# Dairy Farm Energy Consumption

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**Summary**

- Energy audits have shown that electricity usage contributes on average, 0.60 cent/litre to milk production costs. In terms of electricity consumption per dairy cow milked, the figures vary from 4 kWh/cow/week to 7.3 kWh/cow/week. This is equivalent to €0.60/cow/week to €1.10/cow/week.
- Key opportunities for reducing energy consumption include;
  - Eliminate energy wastage; fix all hot water leaks, insulate all hot water piping and refrigerant gas piping and use lights only when necessary. A leak as small as one litre per hour can waste 8500 litres of hot water and 3800 kWh per year.
  - Optimise plate cooling by increasing water flow to achieve the correct water to milk flow ratios. Increasing the milk to water flow ratios from 1:1 to 1:3 can reduce power consumed by the bulk tank by over 40%.
  - Switch all water heating to night rate only; consider using an oil fired boiler.
  - Consider using a variable speed drive controller on vacuum pumps. This can save over 60% on vacuum pump running costs.
  - Use energy efficient lighting.
- There is scope for Irish dairying to increase energy efficiency thereby helping to reduce costs while at the same time reduce greenhouse gas emissions.

## Introduction

The cost of electrical energy will increase dramatically in the future and awareness of energy consumption in the dairy industry is becoming an issue in the cost of milk production. The recently established energy research programme at Moorepark aims to reduce electricity consumption/costs on Irish dairy farms and hence their carbon footprint. Commencing the programme in January 2009 the first objective was to carry out detailed energy audits on 3 dairy farms. Electricity consumption data was collected from 3 Teagasc Research Farms that were fitted with electricity monitoring equipment over a 30 week period from March to November 2009. A summary of the results can be seen in ***Figure 1*.** The audit showed that milk cooling is the largest consumer of electricity (37%) followed by water heating (31%), vacuums pumps (19%) and lighting (10%). Other items such as wash pumps, milk pumps, feed augers and air compressors make up the balance (3%).

