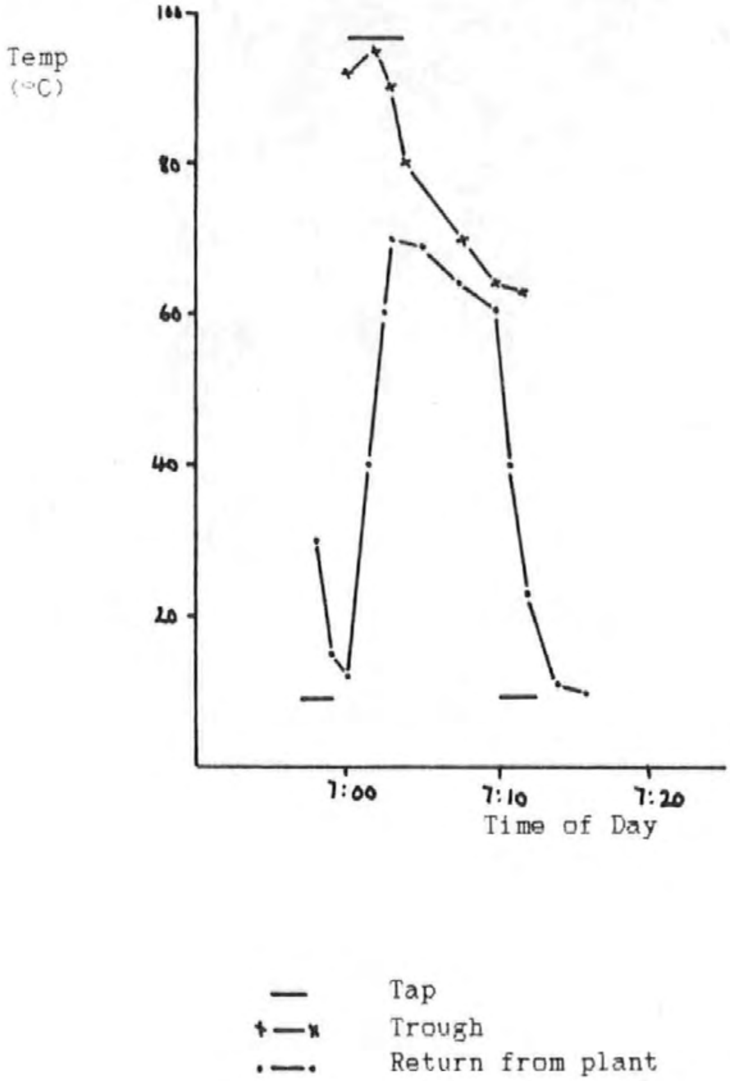
Summary of Water and Electricity Use

Water Use		
Plant cleaning water	4345.3	litres / month
	14.3	litres / unit / wash
Udder washing water	13495.2	litres / month
	1.7	litres / cow / milking
Electricity Use		
Total dairy and parlour use	3078.2	kWh / month
Plant cleaning water heater	714.9	kWh / month
	2.3	kWh / unit / wash
as percentage of total	25.0	%
Udder washing water heater	535.9	kWh / month
	0.079	kWh / cow / milking
as percentage of total	17.5	%

The plant cleaning water heater at Farm M is an unpressurised dairy type, with capacity of 160 litres and rating of 3 kW. The thermostat is set at 104°C as the farmer is of the opinion that this is necessary with such a long parlour (20 standings). However the thermostat actually operates at 95°C A vacuum valve prevents inlet of cold water until after the vacuum pump is turned off after cleaning. The heater is fitted with a timeswitch which is set to allow heating for 5½ hours in the morning and 1½ hours at night. However frequent examinations of the heater suggested that the timeswitch did not work.

A good circulation technique is used, with circulation temperatures between 60 and 70°C, as shown in Figure 5.13.2. This is achieved by a high initial water temperature, of 95°C, which is expensive to produce; Farm M has the second highest plant cleaning costs of the nine farms using circulation cleaning. Data from a Rustrak recorder shows that the observed routines are typical of those followed on all occasions.

Figure 5.13.2.
Plant Cleaning Water Temperatures, Farm M



A report was sent to the farmer detailing the high cost of heating plant cleaning water, and describing the good circulation cleaning technique. It was suggested that the cost of heating plant cleaning water would be reduced by repair of the timeswitch. This was carried out, however data from a Rustrak recorder revealed that the timeswitch soon broke again, and was not repaired.

Visual assessment of the plant indicates that while the cleaning standard of the rubber and metal parts is fair that of the glass parts is poor. Results from the Total Bacterial Count tests placed the milk quality in Band A.

6.0 GENERAL DISCUSSION

6.1 Udder Washing

Water and electricity consumption was expected to be very variable both between farms and from week to week on each farm, due to different demands for udder washing water. Some farms will have an overall higher demand due to the conditions that the cows are kept under, for example; whether their winter housing is cubicles or loose-housing. On any given farm the demand for water will vary from week to week, for example the cows will be muddier during wet weather. This expected variability has been found, but other factors have also been revealed.

The variation in udder washing water use from week to week on two farms, F and H is shown as Figures 6.1.1. Both of these farms show a seasonal variation, with a reduction in the demand for udder washing water in the summer, and consequent lower electricity consumption. There is however much variation from week to week within the overall trend, caused by variation in the sediment levels on the udders.

Little action can be taken to affect the changing demand for udder washing water, as it depends on factors outside of the control of the herdsman. However certain stategies have been observed on the survey farms which affect the demand for udder washing water. Table 6.1.2 shows water consumption for udder washing water on twelve survey farms over two years, in order of consumption per cow. The farms can be split into three groups, with low, average and high consumption. The three farms with low consumption, L, X and C have reduced their consumption by washing fewer cows; their udder washing policy is to wash only those udders which are dirty. At Farm C no water was used for some weeks in the summer. Three farms have higher consumption than average, A, M and E; all of these farms suffer very wet conditions in the winter.

Figure 6.1.1.
Weekly Udder Washing Water Use, Farms F and H

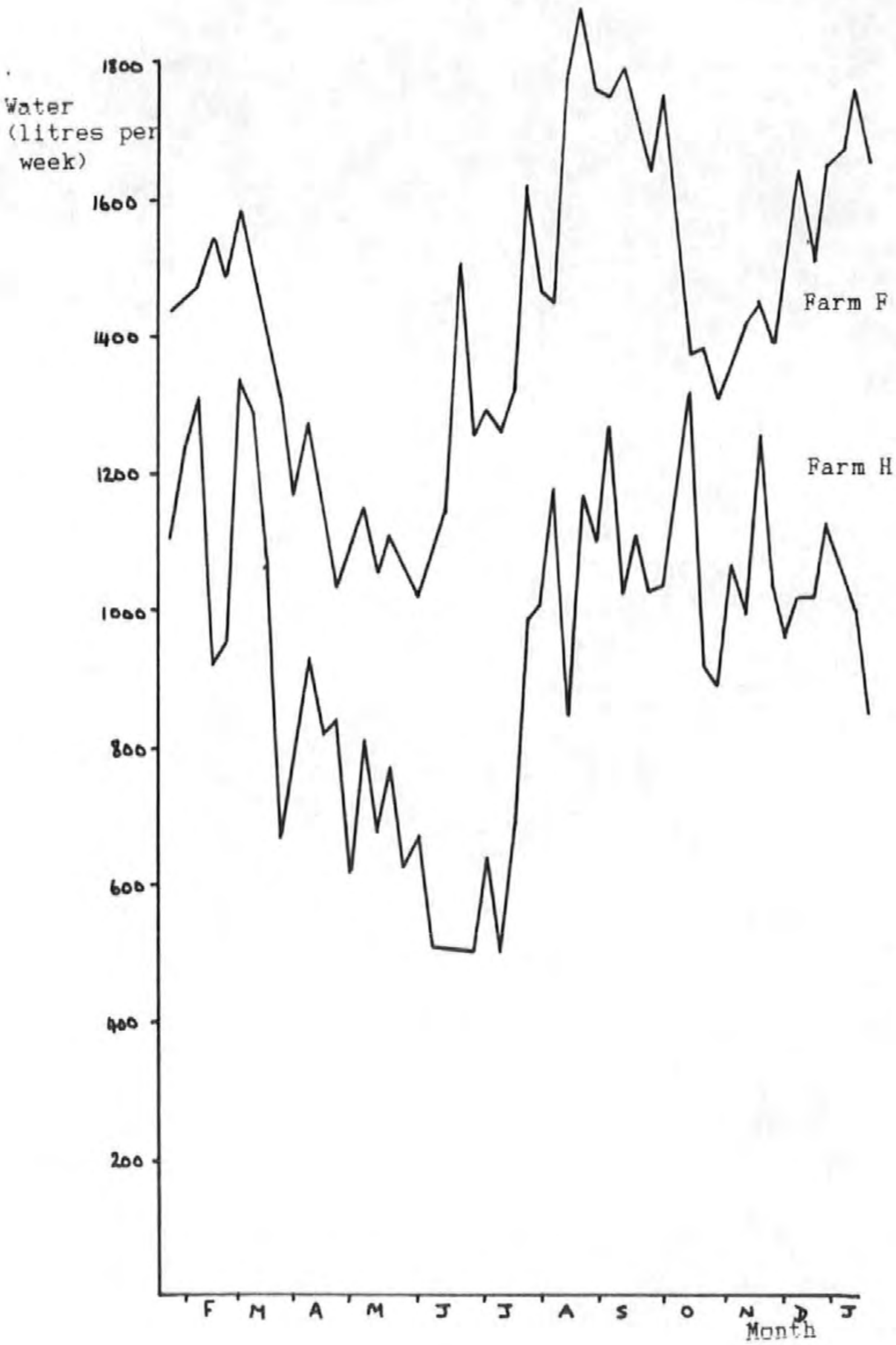


Table 6.1.2

Water Consumption for Udder Washing

Farm	litres/month	litres/cow/milking
L	1043	0.1
X	373	0.1
C	589	0.2
J	2490	0.4
D	2303	0.6
H	4235	0.7
F	5266	0.9
K	8384	1.0
B	2969	1.1
A	5076	1.5
M	13495	1.7
E	7315	1.9
mean		0.85

Table 6.1.3

Electricity Consumption for Udder Washing

Farm	kWh/month	Wh/cow/ milking	percentage of total electricity
K	56	7.1	2.1
C	42	13.1	2.6
L	159	21.2	4.6
D	85	22.8	5.4
X	108	23.1	4.9
H	161	26.6	6.1
J	168	28.2	7.0
E	198	29.8	10.4
B	86	31.4	8.9
A	111	33.3	10.1
F	248	44.0	12.7
M	536	79.4	17.5
mean		30.0	

Of the farms, C and K have low udder washing costs, due to their policy of switching off the udder washing water heater during the summer months. At Farm C no udder washing is carried out for some weeks during the summer. At Farm K the udders are still washed, but with cold water and the electricity demand is further reduced by the udder washing water heater being fed by water from the Heat Recovery Unit. One farm, M has a very high electricity consumption. This is partly due to the high water use, but also due to the poor condition of the heater. While most farms have a small capacity (nine litres) heater, the heater at Farm M has a capacity of 180 litres. In addition the heater is very badly lagged and is left switched on, leading to high heat losses.

Some of the farmers (C, H, B and A) attempted to reduce electricity consumption by switching off the heater between milkings. This, however, seems to have little effect as not all these farms have low electricity consumption, for udder washing. Both Farms A and B have higher than average consumption.

6.2 Plant Cleaning

Prior to collection of the audit data it was expected that water consumption for plant cleaning would be constant for any given parlour, and would vary between farms due to parlour size. This assumption is made in most published work on milking plant cleaning. It was expected that the amount of water consumed would be a direct consequence of plant size, cleaning method and frequency of hot washes so that the water volume would not change from week to week and could be easily calculated for a given parlour if these three variables were known.

It was expected that all farms would follow the general formula;

weekly water consumption = milking units * constant[1] * number of hot washes[2]

[1] depends on cleaning method.

[2] i.e. the number of hot washes in a week, generally 7 or 14.

Given a constant water use, it was expected that electricity consumption for heating plant cleaning water would then vary only according to the ambient and inlet water temperatures. A seasonal fluctuation was expected with electricity consumption being greater in the winter due to;

i) lower inlet water temperature, requiring more electricity to heat the water to a standard temperature of use.
ii) lower ambient temperatures, leading to greater heat loss from the water heater and subsequent increased electricity use.

In conclusion, it has been assumed to date that given the parlour size and washing method both water and electricity consumption could be easily calculated. However, as described in the individual farm discussions, water use for plant cleaning on a given farm is not constant, but is influenced by many factors. There are differences between farms which are not due to size of parlour and cleaning method.

The factors which have been found to cause variation fall into two groups; equipment and management. The equipment factors are; number of milking units, size of water heater, provision and setting of thermostat and timeswitch for heater control, and the use of energy saving devices such as Heat Recovery Units. These factors will be examined in turn and their effect on water volume and electricity consumption will be described.

6.2.1 Equipment Factors

The size of a milking parlour is quoted as the number of milking units and the number of standings, e.g. a 5/10 parlour has 5 milking units and 10 standings. The size of milking parlour on a farm is determined by the number of cows in the herd and is generally the smallest which will allow the herd to be milked in a two hour period during the time of year that most milk is being produced. However the installation of the milking plant and its building is a very large capital item and so it is not changed unless the change is essential. For this reason the size of the parlour is taken to be fixed in this study, and not open to change for water or electricity saving reasons.

The volume of water used for plant cleaning will, in part, depend on the volume of hot water available from the water heater. The capacity of heater installed on a farm will depend on the range available from the manufacturers, which are provided in a discrete range of sizes. The heaters installed on the survey farms provide from 15 to 27 litres of hot water per milking unit, as shown in Table 6.2.1.1, although the maximum recommendation is 18 litres per milking unit.

