MILK DEVELOPMENT COUNCIL

Bulk Milk Tanking Cooling Efficiency

Project No. 95/R1/19

1. Summary

The results of this project have shown that some new milk cooling systems (MCS) can cost half as much to run as others. However, in most cases this also means a higher capital cost that cannot normally be justified on running cost savings alone. Other performance related factors such as the speed of cooling and the effect of 'hidden costs' such as building alterations and electricity supply reinforcement tend to be more important.

Although there are exceptions, the following conclusions apply to the majority of farms looking to update their MCS:

- The new system will cost less to run than the existing one
- The difference in running cost between new systems is not normally the deciding factor
- The total installed cost, ease of integration within existing farm limitations and dealer support are the most important factors to consider when purchasing a new MCS

The results of this project have been widely accepted by all sides of the industry and have been used by farmers, manufacturers, milk buyers and consultants to form the basis of a purchasing decision that can affect the dairy farming business for in excess of twenty years.

In addition to the exhibitions attended by the Farm Energy Centre (FEC), the results have been very widely publicised by the technical and specialist press and radio interviews. The largest number of enquiries have come from farmers telephoning the FEC to discuss their own individual situation. In most cases, by the end of the call, the farmers have decided which system is best matched to their requirements. In each case the results of the project were sent for reference and to reinforce the points discussed.

To date in excess of 500 enquiries specifically relating to milk cooling systems have been handled by engineers at the Farm Energy Centre. Although the project has been completed the Farm Energy Centre will continue to promote the results of this project to as wide an audience as possible as part of the service it provides farmers on behalf of the Regional Electricity Companies.

2. Introduction

Since deregulation of the milk market there has been a marked increase in the number of new or upgraded MCS installed. This has been due to two main factors:

- Increasing herd size to reduce production costs
- The move towards every other day collection (EODC) by some of the milk buyers

Many of the equipment manufacturers promoted running cost as a buying factor when comparing one MCS to another. This had the effect of increasing farmer awareness, however there was a lack of up to date, reliable and independent data comparing one cooling system (not manufacturer) to another.

Before this project was completed the only information available was that brought together from a number of different sources by the Farm Energy Centre over 10 years ago. These included work carried out by the Farm Energy Centre itself, Fabdec, NORWEB and the National Institute for Research in Dairying. Advances in technology, changes in normal working practice and increasing food hygiene standards all brought into question the applicability of these figures to the current situation. There was therefore the need for up to date independent information relating not only to running costs but also the other factors influencing the choice of a new MCS.

Twelve on farm MCS were monitored to assess their performance characteristics and to identify any other issues of relevance when considering the purchase of a new system. Monitoring included energy consumption, water consumption (where applicable) and milk temperatures at key points throughout. This enabled the running cost, speed of cooling and many other less obvious characteristics to be assessed.

3. Site selection

3.1 Overview of different cooling systems

3.1.1 Tank type

3.1.1.1 Ice bank tank (IB)

An IB tank works by using a small compressor / compressors to build up a reserve of 'coolth' in the form of ice over a long period of time (7-14 hours/day). The ice is formed on copper pipes through which the refrigerant passes. The ice in turn is surrounded by water at close to freezing point.

When milk cooling is required contact between the chilled water and the outer surface of the milk holding vessel is facilitated by two different means:

- Sump and spray - the ice reserves are in the base of the tank and the chilled water is sprayed onto the outer surface of the milk holding vessel using a pump and dribble bars
- Ice jacket - the ice reserves are formed around the milk holding vessel and the chilled water is in continuous contact with its outer surface

3.1.1.2 Direct expansion tank (DX)

In a DX tank the refrigerant is placed in direct contact with the outer surface of the milk holding vessel. Heat is transferred directly into the refrigerant rather than indirectly through water and ice as with the IB tank.

As there is no means of storing 'coolth' the compressor / compressors only operate when milk cooling is required, this is typically the duration of milking plus 20 minutes. Therefore to be able to satisfy the short term, high speed cooling demand much larger compressors are required.

3.1.2 Pre-cooling

Pre-cooling takes two forms:

- Mains / bore hole water supplied
- Chilled water supplied

Both methods typically use a plate heat exchanger (PHE). The two can be combined in series to give a greater overall cooling effect and tend to be supplied as a single unit known as a two stage plate cooler.

The supply of chilled water can be taken from an existing IB tank or from a separate ice builder unit.

3.1.3 Control systems

Thermostatic control linked with the agitator and water circulation pumps (if required) are essentially standard equipment. Additional control systems relate primarily to an MCS with ice storage facilities i.e. an IB tank or an ice builder.

Without any advanced control an ice storage system will always build ice up to the maximum level possible. As soon as a small amount of ice has melted the compressors will turn on until that level has been restored.

Advanced control systems allow the ice to melt to a lower minimum level before turning the compressors on. If the level of ice is between these two points the compressor can be set to run during periods when the electricity is cheaper (Economy 7). Hence Economy 7 (E7) control systems.

3.1.4 Every other day collection

EODC could have two effects on the characteristics of a MCS:

- Increased running costs
- Lower average milk temperatures

Increased running costs could result from the need to keep the milk cool for a longer period of time. However the heat gain through the insulation of the tank will be the same irrespective of the volume of milk stored. It is affected primarily by the difference in temperature between the milk in the tank and the ambient temperature, the temperature of the tank contents will be the same (4^{o}C) irrespective of the volume stored. Furthermore, the only time when milk will be in the bulk tank when it would otherwise not have been, for every day collection, is between the milk collection time and third milking. This would be typically less than 8 hours.

There would however be a small additional heat gain because of the increased area of the outer surface of the tank. It should be noted that the vast majority of the electrical running cost of a MCS is cooling the milk, not keeping it cool.

The 'dilution' effect of adding warm milk to an increasing volume of cold milk will reduce the peak milk temperature during the third and fourth milking when compared to the first and second milking normally associated with every day collection.

3.2 Selection criteria

The selection of farm installations was based upon the following criteria:

- Bulk tank type - direct expansion or ice bank
- Bulk tank control system (only applicable to ice bank tanks) - none or tariff based
- Pre-cooling (mains/bore hole water) - used or not
- Pre-cooling (chilled water) - used or not
- Herd size - national average approximately 70 cows
- Every day collection / EODC

In addition experience and knowledge of the industry added the following general considerations:

- If chilled water pre-cooling is used the ice used to create it is always produced using E7 based control
- Direct expansion tanks with ice-builders tend only to be used on larger farms

3.3 Farm / milk cooling systems monitored

There was a certain amount of duplication of MCS whereas some combinations were not covered. This was because the combination in question was not common practice (such as an ice bank tank with an ice builder), or the effect of pre-cooling (either mains or chilled water) on the operation of the bulk tank could easily be applied to different tank types and control regimes. Furthermore the average herd size was higher than the national average, this was mainly due to larger farmers being more interested in the performance / cost effectiveness of their MCS. This in turn meant that they were generally more helpful and fully involved throughout the duration of the project.

Table 1 - farm data

Site	Bulk Tank	Bulk Tank	Pre-	Chilled water	Herd	Other notes

	Type/Size	Control	cooling	pre-cooling	size	
1	Ice bank 1,800 l	-	-	-	70	Old installation
2	Ice bank 2,900 l	Tariff based	-	-	100	Old installation
3	Ice bank 1,800 l & 700 l	-	Mains water	-	110	Old installation, 2 tanks
4	Ice bank 4,700 l	Tariff based	Mains water	Chilled water from bulk tank	175	Recent installation
5	Ice bank 3,700	Tariff based	Mains water	Chilled water from bulk tank	100	Old installation Part time EODC
6	Direct expansion 8,000 l	-	-	-	150	Recent installation, EODC
7	Direct expansion 5,200 l	-	-	-	100	Recent installation
8	Direct expansion 2,300 l	-	Mains water	-	85	Recent tank Older plate cooler
9	Direct expansion 6,000 l	-	Bore hole water	-	160	Recent installation
10	Direct expansion 4,200 l	-	-	Chilled water from an ice builder	150	Older installation
11	Direct expansion 5,000 l	-	Mains water	Chilled water from an ice builder	200	Recent installation
12	Direct expansion 12,000 l	-	Mains water	Chilled water from an ice builder	250	Recent installation 3 times a day milking

4. Monitoring / methods of data capture

4.1 Parameters recorded

4.1.1 Milk Production

The data source was the farmers own records which in turn came from the milk collection ticket or monthly statement from the milk buyer.

4.1.2 Electricity consumption

When looking at the running cost of an MCS electricity consumption is the only cost normally considered. Other elements such as the cost of capital, repairs / maintenance etc. are extremely variable and beyond the scope of this project.

As it is considered that all dairy farms should be on a two rate tariff, a standard two rate electricity meter with a time switch was fitted to the supply to the MCS. This meant that the split between E7 (night rate) and day rate electricity consumption could be measured.

4.1.3 Water consumption

The performance of mains / bore hole pre-cooling is normally related to the ratio of water consumed to milk cooled and the temperature reduction of the milk.

Where mains or bore hole water pre-cooling was employed a totalising water meter was installed to measure all the water passing through the PHE.

4.1.4 Temperature

4.1.4.1 Bulk storage tank

This was required to measure the milk temperature and the speed of cooling.

Specially constructed stainless steel probes incorporating a thermistor bead temperature sensor were used. These were normally installed via the dipstick or air ventilation points so that the tip of the sensor was immersed in the milk.

4.1.4.2 Pre-cooling

To fully understand the effect of the PHE it was necessary to record the temperature of the milk and water both entering and leaving it. This gave the amount of cooling carried out by this part of the system and allowed the effect of pre-cooling to be transferred to those systems being monitored that did not have any. In addition the performance of different mains / bore hole PHE installations could be compared. Where mains / bore hole and chilled water pre-cooling were both used two stage plate coolers were used. These effectively combine two PHE in one, the result is that the point at which milk exits the first stage (mains / bore hole) is within the body of the PHE and therefore temperature measurement is not possible. In these cases only the final temperature of the milk after the two stages could be measured.

The use of invasive temperature sensors (direct contact with the liquid) was considered, however this was not possible due to the potential for hygiene problems associated with cleaning the probes whilst in the milk pipeline. Thermistor based temperature sensors were fixed to the surface of metal pipe as close as possible to the plate heat exchanger (PHE) and were insulated to give as true a reading of the actual liquid temperature as practically possible.

4.1.4.3 Compressor operation

The times at which the compressor / compressors operated through the day were required to be able to assess the operation of the control system and to allow modification of the electricity consumption figures according to milking time and tariff periods.

A relay was connected to the compressor itself so that during operation of the compressor a ‘volt free contact’ was made which could then be recognised by the data logging equipment.

4.2 Data logging equipment / measurement frequency

4.2.1 Milk production, electricity / water consumption

Electricity and water consumption were simply read from the appropriate meters or farm records. Milk production data was taken from the farmers own records.

Readings were taken monthly, this was considered to be frequent enough to detect any seasonal variation without imposing too much on the farmer. In most cases monthly records of milk production were kept so integration with normal practice helped to ensure that the readings were taken regularly.

4.2.2 Temperatures and compressor operation

All the temperatures and compressor operation were recorded automatically using an Envirolog data logger. Taking into consideration the operation of the MCS, the limitations of the data logger and the amount of data to be handled, readings were taken every 5 minutes.

It was both impractical and unnecessary to record this data continuously throughout the twelve month period. Data was recorded during four two week periods split across the twelve month monitoring period to identify any variation due to seasonal effects.