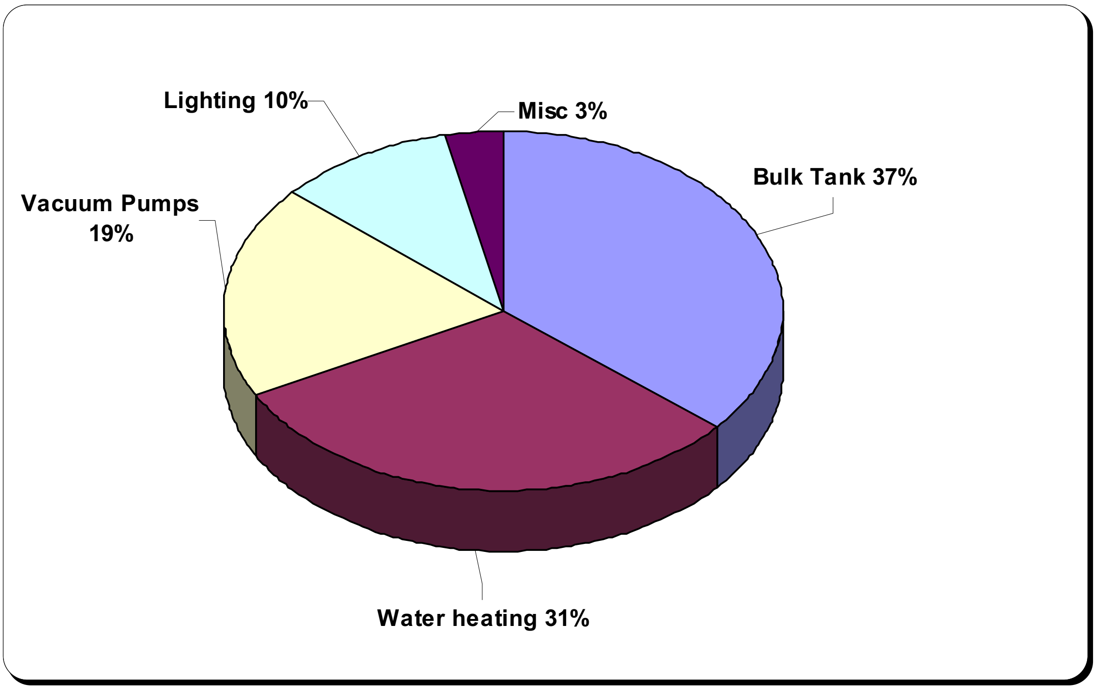



***Figure 1;*** **Summary of electricity audit on three Teagasc Research Farms**

Milk production data was also collected for this 30 week period which allowed electricity cost, in cents per litre of milk produced to be calculated. These figures varied from 0.47 cent/litre to 0.69 cent/litre. The average figure for the three farms was 0.60 cent/litre. In terms of electricity consumption per dairy cow milked, the figures varied from 4 kWh/cow/week to 7.3 kWh/cow/week.

## Opportunities for reducing energy consumption

Results to date indicate that electricity usage on dairy farms can be reduced by over 50%. The first step is to reduce energy wastage i.e. fix hot water leaks, insulate hot water piping and refrigerant gas piping, using lights only when necessary and make use of night rate electricity. Applying these good management practices will reduce energy costs without any capital expenditure. The benefits of reducing electricity consumption are two fold. Reducing milk production cost is an obvious benefit but also due to the fact that 86% of electricity generated in Ireland is from fossil fuels, 531g $CO_2$ are produced for every kWh of electricity used. Hence reducing electricity consumption will also reduce the industries carbon footprint.

## 1. Water Heating

The heating of water is a substantial energy input in the operation of a modern dairy farm. Electricity used by water heating equipment can add up to two kWhs per cow per week. The most common method of providing hot water on dairy farms is electrical water heating, with oil fired boilers also being a popular choice, particularly on larger dairies. Both systems differ significantly in terms of efficiency and have relative strengths and weaknesses. **Table 1** displays the results of a recent water heating trial in Moorepark where 500 litres of water was heated from 14°C to 80°C with i) a 3kW element and ii) a 26kW oil fired burner running on kerosene. The amount of usable water was defined as the quantity of water drawn off from the cylinder between 60°C and 80°C. Inspection of **Table 1** shows that a 3kW immersion element takes over 16 hours to heat the 500 litre tank to the final temperature of 80°C. This would not be satisfactory as night rate electricity should be utilised for electrical water heating. This element would not be capable of heating the water on night rate alone. **Table 1** shows a comparison of electrical and oil to heat water. Tariffs used for these calculations are shown in **Table 2.**

***Table 1*****:** Comparison of electricity and oil for water heating

| Heating Method | Power Consumed (kWh) | Time (Hrs) | System Efficiency* | Useable Water ** (litre) | Cost per 100 litres (€) Night/Day Rate | Kg of $Co_2$ Produced |
|---|---|---|---|---|---|---|
| Electricity | 48.24 | 16.5 | 79% | 411 | 0.87 / 1.77 | 25.6 |
| Oil | 45.5 (4.4l Kerosene) | 1.75 | 84% | 415 | 0.60 | 12.7 |

*System efficiency is the ratio of energy extracted from the system in terms of hot water, to energy consumed by the system (i.e. electricity or oil)

**Useable water is defined as the amount of water drawn from the cylinder between 60°C and 80°C

***Table 2:*** Tariffs used for calculating water heating costs (Correct on 15/10/2010)

| **Unit Type** | **Cost per Unit (€) Ex VAT** | **Tariff** |
|---|---|---|
| Electricity Day units (kWh) | 0.15 | ESB Rural night saver |
| Electricity Night units (kWh) | 0.07 | ESB Rural night saver |
| Kerosene (Litre / kWh) | 0.57 / 0.06 | Based on quote for 1000l |