Table 6.2.1.1

Heater Sizes on Survey Farms

Farm	Parlour Size	Heater Capacity	Litres water, per Milking unit
L	12/12	180	15
K	10/10	160	16
M	10/20	160	16
H	8/16	135	17
J	8/16	135	17
A	5/10	90	18
X	6/12	135	22
F	12/12	270	22
E	5/10	115	23
C	5/10	120	24
B	5/10	135	27
D	5/10	135	27

Heating each extra litre of water will cost 0.08 kwh per wash (assuming a 70°C temperature rise, from 15 to 85°C). This will lead to an increased electricity demand of, for example, 25 kWh per week for Farm X.

Most recommendations on water use for plant cleaning are given in terms of litres per milking unit, as the number of milking units provides an easily applied estimate of the area to be cleaned. It was therefore expected that all the farms would have a similar water consumption if litres of hot water per milking unit was examined. Table 6.2.1.2 shows hot water consumption, as measured by the water meters, in terms of litres of water per milking unit, in order of increasing consumption.

Table 6.2.1.2

Water Use per Milking Unit - Water Meter Data

Farm	number of hot washes per week	litres/unit
F	7	9.9
B	7*	10.5
A	7	10.8
K	7	11.7
H	14	11.8
M	7	14.3
L	14	14.6
D	14	14.7
X	14	14.9
E	7	26.7
C	14	30.6
J	7	37.6
mean		18.3

*As reported by the farmer.

This table shows two items of interest, firstly there is an unexpectedly wide spread of values of hot water use per milking unit. Secondly Farms E, C, L, and J are, apparently, using more hot water for plant cleaning than the maximum heater capacity. Cleaning routines on all farms were observed, with hot water meters being read before and after the cleaning water had been taken from the heater, to establish the volume of water actually used for plant cleaning. This volume is shown in Table 6.2.1.3. as litres used. The final column shows the difference between metered use (from water meter data) and observed use (recorded during cleaning observations).

Table 6.2.1.3

Observed Water Use For Plant Cleaning

Farm	litres used	litres/unit	metered use less observed use
B	90	18.0	-7.5
D	82	16.4	-1.7
M	144	14.4	-0.1
L	176	14.7	-0.1
H	92	11.5	0.3
F	95	7.9	2.0
K	95	9.5	2.2
A	41	8.2	2.6
X	63	10.5	4.4
E	101	20.2	6.5
C	120	24.0	6.6
J	135	16.9	20.7

The difference between the metered water use and the observed water use is not significant on three farms - H, L and M. Other farms, ie. A, D, F and K, show a small difference between the metered hot water use and the observed hot water use. Of these Farm D has a negative difference, indicating that generally less water is used for plant cleaning than was used when the cleaning was observed. This is explained by the herdsman's statement that he does not always carry out an evening wash, omitting it if he is late finishing milking. Farms F and K use some water from the plant cleaning water heater for feeding calves, so the metered use is higher than the actual use of hot water for plant cleaning.

The remaining farms show a larger difference betweeen metered and observed water uses. Farm B is unusual in that much less water is used in a month than would be indicated by the volume used for a single wash. The farmer was questioned about this and stated that he did not "wash every day, it depended on other work". The Rustrak temperature recorder was used to examine how frequently water was removed from the heater and this was generally on alternate days. At Farm C, which uses A.B.W., cold water was allowed to enter the heater while the hot water is being extracted, so the metered values include some cold water. As discussed in section 5.3 this practice was stopped following advice to the farmer. At Farms E, J and X, water is taken from the plant cleaning water heater for purposes outside the dairy. This is a particularly high use at Farm J, where the volume of hot water for 'other uses' is actually higher than the volume for plant cleaning.

Following the volume of hot water used the major factor affecting electricity consumption is the temperature to which the water is heated. The major control on the temperature is the setting of the thermostat. All the survey farms have thermostats fitted to the plant cleaning water heaters, although the accuracy of some of these is suspect. At farm H, for example, the water was observed to reach boiling point before the thermostat operated, although it was set to 93°C

The effect of the thermostat on electricity consumption in the water heater is difficult to isolate from other factors, for example the heater may be so used that the thermostat cut out temperature is never reached. This is the case at Farm A, where the heater is turned on at the start of milking and then switched off after milking and used immediately for plant washing. When it is used the water is at 80 - 85°C and the thermostat, which is set at 88°C, has not operated. This has been confirmed by observation of the heater during milking. Also, if the water was regularly heated to the same temperature, as it would if the thermostat controlled the operation of the heater, there would be a direct relationship between hot water use and electricity consumption by the heater. This is not the case, regression analysis indicates that only 35.9% of the variation in electricity is explained by variation in water consumption, which indicates a poor relationship.

Electricity consumption is also affected by the use of a timeswitch. Five of the survey farms (A, B, D, E, J) do not have timeswitches on the plant cleaning water heater. Of these, one farmer (Farm A) exerts a manual time control on the water heater action, by switching on the heater at the start of milking and off at the end. The other heaters are permanently switched on under the control of the thermostat.

The effect of a timeswitch on the electricity consumption of the heater was examined by calculating the volume of water heated per kWh of electricity used by the heater, as shown in Table 6.2.1.4. It was expected that those heaters with timeswitches would heat more water per kilowatt hour, as there should be lower heat losses, caused by the shorter time that the water is hot.

Table 6.2.1.4

Volume of Water Heated per kWh

Farm	litres/kWh	timeswitch fitted?
M	6.08	timeswitch
B	7.74	no timeswitch
X	7.75	timeswitch
H	7.80	timeswitch
L	7.80	timeswitch
D	8.26	no timeswitch
C	9.23	timeswitch
A	9.59	manual time control
J	11.98	no timeswitch
K	13.52	timeswitch
E	19.68	no timeswitch
F	42.79	timeswitch

This table indicates that the presence of a timeswitch has little effect on the volume of water heated per kilowatt-hour and that other factors must be involved. A regression analysis of electricity used for heating plant cleaning water in terms of the volume of water used and ambient temperature was carried out (see Table 6.2.1.5). In this analysis R^2 is a measure of the percentage of the variation in electricity consumption which is explained by variation in water use and ambient temperature

Table 6.2.1.5

Regression Analysis of Plant Cleaning Electricity in Terms of Water Use and Ambient Temperature

Farm	R^2	timeswitch fitted?
B	91.3	no timeswitch
L	89.5	timeswitch
J	80.5	no timeswitch
D	73.1	no timeswitch
E	70.4	no timeswitch
C	61.0	timeswitch
H	56.6	timeswitch
A	46.6	manual time control
M	27.4	timeswitch
X	18.5	timeswitch
F	10.6	timeswitch
K	8.3	timeswitch

In general those heaters without timeswitches have a higher value of R^2 than do those heaters with timeswitches. This indicates that a high proportion of the variation in electricity consumption by the plant cleaning water heaters without timeswitches can be explained by variation in the volume of water used and the ambient temperature. The heaters which are fitted with timeswitches do not have this direct relationship between water use and electricty consumption. This indicates that the water is not always used at the same temperature. The water may be used at a lower temperature for plant washing if the timeswitch is set for too short a heating period and the water does not reach the thermostat cut-out temperature. Alternatively water may be taken from the heater for purposes other than plant cleaning. If this occurs after the plant has been cleaned the water will be at a considerably lower temperature as it will not have been heated.

Two farms (F and K) stand out as having an extremely weak relationship between water and electricity use. These farms are fitted with Heat Recovery Units which provide warm water to the plant cleaning water heater. The temperature of this water will then become a major factor in electricity consumption.

There are three farms, E, F and K, which have Heat Recovery Units fitted. At Farm F the HRU is fitted with an electric element so water is heated in one vessel. At Farms E and K the water is pre-heated in the HRU and transferred to a separate water heater for heating to the required temperature. Of the three, Farm F has the lowest water heating bill, averaging 0.2 kWh/unit/wash (average of 7 other farms using circulation cleaning is 1.8 kWh/unit/wash). As discussed previously (Section 5.7), at times no electricity is used for heating plant cleaning water and the temperature of the cleaning water is lower than recommended, but the plant hygiene is satisfactory and clean milk is produced. Farm K also has a lower electricity consumption, at 0.7 kWh/unit/wash, than other farms using A.B.W. cleaning (average of two other farms using A.B.W. is 3.4kWh/unit/wash). At Farm E the Heat Recovery Unit has less effect as the electricty consumption, at 1.3 kWh/unit/wash is closer to the average of 1.8 kWh. The inefficient use of this H.R.U. has been discussed in section 5.6, which describes how much of the heat in the water from the H.R.U. is lost when the water is transferred to the plant cleaning water heater.

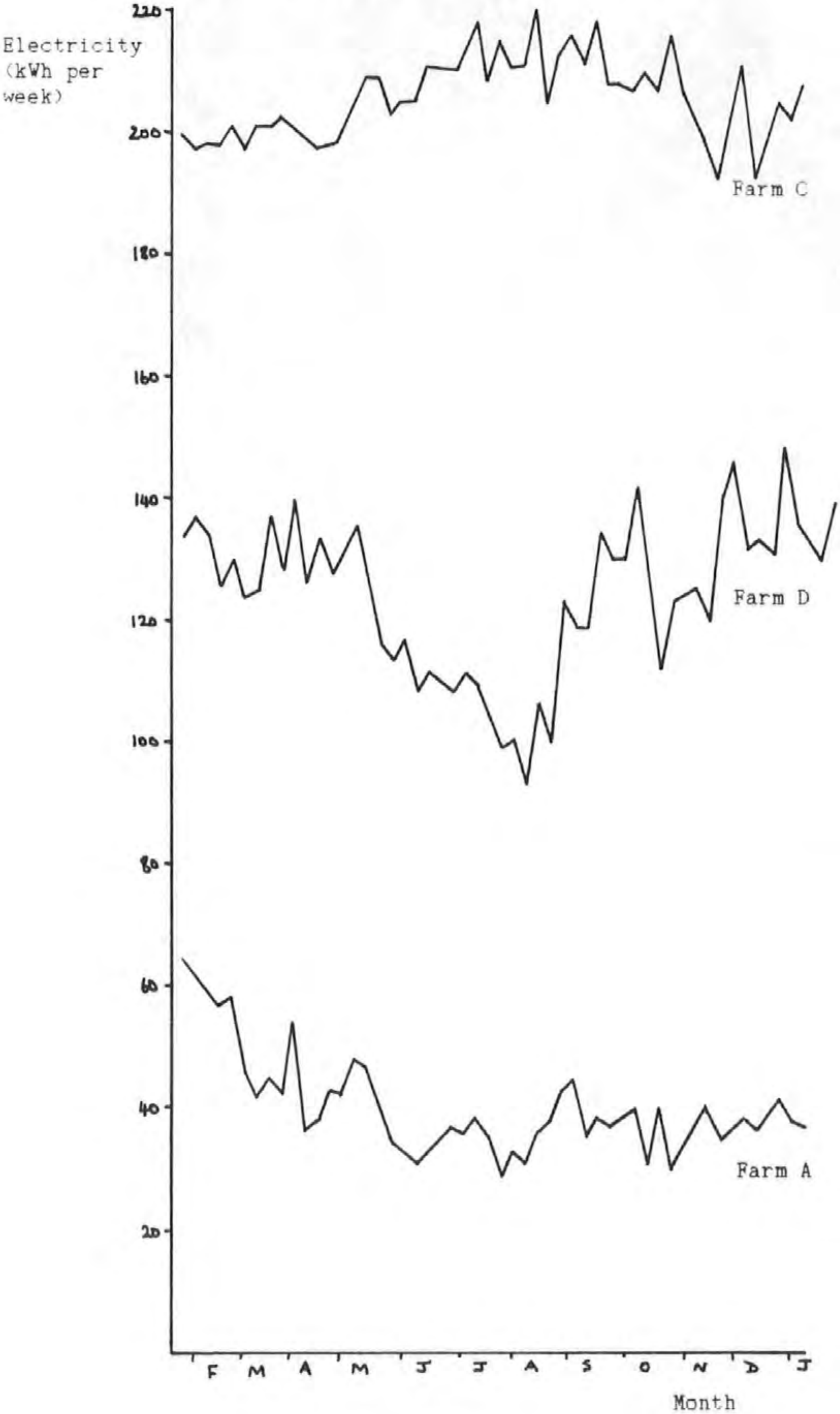
6.2.2 Management Factors

Given a set of equipment, management decisions may affect its use in both the long and short term. Long term decisions are the responsiblity of the owner or farm manager and involve selection of cleaning method and frequency of hot washes, setting of timeswitches and thermostats and evaluation of the effectiveness of the choosen cleaning routine. Short term decisions are the responsibility of the herdsman and his relief and involve the volume of water used for each wash, the time of cleaning and the care of using hot water - that is ensuring that heat loss is kept to a minimum. The efficiency with which long term decisions taken by owner or manager influence the day to day actions of the herdsman depends on the quality of communication between them. On some farms the owners generally milk their own cows (B, C, F), on others the 'chain of command' is long, especially with X, D and J which are owned by institutions. Between these two extremes lie family farms with a single herdsman (A, E, H).

The most important management decisions regarding energy use for plant cleaning are the choice of cleaning method and frequency of hot washes. Figure 6.2.2.1 shows electricity consumption for heating plant cleaning water on three farms, A, C and D, which all have 5/10 parlours. In this group Farm C uses A.B.W. cleaning and Farms A and D use circulation cleaning. The increased energy consumption necessary for A.B.W. cleaning is shown by the relative positions of Farms D and C. The electricity saving possible by reducing hot washing of the plant to once daily is illustrated by the lower consumption of Farm A compared with Farm D.

Variation in the daily cleaning routine may also affect energy consumption. The A.B.W. method was designed to reduce operator error, is therefore semi-automatic and should not be subject to daily variation. This system should ensure that the correct volume of water is used at each wash so that electricity consumption should be relatively constant. Figure 6.2.2.1 shows that electricity use for Farm C, which uses A.B.W., shows less fluctuations than Farm D.