5. Results

5.1 Methods of data manipulation / analysis

All calculations and production of graphs was carried out using the spreadsheet Microsoft Excel.

Determination of the key performance characteristics for each site involved the same processes in each case, the only difference being whether or not pre-cooling was fitted. These included:

- Electricity cost pence / 100 litres milk
- Litres of milk cooled per kWh
- Water : Milk ratio
- Speed of cooling
- Plate heat exchanger performance

The main difference being that water consumption and PHE performance was not required on those sites without any form of pre-cooling.

Site 5, an ice bank tank with mains and chilled water pre-cooling included all the above elements. Full details of the data manipulation / analysis for this site is followed by the summary data for each of the remaining sites.

5.1.1 Detailed analysis of site 5

5.1.1.1 Electricity / water consumption

5.1.1.1.1 Raw data

Table 2 below shows the format of the data recorded on a monthly basis by the farmer. It can be seen that the dates of the meter readings do not always coincide with the start of the month, in one particular instance it was 11 days late. The milk production figures however were always the total for that month. Therefore the difference between successive meter readings had to be adjusted to allow for this effect.

Table 2 - meter readings

	Electricity (kWh)		**Water (m^3)**	**Milk (l)**
Date	**E7**	**Normal**		
01-Aug	330	323	39.608	21490
01-Sep	632	830	55.369	29914
01-Oct	887	1291	77.536	49310
01-Nov	1459	1774	118.399	80845
07-Dec	2227	2243	183.952	81884
01-Jan	2746	2655	226.014	82059
01-Feb	3300	3096	286.027	66944
04-Mar	3897	3572	334.986	68568
02-Apr	4409	3819	380.929	63059
12-May	5116	4347	439.410	59180
06-Jun	5559	4713	471.024	46876
30-Jul	6039	5182	496.840	34394
01-Aug	6602	5786	511.525	

5.1.1.1.2 Data correction

The adjustment was carried out by taking the difference between successive meter readings, dividing by the number of days between them, to give an average daily consumption, and multiplying by the number of days in that month.

Example
E7 electricity consumption between 2nd April and 12th May

Actual amount consumed	= 5116 - 4409	= 707 kWh
Number of days between readings		= 40
Therefore average daily consumption	= 707 / 40	= 17.67 kWh
Total consumption during April	= 17.67 x 30	= **530 kWh**

This process was repeated for all the meter readings, including water, to give the corrected monthly consumption figures as shown in table 3 below.

Table 3 - corrected monthly consumption / production figures

	Electricity Use (kWh)		Water Use (m^3)	Milk (l)
	E7	**Normal**		
August	302	507	15.76	21490
September	255	461	22.17	29914
October	572	483	40.86	49310
November	640	391	54.63	80845
December	644	511	52.16	81884
January	554	441	60.01	82059
February	541	431	44.37	66944
March	547	264	49.11	68568
April	530	396	43.86	63059
May	549	454	39.20	59180
June	600	586	32.27	46876
July	545	585	14.23	34394

5.1.1.1.3 Calculation of performance indicators

The electricity costs used in all cases were as follows:
Day rate (07:30 - 00:30 GMT) = 8.5 p / kWh
E7 rate (00:30 - 07:30 GMT) = 2.7 p / kWh

Example
For January

Total cost of electricity	= (554 x 2.7) + (441 x 8.5)= 5244 p	
Cost / 100 litres	= (5244 / 82059) x 100	= **6.39 p / 100 litres**
Total kWh consumed	= 554 + 441	= 995 kWh
Litres milk cooled / kWh	= 82059 / 995	= **82.5 l / kWh**
Water to milk ratio	= (60.01 x 1000) / 82059	= **0.73**

This was applied to the results for each month giving the results shown in table 4 below.

Average figures were taken from the full 12 months use / production and not the average of the actual monthly figures.

Table 4 - monthly performance indicators

	Cost (p/100 litres)	Litres cooled (kWh)	Water to Milk ratio
August	23.9	27	0.73
September	15.4	42	0.74
October	11.5	47	0.83
November	6.3	78	0.68
December	7.4	71	0.64
January	6.4	83	0.73
February	7.7	69	0.66
March	5.4	85	0.72
April	7.6	68	0.70
May	9.0	59	0.66
June	14.1	40	0.69
July	18.7	30	0.41
Average	**8.5**	**63**	**0.68**

5.1.1.2 Speed of cooling

The speed of cooling is quoted in two different ways, these are:

- The milk must have been cooled to less than 4^{o}C within 2 ½ hours of starting milking
- The milk must have been cooled to less than 4^{o}C within ½ hour of finishing milking

The latter is that most commonly quoted by farmers when asked how quickly their milk is cooled, hence the time taken to cool the milk to less than 4^{o}C after completion of milking was used as the value to quantify the speed of cooling of the MCS on each site.

Table 5 overleaf shows a small section of the temperature and compressor operation data recorded by the Envirolog data loggers and imported into Excel. Fig 1 also shows the data for the whole day in graphical form.

To determine the 'speed of cooling' the time at which milking finished must be identified. This was done by following the trend milk in temperature as in table 5. At 05:45 the temperature was 31.75^{o}C indicating that milking was definitely still in progress. The following reading had fallen to 29.5^{o}C this would not necessarily mean that milking had finished because it is still a realistic value (at 05:20 the milk in temperature fell to 28.5^{o}C). However the temperature at 05:55 had fallen further to 26.25^{o}C showing that milking had definitely finished by this time. From this it can be concluded that milking finished at or around 05:50.

Looking at the bulk tank temperature it can be seen that it is down to 4^{o}C before milking had even finished. Therefore the time to cool the milk after the completion of milking was 0 minutes.

This process was repeated for each milking during each of the four intensive monitoring periods to produce an average cooling time for each time of year (see table 6 below).

In this case it is obvious that something 'out of the ordinary' happened during the July monitoring period. The longer than normal cooling times were due to the fact that there was a fault with the chilled water side of the PHE and the mains water side could not be used all the time without allowing the water flow to waste.

Table 5 - raw temperature data

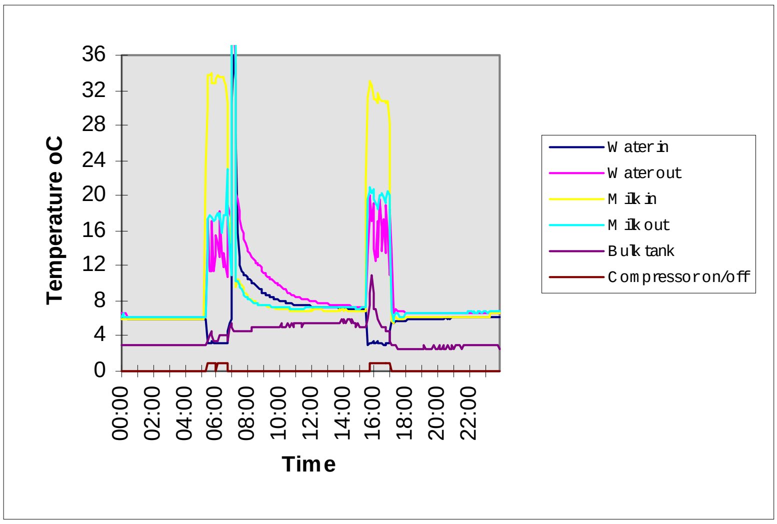
Date	Time	Water in ^{o}C	Water out ^{o}C	Milk in ^{o}C	Milk out ^{o}C	Bulk tank ^{o}C	Compressor 0=off, 1=on

18/04/96	04:20	8	7.75	7.5	7.5	2	1
18/04/96	04:25	8	7.75	7.5	7.5	2	1
18/04/96	04:30	8.25	7.75	7.5	7.75	2	1
18/04/96	04:35	8.25	7.75	7.5	7	2	1
18/04/96	04:40	8	18.25	27.25	10.75	3	1
18/04/96	04:45	8.25	17.25	26.5	13	3.5	1
18/04/96	04:50	8	20	29.75	10.75	4	1
18/04/96	04:55	8	21.25	32.5	8.5	5	1
18/04/96	05:00	7.75	23.75	32.75	12.25	5	1
18/04/96	05:05	8.75	21	31	6.25	4.5	1
18/04/96	05:10	8.25	21.5	32.25	8.75	4.5	1
18/04/96	05:15	8	20.75	33.25	9.25	4.5	1
18/04/96	05:20	8.5	21.25	28.5	9	4.5	1
18/04/96	05:25	8.75	25.5	31.75	8.25	4.5	1
18/04/96	05:30	8.5	22.25	31.5	9	4.5	1
18/04/96	05:35	8	24	33	12.25	4.5	1
18/04/96	05:40	9	18.75	31.5	5.75	4	1
18/04/96	05:45	8	22.75	31.75	11.75	4	1
18/04/96	05:50	9.5	20.5	29.5	6	4	1
18/04/96	05:55	8.5	18.25	26.25	8.75	4	1
18/04/96	06:00	10	15	12	11.75	4	1
18/04/96	06:05	11.25	24.5	32.5	40	3.5	1
18/04/96	06:10	36.5	40	40	40	3.5	1
18/04/96	06:15	40	40	40	40	3.5	1
18/04/96	06:20	40	40	39.75	35.25	3.5	1
18/04/96	06:25	25.25	23.5	15.75	16.25	3	0
18/04/96	06:30	20.75	23	14.75	17.75	3.5	0
18/04/96	06:35	18.75	21.5	13.25	18	3	0
18/04/96	06:40	17.5	20	12	17	3.5	0
18/04/96	06:45	16.75	19	11.25	16	3	0
18/04/96	06:50	16.25	18	10.5	15	3.5	0
18/04/96	06:55	15.5	17	10.25	14.25	3.5	0
18/04/96	07:00	15	16.5	10	13.5	3	0

Table 6 - milk cooling time

Date	**a.m. milking**	**p.m. milking**
October '95	1	3
January '95	1	2
April '96	0	8
July '96	22	29
Average	**6**	**11**

Fig 1. - typical daily temperature profile



5.1.1.3 Plate heat exchanger performance

The ratio of water to milk in a mains / bore hole water fed PHE is a useful indication of its likely performance. However the only true means of quantifying it is to measure the average temperature of the milk leaving the PHE.

This was not as simple as it would seem, the normal operating cycle of a PHE is as follows:

- When the milk pump turns on, the water supply is turned on cooling the milk as it passes through the PHE
- When the milk pump turns off, the water continues to flow for a pre-set time period (typically 15 seconds) and cools the now static contents of the PHE further

The result is that the temperature of the milk leaving the PHE can vary significantly over periods of less than 1 second. In on farm situations it was not possible to measure these changes, the buffering effect of fixing the temperature sensor to the metal milk pipe coupled with a knowledge of the expected performance of each system only allowed the average milk outlet temperature to be assessed.

Experience suggests that with a known water to milk ratio of 0.7 for the period when the data for fig 1 was collected and the fact that the MCS was quite old, the milk would be cooled to 6-10^{o}C. Looking at the data in table 5 a figure of 9^{o}C appears to be typical for this combination.

Similar analysis of the water in / out and milk in / out temperatures helped to build a more complete analysis of the PHE performance. Carrying out this analysis for each milking during each of the monitoring periods produced the average temperatures as shown in table 7 below. As with the cooling times, the July figures were distorted.