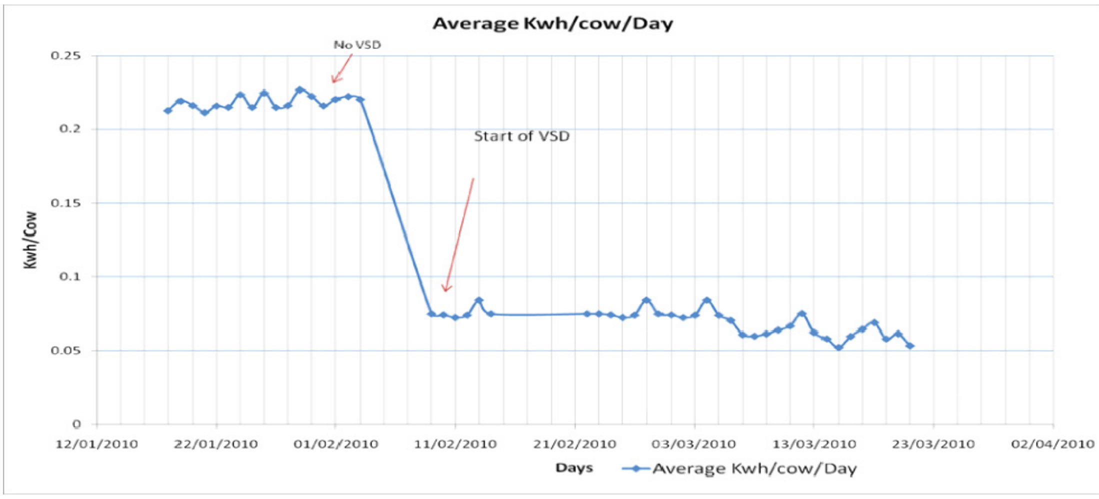
The importance of using night rate electricity is immediately apparent. **Table 1** show that the oil boiler can produce 100 litres of usable water at a much lower cost than the 3kW element on night rate and substantially cheaper than the electrical element on day rate. Oil prices can fluctuate but the price of kerosene would need to increase by 45% from today's price to match the cost of the electrical heating system. The oil fired system also has a number of other advantages. Firstly the recovery time is very low and this means that hot water will be available both morning and evening if required which is an important factor in system selection for many farmers. Secondly the amount of $CO_2$ emitted by the oil fired system is much lower that the comparable electrical system. Naturally the capital investment of the oil fired system will be higher than the electrical system but as **Table 1** illustrates the savings involved can be noteworthy depending on hot water usage and whether or not night rate electricity is available. In any case serious consideration should be given not only to initial purchase cost but also to running costs and environmental impact.

## 2. Vacuum Pumps

Conventional vacuum systems incorporate a vacuum pump operating at a fixed speed, a vacuum regulator and a load. The load consists of the air admitted by the components that make up the milking system including milking units, pulsators, claws and other devices that admit air during operation. To maintain a set vacuum level, the vacuum pump must remove air from the milking system at the same rate as air is being admitted. Since the air admitted is dynamic and the pump out rate is constant, a vacuum regulator is necessary to admit the difference between the pump capacity and the air load. The typical vacuum regulator is a mechanical device that adjusts the rate of air admission into the system. The vacuum regulator provides airflow into the system so that the sum of the air admitted by the milking system plus the air admitted through the regulator exactly matches the fixed airflow at the vacuum pump. When the air load is low, the regulator must admit nearly the entire pump capacity. When the load increases the regulator must close and admit less air. Introduction of variable speed drive (VSD) technology for controlling vacuum in a milking system can contribute to reduction in energy use, while still producing equivalent vacuum stability. The VSD is able to adjust the rate of air removal from the milking system by changing the speed of the vacuum pump motor to equal the rate air is admitted to the system at a given vacuum level. All of the energy used to move air through the conventional vacuum regulator is saved. Variable speed drive “vacuum regulators” consist of a sensing element, a controller, and a variable frequency motor drive. The sensing element is an electronic vacuum transducer that converts the vacuum signal into an electrical signal for processing by the controller. The controller monitors the vacuum level signal from the transducer and determines the appropriate speed to operate the vacuum pump in order to maintain the desired vacuum level. The controller contains the operator interface where vacuum level settings are adjusted. The variable frequency motor drive is a device that converts standard line voltage at 50Hz to a variable frequency and variable voltage output to drive a 3 phase induction motor. By reducing the frequency and voltage supplied to the motor, the speed and the power consumed by the motor will be reduced. As with conventional, mechanical regulators, placement of the sensing element of a variable speed regulator is very important. The sensing element should be located as close to the receiver as possible.