Figure 6.2.2.1.
Weekly Plant Cleaning Electricity Use, Farms A, C and D



Circulation cleaning, in contrast to A.B.W. cleaning, is not generally an automated process; the volume of water used, the care with which it is used and the length of the circulation period are all determined by the operator. The last two factors will affect the management decisions regarding the setting of the thermostat. If excessive heat is lost during cleaning then a higher initial temperature is required to give the chosen circulation temperature, this effect has already been discussed for Farm M. If the circulation period is excessively long it will allow greater reduction in temperature increasing the risk of redeposition of soil, again necessitating a higher initial temperature. The volume of water drawn from the water for any single wash will affect the temperature of the resultant mix of water after the heater has been refilled with cold water. This will affect the energy required to heat the water to the required temperature for the next wash.

If the operator is consistent from day to day the variation in energy requirement will be small, but where two herdsmen clean the parlour the variation can be significant. Figure 5.5.3 illustrates this on Farm X, where the relief herdsman milks on alternate weekends, for a total of four milkings of the fourteen in a week. On the other weeks the regular herdsman does all the milkings. The mean consumption of plant cleaning water during the weeks when only the regular herdsman milks is 1495 litres/week, 242 litres higher than the consumption when both herdsmen are involved. These figures indicate that while the regular herdsman is using an average of 107 litres for each hot wash, the relief herdsman is only using 46 litres. There is a similar difference in electricity consumption, when the regular herdsman carries out all the milkings 32.3 kWh more electricity is used, at 232.7 kWh/week. (Both these differences are statistically significant, $p > 0.999$).

6.2.3 Conclusions

It has been found, in the survey of commercial dairy farms that there is a wide variation in the plant cleaning techniques practiced. The volume and temperature of hot water used and the frequency of the hot washes is more variable in practice than is reported in the literature.

It has also been found that the factors affecting the cost of heating the water are complex, and that the cost cannot be evaluated by applying a simple formula, as has been the practice of advisory bodies to date. In order to provide advice to farmers as to the effect of their management decisions on electricity consumption and cost the computer model of plant cleaning water heaters described below, has been developed. The purpose of this model is to allow farmers to evaluate the cost of their plant cleaning practices, and to assist them to find the least-cost solution within the bounds of their own requirements. It is not the purpose of the model to advise farmers on the method, orthodox or otherwise, which they should use, but to allow them an accurate assessment of the cost of the various methods. It is then the responsibility of the farmer to weigh cost, efficiency and ease of use of the available methods, and to reach his own conclusions as to which is the best method for his system.

7.0 THE MODEL OF PLANT CLEANING WATER HEATING

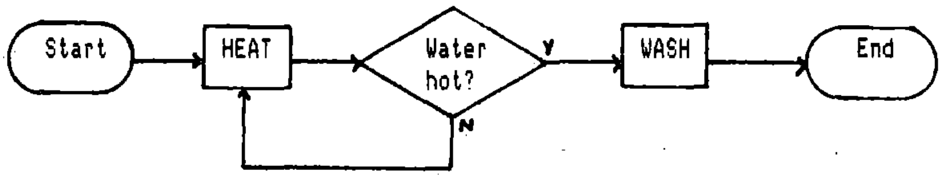
7.1 Development of the Model

7.1.1 Model of a Single Heating Process

The first model written predicted the electricity used by a plant cleaning water heater for a single plant cleaning process. The model calculates the water temperature using the initial water temperature, the power input from the electric heater and the heat loss through the heater surface. It is assumed that all the water in the heater is initially at the inlet temperature, it heats evenly with no stratification until the chosen maximum temperature is reached, when all the heated water is used immediately.

Figure 7.1.1.1

Flow Diagram of Plant Cleaning Water Heater, Single Heating Cycle.



This model consists of two routines, shown above as HEAT and WASH. The HEAT routine simulates the heating of the water within the plant cleaning water heater, by calculating the temperature at the end of each timestep using Equation 1.

Equation 1

Calculation of Temperature After a Single Timestep

$$T_2 = \frac{P * TS - (((UA * T_1 * TS) / 2) - (UA * T_3 * TS) - (M * Cp * T_1))}{(M * Cp) + ((UA*TS) / 2)}$$

Where P = Power of the heater (kW)

TS = Timestep of the model (s)

T_1 = Temperature at the start of the timestep (°C)

T_2 = Temperature at the end of the timestep (°C)

T_3 = Ambient temperature (°C)

UA = Heat loss rate from the body (kW/°C)

M = Mass of water in heater (kg)

Cp = Specific heat capacity of water (kJ/kg/°C)

In this equation the heat loss from the body of the heater and water is expressed as a single term, UA, which is calculated as follows:

Equation 2

Calculation of UA

$$UA = U * A$$

Where U = Rate of heat loss per unit area per degree Centigrade difference between water and ambient temperatures ($W/m^2\ °C$)

A = Surface area of the heater (m^2)

The WASH routine simulates the extraction of water from the heater for washing purposes and calculates the electricity used. This is accomplished by calculating the elapsed time from the length of the timestep and the number of timesteps which have occured. The elapsed time is then multiplied by the rating of the heater to obtain electricity consumption.

7.1.2 Calculation of Water Temperature After Water Use

It is essential that the water in the heater is used at the correct temperature, so purpose built plant cleaning water heaters are specifically designed to prevent cold water entering the heater until after the hot water is removed. However the element must be protected from overheating should the heater still be switched on when the hot water is removed. This is accomplished by preventing removal of all the water, sufficient being retained to cover the element. After the hot water is removed cold water enters the heater, mixing with the hot, until the heater is full - the volume of cold water entering the heater will be equal to the volume of hot removed. The temperature of the water at the start of the heating period will therefore initially depend on the temperature of the water at the end of the previous heating period following mixing of the remaining hot water with cold water. The temperature of this water is calculated, assuming complete mixing, using the following equation:

Equation 3

Temperature of mixed water

$$T_2 = \frac{(Mh * T_3) + (Mc * T_4)}{(Mh + Mc)}$$

Where
T_2 = Final water temperature (°C)
T_3 = Temperature of residual hot water (°C)
T_4 = Temperature of inlet cold water (°C)
Mh = Mass of residual hot water (kg)
Mc = Mass of inlet cold water (kg)

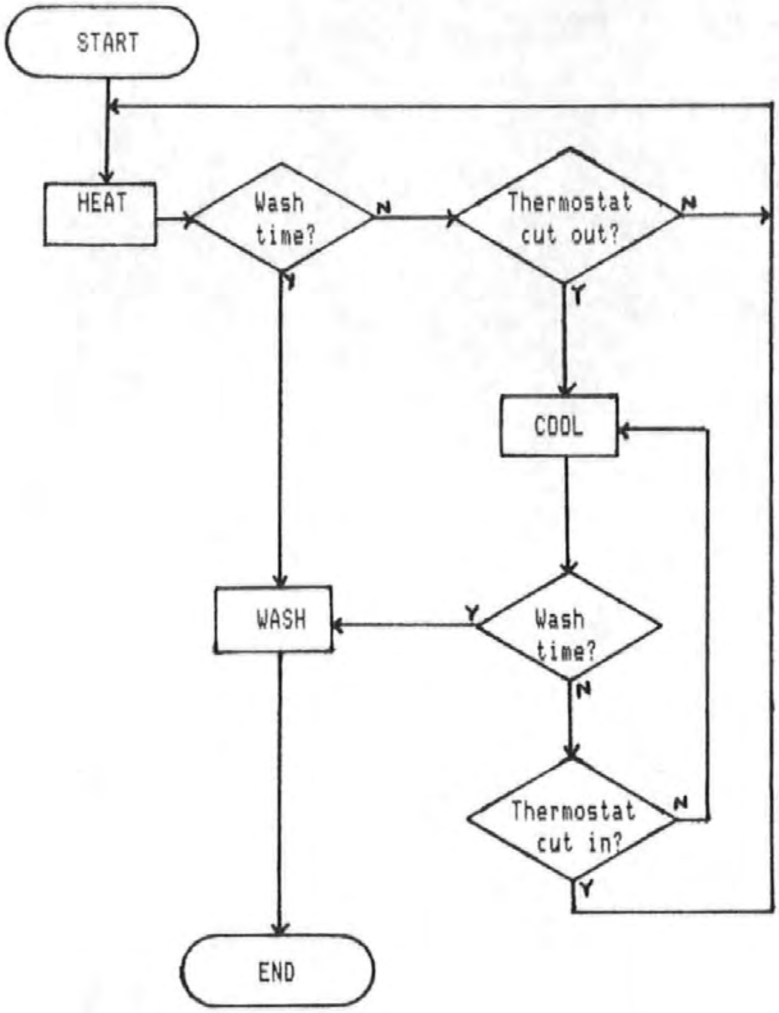
7.1.3 Simulation of Thermostat Action

In practice all plant cleaning water heaters are fitted with a thermostat to control the temperature to which the water is heated. This is simulated in the model by two temperature settings; the thermostat cut-out temperature, which is the maximum water temperature required, and the thermostat cut-in temperature. The water is heated until the cut-out temperature is reached. then the water cools until the cut-in temperature is reached, when it is reheated. The cooling period is simulated by a new routine, COOL, in which the temperature at the end of each timestep is calculated from Equation 1. In this routine the value of P, the power of the heater, will be zero and so the temperature will be lower at the the end of each timestep.

The heating and cooling cycle will continue until the water is used. It is no longer assumed that the water is used as soon as it has reached the required temperature so a new check is introduced, and the water used at a preset wash time. A flow diagram of this model is shown as Figure 7.1.3.1

Figure 7.1.3.1

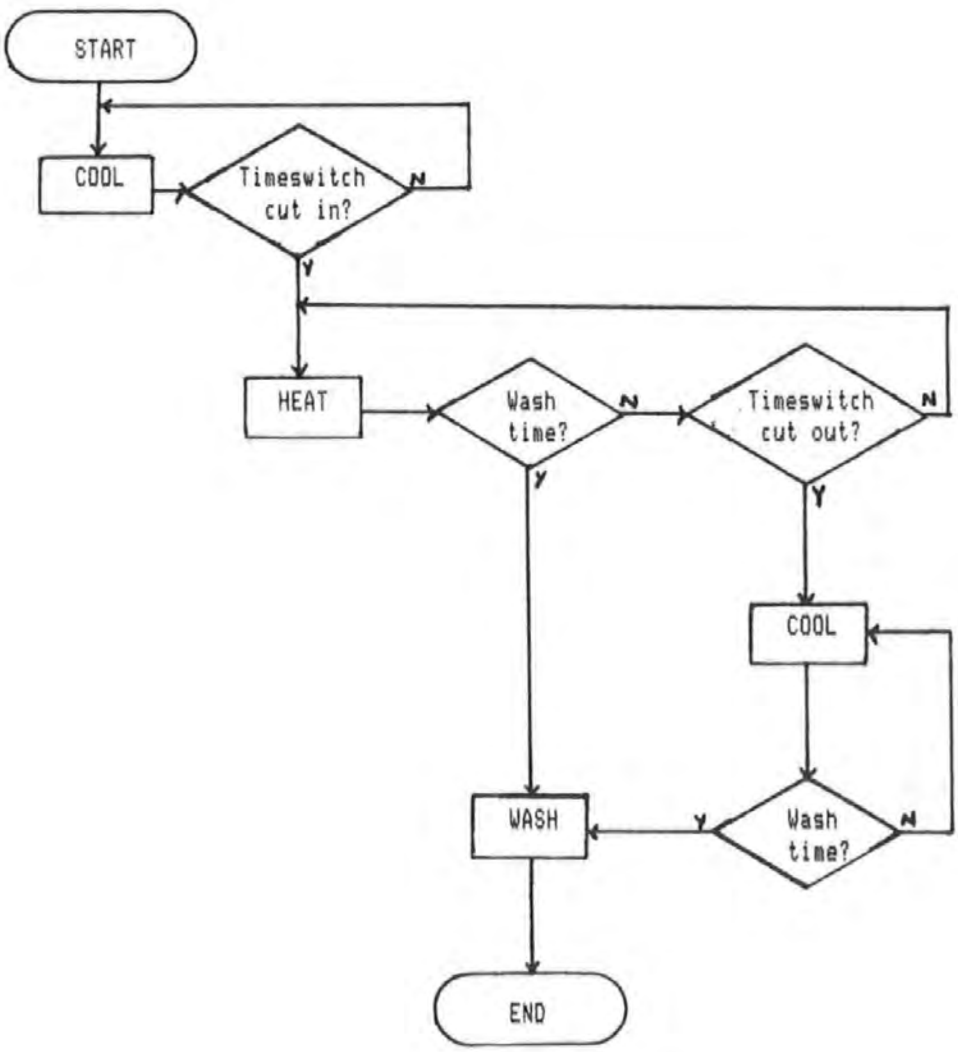
Flow Diagram of Plant Cleaning Water Heater, Controlled by Thermostat



7.1.4. Simulation of Timeswitch Action

Many plant cleaning water heaters are fitted with a timeswitch to control the heating of the water. In this case, after the water is used for plant cleaning it will cool until the timeswitch operates. To simulate this the elapsed time is compared to preset timeswitch cut-in and cut-out times to control the model entering heating and cooling routines. The model may only enter the heating period after the timeswitch cut-in time and before the timeswitch cut-out time. This model is shown as Figure 7.1.4.1

Figure 7.1.4.1
Flow Diagram of Plant Cleaning Water Heater, Controlled by Timeswitch.