Table 7 - average plate cooler temperatures

Date	**Water In (^{o}C)**	**Water Out (^{o}C)**	**Milk in (^{o}C)**	**Milk Out (^{o}C)**
October '95	12	25	32	8
January '95	7	23	30	7
April '96	8	23	31	7
July '96	14	25	31	22
Average	**10**	**24**	**31**	**11**

5.1.1.4 Compressor operation

The normal daily operating times of the compressor can be seen in figure 1. In this instance it can be seen that the compressor starts at 21:15 and runs continuously until 06:20 with a short period of operation around 17:05.

The reason for this operational pattern was that the farm was on an evening / weekend / E7 tariff which gives an additional mid priced tariff period between the hours of 19:30 and 00:30 every week day and between 07:30 and 00:30 on Saturday and Sunday. As the compressors were not capable of making sufficient ice during the seven hour E7 period alone the control system was set to make it operate during the mid priced tariff period thus avoiding operation during the highest price tariff period.

Further analysis of the data allowed the total daily operating times to be calculated along with the split between E7 and day rate operation. The average figures for each monitoring period are shown below in table 8 below.

Table 8 - compressor operation

Date	**Total hours**	**% Economy 7**	**% Day rate**
October '95	9.4	61	39
January '95	10.5	63	37
April '96	9.5	62	38
July '96	12.5	47	53
Average	**10.5**	**58**	**42**

Once again, as with the cooling speed figures, the July figures have been distorted .

5.2 Summary data for each site

5.2.1 Site 1 - ice bank tank, no tariff based control

5.2.1.1 Summary data

Fig 2 - typical daily temperature profile

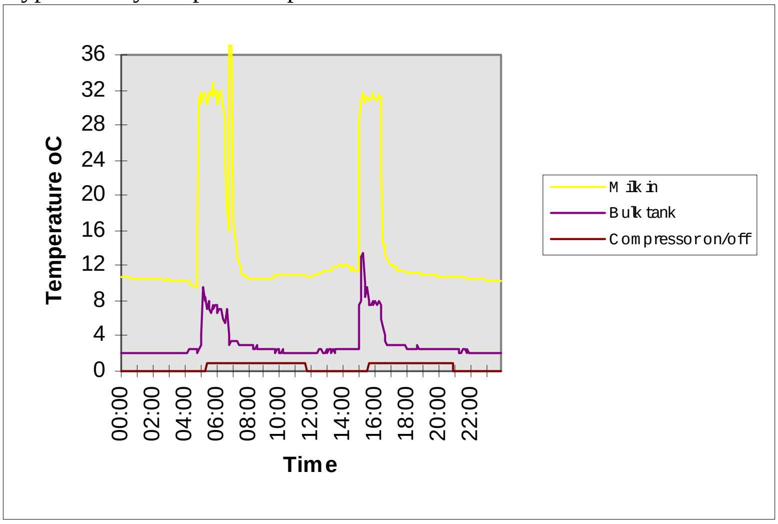


Table 9 - monthly electricity consumption data

Month	% Economy 7	% Day rate	l / kWh	Cost p / 100l
January	17	83	52	14.6
February	13	87	55	14.1
March	14	86	48	16.1
April	23	77	52	13.9
May	20	80	48	15.2
June	18	82	41	17.9
July	19	81	37	19.8
August*	20	80	33	22.2
September	26	74	40	17.3
October	26	74	41	17.1
November	16	84	45	16.9
December	17	83	50	15.2
Average	**19**	**81**	**45**	**16.6**

[1] monitoring started this month

Table 10 - compressor operation / cooling time

Month	Total hours	% Economy 7	% Day rate	a.m. cooling time	p.m. cooling time
August '95	12.4	18	82	23	17
November '95	8.2	11	89	21	16
February '96	9.9	8	92	18	14
May '96	12.4	17	83	30	15
Average	**10.7**	**14**	**86**	**23**	**16**

5.2.1.2 *Comments / overview*

The short peak temperature at the end of the morning milking was due to the parlour circulation cleaning process.

Table 9 shows two significant trends:

- Reduced efficiency (l / kWh) during the summer months, especially August which was much warmer than the average for that time of year.
- A marginal increase in E7 electricity usage when British summer time applied which typically moves the time period from 00:30 - 07:30 to 01:30 - 08:30.

As can be seen from fig 2 compressor operation started shortly after the start of each milking and continued for several hours after milking completed in order to rebuild the ice reserves.

Table 10 shows the varying compressor operating times which were mainly the result of different milk production levels throughout the year. Lower ambient temperatures in the winter months would also tend to reduce compressor operation time for a given volume of milk. There was a slight difference between the percentage E7 / Day rate in this table and table 9. This was because of the operation of the agitator and chilled water pumps at different times to the compressor, using more electricity during the day rate period.

The cooling times, table 10, were within currently accepted standards. The a.m. cooling time was consistently greater than the p.m. milking. This would appear to be due to a longer duration of a.m. milking i.e. a greater volume of milk to be cooled.

5.2.2 Site 2 - ice bank tank with E7 control

Fig 3 - typical daily temperature profile

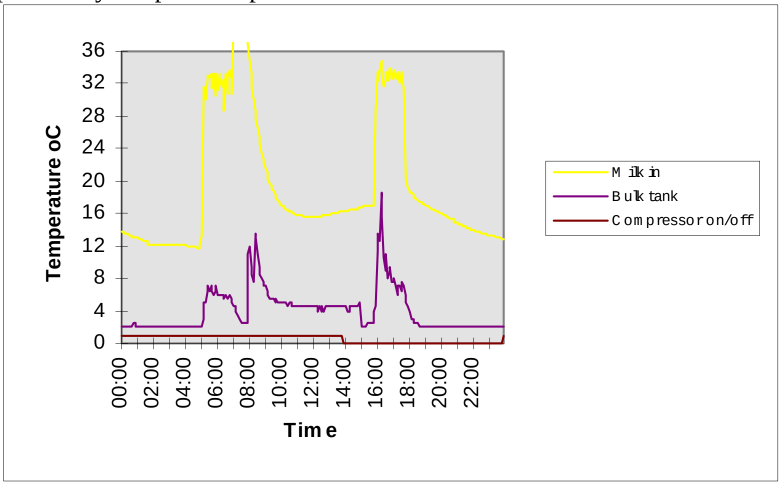


Table 11 - monthly electricity consumption data

Month	% Economy 7	% Day rate	l / kWh	Cost p / 100l
January*	45	55	56	10.5
February	49	51	55	9.4
March	51	49	52	10.7
April	30	70	35	19.6
M/J/J	51	49	44	10.5
August	55	45	42	12.6
September	53	47	44	12.3
October	35	65	44	14.7
November	44	56	53	10.2
December	19	81	56	13.2
Average	**44**	**56**	**49**	**12.0**

* monitoring started this month

Table 12 - compressor operation, cooling time

Month	Total hours	% Economy 7	% Day rate	a.m. cooling time	p.m. cooling time
January '96	13.3	48	52	25	29
April '96	13.8	51	49	26	33
July '96	14.6	48	52	18	25
October '97	11.5	61	39	23	29
Average	**13.3**	**52**	**48**	**23**	**29**

5.2.2.1 Comments / overview

Some of the trends at site 1 were repeated at this site. There were however several significant differences.

A rapid rise in bulk tank temperature shortly after the a.m. milking. An automatic cold water tank washing system used on this farm. This was normally turned on by the tanker driver as soon as the tank had been emptied.

Compressor operating times. This system had an E7 type controller fitted which was set to turn the compressor on at 00:00 and run it until approximately 13:30. If it was set to stop at 07:30, although more than the minimum level of ice remained in the tank, there were insufficient ice reserves to cool the whole of the p.m. milking. This would have forced the compressors to turn on at the minimum ice level at some point during the p.m. milking. This would not have been a problem from a running cost point of view, however the low ice reserves combined with a smaller than standard compressor meant that cooling times would have been adversely affected. Ensuring sufficient ice reserves were built prior to the start of the p.m. milking overcame this problem with the added benefit of reducing the total electricity demand on the farm during milking.

In table 11 the April and December E7 usage was particularly low. This was caused by the incorrect setting of the E7 controller.

The p.m. cooling time was very close to the accepted standard and even exceeded it on one occasion. The farm operates close to 12 hour milking resulting in similar levels of milk production from each milking. The difference in cooling times is expected to be due to a lower surface area of the milk holding vessel being in direct contact with the milk (1/2 full), resulting in a lower rate of heat transfer between the milk and chilled water.

5.2.3 Site 3 - ice bank tank with a mains water PHE

Fig 4 - typical daily temperature profile

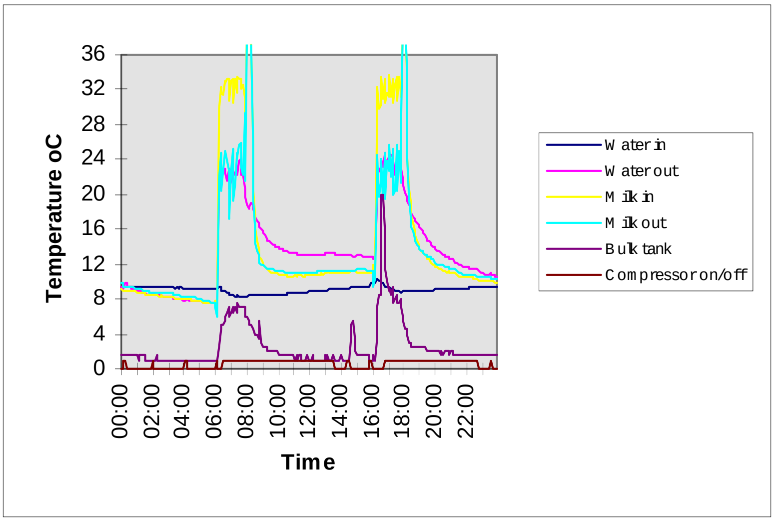


Table 13 - monthly electricity / water consumption data

	Electricity				Mains PHE
Month	**% Economy 7**	**% Day rate**	**l / kWh**	**Cost p / 100l**	**Water : Milk**
January	9	91	71	11.3	0.41
February	8	92	73	11.1	0.41
March	9	91	69	11.6	0.40
April	15	85	57	13.5	0.40
May	14	86	52	14.9	0.31
June	14	86	41	18.6	0.33
July	15	85	38	20.1	0.53
August	16	84	39	19.4	0.44
September	14	86	45	17.1	0.46
October	13	87	50	15.5	0.45
November*	9	91	60	13.3	0.43
December	9	91	71	11.2	0.44
Average	**11**	**89**	**58**	**13.5**	**0.40**

* monitoring started this month

Table 14 - compressor operation

Month	Total hours	% Economy 7	% Day rate
October '95	14.0	11	89
January '95	9.2	10	90
April '96	13.0	16	84
July '96	14.8	16	84
Average	**12.8**	**13**	**87**

Table 15 - plate cooler temperatures, milk cooling time

Month	Water in (^{o}C)	Water out (^{o}C)	Milk in (^{o}C)	Milk out (^{o}C)	a.m. cooling time	p.m. cooling time
October '95	15	27	33	24	3	18
January '95	8	23	33	19	45	0
April '96	9	23	32	22	33	0
July '96	17	29	35	28	26	20
Average	**12**	**26**	**33**	**23**	**21**	**19**

5.2.3.1 Comments / overview

The temperature trends in fig 4 were broadly similar to those in previous sites. The exceptions were that circulation cleaning was carried out twice each day resulting in an additional peak after the p.m. milking. The tank was also cold washed in the early afternoon.

The somewhat erratic nature of the PHE specific temperatures in fig 4, milk out in particular, reinforce the measurement problems described in section 5.1.1.3. However, for this particular day it clearly shows an average milk temperature reduction of around 10^{o}C.

