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Direct energy consumption and saving possibilities in milk production

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Abstract. Direct energy consumption in milk production varies largely because of machinery, production systems, working habits and maintenance. There are good possibilities to save energy in milk production. The magnitude of energy savings are in the order of tens of percent, which means that energy saving potential is quite high. Energy saving can be achieved with efficient system and machinery choices. Also adjustments and maintenance have an effect on energy consumption. To save energy the farmers should have means to measure energy and follow energy consumption. There should also be more information of energy saving possibilities and machinery energy consumptions.

Key words: energy, milk production, ventilation, lighting, milking, milk cooling.

INTRODUCTION

Energy consumption in milk production can be divided into two categories, direct and indirect. Direct energy is bought directly to the production, for instance electricity, gas and diesel oil. Indirect energy is used outside the main production, for instance feed material production needs energy but this energy is used mainly in field operations. In this study we concentrate on the direct energy used in the cattle house.

Fig. 1 shows energy consumption and its variation in milk production (Ludington & Johnson, 2003; Eerola, 2006; Vergicht et al., 2007; Hörndahl, 2008; Neuman, 2008). The variation in consumption is high depending on the machinery, production system and also working habits and maintenance. The four largest direct energy consumption will be handled in this study: lighting, milking and milk cooling, ventilation and feeding. In cowhouses the trend has been to move towards cold or semi-cold buildings with natural ventilation and with no or light heat insulation. This means that the cowhouse do not need heating. Only milking parlour, offices and dressing rooms need heating but this is minor consumption, normally less than 20 Wh kg^{-1} milk (Turunen 2013).

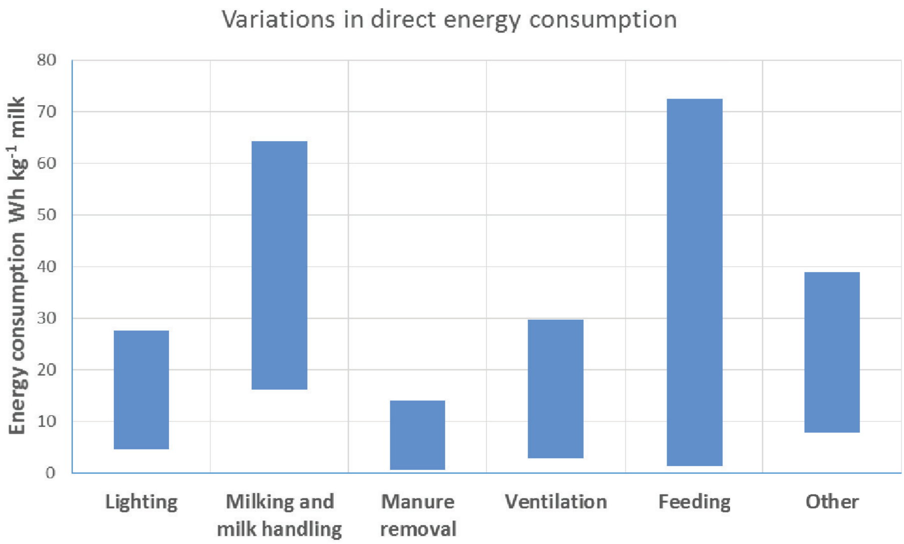

Figure 1. Direct energy consumption variation in milk production.

MATERIALS AND METHODS

Ventilation

The main purpose of building is to offer shelter to the cows and also to humans working in the building. For a good microclimate ventilation is needed to remove the harmful emissions and bring fresh air into the building. Water is used for washing and as drinking water, and part of this is also vaporized and needs to be removed from the building. Also cows produce moisture. Ventilation criteria changes mainly according to the ambient temperature. During warm and hot periods ventilation is needed to cool the cowhouse. During cold periods heat removal is not needed and then moisture and gas (mainly CO_2) dictate the ventilation rate.

The energy needed to run forced ventilation can be calculated from Equation (1).

$$E_v = \frac{q_v \cdot \Delta p}{\eta} \cdot t \, . \tag{1}$$

where: q_v is the air volume flow; Δp the pressure difference between the fan inlet and outlet; η the combined efficiency of the fan and motor running the fan and t is the time the ventilation is running.

For animal welfare and energy use it is important that the ventilation rate is according to need. Instead of forced ventilation, natural ventilation can be used. It is used typically in cold or semi-cold cowhouses and the ventilation rate is controlled with the adjustment of the openings and outlets. The micro climate in these buildings is, in most cases, good because of a sufficient ventilation rate and the energy consumption is minimal.

Lighting

Lighting is an animal welfare question but also proper lighting is needed for human workers. When animals are kept in building lighting is needed but also appropriate period is needed for rest without artificial lighting. Illumination affects safety, animal growth, fertility and production. Proper lighting can increase milk yield 5–16% (Crill et al., 2002). The light intensity (lx) recommendations depend on the operation of the room. In table 1 are typical recommendations for cattle houses.