7.1.5. Model of Correctly Used Plant Cleaning Water Heater

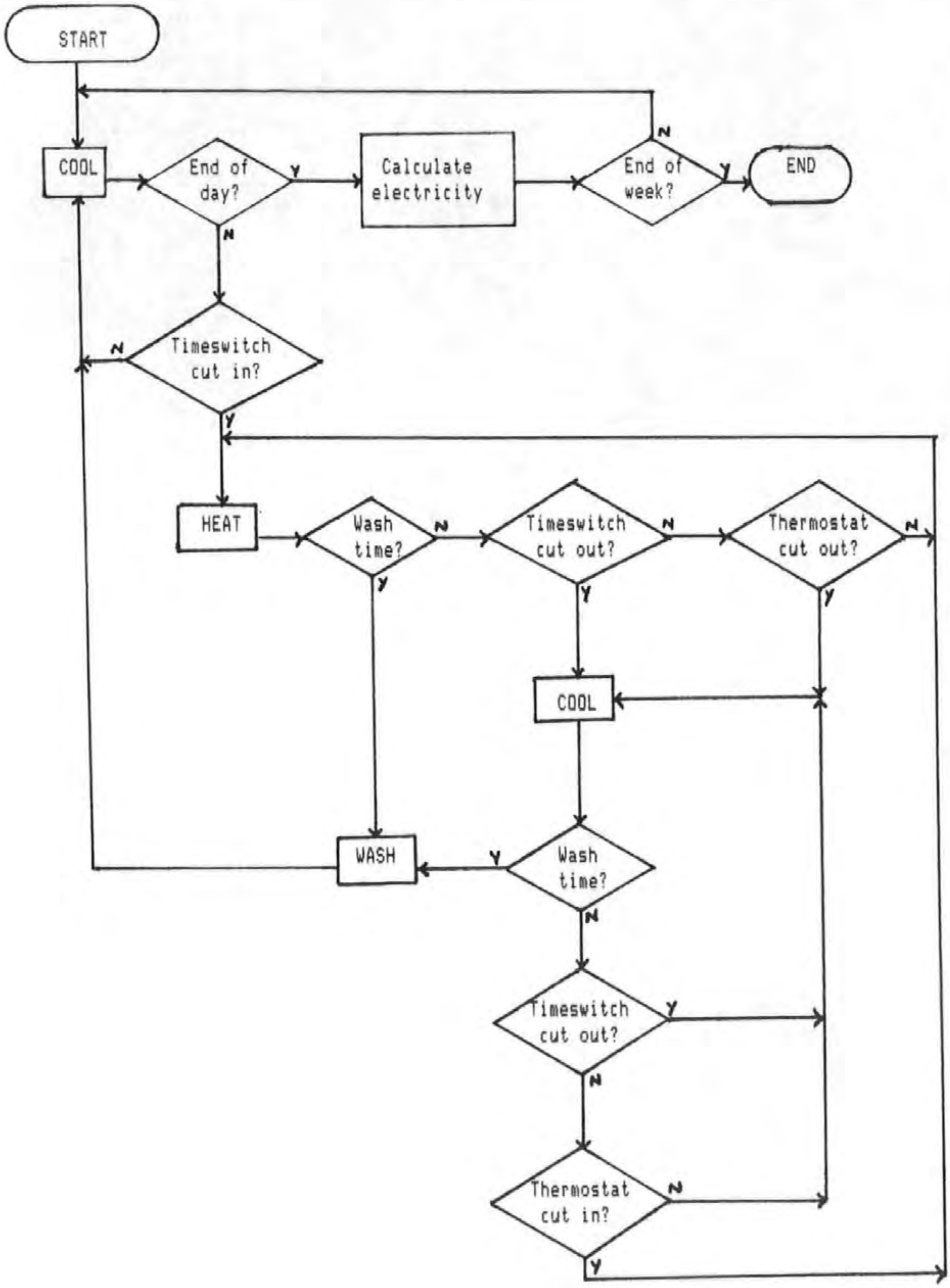
In general, plant cleaning water heaters are fitted with both thermostat and timeswitch to control the heating period. The combined model is shown as Figure 7.1.5.1. At the start of the day the model repeats the COOL routine until the timeswitch cut-in time has been reached. The model then repeats the HEAT routine until either the wash time is reached, when the WASH routine occurs or the timeswitch cut-out time or the thermostat cut-out temperature is reached when a COOL routine occurs. If the elapsed time is past the timeswitch cut-out time then the COOL routine is repeated until the elapsed time reaches the wash time and the WASH routine occurs. If the elapsed time has not passed the timeswitch cut-out time and, after the COOL routine, the temperature of the water has fallen to the thermostat cut-in temperature the model will return to the HEAT routine. After the WASH routine occurs the model enters a COOL routine which it repeats until the elapsed time exceeds 24 hours when the electricity consumption for the day is calculated.

The model is run for 8 days, the first of which is disregarded, its purpose is to provide the correct starting temperature for the second day.

The model shown as Figure 7.1.5.1 fully simulates a plant cleaning water heater which is controlled by timeswitch and thermostat and which is correctly used. The model may be used to simulate A.B.W. or circulation cleaning, by manipulation of the thermostat setting, with hot washing carried out once or twice a day - the latter by addition of a second set of timeswitch cut-in and cut-out times. It has been used successfully to examine plant cleaning water heating on Farm C, where the output from the model was used to advise on a change of routine.

Figure 7.1.5.1

Flow Diagram of Correctly UsedPlant Cleaning Water Heater



7.1.6 Simulation of unorthodox management practices

Further development of the model was required to allow simulation of unorthodox management practices. The following management practices have been revealed by study of the survey farms;

Absence of timeswitch.

Poor setting of timeswitch, allowing the heating of water after extraction of hot water for cleaning.

Failure to carry out plant cleaning.

Plant cleaning carried out less frequently than once a day.

Use of water from the heater for two washes, with a single heating period.

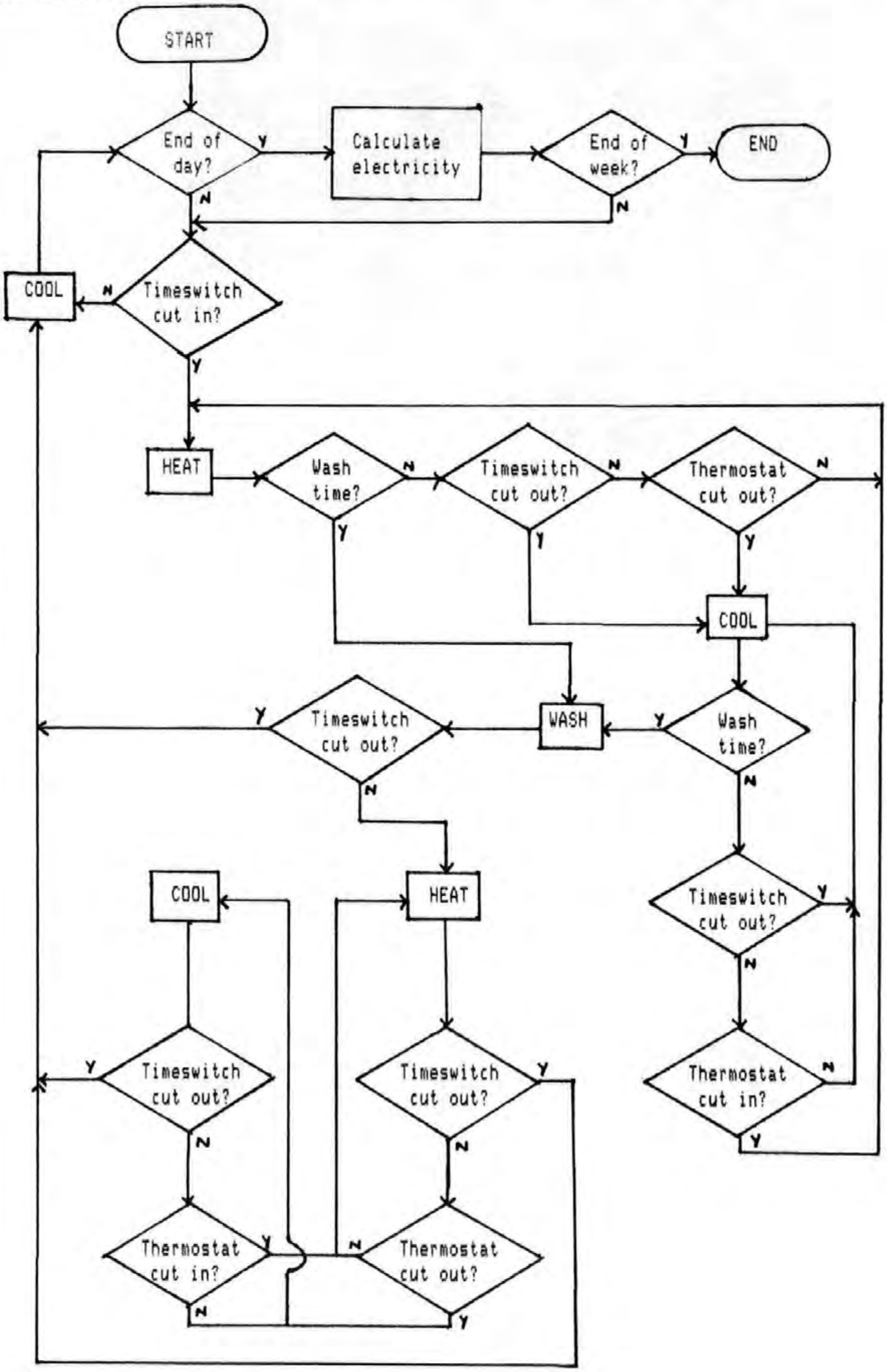
Removal of water for purposes other than plant cleaning.

The absence of a timeswitch, or its incorrect setting, allows heating of the water after cleaning, therefore the model enters a heating cycle after washing, rather than the cooling cycle. If there is no timeswitch the heating continues, under the control of the thermostat, until the next wash routine. If there is a timeswitch the model enters the cooling cycle when the elapsed time is equal to the timeswitch cut-out time.

The additional processing required in the model is shown in Figure 7.1.6.1. This allows the model to enter heating or cooling routines under the control of the thermostat, after plant cleaning has occured. The absence of a timeswitch is simulated by using timeswitch cut-in times of 0:00 and 12:00, and cut-out times of 12:00 and 24:00. This allows heating at all times, under the control of the thermostat. By using these times the model may return to the 'end of day' calculations and to the wash routine as appropriate.

Figure 7.1.6.1

Flow Diagram of Plant Cleaning Water Heater, with Incorrectly Set Timeswitch



Failure to carry out plant cleaning or cleaning less frequently than once per day is simulated by bypassing the wash routine, so that the model can enter the normal cooling period without water being removed from the heater. This will occur if plant cleaning is less frequent than heating, for example if the plant is only washed once in a day when the water is heated twice or if the water is heated every day but the plant is washed less frequently. If there is neither cleaning or water heating on a given day the model enters a 24 hour cooling cycle.

Use of water from the heater for purposes other than plant cleaning or for a cold wash is simulated by a new routine EXTRACT, whereby a preset volume of water is removed from the heater at a specified time, the resultant water temperature is calculated by equation 3. This routine can be carried out as many times as required at any time of day.

Figure 7.1.6.2

Flow Diagram of Plant Cleaning Water Heater, Allowing Unorthodox Management Practices