The data in tables 13-15 is confused to some degree by the fact that a new direct to line parlour was installed during July, replacing an old jar parlour. Between December and March both tanks were used as opposed to only one during the remainder of the year.
The new parlour coincided with a slight increase in the water:milk ratio, although this was not reflected in an improved MCS performance. Although this was not proven it is expected that the milk from a direct to line parlour will be warmer than that from a jar parlour as it reaches the MCS much more quickly, this could explain the lack of improvement in MCS efficiency expected as a result of the increased water: milk ratio.

Temperature monitoring was only carried out on the larger of the two tanks, this was the one filled first when both tanks were used. An every day ice bank tank is designed to be able to satisfactorily cool up to 60% of its volume during one milking cycle. Between January and

April volumes in excess of this were added to the tank during the a.m. milking with relatively little added during the p.m. milking. The effect on the cooling times can be clearly seen in table 15. The correct way of operating such a system would be to half fill each tank first, before completely filling them during the a.m. milking.

Note, fig 4 shows the operation when only one tank was used.

5.2.4 Site 4 - ice bank tank with E7 control and two stage plate cooler

Fig 5 - typical daily temperature profile

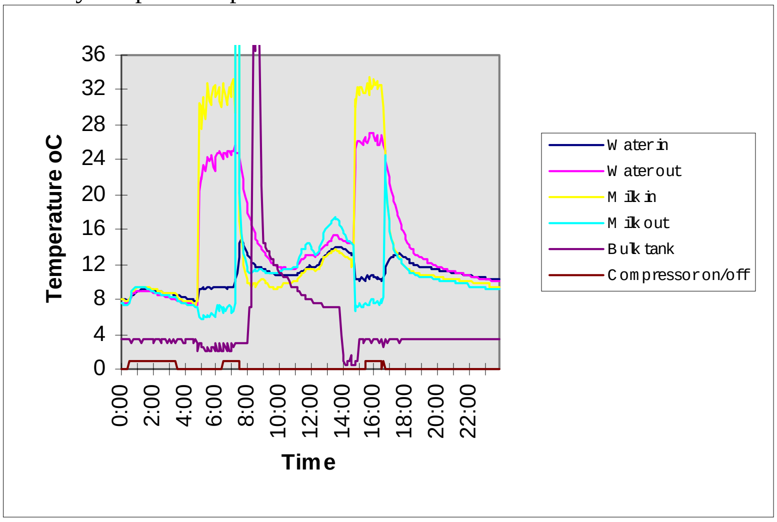


Table 16 - monthly electricity / water consumption data

	Electricity				Mains PHE
Month	**% Economy 7**	**% Day rate**	**l / kWh**	**Cost p / 100l**	**Water : Milk**
January	53	47	101	5.4	0.64
February	58	42	107	4.8	0.63
March	61	39	104	4.8	0.67
April	71	29	90	4.8	0.67
May	73	27	85	5.0	0.73
June	67	33	75	6.2	0.67
July	60	40	59	8.5	0.65
August*	54	46	54	9.9	0.29
September	52	48	61	9.1	0.41
October	44	56	63	9.4	0.41
November	40	60	68	9.1	0.42
December	56	44	95	5.5	0.42
Average	**57**	**43**	**76**	**6.8**	**0.56**

* monitoring started this month

Table 17 - compressor operation

Month	Total hours	% Economy 7	% Day rate
August '95	7.4	62	38
November '95	6.1	41	59
February '96	3.9	54	46
May '96	5.5	83	17
Average	**5.7**	**60**	**40**

Table 18 - plate cooler temperatures, milk cooling time

Month	Water in (^oC)	Water out (^oC)	Milk in (^oC)	Milk out (^oC)	a.m. cooling time	p.m. cooling time
August '95	20	32	33	9	0	0
November '95	11	27	31	7	0	0
February '96	5	24	31	5	0	0
May '96	10	25	32	7	0	0
Average	**12**	**27**	**32**	**7**	**0**	**0**

5.2.4.1 *Comments / overview*

As this site used a two stage PHE, mains and chilled water from the ice bank tank, the milk was significantly cooled before it even entered the bulk tank. On the day shown in fig 5 the milk was cooled to around 7^{o}C, the result being that the temperature in the bulk tank itself never rose above 4^{o}C.

In addition to the circulation cleaning temperature peak after the a.m. milking there was also one associated with the bulk tank being hot washed.

Compressor operation occurred primarily during the E7 period, however a number of factors resulted in operation during the p.m. milking period. The first was that the cooling capacity of the ice reserves for this particular tank were less than is considered to be standard. makes the tank much more compact, hence it can fit in more confined spaces. Second, the mains side of the PHE had a low water:milk ratio therefore not removing as much heat from the milk as might have been expected. The final reason was essentially user related which meant that the time switch on the E7 control was set to turn off an hour early. Minor time switch alterations were implemented in late November, this was reflected in the difference between the November and December % E7 figures in table 16. This was still unsatisfactory from a running cost point of view and he was finally convinced of the benefits of operating the MCS as it should have been. This is reflected in the May data in table 17 and the April/May E7 data in table 16. The June - July E7 figures in table 16 reflected increasing milk yield combined with reducing mains PHE performance (warmer mains water).

A noticeable increase in the water:milk ratio occurred from January onwards. This coincided with the water supply to the parlour being renewed / changed.

5.2.5 Site 5 - ice bank tank with E7 control and two stage plate cooler

Fig 6 - typical daily temperature profile

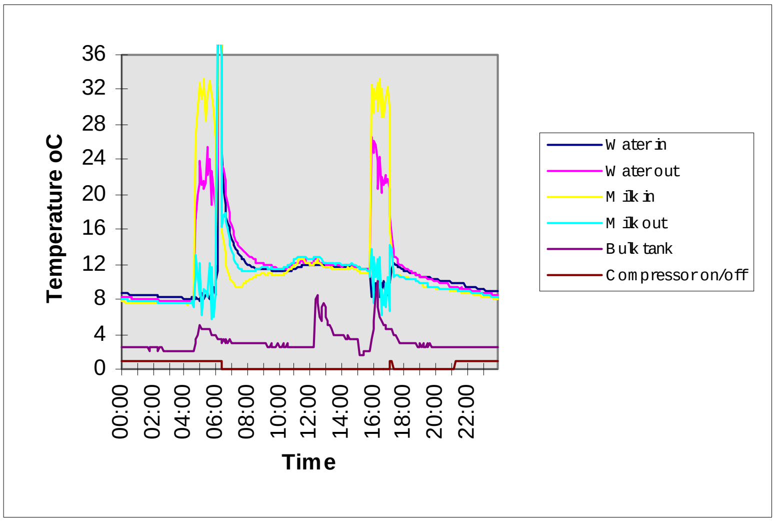


Table 19 - monthly electricity / water consumption data

	Electricity				Mains PHE
Month	**% Economy 7**	**% Day rate**	**l / kWh**	**Cost p / 100l**	**Water : Milk**
January	55	45	82	6.4	0.73
February	56	44	69	7.7	0.66
March	67	33	85	5.4	0.72
April	57	43	68	7.6	0.70
May	55	45	59	9.0	0.66
June	51	49	40	14.1	0.69
July	48	52	30	18.7	0.41
August*	37	63	27	23.9	0.73
September	36	64	42	15.4	0.74
October	54	46	47	11.5	0.83
November	62	38	78	6.3	0.68
December	56	44	71	7.4	0.64
Average	**56**	**43**	**63**	**8.5**	**0.68**

*monitoring started this month

Table 20 - compressor operation

Month	Total hours	% Economy 7	% Day rate
October '95	9.4	61	39
January '95	10.5	63	37
April '96	9.5	62	38
July '96	12.5	47	53
Average	**10.5**	**58**	**42**

Table 21 - plate cooler temperatures, milk cooling time

Month	Water in (^oC)	Water out (^oC)	Milk in (^oC)	Milk out (^oC)	a.m. cooling time	p.m. cooling time
October '95	12	25	33	8	1	3
January '95	7	23	33	7	1	2
April '96	8	23	32	7	0	8
July '96	14	25	33	22	22	29
Average	**10**	**24**	**33**	**11**	**6**	**11**

5.2.5.1 Comments / overview

This system was essentially the same as site 4, it was however much older and had a smaller PHE. Larger ice reserves, in proportion to milk storage capacity, and a smaller compressor resulted in much longer compressor operating times. This meant that the compressor had to operate out of the E7 period. The farm was on a slightly more complex tariff that gave a mid priced tariff during the evening / early night, by changing the settings on the E7 controller it was possible to make the compressors run during this period rather than during the most expensive day rate period. Initially the start time, around 20:00-22:00, was set too early resulting in maximum ice being built up well before the end of the E7 period. Delaying the start time ensured that maximum advantage could be taken of the E7 period whilst still avoiding the day rate period. The effect of this can be clearly seen between the September and October E7 data in table 19.

The August data in table 19 was unusual and can only be attributed to a meter reading error at the start of the project.

The July data in table 21 also appears to be at fault, this was actually the result of on farm problems with the PHE which are also reflected in a reduced average water:milk ratio for July (table 19).

5.2.6 Site 6 - direct expansion tank with EODC

Fig 7 - typical daily temperature profile

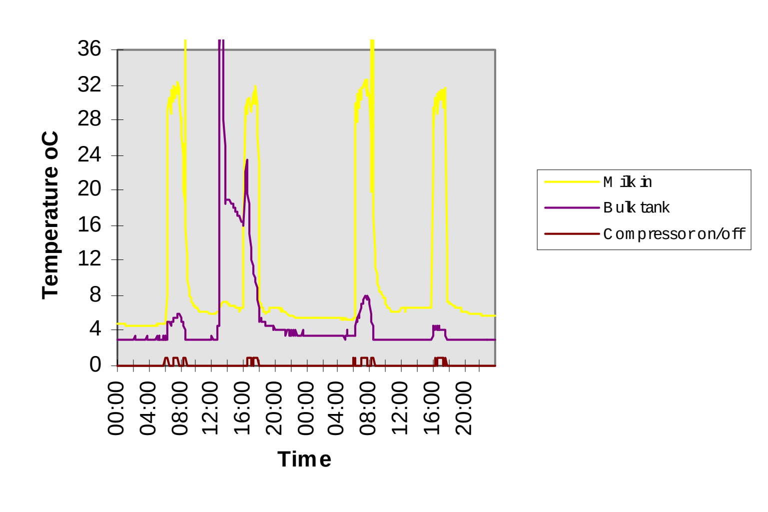


Table 22 - monthly electricity consumption data

Month	% Economy 7	% Day rate	l / kWh	Cost p / 100l
January	23	77	92	7.8
February	29	71	68	10.0
March	32	68	103	6.5
April	32	68	96	6.9
M/J	47	53	72	8.1
July*	39	61	60	10.3
August	37	63	61	10.5
September	38	62	77	8.2
October	31	69	62	10.8
November	23	77	80	9.0
December	23	77	99	7.2
Average	**35**	**65**	**75**	**8.5**

* monitoring started this month

Table 23 - compressor operation

Month	Total hours	% Economy 7	% Day rate
August ‘95	4.7	45	55
November ‘95	3.9	25	75
February ‘96	3.0	28	72
May ‘96	3.7	53	47
Average	**3.8**	**38**	**62**

Table 24 - milk cooling time

Month	Milking 1	Milking 2	Milking 3	Milking 4
August ‘95	25	21	30	24
November ‘95	5	0	10	5
February ‘96	5	14	7	17
May ‘96	10	17	7	14
Average	**12**	**13**	**14**	**15**

5.2.6.1 Comments / overview

Fig 7 shows 2 days / 4 milkings and demonstrates the ‘dilution’ effect of EODC as discussed in section 3.1.4. The peak bulk tank temperature coincides with it being hot washed after collection of the milk. Milking 1 being the first milking to enter the tank after it had been emptied (16:00).