Table 1. Recommended illumination intensities in cattle houses (MMM-RMO C3)

Room	Recommended intensity lx
General illumination	60–100
Milking parlour	200–250
Offices	150–300

Energy consumption in lighting depends on e.g. lamp type, distance and angle of light source from the illuminated surface and the time the lights are used.

Milking

In milking most of the energy is used in running the vacuum pump and in washing the milking machine. The energy used in vacuum pump can be calculated with Equation (2).

$$E_m = \frac{q_v \cdot \Delta p}{\eta} \cdot t \tag{2}$$

where: E_m is the energy consumption; q_v is the air flow; Δp is the vacuum; t is running time and η is efficiency.

To reduce energy consumption the air flow should be according to the needs and the vacuum pump running time should be low.

Milk cooling

Milk temperature after milking is 35–38 °C and this has to be cooled to 3–4 °C temperature. The energy released in cooling can be calculated with Equation (3).

$$E_{mc} = m \cdot c_m \cdot \Delta T \tag{3}$$

where: E_{mc} is the released energy; m is the mass of the milk; c_m is the specific heat capacity of milk (≈ 4 kJ kg^{-1} K^{-1} and ΔT is the temperature change in cooling (≈ 33 K). Milk cooling is done with refrigeration systems which normally have an energy efficiency ratios of about 3.

RESULTS

Ventilation

According to Equation (1) ventilation energy consumption depends on airflow, pressure drop in air ducts, ventilation running time and efficiency of fan and motor. The dependence is linear, change in one of this causes a corresponding energy consumption change. Energy consumption can be reduced by optimizing these items. Ventilation rate in forced ventilation should be adjusted according to the need of good microclimate. Ventilation control changes depending on temperatures, number of animals and animal weight; the control system should be able to function with changing criteria. Ventilation control should also be able to stop ventilation if natural ventilation is sufficient.

Air ducts should produce a low pressure drop. This is achieved with good design and cleaning and maintenance of the ducts. Annual cleaning of air ducts and fans can reduce energy consumption 10% (Hinge, 2001; Ludington et al., 2004).

There are differences in fan and motor efficiencies. Unfortunately it is not easy to get reliable information of the fans. EU has introduced efficiency demands for fans (EU 327/2011). The efficiency depends on power, fan type and assembly type. For instance for 1 kW axial fans the efficiency demand is between 30–50% depending on the assembly type. ASAE EP566 (2012) standard specify efficiency with $m^3\ h^{-1}\ W^{-1}$ figure when the pressure drop is 250 Pa. Small fans should produce 16 $m^3\ h^{-1}$ airflow for one watt motor power and large fans 30 $m^3 \cdot h^{-1}$ airflow for one watt motor power.

When natural ventilation is used, energy demand is low, only the control system consumes small amount of energy. In cold climate it is important to avoid freezing of drinking water or manure. During the winter time it is essential not to have too effective ventilation, which could lower the temperature under freezing point.

Lighting

In lighting the trend is to replace incandescent light bulbs with more energy efficient lamps. Luminous efficacy of the bulb can be calculated by dividing the bulb lumen value by the electric power consumption of the bulb. The higher this value, the more energy efficient the bulb is. Incandescent lightbulbs' efficacy is 10–15 lm W^{-1}, energy saving lamps have 50–70 lm W^{-1} efficacy (Tetri et al., 2011). LED lights can have higher efficacies. For instance LED light bulb efficacies varied in tests from 57 to 110 lm W^{-1} (PremiumLight 2015).

Although the energy demand of a single bulb is low, the number of them in cow houses is high and they can be on continuously making the energy use high. For instance in milk production, lights can consume 10–30% of the total electricity used (Ludington & Johnson 2003; Hörndahl 2008). To save energy the lights should be used only when needed and with special lighting programs. In addition places which are seldom used could have automatic light switching systems.

Good natural lighting can be achieved with 10–15% transparent roof area (DairyCo, 2012). Depending on the time of the year the length of daylight period varies and especially in northern and southern parts of the hemisphere artificial lights are needed during the dark periods of the year.

In cattle houses the lights are covered with dust and dirt reducing the light power. Dunn et al. (2010) noticed that during two year period the light intensity was reduced by

30% because of dirt. Gooch & Ludington (2003) recommend that the lights should be cleaned in 6 months periods.

With dimming energy consumption can be also reduced. This can be utilised when natural light does not have sufficient luminosity or the cows have a rest time. For dimming the lamps must be dimmable type and there should be an automatic control system.

Milking

At the teats the vacuum should be constant and it should remain constant even if some of the clusters are kicked off. Washing operation needs a higher air flow than milking. This means that air flows in milking pumps are much higher than what is needed only for milking. Most of the vacuum pumps are working all the time with full capacity using a valve which regulates the vacuum by passing air to the system. Energy can be saved using variable speed motors, which change their speed according to the need. This saves energy up to 40–50% (Dunn et al., 2010).