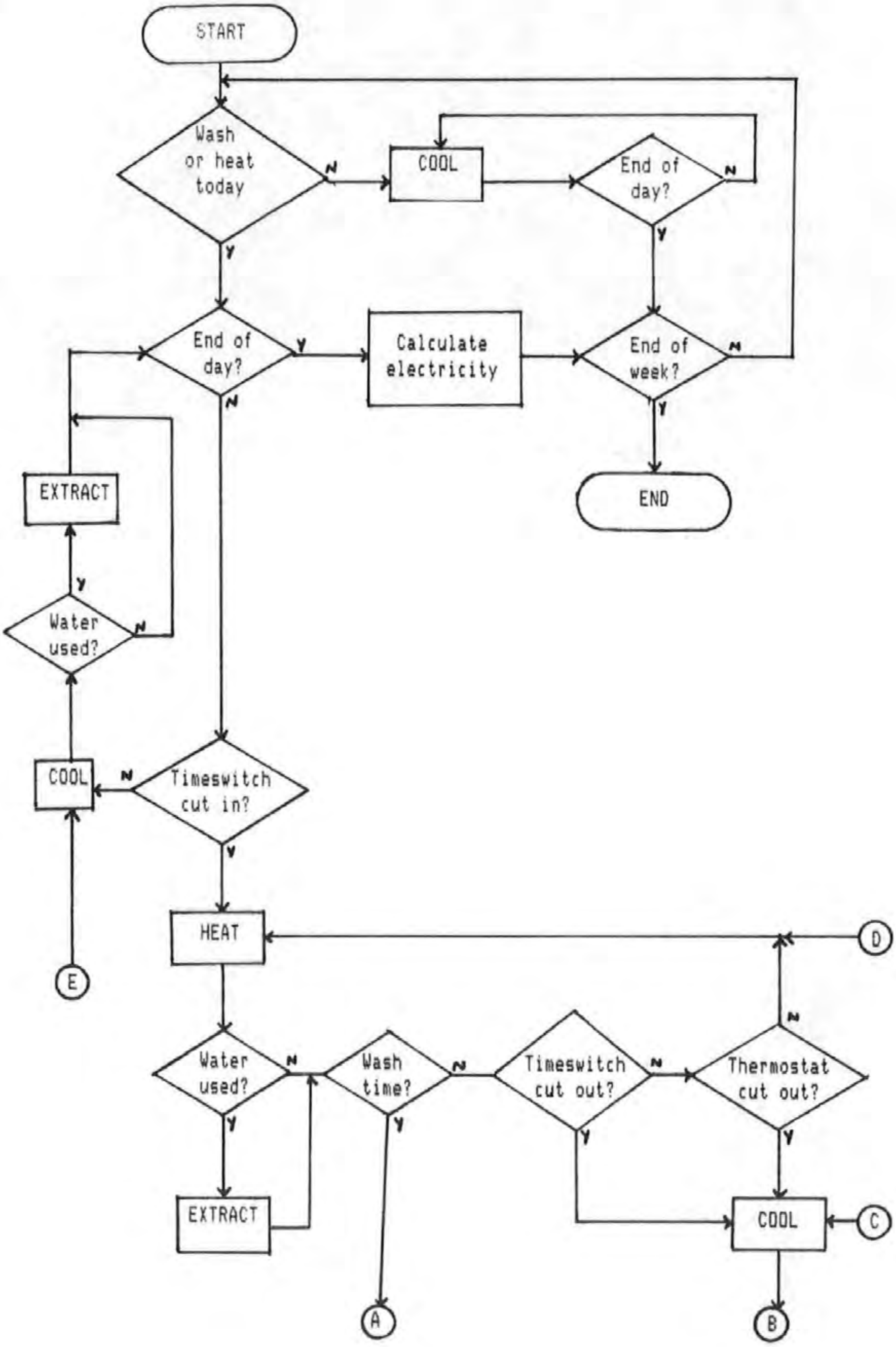
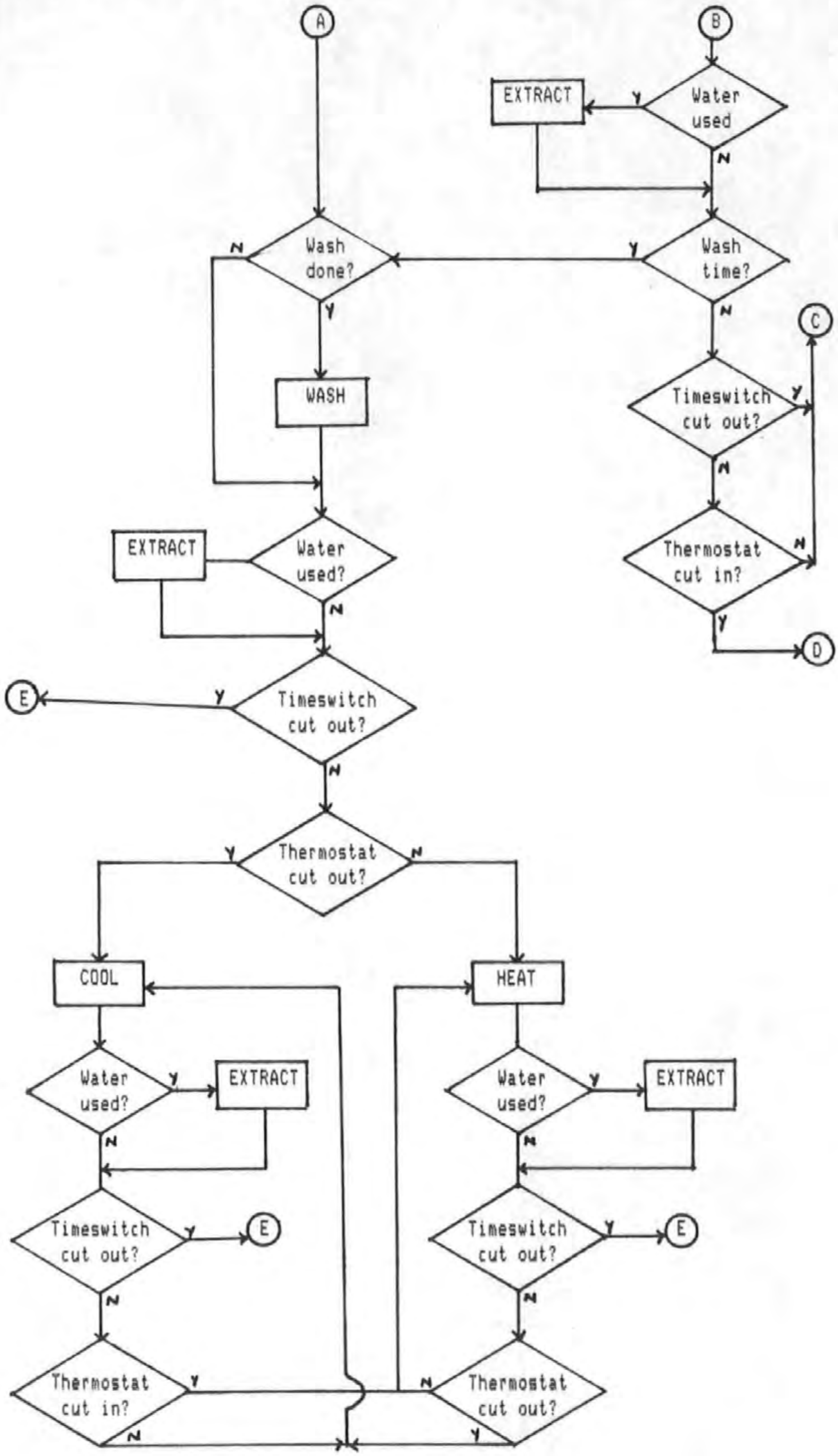


Figure 7.1.6.2 (continued)



7.2 Testing of the Model

7.2.1 Sensitivity Analysis of the Model

In order to use the model as a management tool various parameters must be ascertained for a heater under investigation. It is necessary to know the care with which these variables need to be measured, so that the model output is as accurate as possible without excessive time being taken in obtaining values.

The first model, of a single heating cycle, was used to examine the sensitivity of the model to its physical parameters. Each variable in the model was manipulated to examine the sensitivity of the output of the model, that is electricity consumption, to variation in the given variable. Initially each variable was altered by 10%, 25% and 50% of the standard value, and the resultant percentage change in electricty use was calculated. The results are shown as Table 7.2.1.1.

Table 7.2.1.1

Sensitivity of the Model to Physical Parameters

Variable	Standard value	Percentage change in variable value -50%	-25%	-10%	+10%	+25%	+50%
Water mass	90 l	-50.0	-25.0	-10.0	9.9	25.0	50.0
Inlet water temp	10°C	4.9	2.5	1.0	-1.0	-2.5	-5.1
Ambient temp	10°C	1.2	0.5	0.2	-0.3	-0.6	-1.3
Final water temp	100°C	-58.0	-30.1	-12.2	12.4	32.1	67.0
Power	3kW	14.3	4.2	1.3	-1.1	-2.4	-3.8
Timestep	10 s	-0.1	-0.1	-0.1	0.0	0.0	0.0
Heat loss coefficient	6.7×10^{-3}	-5.5	-2.9	-1.2	1.2	3.1	6.5
Specific heat capacity of water	4.18	-50.2	-25.0	-10.3	10.4	25.8	50.6

This analysis suggests that the model output is very sensitive to variation in water mass, the specific heat capacity of water and the final water temperature. Of these, the specific heat capacity of water is well established, and published values may be used. It further suggests that the timestep of the model and ambient temperature are relatively unimportant within the model.

For further analysis each variable was examined in turn, with all other variables held constant at the value quoted in Table 7.2.1.1., above. In each case a range of values on each side of the standard value for the variable was examined.

7.2.1.1. Timestep

Analysis of the effect of the model timestep is shown as Figure 7.2.1.1.1. This shows that the electricity consumption is constant up to a timestep of 600 seconds. If the model runs for an extra timestep, with timesteps of 1200 seconds and over there will be a large, erroneous temperature increase, causing an error in the electricity calculation. With smaller timesteps, an extra step results in a very small temperature increase, which has little effect on electricity consumption. A timestep of 600 seconds will provide an accurate output from the model, with the minimum of calculation time.

Table 7.2.1.1.1.
Effect of Change in Timestep on Model Output.

Timestep s	Final temp °C	Electricity kWh	Percentage error in electricty
1	100.00	10.49	0.00
10	100.06	10.50	0.08
30	100.06	10.50	0.08
60	100.06	10.50	0.08
300	100.06	10.50	0.08
600	100.06	10.50	0.08
1200	103.87	11.00	4.85
1800	100.07	10.50	0.08
3600	111.39	12.00	14.38

7.2.1.2. Inlet Temperature

Cold water inlet temperatures have been measured and reported to vary between 6°C and 20°C, following the seasons (Sun at Work, 1981). The model was run using these inlet temperatures, as shown in Table 7.2.1.2.1..

Table 7.2.1.2.1.

Effect of Change in Inlet Temperature on Model Output.

Inlet Temp. °C	Final temp. °C	Duration H: M	Electricity kWh
6.0	100.00	3:38	10.91
7.0	100.03	3:38	10.81
8.0	100.06	3:34	10.71
9.0	100.03	3.32	10.60
10.0	100.06	3:30	10.50
11.0	100.03	3:38	10.39
12.0	100.01	3:26	10.28
13.0	100.05	3:24	10.18
14.0	100.02	3:22	10.08
15.0	100.00	3:19	9.97
16.0	100.05	3:17	9.87
17.0	100.03	3:15	9.76
18.0	100.01	3:13	9.65
19.0	100.06	3:11	9.55
20.0	100.05	3:09	9.44

When using the model for comparative purposes, e.g. alteration of timeswitch settings, a standard value of 12°C is used. When annual calculations are carried out for financial analysis four seasonal values of 8, 12, 18 and 12°C are used, these being the reported average values for January, April, July and October.

7.2.1.3. Ambient Temperature

Ambient temperatures were measured on the survey farms by thermographs and the average for each week calculated. The lowest average weekly value recorded is 1°C and the maximum is 18°C. The model was run using temperatures between these values.

Table 7.2.1.3.1

Effect of Change in Ambient Temperature on Model Output

Ambient temp °C	Final temp °C	Time H: M	Electricity kWh
1.0	100.01	3:35	10.73
2.0	100.03	3:34	10.71
3.0	100.04	3:34	10.68
4.0	100.06	3:33	10.66
5.0	100.01	3:33	10.63
6.0	100.02	3:32	10.60
7.0	100.03	3:32	10.58
8.0	100.04	3:31	10.55
9.0	100.05	3:31	10.53
10.0	100.06	3:30	10.50
12.0	100.01	3:29	10.44
14.0	100.02	3:28	10.39
16.0	100.03	3:27	10.34
18.0	100.03	3:26	10.29

This analysis shows that variation in ambient temperature, within the range found on the survey farms, has little effect on the output of the model. For this reason a standard value of 10°C is selected as it is the average temperature recorded on survey farms.

7.2.1.4. Thermostat Cut-Out Temperature

An initial analysis was carried out, examining thermostat cut-out temperatures between 30°C and 100°C, as shown in Table 7.2.1.4.1.

Table 7.2.1.4.1

Effect of Change in Thermosat Cut-Out Temperature on Model Output

Thermostat cut-out temp. °C	Final temperature °C	Duration H: M	Electricity kWh
30.0	30.04	0:43	2.14
40.0	40.05	1:05	3.25
50.0	50.05	1:28	4.38
60.0	60.03	1:51	5.54
70.0	70.04	2:15	6.73
80.0	80.07	2:39	7.96
90.0	90.04	3:04	9.21
100.0	100.06	3:30	10.50

This indicates that there is a direct, linear relationship between thermostat cut-out temperature and electricity consumption for heating the water, as expected. Further analysis of this relationship was carried out with particular reference to temperatures around 80°C, this being the accepted final water temperature for circulation cleaning.

Table 7.2.1.4.2

Effect of Change in Thermostat Cut-Out Temperature on Model Output

Thermostat cut-out temp. °C	Final temperature °C	Duration H: M	Electricity kWh
72.0	72.0	2:19	6.95
74.0	74.0	2:24	7.20
76.0	76.0	2:29	7.45
78.0	78.0	2:34	7.70
80.0	80.0	2:39	7.95
82.0	82.0	2:44	8.20
84.0	84.0	2:49	8.45
86.0	86.0	2:54	8.70
88.0	88.0	2:59	8.95

This analysis shows that, when the model is used as a management tool, it is important that the exact temperature (within one degree centigrade) at which the thermostat operates is used in the model. This temperature must be found by measurement as it has been found that, firstly farmers do not always know the thermostat setting on the heater and secondly the temperature at which the thermostat operates may be several degrees different to the set thermostat temperature. Table 7.2.1.7. shows the temperatures as follows;

Stated temperature - the thermostat setting as stated by the farmer, prior to the start of the survey.

Set temperature - the setting on the thermostat itself.

Actual temperature - the temperature at which the thermostat operates.

Table 7.2.1.4.3

Thermostat Setting on Survey Farms.

Farm	Stated temperature °C	Set temperature °C	Actual temperature °C
A	71	88	- *
B	71	65	66
C	95	99	93
D	65	90	92
X	82	80	73
E	71	90	- *
F	71	85	- *
H	82	93	89
J	82	82	90
K	95	95	95
L	95	95	98
M	82	104	95

* Water does not reach cut-out temperature

7.2.1.5. Thermostat Cut-In Temperature

After the thermostat has cut out the water cools until a pre-set 'thermostat cut-in' temperature is reached, when the heating element will cut in. With a small gap between the cut-in and cut-out temperatures the water is maintained at a more constant temperature, however these, more sensitive thermostats are expensive and so a compromise of a 2°C gap is generally accepted by manufacturers (Denton 1981).

The effect of the thermostat cut-in temperature was examined by running the model for a standard time period of 20 hours. The water started at 10°C, it was heated to 100°C and then maintained at a temperature determined by the thermostat cut-in temperature.

Table 7.2.1.5.1

Effect of Change in Thermostat Cut-Out Temperature on Model Output

Thermostat cut-in °C	Final temp °C	Electricity kWh	Number of times heater cuts in
99.0	99.25	20.77	77
98.0	98.48	20.37	37
97.0	99.55	20.34	25
96.0	96.76	19.95	18
95.0	96.86	19.88	15
94.0	97.70	19.90	12
93.0	95.33	19.58	10
92.0	98.71	19.88	9
91.0	98.93	19.83	8
90.0	96.67	19.54	7

There is little effect on the electricity consumption over this range of values, so a standard difference of 2°C between thermostat cut-out and cut-in temperatures will be used.

7.2.1.6. Mass of Water Used for Plant Cleaning

The mass of water used for each session of plant cleaning will affect the temperature of the water in the heater after it has been refilled with cold water. This will affect the temperature of the water at the start of the next heating period, which will then affect the electricity consumption required to heat the water to the thermostat cut out temperature.

Table 7.2.1.6.1

Effect of Change in Mass of Water Used on Temperature of Water After Refilling of the Heater

Water used litres	Temperature of mixed water °C
70	23.89
60	33.33
50	42.78
40	52.22
30	61.67
20	71.11
10	80.56

As discussed previously, the mass of water extracted for plant cleaning, particularly when the circulation cleaning method is used, varies greatly. This variation is not only between farms, but also on a given farm, between one cleaning period and the next.