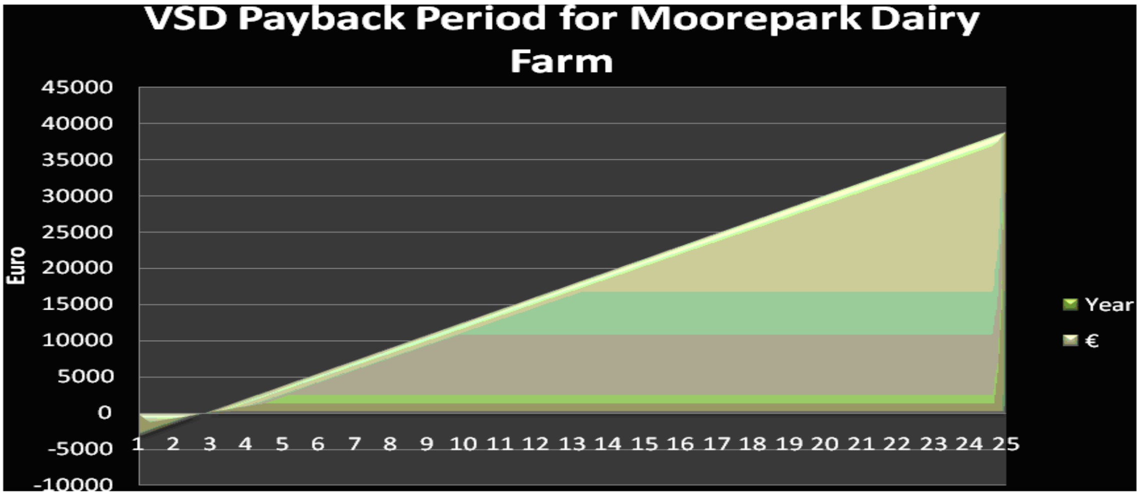
Over a two month period at Moorepark the power usage of the vacuum pumps was monitored, pre, and post VSD installation on a 30 unit herringbone milking machine. The milking equipment consists of a highly automated 30 unit milking machine with two DM 5 vacuum pumps driven by two 4kW motors. The vacuum pump capacity is 2600 litres of free air per minute. The plant consumption is 1200 litres per minute during milking. The unit chosen was an Invertek optidrive E2 AC variable speed drive. In addition to power consumption, cow numbers milked, milk yields and mlilking time were all recoded.

***Figure 2***: Power consumption of vacuum pumps pre and post VSD insatllation




The annual energy consumption of the vacuum pumps before the VSD was installed was over 16,300kWh. With the installation of the VSD the electrical energy use dropped to 4,700kWh, this gives a saving of 11,600kWh. The payback for the VSD installation is 2.85 years based on an initial cost of €5,000 and an annual cost saving of €1,752. The annual saving of $CO_2$ as a result of the VSD installation are 6.2 tonnes/ year.

**Figure 3:** Projected payback for VSD installation in Moorepark




## 3. Milk Cooling

Milk cooling is the largest consumer of energy on Irish dairy farms. The cooling of milk immediately after milking is vital to maintaining high milk quality levels. On a typical Irish dairy farm the cooling process is completed in two stages; pre-cooling and refrigeration. Pre-Cooling is achieved by passing the hot milk through a Plate Heat Exchanger (PHE) before entry to the bulk tank. Cold water is pumped through the opposite side of the PHE. The cold water absorbs a portion of the heat, thus pre-cooling the milk. A PHE is designed to run at certain operating conditions; each PHE

has a specific milk to water flow ratio and extra plates can be added to accommodate for very large milk flow rates. The goal of pre-cooling is to bring the milk temperature as close as possible to that of the water. In July 2010 Teagasc Moorepark conducted a series of audits on plate heat exchangers currently being used on active dairy farms. The results from these audits concluded that the vast majority of plate heat exchangers were performing at only a fraction of their full cooling effectiveness. This was mainly due to the improper milk to water flow ratios being employed, the average of which was 1:1.2. PHE manufactures recommend milk to water flow ratios of between 1:2.5 and 1:3 depending on the model. If a PHE is sized correctly in relation to the power of the milk pump and the correct ratio of water is supplied then the power consumed during the refrigeration stage can be dramatically reduced.
**Table 3** represents the results of PHE testing carried out at Moorepark Engineering Laboratories. A PHE was analysed at varying milk to water flow rates and with an increasing number of plates. The milk and water entry temperatures were set to 35°C and 10°C respectively and the milk exiting temperature from each test was recorded.