Also the running time of the vacuum pump could be reduced by good arrangement of milking work. The shorter the vacuum pump running time is the less energy is used in milking.

Milk cooling

The energy released in milk cooling could be utilised. The easiest way to do this is to direct the warm air of the condenser to heating of the building. The warm air should be moved out from the refrigerator room. Otherwise the room is warmed up and the energy efficiency ratio of the system is decreased. This means an increase in electricity consumption.

The temperature of the milk can be reduced with precooling the milk before it flows into tank. This can be done with heat exchanger, where milk is cooled with cold water. When the water flow was equivalent to milk flow Karlsson et al. (2012) measured that milk temperature was cooled to 17 °C. According to Equation (3) this means about 50% saving in the cooling of the milk in the milk tank. The warmed water could be utilised in hot water production or heating.

A heat recovery system can be used in milk cooling, which utilises the heat of the cooling media. These systems can utilize two thirds of the cooling media energy (Karlsson et al., 2012).

One problem with heat recovery systems is that milking is only on milking robots rather continuous. In milking parlours milking is done twice or three time a day and heat can be recovered only during the milking times. There should be during milking an equivalent heat demand or adequate hot water boiler, where the heat could be stored, otherwise the excess heat cannot be utilised.

Feeding

Energy consumption in feeding consist normally from four different operations: transportation from the storage, feed material handling (milling, chopping), mixing and distribution. There are many different ways in arranging the feeding and it also depends how much grass and concentrates are used. Energy consumption in feeding can be quite high according to Fig. 1. Energy consumption in feeding also varies in large extends,

Table 2. Hörndahl (2008) measured energy consumptions on five farms and the feeding energy consumption was from 160 to 652 kWh cow^{-1} a^{-1}.

Table 1. Energy consumption in feeding

Operation	Energy consumption	Machine type	Reference
Loading and mixing of silage	118–645 kWh cow^{-1} a^{-1}	Tractor front loader/wheel loader and tractor mixer	Hörndahl, 2008
Silage distribution	5.7 kWh cow^{-1} a^{-1}	Rail feed wagon	Hörndahl ,2008
	12.7 kWh cow^{-1} a^{-1}	Belt feeder	Hörndahl, 2008
Bale shredder	10–20 kWh cow^{-1} a^{-1}	Straw, hammer mill	Jakop & Jakop, 1976
Bale shredder	140–320 kWh cow^{-1} a^{-1}	Fast speed silage bale shredder	O'Kiely et al., 1999
Bale shredder	20 kWh cow^{-1} a^{-1}	Slow speed silage bale shredder	Turunen & Malvisto, 2011
Diet mixer	168 kWh cow^{-1} a^{-1}	Electrical motor driven mixer	Hörndahl, 2008
	163 kWh cow^{-1} a^{-1}	Tractor driven mixer	Hörndahl, 2008
Grinding	3–9 kWh t^{-1}	Roller mill	Hörndahl, 2008; Pedersen & Hinge, 2002
Grinding	10–20 kWh t^{-1}	Hammer mill	Hörndahl 2008; Pedersen & Hinge, 2002; Voss, 1974
Grinding	9–12 kWh t^{-1}	Plate mill	Pedersen & Hinge, 2002; Voss, 1974
Transport of concentrates	1 kWh t^{-1}	Spiral conveyor	Pedersen & Hinge, 2002
Transport of concentrates	0.2–0.4 kWh t^{-1}	Horizontal screw conveyor	Pedersen & Hinge, 2002; Ringel et al., 1987
Transport of concentrates	0.5–3 kWh t^{-1}	Pneumatic conveyor	Pedersen & Hinge, 2002; Ringel et al., 1987

Feeding consist of several parts and it can be arranged in different ways. Energy consumption figures should be available when feeding strategy and systems are designed and purchased. Unfortunately this kind of information is seldom available.

In feeding machines proper maintenance is required. It is known from hay making machines that dull knives can increase energy consumption 15–20% and very dull knives can almost double it (Sauter & Dürr 2005; Küper, 2012).

Straw length has an effect on shredder energy consumption. Jones (2009) found that short straw consumed only half of the energy compared to long straw. In this way energy consumption is related to field work machinery.

CONCLUSIONS

Direct energy consumptions in milk production can vary in large extent. There are possibilities to save energy but there is not much information available how to save energy and when investments are profitable. The magnitude of energy savings are in the order of tens of percent, which means that energy saving potential is quite high. Energy saving can be achieved with efficient system and machinery choices. It must also be remembered that adjustments and maintenance have an effect on energy consumption. This could be solved with good advice work.

It would help the farmers if the electric driven devices had power and energy meters. With these it would be easy for the operator to see how different adjustments effect on energy consumption.

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