7.2.1.7. Electrical Rating of the Water Heater

The electricity consumption for heating a given volume of water is inversely proportional to the rating of the heater. With a lower rating the heating period will be longer which allows a longer time for heat loss, which requires increased electricity consumption to replace.

Table 7.2.1.7.1

Effect of Different Electrical Rating of Heater on Electricity Consumption

Rating kW	Final temperature °C	Length of time H: M	Electricity consumption kWh
2.0	100.03	5:36	11.18
2.5	100.03	4:18	10.76
3.0	100.06	3:30	10.50
3.5	100.07	2:57	10.33
4.0	100.09	2:33	10.20
4.5	100.06	2:15	10.10
5.0	100.08	2:00	10.03
5.5	100.03	1:49	9.96
6.0	100.07	1:39	9.92

In practice, most plant cleaning water heaters are 3kW, with some of 4 or 6kW. When the model is used as a management tool this must be ascertained.

7.2.1.8. Specific Heat Capacity of Water

Values for the specific heat capacity of water for temperatures from 0°C to 100°C, in increments of 10°C, were examined.

Table 7.2.1.8.1

Variation in Specific Heat Capacity of Water with Temperature

Water temperature °C	Specific heat capacity kJ/kg/K
0.0	4.22
10.0	4.19
20.0	4.18
30.0	4.18
40.0	4.18
50.0	4.18
60.0	4.18
70.0	4.19
80.0	4.20
90.0	4.20
100.0	4.22

Table 7.2.1.8.2

Effect of change in specific heat capacity on electricity consumption

Specific Heat capacity kJ/kg/K	Final temperature °C	Time H: M	Electricity kWh
4.18	100.10	3:30	10.50
4.19	101.74	3:35	10.75
4.20	101.66	3:35	10.75
4.22	101.28	3:35	10.75

This analysis indicates that the maximum variation in electricity consumption is 0.25 kWh, for temperatures of 0°C and 100°C. This variation is 2.4%, which is considered to be not significant, so the value for the specific heat capacity of water will be taken as 4.18 kJ/kg/K for all purposes.

7.2.1.9. Overall Heat Loss Coefficient

Calculation of the value of the overall heat loss coefficent of the heater from physical parameters indicated that it lay in the range 2.0×10^{-3} to 8.0×10^{-3}. This range of values was investigated using the model.

Table 7.2.1.9.1

Effect of Variation in Overall Heat Loss Coefficient on Electricity Consumption.

UA $\times 10^{-3}$ kW/C	Finish temp °C	Time H: M	Electricity kWh
2.0	100.09	3:35	10.75
3.0	100.04	3:38	10.90
4.0	100.36	3:42	11.10
5.0	100.19	3:45	11.25
6.0	100.36	3:49	11.45
7.0	100.08	3.52	11.60
8.0	100.10	3:56	11.80

Changing the overall heat loss coefficient from the minimum to the maximum of this range results in an increase in electricity consumption of 9.8%. As this is is a large variation the effect on the cooling of water was also investigated. The final temperature of the water after 20 hours of cooling was examined; this being the maximum period of cooling if the water is to be heated each day.

Table 7.2.1.9.2

Effect of Variation in Overall Heat Loss Coefficient on Final temperature. After 20 Hours of Cooling

UA $\times 10^{-3}$ kW/C	Finish temp °C
2.0	71.4
3.0	60.7
4.0	51.9
5.0	44.6
6.0	38.5
7.0	33.6
8.0	29.5

In this case the variation in the final temperature from the minimum to the maximum value of the overall heat loss coefficient results in a reduction of temperature of 41.9°C. This would result in a reduction in the electricity consumption for subsequent heating periods. The overall heat loss coefficient was determined experimentally as 3.5 x 10^{-3} kW/°C.

7.2.2. Testing the Model

In order to test the model an experimental water heater was set up under laboratory conditions. In this experiment the temperature of the water, the length of time the heater was on and the electricity consumption was measured. Hot water was withdrawn from the heater on a daily basis to mimic water use for plant cleaning.

The first tests investigated the simulation of temperature increase in the heater, results from one of the tests are shown as Table 7.2.2.1. It can be seen that the model predicts a slightly higher temperature increase than is the case in the experiment.

Table 7.2.2.1

Comparison of Temperature in Model and Experiment

Time	Water Temperature °C	
hours	Experiment	Model
0.00	30	27
0.30	39	41
1.00	54	55
1.30	69	69
2.00	81	83
2.30	93	96
Increase in temperature	63	69

The experiment was then run for a period of two days, with temperature, water volume and electricity consumption being recorded. The results for the first day were discarded, its purpose being to allow the heater to start the second day of testing at the correct water temperature. The model was then run to simulate the same water volume, timeswitch and thermostat settings and water use. The results for the second day of the experiment were then compared to the model output as shown in Table 7.2.2.2

Table 7.2.2.2

Comparison of Model and Experiment for Twenty-Four Hours

Time hours	Water Temperature °C Experiment	Model
0.00	30	30
1.00	30	30
Timeswitch cut in at 1.00		
1.30	43	43
2.00	57	58
2.30	71	71
3.00	83	85
3.30	94	99
Thermostat cut out (Expt = 3.30, 94°C: Model = 3.30, 99°C)		
4.00	93	96
Plant cleaning (Expt = 4.25, 91°C: Model = 4.30, 94°C)		
5.00	35	33
6.00	37	32
7.00	37	32
8.00	37	32
9.00	37	32
10.00	37	32
11.00	37	31
12.00	37	31
13.00	36	31
14.00	36	31
15.00	34	30
16.00	34	30
17.00	33	30
18.00	33	30
19.00	32	29
20.00	32	29
21.00	32	29
22.00	31	28
23.00	31	28
24.00	30	27

It can be seen the model simulates the heating period closely, with a 6°C difference in temperature when the thermostat cuts out. The model therefore accurately reflects the electricity use by the heater, but slightly over estimates the temperature of the plant cleaning water. Electricity consumption by the model and the experiment are shown as Table 7.2.2.3.

Table 7.2.2.3

Electricity consumption by Model and Experiment

Day	Electricity Consumption (kWh) Model	Experiment
1	8.7	8.9
2	7.5	7.6
3	7.5	7.7
4	7.5	7.4
5	7.5	7.5

The higher values on Day 1 are due to the lower starting temperature, as all the water is at the inlet temperature, there being no residue of warm water from the previous day. The model predicts a constant electricity consumption, which is not found in the experiment due to changes in ambient and inlet water temperatures. The average electricity consumption by the experiment (discarding Day 1) was 7.55 kWh, compared to the 7.5 kWh predicted by the model. This experiment was repeated a further four times, the average electricity consumption values for these subsequent runs were 7.02, 7.62, 6.70, 7.06 (mean = 7.1 kWh)

The experiment and model were then run to investigate alterations in the management practices, the results are shown as Table 7.2.2.4

Table 7.2.2.4

Effect of Change in Management Practice, on Electricity Consumption by Model and Experiment

Factor changed	Model kWh	Experiment (4 days) kWh				Mean kWh
Thermostat 60°C	5.0	5.24,	5.00,	4.76,	5.28	5.04
Less water 35 l	6.0	6.25,	6.34,	5.98,	6.07	6.16
Timeswitch on for 1 hour after wash	9.0	8.76,	9.50,	8.62,	9.40	9.07
No timeswitch	12.5	12.50,	13.12,	13.06,	12.44	12.78

7.3. The Model as a Management Aid

7.3.1. General Advice

The model was first used to examine the effect of certain management practices on electricity consumption for heating plant cleaning water. To do this the model was run with standard values to obtain a reference electricity consumption for once or twice daily cleaning for A.B.W. or circulation cleaning. The standard values used are shown as Table 7.3.1.1, with the results from the model in Table 7.3.1.2.

Table 7.3.1.1

Standard Values for Model

Variable	Standard Value
Thermostat setting	85°C (circulation cleaning) 98°C (A.B.W.)
Mass of water - in heater 90 litres	
- used for cleaning	70 litres
Rating of heater	3 kW
Washtimes - morning	08.00
- afternoon	16.00
Timeswitch settings - on	04.00
- off	08.00
- on	12.00
- off	16.00

Table 7.3.1.2

Reference Values for Electricity Consumption

Cleaning Method	Frequency washes / day	Electricity Consumption kWh
Circulation cleaning	1	7.5
	2	14.5
A.B.W.	1	9.0
	2	16.5

When these values had been established the model was run with various parameters altered to examine the effect of different management practices, all other parameters were unchanged. The results from this analysis are shown as Table 7.3.1.3.

Table 7.3.1.3

Effect of Management Practices on Electricity Consumption

Cleaning practice		Electricity consumption	Change in consumption kWh	%
No timeswitch;				
C.C.	once/day	12.5	5.0	66.6
	twice/day	17.5	3.0	20.7
A.B.W.	once/day	14.0	5.0	35.7
	twice/day	21.0	4.5	27.7
Timeswitch wrongly set, heating for 1 hour after washing;				
C.C.	once/day	9.0	1.5	20.0
	twice/day	15.5	1.0	6.9
A.B.W.	once/day	10.5	1.5	16.6
	twice/day	18.0	1.5	9.1
Thermostat set lower;				
C.C.	once/day	5.0	-2.5	-33.3
	twice/day (60°C)	9.5	-5.0	-34.5
A.B.W.	once/day	8.0	-1.0	-11.0
	twice/day (90°C)	11.5	-5.0	-30.3
Thermostat too high;				
C.C.	once/day (90°C)	8.0	0.5	6.7
	twice/day (95°C)	12.0	2.5	17.2
A.B.W.	once/day (100°C)	9.0	0.0	0.0
	twice/day	17.5	1.0	6.5
More hot water used, 90 litres per wash;				
C.C.	once/day	8.5	1.0	13.3
	twice/day	17.0	2.5	17.2
A.B.W.	once/day	10.0	1.0	11.1
	twice/day	20.0	3.5	21.2
Less hot water used, 35 litres per wash;				
C.C.	once/day	6.0	-1.5	-20.0
	twice/day	9.5	-5.0	-34.5
A.B.W.	once/day	7.0	-2.0	-22.2
	twice/day	11.5	-5.0	-30.0
Smaller Heater (capacity; 55 litres, 35 litres used for each wash);				
C.C.	once/day	5.0	-2.5	-33.3
	twice/day	9.0	-5.5	-37.9
A.B.W.	once/day	6.0	-3.0	-33.3
	twice/day	10.5	-6.0	-36.6
Cold water used from the heater, for cold washing of the plant;				
C.C.	once/day	7.5	0.0	0.0
A.B.W.	once/day	9.0	0.0	0.0

These results indicate the importance of the timeswitch in energy saving, particularly if the plant is hot washed only once per day. The results show, for this size of heater used for twice daily hot washes, that addition of a timeswitch will reduce the electricity consumption per day by 5.0 kWh, which will result in an annual saving of £90. It is therefore advised that all farmers fit a timeswitch to the plant cleaning water heater. However this timeswitch must be carefully set and, in particular, must not allow the heating of water after washing has taken place. If the timeswitch does allow heating for one hour after cleaning this leads to significantly increased electricity consumption, in the case of circulation cleaning once per day this is an increase of 20% over the consumption if the timeswitch is correctly set.

Reduction of the thermostat setting also leads to reduced electricity consumption, but in this case it may reduce the effectiveness of the cleaning routine, and so is not advised.

If a smaller volume of water is required it is preferable to heat this in a smaller heater, rather than use a large heater. The cost of using a 90 litre heater to provide 35 litres of hot water, rather than a 55 litre heater is generally one kilowatt-hour per wash, a annual cost of £18.

The model was also used to investigate the effect of using water from the heater for purposes other than plant cleaning.

Table 7.3.1.4

Effect of Using Water for Purposes Other than Plant Cleaning

Extraction During Cooling Periods

	Electricity Consumption (kWh)	
Volume of water	Circ. Clean.	A.B.W.
none	7.5	9.0
10	7.5	9.0
20	8.0	9.0
30	8.0	9.0
40	8.0	9.5
50	8.0	9.5

These results indicate that using water after cleaning has little effect on the electricity consumption by the heater, the maximum increase in consumption being 0.5 kWh per day.

Table 7.3.1.5

Effect of Using Water for Purposes Other than Plant Cleaning Extraction During Heating Period

	Electricity Consumption (kWh)	
Volume of water	Circ. Clean.	A.B.W.
none	7.5	9.0
10	8.5	10.0
20	9.5	11.0
30	10.5	12.0
40	10.5	12.0
50	10.5	12.0
60	11.0	12.0
70	11.0	12.0

When water is taken from the heater during the heating period prior to plant cleaning there is a greater effect on plant cleaning. In this simulation the water was taken at 7.00 a.m., cleaning being at 8.00 a.m. Electricity consumption increases by up to 3.5 kWh per day (1095 kWh p.a.). In addition the temperature of the water available for plant cleaning is reduced if more than 40 litres is used before cleaning. Farmers must therefore ensure, if water is to be used before plant cleaning, that there is time for the water in the heater to reach cleaning temperature before the end of milking.

Table 7.3.1.6

Effect of Using Water for Purposes Other than Plant Cleaning

Extraction After Washing, No Timeswitch

Volume of water	Electricity Consumption (kWh) Circ. Clean.	A.B.W.
none	12.5	14.0
10	13.0	15.0
20	13.5	16.5
30	14.5	16.5
40	15.5	17.5
50	16.0	18.0
60	17.0	19.0
70	17.5	20.0

The importance of a timeswitch is again highlighted in Table 7.3.1.6. The increase in electricity consumption with increased extra water use is linear. For each extra 10 litres of water used at 85°C electricity consumption is increased by 0.7 kWh.

7.3.2. Use of the Model for Individual Farm Advice.

The model was used to examine water heating costs at Farm C which uses A.B.W. cleaning and has a particularly high electricity consumption for water heating at 2.9 kWh/unit/wash (average of 3 farms using A.B.W. is 1.8 kWh/unit/wash). When the model was run with data from Farm C it predicted an electricity consumption of 15 kWh per wash. The heater actually used 14.85 kWh per wash.
The model was used to provide information that will assist the farmer in improving the use of his plant cleaning water heater. For farm C the model was used to examine the effects of changing the cleaning method, the frequency of hot washes and the volume of water used for each hot wash. For the case of once daily cleaning the effect of changing the cost of electricity from the standard rate of 4.9 p/kWh to the Farm Day/Night Tariff rate of 1.82 p/kWh for electricity used at night, was examined.