The cooling times, table 24, were especially high during August '95 compared with the other monitoring periods. As with some previous sites this was due to abnormally high ambient temperatures during that particular monitoring period.

There was a small but consistent trend for cooling times to increase as a greater volume of milk was in the tank. Although unproven this could be due to a progressively lower average milk temperature in the tank which in turn reduces the performance of the compressor.

Being a DX tank the compressors only operated when cooling was required i.e. during and shortly after each milking. Therefore the amount of electricity consumed during the E7 period was highly dependant on the a.m. milking time.

It should be noted that the compressors did not operate at all between each milking demonstrating a very high level of bulk tank insulation and no appreciable increase in running cost associated with maintenance of milk temperature once cooled (see section 3.1.4).

5.2.7 Site 7 - direct expansion tank with EODC

Fig 8 - typical daily temperature profile

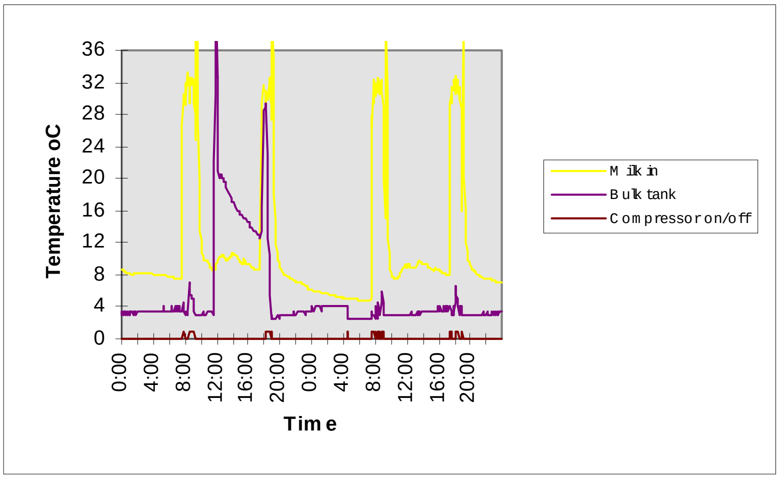


Table 25 - compressor operation

Month	Total hours	% Economy 7	% Day rate
February '96	5.6	5	95
May '96	4.5	24	76
August '96	2.7	20	80
November '96	5.2	1	99
Average	**4.5**	**13**	**87**

Table 26 - milk cooling time

Month	Milking 1	Milking 2	Milking 3	Milking 4
February '96	4	3	0	0
May '96	5	0	0	0
August '96	10	0	0	0
November '96	6	0	0	0
Average	**6**	**2**	**0**	**0**

Table 27 - monthly electricity consumption data

Month	% Economy 7	% Day rate	l / kWh	Cost p / 100l
January*	14	86	99	7.8
February	15	85	109	7.0
March	18	82	101	7.4
April	34	66	96	6.8
May	31	69	91	7.3
June	29	71	79	8.7
July	33	67	72	9.1
August	33	67	70	9.5
September	34	66	71	9.1
October	31	69	73	9.2
November	19	81	93	8.0
December	20	80	82	9.0
Average	**26**	**74**	**87**	**8.0**

* monitoring started this month

5.2.7.1 Comments / overview

Although the same type of MCS as site 6 there were a number of differences that affected its performance.

- A newer potentially more efficient type of compressor was used
- The parlour was quite small for the herd size giving a more extended milking time
- The start of the a.m. milking was later than most of the other sites.
- Block calving gave a highly variable milk output

The size and duration of the peak bulk tank temperature at the start of milking 1 was a result of low milk production at this particular time of year. With a DX tank the paddle of the agitator must be covered before cooling is started otherwise there is the risk of freezing the milk because it is in direct contact with the refrigerant which will typically be between 0 and -5^{o}C. This is not a problem with IB tanks because the chilled water temperature can never fall below 0^{o}C. This had a slight effect on the cooling time of milking 1, but as can be seen they were all generally very low. This was a result of the longer milking times giving the compressors more time to cool the milk before the end of milking. Thus the reason for the second cooling speed criteria of ‘down to 4^{o}C within 2 ½ hours of starting milking’ (section 5.1.1.2.).

The effect of a later than normal start to the a.m. milking was reflected in the low E7 usage in tables 25 and 27. This was however counteracted by a higher efficiency (l / kWh) to give a marginally lower running cost than site 6.

5.2.8 Site 8 - direct expansion tank with a mains water PHE

Fig 9 - typical daily temperature profile

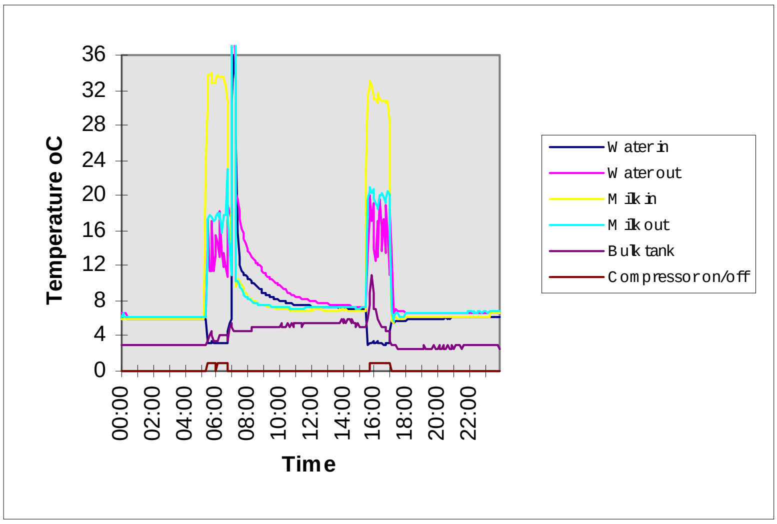


Table 28 - monthly electricity / water consumption data

	Electricity				Mains PHE
Month	**% Economy 7**	**% Day rate**	**l / kWh**	**Cost p / 100l**	**Water : Milk**
January	53	47	153	3.7	1.15
February	54	46	157	3.6	1.46
March	52	48	191	2.9	0.60
April	51	49	170	3.3	0.94
May	48	52	136	4.1	1.10
June	47	53	123	4.5	1.06
July	49	51	113	4.9	1.00
August*	46	54	108	5.0	1.00
September	48	52	117	4.8	1.00
October	47	53	123	4.6	0.91
November	52	48	125	4.5	1.11
December	54	46	174	3.2	0.87
Average	**50**	**50**	**139**	**4.0**	**1.0**

* monitoring started this month

Table 29 - compressor operation

Month	Total hours	% Economy 7	% Day rate
August '95	3.2	47	53
November '95	3.1	55	45
February '96	2.3	49	51
May '96	2.7	43	57
Average	**2.8**	**49**	**51**

Table 30 - plate cooler temperatures, milk cooling time

Month	Water in (^oC)	Water out (^oC)	Milk in (^oC)	Milk out (^oC)	a.m. cooling time	p.m. cooling time
August '95	21	27	35	27	16	34
November '95	10	19	32	22	7	8
February '96	3	16	32	18	1	6
May '96	10	19	34	21	5	23
Average	**11**	**20**	**33**	**22**	**7**	**18**

5.2.8.1 *Comments / overview*

The most significant factor affecting the performance of the MCS on this site was the very early start to the a.m. milking. This resulted in virtually all the a.m. milking being cooled during the E7 period even though a DX tank was being used. On occasions more E7 electricity was used than day rate, this can be attributed to the fact that cows generally produce more milk during the a.m. milking than during the p.m. milking.

The high efficiency of the system, due to the use of a mains PHE, combined with the high level of E7 use gave very low running costs. The water:milk ratios for February and March were both unusual and could be explained by a water meter reading error as all the other data appears to follow reasonable trends.

As with other systems monitored during August '95 the cooling times were much higher than the remaining monitoring periods.

As with site 7 the p.m. milking (milking 1) cooling times were generally higher as a result of the risk of freezing with DX tanks.

5.2.9 Site 9 - direct expansion tank with a bore hole water PHE and EODC

Fig 10 - typical daily temperature profile

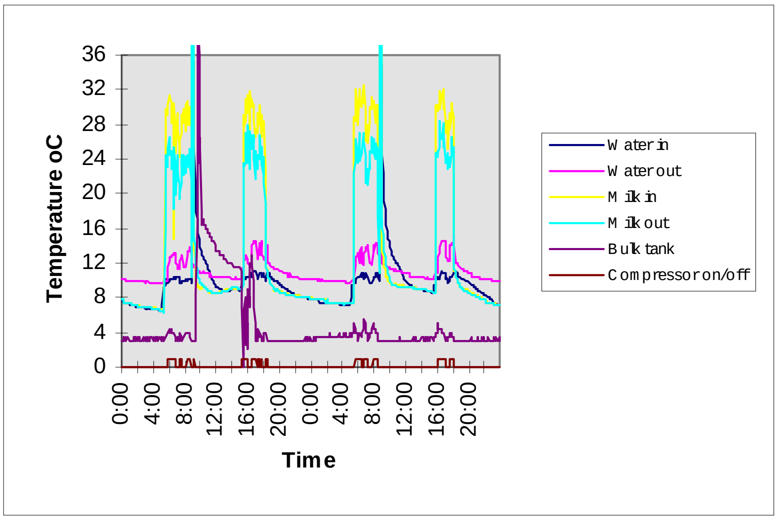


Table 31 - monthly electricity / water consumption data

	Electricity				**Mains PHE**
Month	**% Economy 7**	**% Day rate**	**l / kWh**	**Cost p / 100l**	**Water : Milk**
January	45	55	137	4.3	1.40
February	43	57	125	5.0	1.52
March*	27	73	104	6.7	1.57
April	69	31	190	2.4	1.56
May	50	50	106	5.3	2.05
June	38	62	114	5.6	2.16
July	42	58	109	5.6	2.01
August	43	57	124	4.9	1.77
September	44	56	84	7.1	2.69
Oct/Nov	42	58	120	5.1	2.32
December	42	58	161	3.8	1.80
Average	**43**	**57**	**119**	**5.0**	**1.9**

* monitoring started this month

Table 32 - compressor operation

Month	Total hours	% Economy 7	% Day rate
February '96	4.7	38	62
May '96	5.7	47	53
August '96	5.8	44	56
November '96	3.6	35	65
Average	**5.0**	**41**	**59**

Table 33 - plate cooler temperatures

Month	Water in (°C)	Water out (°C)	Milk in (°C)	Milk out (°C)
February '96	10	15	31	25
May '96	16	20	32	24
August '96	12	17	32	26
November '96	12	16	30	25
Average	**12.5**	**17**	**31**	**25**

Table 34 - milk cooling time

Month	Milking 1	Milking 2	Milking 3	Milking 4
February '96	0	0	0	0
May '96	0	0	0	0
August '96	0	0	0	0
November '96	0	0	0	0
Average	**0**	**0**	**0**	**0**

5.2.9.1 Comments / overview

From the milk in temperatures it can be seen that each milking was split into two parts. This gave the MCS some 'breathing space' and combined with the PHE resulted in the milk always being cooled to 4°C by the time milking was finished.