***Table 3**:* Milk exit temperatures ($^{o}$C) for a PHE ratio and plate capacity test

| | **Milk:Water ratio** | | | |
|---|---|---|---|---|
| **No. Plates** | **1:1** | **1:2** | **1:3** | **1:4** |
| **25** | 20.8 | 16.8 | 14.8 | 13.7 |
| **29** | 20.7 | 16.6 | 14.6 | 13.6 |
| **33** | 20.5 | 16.3 | 14.5 | 13.5 |
| **37** | 20.5 | 16.1 | 14.3 | 13.3 |
| **41** | 20.4 | 16.0 | 14.1 | 13.2 |
| **45** | 20.4 | 15.9 | 14.0 | 12.9 |

The most noticeable result from the above test is the reduction in milk exiting temperature corresponding with the increased milk to water ratio. However it takes an ever increasing water flow rate to reduce the milk temperature, as the ratio increases the cooling effect per litre of water is reduced.

Another observation from the test is the influence of increased plate capacity on milk temperature. The extra plates have a mild effect on the performance of the PHE. The addition of extra plates to the heat exchanger increases its heat transfer area however this also increases the number of flow channels, thus reducing the milk flow velocity and water flow velocity at a set flow rate. This reduction in flow velocities retards the heat transfer rate in the PHE. The resulting effect is that increasing the number of plates on a PHE produces only a modest increase in cooling performance.

## Milk Cooling Systems & Smart Metering

Two types of milk cooling systems are used on Irish dairy farms. Firstly “Direct expansion” (DX) refers to a system where the evaporator plates are incorporated in the lower portion of the storage tank in direct contact with the milk. Liquid refrigerant expands inside the evaporator taking heat out of the milk directly thus the name "direct expansion". Milk cooling takes place within the tank. Generally, this milk cooling system cannot cool the milk as fast as the milk enters the tank. The cooling system must run for a period during and after milking. DX cooling systems are the most efficient cooling system in terms of kWhs consumed per litre of milked cooled however the must operate on "day rate" electricity.

"Instant" cooling is where the milk cooling is completed external to the storage tank and then pumped into storage. An intermediate cooling fluid, such as chilled water from an ice builder is used to cool milk rapidly in a dual phase plate heat exchanger. This cooling system is less efficient in terms of kWh consumed per litre of milk cooled however ice bank builders can generate enough ice at night to meet the entire milk cooling demand the next day. This system takes advantage of significantly cheaper night rate electricity.

In 2009 the Central Energy Regulator (CER) began trialling a new electricity pricing system called Smart Metering, see **Figure 4**. Smart Metering allows for the dynamic pricing of electricity dictated by the load on the national grid.


***Figure 4:*** *Smart Metering Plan*

Over the next decade this new structure will be rolled out nation wide. Smart Metering will result in cheaper electricity during the night time and much more expensive electricity during the peak period. Bearing these planed developments in mind along with the fact that the evening milk cooling load may land partially or entirely on the "peak" time of use tariff, the case for ice builders with instant cooling will become stronger. The trend towards larger milking herds, greater milk production per cow and larger more efficient milking machines will increase milk flow rate (litre/minute), with large volumes of milk to be cooled within a 24-hour period. The "instant" cooling system is not limited by the amount of surface cooling area in the storage tank which is another important attribute in favour of the ice bank system. This milk cooling strategy has been flagged as a priority research area for engineers in Moorepark in the coming years.