To examine the financial implications of the above choices the model was used with the following variations:

a) Maximum temperature 98°C (A.B.W.).

   i. 120 litres per wash (present use).

   ii. 90 litres per wash (maximum recommended volume).

   iii. 70 litres per wash (minimum recommended volume).

b) Maximum temperature 85°C (Circulation cleaning).

   i. 75 litres per wash (maximum recommended volume).

   ii. 50 litres per wash (minimum recommended volume).

Each of the above combinations of volume and temperature were costed for 7 or 14 washes per week at 4.9 p/kWh and for 7 washes at 1.82 p/kWh, the results are shown as Table 7.3.2.1.

Table 7.3.2.1

Cost of Heating Water for Plant Cleaning on Farm C.

Cleaning method	Water heated litres	Electricity used kWh per wash	Cost of heating water (£ p.a.) Normal tariff twice/day	once/day	Farm Day/night once/day
	120	15	495	248	92
A.B.W.	90	10	372	186	69
	70	8	290	145	54
C.C.	75	7	264	132	49
	50	5	177	88	33

This analysis indicates that circulation cleaning once per day using the Farm Day/Night Tariff is the cheapest method of cleaning the parlour. However, for reasons described in section 5.3, A.B.W. once per day, using 120 litres, heated by normal tariff electricity was selected. Subsequent to these changes the electricity consumption fell from 893.7 kWh per month to 459.0 kWh per month, a saving of £255 per annum.

7.3.3 Using the Model as an Advisory Tool

Prior to running the model an enquiry program is run to establish the parameters of the specific farm under investigation. A sample run from this program is shown as Table 7.3.3.1, responses being shown in italics.

Table 7.3.3.1

Sample Run from Enquiry Program

Water Heater Enquiry Program

Please answer all 'yes/no' questions with 'Y' or 'N'.
Enter all times on a 24 hour clock in the format HH.MM
For example half past eight in the morning should be entered as 8.30

What is the name of your farm? *Farm Z*

How often do you hot wash your plant?
1) Once per day
2) Twice per day
Please choose 1 or 2 *1*

When you cold wash do you use water from the heater? *N*
At what time do you wash the plant? *9.00*

Do you have a timeswitch? *Y*
How many times is the water heated per day? *1*
What time does your timeswitch cut in? *6.00*
cut out? *8.50*

At what temperature is your thermostat set (°C) *85*
What is the capacity of your heater (litres)? *120*
How much water do you use for each hot wash (litres)? *100*

What is the electrical rating of your heater (kW)? *3*

These are the values you have input:

Your farm is called Farm Z

You wash your plant once per day with hot water, at 9.00.

You have a timeswitch, which is set to cut in at 6.00,
and cut out at 8.50

The thermostat is set at 85°C
The capacity of the heater is 120 litres, of which you use 100 litres for each wash.
The heater rating is 3 kW.

Do you wish to change any of these values? *N*
Do you wish to save these values to file? *Y*
What file name? *FarmZ*

These values are saved to a disc file, and this is then used to initialise the values to be used in the model. When the model is run the time of day and the temperature of the water in the heater is output, to the screen, for each timestep. When the status of the heater changes a comment is output, to screen and paper; for example "Timeswitch cut in". The output for "Farm Z" is shown as Table 7.3.3.2.

Table 7.3.3.2

Output from Model for "Farm Z"

```
                   Plant Cleaning Simulation Model

File used: FarmZ
 To study: Farm Z

Day = 1

Timeswitch cut in  at  6:00   Water temperature is 17.6°C
Thermostat cut out at  8:20   Water temperature is 85.8°C
Timeswitch cut out at  8:50   Water temperature is 84.8°C

     Plant cleaning at 9:00   Water temperature is 84.6°C
                100 litres of water used
     Temperature of mix water is 22.4°C

Day = 1
Electricity used = 10 kWh
```

8.0 CONCLUSIONS FROM THE PRESENT WORK

The survey of commercial dairy farms has revealed much information which has not been previously reported.

1) Many unorthodox plant cleaning practices were found, which include:
Low temperatures of cleaning water, (on one farm circulation temperatures were in the range 30 - 40°C).
Low volumes of cleaning water, (three farms use less than 10 litres of hot water per milking unit).
Infrequent hot cleaning; despite cleaning with hot water being recommended after every milking. However, cleaning once per day is common; failure to clean every day has been found on some installations.

2) Despite the unorthodox cleaning practices all farms produced clean milk; all but one farm produced milk which was within Band A of the Total Bacterial Count classes.

3) It is not possible to predict the hot water use for plant cleaning from the number of milking units. The volume of water used on the farms varied between 8 and 20 litres per milking unit.

4) Water consumption for plant cleaning was not consistent from week to week on individual farms, particularly those using circulation cleaning. On one farm water use varied by 50% between two herdsmen.

5) On some farms a considerable volume of water is taken from the plant cleaning water heater for purposes other than plant cleaning. The farmers were not all aware of the high level of this use until it was revealed by monitoring.

6) Variation in electricity consumption for plant cleaning was mainly due to variation in water use, not to changes in ambient and water inlet temperatures, as previously reported.

7) The effect of Heat Recovery Units on reducing electricity consumption was not uniform. On two farms the HRU was carefully used, and resulted in lower electricity use, but on a third farm poor fitting and management of the HRU resulted in little reduction in consumption.

8) Energy consumption for plant cleaning was found to vary widely from farm to farm due to many factors. It was not possible to isolate these factors in order to study their individual effects.

9) A model of plant cleaning water heaters was therefore developed so that the effect on electricity consumption of all factors pertaining to a particular site could be determined. The model was used successfully to advise one farmer on a change of plant cleaning routine, resulting in a saving in excess of 5 000 kWh p.a.

10) The importance of a correctly set timeswitch on plant cleaning water heaters was demonstrated by the model.

11) It was found that farmers gave answers to the initial survey that were more "correct" than their later answers, in that the original replies better fitted published recommendations. The true situation was revealed in two ways. Firstly, in some cases, measurements revealed that the initial "correct" answers were not a true reflection of actual practice. Secondly a good personal relationship was built up such that farmers became aware that they would not be critised for unorthodox practises.

12) Water and electricity consumption for udder washing was found, predictably, to be very variable. Water use for udder washing varied between 0.1 and 1.9 litres per cow per milking (mean 0.85 litres). Some farmers reduced udder washing water use by washing only those cows which appeared dirty, others do not wash any udders in the summer months.

13) Electricity use varied between 7 and 79 Wh per cow per milking, with a mean of 30 Wh per cow per milking. Methods of reducing electricity consumption used by the farmers include washing fewer cows (see 12), using cold water in the summer and utilising warm water from a Heat Recovery Unit.

14) Some farmers attempted to reduce electricity consumption by the udder washing water heater by switching the heater off between milkings, but this had little effect.

9.0 RECOMMENDATIONS FOR FURTHER WORK

Many of the farmers in the survey used unorthodox cleaning methods but all farms produced milk which attracted quality premium for cleanliness. From this it may be implied that the milk quality criteria used are insufficiently stringent, alternatively that plant cleaning recommendations are excessive. Investigation of further farms, in other areas of England, would further establish the extent of the use of such cleaning practices as lower volumes and lower temperatures of cleaning water and washing less frequently than once per day. Investigation of farms which do not meet the criteria for Band A or B of the Total Bacterial Count should be carried out, to establish their plant cleaning practices, as this study would suggest that such farms have very poor cleaning systems.

The model of plant cleaning water heaters accurately simulates the electricity requirement for producing hot water. Further modelling work should examine milk cooling, the other main use of electricity in the farm dairy.

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APPENDIX 1 DATA FROM FARM H

A1.1 Monthly Data

Table A1.1.1

Electricity and Water Use - Monthly Data

	Electricity - kWh			Water - litres		Ambient	Milk	cows in
Mon	Total	Plant	U.W.	Plant	U.W.	Temp°C	litres	milk
1980								
Apr	2784	747	188	6444	4875	12.0	67960	117
May	2902	753	158	8207	4309	14.5	67398	113
June	2517	720	126	6253	3422	15.2	53361	98
July	2150	722	110	5422	3088	16.4	38364	71
Aug	1878	709	88	5325	2293	17.2	25026	56
Sept	2241	694	120	5277	3299	15.5	38970	72
Oct	2561	750	160	6212	4770	11.2	55543	84
Nov	2623	747	186	5820	4714	7.9	66472	94
Dec	3006	773	199	6026	4801	7.4	77789	108
1981								
Jan	3004	787	210	6133	4776	7.1	79998	113
Feb	2557	702	197	5208	4217	5.1	68912	114
Mar	2877	762	204	6017	4915	8.2	74447	116
Apr	2668	740	184	5434	4871	8.3	67528	116
May	2720	767	186	6565	5898	11.3	61479	109
June	2751	718	160	5581	5389	12.9	48042	95
July	2434	688	90	4345	4520	15.0	35255	71
Aug	2157	697	133	5064	28930	16.0	23437	55
Sept	2558	688	124	5214	4250	13.0	36111	76
Oct	2708	759	153	6113	4170	9.0	58460	101
Nov	2794	723	167	5816	4233	8.0	77317	115
Dec	2847	739	193	5393	4256	4.0	86009	126
1982								
Jan	2971	775	197	6098	4518	4.0	88518	128
Feb	2561	695	159	5377	3587	6.0	75682	135
Mar	2814	761	185	5465	4252	6.0	79149	136
Apr	2826	718	175	4951	4187	9.0	76877	133

A1.2 Statistical Analysis of Monthly Data Farm H

Table A1.2.1

Key to Computer Printout Codes

Measured values

C1 Month, number (1 = January 1980)
C2 Plant water - litres
C3 Plant electricity - kWh
C4 Udder washing water - litres
C5 Udder washing electricity - kWh
C6 Total electricity - kWh
C7 Cows in milk
C8 Ambient temperature - °C
C9 Milk volume - cubic metres
C10 Days in month

Calculated values

C11 Plant electricity as percentage of total dairy and parlour use
C12 Udder washing electricity as percentage of total dairy and parlour use
C13 Water heating electricity as percentage of total dairy and parlour use
C14 Plant cleaning water heater - litres / kWh
C15 Udder washing water heater - litres / kWh
C16 Plant water - litres / unit / wash
C17 Plant electricity - kWh / unit / wash
C18 Udder washing water - litres / cow / milking
C19 Udder washing electricity - kWh / cow / wash
C20 Plant electricity - kWh / cubic metre milk
C21 Udder washing electricity - kWh / cubic metre milk
C22 Water heating electricity - kWh / cubic metre milk
C23 Total dairy and parlour electricity - kWh / cubic metre milk
C24 Plant electricity - kWh / cubic metre of water heated
C25 Udder washing electricity - kWh / cubic metre of water heated

Table A1.2.2.

Averages

Code	Count	Mean	Standard Deviation	Sum
C2	24	5721.6	733.0	137317.
C3	24	732.92	30.5	17590.
C4	24	4234.5	811.0	101628.
C5	24	161.13	36.1	3867.1
C6	24	2630.3	291.0	63127.
C7	24	101.35	24.4	
C8	24	10.342	4.22	
C9	24	60.839	19.4	1460.1
C10	24	30.417	0.881	
C11	24	28.151	2.92	
C12	24	6.0724	0.944	
C13	24	34.223	2.66	
C14	24	7.7943	0.830	
C15	24	27.009	6.11	
C16	24	11.755	1.43	
C17	24	1.5063	0.0544	
C18	24	0.71078	0.153	
C19	24	0.026572	0.00437	
C20	24	13.714	5.82	
C21	24	2.8081	0.731	
C22	24	16.522	6.43	
C23	24	47.691	15.5	
C24	24	129.50	12.1	
C25	24	38.335	6.32	

Table A1.2.3

Plant Cleaning water volume (C2) and electricity (C3)

Month	C2	C3
5	8207.8	753.5
6	6253.9	720.9
7	5421.8	722.7
8	5324.7	708.6
9	5276.9	693.7
10	6211.8	750.3
11	5820.0	747.2
12	6025.9	772.8
13	6133.2	787.5
14	5208.4	702.0
15	6016.9	761.8
16	5433.9	740.2
17	6565.0	767.4
18	5581.1	718.0
19	4345.0	688.5
20	5064.0	697.5
21	5214.0	687.9
22	6113.0	759.2
23	5816.0	723.4
24	5393.0	738.7
25	6098.0	774.6
26	5377.0	694.7
27	5465.0	760.7
28	4951.0	718.4

Correlation of C3 and C2 = 0.624

Regression of C3 with C2 and C8

Regression equation: C3 = 622 + (0.0255 C2) - (3.35 C8)

R-squared = 60.3 percent.

R-squared = 56.6 percent, adjusted for degrees of freedom.

Regression of C3 with C2

Regression equation: C3 = 585 + (0.0259 C2)

R-squared = 38.9 percent.

R-squared = 36.1 percent, adjusted for degrees of freedom.

Table A1.2.4.

Water Heater Action: litres of water heated per kWh electricity (C14)

Month	C14
5	10.8929
6	8.6751
7	7.5021
8	7.5144
9	7.6069
10	8.2791
11	7.7891
12	7.7975
13	7.7882
14	7.4194
15	7.8983
16	7.3411
17	8.5549
18	7.7731
19	6.3108
20	7.2602
21	7.5796
22	8.0519
23	8.0398
24	7.3007
25	7.8724
26	7.7400
27	7.1842
28	6.8917

Correlation of C14 and C8 (ambient temperature) = 0.144

Regression of C14 with C8

Regression equation: C14 = 7.50 + (0.0284 C8)

R-squared = 2.1 percent.

R-squared = -2.4 percent, adjusted for degrees of freedom.