The performance of the PHE was confused by the fact that, unlike most systems, the water flowed continuously regardless of milk pump operation. This gave a much higher water:milk ratio without a significant improvement in milk temperature reduction. In this case the water was essentially free (bore hole), therefore even if it was flowing to waste there was no economic reason to add a solenoid valve linked to the milk pump operation.

The electricity data for March - April was unusual and was more than likely the result of a meter reading error.

5.2.10 Site 10 - direct expansion tank with an ice builder

Fig 11 - typical daily temperature profile

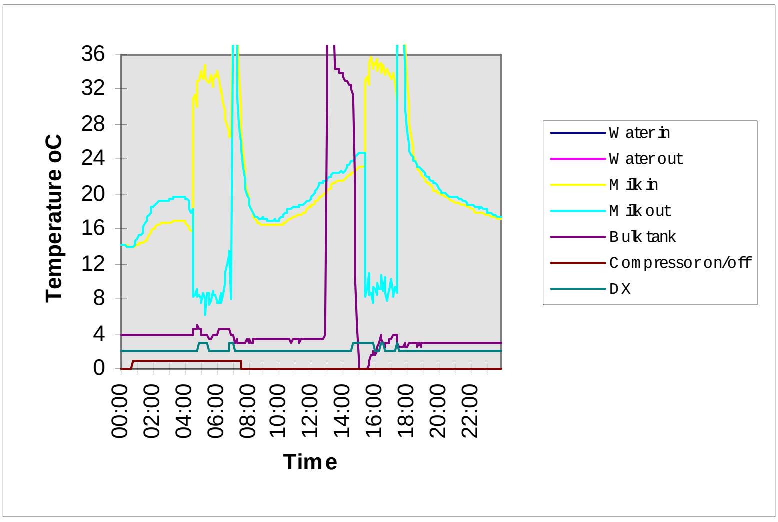


Table 35 - monthly electricity consumption data

Month	% Economy 7	% Day rate	l / kWh	Cost p / 100l
January	80	20	57	6.7
February	81	19	59	6.5
March	81	19	61	6.3
April	82	18	54	7.0
May	82	18	50	7.5
June	83	17	41	9.1
July	82	18	36	10.4
August	82	18	38	10.0
September	82	18	40	9.3
October				
November*	78	22	51	7.8
December	81	19	56	6.8
Average	**81**	**19**	**49**	**7.7**

* monitoring started this month

Table 36 - compressor operation

	Ice builder			DX		
Month	**Total hours**	**% E7**	**% Day rate**	**Total hours**	**% E7**	**% Day rate**
January '96	6.9	99	1	5.3	33	67
April '96	6.9	98	2	2.7	15	85
July '96	6.8	99	1	2.7	37	63
Average	**6.9**	**99**	**1**	**3.6**	**28**	**72**

Table 37 - plate cooler temperatures, milk cooling time

Month	Milk in (^{o}C)	Milk out (^{o}C)	a.m. cooling time	p.m. cooling time
January '96	30	12	0	5
April '96	34	9	0	0
July '96	34	11	0	0
Average	**33**	**11**	**0**	**2**

5.2.10.1 Comments / overview

The MCS on this site whilst only a few years old was one of the first of its type to be installed, as a result its installation but not operation was slightly different to current practice.

The difference was that separate compressors were used for the DX and IB elements. Current practice is to use one set of compressors to supply both parts with solenoid valves controlling the flow of the refrigerant. From a monitoring point of view this gave the added benefit of being able to record the operation of the DX and IB elements separately.

Since installation of the MCS milk production had increased and at peak production there was insufficient ice for it to operate as designed. This caused an increased use of the DX element at certain times of the year (January '96, table 36).

Fig 11 shows a day during normal operation of the system. Operation of the IB compressor can clearly be seen as only occurring during the E7 period whilst the DX compressor operated intermittently during each milking.

An indication of the potential for freezing milk with a DX tank can be seen on the bulk tank temperature line just before the start of the p.m. milking where the cooling system had already been turned on reducing the temperature to below 0°C.

The milk was always cooled to 4°C by the end of each milking apart from the January p.m. milking due to the lack of ice as described earlier.

The site itself was actually closed down one month before the end of the project hence the incomplete set of data.

5.2.11 Site 11 - direct expansion tank with ice builder and two stage plate cooler

Fig 12 - typical daily temperature profile, no mains PHE

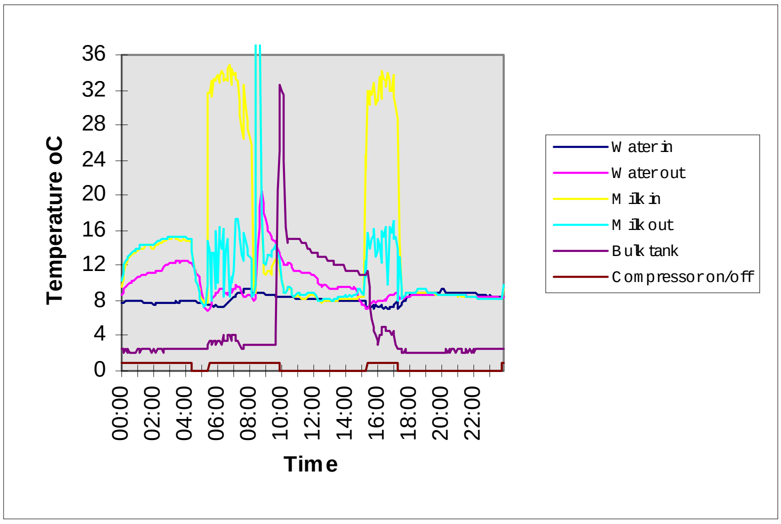


Fig 13 - typical daily temperature profile, no chilled water PHE

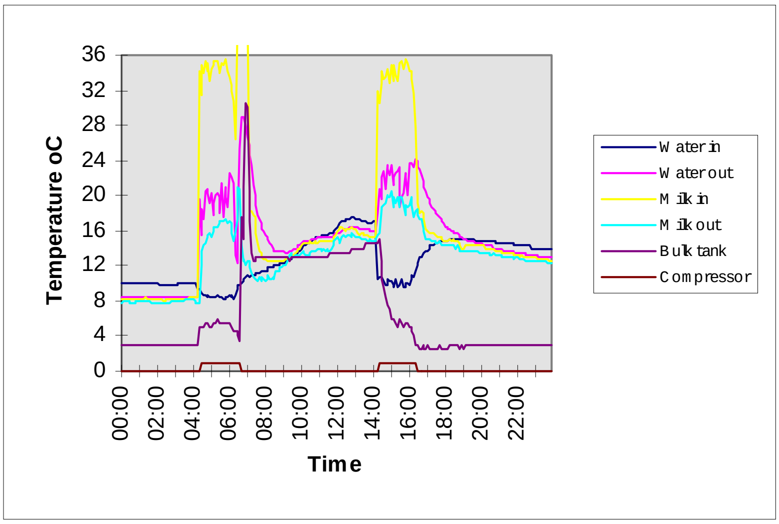
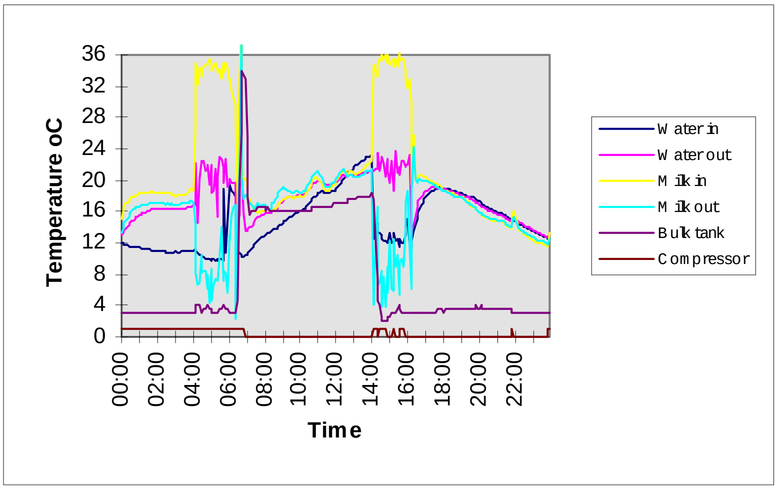


Fig 14 - typical daily temperature profile, correct operation



5.2.11.1 Comments / overview

A multitude of problems, due to both the equipment and its operation meant that little meaningful operating data was obtained. Fortunately this type of MCS was one of those duplicated. It was possible however to measure the temperature based performance of this system operating in several different configurations, though not over long periods of time.

Fig 12 shows the performance when operating without the mains water PHE (same as site 10). The compressor operation started at around 00:00 and continued until just before the start of the a.m. milking when maximum ice had been built. Because the ice builder capacity had been sized allowing for the mains PHE, its capacity at this instance was inadequate. In order to maintain the speed of cooling the compressors were allowed to operate, building additional ice, until 10:00.

Fig 13 shows the performance when operating without the chilled water PHE (same as sites 8,9). The performance of the mains PHE in this instance was very good, in excess of 15°C was removed from the milk before it entered the bulk tank.

Fig 14 shows the performance of the MCS as it should have been operating all the time. The temperature of the milk entering the tank was around 6-8°C and the temperature in the tank never rose above 4°C.

Under ideal operating conditions this type of MCS should have been able to cool the milk to 4°C before it even entered the tank. The limiting factor appeared to be a high capacity milk pump which reduced the residence time of the milk within the PHE, thus reducing the time available for heat transfer to take place.

5.2.12 Site 12- direct expansion tank with ice builder and two stage plate cooler

Fig 15 - typical daily temperature profile

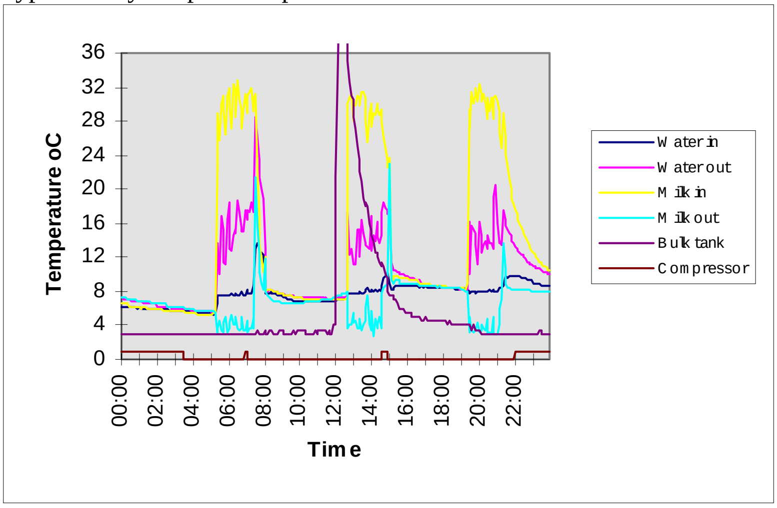


Table 38 - monthly electricity / water consumption data

	Electricity				Mains PHE
Month	**% Economy 7**	**% Day rate**	**l / kWh**	**Cost p / 100l**	**Water : Milk**
January	40%	60%	123	5.0	1.32
February	37%	63%	156	4.1	1.47
March	28%	72%	137	5.0	1.42
A/M/J/J	66%	34%	89	5.3	1.44
August*	86%	14%	134	2.6	1.52
September	45%	55%	68	8.7	1.23
October	46%	54%	86	6.8	1.33
November	46%	54%	94	6.2	1.20
December	41%	59%	120	5.1	1.26
Average	**52**	**48**	**101**	**5.4**	**1.3**

* monitoring started this month

Table 39 - compressor operation

Month	Total hours	% Economy 7	% Day rate
October '95	9.8	54	46
January '95	8.6	54	46
April '96	7.1	48	52
July '96	10.4	63	37
Average	**9.0**	**55**	**45**

Table 40 - plate cooler temperatures, milk cooling time

Month	Water in (°C)	Water out (°C)	Milk in (°C)	Milk out (°C)	a.m. cooling time	p.m. cooling time	eve. cooling time
October '95	16	20	31	9	0	38	0
January '95	9	15	30	7	0	37	0
April '96	9	18	31	6	0	26	2
July '96	16	24	31	9	0	0	19
Average	**13**	**19**	**31**	**8**	**3**	**25**	**5**

5.2.12.1 Comments / overview

This system was essentially the same as site 11, the major difference being that three times a day milking was carried out. The system was actually sized for EODC, this only affects the size of the bulk tank not the cooling capacity, however during the duration of the project the milk was collected daily.