## 4. Lighting

The cumulative magnitude of energy used by lighting equipment in all areas of the milking operation is somehow perceived to not be as significant as it really is. In fact electricity used by lighting can add up to 1 kWh per cow per week. Moisture resistant double fluorescents or high bay metal halide lamps are the most common types of luminary used on Irish dairy farms. Energy audits have shown that similar size dairies using metal halide luminaries can use over three times more electricity on lighting than a farm using fluorescent type luminaries. This is due to the high wattage of the metal halide fittings. Metal halide fittings are typically suspended from the dairy roof in a singe row over the milker's pit. The nature of this lighting strategy leads to shadows being cast by the milking machine, stallwork, milk meters and automatic cluster removers. Lux measurements taken in the milker's pit tend to be well below desired levels when excessive shadows are cast. The alternative fluorescent lighting generally consists of two rows of double tube luminaries mounted over the edges of the pit. These provide uniform lighting with little or no shadows as illustrated in ***Figure 5.***

***Figure 5:*** Well lit parlour with 2 rows of double fluorescent fittings

During the course of the lighting experiments in Moorepark it was noted that modern fluorescent tube fittings tend to interfere with milking parlours automatic cow identification systems, reducing the effective distance from the cows' ear tag to the antenna. The underlying reason for this is the use of high frequency switching ballasts within the light fittings themselves. These ballasts give out high frequency nuisance signals which interfere with the automatic identification antenna. **Table 4** illustrates the dramatic effect these lights have on the tag reading abilities of the automatic identification system when suspended 1 meter above the antenna. The older switch start or magnetic ballast fluorescent tubes are still commercially available and where automatic identification systems are installed these lights are the only viable option. While not the most efficient solution, they will however offer substantial savings over the high-bay metal halide lamp and will provide sufficient lux levels at the cows' udder. Where automatic cow identification does not exist any type of fluorescent can be used and focus can be given to energy efficiency.

The most commonly used type of fluorescent tube found in the dairy is the double five foot fluorescent tube. These tubes have a diameter of 1 inch and are referred to as 'T8' fittings in the lighting industry. A number of options exist to improve the efficiency of these fittings. The 'T5' fitting is an increasingly popular development in fluorescent lighting. 'T5' lamps have a diameter equal to 5/8". These lamps are approximately 40% smaller than 'T8' lamps. Traditionally upgrading to 'T5' lamps required the purchase of a new light fixture. 'T8' to 'T5' converters are now commercially available to convert existing 'T8' fittings to higher efficiency 'T5' fittings without the requirement to change the fixture itself. 'T8' LED (Light Emitting Diode) tubes are also available, although these are quite new to the market. Luminous efficiency, power consumption, and a lux value recorded one meter from the light fittings are displayed in **Table 4**. Using the double 58 watt 5Ft 'T8' as the benchmark and current industry standard, it is clear that efficiency gains can be made by upgrading existing lighting. The IES (Illuminating Engineering Society) recommend 500 lux on the operating plane (at the cows' udder) for the milking routine. One point to note is that the lux values for the 'T5' fitting are far higher than required, in fact the number of luminaries in the dairy could be halved while still meeting the required 500 lux on the working plane (at the cows udder). Moving from double 'T8' fittings to half the number of 'T5' fittings would reduce power consumption on lighting by 40% while still providing the 500 lux recommended by the IES. Simply using a 'T8' to 'T5' converter will save 30% on lighting power usage. LED tubes are very efficient and would save 48% on power usage, however at over €85 per tube the price will need to come down considerably before they will be widely adopted.

***Table 4:*** Results of the Lighting Experiment carried out in Moorepark

| | Double 19W LED | Double 49W T5 | T8 to T5 converter | Double 58W T8 High Frequency | Double 58W T8 Switch Start (Magnetic) |
|---|---|---|---|---|---|
| **Luminous Efficiency (%)** | 16.32 | 15.15 | 11.91 | 10.4 | 10.6 |
| **Energy Use (I)** | 0.16 | 0.4 | 0.23 | 0.33 | 0.53 |
| **Lux at 1 Meter** | 653 | 1516 | 685 | 853 | 1402 |
| **Tag read distance * (cm)** | 31 | 28 | 37 | 55 | 102 |

* Tag read distance is the functional distance from the antenna to the ear tag with the light fitting suspended 1 meter above the antenna

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