Regression of C14 with C2 and C8

Regression equation: C14 = 1.23 + (0.0011 C2) + (0.0330 C8)

R-squared = 94.2 percent.

R-squared = 93.6 percent, adjusted for degrees of freedom.

Table A1.2.5

Water (C16) and Electricity (C17) Use per Milking Unit

Month	C16	C17
5	16.5480	1.51915
6	13.0290	1.50187
7	10.9310	1.45706
8	10.7353	1.42863
9	10.9935	1.44521
10	12.5238	1.51270
11	12.1250	1.55667
12	12.1490	1.55806
13	12.3653	1.58770
14	11.6259	1.56696
15	12.1308	1.53589
16	11.3206	1.54208
17	13.2359	1.54718
18	11.6273	1.49583
19	8.7601	1.38810
20	10.2097	1.40625
21	10.8625	1.43312
22	12.3246	1.53064
23	12.1167	1.50708
24	10.8730	1.48931
25	12.2944	1.56169
26	12.0022	1.55067
27	11.0181	1.53367
28	10.3146	1.49667

Table A1.2.6

Udder washing water (C4) and Electricity (C5) Use

Month	C4	C5
5	4309.0	158.8
6	3422.0	126.4
7	3088.0	110.2
8	2293.0	88.2
9	3299.0	119.9
10	4770.0	160.0
11	4714.0	185.6
12	4801.0	198.7
13	4776.0	210.5
14	4217.0	196.6
15	4915.0	204.4
16	4871.0	184.3
17	5898.0	186.3
18	5389.0	160.5
19	4520.0	89.8
20	2893.0	133.2
21	4250.0	124.4
22	4170.0	153.1
23	4233.0	166.7
24	4256.0	193.4
25	4518.0	197.4
26	3587.0	159.1
27	4252.0	184.8
28	4187.0	174.8

Correlation of C4 and C5 = 0.653

Regression of C5 with C4
Regression equation: C5 = 38.0 + (0.0291 C4)
R-squared = 42.6 percent
R-squared = 40.0 percent, adjusted for degrees of freedom

Regression of C5 with C4, C8 and C7
Regression equation: C5 = 130 + (0.0141 C4) - (4.95 C8) + (0.221 C7)
R-squared = 81.4 percent.
R-squared = 78.6 percent, adjusted for degrees of freedom.

Regression of C5 with C8 and C7
Regression equation: C5 = 184 - (5.59 C8) + (0.348 C7)
R-squared = 73.7 percent.
R-squared = 71.2 percent, adjusted for degrees of freedom.

Regression of C4 with C8 and C7
Regression equation: C4 = 3789 - (45.2 C8) + (9.01 C7)
R-squared = 23.5 percent
R-squared = 16.3 percent, adjusted for degrees of freedom

Table A1.2.7

Udder washing water heater action: litres water heated per kWh (C15)

Month	C15
5	27.1348
6	27.0728
7	28.0218
8	25.9977
9	27.5146
10	29.8125
11	25.3987
12	24.1620
13	22.6888
14	21.4496
15	24.0460
16	26.4297
17	31.6586
18	33.5763
19	50.3341
20	21.7192
21	34.1640
22	27.2371
23	25.3929
24	22.0062
25	22.8875
26	22.5456
27	23.0087
28	23.9531

Correlation of C15 and C8 = 0.488

Regression of C15 with C8
Regression equation: C15 = 19.7 + (0.707 C8)
R-squared = 23.9 percent.
R-squared = 20.4 percent, adjusted for degrees of freedom.

Regression of C15 with C4 and C8
Regression equation: C15 = -2.50 + (0.0043 C4) + (1.09 C8)
R-squared = 49.6 percent.
R-squared = 44.8 percent, adjusted for degrees of freedom.

Regression of C15 with C7 and C8
Regression equation: C15 = 24.0 - (0.0286 C7) + (0.570 C8)
R-squared = 24.3 percent.
R-squared = 17.1 percent, adjusted for degrees of freedom.

Regression of C15 with C4, C7 and C8
Regression equation: C15 = 6.85 + (0.0045 C4) - (0.0695 C7) + (0.774 C8)
R-squared = 51.9 percent.
R-squared = 44.7 percent, adjusted for degrees of freedom.

Table A1.2.8

Udder washing water (C18) and electricity (C19) per cow

Month	C18	C19
5	0.61778	0.02276
6	0.58020	0.02143
7	0.69953	0.02496
8	0.66279	0.02549
9	0.76792	0.02791
10	0.91481	0.03068
11	0.83849	0.03301
12	0.71899	0.02976
13	0.68110	0.03002
14	0.66347	0.03093
15	0.68576	0.02852
16	0.70046	0.02650
17	0.87596	0.02769
18	0.94743	0.02822
19	1.02681	0.02040
20	0.84839	0.03906
21	0.93202	0.02728
22	0.66592	0.02445
23	0.61348	0.02416
24	0.54480	0.02476
25	0.56930	0.02487
26	0.47447	0.02104
27	0.50427	0.02192
28	0.52469	0.02190

Correlation of C18 and C8 = 0.483

Regression of C18 with C7 and C8

Regression equation: C18 = 1.36 - (0.0055 C7) - (0.0090 C8)

R-squared = 47.2 percent.

R-squared = 42.2 percent, adjusted for degrees of freedom.

Regression of C18 with C8

Regression equation: C18 = 0.530 + (0.0175 C8)

R-squared = 23.3 percent.

R-squared = 19.8 percent, adjusted for degrees of freedom.

Table A1.2.9

Plant Cleaning (C11) and Udder washing (C12) electricity as a percentage of Total dairy and parlour electricity (C6) consumption

Month	C6	C11	C13
5	2902.2	26.0	5.5
6	2517.9	28.6	5.0
7	2150.5	33.6	5.1
8	1878.5	37.7	4.7
9	2241.1	30.9	5.3
10	2560.9	29.3	6.2
11	2622.9	28.5	7.1
12	3005.9	25.9	6.6
13	3005.9	26.2	7.0
14	2556.7	27.4	7.7
15	2876.8	26.5	7.1
16	2667.8	27.7	6.9
17	2720.4	28.2	6.8
18	2751.2	26.1	5.8
19	2434.2	28.3	3.7
20	2157.2	32.3	6.2
21	2557.6	26.9	4.9
22	2707.6	28.0	5.6
23	2794.4	25.9	6.0
24	2847.5	25.9	6.8
25	2970.7	26.1	6.6
26	2561.0	27.1	6.2
27	2813.9	27.0	6.6
28	2826.0	25.4	6.2

Correlation of C6 and C11 = -0.923

Correlation of C6 and C12 = 0.534

A1.3 Cleaning Observation Results

Table A1.3.J.

Cleaning Observation Results

Farm; H   Date; 14.10.81 a.m.

Meter Readings

	Initial	Final	Difference
Electricity	18872.4	18882.6	10.2
Water	117312.6	117418.2	105.6

Temperature Recordings

Time	Water Temperatures °C				Comments
	Tap	Trough		Return	
		Hot	Cold		
9:37	87		10		
38	88	79	10	11	Cold rinse, discharge to waste
	87	79	10		
39	87	80	10	10	
	87	79		11	Hot wash starts, discharge to waste
40	87	81		16	
	87	81		27	
41	87	82		37	
	87	82		49	
42	81	82		53	Chemicals added
	86	80			Hot tap off
43		71		58	Circulation starts
		62		60	
44		61		60	
		61		61	
45		61		61	
		59		60	
46		57			
		56		54	
47		51		52	End of circulation, discharge to waste
		52		51	
48		51		51	
		51		50	
49			11		Cold rinse, discharge to waste
			11	49	
50			11		
			11	35	
51			11	28	
52			11	21	
53			11	19	

Table A1.3.2

Cleaning Observation Results

Farm; H   Date; 10.2.82 p.m.

Meter Readings

	Initial	Final	Difference
Electricity	21022.8	21033.1	10.3
Water	131931.2	132027.2	96.0

Temperature Recordings

Time	Water Temperatures °C				Comments
	Tap	Trough		Return	
		Hot	Cold		
5:50			10		Cold rinse, discharge to waste
			11	13	
51	91	82	11	13	
	92	84		12	
52	91	83		13	Hot wash starts, discharge to waste
	91	83		17	
53	91	84		24	
	91	84		33	
54	91	84		42	
	91	84		49	
55	91	85		54	Hot tap off
		84		56	Chemicals added
56		68		60	Circulation starts
		66		61	
57		65		62	
		64		60	
58		62		60	
		60		59	
59		59		56	
		57		54	
6:00		56		54	
		55		52	
01		53	10	51	End of circulation, discharge to waste
			10	51	
02			10	51	Cold rinse, discharge to floor
			10	42	
03			10	35	
			10	29	
04			10	25	

Table A1.3.3

Cleaning Observation Results

Farm; H   Date; 11.2.82 a.m.

Meter Readings

	Initial	Final	Difference
Electricity	21033.1	21043.2	10.1
Water	132027.2	132127.8	100.7

Temperature Recordings

Time	Water Temperatures °C				Comments
	Tap	Trough		Return	
		Hot	Cold		
9:35	85		11		Cold rinse, discharge to waste
	86	76	11	13	
36	85	78		11	Hot wash starts, discharge to waste
	85	78		11	
37	85	78		14	
	86	78		23	
38	85	79		33	
	85	80		46	
39	85	80		49	
	85	80		51	Chemicals added
40	85	80		57	Hot tap off, circulation starts
		66		58	
41		62		59	
		61		60	
42		61		60	
		60		58	
43		58		56	
		57		55	
44		55		54	
		54		53	
45		53		52	
		52		51	
46		51		50	
		50		49	End of circulation, discharge to waste
47			11	48	Cold rinse, discharge to waste
			11	47	
48			11	41	
			11	38	
49			11	32	
			11	27	
50			11	24	
			11	20	
51			11	19	
			11	16	
52			11	16	

Table A1.3.4

Cleaning Observation Results

Farm; H Date; 18.5.82 p.m.

Meter Readings

	Initial	Final	Difference
Electricity	23442.8	23453.6	10.8
Water	148748.8	148885.4	136.6

Temperature Recordings

Time	Water Temperatures °C				Comments
	Tap	Trough		Return	
		Hot	Cold		
6:09	71	66	13		Cold rinse, discharge to waste
	70	66	13		
10	70	66	14	14	
	70	66		14	
11	69	66		13	Hot wash starts, discharge to waste
	69	66		15	
12	67	66		19	
	67	66		25	
13	66	65		30	
	67	65		40	
14	67	64		45	Chemicals added
	67	64		48	
15	68	63		50	Circulation starts
	67	63		50	
16	65	57		52	
	65	57		52	
17	63	56		53	Hot tap off
		56		53	
18		56		52	
		56		52	
19		54		52	
		54		52	End of circulation, discharge to waste
20		53	11	51	Cold rinse, discharge to waste
			11	51	
21			12	48	
			12	36	
22			12	27	
			12	25	
23				22	

Table A1.3.5

Cleaning Observation Results

Farm; H Date; 19.5.82 a.m.

Meter Readings

	Initial	Final	Difference
Electricity	23453.6	23464.6	11.0
Water	148885.4	149003.3	117.9

Temperature Recordings

Time	Water Temperatures °C				Comments
	Tap	Trough		Return	
		Hot	Cold		
9:53	73	67	11		Cold rinse, discharge to waste
	67	67	11	15	
54	67	67	11	13	
	67	66	11	13	
55	67	66	11	12	
	67	66		16	Hot wash starts, discharge to waste
56	67	66		21	
	69	66		33	
57	72	66		38	
	73	66		37	
58	76	66		35	Hot tap off, chemicals added
		66		42	Circulation starts
59		54		51	
		54		51	
10:00		53		54	
		53		52	
01		53		52	
		52		50	
02		50		49	
		48		49	
03		47		47	
		46		45	End of circulation, discharge to waste
04			11	46	Cold rinse, discharge to waste
			11	44	
05			11	41	
			11	29	
06			11	23	
			11	23	
07				21	
				19	
08				18	

Table A1.3.6.

Cleaning Observation Results

Farm; H   Date; 11.8.82 p.m.

Meter Readings

	Initial	Final	Difference
Electricity	25155.4	25165.7	10.3
Water	162810.0	162750.6	140.6

Temperature Recordings

Time	Water Temperatures °C Tap	Trough Hot	Trough Cold	Return	Comments
16:59	85	74	16		Cold rinse, discharge to waste
	85	79	16	23	
17:00	85	82	16	18	
	85	80	16	18	
01	80	80		19	Hot wash starts, discharge to waste
	79	80		22	
02	78	79		26	
	78	78		37	
03	78	78		46	
	78	77		53	Chemicals added
04	80	75		57	Circulation starts
	79	75		60	
05	79	70		61	Hot tap off
		70		61	
06		68		62	
		67		61	
07		64		61	
		64		61	
08		62		59	
		62		59	
09		60		58	End of circulation
			16	57	Cold rinse, discharge to waste
10			16	56	
			16	55	
11			16	54	
			16	43	
12			16	40	
			16	34	
13				30	
				25	

Table A1.3.7

Cleaning Observation Results

Farm; H Date; 12.8.82 a.m.

Meter Readings

	Initial	Final	Difference
Electricity	25165.7	25176.3	10.6
Water	162750.7	162874.4	123.8

Temperature Recordings

Time	Water Temperatures °C				Comments
	Tap	Trough		Return	
		Hot	Cold		
8:23	86	78	16		Cold rinse, discharge to waste
	83	78	16		
24	82	80	16	17	
	82	80	16	17	
25	82	80		17	Hot wash starts, discharge to waste
	82	80		17	
26	81	78		17	
	83	78		32	
27	85	79		46	
	86	80		53	
28	87	82		56	Hot tap off, chemicals added
		77		59	Circulation starts
29		66		61	
		65		61	
30		63		62	
		62		60	
31		60		58	
		60		57	
32		58		54	
		56		54	
33		55		54	
		53		54	End of circulation, discharge to waste
34			15	53	Cold rinse, discharge to waste
			15	47	
35			16	38	
			16	29	
36			16	26	
			16	23	
37				22	