Fig 15 shows the system operating at its best, the milk entering the tank already being cooled to 4^{o}C. This was not always the case due to the variability of the mains PHE performance, the average temperature of the milk entering the bulk tank was 8^{o}C.

The bulk tank temperature during and after milking 1 (midday) appears to take several hours to fall below 4^{o}C. This was because the tank was so large that it was not possible to immerse the temperature sensor in the milk until part way through the second milking. It was still possible to determine the cooling speed by checking when the compressor turned off (DX operation) towards the end of the milking period.

As with other DX based systems, especially those sized for EODC, the risk of freezing meant that the DX component could not be turned on until part way through the first milking after the milk had been collected. As access between the parlour and tank room was difficult during milking and because the two stage PHE performed so well it was common for the DX element of the MCS not to be turned on until the end of the milking period.

The milk was normally collected just before the midday milking, in July '96 it changed to just afterwards. The effect of this was to shift the longer cooling times from the p.m. milking to the evening milking.

As with site 5, the farm was on a tariff with a mid-priced tariff rate during the evening / early night time. This is reflected by the compressor starting operation at 22:00.

5.3 Discussion

Each site had its own set of circumstances / characteristics that had significant effects on the performance of the MCS especially the running cost. Even where duplication occurred the standard performance characteristics varied depending on several factors:

- Milking time - influences amount of E7 usage, particularly with a DX based MCS
- Mains water PHE performance - dependant on water and milk flow rates, size of PHE, water temperature.
- Tariff - some sites were on a less common tariff which meant that analysis using a 'standard' tariff distorted the results. This meant that the site specific running costs were higher when applied to the standard tariff than if the actual farm tariff had been applied.

It was possible however to draw some general comparisons / conclusions from the data in its site specific form.

When the MCS is operated correctly:

- All the MCS monitored were capable of cooling the milk to 4^{o}C within ½ hour of finishing milking
- The use of a mains / bore hole water fed PHE can significantly reduce running costs
- The use of a mains / bore hole water fed PHE can significantly reduce cooling times when used with a compressor sized for an equivalent system without a PHE
- The use of a chilled water PHE will not significantly reduce running costs when the chilled water supply is from an existing IB tank, but it will increase the speed of cooling

- The use of a chilled water PHE will significantly reduce running costs if the water supply is from an additional ice-builder operating mainly during the E7 period
- The use of a chilled water PHE will ensure that the milk in the bulk tank will be cooled to 4^{o}C by the end of each milking period
- Care needs to be taken with DX tanks, especially those sized for EODC, as freezing of the milk is possible
- IB tanks cannot freeze the milk

6. Running cost comparison

From the individual site analysis in section 5 it is obvious that too many site specific factors have affected the running cost of each MCS. To enable a direct comparison to be made between the running cost of each MCS, the key performance characteristics had to be extracted and applied to a standard set of conditions. These combined with an explanation of the limitations / operational characteristics of each one would give a much clearer picture of their comparative merits.

The key performance characteristics required were as follows:

- MCS efficiency without a mains / bore hole PHE (litres of milk cooled per kWh)
- Mains / bore hole PHE performance (temperature reduction of the milk)

The standard conditions required were:

- Milking time / duration
- Compressor operation relative to milking time, tariff periods and control system where applicable
- Effect of PHE on compressor operation

6.1 Key performance characteristics

6.1.1 MCS efficiency of operation

The efficiency of operation (l / kWh) of each MCS type without the effect of a mains / bore hole PHE could only be extracted from those sites where one was not used. A number of mathematical heat transfer mechanisms were applied to those sites with a PHE, however the intermittent nature of the PHE operation meant the results were unreliable. The sites with applicable efficiency figures were:

- Site 1 - Old ice bank tank, no E7 control 45 l / kWh
- Site 2 - Old ice bank tank, E7 control 49 l / kWh
- Site 6 - New DX tank 75 l / kWh
- Site 7 - New DX tank, new compressor type 87 l / kWh

Although the monitoring of these sites was much more comprehensive than any previous work carried out it was considered to be beneficial to the accuracy of the final results to take into account any other work carried out.

Over a period of 18 months short term monitoring was carried out by Northern Ireland Electricity on five different new IB tank installations. These showed an improvement in efficiency in the order of 10% over an old IB tank. It was therefore considered necessary to introduce a ‘new IB tank’ category. It was not considered necessary to allow for new vs. old DX tanks as so few old ones are in existence.

For reference it is also worth noting that the historical data as mentioned in section 2 used MCS efficiency figures of 45 and 65 l / kWh for IB and DX tanks respectively. When this work was carried out DX tanks had very limited market penetration and were in earlier stages of development.

Taking all this information into account it can be seen that the old IB tank efficiency figures obtained from this work compare very well with those previously used (45 l / kWh).

The increased efficiency of the DX tank at site 7 compared to site 6 was of the order expected as a result of the new compressor type being used (10%). Although increasing in use the market is still dominated by other compressor types. These were therefore used as the basis for all the running cost calculations. Allowing for this sites 6 and 7 performed similarly. A significant increase in efficiency of DX tanks was observed (65 - 75 l / kWh). This was expected as a result of advances in this type of technology over recent years.

The MCS efficiency figures used as the basis for running cost calculations were as follows:

Old IB tank ***45 l / kWh***
New IB tank ***50 l / kWh***
DX tank ***75 l / kWh***

6.1.2 PHE performance

The average performance of the mains / bore hole PHE on those sites where it was possible to monitor as a separate item with no chilled water effect, was to reduce the milk temperature by 10^{o}C.

Most manufacturers of plate coolers recommend a water:milk ratio of 2:1. On all the sites monitored this was only achieved on one which had no water control system linked to the milk pump.

Although possible this 2:1 is rarely achieved, a reduction of 10^{o}C at a ratio of 1:1 was considered to be realistic and running cost reductions based on this assumption would be easily achieved in the majority of cases.

6.2 Standard conditions

6.2.1 Milking time, compressor operation

The effect of different milking times has the most significant effect on the running cost of a DX tank. Once all the a.m. milking, and associated milk cooling, occurs during the E7 period any further change (earlier start) would have no effect. The majority of farms have electricity meters that are controlled by a time switch positioned next to it. This time switch is normally set to GMT and is not changed when the clocks change to / from BST The effective operating period for E7 during the summer months is therefore 01:30 - 08:30 as opposed to 00:30 - 07:30 during the winter months. The milking time of most farms remains the same (real time) therefore the effect of summer vs. winter operation also needs to be allowed for.

IB tanks with an E7 type control system are affected to a lesser degree by milking time. Due to the size of the compressors on an old IB tank, and hence their extended operating times, they will always need to operate for the full seven hours of the E7 period plus a period during the day rate.

There is however an effect when considering a new IB tank. The compressor size tends to be such that maximum ice levels can be reached in as little as three hours. Therefore as soon as milk enters the tank the ice will start to be consumed and if it is still during the E7 period the compressors will operate to try and rebuild the maximum ice level until the end of the E7 period. If the ice reserves at the end of the E7 period are insufficient to cool the p.m. milking the compressors will turn on towards the end of the p.m. milking when the minimum ice level has been reached. They will operate only until the milk has been fully cooled and the minimum ice level has been reached.

If the IB tank does not have an E7 type control system, the compressors will start to operate shortly after the start of milking and continue to operate through the morning. The time of the a.m. milking therefore affects the proportion of the operation that takes place during the E7 period. The same operating characteristics apply to the p.m. milking, but this will always be during the day rate period.

Experience has shown that the a.m. milking typically starts at around 06:30 and takes between 1½ and 2 hours to complete.

6.2.2 Mains / bore hole PHE

The addition of a mains / bore hole water fed PHE is to reduce the total operating time of the MCS compressors. When considering a DX or IB tank without any form of tariff based control system the effect is the same. The reduction in operating time comes from the end of each compressor operating period. This will always, apart from exceptional circumstances, be during the day rate period. Therefore, although the effect of a PHE may be to reduce the cooling requirement by say 30%, a reduction in running cost greater than 30% will be achieved because the savings are made from the most expensive operating period. If the circumstances were such that a DX tank was operating mostly during the E7 period during the a.m. milking then , depending on the PHE performance, some savings during the E7 period would occur. This is likely to happen during the summer months (BST) when the E7 period is between 01:30 and 08:30.

The effect on an IB tank with an E7 type control system will be slightly different. Initial savings would be from the day rate operation. However, the shorter operating times of a new IB tank during the day rate period mean that compressor running cost savings during the E7 period would be possible. A further consideration is that even though all compressor operation may be during the E7 period the water circulation pump would still have to operate during the p.m. milking. This leaves a small amount of day rate operation even if all the compressor operation was during the E7 period. Operation of the agitator is also similarly affected for all tank types.

With a DX tank / ice builder combination, the majority of installations use the DX element to remove the last 2-6^{o}C from the milk. The addition of a mains / bore hole PHE would reduce the temperature of the milk entering the tank and therefore the cooling duty of the DX element. The ice builder operation would only be significantly affected once all the DX element has been removed.

6.2.3 Running cost calculation

A spreadsheet was developed to enable the entry of each of the key performance characteristics combined with the standard conditions. An extract from the spreadsheet showing the final data used to calculate the running costs is shown in fig 16.

Fig 16

Assumptions Forming Basis For All Calculations											
Electricity											
Low			2.7								
Normal			8.5								
Operating Efficiencies											
			l/kWh								
DX			75								
Old IB			45								
New IB			50								
DX&IB (25/75 split)	0.25	0.75	56.25	Calculated from new IB and DX in proportion, proportions are related to kWh consumed not the amount of cooling							
Low / Normal Split (no PC)											
			Average			Summer		Winter			
			L	N		L	N	L	N		Notes
DX			37.50%	62.50%		45.00%	55.00%	30.00%	70.00%		PC summer savings off L&N equally, winter all off N
Old IB E7			50.00%	50.00%		50.00%	50.00%	50.00%	50.00%		PC max possible savings from N, as 10% cooling load is puming etc
Old IB no E7			20.00%	80.00%		25.00%	75.00%	15.00%	85.00%		PC max possible savings from N, as 10% cooling load is puming etc
New IB			77.50%	22.50%		80.00%	20.00%	75.00%	25.00%		PC max possible savings from N, as 10% cooling load is puming etc
Ice-Builder (inc pump)			95.00%	5.00%		95.00%	5.00%	95.00%	5.00%		
DX&IB (25/75 split)											PC savings on DX part first
IB part						71.25%	3.75%	71.25%	3.75%		
DX part						11.25%	13.75%	7.50%	17.50%		
Net Effect			80.63%	19.38%		82.50%	17.50%	78.75%	21.25%		
											No E7 means no E7 control, but E7 tariff
Plate Cooler Performance											
Milk In	35		Utilisation factor		1						
Milk Out	25		kWh reduction factor		0.677419						
Final Milk	4										

The final running cost results are shown in table 40 below.

Table 40

	Running cost p / 100 litres	
MCS type	**No mains PHE**	**With mains PHE**
DX tank	8.43	5.34
Old IB tank	16.31	10.22
Old IB tank with E7 controller	12.44	6.35
New IB tank	14.67	5.72
New IB tank with E7 control[1]	8.01 (5.98)	4.24
DX tank with ice builder (chilled water PHE)[2]	5.98	4.24

[1] The figure in brackets is the running cost if all the compressor operation is during the E7 period. Where no mains / bore hole PHE is used this is only possible when using an every day collection tank, with ice reserves sufficient to cool 60% of its nominal milk holding capacity, as an EODC tank. This usually relates specifically to reconditioned / refurbished tanks.

[2] This assumes that all the ice is produced during the E7 period and that all the cooling is done by the chilled water PHE.

7. Cooling system characteristics

The following is a summary of many of the points already discussed in the site specific summaries. Some further points have been added following experience gained by the FEC during this project, feedback from farmers and discussions with manufacturers / dealers.

7.1 Every other day collection (EODC)

In most cases the running cost of a new every day collection (EDC) tank will be very close to that of an EODC tank because most of the cost of running a tank is cooling the milk, not keeping it cool.

Although, for a given milk production, the energy consumption of every day and EODC systems are similar, an every day ice bank tank used as an EODC tank can be cheaper to run than an EODC tank used for EODC because it has bigger ice reserves that can all be produced during the E7 period. This is because most ice bank tanks have an ice storage capacity sized to be able to cool 60% of the daily milk production, all of which can be produced during the E7 period. For example, the ice reserves in a 2000 l every day tank can cool 1200 l compared to 600 l for a 2000 l EODC tank. A farm producing 1000 l/day with a 2000 l every day tank would be able to cool all the milk using ice produced during the E7 period with a bit to spare, a 2000 l EODC would only be able to cool 600 l and the compressors would have to run during the day rate to cool the remaining 400 l. See table 43 note 1. This is especially relevant when considering the purchase of a reconditioned every day tank for use as an EODC tank.

7.2 Physical size of the tank

In some cases an EODC DX tank will fit into the same building as an old every day ice bank tank because there is no ice storage and pumps in the base of the tank. This is less likely to be the case for an EODC ice bank tank, although new ice bank tanks tend to be higher with a smaller footprint.

Ice builders can be situated some distance from the bulk tank giving added flexibility in installation because the water is pumped along pipes to where the PHE is installed.

7.3 Electricity supply

The compressors for a DX tank alone will typically be at least twice the size of those for an equivalent ice bank tank. This can ‘eat into’ the farms electricity supply. In a limited number of situations supply reinforcement may be required which can be expensive.

Future electricity supply requirements should also be considered.

Larger compressors are more likely to be three phase than single phase.

7.4 Integration with an existing parlour

This relates specifically to the installation of a PHE (mains or chilled).

The performance of any PHE is reduced by high capacity milk pumps because the residence time of the milk in the PHE is reduced. The installation of a balancing tank, milk pump speed control or a simple valve to restrict the milk flow rate through the plate cooler will all improve the performance by varying amounts. The added installation costs may however be prohibitive.

With a DX tank and ice builder supplying a chilled water PHE, it is more difficult to cool the milk to 4°C before it reaches the tank when high milk flow rates are used. This will mean that the DX part will be required to remove the last 2-6°C resulting in increased use of day rate electricity and increased cooling costs. The use of a larger plate cooler and/or reducing the milk flow rate as above will help to reduce this problem.

7.5 Speed of cooling

A DX tank with an appropriately sized compressor will cool milk at the same speed as an ice bank tank.

The addition of a mains water plate cooler will reduce the milk cooling time by similar amounts in both cases.

The addition of a plate cooler supplied with chilled water can give almost instant milk cooling. The chilled water supply can be from a separate ice builder or, in the case of an IB tank from the existing chilled water supply.

7.6 Effect of a power cut

A DX tank will need a larger standby generator than an ice bank tank due to its larger compressor size.

Once power is restored a DX tank will cool the milk just as quickly as it would normally. In the event of low ice reserves remaining in an IB tank the speed of cooling will be significantly reduced until the ice reserves are rebuilt.

7.7 Reliability

DX tanks are much simpler than ice bank tanks, hence increased reliability / reduced maintenance costs would be expected. In practice ice bank tanks are extremely reliable and there is little difference between the two.

An experienced local dealer with good manufacturer backup is very important.

7.8 Compressor

Type

Hermetic, the least efficient and normally the cheapest. The compressor itself (not the condensing unit) is 'sealed for life' and cannot be taken apart therefore repairs are limited to a replacement unit.

Semi-hermetic, the most widely used type. Most bulk tanks over 10 years old will have a compressor of this type. They are more expensive, but more efficient than a hermetic compressor. The compressor can be taken apart and repaired but anything other than very simple faults need a 'factory rebuild'. Reconditioned/rebuilt units are widely used as replacements rather than trying to repair a compressor on the farm.

Scroll, relatively new to the agricultural market but with a rapidly increasing market share. They have been widely used in other industries for several years. They are the most efficient type, up to 10% better than a hermetic compressor, but they tend to be the most expensive. However prices are falling and the more popular sizes can now be the cheapest of the three types available. The compressor itself is 'sealed for life' as with the hermetic. It is a rotary rather than a piston compressor, this results in fewer moving parts, quieter operation and lower starting currents. The latter can be of benefit when considering electricity supply implications.

Size (kW)

This is normally quoted as the power drawn by the compressor motor. For a DX tank the compressor should be big enough to ensure that the milk is cooled to 4^{o}C within 2.5 hours of starting milking or within 30 minutes of completing milking. For an new ice bank tank the compressor should be at least big enough to build the ice to its maximum level during the E7 period.

The sizes of different compressor types for the same size and type of tank should be similar, the difference in performance between them is minimal and should have little effect. Any differences usually result from selecting the model closest to the actual requirement, different types will not necessarily have models of exactly the same size.

Installation

Ensure good airflow to and from the condensing unit. Anything that restricts the supply of fresh air and / or causes the recirculation of warm air will increase running costs and reduce compressor life.

Easy access to the front of the cooling fins on the condensing unit will help to ensure that they are cleaned regularly.

Insulation of refrigerant pipes, the pipe supplying liquid refrigerant to the tank/ice builder should not be insulated, the pipe returning the gaseous refrigerant to the compressor should be insulated.

7.9 Refrigerants

Most new systems are fitted with R22. This is a HCFC (more ozone friendly than CFCs), however its production, but not use, will be phased out by the year 2015.

The most likely replacement for R22 will be R407c. This is a HFC and it is totally ozone benign (friendly).

R407c is currently more expensive than R22. It is expected that as 2015 approaches the cost of R22 will increase to that of R407c as its production is reduced.

All new compressors should be capable of operating with R407c without the need for major alterations.

7.10 Plate heat exchanger

Adding extra plates to an existing installation or specifying a larger than normal PHE at purchase will improve its performance. However the law of diminishing returns applies and once a reasonable size has been specified further increases will give little additional benefit.

Most manufacturers recommend a water:milk ratio of 2:1, in practice 1:1 is more typical giving an average milk temperature reduction of 10^oC. This should form the basis of more realistic energy / running cost savings as with the results presented in this report.

Ensure that the water supply is capable of giving a realistic water:milk ratio otherwise a header tank and pump may need to be installed to give a reasonable performance.

Mains water should be supplied via a type ‘B’ air gap or be fitted with a double check valve (Water Bylaws).

A time delay solenoid valve should be fitted to the water supply so that the water flow starts at the same time as the milk pump and continues to flow for a short time after the pump has stopped. This will improve the performance of the plate cooler, compared to on / off exactly in time with the milk pump. It will also ensure that no more water is used than is necessary thus reducing the volumes that have to be reused (mains water). The time delay should be no longer than 20-30 seconds. Anything in excess of this carries out little useful cooling as the milk within the PHE will have been cooled very close to the temperature of the water entering it.

All the water should be reused, if mains water is going to waste the economics of plate cooling are questionable. This does not apply to bore hole or spring water as it costs very little, however if it is disposed of via the slurry / dirty water system additional ‘hidden’ costs can be incurred.

For a new installation and if the plate cooler can be used all year round without wasting the water it is possible to reduce the size of the compressor on a DX tank by up to 33% whilst keeping cooling speeds within acceptable limits. It is worth noting that mains water is normally warmer during the summer months hence the plate cooler will be less effective. The compressor will also be working harder as a result of higher ambient temperatures. A reduction in compressor size is therefore rarely done as the risk associated with extended cooling times does not normally outweigh the capital cost savings. The size of an ice bank tank compressor is normally unaffected because it is dictated by its ability to build maximum ice during the E7 period and not by the speed of cooling.

8. Promotion / distribution of findings

8.1 Press

The Farm Energy Centre has very good links with both the national and regional press. A large amount of press coverage has been obtained particularly with the major industry periodicals such as ‘The Dairy Farmer’, ‘The British Dairying Magazine’ and ‘The Farmers Weekly’.

Copies of the majority of the press coverage achieved are in appendix 2, the majority of these were circulated nationally and ranged from a small column to two page technical articles and on farm stories.

The FEC has provided press releases and copies of results / reports to a number of organisations for inclusion in their own newsletters, promotional material etc. These include:

- Milk Marque
- Nestle
- NORWEB

All the above have included the results in publications mailed to every one of their dairy farming customers.

8.2 Exhibitions

The Farm Energy Centre exhibits at many national and an increasing number of regional events including:

- The European Dairy Farming Event, NAC
- The Royal Smithfield Show, Earls Court
- The Royal Show, NAC
- The South West Dairy Show, Shepton Mallet
- DairyScot, Ingliston

The results of the project have been promoted at all the above events and will continue to be promoted where applicable.

8.3 Farm Energy Centre Publications

The results of this project have been included in the Farm Energy Centre technical note no. 53 ‘Milk cooling costs’ (copy in appendix 1). This publication is used extensively in response to enquiries made by farmers relating to this specific subject.

8.4 Farm Energy Centre technical enquiry service

The FEC provides a technical enquiry service on behalf of the Regional Electricity Companies. The source of these enquiries is mainly from the activities described previously in this section.

In the majority of cases the farmer, whether enquiring at a show or telephoning the FEC as a result of reading a press article, speaks directly to a member of the engineering staff at the FEC. This means that each farmer contacting the FEC has been able to discuss his / her individual requirements in detail. This is normally followed up with a copy of technical note 53 and any other relevant FEC publications.

9. Acknowledgements

The Farm Energy Centre would like to thank everybody who took part in this project, in particular:

- All the farmers who participated in this project for their co-operation and time taken to read meters and provide milk production figures
- Manufacturers for supplying technical information
- Dealers for supplying site details and installing monitoring equipment

Appendix 1 - FEC technical publications

The following is a copy of the Farm Energy Centre technical note 53 ‘Milk Cooling Costs’ which is used in response to all enquiries relating to milk cooling systems.

Appendix 2 - press articles

The following are copies of the majority of the press insertions achieved throughout the duration of the project. It is not expected to be comprehensive, the most notable omissions are those in the milk buyers own newsletters.